TRANSISTOR CIRCUIT HANDBOOK

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To

BENNETT WELLINGTON COOKE, SR.

President of

Coyne Electrical School

from 1919 to 1956

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TRANSISTOR CIRCUIT HANDBOOK

By

LOUIS E. GARNER, JR.

A PRACTICAL REFERENCE BOOK COVERING BASIC CIRCUITS, PRACTICAL APPLICATIONS AND DATA ON USES FOR TRANSISTORS.

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Circuits shown in this book are provided for informational and educational purposes only—to provide the design engineer with practical circuit information and to provide the experimenter and student with simple construction projects to aid him in his work. The inclusion of any circuit in this book does not constitute an automatic license to manufacture and/or sell equipment using said circuit where a valid patent exists covering the circuit or modifications thereof. Therefore, neither author nor publisher can be responsible for possible infringement of issued or pending patents caused by disclosures contained in material published in this volume, and readers are advised to investigate the possibilities of such infringement before making, using, or selling articles or techniques described.

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AUTHOR'S PREFACE

After the invention of the triode early in the year of 1906, the vacuum tube ruled unchallenged as an amplifying device for several decades. When a semiconductor amplifier, the transistor, was announced in 1948 by Messrs. Shockley, Bardeen and Brattain of the Bell Telephone Laboratories, it seemed to offer the first real challenge to the undisputed supremacy of the vacuum tube. And that challenge has been justified! For in less than a decade since its announcement as a successful laboratory experiment, the transistor has passed from the experimental stage to mass production as a practical commercial device. Today, the transistor has virtually replaced the vacuum tube in some types of instruments and is seriously challenging it in other fields.

The advantages of the transistor as an amplifying device are numerous . . . it is, at one time, more compact, lighter in weight, longer lived, more rugged, fantastically more efficient, and, potentially, less costly than its older competitor, even though just as versatile in circuit application. With all of these desirable characteristics, it is no wonder, then, that the transistor is finding increasing uses in military and civilian electronic equipment, that home experimenters and hams are starting to use and to work with it in their basement laboratories, and that electronic engineers are given more frequent assignments to transistorize existing gear or to design new equipment efficiently utilizing the unique physical and electrical characteristics of this fabulous semiconductor amplifier.

In the early days of the transistor, published technical papers, magazine articles, and books were concerned primarily with the physics and mathematics of semiconductor operation, with transistor construction details, and with predictions of future uses. Today, with transistor design starting to crystallize, the emphasis is shifting to practical applications, to transistor circuit design, and to production and test techniques. This is as it should be, for any new development, marvelous as it may be in the laboratory, and as intriguing as it may be as an experiment, becomes of real value only when it can be utilized in down to earth practical devices. Until a new invention can be put to work in day-to-day activities, it can be classified as little more than a curiosity as far as the mass of humanity is concerned.

AUTHOR'S PREFACE (Continued)

The author, realizing the value of actual circuit information in practical laboratory work, felt that a collection of transistor circuits would be welcomed by the design engineer and home experimenter alike. Hence the present volume. In this book, the author has included as many transistor circuits as is practicable within the space and economic limitations imposed. An effort has been made to show not only basic circuits, such as might be used in the design of complex equipment, but also complete circuits for simple instruments, controls, and transistorized equipments.

In line with the purpose of providing a maximum number of circuits, theory and mathematics have been minimized, if not eliminated altogether. Where the reader requires theoretical information, it is suggested that he refer to one or more of the publications listed in the Bibliography.

This book is not intended to be read as a novel nor studied like a textbook. Instead, it should serve the reader as a reference source of practical circuit information . . . to be referred to when needed, and to be glanced through occasionally so that the owner might be familiar with its general contents. To simplify the use of this volume as a true *Handbook,* the contents have been divided into four relatively independent parts.

PART I covers, briefly, basic *Laboratory Practice* as far as transistor circuitry is concerned. It is not intended to be all-inclusive nor complete to the last detail, for this is a circuit handbook, not a laboratory manual. However, it is intended that this section will point up some of the more important factors to remember and to outline many of the basic techniques which will prove helpful when working with transistor circuitry.

PART II is devoted to *Basic Circuits.* These are circuits which may be used alone for class work and experimental study, or which may be used as "building blocks" in various combinations in the design of complete instruments and equipments. The design engineer should find this part of the book of especial interest.

PART III covers *circuit applications.* In some cases practical construction hints will be given. In all cases, parts vlaues will be shown and component types specified. It is felt that the ham, gadgeteer, and home experimenter will find this part of the volume particularly valuable in the pursuit of his hobby.

PART IV covers general *Reference* material of value in circuit work, but not given elsewhere in the volume.

Some of the circuits given were worked out specifically for this volume. Some were adopted from the author's many published magazine articles and technical papers. Others were suggested by transistor and transistor component manufacturers. Others represent transistorized versions of well known vacuum tube circuits. Still others represent practical versions of theoretical circuits described in patents or in advanced technical papers. No one source contributed the majority of circuits shown, and hence individual credits have not been given. However, general credits are listed in the Acknowledgements as well as the Bibliography.

LOUIS E. GARNER, JR.
Wheaton, Maryland

July, 1956

ACKNOWLEDGEMENTS

Few modern technical books are the work of a lone individual. Nearly all writers must depend on assistance from many sources. This is especially true of a book of this type, which surveys virtually the entire field of transistor circuitry. This volume became possible only when leading semiconductor and component manufacturers indicated their willingness to cooperate with the author . . . by furnishing encouragement, technical advice, and, in many cases, samples of their products. Had test components not been available, the author would have found it impossible to bench-test the nearly two hundred circuits described . . . and, without bench-testing, these many, many circuits would be of questionable value as practical examples of transistor applications. Therefore, the author wishes to acknowledge here the assistance received and to list, in detail, the firms who helped him in the research necessary to produce this volume.

The careful reader may note that a few rather well-known manufacturing firms are not listed. Lest the author be accused of being partial, he hastens to point out that he made a sincere effort to contact *every* transistor and transistor component manufacturer in the nation. However, some few firms refused to cooperate as a matter of "Company Policy" which prohibited the disclosure of any material which might be considered "trade secrets"; some few others had not yet crystallized their designs and production plans and thus were reluctant to release any information or samples; and, finally, some few others were interested only in Government and limited Industrial sales of their products and, therefore, objected to any general type of publicity.

The author has long felt that the usual acknowledgement list, which gives firm names only, fails to convey the truly personal help extended by individuals within those firms. Therefore, in this instance, the author wishes to depart from usual custom and to acknowledge the help of *both* individuals and firms . . . to all, the author's thanks:

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PART I — LABORATORY PRACTICE

Chapter 1

INTRODUCTION

Amplifier vacuum tubes may be considered as a sub-group within a large class of thermionic tubes, which includes diodes, power rectifiers, phototubes, and special purpose vacuum and gas-filled tubes. In an analogous manner, transistors may be considered as a group within a general class of semiconductor devices, including diodes, photo-cells, and special purpose units. There are other analogies between these two classes of electronic devices. With thermionic tubes, there are triodes, tetrodes, and other types. Similarly, with transistors, there are both triodes and tetrodes, with special purpose types theoretically possible, and many now in a developmental stage. With thermionic tubes, triodes, for example, may be obtained with varying characteristics to suit them to particular applications . . . with high or low gain, with low inherent

BASIC AMPLIFIER CHARACTERISTICS
(Junction Transistors)

Type Amplifier	Input Impedance	Output Impedance	Voltage Gain	Power Gain	Phase
*Grounded-Emitter**	Moderate	Moderate to High	High	High	Reversal
Grounded-Base	Very Low to Moderate	High	Moderate	Moderate to High	In Phase
Grounded-Collector	High	Moderate to Low	Low (Less than 1)	Low	In Phase

*With high power transistors in the *grounded-emitter* configuration, both input and output impedances are likely to be low.

TABLE A

noise, and with other special characteristics. Similarly, with transistors, special types are available having either high or low gain . . . and low noise types are avaliable for critical audio applications.

All transistors depend for their operation upon the electrical properties of a class of materials known as semiconductors. Among the semiconductors are both chemical elements such as selenium, germanium and silicon, and compounds, including certain metallic sulphides, such as cadmium sulphide and lead sulphide, some oxides, such as copper oxide, and many others. Almost all the semiconductors are crystalline substances which are neither good insulators nor good conductors, but which may act as either, depending on the physical and electrical conditions to which they are subjected. When a semiconductor acts as a conductor, electrical current flow through the substance may take place in two ways—by means of a movement of free electrons, as in an ordinary conductor, or by the gradual migration of positive "holes" through the molecular structure. A "hole" is the *absence* of an electron needed to complete the structure of a molecule or atom. This deficiency can be made up by robbing a nearby molecule of one of its electrons and the "hole," in this manner, can travel slowly through a crystalline structure, just as if it were a real particle. Since electrons carry a negative charge, semiconductors in which current flow occurs primarily by means of free electrons are termed "negative" or *N-type* semiconductors. Since a "hole" is the absence of an electron, it may be considered to carry the opposite charge and, thus, semiconductors in which current flow occurs primarily by means of holes are termed "positive" or *P-type* semiconductors. Both N-type and P-type semiconductors are needed in a transistor.

Semiconductor Materials: At the present writing, germanium and silicon are the most popular semiconductor materials for transistor manufacture, but selenium, copper sulphide, copper oxide, and other semiconductors are used extensively in the production of diodes, power rectifiers,

photo-cells and other devices. In practice, the conduction characteristics of a semiconductor may be changed by adding a small quantity of properly chosen impurity to the pure material. If the impurity has the effect of increasing the number of free electrons in the material, it will make the semiconductor have N-type properties. Since the impurity adds or "donates" electrons to the structure, such materials are called *donors*. On the other hand, if the addition of the impurity results in an increase in the number of "holes" in the crystalline structure, it gives the basic semiconductor P-type properties, and, since these holes can accept free electrons, this type of impurity is called an *acceptor*. As far as germanium is concerned, typical *donor* impurities are phosphorus, arsenic, and antimony, while typical *acceptor* impurities are indium, aluminum, boron and gallium.

TYPES OF TRANSISTORS

Today, transistors are available in a wide variety of styles and types (see Fig. 1-1), each with its own individual electrical characteristics. An even greater variety of types may be expected in the future. Subminiature types are available for compact wiring, larger types for power work. A hearing aid transistor and a power unit are compared in Fig. 1-2. Some transistors are designed primarily for switching and control operations, others for audio work, and still others for high frequency circuitry. Experimental transistors have been used in R.F. circuits at frequencies as high as several hundred megacycles. However, regardless of their individual electrical characteristics, all transistors may be classed in general groupings based on (a) their type of construction, (b) number of electrodes, triodes, tetrodes, etc., and (c) the arrangement of semiconductors used. Let us discuss each grouping individually.

Type of Construction: The four basic types of transistor construction currently employed are illustrated schematically in Fig. 1-3. Only triode transistors are shown in this illustra-

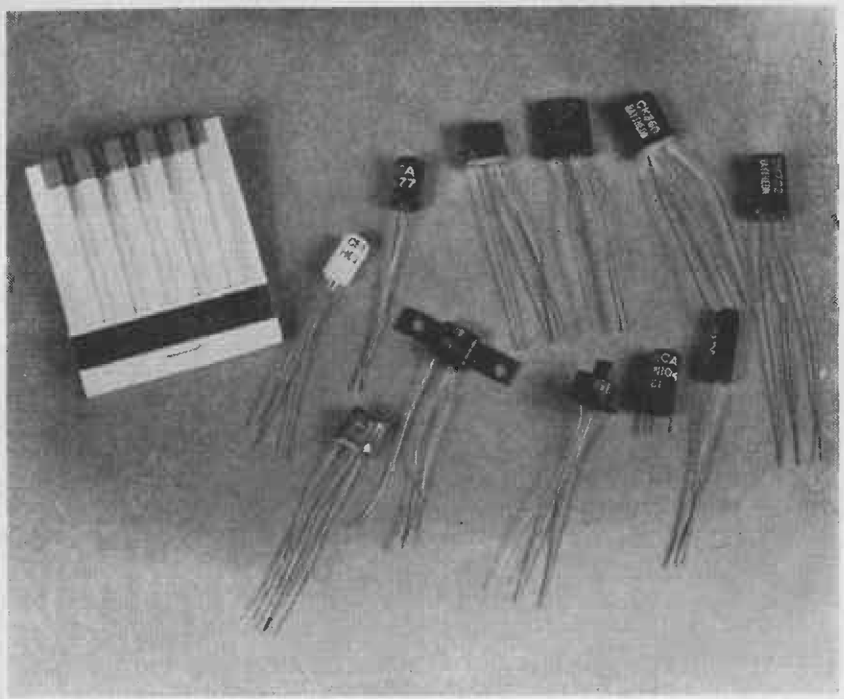


Fig. 1-1.—A collection of typical transistors. A match book is included for size comparison. Transistors shown include units manufactured by RCA, GE, CBS-HYTRON, SYLVANIA, RAYTHEON, RADIO RECEPTOR, AMPEREX, TRANSISTRON, and GERMANIUM PRODUCTS.

tion, with the *emitter, base,* and *collector* electrodes roughly analogous to the *cathode, grid,* and *plate,* respectively, of a vacuum tube. Of the types shown, the *point-contact* transistor is the oldest, having made its first public appearance in 1948 at the Bell Telephone Laboratories in New York. The *junction* transistor was not announced until three years later, in July of 1951. The *surface-barrier* transistor is the newest type, having, at this writing, just been released in commercial production quantities (1955). All four types may be used in circuit work but the point-contact transistor appears to be rapidly approaching obsolescence, for almost all major transistor manufacturers contacted by the author have indicated

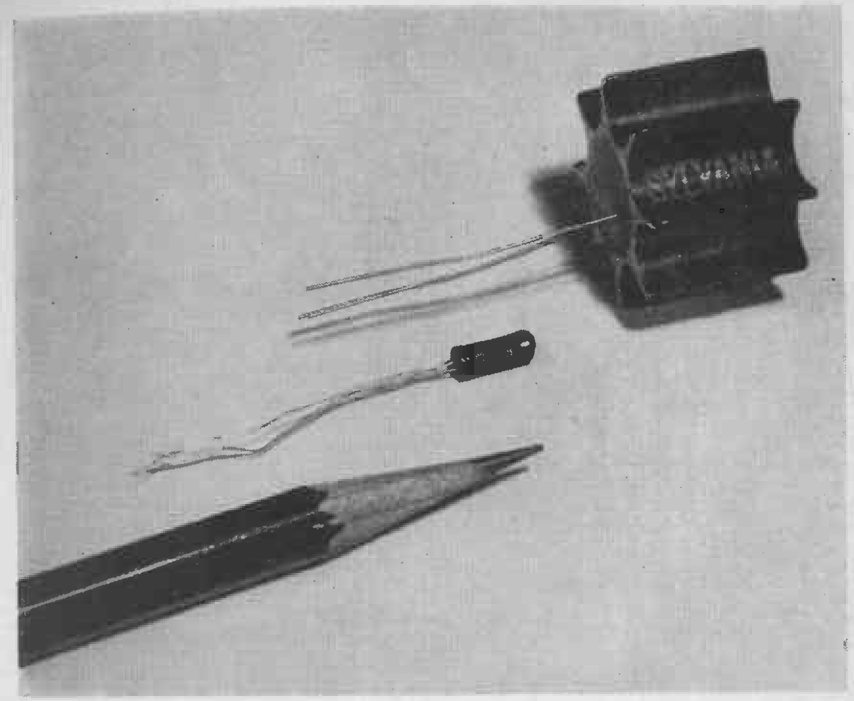


Fig. 1-2.—A TRANSISTRON hearing aid type transistor compared to a SYLVANIA power transistor to show relative sizes. Pencil gives an idea of true size.

that they have discontinued or are planning to discontinue the production of point-contact units.

In construction, the point-contact transistor consists of a minute block of N-type or P-type semiconductor material, with two fine, closely spaced "cat's-whiskers" or point electrodes making pressure contact against its surface. The semiconductor may be a small square measuring only 1/20 of an inch on each side by about 1/50 of an inch thick. The cat's-whiskers are separated by only a few thousandths of an inch. One electrode serves as the emitter and the other as the collector, with the small block of semiconductor material itself serving as the base. The enlarged photograph of a point-contact transistor given in Fig. 1-4 clearly illustrates the type

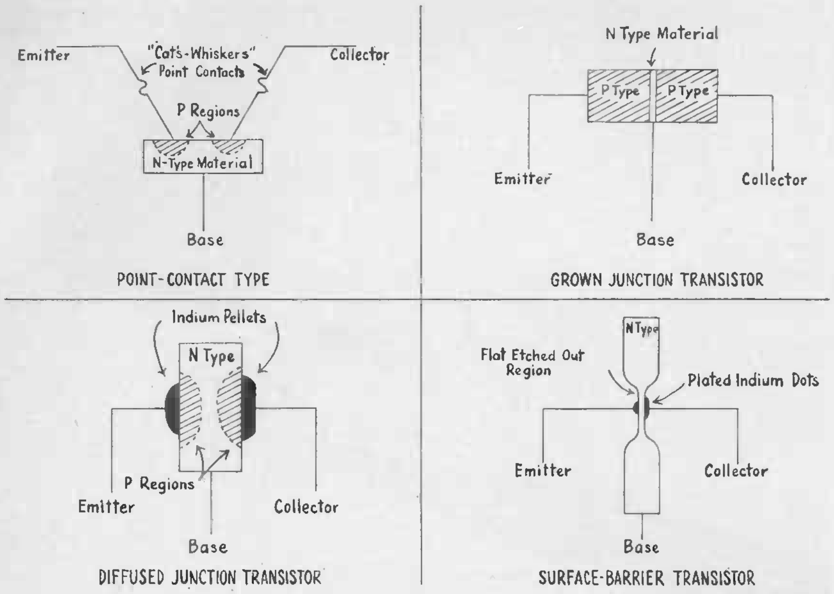


Fig. 1-3.—The four types of transistor construction are shown schematically in this sketch.

of construction employed . . . both cat's-whiskers as well as the small piece of semiconductor material are clearly visible. During the manufacturing process, small regions are formed under each electrode's contact point with a conductivity type opposite to that of the base. Where the base is N-type material, as in Fig. 1-3, these regions are given P-type properties, and vice-versa. The characteristics of the base material identifies the transistor. Thus, we have both N-base and P-base point-contact transistors.

Junction transistors may be manufactured in two ways—as either *grown* or as *diffused* junction units. Both types are shown in Fig. 1-3. Their electrical characteristics are quite similar and they may be used in much the same circuits. The grown junction transistor is the more difficult to manufacture and consists of a single crystal of semiconductor material having alternate layers of P-type and N-type substances. The

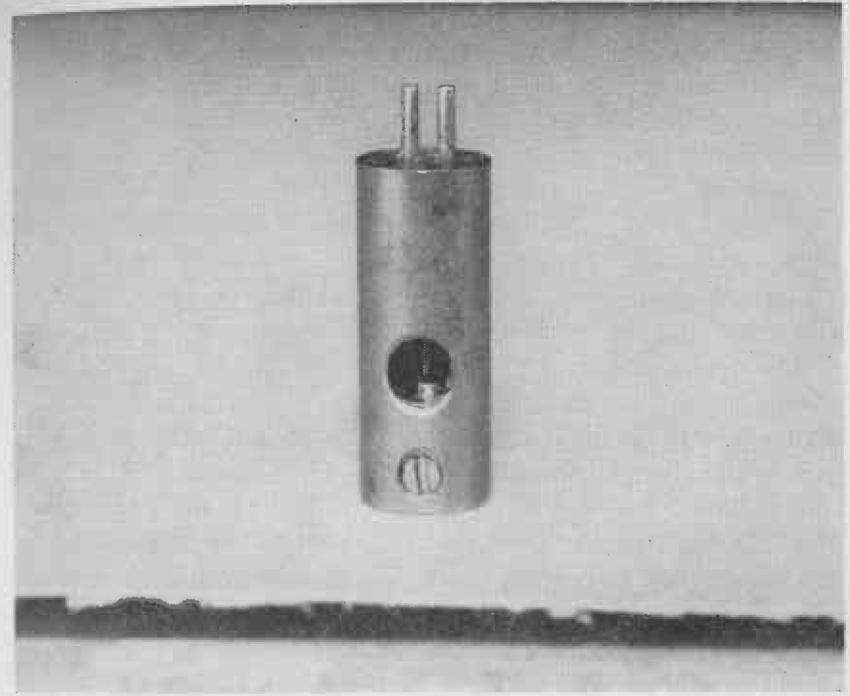


Fig. 1-4.—Enlarged photograph of a point-contact transistor. The two cat's-whiskers and the small block of semiconductor material are clearly visible.

central layer of the "sandwich" formed is much thinner than the outer layers and serves as the base. In practice this layer may have a thickness of only only one one-thousandths of an inch. To produce a grown junction crystal, certain impurities are added to a semiconductor, such as germanium, while it is in a molten state. These impurities are chosen so as to "dope" the material to give it either N-type or P-type characteristics. A large single crystal may then be grown by dipping a "seed" crystal into the molten metal and slowly withdrawing it under rotation. Additional impurities are added during the drawing process to produce alternate N-type and P-type layers in the single crystal. Later, the large crystal may be cut into smaller sections and leads attached at the proper points to produce individual transistors. A diffused junction transistor is made by melting a button or pellet of proper substance on either side of a small thin wafer of semiconductor material. If N-type germanium is used for the wafer, the pellets might be of indium, gallium or boron. The melted pellets diffuse into the semiconductor from either side, changing it to the opposite conductivity type in a limited region (thus, N-type is changed to P-type). The final result is, again, alternate regions of N-type and P-type semiconductor material. One pellet (usually the smaller) serves as the emitter connection, the other as the collector, with the thin wafer becoming the base.

The *surface-barrier* transistor bears a superficial resemblance to the diffused junction unit in that small dots or pellets of a selected material are deposited on either side of a thin wafer of semiconductor crystal, but, regardless of this resemblance, the two types are not alike. No diffusion takes place. Instead, the dots are simply *plated* on the surface of the semiconductor. In manufacture, two fine streams of a metallic salt solution are played against opposite faces of a thin semiconductor wafer. At the same time, a direct current is applied to the streams of salt solution and the wafer so as to electrolytically etch away the sprayed areas. After this etching process has been carried on until the center of the wafer is only a few ten-thousandths of an inch thick, the polarity of the applied D.C. is reversed, stopping the etching process and electroplating metallic dots on directly opposite faces of the wafer. These dots serve as the emitter and collector of the completed transistor, with the semiconductor wafer becoming the base. Where the wafer is N-type germanium, an indium sulphate solution might be used for the etching process, with indium dots electro-plated on the surface in the final steps.

Generally speaking, point-contact transistors are capable of operating at much higher frequencies than junction units. In addition, they have a longer history, being the first type to be manufactured; they are just as small as junction units physically (see Fig. 1-5) and may have much higher *alpha* (current amplification factor in a grounded-base circuit). In

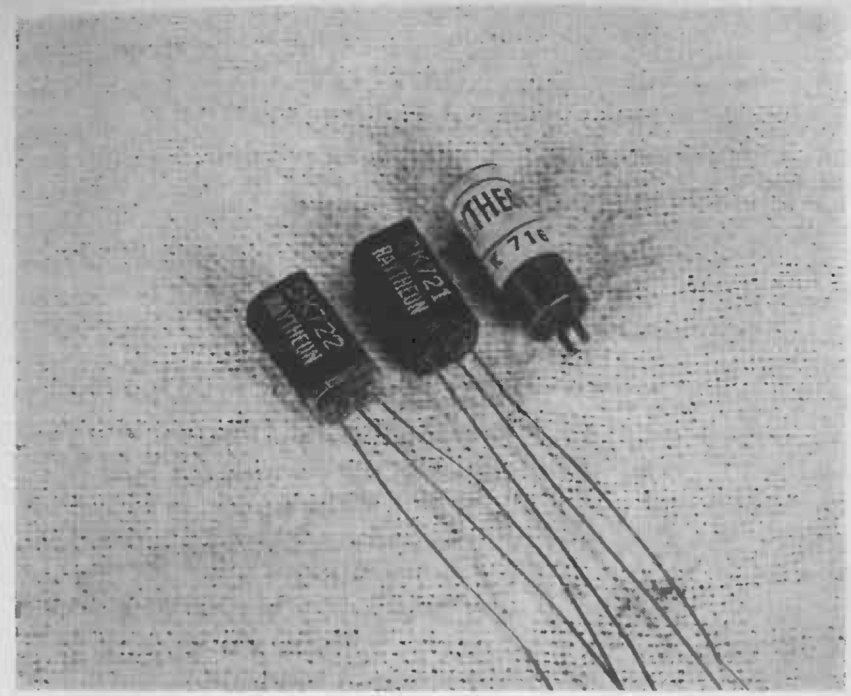


Fig. 1-5.—As this photograph shows, point-contact transistors are no larger than junction units. The cylindrical unit is an early point-contact transistor, the other two are junction units. All three are produced by the same manufacturer—RAYTHEON.

view of these facts, it may appear strange that point-contact units are becoming obsolete. However, since the cat's-whiskers used in point-contact transistors must be very accurately placed, these units are more difficult to manufacture than junction transistors from a production viewpoint and hence are more costly. In addition, junction transistors have the edge as far as efficiency, operating voltage, ruggedness, noise level, and power handling capabilities are concerned. It is for these sound economic and technical reasons that junction transistors predominate at the present writing, and, because of this predominance, *the circuits given in this handbook will refer specifically to junction transistors unless otherwise* *stated.* It is possible, of course, that modified point-contact transistors will again be manufactured in production quantities in the future, perhaps for use in special purpose applications.

Number of Electrodes: The majority of present day transistors are triodes, although both point-contact and junction tetrode units have been manufactured in moderate production quantities. Light sensitive phototransistors, in general, have only two electrodes, the third electrode being replaced by the light sensitive surface, and thus they may be considered as a type of diode. A number of specialized transistors have been suggested as theoretical possibilities, and some have even been hand-assembled for laboratory tests. Such units include the *analog transistor, PN "Hook" transistor,* and various *multi-purpose transistors.* The analog transistor is a theoretical type utilizing a special construction to obtain electrical characteristics similar to those obtained with vacuum tubes (i.e., high input and high output impedances). The *PN* "Hook" transistor is a special type junction transistor using three junctions instead of the usual two (such as a *PNPN* transistor) and, theoretically, may have a gain many times greater than that obtained with conventional junction units. Multi-purpose transistors are roughly analogous to multi-purpose vacuum tubes, in which several relatively independent tube assemblies are contained within a single envelope, often with a common cathode. As far as transistors are concerned, one possible type might be a unit combining a *PNP* and a *NPN* junction transistor into a single unit, for application in push-pull stages using the complementary symmetry principle.

Arrangement of Semiconductors: As we have seen, most transistors are made up of alternate regions of N-type and P-type semiconductor materials. Even the point-contact transistor falls within this category, because small regions under each electrode point are converted to a conductivity type opposite that of the base material during the manufacturing process. The exact arrangement of semiconductor materials within the transistor determines the polarities of the D.C.

power supply voltages applied to the electrode terminals when the transistor is connected in a practical circuit. The application of incorrect voltages may very easily ruin the transistor. Hence it is extremely important that the worker be familiar with the semiconductor arrangement in the transistors he employs and, further, that he know the proper D.C. supply voltages for each basic transistor type.

Junction transistors are identified as *PNP* or *NPN,* with the middle letter designating the conductivity characteristic of the base material. The schematic symbol employed is similar for both types and consists of a heavy straight line representing the base, together with slanting lines to the base representing the emitter and collector terminals. An arrowhead identifies the emitter terminal. It points *towards the base* in the case of *PNP* transistors, as shown at (a) in Fig. 1-6, and *away from the base* in the case of *NPN* units, as shown at (b) in Fig. 1-6. Proper power supply connections for both types of transistors, connected as *grounded-emitter* amplifiers, are given in Fig. 1-6. Note that with the *PNP* transistor, both the base and collector are *negative* with respect to the emitter. With the *NPN* unit, the base and collector are *positive* with respect to the emitter.

Point-contact transistors are identified by the type of base material used in their construction rather than by the three letter designation employed to identify junction units. Thus, we have both N-base and P-base point-contact transistors. However, as far as the schematic symbols and D.C. power supply polarities are concerned, the N-base point-contact transistor may be considered as equivalent to the *PNP* junction transistor, while the P-base point-contact unit is equivalent to the *NPN* junction transistor.

CIRCUIT CONFIGURATIONS

In Fig. 1-6, the basic circuit arrangement for a *grounded-emitter* transistor amplifier stage was used to illustrate the power supply connections for *PNP* and *NPN* transistors.

Actually, there are three basic circuit arrangements that may be employed, depending on the way a signal is applied to a stage, the location of the output load impedance, and on how the output is obtained from the stage. These are roughly analogous to the three basic vacuum tube amplifier circuits, with the *grounded-emitter* circuit approximately equivalent

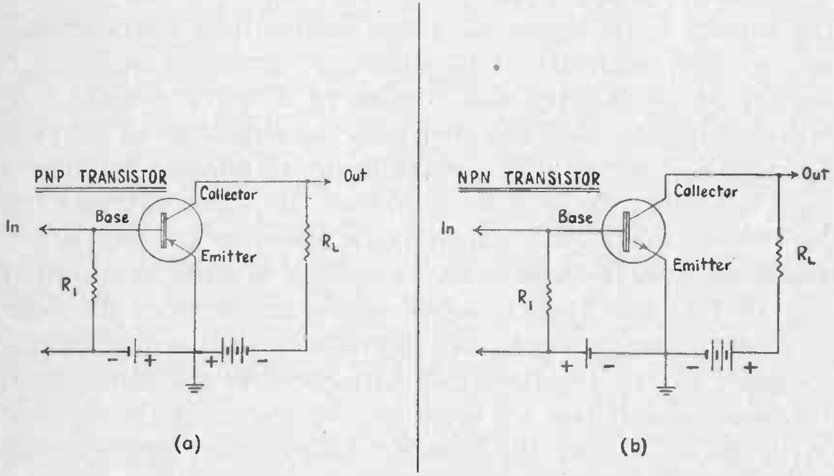


Fig. 1-6.—The schematic symbols and D.C. power supply connections for PNP and NPN transistors are shown here. The only difference in the schematic symbols is in the direction in which the arrowhead points on the line representing the emitter electrode.

to the grounded cathode tube circuit, the *grounded-base* to the grounded-grid, and the *grounded-collector* to the grounded plate or cathode follower. All three circuits are shown in Fig. 1-7, together with the corresponding vacuum tube circuit arrangements. In each case, the power supply connections are for *PNP* junction transistors. With *NPN* units, supply polarities would be reversed. Each stage is identified by the transistor element (or tube electrode) that is *common to both the input and output circuits.* This is generally called either the "grounded" or the "common" element but, in

actual practice, this element need not necessarily be connected to circuit ground.

Referring to Fig. 1-7, with the grounded-emitter circuit arrangement (a), the input signal is applied between the base and emitter, with the output signal appearing between collector and emitter. The emitter is thus common to both circuits. In the grounded-base circuit (b), the input signal is applied between emitter and base, with the output appearing

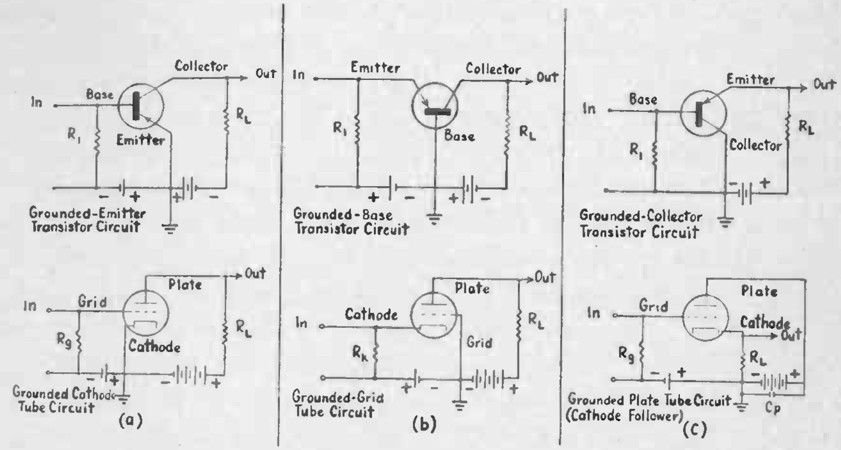


Fig. 1-7.—The three basic transistor circuit configurations with the roughly equivalent vacuum tube circuit arrangements. Power supply polarities shown are for PNP transistors . . . polarities would be reversed for NPN units. See TABLE A for a comparison of their basic electrical characteristics.

between collector and base, and the base is common to both the input and output circuits. Finally, with the grounded-collector cricuit (c), the input is applied between base and collector and the output appears between emitter and collector, with the collector becoming the common element. Signal phase reversal occurs in the grounded-emitter, but not in the grounded-base and grounded-collector configurations. A single battery may be used to supply all D.C. operating voltages or a separate "bias" battery may be provided in the base circuit, at the option of the individual designer. Two batteries are shown at (a), a single battery at (c). The basic characteristics of the three standard transistor circuit configurations are summarized in Table A. The characteristics listed are based on currently available transistor types.

PART I — LABORATORY PRACTICE

Chapter 2

TECHNIQUES

Experimental transistor circuit work may be undertaken with many of the same tools, laboratory test instruments and mechanical skills that are used in the assembly and test of conventional vacuum tube circuits. Except where fundamental semiconductor research is involved, the individual or laboratory contemplating transistor circuit experiments need not anticipate more than a modest expenditure for special tools or laboratory equipment, nor need the worker have to spend a long training period to acquire new skills or to learn new techniques. In most cases, any special skills that are needed may be acquired on the job, simply by approaching early projects with care and forethought, following the advice given in an old proverb . . . "to make haste slowly!"

Perhaps the most important practical skill the laboratory technician or home experimenter need acquire is the ability to work with components many times smaller than those used in conventional electronics work. There is no question that somewhat greater skill, and certainly greater patience, is required when working with subminiature components than when working with 'full-sized" parts. In addition to sharpening his mechanical skills, if the technician has worked with vacuum tube circuits exclusively for a long period of time, he may have to rechannel his thinking somewhat so that he can readily accept and work with voltage, current and impedance values of a different order than those with which he may have been familiar. When working with vacuum tube circuits, for example, D.C. operating voltages in the neighborhood of several hundred volts are the rule—but with transistors, high voltages are seldom used, even in higher power circuits. Supplies of a fraction of a volt may be encountered in some circuits. Then, too, when dealing with the usual transistor circuits, he will have to pay close attention to power supply polarities . . . reversed plate voltage may seldom damage a vacuum tube, but reversed D.C. supply voltage is almost sure to ruin a transistor. To complicate matters, different types of transistors may require exactly opposite supply voltage polarities (i.e., PNP and NPN units), and, in some cases, both types may be used in the same circuit (i.e., complementary symmetry push-pull amplifiers). In using transistors for the first time, the worker will be faced with the seeming paradox of working with components that are simultaneously more rugged mechanically, yet more easily damaged electrically than vacuum tubes.

TOOLS AND LABORATORY EQUIPMENT

Transistor circuits may be wired into either "full-sized" or subminiature equipment. But even if no special attempt is made at subminiaturization, since transistors and most transistor components are much smaller than conventional electronic components, they are a little awkward to handle with full-sized hand tools. For this reason, the technician planning appreciable transistor circuitry work should be outfitted with scaled-down tools. Jeweler's pliers are ideal for this type of work and are now stocked by many Electronic Parts Distributors. A typical assortment of hand tools especially selected for transistor circuit work is shown in Fig. 2-1. Included are a cased set of jeweler's pliers, an *ORYX* subminiature soldering instrument, a scribe, tweezers, small brush, pocket magnifier, and a set of jeweler's screw-drivers. The small screwdrivers are not essential to wiring, of course, but are useful when working with the miniature assemblies in which transistors are frequently installed. Additional tools which would be useful in subminiature assembly work, but which are not shown in the photograph, would include a small hand or bench vise, fitted with smooth soft-metal jaws, a penlight,

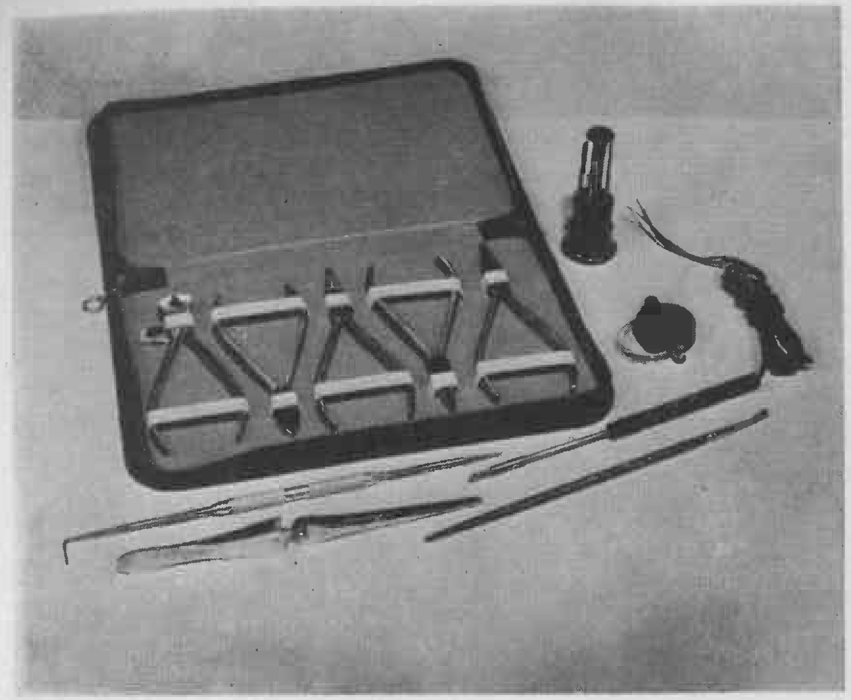


Fig. 2-1.—Hand tools useful when working with transistor circuits.

miniature socket wrenches, a set of Swiss Needle Files, and a power tool kit, including the power unit, small drill bits, rotary brushes, and similar accessories.

Techniques: Although the majority of small tools are handled and used in the same way their conventional sized counterparts are employed, there are a few special techniques which the worker may wish to learn. The use of a jeweler's screwdriver is illustrated in Fig. 2-2. The cap on the screwdriver's handle is free to rotate and is held lightly with one finger, which both applies pressure and guides the tool. The body of the handle is rotated gently by the thumb and another finger. This technique makes it difficult to apply excessive torque, thus minimizing the danger of damage to the screwdriver's blade or any tendency to "strip" the threads of small

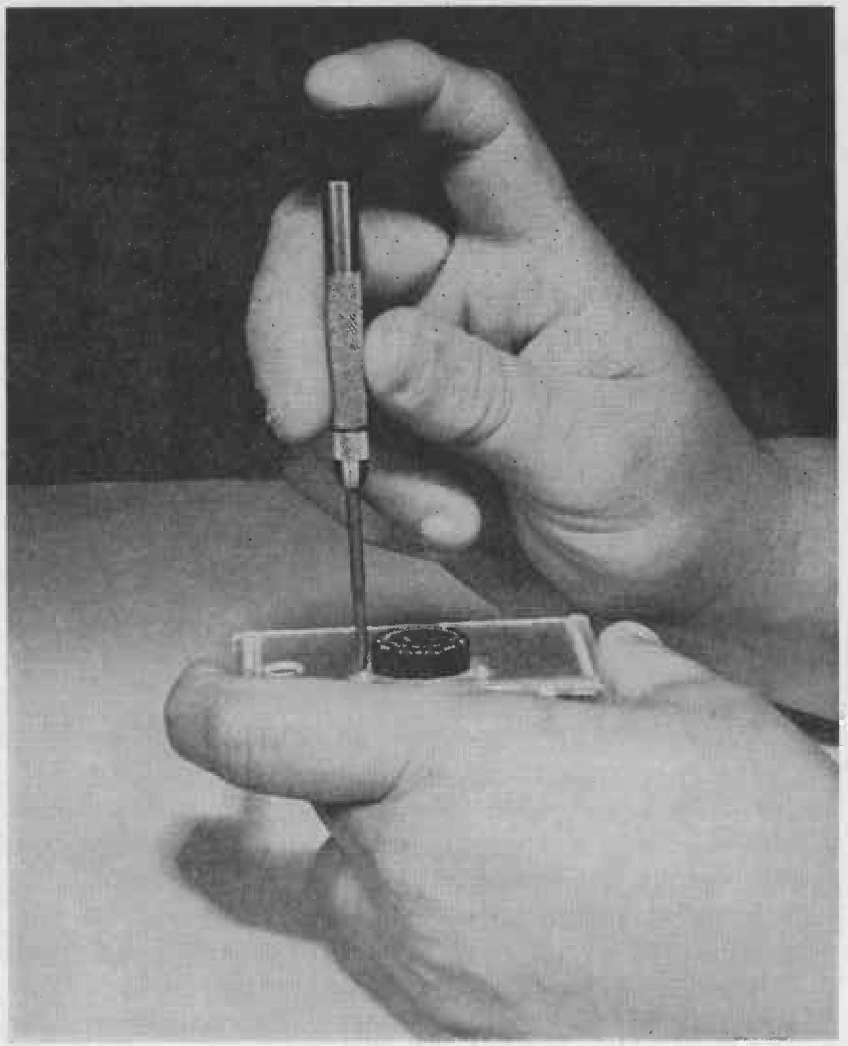


Fig. 2-2.—Proper technique for using a jeweler's screwdriver.

machine screws. When wiring transistorized circuits, a small pencil-type soldering instrument is preferable to a full-sized tool. The tip should be kept clean and well-tinned so all soldering operations may be completed as quickly as practi-

cable. The use of a heat sink is recommended (see section on CARE OF TRANSISTORS and Fig. 2-9). In subminiature wiring, simple lap joints are frequently employed in preference to the "wrap-around" connections common in conventional electronic assemblies. In some instances, the worker may find it easier to clamp his soldering instrument in a vise, holding the components to be wired in his hands, as shown in Fig. 2-3. While resistors and small capacitors may be held

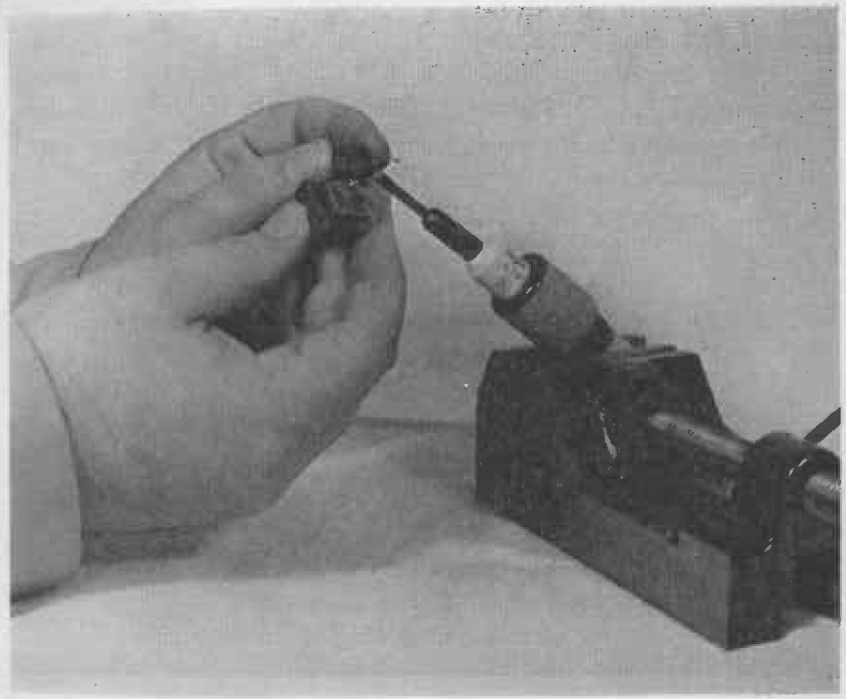


Fig. 2-3.—Some technicians prefer to clamp their soldering instrument in a vise.

in place by their leads, transformers and other large components are frequently mounted either by cementing in place or by clamping in position with small spring or wire clips. Other special assembly techniques employed in transistor circuit work include the use of etched or printed circuits and the potting of sub-assemblies in plastic. These special topics will be discussed in Part IV of this volume.

Test Equipment: Audio and R.F. Signal Generators, Oscilloscopes, VTVMs, Impedance Bridges, in fact, almost every type of electronic test equipment found useful in vacuum tube circuit work will find similar applications in experimental transistor work. Some test equipment items are especially important. A good assortment of individual meters is highly desirable and, for circuit development work, almost mandatory. If voltmeters are sometimes considered a shade more valuable than current meters in vacuum tube work, with transistors the reverse is true. Thus, while the meter assortment should include several D.C. microammeters for checking base current values and milliammeters for collector and emitter current measurements (or, in the case of high power transistors, D.C. *ammeters*), one or two D.C. voltmeters should be ample for general work, especially if multi-range instruments are provided. Since battery power supplies are used extensively in transistor circuitry, a good Battery Tester would be a desirable addition to the lab. The tester chosen should be designed to check the batteries under load conditions. If precise circuit tests and transistor parameter measurements are to be made, one or more adjustable output *Constant Current* power supplies are desirable. However, for general experimental work, any standard adjustable voltage D.C. supply will be found almost as useful, provided its output can be reduced to near zero and that low voltages can be obtained without difficulty. Where circuit development is undertaken with a view towards eventual mass production, enviromental test chambers are a desirable addition to the laboratory's complement of test equipment, to permit the thorough checking of compensation circuits under actual conditions. At this writing, commercially available transistors are somewhat more sensitive to temperature and humidity variations than are vacuum tubes and a thorough enviro-

mental test of circuits contemplated for production is good engineering practice.

Breadboarding: It is standard engineering practice to *breadboard* or to "rough assemble" new circuits, not only as a double-check on the validity of a theoretical design, but also for determining circuit values that are difficult either to calculate or to estimate in advance. Breadboarding may be used for checking mechanical and electrical layouts and for locating unforeseen "bugs" in a design. In addition, a breadboard assembly, once checked out, is useful for determining the practical effect of component tolerances on circuit operation. Many experienced practical electronics engineers prefer to work up a new circuit design right on a breadboard chassis, keeping mathematical calculations and other paper work to a

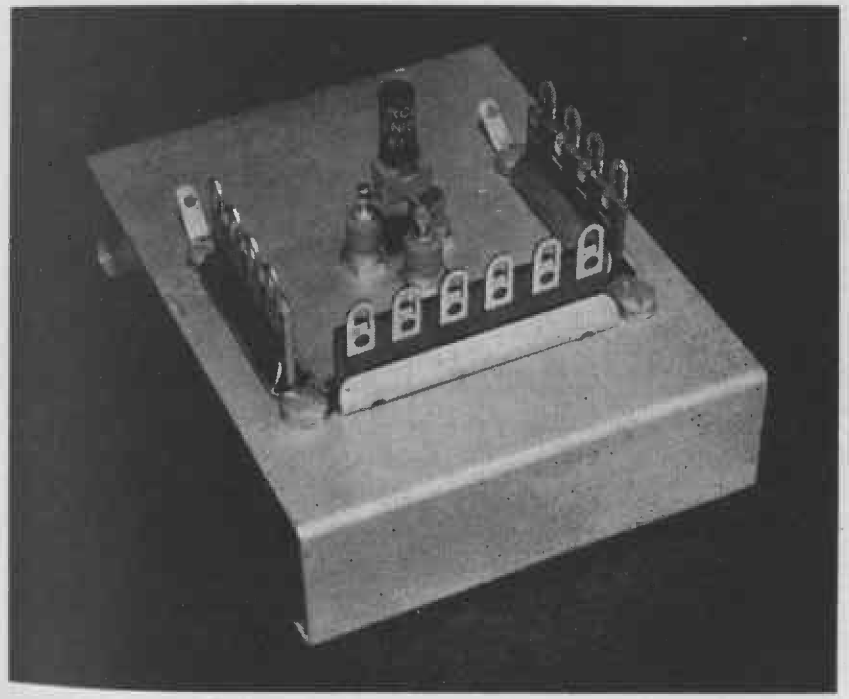


Fig. 2-4.—A "Universal" Breadboard chassis designed for transistor tests.

minimum. With transistors, the breadboard check of a circuit design is, if anything, more important than with vacuum tube circuits. Unfortunately, the small physical size of transistors makes them a little difficult to handle conveniently on the lab. bench. For this reason, the individual laboratory worker may find it worthwhile to assemble a "breadboard" chassis specifi-

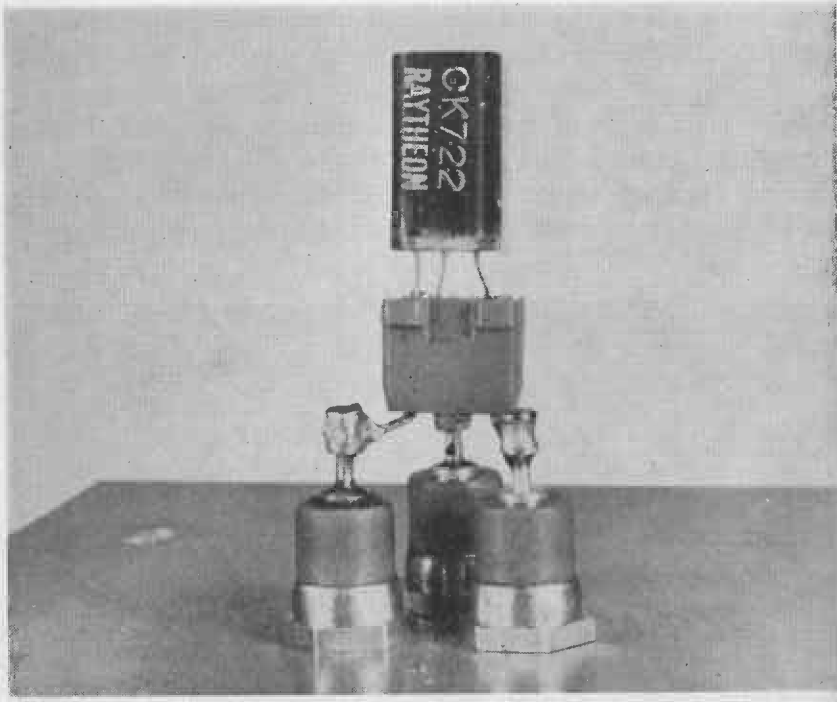


Fig. 2-5.—Detail of transistor socket mounting.

cally for checking transistor circuits. One such "universal breadboard" chassis is shown in Fig. 2-4. A subminiature in-line tube socket serves as a transistor socket, and is mounted on three small stand-off terminals. A detail view of the socket mounting is given in Fig. 2-5. Several terminal strips are provided on the chassis to permit the easy mounting and wiring of resistors, capacitors, and other components. The use

of a breadboard chassis is illustrated in the typical lab. bench set-up shown in Fig. 2-6. For maximum utility, the basic chassis is used in conjunction with clip type test leads and panel meters. In addition to home built chassis, commercial "breadboards" are available—see Part IV. Other useful accessories, not shown in the photograph, would include Resistance

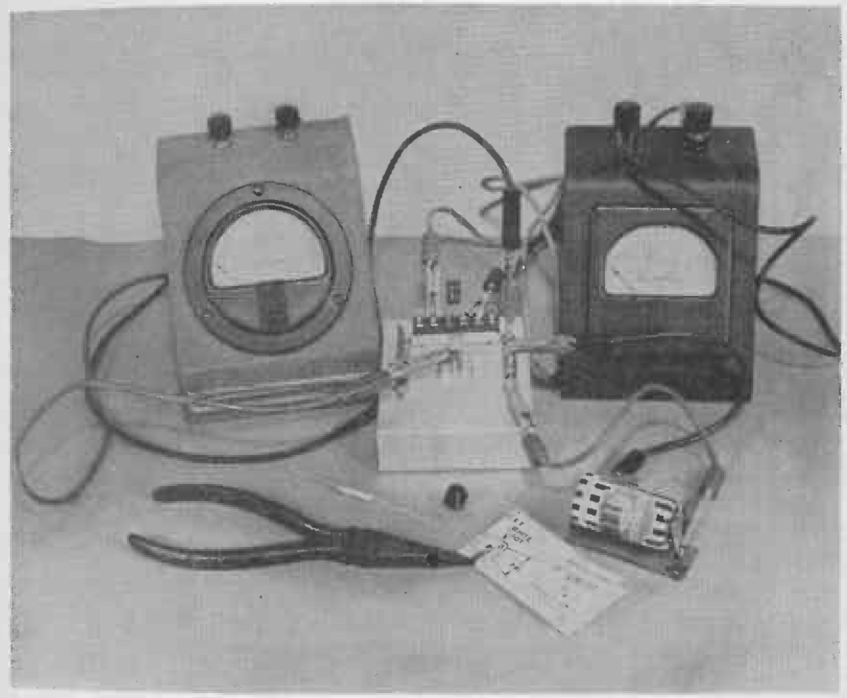


Fig. 2-6.—A typical experimental set-up for checking a breadboarded transistor circuit.

and Capacitor Substitution Boxes, and an assortment of small "universal" transformers and inductors. Proper electrode pin connections for a standard triode transistor are shown at (a) in Fig. 2-7, for a tetrode junction transistor at (b) in the same illustration. However, not all manufacturers adhere to this "standard" pin arrangement. Pin connections for certain transistors of three popular manufacturers are shown at (a), (b), and (c) of Fig. 2-8. The pin arrangement shown at (a) is used on *TRANSITRON* subminiature types 2N88, 2N89 and 2N90. The connections shown at (b) are employed by *PHILCO* on their types 2N47, 2N49 and SB-100. And the pin arrangement used by *RAYTHEON* on their types CK721, CK722, CK725 and CK727 is shown at (c).

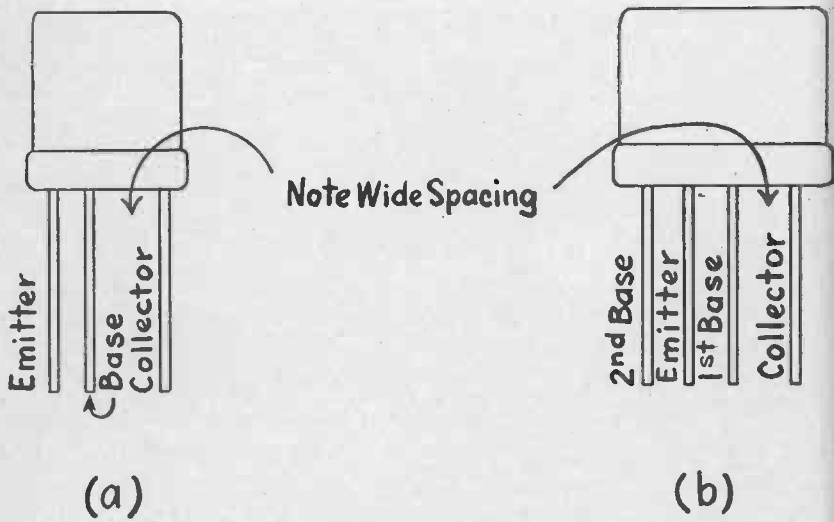


Fig. 2-7.—Pin connections for standard triode (a) and tetrode junction (b) transistors.

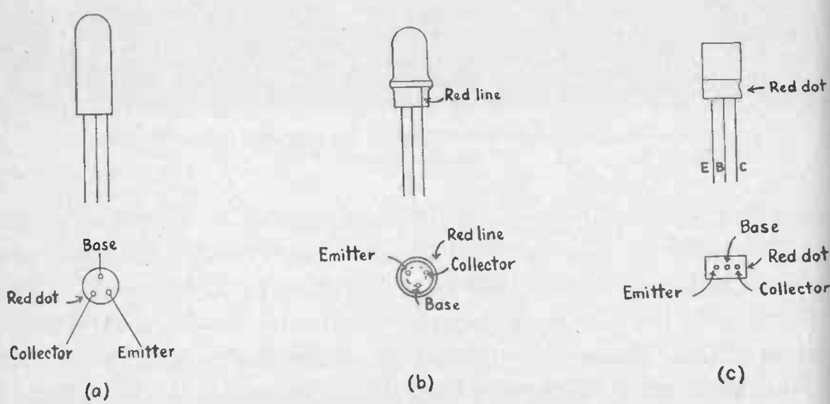


Fig. 2-8.—Special transistor pin connections used by some manufacturers. TRANSITRON (a); PHILCO (b); RAYTHEON (c).

CARE OF TRANSISTORS

It is unlikely that transistors will ever be "given away" in quantities, and therefore, regardless of how inexpensive they may become, they still represent a financial investment, whether their cost is borne by the Research Account of a large corporation or the "hobby budget" of a home experimenter. And any investment should be handled with care. It has been mentioned that transistors are many times more rugged than vacuum tubes as far as mechanical shock is concerned. Some transistors may successfully withstand an acceleration of 20,000 to 30,000 *g*,* whereas an acceleration of 750 *g* is about the upper limit as far as vacuum tubes are concerned. But this inherent ruggedness is no excuse for deliberate abuse. Although mechanically rugged, transistors may be easily damaged by electrical overload or excessive heat. Therefore, the laboratory worker will find it profitable to adopt a few "rules of practice" to follow when working with transistors. Later, as he gains experience, he will find himself following these rules almost subconsciously. For ease in reference, the basic rules are listed below in numerical order . . . but remember that the order of listing does not indicate the order of importance—all are equally important.

1. **Avoid Excessive Heat** — High temperatures, whether applied externally or internally generated, may cause permanent damage to a transistor or permanent change in its electrical characteristics. Excessive heat may be avoided by taking care in soldering (see comments under WIRING TECHNIQUES, as given below), by avoiding operation close to hot vacuum tubes, power resistors or other components likely to dissipate quantities of heat, and by avoiding operation at near maximum ratings under conditions of high ambient temperatures. When transistors are used at higher than normal temperatures, their operational specs should be "derated" accordingly . . . refer to the manufacturer's specification sheets for specific suggestions.

* *g* = Acceleration due to gravity; the standard unit for measuring acceleration; equal to 32 ft./sec.².

2. **Avoid Electrical Transients** — Voltage or current surges which exceed the transistor's maximum ratings, even if only momentarily, may cause permanent damage. When working with new transistor circuit designs, transient pulses may be minimized by avoiding the sudden application of supply voltages—use a variable supply and adjust slowly to final values. Avoid the use of circuits which involve extensive switching of high level signals or D.C. voltages. When working with assembled circuits or built-up equipment, do not insert or remove transistors from their sockets with the power ON unless absolutely necessary.

3. **Always Double-Check Transistor Type and Voltage Polarities** — Remember that different types of transistors require different D.C. supply voltage polarities for operation, and that the application of an incorrect voltage may damage the transistor. Before wiring a circuit, make sure you know whether the transistor is a *PNP* or *NPN* unit (or a P-base or N-base type, if it is a point-contact transistor), and check to see that all supply voltages are applied with the proper polarity.

4. **Observe the Maximum Ratings** — Although some electronic components are conservatively rated and may be slightly overloaded without damage, the *Absolute Maximum Ratings* specified by transistor manufacturers mean exactly that. Even a momentary overload may cause irreparable damage. When breadboarding or testing new circuits, it is a good idea to connect D.C. current meters in series with each electrode to maintain a constant check on emitter, collector and base currents. The meters should be by-passed with appropriate capacitors when working with A.C. amplifiers, oscillators, and similar circuits, of course.

WIRING TECHNIQUES: In order to avoid possible heat damage, all transistor circuit wiring should be carried out as quickly as possible, using a hot, clean, well-tinned soldering instrument. Do not solder to transistor socket terminals without first removing the transistor, and allow ample time for

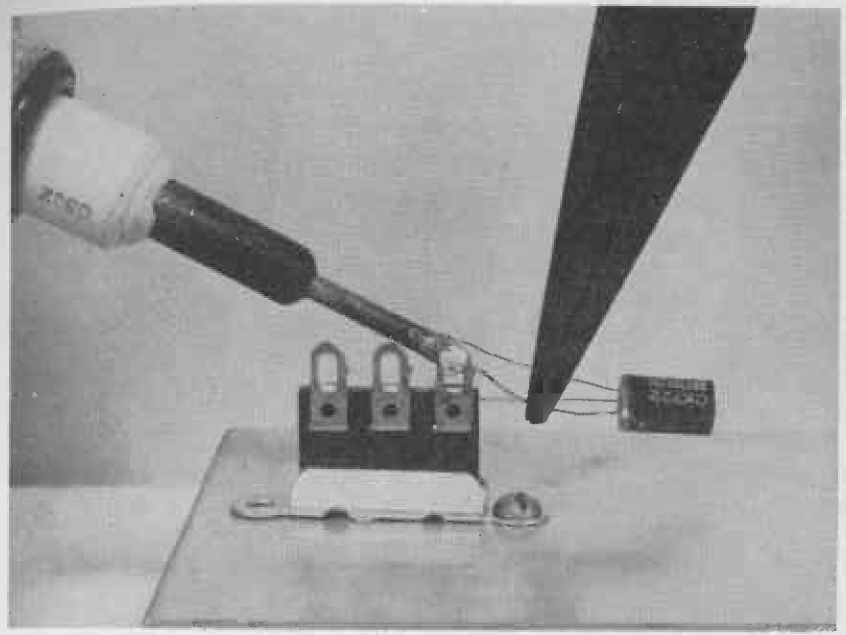


Fig. 2-9.—Proper use of a heat sink in soldering a transistor lead.

the joints to cool before reinserting the transistor. Where a transistor is wired directly into a circuit by means of its leads, use the maximum lead length consistent with good electrical layout and circuit design, protecting the bare wire with spaghetti tubing. For maximum protection, use a *heat sink* on the transistor lead between the soldered joint and the body of the transistor itself. The proper use of a heat sink is clearly illustrated in Fig. 2-9. The transistor lead being soldered is grasped with a pair of long-nosed pliers, which act to conduct heat away from the transistor proper. When installing *surface-barrier* transistors, care should be taken to avoid voltage surges derived from soldering irons operating from A.C. lines. As a precaution against such surges, the use of gun-type soldering instruments or isolation transformers is recommended.

POWER TRANSISTORS: High-power transistors present special problems in practical circuit work. First, because they are designed to handle *watts* instead of *milliwatts,* they generate a good deal of internal heat. Most commercial power transistors are designed to dissipate as much of this heat as possible. Two techniques are used. One is to design the external case to act as a heat radiator by providing cooling fins. Another is to make provision for mounting the transistor directly to a metal chassis, which then acts as an external heat sink. Often, both techniques are used at the same time, as shown in Fig. 2-10. Another problem encountered with high-power units, especially with germanium transistors, is that of "runaway." This generally occurs at high ambient temperatures when the internal power dissipation through self-heating lowers the resistance of the semiconductor, materially increasing collector current, thereby increasing power dissipation

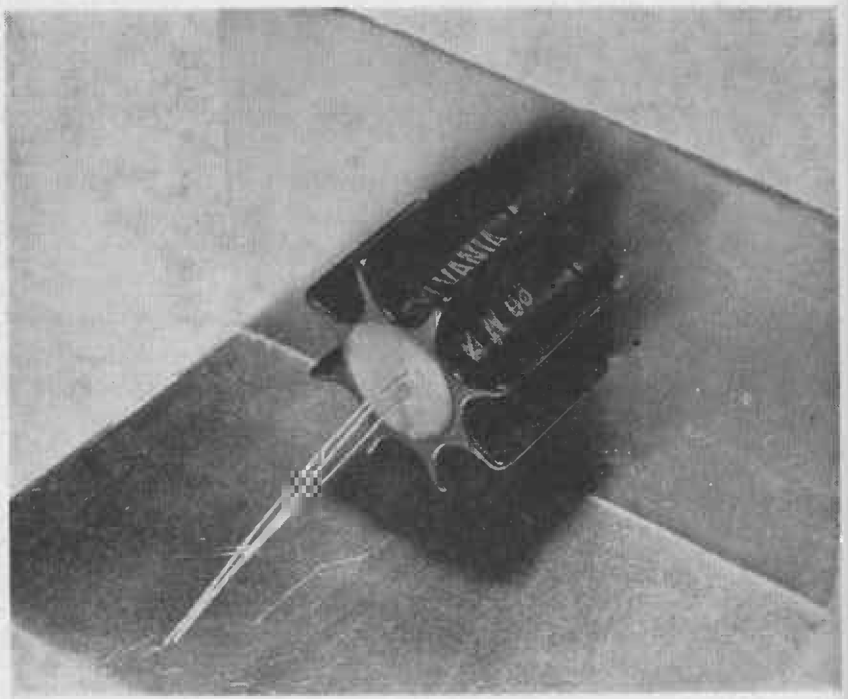


Fig. 2-10.—High-power transistor mounted on a chassis for maximum heat dissipation.

and raising the temperature still further. This can lead, eventually, to serious damage, if not complete destruction, of the transistor. Even if the transistor itself is not seriously damaged, the circuit becomes unstable. To guard against the possibility of collector current runaway, stabilization of D.C. operating points is strongly recommended in all applications involving the use of high-power transistors.

TESTING TRANSISTORS

The practical laboratory worker has several testing techniques at his disposal. First, he can use a laboratory-type Transistor Test Set. These instruments are currently produced by a number of manufacturers and, for the most part, incorporate facilities for completely evaluating all important characteristics and parameters of both point-contact and junction transistors. Transistor Testers are discussed in Part IV.

If the worker does not have a commercial Transistor Test Set available, he can duplicate most of the tests by using individual instruments. The basic instruments needed for most tests include a high-impedance VTVM, individual current meters and at least two adjustable output *constant-current* D.C. power supplies—one for each transistor electrode in the standard configurations. Where an especially built constant-current supply is not available, a satisfactory substitute may be assembled by connecting a high value resistor in series with a conventional adjustable B voltage supply. For best results the series resistor should have a value at least 100 (and preferably 1000) times higher than the expected load—this means the D.C. output current will be virtually independent of load and the assembly will act like a true constant-current supply. The expected load may be determined by referring to the manufacturer's specification sheet for the transistor to be tested; the load is the D.C. resistance of the electrode in question. Referring to the data sheet on the transistor, the equipment is set up to supply specified currents to the various electrodes and the D.C. electrode voltages are measured using the VTVM. These are actual electrode voltages . . . not source voltages, for a considerable drop will occur across the series resistor. A series of tests may then be made, with one electrode current kept constant and the other electrode current varied in small steps. These measured values may be plotted on a graph and compared to the characteristic curves given in the transistor manufacturer's data sheet. Essentially the same technique is employed to make tests of both grounded-base and grounded-emitter circuits, and to obtain data to plot such curves as emitter current vs, emitter voltage for a constant collector current (grounded base configuration), collector current vs, collector voltage for a constant emitter current (grounded base), collector current vs. collector voltage for a constant base current (grounded emitter), etc. *When making tests of this nature, all the precautions mentioned in the section CARE OF TRANSISTORS should be observed.*

Detailed tests of transistor characteristics, as important as they may be in a complete over-all evaluation of the component, are much too time consuming for most types of practical circuit work. A simpler and much more rapid test may be made by setting up a basic amplifier stage, applying a known input signal and proper D.C. operating voltages to the transistor, then checking over-all gain and individual electrode currents. While such a test does not give a quantitative evaluation of the transistor, it does give a qualitative "Good-Bad" check. If the gain is unusually low, or if the various electrode currents run high, or both, the transistor may be considered defective. This test is more effective in those cases where the transistor manufacturer has supplied "Typical Operating Characteristics" as part of his specification sheet, for the measured values may be compared directly to known standards. *However, when making such a comparison, a one-to-one correspondence should not be expected, for all transistors are manufactured within broad tolerance limits . . . only where the measured values are far different from expected values should the transistor be considered defective.* The "Typical Operating Characteristics" may also be used as a guide in setting up the original test circuit.

Where a transistor is to be used in a fairly critical circuit, such as a high-gain, low noise audio amplifier, or as a high frequency R.F. oscillator, there is no really satisfactory test other than that of substitution. That is, the suspected transistor is actually tried in the desired circuit. If it fails to give satisfactory performance, it is considered "Bad," at least as far as the one circuit is concerned. Of course, transistors failing this test may still be satisfactory for other, less critical, applications. A modification of this test technique, sometimes used by manufacturers of transistorized equipment, is to set up a test circuit which electrically duplicates the equipment being produced. *All* transistors are first checked in the test circuit and individually selected for best performance in various stages of the equipment. As an example, in the manufacture of a transistorized superheterodyne receiver, some units may be selected to give their best performance as local oscillators, others as I.F. amplifiers, and still others as detectors and audio amplifiers.

CIRCUIT MODIFICATIONS

Although all the circuits given in this volume have been "bench-tested" in the laboratory, economic considerations have prohibited their production engineering. It is to be expected, therefore, that the individual experimenter who assembles the circuits may, in some instances, find it necessary to make minor changes in component values when working with transistors or other components having characteristics different from those used by the author, even if due only to normal tolerance variations. In addition, since any circuit design generally represents a compromise between different, often conflicting, situations, if the individual builder or experimenter wishes his circuit to excell in one special characteristic, such as having maximum battery life, maximum gain, minimum distortion, minimum noise, maximum selectivity, or maximum power output, he will find it necessary to make experimental changes in the circuit to emphasize the desired characteristic. In some cases, the change may be little more than the adjustment of one or two component values. In other cases, considerable modification of the basic circuit may be necessary. Unless otherwise indicated, special temperature and humidity compensation or D.C. stabilization circuits have not been included as part of the experimental circuits shown, for the use of such circuits is largely a matter of individual need and, therefore, is best left to the individual designer.

Several general rules should be followed when making experimental circuit modifications. First, of course, the worker should adhere to all the suggestions given in the section *CARE OF TRANSISTORS*. In most circuits, *NPN* junction transistors may be substituted for *PNP* units with corresponding characteristics, *provided power supply polarities are reversed*. Before changing components or connections in any transistor circuit, the experimenter will find it desirable to connect D.C. current meters in series with the various transistor electrode leads, so that he can monitor changes in current values at all times, making sure that no circuit or component change permits the maximum ratings of the transistor to be exceeded. For additional information of value in modifying and re-designing circuits, the reader will find it worthwhile to refer to the general Reference Data given in *Part IV* of this volume and especially to the reference sources listed in the Bibliography.

PART I — LABORATORY PRACTICE

Chapter 3

COMPONENTS

Many of the electronic and hardware components used in transistor circuitry are simply scaled-down versions of conventional parts. This is not too surprising, for these semiconductor amplifiers almost naturally call for subminiature components to match their own minute physical size. But the mere desirability and need for subminiature components is not, in itself, enough to insure their design and production. They must be feasible as well, both from an economic and a production engineering viewpoint. Fortunately, the unique electrical characteristics of transistors almost ideally fit them for the design of subminiature components.

It is an established fact that the physical size of electronic components is dependent, to a large extent, upon their power handling capacity and voltage breakdown characteristics. A high-capacity, high-voltage capacitor must be large physically because a comparatively thick dielectric is needed to withstand high voltage stresses and the thick dielectric, in turn, reduces capacity, necessitating a larger unit to obtain high capacity. A high wattage resistor must be large to obtain sufficient surface area to dissipate a quantity of heat. And, similarly, high power transformers are large because heavier conductors are required to carry large currents, thicker insulation is needed to withstand high voltages, and more iron is needed in the core to handle the strong magnetic fields produced without reaching saturation. With the majority of transistor circuits, powers are measured in the milliwatts and currents in the micro- and milliamperes; operating voltages are low—but a fraction of those found in vacuum tube circuits. Hence, the subminiaturization of components designed specifically for transistor circuitry is not only desirable, but economically feasible as well—and such subminiaturization may be considered good engineering practice.

RESISTORS AND CONTROLS: Several subminiature resistors, a volume control and a selector switch well suited to transistor circuitry are shown in Fig. 3-1. A transistor and a package of bookmatches are included for size comparison purposes. The transistor is a *GE* PNP junction triode, the resistors are manufactured by *FORTIPHONE, LTD.* of England, the volume control is a *CENTRALAB* item and the selector switch is a standard *GRAYHILL* unit. Subminiature resistors and controls, like a number of other subminiature components, were manufactured commercially long before transistors became practical commercial items. Prior to the practical

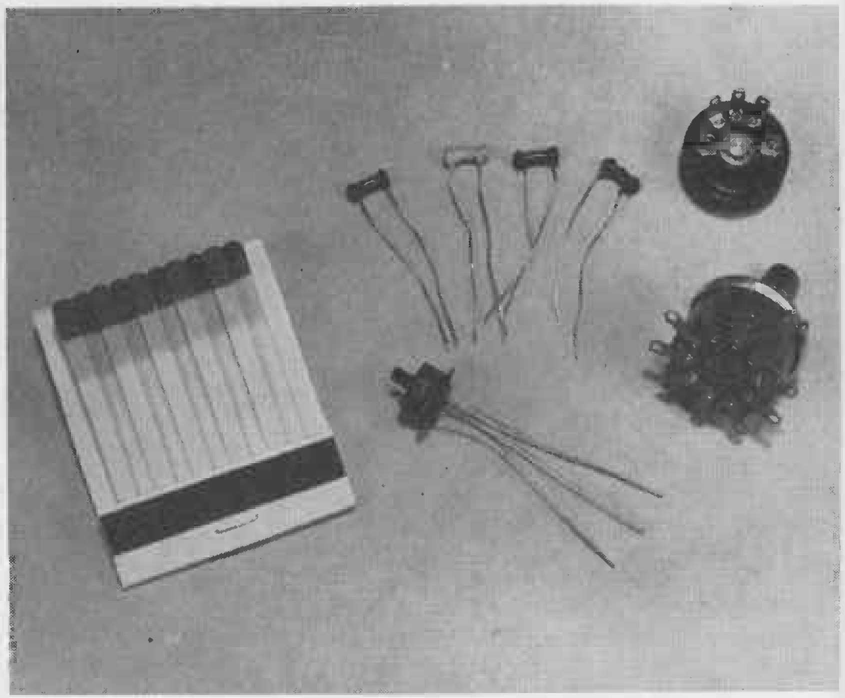


Fig. 3-1.—Subminiature resistors, volume control, and selector switch. Transistor and bookmatches included for size comparison.

development of the transistor, such components were used principally in vacuum tube hearing aids, in miniature instruments, and in specialized types of military equipment. In general, except for their physical size and minor refinements in construction, subminiature resistors are similar to their larger counterparts.

CAPACITORS: The low input impedance of the average transistor amplifier stage necessitates the use of fairly large interstage coupling capacitors in R-C and impedance-coupled transistor audio amplifiers. In the past, large capacity and small size were not considered compatible features, but with the development and successful commercial production of low voltage aluminum and tantalum electrolytic capacitors, it is now possible to obtain fairly large capacities in units

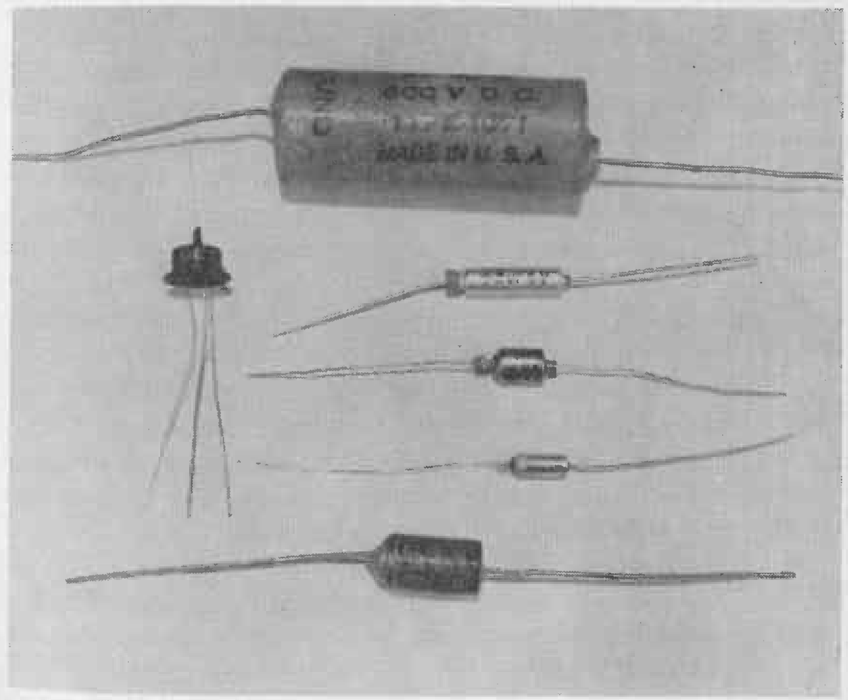


Fig. 3-2.—Subminiature electrolytic capacitors compared to a standard paper unit.

which, in some ratings, are smaller, physically, than the transistors with which they are used.

A typical assortment of subminiature capacitors is illustrated in Fig. 3-2, with a *GE* PNP triode transistor and a normal-sized paper capacitor included for size comparison purposes. The large capacitor shown is a standard 0.25 Mfd., 600 volt paper capacitor manufactured by *GUDEMAN*. One aluminum and two small tantalum capacitors are shown; all three are rated at 2.0 mfd. or more, with working voltages from 6 to 18 volts. Three manufacturers are represented—*BARCO, MALLORY,* and *GE*. Also shown is a miniature metallized paper capacitor, made by *AEROVOX*. Although rated at 0.5 Mfd., 200 volts, the unit is considerably smaller than the standard paper tubular item. In spite of their larger size, miniature metallized paper capacitors are sometimes used in transistor circuits in place of electrolytics where special characteristics are needed for critical applications.

Some idea of the comparative sizes of commercially available capacitors may be obtained by comparing their relative volumes in terms of units having the same capacity and working voltage. Taking a 1Mfd., 150 volt foil-type capacitor as the "standard," if a paper unit has a volume of 100%, a metallized paper unit will have a volume of 40%, an aluminum electrolytic a volume of 15%, and a tantalum electrolytic a volume of 10%. Of course, low working voltages are the rule rather than the exception in transistor circuitry, and, in low voltages, the size differential between the different capacitor types is even greater.

Application-wise, aluminum electrolytics are less costly than tantalum units, but the tantalum units have the edge as far as life and temperature characteristics are concerned. Tantalum electrolytic capacitors are manufactured in two forms. One employs the conventional foil construction and is made by winding two paper-separated foil electrodes into a cylindrical unit. The electrolyte is held by the absorbent paper. During the manufacturing process, an oxide film is formed on the foil, and this serves as the dielectric, just as in a conventional electrolytic capacitor. Non-polarized designs are possible if both foils are filmed with oxide. The other form employs an electrode of sintered powdered tantalum. The anode is made by compressing the powdered tantalum into the proper shape, then welding the particles together by sintering in a vacuum furnance. The final result is a very porous mass which has a large surface area for dielectric oxide formation. In the foil type of construction, the outer case serves simply to contain the wound foil capacitor, but in the sintered anode type, the case, generally made of silver, serves as the cathode.

In transistorized R.F. circuits, small paper as well as both ceramic and silver mica capacitors are employed. Variable capacitors may be compression trimmers, conventional rotating air dielectric units, or a newly introduced type which employs a teflon dielectric. Other types are in a developmental stage and may be available in the near future.

R.F. COILS AND TRANSFORMERS: The subminiaturization of R.F. coils presents special problems to the design engineer. As coils are made smaller, finer wire must be used in their construction, increasing both D.C. and A.C. resistances. In addition, more compact construction generally means higher distributed capacities and greater losses. All of these factors tend to reduce coil "Q" and efficiency, both at high frequencies where distributed capacities are important and at low frequencies which require larger inductance values. As if these problems were not discouraging enough to the designer, the transistors with which the coils and transformers are used offer a low impedance loading, coupled with fairly high internal capacities . . . additional factors to reduce over-all circuit "Q." Nonetheless, R.F. coil manufacturers have been able to design successfully and to produce in production quantities R.F. coils and transformer suitable for subminiature transistor circuitry.

A selection of commercially available coils is shown in Fig.

3-3, together with a *RAYTHEON* type CK722 PNP junction transistor and a package of bookmatches for size comparison purposes. Included are two shielded I.F. transformers and a local oscillator coil for a broadcast band superheterodyne receiver. One of the I.F. transformers is manufactured by

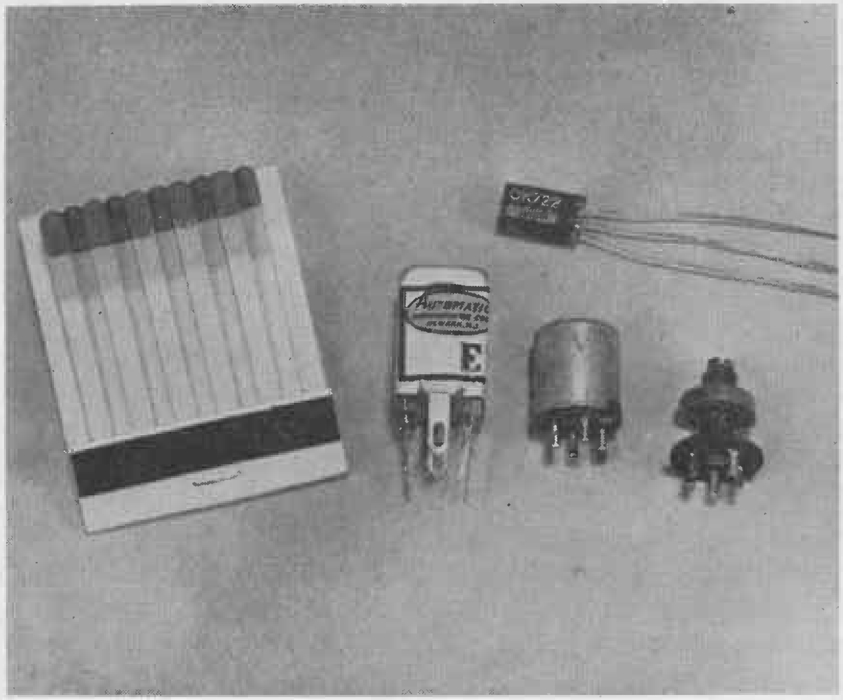


Fig. 3-3.—Subminiature R.F. coils and I.F. transformers.

AUTOMATIC MANUFACTURING CORPORATION, the other I.F. transformer and the oscillator coil are products of the *VOKAR CORPORATION.* In all three units, powdered iron cores are used, both for tuning and to help maintain good stability and a reasonably good "Q" in a small volume coil. As an example of the specifications encountered in this work, the smaller I.F. transformer *(VOKAR)* is permeability tuned, incorporates a 200 Mmf. capacitor within its shielding case, and is designed to resonate at 262 Kc with

an unloaded "Q" of not less than 80. The mechanical design is such as to permit installation on a printed circuit wiring board, with final connections accomplished through a dip soldering process.

AUDIO COILS AND TRANSFORMERS: The size of the copper wire used in the winding and the amount of iron in the core laminations of an audio transformer are both dependent on the direct current which flows through the winding as well as on the power handled by the unit. The amount and type of insulation required between individual windings and between the winding and core depends on the voltages applied to and developed within the transformer. All three factors . . . core size, winding, and insulation . . . affect the over-all size of the transformer. Except for special "high-power" applications, in the majority of transistor audio circuits D.C. currents are small, on the order of one or two milliamperes; D.C. voltages are low, from 1.5 to 12 volts or so; and, of course, powers are small, perhaps from a fraction of a milliwatt up to 20 or 30 milliwatts. In the "high-power" circuits, D.C. voltages may run from 6 to 60 volts, or more, and currents from 100 Ma. up to several amperes. However, in the low power circuits, subminiaturization of audio input, coupling and output transformers is both feasible and desirable.

Several typical miniature iron-core audio transformers are shown in Fig. 3-4, together with a *GE* PNP junction transistor and a package of bookmatches. The largest unit shown is an English-made audio choke, designed primarily for hearing aid applications. The remainder are American-made audio transformers. The two middle units are, respectively, a "Sub-Ouncer" and a "Sub-subouncer," both manufactured by *UTC.* The smallest transformer shown is not appreciably larger than the transistor itself and is one of a series of the smallest iron-core transformers currently manufactured for commercial use. Some of these units weigh only about 1/10 of an ounce. They are manufactured by the *CHICAGO*

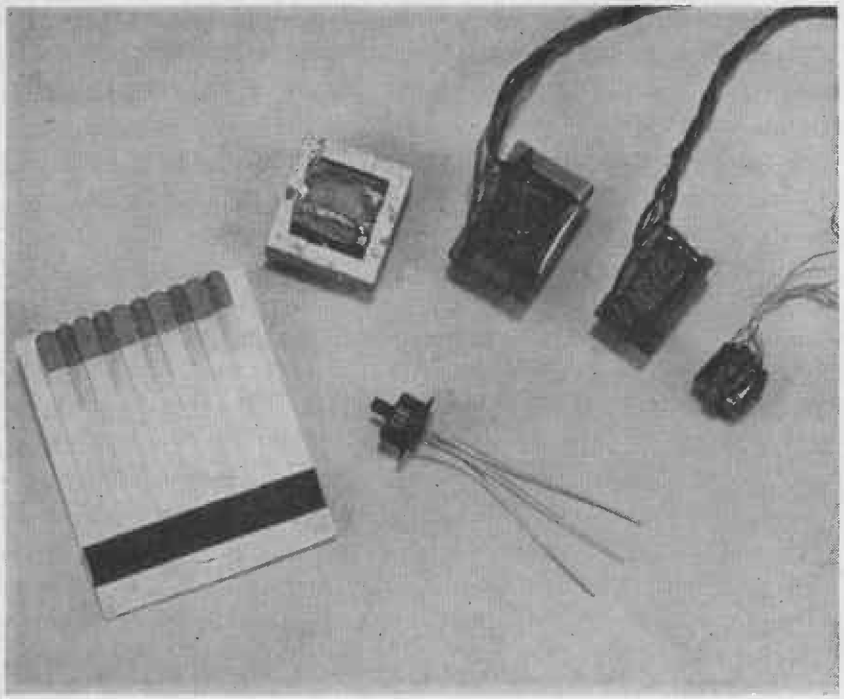


Fig. 3-4.—Subminiature iron-core audio transformers and choke.

STANDARD TRANSFORMER CORPORATION. Notwithstanding their small size, they are quite well made and have a frequency response more than adequate for their intended applications.

AUDIO TRANSDUCERS: Hearing aids and other types of audio amplifiers require some kind of electromechanical transducer to convert acoustic energy into electrical signals and vice versa. When dealing with transistorized circuits, it is often desirable to use audio transducers which are comparable in physical size to the transistors and their related subminiature electrical components. A selection of typical units especially designed for transistor circuitry is shown in Fig. 3-5 along with a *SYLVANIA* transistor. Again, a package of bookmatches is included for size comparison purposes. The loudspeaker is a miniature, high-efficiency PM unit

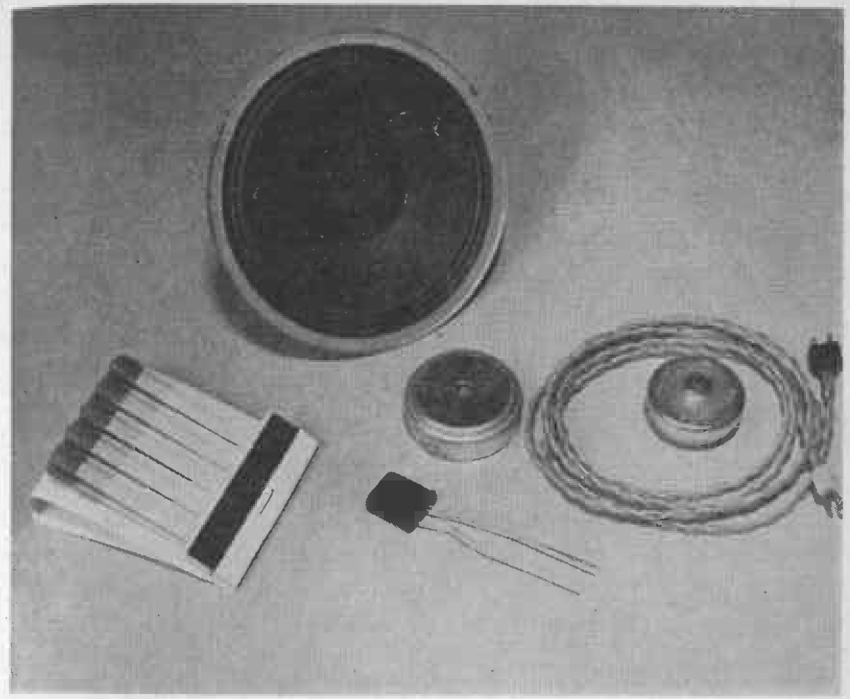


Fig. 3-5.—Subminiature audio transducers . . . loudspeaker, microphone, and earphone. Bookmatches and transistor give some idea of relative sizes.

designed and manufactured by the *JENSEN MANUFACTURING CO.* of Chicago, Illinois. Measuring only 1⅛″ deep by 2¾″ in diameter, the unit weighs less than 2¾ ounces, yet has a power rating of 150 milliwatts and a useful frequency range from 250 to 3000 cps. In the center of the photograph, next to the transistor, is a *SHURE BROTHERS* magnetic microphone cartridge. With good sensitivity and an output impedance of only 1000 ohms, this unit provides an excellent match directly to the input of a junction transistor connected as a grounded-emitter amplifier. Also shown in the illustration is a magnetic hearing aid type earphone, together with its matching miniature cord. Manufactured by *FORTIPHONE, LTD.* of England, this item is available in a number of impedance values to meet almost any desired output circuit. In most cases, hearing aid earphones are used in conjunction with a plastic earpiece custom molded to fit the individual user. Because of the comparatively low impedances encountered in transistor circuits, electromagnetic transducers are used to a greater extent than piezoelectric units, as demonstrated by the sample units described.

SOCKETS: There is an increasing tendency on the part of manufacturers of transistorized equipment to permanently solder or to weld transistors in their circuits. This is reasonably good practice, both from an economic and an engineering viewpoint. Economically speaking, it requires less labor and time, not to mention the cost of a socket, to permanently wire a component in position than to first wire a socket in place, and then to insert a component in the socket. Where printed circuit boards are used, coupled with the automatic assembly of components and dip-soldering techniques, the savings are appreciable. Engineering-wise, if the transistor ratings are carefully observed in the design of the equipment, and if quality units are used, there is no reason why the transistor should not be considered as permanent a component as the resistors, coils, and capacitors which make up the balance of the circuit. But even if the permanent installation of transistors in circuits becomes universal practice, sockets are still useful for the assembly and test of experimental circuits.

Several typical transistor sockets are illustrated in Fig. 3-6, together with an *RCA* type 2N104 transistor and a standard paper clip, included for size comparison. The flat sockets are "inline" units designed for use with transistors employing the standard linotetrar 3-pin base (Fig. 2-7). The socket design was adapted from the 5-pin inline socket used with subminiature vacuum tubes. The larger socket shown is for a point-contact transistor of the type shown in Fig. 1-4.

HARDWARE: As of this writing, only a limited amount of especially designed "transistor circuit hardware" is available commercially. It may be expected, however, that the variety

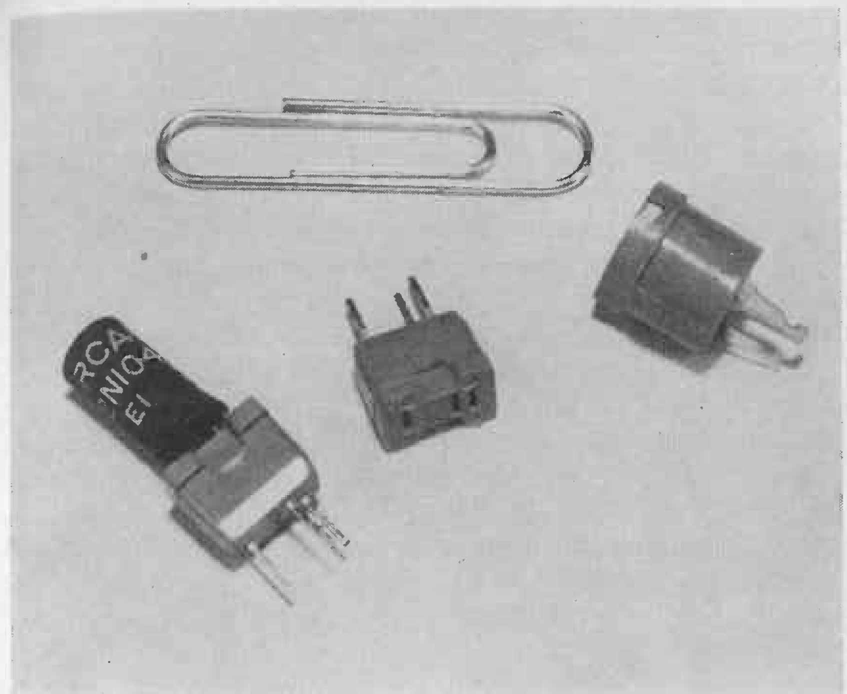


Fig. 3-6.—Transistor sockets. Paper clip shows small size.

will increase as time goes by and as transistors are used in larger and larger quantities. Among the items currently available are battery boxes, transistor clips, and subminiature plugs and jacks, as well as small machine screws, nuts, lockwashers, and similar assembly hardware. The battery boxes are, for the most part, units adapted from battery clips and boxes originally designed for battery operated vacuum tube equipment, such as R/C models, portable receivers, Geiger Counters, etc., but modified to handle the types of batteries used primarily in transistor circuitry. The transistor clips are small spring metal clips designed to hold a transistor firmly against a metal chassis or a mounting board. They are useful for reducing mechanical strain on the transistor leads and also serve to improve the transistor's performance by providing a heat sink against the transistor's case which helps conduct away internally generated heat.

POWER SUPPLIES: Since the operating voltages needed by transistor circuits are low, with current requirements minute, both A.C. line-operated units and batteries are practical for use as transistor power supplies. With the exception of special "high-power" transistor circuits, A.C. power supplies, where used, are generally much simpler, more compact, and considerably lighter than their vacuum tube counterparts. R-C filter networks are practical because of the low currents needed and, therefore, are used extensively in place of the more costly L-C filters favored for vacuum tube power supplies. Constant current power supplies are needed for measuring transistor parameters and for other laboratory tests and, theoretically at least, should always be used for bias current purposes in transistor circuits. Nonetheless, in actual practice more conventional power supplies are generally employed, with a large value series resistor serving to limit current flow and to give the practical effect of a constant current supply. Although line-operated power supply systems are quite practical for transistor work, and may be used in laboratory development and in "high-power" non-portable applications, by far the most popular transistor power supplies are chemical batteries, even though the transistorized equipment in which they are employed is subject to almost continuous use.

Both zinc-carbon and mercury batteries are used extensively in transistor circuitry. An assortment of typical commercial transistor batteries is shown in Fig. 3-7, together with a *GE* PNP junction transistor, included for size comparison. The *RCA Transistor Battery* shown at the left is a special unit designed primarily for experimental work. It is made up of fifteen individual 1.4 volt cells stacked to give a total of 21 volts, yet so designed that it may be cut into smaller sections to give any voltage desired, from a minimum of 1.4 volts from a single cell up to a maximum of 21 volts, in 1.4 volt

Fig. 3-7.—Battery-type transistor power supplies. See text for detailed description of the units shown.

increments. Grouped close to the transistor itself are four *MALLORY* mercury batteries. The smallest unit, seen from the end in the photo, is a single cell which measures only a little over ½" in diameter by less than ¼" high, yet has a rated life of 250 Milliampere-hours (MaH). The largest unit shown in the photograph is only slightly larger than a conventional penlight cell, yet has a capacity of 3600 MaH. Two "stacked" mercury batteries are also shown, both with a capacity of 250 MaH, but rated at 2.5 and 6.5 volts, respectively. When it is remembered that a transistor circuit may require less than 1 milliampere for operation, these life ratings become significant. *Some circuits have been designed which will operate continuously from a single battery for several years.* To the left in the illustration is shown a collection of four *BURGESS* zinc-carbon batteries which are especially popular for transistor work. Included are a standard No. 7 penlight cell, a compact 30 volt battery, and two 22½ volt batteries employing different physical construction. In general, mercury batteries have a greater capacity and much longer shelf life than zinc-carbon batteries of comparable physical size. Because of this, mercury cells are frequently preferred in low-voltage transistor applications where their longer life justifies their considerably higher initial cost. On the other hand, zinc-carbon batteries are generally preferred for higher voltage, low-current applications because of their more compact size. And with comparatively recent improvements in mechanical and chemical design and construction, pioneered by *BURGESS* and others, the shelf and operating life of zinc-carbon batteries is quite adequate for many applications.

Transistor amplifier and oscillator circuits are marvelously efficient. Class A transistor amplifiers may closely approach the theoretically ideal figure of 50% efficiency, while Class C circuits may hit 98 to 99%, almost reaching the "perfect" figure of 100%. Oscillator circuits run somewhat better than 70% efficient. Because of this high efficiency, the engineer called on to design a power supply for a transistor circuit will find it easy to determine total power requirements. He need only design the supply to have a little over twice the power capacity of the total wattage rating of all Class A stages, plus a little more than the total of all Class C stages. Where gain, rather than power, stages are used, overall power requirements may be measured in micro- or milliwatts. This means that heretofore untapped sources of power may well be used to operate certain specialized transistor circuits. Such special power supplies may include "Solar Batteries" (self-generating photocells), thermocouples, or, theoretically, electrical power from bio-chemical sources. Experimental light- and heat-powered oscillators, amplifiers, and receivers have been built and demonstrated in the past, and may well become commercial reality in the future.

PART II — BASIC CIRCUITS

Introduction to PART II

Chapters 4, 5, and 6 which, together, make up Part II of this *Handbook,* cover Basic Transistor Circuits. These are, for the most part, one and two stage circuits which may be used individually, if desired, but which will generally be used by the engineer and circuit designer as "building blocks" in the design of more complex circuits and complete equipments. In the interest of space conservation, only transistor circuits are covered. Subsidiary circuits made up only of R, C, and L parameters, such as filter networks, differentiation and integration networks, etc., will not be covered as such, for detailed information on such circuits is readily available in other texts. Nor will design formulae be given at this time. Although design techniques and formula derivation fall within the province of more conventional textbooks, some basic design equations will be given as part of the General Reference material found in Part IV of this volume.

Virtually all the basic circuits shown have been bench-tested in the laboratory. Except for a few of the more critical circuits, typical component values are specified in order to aid the practical engineer and the experimenter to wire a "breadboard" circuit with a minimum of calculation. Circuit values are not necessarily optimum for all types of transistors, for although each circuit for which parts values are listed has been checked out with a number of transistors, minor adjustments in circuit parameters may be desirable for best operation with specific units. Unless otherwise stated, all parts values given in Chapters 4, 5, and 6 are based on the use of medium to high gain, low power transistors, including such *PNP* units as *AMPEREX* 0C70, 0C71, *CBS-HYTRON* 2N37, 2N38, *GENERAL ELECTRIC* 2N76, 2N107, *RADIO RECEPTOR* RR34, RR20, *RAYTHEON* CK721, CK722, *RCA* 2N104, *SYLVANIA* 2N34, and *TRANSITRON* 2N34, and such *NPN* units as *GERMANIUM PRODUCTS* 2N97, 2N103, and *SYLVANIA* 2N35. Most of the R.F. amplifier and high frequency oscillator circuits were checked with *RAYTHEON* 2N112 (CK760) and 2N113 (CK761) *PNP* transistors. The tetrode circuits given in Chapter 6 were checked with *GERMANIUM PRODUCTS* 3N23 (RDX 302) double-base *NPN* tetrode units. The phototransistor circuits given in Chapter 6 were checked with *RADIO RECEPTOR* RR66 *PNP* phototransistors. Either batteries or AC-operated D.C. supplies may be used as power sources for the circuits.

The individual experimenter should not hesitate to make modifications in the basic circuits. However, in making changes, he should follow the general suggestions given in the earlier sections *CARE OF TRANSISTORS* and *CIRCUIT MODIFICATIONS* in *Chapter 2* (TECHNIQUES) of this volume. Perhaps the most common change will be the substitution of a different general type of transistor for the type specified in the circuit diagram (for example, substitution of a *NPN* transistor for a *PNP* unit). This type of modification may be made if all D.C. polarities are reversed. Another modification may be the addition of a D.C. stabilization circuit to a basic amplifier or oscillator to reduce operational variations with temperature changes and to improve transistor interchangeability in a given circuit, thus better suiting the circuit to commercial applications. Typical D.C. stabilization methods are given in *Chapter 4,* and these may be used with almost any basic circuit. Still another type of modification is the adaptation of a particular circuit to a different configuration. For example, a grounded-emitter Hartley type oscillator may be modified for operation as a grounded-base circuit. Such modifications are feasible if the designer takes impedance and phase conditions into account.

PART II — BASIC CIRCUITS

Chapter 4

AMPLIFIERS

Transistor amplifier circuits may be classified in any one of several ways. From a theoretical viewpoint, it is convenient to group all circuits according to one of the three basic configurations . . . grounded-emitter, grounded-collector, or grounded-base . . . then to treat circuit parameters and loads as complex impedances. It is then a comparatively routine, albeit tedious and perhaps difficult, matter to analyze the operation of the circuit in general mathematical terms. Both a static and a dynamic analysis of each circuit may be made and its theoretical response to varying conditions may be determined in general terms. By substituting measured or known values for the general transistor characteristics and for independent variables in the derived equations, dependent variables may be determined and the operation of the circuit described in quantitative terms. Purely resistive or resonant loads may be handled as special cases of a general problem.

While such an approach to circuit classification and description is possible, and has the advantage of reducing virtually all transistor amplifier circuits to one of three basic types, the practical engineer and technician can hardly afford the time required to wade through pages of mathematical analysis to obtain a final circuit design. From a practical viewpoint, it is much more convenient to classify transistor amplifier circuits according to the *type of signals* handled, and to describe the circuits in terms of schematic diagrams and typical component values. Therefore, it is this approach we will use in this volume.

DIRECT-COUPLED AMPLIFIERS: In vacuum-tube amplifier circuits using the popular grounded-cathode configuration the grid and plate electrodes are supplied with D.C. operating voltages of exactly opposite polarities with respect to the grounded electrode (cathode). In addition, these two voltages have different orders of magnitude . . . grid potentials are measured in volts, plate potentials in hundreds of volts. Direct-coupling between successive stages becomes quite difficult. With transistors, on the other hand, the base (analogous to a vacuum tube's grid) and collector (analogous to a vacuum tube's plate) electrodes are supplied with voltages having the same polarity with respect to the emitter (corresponding to the vacuum tube's cathode) and, further, on the same order of magnitude. Since the transistor is essentially a current-operated device, contrasted to the vacuum tube, a voltage-operated device, currents are of more importance in determining operating conditions than are voltages. And currents may be limited or controlled quite easily by using resistors. Therefore, from a purely practical viewpoint, it is somewhat easier to direct-couple transistor amplifier stages than it is to direct-couple vacuum tubes. Direct-coupled amplifiers may be of two types . . . (a) *D.C.* amplifiers and (b) *A.C.* amplifiers. With D.C. amplifiers, the direct-coupling is carried out throughout, from input to output, and the circuits are capable of handling signals of essentially zero cycles per second. With A.C. amplifiers, on the other hand, direct-coupling techniques are employed only between succeeding stages, with capacitive or transformer coupling employed at either the input or output, or both. The frequency response of such an amplifier, while it may be better than that of a conventional A.C. amplifier, still does not extend down to zero cycles per second (D.C.).

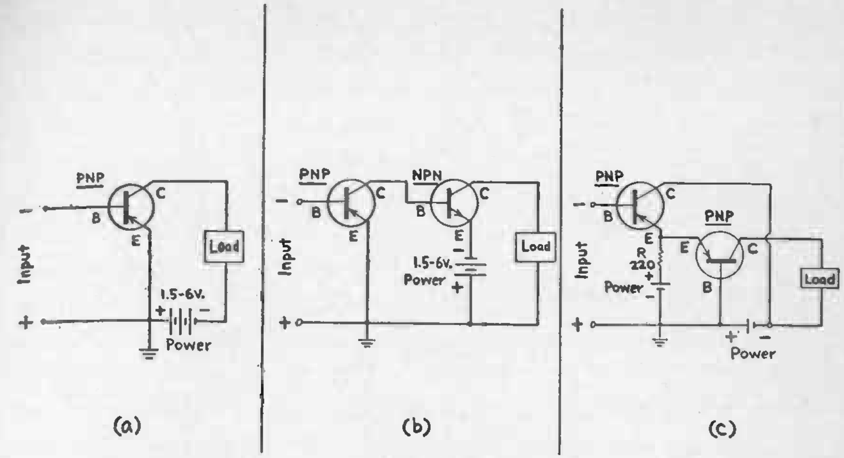


Fig. 4-1

D.C. TYPE DIRECT-COUPLED AMPLIFIERS — (a) Single stage amplifier; (b) Two-stage amplifier utilizing the *complementary symmetrical* characteristics of *PNP* and *NPN* transistors; (c) Two-stage circuit using transistors of the same type . . . essentially a grounded-collector stage directly coupled to a grounded base stage. In all three cases, the "Load" may be a meter, relay, resistor, or similar device. In circuits (a) and (b), the application of D.C. to the input, with the polarity shown, results in an increase in the current through the load. In circuit (c), the current through the Load is reduced with the application of an input signal . . . it is at its maximum with zero input.

All three circuits may be used as *A.C. Type Direct-Coupled Amplifiers* if proper bias currents are provided and if the inputs are isolated from external D.C. voltages. Of the three circuits, (b) has the highest gain. The operation of circuit (b) may be changed by interchanging the position of the *PNP* and *NPN* transistors and reversing the polarity of the power source . . . with this arrangement, the input signal should be positive with respect to circuit ground. The operation of these circuits may be checked by connecting a variable D.C. voltage source to the input through a current limiting resistor (1 Megohm is satisfactory), then varying the input current in discrete steps, checking the Load current at the same time.

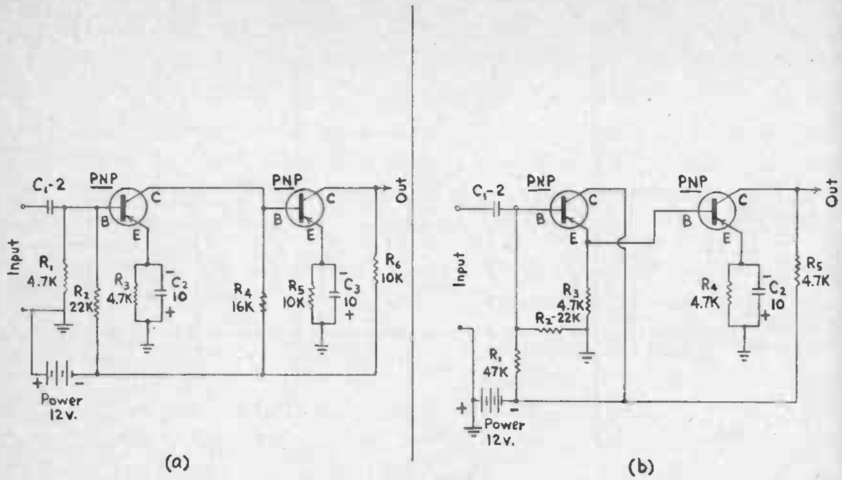


Fig. 4-2

A.C. TYPE DIRECT-COUPLED AMPLIFIERS — (a) Two-stage amplifier made up of cascaded grounded-emitter stages; (b) Two-stage amplifier made up of a grounded-collector stage direct-coupled to a grounded-emitter stage. Of the two circuits shown, circuit (a) has by far the greater gain, but circuit (b) has a higher input impedance.

The general arrangement shown at (a) may be extended to three or four stages, if desired, provided proper collector load and emitter resistors are chosen. In both circuits, a degree of D.C. stabilization is attained by the use of a voltage divider (R_1 and R_2) to provide bias for the first stage and the use of by-passed emitter resistors. Total current drain, for either circuit, was checked at less than 2.0 Ma. at the voltages specified. Small electrolytic capacitors may be used for coupling and by-pass purposes.

Due to the differences between the input and output impedances of the grounded-emitter stage, the gain of the direct-coupled amplifier (a) is considerably less than could be obtained with a transformer-coupled circuit. Either of these circuits, with modifications, may be used as *D.C. Type Direct-Coupled Amplifiers.* Essential modifications are the removal of the input blocking capacitors (C_1) and a change in the input bias arrangement.

AUDIO AMPLIFIERS: Unlike *Direct-Coupled* transistor amplifiers, which are likely to be much simpler than their vacuum tube counterparts, transistor audio amplifiers are, in many ways, just as complex as related vacuum tube circuits. This increase in complexity is the result of the differences between the input and output impedances of a single stage. With

most vacuum tube amplifier circuits, both input *and* output impedances are high, and no special techniques are needed to match impedances in interstage coupling. With transistor amplifiers, on the other hand, input impedances are generally low and output impedances high. If maximum gain is to be obtained from a given number of stages, special steps must be taken to match these impedance differences. Of course, a similar problem exists in the case of the *Direct-Coupled* amplifier, but the very nature of direct-coupled circuits precludes the possibility of obtaining maximum gain and thus the problem is minimized. In addition to the problem of impedance matching, transistor amplifiers differ from vacuum tube circuits in another important aspect. In vacuum tube circuits, the input and output of a single stage may be considered as completely isolated except at high frequencies (due to small interelectrode capacities). With transistors, on the other hand, *there is a direct resistive connection* between the input and output terminals of the transistor. While this interelectrode connection may be ignored in some types of practical design work, it does exist, and may become of real importance in critical circuits. Finally, vacuum tubes operate as temperature-saturated devices and, for most practical work, ambient temperatures may be ignored in circuit design. Such is not the case with transistors. Germanium transistors, especially, are quite sensitive to temperature variations. This fact must be given consideration in the design of commercial (as opposed to experimental) circuits.

In designing transistor audio amplifiers, in addition to the special problems encountered due to the very nature of these semiconductor devices, there are the usual problems which are common to both vacuum tube and transistor audio circuits. These include the design of gain (volume) and frequency response (tone) control circuits, feedback circuits, phase splitters, push-pull circuits, and power amplifiers. Of course, the Class of amplifier operation must be considered also. As with vacuum tubes, single-ended transistor audic amplifiers are generally operated Class A, while push-pull circuits may be either Class A, Class AB, or Class B. With transistor amplifiers, it is *bias current,* rather than voltage, that determine the location of the operating point and hence the Class of operation.

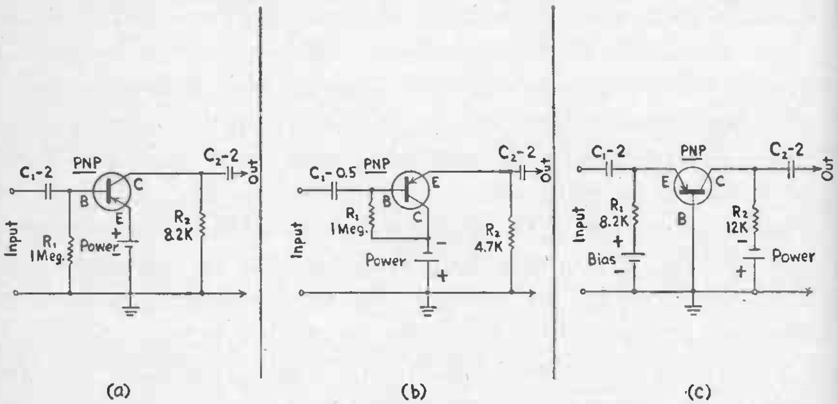


Fig. 4-3

BASIC AMPLIFIER CONFIGURATIONS—(a) Grounded-emitter; (b) Grounded-collector; (c) Grounded-base. Resistive loads and capacitive coupling are shown in all three circuits. Signal phase reversal occurs in the grounded-emitter circuit (a), but not in the grounded-collector (b) and grounded-base (c) circuits.

All three circuits can contribute power gain, but voltage gain can be obtained only with the grounded-emitter and grounded-base circuits. The voltage gain of the grounded-collector circuit is always less than 1.0 with currently available junction transistors. The input impedance of the grounded-base circuit is low; of the grounded-emitter circuit moderate; of the grounded-collector circuit high . . . approaching the input impedance of vacuum tube circuits.

There is considerable spread in both input and output impedances, however, depending on the characteristics of the individual transistor. As far as output impedances are concerned, the grounded-base circuit has a fairly high output impedance, the grounded-emitter circuit a moderately high value, and the grounded-collector circuit a moderate to low value.

It is interesting to note that the *output* impedance of the grounded-collector circuit approximates the *input* impedance of the grounded-emitter circuit. In all three circuits, either dual ("Bias" and "Power") or single ("Power") D.C. supply sources may be used. A single D.C. source is shown at (a) and (b), a

dual source at (c). To use a single D.C. source in the grounded-base circuit, omit the "Power" source, connecting R_2 directly to ground. Connect a suitable resistor between base and ground, by-passed by a large capacitor (typical value may be 150,000 ohm resistor, by-passed by 1 Mfd.). The "Bias" source then serves as the power supply. Of the three circuits, the grounded-emitter configuration supplies the greatest voltage and power gain.

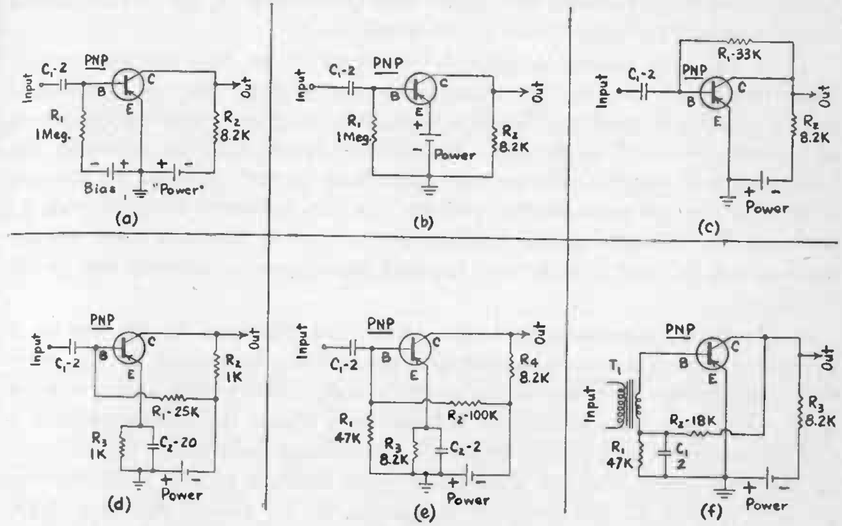


Fig. 4-4

D.C. STABILIZATION AND TEMPERATURE COMPENSATION—Circuits (a) and (b) do not provide stabilization and are included simply to illustrate basic bias methods using a dual (a) and single (b) power source. In both cases R_1 determines base bias current and hence the D.C. operating point; R_2 serves as the collector load. The grounded-emitter configuration is used throughout for purposes of simplification. However, similar techniques may be employed in the grounded-base and grounded-collector configurations. Circuits (c), (d), (e), and (f) all illustrate various techniques of D.C. stabilization. With proper design, all the techniques shown will give satisfactory results, but the circuits shown at (e) and (f) are probably the best for highly critical applications.

The purpose of D.C. stabilization is to establish the transistor's D.C. operating point in such a way that it is virtually independent of individual transistor characteristics and of changes in those characteristics due to fluctuations in ambient temperature conditions or in junction temperature due to "self-heating" effects. The operating point is established by the bias current and hence the basic method of D.C. stabilization is (1) to fix the bias current as independent of transistor characteristics and (2) to permit the bias current to automatically adjust for changes in collector current as may occur due to changes in ambient temperatures. With germanium transistors, as junction temperature is increased, the collector current tends to increase. Thus, good stabilization will require that bias current vary in such a manner as to keep collector current constant. In this manner, the operation of the circuit will remain essentially constant with temperature variations. In addition, transistor interchangeability in the circuit is improved.

Since collector current is directly proportional to bias current, proper stabilization will require that a tendency for collector current to *increase* should result in a tendency for *bias current to decrease*, restoring the circuit to normal. In circuit (c) the D.C. stabilization is obtained by returning the base resistor R_1 to the collector electrode. Base current depends on the size of R_1 and on collector-emitter valtage. As the collector current tends to increase, the collector-emitter voltage drops, due to the increased voltage drop across R_2, and this, in turn reduces bias current, restoring the circuit to normal.

In circuit (d), essentially the same results are obtained by the use of a by-passed resistor between emitter and ground (R_3, by-passed by C_2); note that base resistor R_1 returns to the negative side of the power supply instead of to the collector electrode. The voltage drop across the emitter resistor is such as to oppose normal bias and since this voltage depends on the collector current, the emitter resistor provides a good method of D.C. stabilization. Circuits (e) and (f) are similar in operation to the circuits just described, except that the action is further improved by the use of a voltage divider network (R_1 and R_2). Circuit (f) is especially well suited to transformer-coupled circuits.

As mentioned elsewhere, D.C. stabilization is not always necessary, but should be added to circuits intended for military or industrial applications. Unless otherwise noted, D.C. stabilization has been omitted from the majority of transistor circuits shown in this volume in the interests of circuit simplification.

The circuits shown here illustrate the use of D.C. stabilization methods as applied to simple audio amplifiers. However, almost identical techniques are used in the case of D.C. amplifiers, R.F. amplifiers, and A.F. and R.F. oscillators. These techniques also may be applied to special purpose circuits such as multivibrators, clippers, and flip flops. In the case of R-C controlled oscillators, including relaxation circuits, D.C. stabilization is important for maximum transistor interchangeability.

In extremely critical applications, such as instrumentation circuits, the Design Engineer may find it worthwhile to consider the use of thermistors or varistors in place of pure resistors in the D.C. stabilization network. Space prohibits a detailed discussion of such techniques here.

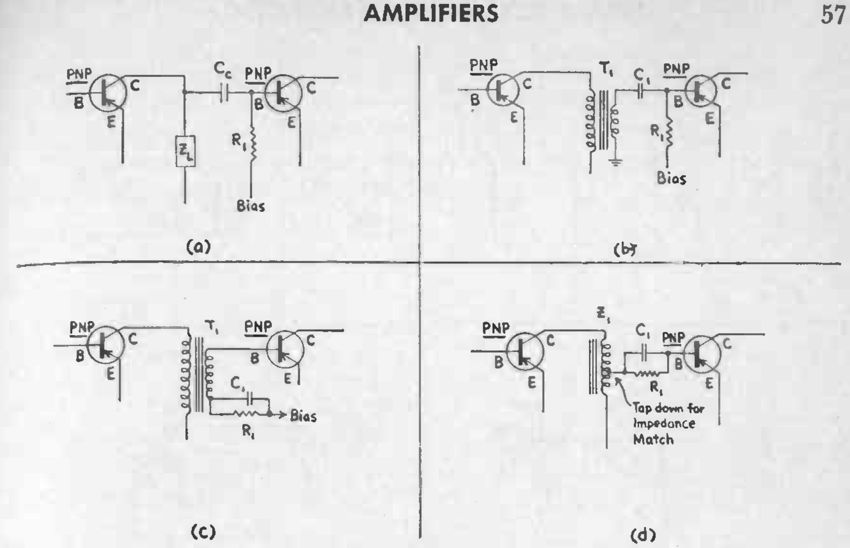


Fig. 4-5

INTERSTAGE COUPLING – Capacitive coupling is shown at (a); transformer coupling at (b) and (c); tapped impedance coupling at (d). In all four cases it is assumed that the grounded-emitter configuration is employed and that the coupling is from the collector of one stage to the base of the following stage. And in all four circuits the D.C. bias current is established by base resistor R_1. In (a) the collector load Z_L may be a resistor, a choke coil, or a complex impedance, while C_C serves as the coupling capacitor.

Because of the low input impedance of the following stage, the reactance of C_C must be kept low to minimize signal loss and low frequency phase shift. At audio frequencies C_C may have a value of several microfarads. In circuits (b) and (c), a small transformer, T_1, is used to match impedances. The primary winding has a high impedance, matching the high output impedance of one stage, while the secondary has a low to moderate impedance, matching the input of the following stage. Circuits (b) and (c) are quite similar in operation.

The chief difference in the two circuits is the method of supplying base bias current. A shunt-fed system is shown at (b), with C_1 serving as a D.C. blocking capacitor to prevent a short of bias current by the low D.C. resistance of the transformer's secondary winding. This arrangement may be used where it is desirable to keep D.C. out of the transformer's secondary. A series-fed system is shown at (c). Here C_1 by-passes base resistor R_1 and keeps it from affecting the signal current. Circuit (d) is similar in operation to circuit (c) except that a tapped impedance rather than a transformer is used for impedance matching. If desired, Z_1 may be considered as a type of auto-transformer, however. Of the four circuits, (a) offers the least gain . . . (b), (c), and (d) have similar gain.

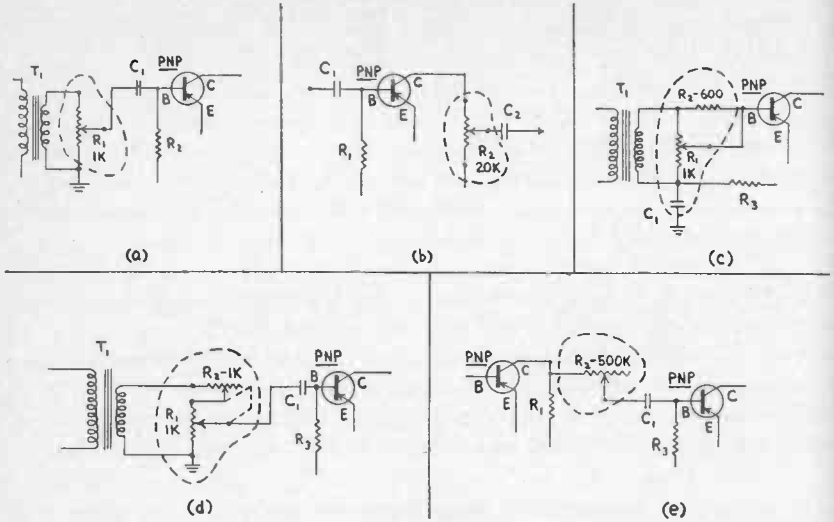


Fig. 4-6

GAIN CONTROLS — An input gain control is shown at (a); an output gain control at (b); two types of "constant impedance" controls at (c) and (d); a series type gain control at (e). The actual control circuits are enclosed by dotted lines.

In choosing a gain control for a transistor circuit, it is important that the arrangement used not affect direct currents in the circuit and that variations in circuit impedance values as the control is varied be kept to a minimum. The control arrangements shown at (a) and (b) are probably the most popular. Unfortunately, circuit (a) does permit a small change in the loading of the transformer secondary as the control is adjusted and this change, in turn, is reflected back into the primary circuit. With the control arm at ground position (minimum gain), the transformer's secondary sees a load equal to the impedance of the control (R_1), or approximately 1,000 ohms. On the other hand, when the control arm is in its maximum gain position, the low input impedance of the transistor is effectively shunted across the control and the transformer secondary looks into this parallel load . . . the total loading may drop from 1,000 ohms to 500 ohms or less . . . that is, about half the load presented with the control in its minimum gain position.

Circuits (c) and (d) are modifications of the basic gain control circuit (a) in an attempt to equalize the loading of the transformer's secondary with minimum and maximum gain adjustment. The output gain control shown at (b) is suitable where the circuit feeds a high impedance load. This control circuit is not satisfactory if the load is the primary of a transformer, for example.

Because of the low input impedance of a transistor amplifier stage, a series type gain control is practical, as illustrated at (e). The series type control has two minor disadvantages, however . . . (1) there is a change in the loading of the preceding stage as the control is adjusted and (2) the signal level cannot be reduced to zero.

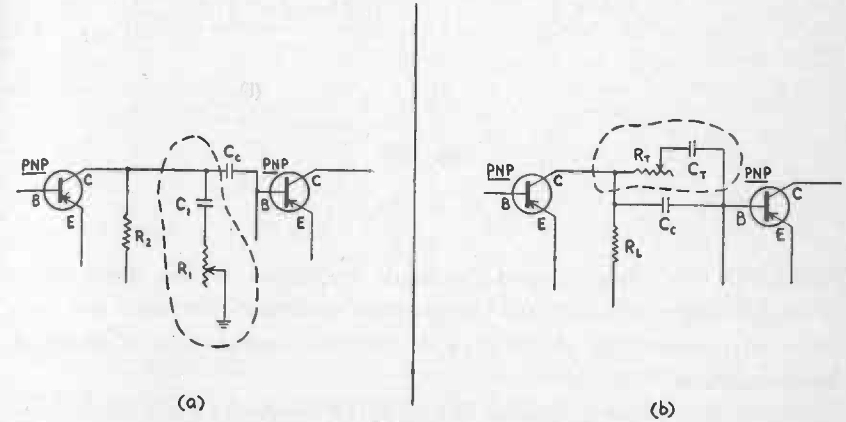


Fig. 4-7

TONE CONTROLS — (a) Treble "losser" control; (b) Bass "losser" control. In both circuits, the tone control network is enclosed by a dotted line. In circuit (a), coupling capacitor C_C has a normal value, C_1 may have a value as low as 0.01 mfd to as large as 0.5 mfd, depending on circuit requirements, and R_1 may have a value from 5K to 50K.

In operation, adjusting R_T reduces the collector-to-ground impedance at high frequencies, reducing gain at these frequencies and lowering the high frequency response of the amplifier. In circuit (b), coupling capacitor C_C is made much smaller than normal . . . it may have a value as low as 0.05 mfd instead of the usual value of several microfarads; C_T may have a value of from 1.0 to 20 mfd, and R_T a value from 1.0K to 20K.

In operation, the small coupling capacitor C_C permits the interstage coupling of high frequency signals without appreciable attenuation. Low frequencies, on the other hand, may be attenuated by the adjustment of R_T. Circuits (a) and (b) are called "losser" type tone controls because their operation depends on reducing the gain of the amplifier over the desired frequency range by "losing" the signals at those frequencies. Both circuits are direct adaptations from their counterparts in vacuum tube amplifier circuits.

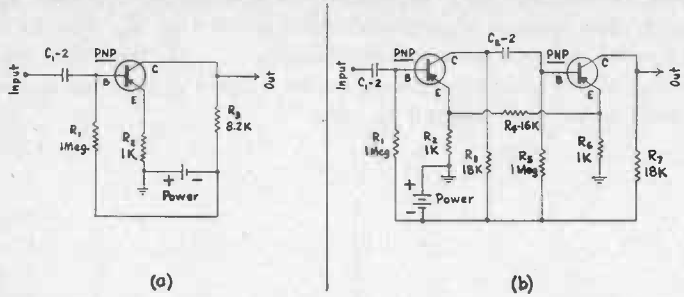


Fig. 4-8

FEEDBACK — (a) Degenerative feedback introduced into a single stage grounded-emitter amplifier; (b) Degenerative feedback introduced into each stage of a two-stage amplifier, with cathode-coupled positive feedback between stages.

When an un-bypassed resistor is introduced between emitter and ground in a grounded-emitter amplifier stage, several changes take place in the circuit's operation. First, a degree of D.C. stabilization is introduced (see Fig. 4-4). Secondly, the input impedance is increased. Thirdly, the over-all gain of the stage is reduced as a result of the degenerative (inverse) feedback voltage developed across the resistor; this inverse feedback also reduces distortion.

In addition to these effects, the output capacity of the stage is reduced, extending the frequency response of the amplifier. The effects obtained are thus analogous to those encountered in vacuum tube amplifiers where an un-bypassed cathode resistor is used. In circuit (a) emitter resistor R_2 provides degeneration; in circuit (b) emitter resistors R_2 and R_6 provide inverse feedback in their respective stages. However, in circuit (b) part of the gain loss through degeneration is recovered by providing a positive feedback signal from the second stage to the first. This is accomplished through resistor R_4 which serves to couple the two emitters together.

In both circuits the amount of degeneration is directly proportional to the size of the emitter resistor. In circuit (b) the positive feedback between stages is inversely proportional to the size of coupling resistor R_4.

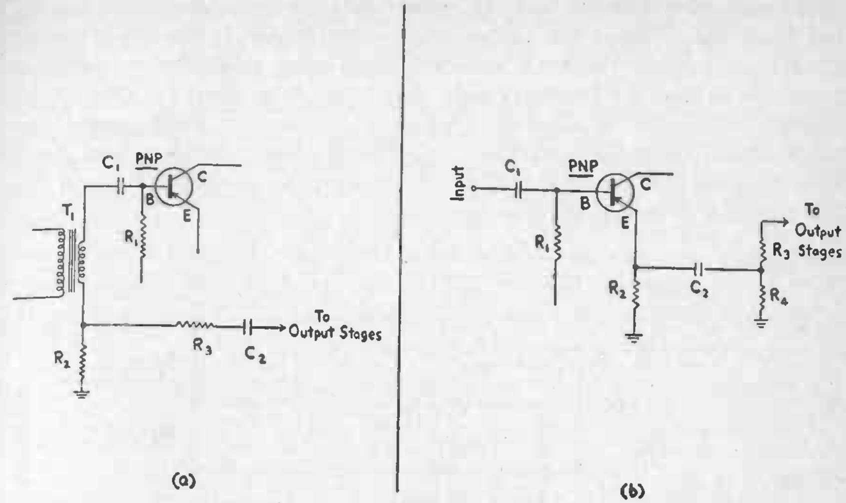


Fig. 4-9

OVERALL FEEDBACK — (a) Series type base-coupled; (b) Emitter-coupled. As with vacuum tube audio amplifiers, the over-all frequency response may be improved and distortion reduced if inverse feedback is used between the output and input stages of a multi-stage transistor amplifier.

In circuit (a) the feedback signal is obtained across the output stage's load impedance and fed back through blocking capacitor C_2 to resistive voltage divider R_2-R_3. The ratio of these two resistors determines the amount of inverse feedback. The feedback signal is coupled into the input stage in series with the driving signal. In circuit (b) the negative feedback is coupled into the emitter circuit of the input stage, appearing across the un-bypassed emitter resistor R_2 . . . the amount of feedback is determined by the ratio of the two resistors R_3 and R_4 in the voltage divider circuit.

In addition to the two methods shown, an inverse feedback signal may be coupled directly into the base circuit in some cases . . . that is, essentially in parallel with the input signal. In both circuits C_2 will normally be quite large so as to offer negligible reactance at the lowest frequency to be amplified. However, proper choice of this capacitor will permit a considerable boost in low frequency response of the amplifier . . . to obtain this boost, C_2 is made smaller so as to reduce the amount of inverse feedback at lower frequencies. Depending on where the feedback signal is obtained, C_2 may not always be necessary.

In general, the inverse feedback signal may be obtained from two places . . . (1) across the output stage's load, (2) from the secondary of the output transformer. However, regardless of the choice of feedback signal source, or the method of injection into the input stages, care must be taken that the fed back signal bears the proper phase relationship to the input signal. Otherwise, positive feedback and oscillation may result. Incorporating a tuned circuit into the feedback path may result in a boost (or dip) of the amplifier's response at a specific frequency . . . such an arrangement may be desirable for some specialized applications. Again, since a bass boost may be given the amplifier by the adjustment of C_2 in circuits (a) and (b), this provides a means of tone control.

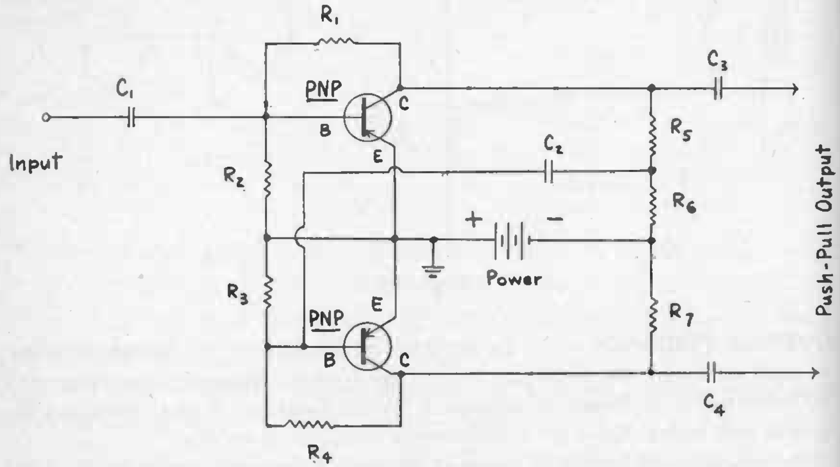


Fig. 4-10

BASIC PHASE INVERTER — Using two transistors, the phase inverter circuit shown is a direct adaptation of its vacuum tube counterpart. Component values are not given for they will vary considerably with the characteristics of the transistors used*. Both transistors are connected using the grounded-emitter configuration. Voltage Divider R_1-R_2 provides bias current and D.C. bias stabilization for the upper transistor, while R_3-R_4 serves a similar function for the lower unit.

In operation, a signal applied through C_1 to the input of the upper transistor is amplified, appearing across collector load R_5-R_6, where it is applied to the following stage through C_3. The portion of the amplified signal appearing across R_6 is applied through C_2 to the input of the lower transistor,

*NOTE: *Where component values are given in PART II of this HANDBOOK, the circuits shown have been checked with several transistors of similar types and the circuits have been found reasonably non-critical . . . or only minor changes in values have been needed to obtain operation. Where component values are not given, it means either that the values are similar to those given in related circuits or that the circuit appears to be critical on the basis of tests with available transistors, and the author feels that listing specific values might tend to lead the worker astray. In PART III of this HANDBOOK, dealing with complete "equipment" circuits, all component values as well as transistor types will be specified.*

where further amplification occurs, with the signal appearing across collector load R_7 applied to the following stages through C_4. Since phase reversal occurs in each grounded emitter stage, the signals appearing at C_3 and C_4 are 180° out-of-phase.

For a properly balanced output, both transistors should have identical gain characteristics and R_7 should equal the collector load of the upper transistor. This load impedance is made up of R_5 in series with R_6, with R_6, in turn, shunted by the comparatively low input impedance of the lower transistor. The ratio of these resistors (R_5/R_6) approximates stage gain. If the two transistors do not have equal gain, the ratio R_5/R_6 may be adjusted until the signals available through C_3 and C_4 are of equal magnitude.

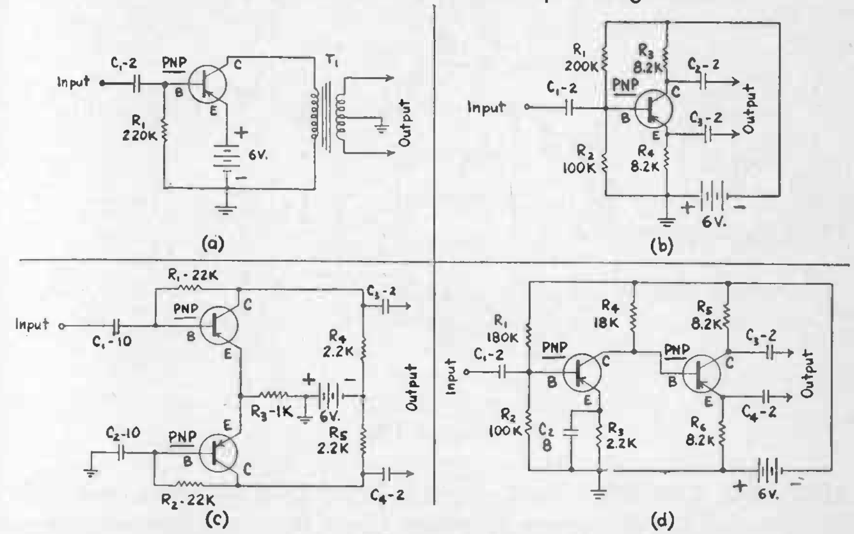


Fig. 4-11

PRACTICAL PHASE INVERTERS — (a) Transformer type; (b) Split-load type; (c) Emitter-coupled type; (d) Split-load type direct-coupled to a grounded-emitter amplifier.

In circuit (a), transformer T_1 not only serves to provide a push-pull signal, but also may be used to match the output impedance of the grounded-emitter amplifier to the input impedance of the following stage.

In circuit (b) voltage divider R_1-R_2 establishes base bias current and provides a degree of D.C. stabilization; collector (R_3) and emitter (R_4) load resistors may have identical values with some types of transistors; with others, different values are needed to obtain a balanced output.

In circuit (c), resistors R_1 and R_2 provide base bias current and D.C. stabilization for their respective transistors; coupling between the two transistors is through the common emitter connection. A reasonably well balanced output can be obtained with circuit (c) if the transistors are well matched and if the common emitter resistor (R_3) has a value considerably higher than the emitter-base impedance. Circuit (d) is the split-load phase inverter shown at (b) direct-coupled to a grounded-emitter amplifier. Of the circuits shown (including the Basic Circuit given in Fig. 4-10), circuit (b) has the highest input impedance.

Although all the circuits provide some gain, circuit (b) gives a voltage gain of less than two. Circuit (a) provides the best impedance match when the phase inverter is coupled to a push-pull transistor amplifier, and is mandatory for driving Class B high power transistor circuits.

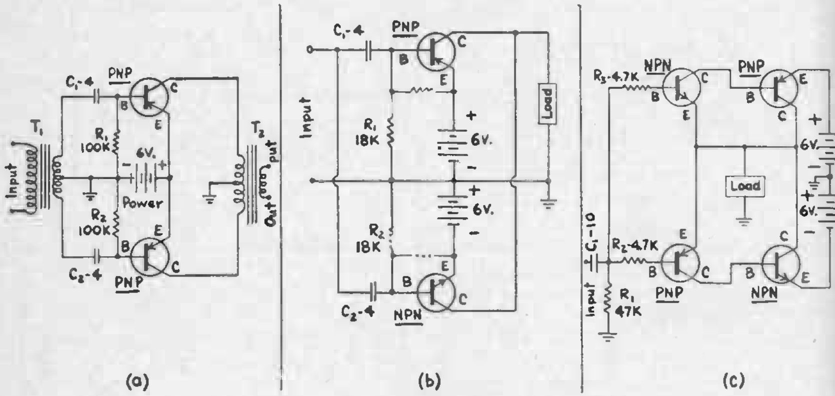


Fig. 4-12

PUSH-PULL CIRCUITS — (a) Conventional; (b) Complementary Symmetry; (c) Cascaded Complementary Symmetry. Circuit (a) is a conventional transformer-coupled push-pull amplifier employing transistors of the same type. The general arrangement is quite similar to its vacuum tube counterpart. D.C. stabilization is not provided in the circuit shown, although it is recommended in power applications (see Fig. 4-4).

Circuit (a) may be operated Class A, AB or B, depending on bias current and drive requirements. It may be used as an output stage, with T_2 driving a loudspeaker voice coil or similar load; it may be used as a driver for another push-pull circuit. The grounded-emitter configuration is shown, but a similar arrangement may be employed using either grounded-base or grounded-collector circuits.

Circuits (b) and (c) utilize the complementary symmetrical characteristics of transistors of different types to obtain push-pull operation with a single-ended input and output; note that center-tapped transformers are not required. In operation, base-current changes in the same directions in *PNP*

and *NPN* transistors cause the collector currents to change in *opposite* directions. If the collector current of the *PNP* transistor increases, that of the *NPN* unit decreases.

In both (b) and (c) the "LOAD" may be a resistor, impedance matching transformer, or similar device . . . or, in some cases, a high impedance loudspeaker voice coil. Thus, these circuits permit a speaker voice coil to be driven directly, without the need of a matching transformer. For best results, reasonably well-matched transistors should be used in circuits (b) and (c). Circuit (c) is the more critical of the two and, in some cases especially selected transistors must be employed.

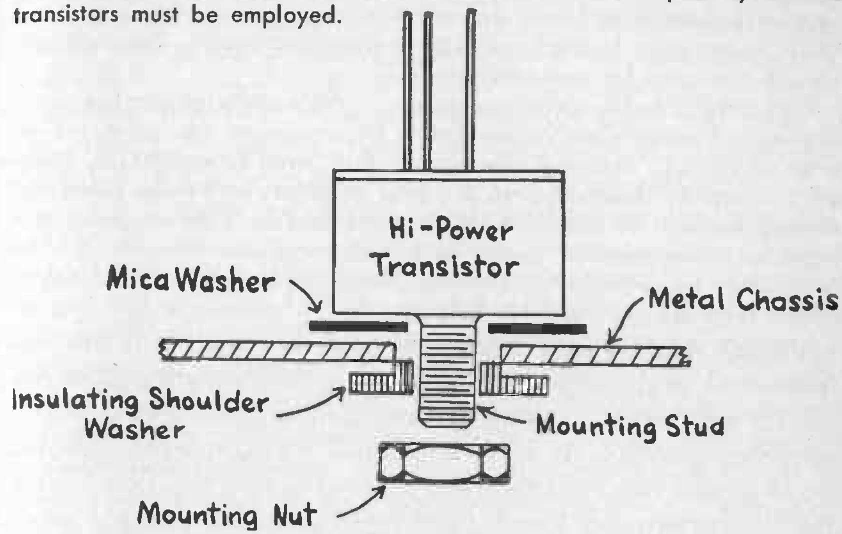


Fig. 4-13

POWER AMPLIFIERS — A typical mounting for a "high power" transistor is shown. In order to improve heat dissipation, power transistors are frequently assembled in a metal case which serves as a heat radiator. This case, in turn, may be mounted on a metal chassis to provide a "heat sink".

With some transistors, one of the electrodes (usually the collector) may be internally connected to the outer case. Unless this electrode is to be grounded, electrical insulation must be provided between the transistor's case and the metallic heat sink, while still permitting maximum transfer of heat energy. Hence the mounting arrangement illustrated in the sketch. The mica washer may be only 0.0015 inches thick and may be coated with silicone oil to improve heat conductivity. The insulating shoulder washer may be fiber or nylon.

The basic circuit arrangements used for power amplifiers are virtually identical to those used in low power circuits (Figs. 4-3, 4-5, and 4-12). The major differences are in the operating currents and voltages employed and in the magnitude of the impedances encountered. These values vary with different transistors, of course, but for a typical high power transistor (1 watt or more . . . up to 50 watts or higher), the input impedance of a circuit employing the grounded-emitter configuration may be around 10 ohms, compared to about 500-1000 ohms in the case of lower-power transistors. The output impedance may be in the neighborhood of 50 to 100 ohms, and collector currents may run from a hundred milliamperes to several amperes . . . compared to a fraction of a milliampere for a low power amplifier. D.C. operating voltages may run from three to twenty-four volts. In general, Class A operation is employed with single-ended circuits, Class AB and Class B operation for push-pull circuits.

D.C. stabilization is almost mandatory for high power circuits, especially where the transistors are operated near their maximum ratings, to prevent collector current "runaway" (see section on *POWER TRANSISTORS,* Chapter 2). Properly designed Class B power amplifiers may have efficiencies running between 75 and 80%. While there may be more distortion in a transistor power amplifier than in an analogous vacuum tube unit, the distortion may be minimized and brought to acceptable levels by the use of inverse feedback (see Figs. 4-8, 4-9).

VIDEO AMPLIFIERS: Except for degree, the problems encountered in the design of wide-band (video) transistor amplifiers are similar to those encountered in the design of audio amplifier circuits. As with analogous vacuum tube circuits, the designer must compensate for low frequency phase shift and high frequency losses. Conventional techniques are used.

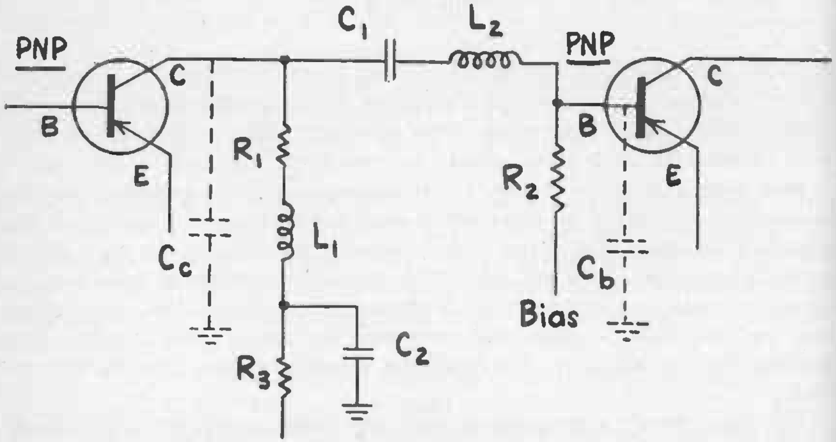


Fig. 4-14

VIDEO AMPLIFIER COMPENSATION (Fig. 4-14) — Wide-band transistor amplifiers may employ the same circuit configurations used at audio frequencies, but with special steps taken to compensate for the loss of gain at the low and high frequency ends of the spectrum. Two major factors limit frequency response . . . (1) the characteritsics of the transistor itself and (2) related circuit characteristics.

In designing a transistorized video amplifier, then, the first step is to select a transistor with a "good" high frequency characteristic. This may be a junction triode with an alpha cut-off frequency of several megacycles, a junction tetrode, a surface barrier unit, or the newly developed "field-effect" transistor. In general, since electrons migrate faster than "holes", *NPN* transistors have better high frequency characteristics than *PNP* units. As far as basic circuit configurations are concerned, the grounded-base arrangement is best for high frequencies because of its low output capacity (approximately equal to the collector capacitance), but not as good for low frequencies due to its low input impedance. The grounded-emitter arrangement has a much higher output capacity, but offers higher gain and a higher input impedance. By using an un-bypassed emitter resistor to provide degeneration, the high frequency response as well as the input impedance of the grounded-emitter configuration may be improved considerably (see Fig. 4-8) at the loss of some gain. However, even with the reduced gain due to degeneration, the grounded-emitter configuration may still provide more gain than the grounded-base arrangement. Therefore, from a practical viewpoint, the grounded-emitter configuration is probably the best.

The low frequency response may be extended by making coupling capacity C_1 as large as is practicable and, where necessary, providing a standard low-frequency compensation circuit as part of the collector load impedance (R_3-C_2 in the diagram). In critical circuits, direct-coupling may be employed to obtain the best low frequency response characteristic.

The high frequency response may be extended by using a fairly low value collector load resistor (R_1), and by providing shunt (L_1) or series (L_2) peaking inductances. In operation, L_1 can be chosen to resonate with the output collector capacitance plus shunt distributed capacities (C_C) at a frequency slightly higher than the desired upper frequency limit, raising the gain at the upper end of the spectrum; L_2 can be chosen to form a series resonant circuit with the input capacity of the following stage (C_B). Both types of peaking may be used in some circuits.

Both the high and low frequency response is improved by the use of an un-bypassed emitter resistor to provide degeneration.

R.F. AMPLIFIERS: Transistor R.F. and audio amplifiers share many similarities but, at the same time, have a number of differences. All three basic circuit configurations may be used at either R.F. or audio frequencies. R.F., like audio, amplifiers may be either single stage or cascaded multiple stages. Both single-ended and push-pull circuits may be employed with either type of amplifier. Both have similar problems of interstage impedance matching and the need for D.C. stabilization. Several Classes of operation may be employed (Class A, AB, B, etc.). However, in other respects, the two types of amplifiers are quite different. Component values may be of a different order of magnitude, especially as far as by-pass and coupling capacitors are concerned. In R.F. amplifiers, resonant circuits are employed as collector loads, so that the resulting amplifier has a frequency response limited to a comparatively narrow band; neutralization may be necessary to minimize circuit instability; especially designed or selected transistors may be needed if reasonable gain is to be obtained at higher frequencies.

Transistor R.F. amplifiers may be divided into three general groupings: (a) narrow band, (b) moderately wide band, and (c) wide band. As with corresponding vacuum tube circuits, as the bandwidth is increased, the gain is reduced. The basic transistor R.F. amplifier, made up by the direct substitution of a resonant R.F. circuit for a resistive load, has a much wider bandwidth than an analogous vacuum tube amplifier. This results from the lowered Q of the resonant circuit which, in turn, is brought about by the resistive loading of the transistor itself. To obtain a narrow band R.F. amplifier, resonant circuits are tapped down at lower impedance points to achieve a closer matching to the transistor. Where an extremely wide band is needed, the usual techniques of (a) resistive loading, (b) overcoupling, and (c) staggered tuning of multiple stages may be employed to achieve the necessary bandwidth.

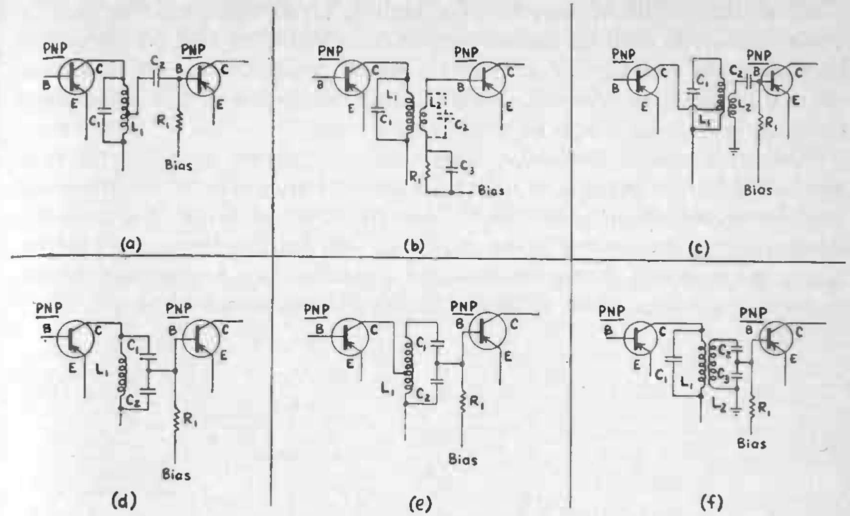


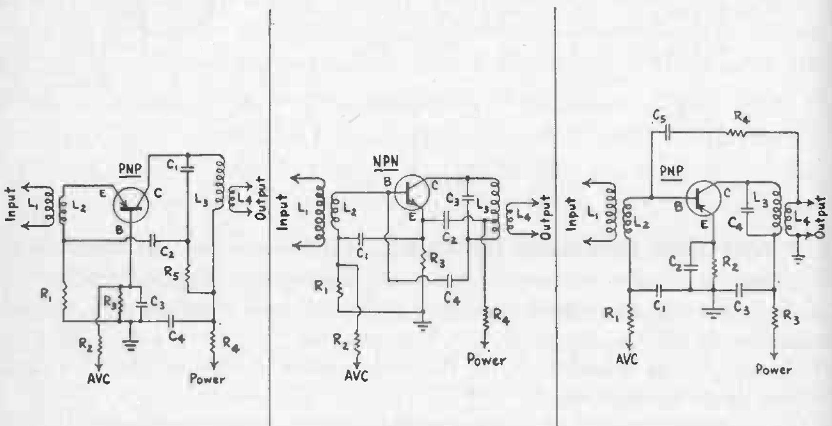
Fig. 4-15

R. F. AMPLIFIER COUPLING METHODS — (a) Tapped coil; (b) Transformer coupling; (c) Tapped-primary transformer coupling; (d) "Tapped" capacitor; (e) Tapped coil and tapped capacitor; (f) Transformer coupling with tapped capacitor. In all the circuits shown, it is assumed that the grounded-emitter configuration has been employed; however, similar techniques could be used for the other configurations.

In (a), tuned circuit L_1-C_1 serves as the collector load impedance for the driving stage, while a tap on L_1 at a low impedance point permits a good match to the input of the following stage. In circuit (b) a step-down R.F. transformer L_1-L_2 provides the proper high to low impedance match; L_1 is tuned by C_1; L_2 may be left untuned, or may be tuned by C_2 if desired. Circuit (c) is similar to circuit (b) in that transformer coupling is used, but the primary winding L_1 is tapped down to minimize the loading effect of the transistor and thus to provide a higher Q circuit and better selectivity. Although a tapped inductance coil is often used for impedance matching, a "tapped" capacitor will do the same job . . . a "tapped" capacitor is made by connecting two capacitors in series. In circuit (d), the collector load is made up of L_1 tuned by C_1 and C_2 in series. The ratio C_2/C_1 determines the impedance match; generally C_2 will have from five to twenty times the capacity of C_1, with correspondingly low reactance. Circuit (e) is similar to circuit (d) except that the coil L_1 is also tapped down to provide a higher Q circuit. Finally, circuit (f) illustrates transformer coupling combined with a series capacitor arrangement for impedance matching.

All the circuits shown may be used both as I.F. or R.F. amplifiers and for power circuits as well as receiver amplifiers. Circuits (c) and (e) permit the best selectivity and highest gain with currently available transistors. Circuits (b) and (f) are good where a wide-band response is desired and where over-coupling techniques are to be employed.

From an economic viewpoint, circuits (a) and (d) are probably the least costly. While it is possible to utilize the internal capacities of the transistor, plus distributed wiring capacities, as part of the tuned circuit, it is generally better practice to "swamp" these capacities with fixed capacitors, minimizing tuning changes with changes in transistor characteristics. Swamping transistor capacities will also result in better transistor interchangeability.



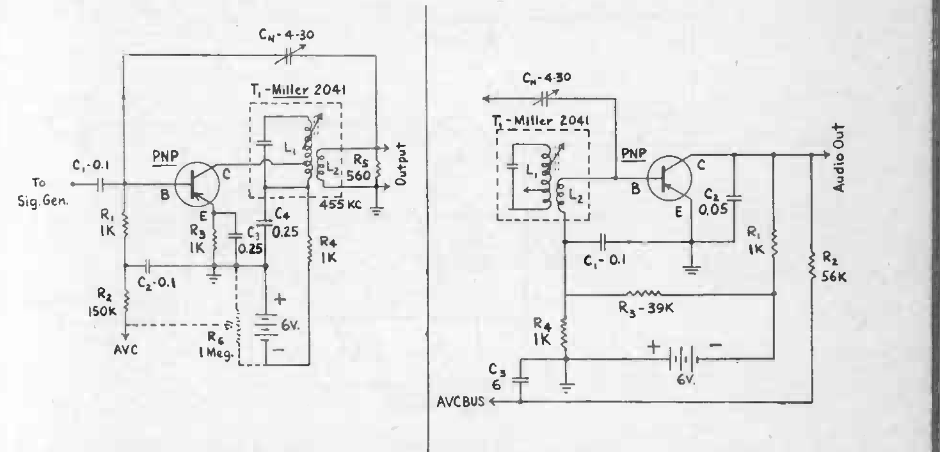
(a) (b) (c)

Fig. 4-16

NEUTRALIZATION METHODS—(a) Grounded-base amplifier; (b) Grounded-emitter amplifier with primary feedback; (c) Grounded-emitter amplifier with secondary feedback. In all three circuits, it is assumed that the transistors are used as receiver R.F. or I.F. amplifiers and hence a source of AVC current is indicated; however, similar techniques may be used with power amplifiers.

In transistorized R.F. amplifiers, neutralization is needed to insure circuit stability and interchangeability of transistors. In circuit (a), the feedback is determined by resistor R_5, which is usually small (under 10 ohms); C_2 is used only for D.C. blocking purposes and, for normal I.F. frequencies, may have a value of about 0.01 mfd.; other circuit values will vary with the transistor used and with the frequency of operation. In circuit (b), the feedback is determined by the tap on primary coil L_3 and by C_4. In circuit (c), feedback is controlled by C_5 and R_4.

In all three circuits, best results are obtained when the feedback is adjusted for the individual transistor. However, it is often possible to arrive at a compromise figure that will work with the majority of transistors of a given type. With currently available transistors in properly neutralized circuits, power gains of from 20 to 35 db per stage are possible.



(a) (b)

Fig. 4-17

PRACTICAL I.F. AMPLIFIER AND AVC CIRCUIT — (a) 455 KC I.F. Amplifier; (b) R.F. Power Detector with AVC Output. In both circuits, component values are for operation at 455 Kc using *Raytheon's* 2N112 (CK760) *PNP* transistor. Circuit (a) is arranged for use as a single stage experimental amplifier. If used in a receiver, C_1 and R_1 would be replaced by the secondary of an I.F. transformer and the secondary of T_1 (L_2) would be coupled to the following stage instead of to a dummy load (R_5).

For test purposes, the lower end of R_2 may be connected to a 1 megohm potentiometer (R_6) across the power supply instead of to an AVC current source. The grounded emitter configuration is used; neutralization is obtained by means of feedback capacitor C_N, which may be adjusted for best results with the transistor used. A grounded-emitter power gain second detector circuit is shown at (b); the circuit is basically a Class B amplifier, supplying a gain of about 10 db; a small bias is supplied by divider net-work R_3-R_4 to bring the transistor out of the low-gain region. Both the audio signal and the AVC control voltage are obtained from the collector, with R_2 and C_3 serving as the AVC filter network. The I.F. transformers shown in both circuits are commercially available items.

SPECIAL PURPOSE AMPLIFIERS: Transistors are adaptable to almost any number of special purpose amplifier applications. Even a partial coverage of the possibilities could easily fill a volume. However, for purposes of illustration, two examples are given.

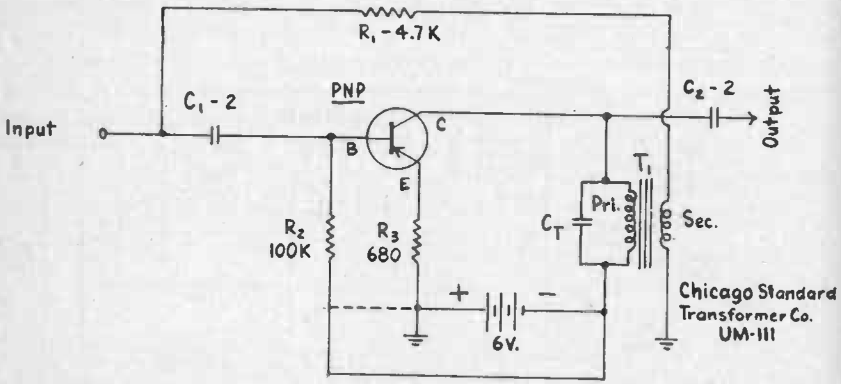


Fig. 4-18

SELECTIVE AMPLIFIER — The circuit shown provides maximum gain at a selected audio frequency, sharply reduced gain at other frequencies. The grounded-emitter configuration is employed. In operation, emitter resistor R_3 introduces degenerative feedback at *all* frequencies, lowering the gain of the stage. The collector load impedance is a tuned circuit made up of the primary winding of transformer T_1 and Capacitor C_T. This alone would insure a peak in the amplifier's response. In addition, however, in-phase energy is fed back from the secondary winding of the transformer through R_1 to the input of the stage. This positive feedback partially cancels the degeneration introduced by R_3, giving an added boost at the selected frequency.

In assembling such a circuit, care must be taken to connect the secondary winding so that an in-phase rather than an out-of-phase signal is fed back to the input. R_1 may be adjusted to provide a greater or lesser feedback signal. If R_1 is made too small, the feedback may become excessive and the circuit will become unstable . . . in some cases oscillation may take place. If R_1 is made too large, negligible feedback will occur and little peaking will be obtained.

In some applications, the base resistor R_2 may be returned to ground instead of to the negative terminal of the power source . . . such a connection is illustrated by the dotted line. C_T is chosen to resonate the primary of T_1 at the desired frequency.

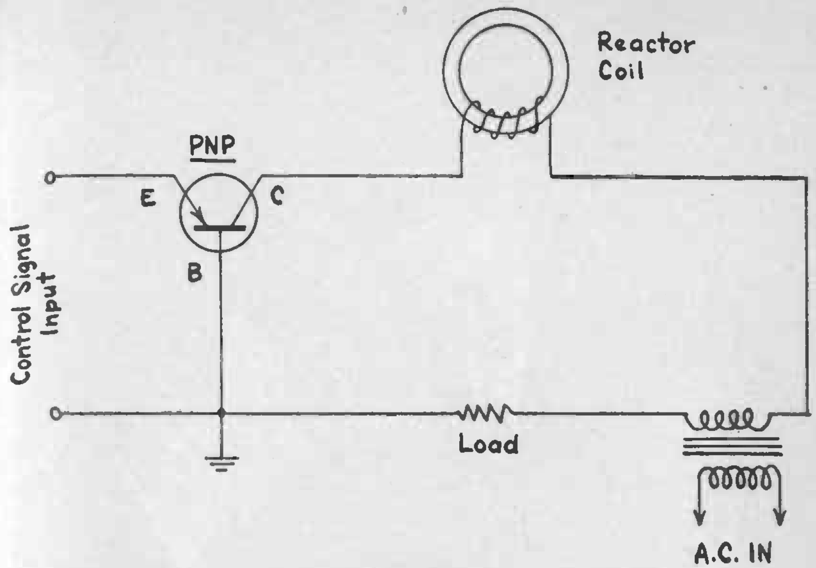
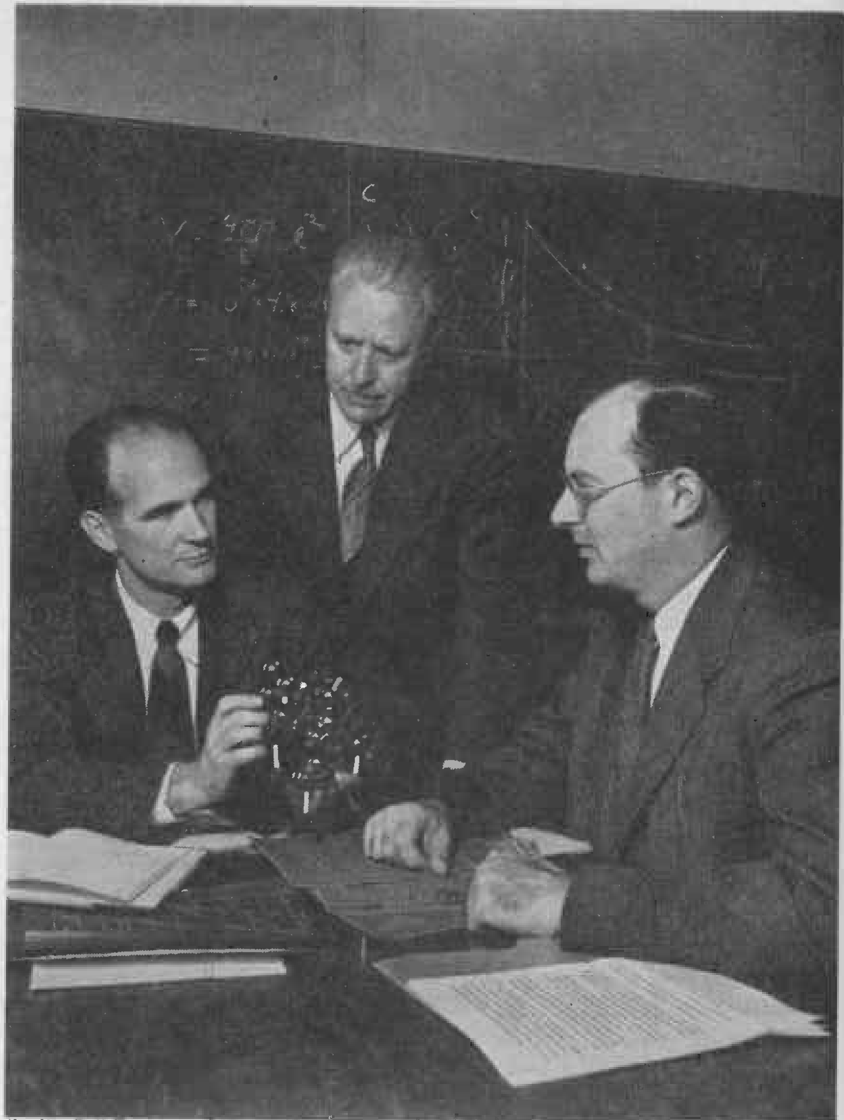


Fig. 4-19

TRANSISTORIZED MAGNETIC AMPLIFIER — A number of approaches are open to the designer wishing to transistorize a magnetic amplifier circuit. One such arrangement is shown. Here, a transistor is connected in the grounded-base configuration. In some other application, a grounded-emitter or grounded-collector configuration might be preferred, although a different circuit arrangement would be required.

It is beyond the planned scope of this volume to give a detailed discussion of magnetic amplifier operation. The circuit shown above is included for reference purposes only. For a more detailed discussion, the reader is referred to Richard H. Spencer's excellent paper TRANSISTOR-CONTROLLED MAGNETIC AMPLIFIER, on pages 136, 137, 138, 139, and 140 of the August, 1953 issue of McGraw-Hill's *Electronics.*



Credit: Bell Telephone Laboratories.

Discussing the crystal structure of semi-conductive materials are these scientists whose work resulted in the Transistor's invention — Dr. William Shockley, Dr. Walter H. Brattain and Dr. John Bardeen. It was through such purely theoretical studies and extensive laboratory investigations that the new physical principle on which the Transistor functions was discovered and explained.

PART II — BASIC CIRCUITS

Chapter 5

OSCILLATORS

Fundamentally, an oscillator is but an amplifier with regenerative feedback. With this in mind, it is a comparatively simple matter to set up the basic requirements of an oscillator. whether it be a vacuum tube or a transistor circuit, and these are:

(1) A signal amplier stage or stages.

(2) A feedback arrangement coupling the amplifier's input and output terminations having the following characteristics:

(a) The feedback signal must be *regenerative*—that is, a change in the output signal in a given direction must result in a feedback signal which continues the change in the same direction up to the limits imposed by the amplifier's operation.

(b) The feedback signal must be of sufficient amplitude to overcome circuit losses, making the operation of the device self-sustaining. In general, this means that the ratio of the output to the feedback signal must approximate or be less than stage gain. The lower the losses, the less feedback needed.

(3) Where a specific frequency of operation is required, a tuned (resonant) circuit must be incorporated either in the amplifier proper or in the feedback path. This may be an L-C circuit, a piezoelectric crystal, or an R-C network with a specific time constant.

In a way, the design of vacuum tube oscillator circuits presents fewer problems than does the design of corresponding transistor circuits. In a vacuum tube circuit, with both high input and output impedances, the problem of obtaining a feedback signal with minimum loss is not generally a difficult one. Rather, the chief problem is that of obtaining a signal with the proper phase relationship to insure regenerative feedback. In a transistor oscillator, on the other hand, the circuit designer is faced with the dual problem of obtaining regenerative feedback and also matching the high output to the low input impedances in such a way as to keep circuit losses to a minimum. In general, this problem is attacked in one of two ways—(a) by incorporating an impedance matching arrangement in the feedback circuit, and (b) by accepting the inherent losses of mis-matched impedances and depending on circuit gain to overcome these losses. The designer working with commercial or industrial circuits must also consider the need for D.C. stabilization (see Fig. 4-4, Chapter 4), especially as it affects output amplitude, signal waveform, and frequency stability.

Transistor oscillators, like transistor amplifiers, may be grouped most conveniently according to the type of signal handled (Audio, R.F., etc.). Hence, in presenting basic oscillator circuits, we shall follow essentially the same outline used in Chapter 4. However, the reader must remember that transistor oscillators also may be classed according to the basic circuit configuration employed.

AUDIO OSCILLATORS: Audio oscillators are generally considered to operate within the frequency range of 20 to 20,000 c.p.s. However, most of the oscillator circuits shown may be used at ultrasonic, and even at R.F. frequencies, with the proper choice of transistors and components. The special problems encountered in the design of audio oscillators are not far different from those encountered in the design of transistorized audio amplifiers. In fact, small iron core transformers designed for the interstage coupling of transistor amplifiers often make excellent oscillator transformers.

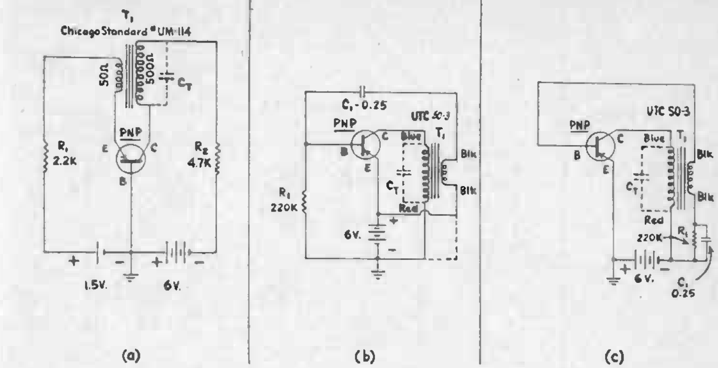


Fig. 5-1

"TICKLER" FEEDBACK CIRCUITS — (a) Grounded-base configuration; (b) Grounded-emitter configuration with shunt-fed base; (c) Grounded-emitter configuration with series-fed base. In these circuits, a small iron-core transformer (T_1) serves the dual function of providing an in-phase feedback signal and of matching the transistor's high output to its low input impedance.

A step-down turns ratio between the primary and secondary windings is used in each case. In general, a greater step-down is used with the grounded-base configuration because the input impedance of this circuit is lower than that of the grounded-emitter arrangement.

In all three circuits, the frequency of operation may be fixed by connecting a small capacitor (C_T) across either the primary or secondary (or both) windings to form a tuned circuit. Circuits (b) and (c) are virtually identical except for the means of supplying base bias current. In circuit (b), a shunt arrangement is used and no D.C. flows through the transformer's secondary winding; the series-fed arrangement used in circuit (c) permits a small D.C. flow through the secondary. In circuit (b), the lower end of the secondary winding may be returned either to the emitter or to the negative side of the power supply, as shown by the dotted line. In circuits (b) and (c), capacitor C_1 should be large enough to prevent series tuning the secondary winding. In all three circuits, if the best quality signal waveform (sinusoidal) is to be obtained, the transformers chosen must properly match the transistors used, and the D.C. resistances must be chosen for the supply voltages and transistors employed . . . these are R_1 and R_2 in circuit (a), R_1 in circuits (b) and (c).

If oscillation is not obtained in an experimental circuit set-up, either the primary or the secondary lead connections should be reversed.

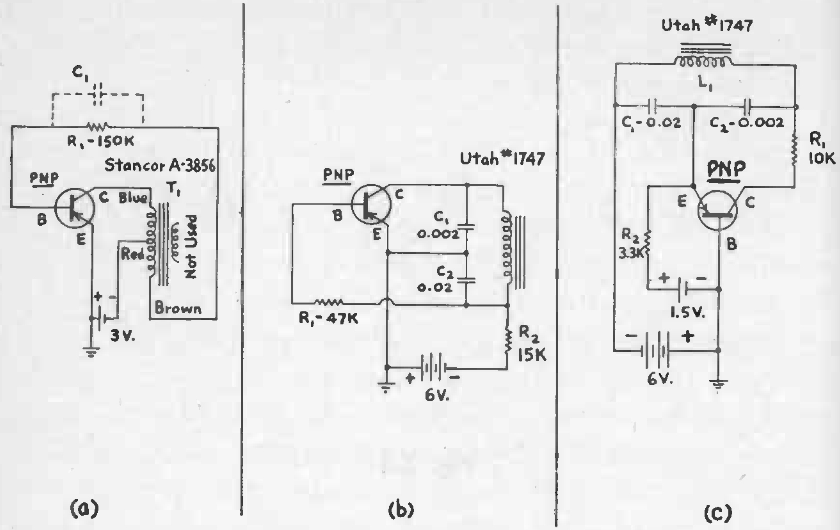


Fig. 5-2

"HARTLEY" AND "COLPITTS" CIRCUITS — a) Hartley oscillator; (b) Colpitts grounded-emitter oscillator; (c) Colpitts grounded-base oscillator. In all three circuits a tapped impedance is used to provide the feedback energy necessary to start and sustain oscillation. In the Hartley circuit (a), a tapped inductance coil is employed; in the Colpitts circuits (b,c), "tapped" capacitors (two capacitors in series) are used. Either the grounded-emitter or the grounded-base configuration may be employed with both types of oscillator circuits.

In circuit (a) the tap on the inductance coil should be located at the proper point to provide an impedance match between the collector and base circuits—the coil (T_1) then acts as a type of auto-transformer. With the proper tap, a by-pass capacitor (C_1) should be provided across the base resistor (R_1). However, in the circuit shown a center-tapped coil is employed and the base resistor R_1 is left un-bypassed to limit the base signal currents. Either a series or a shunt-fed arrangement may be used . . . a series-fed circuit is shown. The coil may be tuned by a parallel capacitor if desired. In circuits (b) and (c), an inductance coil (L_1) is tuned by two capacitors in series (C_1 and C_2).

The impedance ratio of these two capacitors should approximate the ratio of the output and input impedances of the transistor. A good rule of thumb is to make the "input" capacitor approximately ten times larger than the "output" capacitor, although a more precise impedance match will insure the best quality signal waveform. Since one capacitor is much smaller than

the other, and the two are in series, the smaller capacitor (and coil) determines the frequency of operation. The fixed resistors (R_1 and R_2) should be chosen both to limit electrode currents within maximum ratings and to insure a good quality signal.

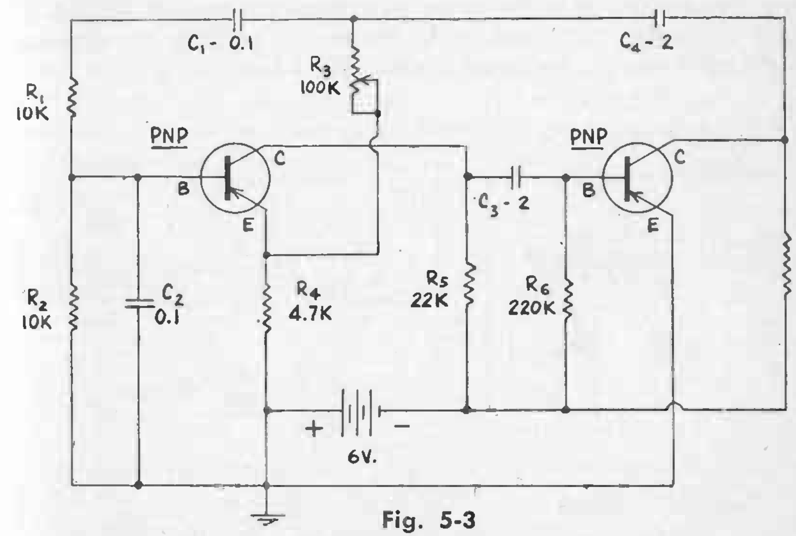
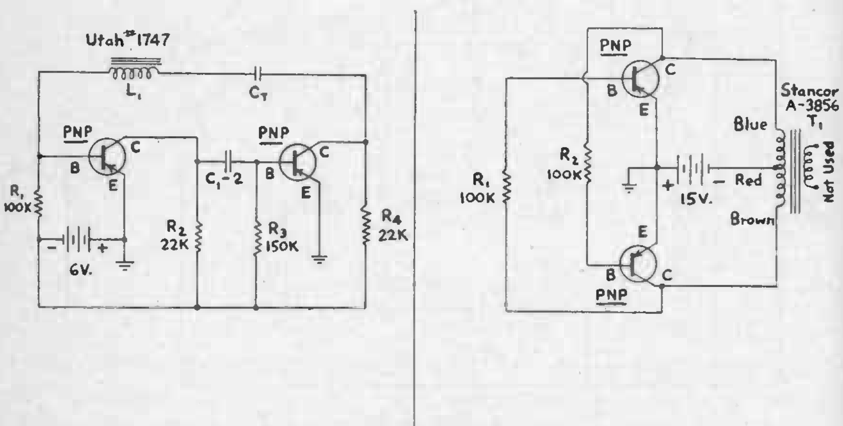


Fig. 5-3

WIEN BRIDGE (R-C) OSCILLATOR — A transistorized version of a standard vacuum tube Wien Bridge audio oscillator is shown. Only the basic circuit is illustrated and, therefore, no provision has been made for D.C. stabilization, output amplitude stabilization, or for minimizing waveform distortion at different frequencies. However, such refinements would be desirable in a commercial version of the circuit. The grounded-emitter configuration is employed.

Since phase reversal occurs in a grounded-emitter stage, a two-stage circuit is needed to obtain a positive (in phase) feedback signal. Conventional R-C coupling is used between stages, with R_5 serving as the collector load for the first stage, C_3 as the coupling capacitor, and R_6 as the base resistor for the second stage. R_7 is the collector load resistor for the second stage and the signal appearing across this resistor is coupled back through capacitor C_4 to the input. As in the corresponding vacuum tube circuit, the frequency of operation is determined by the R_1C_1-R_2C_2 combination. However, in choosing values for this network, the comparatively low input impedance of the transistor must be taken into account. Fortunately, unbypassed emitter resistor R_4 helps raise the input impedance of the stage, although this resistor is part of the bridge circuit.

The adjustment of R_3 determines the quality of the signal produced . . . that is, how closely the waveform approaches that of a "pure" sine wave. Incorrect adjustment of this resistor may prevent oscillation or may result in a badly distorted waveform. The circuit, as shown, operates at a single frequency, but could easily be changed to a variable frequency oscillator by making the components in the frequency determining network (R_1C_1-R_2C_2) variable . . . either continuously or by means of a switching arrangement. With the values shown, frequency is about 120 c.p.s.



(a) (b)

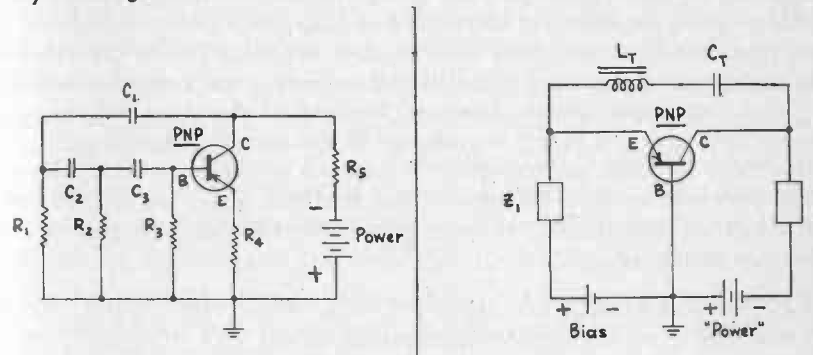
Fig. 5-4

TWO-STAGE AND "PUSH-PULL" OSCILLATORS—(a) Two-Stage oscillator; (b) "Push-Pull" Circuit. The audio oscillator shown at a) is simply a two-stage, grounded-emitter, capacitor coupled amplifier with a series-tuned circuit (L_1-C_T) providing the feedback path between the "output" of the second stage and the "input" to the first stage. The general arrangement is similar to that used in the Wien Bridge Oscillator (Fig. 5-3). R_1 and R_3 are the base resistors, R_2 and R_4 the collector load resistors for the first and second stages, respectively.

Several modifications are possible in the basic circuit, depending on the needs of the individual designer. A few of these are . . . (a) Adding unbypassed emitter resistors to provide degeneration, reducing distortion and improving stability; (b) D.C. bias stabilization; (c) Using a second series-tuned circuit between stages in place of coupling capacitor C_1; (d) Using a *PNP-NPN* direct-coupled circuit configuration; (e) Using a piezo-electric crystal in place of the series-tuned circuit. The "Push-Pull" oscillator shown at (b) utilizes a center-tapped coil or transformer (T_1) and two transistors in a grounded-emitter configuration, with a cross-feed arrangement between

collectors and bases. No attempt is made to match impedances, and hence the series base resistors (R_1 and R_2) are left un-bypassed to limit base signal currents. A series-fed circuit is employed.

Possible modifications in the basic circuit include . . . (1) Taps on the transformer to provide a better impedance match to the bases; (2) A shunt-fed arrangement; (3) "Tuning" T_1 by means of a parallel capacitor; (4) Emitter-to-ground resistor; (5) Shunt capacitors across the base resistors. Circuit (b) is quite efficient and capable of supplying considerable power without overloading the transistors . . . in power applicaions, oscillator transformer T_1 may also serve as the output element by providing a secondary winding.



(a) (b)

Fig. 5-5

SPECIAL AUDIO OSCILLATORS — (a) Phase-Shift Oscillator; (b) Grounded-base Oscillator. In experimental tests, both of these circuits appeared to be relatively critical, with different component values needed to obtain oscillation with different transistors . . . and, in some cases, even with different transistors of the same type. It is difficult to say whether this was due to tolerances in the transistors or in the components used. However, to avoid misleading the worker, component values are not given and the basic circuits are shown for reference purposes only.

The phase-shift oscillator (a) is a direct adaptation of the analogous vacuum tube circuit. The grounded-emitter configuration is employed. Since phase reversal occurs in a grounded-emitter stage, a phase- shifting network is employed between the output (collector) and input (base) electrodes to obtain the necessary in-phase feedback signal to start and sustain oscillation. This network consists of three R-C circuits (R_1C_1, R_2C_2 and R_3C_3) each of which provides a 60° shift, giving a total shift of 180°. The design is critical because of the high losses in the phase-shift network and the low input impedance of the transistor. Emitter resistor R_4 serves a dual function . . . (1) It serves to raise the input impedance of the stage, and (2) it provides degeneration which, in turn, improves stability and reduces distortion; however, its size is fairly critical . . . too large a value here will provide too much degeneration, preventing oscillation, while too small a value may result in excessive distortion or, again, the failure to obtain oscillation (due to the lowered input impedance of the stage). In some cases, better results can be obtained if the base resistor (R_3) is returned to the negative side of the power supply instead of to ground.

Oscillator (b) uses a grounded-base configuration with a series-tuned circuit (L_T-C_T) coupling the input and output. Z_1 and Z_2 are the emitter and collector loads, respectively. Since phase reversal does *not* occur in the grounded-base configuration, a special phase-shifting network is not needed between the input and output circuits. However, because of the great differences between the input and output impedances of this circuit configuration, it is often difficult to obtain sufficient positive feedback to overcome circuit losses and to start and maintain oscillation. Since feedback losses are so great in both circuits (a) and (b), best results can be obtained when high-gain transistors are employed.

R.F. OSCILLATORS: At the present time, the upper frequency limit of transistor oscillators is set not so much by practical circuit design considerations as by the characteristics of available transistors. The majority of transistor R.F. oscillators are quite similar to lower frequency (audio) circuits and analogous to corresponding vacuum tube arrangements. Generally speaking, *NPN* transistors may be used at higher frequencies than *PNP* units, and tetrodes and barrier type transistors at much higher frequencies than conventional triodes. At present, "field effect" transistors appear to be the best as far as upper frequency limit is concerned. However, newly developed manufacturing techniques, including *GE's* new "meltback" process, as well as improvements in basic transistor design, indicate that the eventual upper frequency limit will be comparable to that of vacuum tubes . . . at least into the thousands or tens of thousands of megacycles. In fact, due to the inherent higher efficiency of transistors, as compared to vacuum tubes, and the fact that extremely small electrode elements and close spacings may be used due

to the low operating voltages employed, it appears safe to predict that the upper frequency limit of future transistors may exceed that of present day vacuum tubes. From a practical design viewpoint, transistors appear to be useful as oscillators at much higher frequencies than they can be used as amplifiers, and it is not uncommon to use them as oscillators well past their nominal "alpha cutoff"* frequencies. When designing transistor R.F. oscillators, the engineer should remember that the factors which affect circuit operation at lower frequencies are accentuated at higher frequencies. Stage gain as well as interelectrode resistances and capacitances change with changes in temperature and with variations in D.C. supply currents. At lower frequencies, the gain and resistance variations are the more important. At high frequencies, the effects of capacitance variations predominate. Hence, in designing transistor circuits for industrial or commercial applications, D.C. stabilization is *extremely* important . . . unless specifically mentioned in the captions, D.C. stabilization has not been provided in the basic circuits shown. However, the techniques used in stabilizing oscillator circuits are essentially like those used in amplifier design, as described in Chapter 4 (Fig. 4-4). Where the maximum in frequency stability is desired, it may be necessary to "swamp" interelectrode capacities with external fixed capacitors as well as providing D.C. stabilization.

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*Alpha Cutoff Frequency: Frequency at which Alpha (current gain in grounded-base circuit) is 0.707 its low frequency value.

"Alpha cutoff" is a relatively old term, used with the original point-contact transistors. Although still specified by some transistor manufacturers in giving the electrical characteristics of their products, it is gradually being replaced by newer terms.

One term replacing "alpha cutoff" as indicative of a transistor's frequency response is "beta cutoff." "Beta cutoff frequency" is similar to "alpha cutoff" in that it is the frequency at which the beta (current gain in the grounded-emitter circuit) is down 3 db from its low frequency value. "Beta cutoff" is especially useful when referring to junction transistor circuits.

Still another term coming into use is the "Figure of Merit." This is approximately the frequency at which the power gain of the transistor is reduced to unity (1.0). In general, the "Figure or Merit" will have a much higher value than either "Alpha cutoff" or "Beta cutoff."

All three terms are expressed in kilocycles (kc) or megacycles (mc).

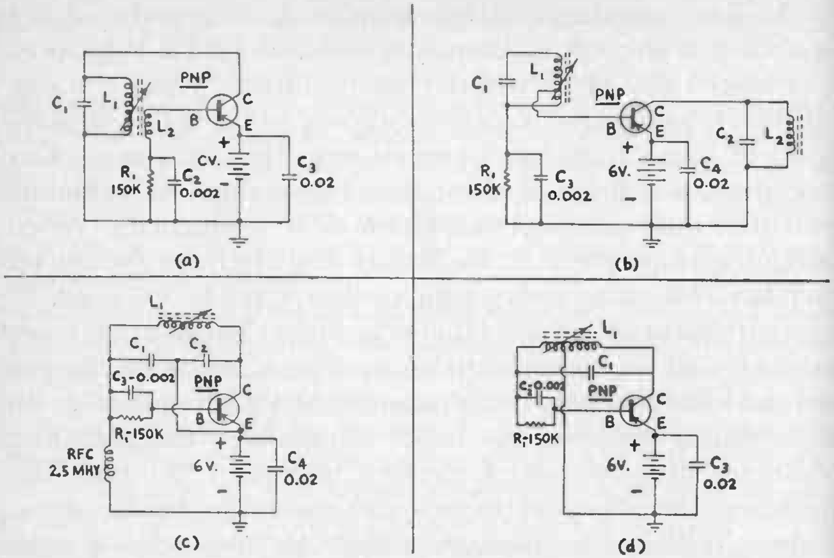


Fig. 5-6

BASIC R.F. OSCILLATOR CIRCUITS — (a) "Tickler" Feedback; (b) TBTC Circuit *(Tuned-Base-Tuned-Collector)*; (c) Colpitts; (d) Hartley. All four circuits are suitable for use over a wide range of frequencies, provided suitable component values and transistors are used. Although most transistors will serve as oscillators at frequencies well past their nominal alpha cutaff values, for best results and maximum interchangeability, "high-frequency" transistor types should be used. Suitable types are *Raytheon's* types 2N112 (CK760), 2N113 (CK761), 2N114 (CK762) and *Sylvania's* types 2N94 and 2N94A.

The *Raytheon* units are *PNP* transistors and may be used in the circuits as shown. The *Sylvania* units are *NPN* transistors and may be used only if the D.C. polarities are reversed. The component values given are suitable for use in the AM Broadcast Band (550-1600 Kc); at other frequencies, minor changes may be necessary. Either permeability or capacitive tuning systems may be employed. Although the grounded-emitter configuration is used in the four circuits shown, only minor modifications are necessary to permit the use of the grounded-base arrangement.

Circuit (a) utilizes a small feedback coil (L_2) to provide the positive feedback signal needed to start and maintain oscillation; for fixed frequency operation in the Broadcast Band C_1 may have a value of 50 mmf. and L_1 may be a high-Q antenna coil such as a *Miller* No. 6300 unit; L_2 may consist of 15-50 turns of #24 enamelled copper wire, close-coupled to L_1; if oscillation is not obtained with the first connections, reverse the leads to *either*

L_1 or L_2. Circuit (b) represents a direct adaptation of the well-known TPTG *(tuned-plate-tuned-grid)* vacuum tube oscillator circuit to transistor operation; a tap is provided on L_1 to prevent excessive loading of the L_1-C_1 tuned circuit by the low input impedance of the transistor; for fixed frequency operation within the broadcast band, C_1 and C_2 may be rated at 270 mmf., L_1 may be a tapped antenna coil similar to the *Miller* No. 2000 unit, and a *Miller* No. 6300 coil may serve for L_2; in some cases it may be necessary to connect a small "gimmic" capacitor (about 5 mmf. or so) between the base and collector electrodes to obtain oscillation.

Circuit (c) represents a transistorized R.F. version of the familiar Colpitts circuit; capacitors C_1 and C_2 are chosen to match the input and output impedances of the transistor as well as to tune the coil (L_1) to the desired operating frequency; for Broadcast Band operation, C_1 may be rated at 1000 mmf., C_2 at 50mmf., and L_1 may be a *Miller* No. 6300 coil. Circuit (d) is similar to circuit (c) except that a tapped coil (L_1) rather than a "tapped" capacitor is used for feedback and impedance matching, thus forming a Hartley circuit; C_1 may be rated at 50 mmf. and L_1 may be a tapped coil such as a *Vokar* C-801 or a *Meissner* 14-1033.

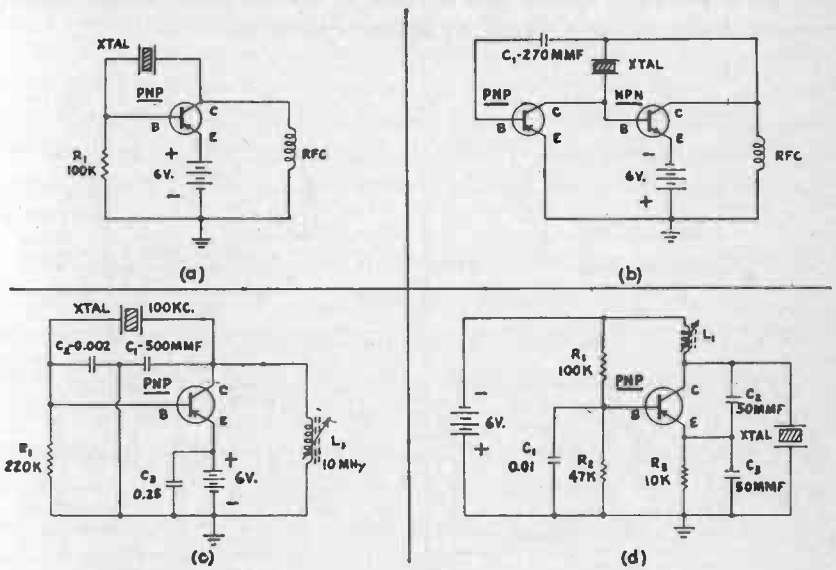


Fig. 5-7

CRYSTAL-CONTROLLED OSCILLATORS — (a) Basic circuit; (b) Complementary-Symmetry circuit; (c) Modified grounded-emitter circuit; (d) Grounded-base configuration. The circuits shown represent but four of a large number of possible crystal-controlled transistor oscillators. Almost every vacuum tube oscillator circuit may be adapted to transistor operation if impedances are taken into account.

Circuit (a) is a basic oscillator circuit and is suitable for a wide range of frequencies, depending on choice of crystal, transistor and R.F. choke (RFC). Circuit (b) is a modified form of circuit (a), but with a direct-coupled amplifier stage added. It is capable of considerably more output than circuit (a).

Circuit (c) represents a "Colpitts-type" oscillator in that capacitors C_1 and C_2 form an impedance matching network between the collector and base circuits. Best results are obtained if L_1 is adjustable. 10 MHy is a nominal value for 100 Kc operation.

Circuit (d) is a "Clapp-type" oscillator using the grounded-base (common-base) configuration. The crystal is connected between collector and ground and a capacitive signal divider network (C_2 and C_3) is between collector and emitter. The base is held at A.C. ground potential by C_1. In circuit (d), if too much inductance is used (L_1), the crystal may lose control. If not enough, oscillation may not occur. D.C. stabilization is shown in circuit (d) but not in the other circuits, and is provided by the R_1-R_3 voltage divider network, aided, to some extent, by emitter resistor R_3.

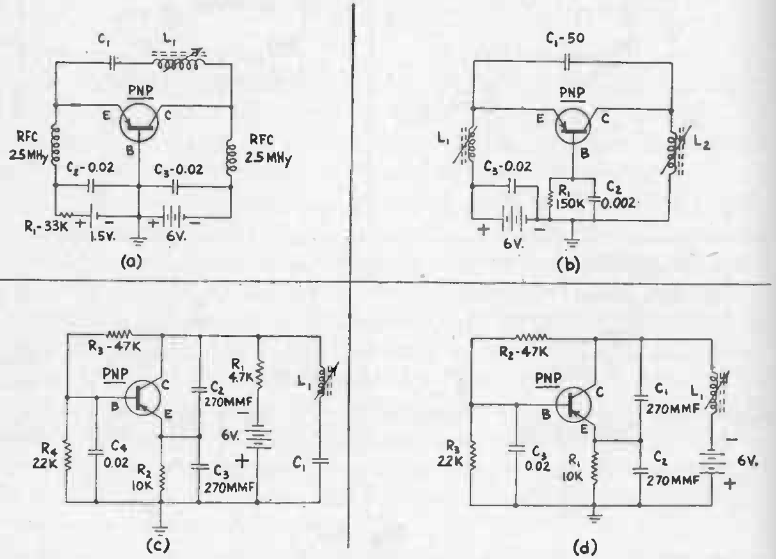


Fig. 5-8

SPECIAL R.F. OSCILLATORS — (a) Grounded-Base oscillator with tuned feedback; (b) Grounded-Base oscillator with capacitive feedback; (c) Shunt-fed "Clapp" oscillator; (d) Series-fed "Clapp" oscillator. Although the base electrode is connected directly to ground only in circuit (a), all four circuits employ the grounded-base configuration, for in the remaining three circuits the base is held at A.C. ground potential by means of appropriate by-pass capacitors.

In circuit (a), a series-tuned circuit (L_1-C_1) provides the feedback path between the emitter and collector loads of the transistor. Circuit (b) is quite similar to circuit (a) except that a capacitive (C_1) feedback arrangement is used and the R.F. chokes used as emitter and collector loads have been replaced by adjustable inductances (L_1 and L_2); in addition, the basic circuit has been modified to permit operation from a single D.C. source instead of the dual supply generally used with the grounded-base configuration and shown in circuit (a). Circuits (a) and (b) both represent practical versions of the basic circuit shown and described in Fig. 5-5.

Circuits (c) and (d) are almost identical except for the D.C. feed arrangements used; both represent modified "Clapp" circuits, with feedback obtained across a capacitive voltage divider . . . C_2-C_3 in (c), and C_1-C_2 in (d); both circuits are D.C. stabilized—by voltage divider R_3-R_4 and emitter resistor R_2 in (c), and by voltage divider R_2-R_3 and emitter resistor R_1 in (d).

The component values listed for all four circuits are suitable for operation at frequencies within the A.M. Broadcast Band or slightly above or below these frequencies. For operation at much higher or lower frequencies, minor changes in values may be necessary. As with the other R.F. oscillator circuits described, best results can be obtained if "high frequency" transistors are employed.

SPECIAL PURPOSE OSCILLATORS: As with vacuum tube circuits, there are a number of transistor oscillators which are not properly classed either as "Audio" or as "R.F." oscillators, either because they may operate in either frequency range with but minor changes in component values, or because they are not generally used to produce sinusoidal signal waveforms. Although virtually every vacuum tube oscillator circuit has a transistorized counterpart, there are some transistor oscillators for which there is no corresponding vacuum tube circuit. The number of possible transistor oscillator arrangements is limited only by the imagination of the individual circuit designer. Space limitations prevent our illustrating more than a few of the more basic types.

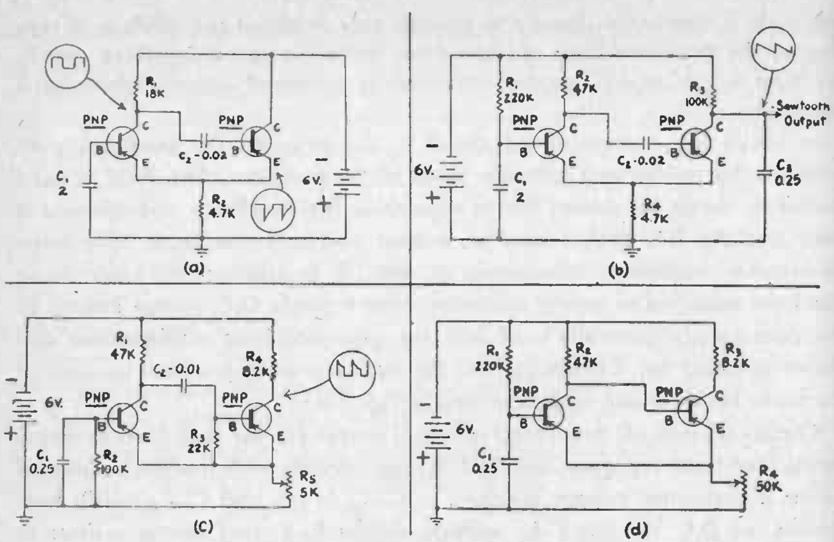


Fig. 5-9

EMITTER-COUPLED MULTIVIBRATORS – (a) Basic Emitter-Coupled circuit; (b) Sawtooth waveform circuit; (c) Adjustable stability circuit; (d) Direct-coupled circuit. The emitter-coupled transistor multivibrator is roughly analogous to the *cathode-coupled* vacuum tube multivibrator.

The basic emitter-coupled circuit is given at (a). Circuit (b) represents the basic circuit modified to supply a sawtooth output signal; the essential modification is the addition of a standard R-C "charge-discharge" circuit (R_3-C_3) as part of the collector load of the second transistor—in operation, C_3 is charged slowly through R_3, then discharged rapidly as the second transistor switches from a non-conducting to a conducting state. Circuit (c) is another version of the basic circuit, but with an adjustable emitter resistor (R_5) to permit a control on circuit stability. Circuit (d) is similar to circuit (c) but illustrates the use of direct-coupling between stages.

In all four circuits, the first transistor is connected using the grounded-base configuration, the second transistor using the common-emitter arrangement; note that the base of the first transistor is heavily by-passed to ground in every case. Thus, with the exception of circuit (b), all the circuits shown operate in essentially the same fashion . . . several versions are given simply to illustrate a few of the many modifications possible. Basic signal waveforms are shown.

Component values may be varied to change the frequency of operation as well as the symmetry and exact waveform of the signals produced . . . operating frequencies are not listed, since they will vary with the transistors used. If desired, any of the circuits may be "locked-in" with an external signal by applying an appropriate sync pulse to the ungrounded collector or base electrodes (collector of first transistor, base of second) or to the emitter circuit.

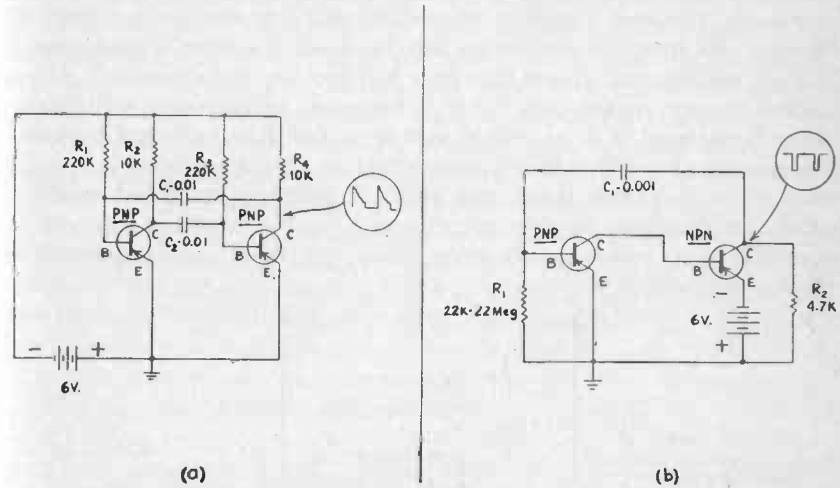


Fig. 5-10

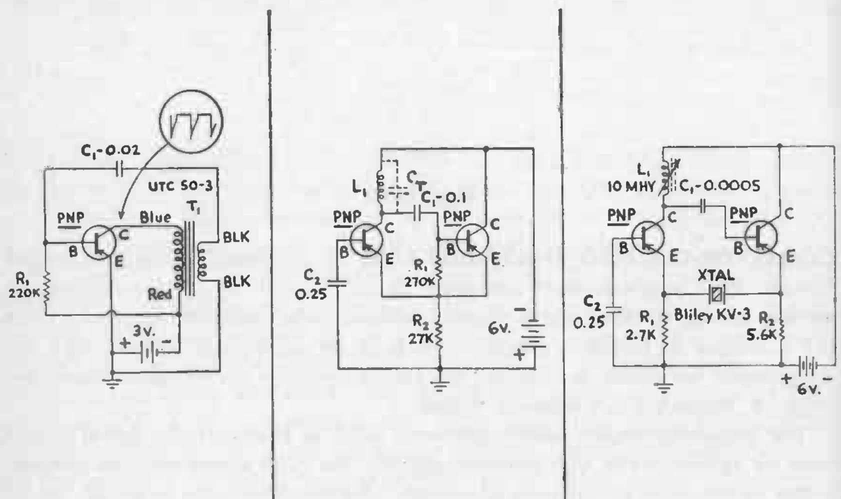
COLLECTOR-COUPLED MULTIVIBRATORS – (a) Basic Collector-Coupled Circuit; (b) Complementary-symmetry circuit. Circuit (a) is a transistorized version of the familiar *plate-coupled* vacuum tube multivibrator, but circuit (b) is unique to transistor circuitry—there is no analogous vacuum tube arrangement, for circuit (b) utilizes the complementary symmetrical characteristics of transistors of different types.

The grounded-emitter configuration is used in both circuits. Either circuit may be synchronized with external signals; the sync signal may be applied either to the base or collector electrodes of either transistor in circuit (a); in circuit (b) the sync signal may be applied to the common collector-base connection between stages.

In circuit (a), if the collector load resistors, base resistors, and coupling capacitors are made equal (i.e., $R_1 = R_3$, $R_2 = R_4$, $C_1 = C_2$), and similar transistors are used, the resulting signal will have a symmetrical time division; a non-symmetrical signal (pulse) will result if corresponding parameters are not equal, with the degree of non-symmetry proportional to the differences in values between corresponding components. In circuit (b), the complementary symmetrical properties of *PNP* and *NPN* transistors are utilized to provide direct interstage coupling, resulting in a multivibrator circuit with a minimum of components.

In all transistor multivibrator circuits, whether collector or emitter-coupled (see Fig. 5-9 also), both the frequency of operation and the signal waveform depend, to a large extent, upon the transistors employed as well as on external circuit parameters. Therefore, if reasonably good stability is desired, as in commercial applications, D.C. stabilization is mandatory; in some cases, to provide maximum transistor interchangeability, it may be necessary to "swamp" the transistor parameters with fixed value external impedances.

Since multivibrator circuits, by their very nature, are dependent on resistance-capacity values both for their frequency of operation and type of signal (waveform), it is not too surprising to find that individual transistor characteristics have a very important effect on circuit operation . . . much more so, in fact, than is the case with L-C or crystal-controlled oscillator circuits. In designing transistor multivibrator circuits, therefore, it is well to remember that, unlike vacuum tubes, there is a direct resistive connection between all electrodes.



(a) (b) (c)

Fig. 5-11

OTHER SPECIAL PURPOSE OSCILLATORS — (a) "Blocking" Oscillator; (b) Emitter-Coupled I-g Oscillator; (c) Emitter-Coupled Crystal-Controlled Oscillator. Circuit (a) is a direct adaptation of a "tickler feedback" audio oscillator circuit; the grounded-emitter configuration is employed, and a shunt-fed arrangement is used in the base circuit. As in the analogous vacuum tube circuit, the repetition frequency is dependent primarily on the R_1-C_1 time constant for any given oscillator transformer (T_1), with the input

impedance of the transistor taken into account. In a practical circuit, if oscillation is not obtained, *either* the primary or secondary leads of transformer T_1 should be interchanged.

Since a pulsed signal is produced, circuit (a) may be used to develop sawtooth waveforms by connecting a standard R-C "charge-discharge" circuit in the collector D.C. supply lead—a fixed resistor is inserted between the negative lead of the power supply and the "red" lead of the transformer, with a capacitor connected between the junction of the resistor and the transformer lead and ground; the time constant of the R-C network thus formed should be several times the repetition rate of the circuit . . . the sawtooth signal appears across the capacitor.

Circuits (b) and (c) represent adaptations of the emitter-coupled multivibrator circuits to L-C and crystal-controlled operation, respectively. In circuit (b), the collector load inductance L_1 may be tuned by a parallel capacitor (C_T) or by distributed capacities. In circuit (c), L_1 should be adjustable for best results . . . with the values given (L_1 has a *nominal* value of 10 MHy) and with the crystal specified, the operating frequency is 100 Kc. These three circuits represent only a small portion of the many possible special purpose transistor oscillator arrangements.

Credit: RCA Victor, Division of Radio Corporation of America.

FINAL EXAM — Highly sensitive and exacting electronic test instruments pass on RCA transistors before they are graduated from the company's plant. Above, a skilled technician is surrounded by layers of finished transistors which are to be put over the final production hurdle.

PART II — BASIC CIRCUITS

Chapter 6

SPECIAL PURPOSE CIRCUITS

Like the vacuum tube, the transistor is by no means limited to amplifier and oscillator circuit applications. There are a large number of transistor circuits which cannot be grouped conveniently with either *Amplifiers* or *Oscillators.* These include such circuits as detectors, clipper-limiters, mixers, and flip-flops, as well as circuits for special transistor types such as phototransistors and junction tetrodes. For convenience in listing, all of these circuits are grouped together in this chapter as SPECIAL PURPOSE CIRCUITS, even though the individual circuit types may not be related; a number of *Test Circuits* are included also.

In referring to these circuits, it is well to remember that the transistor is basically an amplifying device and that virtually all practical circuits utilize this characteristic in some way. Hence, the three basic amplifier configurations — grounded-base, grounded-emitter, and grounded-collector — are fundamental to all transistor circuits. For example, a good many amplifier circuits are shown in *Chapter 4,* but any of these may be classified as belonging to one of the three basic configurations, with the only real difference between circuits residing in the nature of the loads used, in the Class of operation (A, B, etc.), in the interstage coupling methods used, and whether or not degenerative feedback is employed. Again, the oscillator circuits illustrated in *Chapter 5* are but amplifiers with regenerative feedback between their input and output terminations.

In an analogous manner, the "Special Purpose" circuits shown in this chapter might be classed according to the three basic amplifier configurations and discussed as amplifiers or oscillators with special characteristics. A *limiter* then becomes an overdriven amplifier, a *detector* or *mixer* a non-linear amplifier, and a *flip-flop* an oscillator with insufficient feedback to maintain oscillation. However, for purposes of illustration and discussion, we will follow conventional terminology in labeling and grouping the circuits.

DETECTORS, CLIPPERS AND LIMITERS: In a broad sense, detectors, clippers and limiters are all non-linear amplifiers, although the gain, in some cases, may be less than unity. If the term "amplifier" is restricted only to those circuits which provide a gain greater than one, then the expression might be changed from "non-linear amplifiers" to "non-linear devices." Almost every amplifier circuit is non-linear to some degree, and it is this non-linearity which introduces distortion. From the viewpoint of fidelity, a "good" amplifier is one which has a close approach to perfectly linear operation; from the viewpoint of the circuit designer requiring detection or clipping, the opposite may be true. Thus, a "poor" amplifier may be a "good" detector or clipper. A single-ended Class B or Class C amplifier makes an excellent clipper, for example. Detectors, clippers, and limiters all employ similar circuits and are similar in operation. The chief difference in these three devices is in their application. A *detector* is a non-linear device used to demodulate an R.F. signal; it generally accomplishes this function by removing either the positive or the negative-going half of the modulated R.F. signal, allowing a pulsating D.C. to flow through its load impedance; the average value of the pulsating D.C. varies with the modulation. A *clipper* serves to "chop off" or remove a portion of an applied A.C. signal—it may be either the positive or negative-going half of the signal, or one or both peaks. A *limiter* is a specialized type of clipper used to limit the positive and negative peaks of an applied signal.

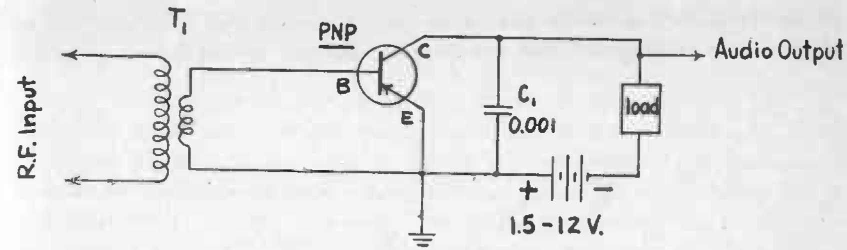


Fig. 6-1

SIMPLE R. F. DETECTOR — The detector circuit shown is essentially a grounded-emitter amplifier stage operated without base bias current. In operation, with no signal applied, D.C. through the collector load is at a minimum. A modulated R.F. signal, supplied by R.F. transformer T_1, is applied to the base; with a *PNP* transistor, the positive-going half cycles of the applied signal have relatively little effect on the transistor, since they are of the wrong polarity to produce base current flow; the negative-going half cycles, on the other hand, do produce base current flow and this, in turn, permits the collector current to increase. Without collector capacitor C_1, the collector current would consist of a series of half-wave pulses, with a repetition rate equal to the frequency of the applied R.F. signal, and an instantaneous amplitude proportional to the peak value of each cycle. Capacitor C_1 acts to smooth out these pulses, however, so that the collector current has an average value proportional to the amplitude of the applied signal and an instantaneous value which varies with the modulation envelope of the signal. Thus, the voltage developed across the collector load, due to the varying collector current, is a composite signal with both A.C. and D.C. components.

The A.C. component may be obtained through an appropriate D.C. blocking capacitor and is the demoduated audio or video signal; the D.C. component is proportional to the R.F. carrier amplitude and may be passed through an appropriate R-C filter and used for AVC purposes. In practice, the load is generally a resistor, but, in some applications, may be an audio choke; in simple receivers, the load may be a pair of high impedance headphones.

Another way of analyzing the circuit action is to consider that the base-emitter circuit acts as a simple junction diode as far as the applied R.F. signal is concerned . . . thus, the detection action is similar to that obtained with a conventional diode detector, but followed by a direct-coupled amplifier.

Somewhat greater gain can be obtained if a small bias current is applied to the base (see Fig. 4-17, *Chapter 4*), but care must be taken that the bias current is not great enough to move the operating point to a linear portion of the transistor's characteristic curves . . . otherwise, the transistor will no longer act as a detector and will become, instead, an inefficient amplifier.

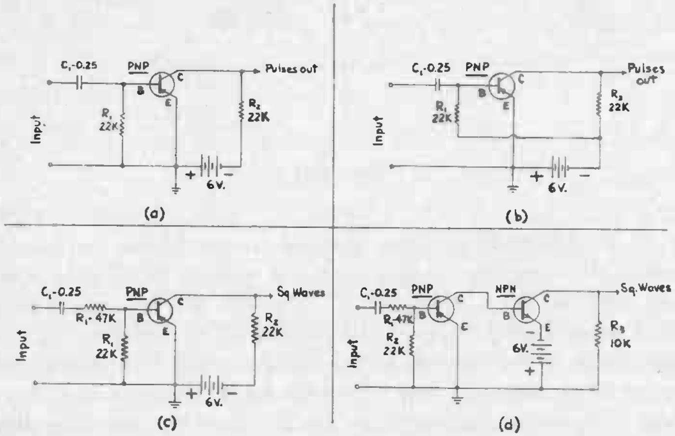


Fig. 6-2

CLIPPERS AND LIMITERS — (a) Simple Clipper; (b) Biased Clipper-Limiter; (c) Square-Wave Clipper; (d) Complementary Symmetry Clipper. The grounded-emitter configuration is used in all four circuits. Circuit (a) is an unbiased (Class B) amplifier and, with a *PNP* transistor, "clips" the positive half cycles of an applied signal. Except for the use of an R-C input arrangement, the circuit is almost identical to the *Simple R.F. Detector* shown in Fig. 6-1, and its operation is similar. *Collector current is at a minimum with zero input signal.* Positive-going pulses appear across collector load R_2. With a low input signal level, the pulses have rounded peaks (assuming sine-wave input); as the input level is increased, the peak collector current also increases until the full source voltage is dropped across R_2; this represents collector current "saturation" and, at this point, the output pulses acquire flat tops. Thus, with proper drive, rectangular pulses appear across R_2.

Circuit (b) is a clipper circuit using a "saturated" amplifier rather than an unbiased one . . . in a way, its operation is just the opposite of that of circuit (a). The base resistor R_1 is returned to the "hot" side of the power source, establishing a bias current; R_1 is then made fairly small, increasing both bias and collector current until "saturation" occurs and virtually the full source voltage is dropped across collector load R_2. Thus, in circuit (b), *collector current is at a maximum with zero input signal.*

With a *PNP* transistor, this circuit "clips" the negative half cycles of an applied signal. Negative-going pulses appear across collector load R_2; these are rounded at low signal levels but become rectangular as drive is increased. Both circuits (a) and (b) have low input impedances and will give their best results when driven with a moderate to low impedance source. Circuit (c) is similar in operation to circuit (a) but with one modification; a resistor (R_1) has been added in series with the input lead. This resistor serves a dual purpose . . . first, it increases the input impedance of the circuit, thus minimizing the loading effect on the signal source, and, secondly, it improves the clipping action of the circuit.

The output of circuit (c), when properly driven, closely approaches a symmetrical rectangular waveform or *square-wave,* as contrasted to the comparatively narrow pulses produced by circuit (a). Square-waves may also be obtained from circuit (d), which is essentially the clipper circuit shown at (c) direct-coupled to an additional clipper-amplifier stage. Different type transistors are employed to take advantage of the complementary symmetry principle in direct-coupling the two stages.

MIXER-CONVERTERS: When two signals are combined in a non-linear device, the output is a complex signal waveform containing the frequencies of both original signals, plus their sum and difference frequencies, plus harmonics. By providing a tuned output load, any one of these different frequencies may be selected. In superheterodyne receiver applications, the difference frequency is the one generally used, and it then becomes the I.F. signal for the receiver. Since non-linear operation is essential to the mixing action, a detector circuit performs well as a mixer, provided a resonant circuit is substituted for the resistive load. The resonant circuit serves two functions—(1) it selects the desired I.F. signal and (2) by virtue of its "fly-wheel" action, it recreates a complete signal from the pulses which the detector supplies. In a radio receiver, one of the two input signals is the desired broadcast signal, the other is a locally generated R.F. signal, provided by a separate oscillator. Of course, it is possible to combine the oscillator and mixer actions in one circuit, in which case the composite circuit may be termed a *converter,* for it "converts" incoming R.F. signals to a fixed I.F. signal. Since the action of either a mixer or a converter is similar to that of a detector, it is common practice to call this stage the "1st Detector" in superheterodyne receivers.

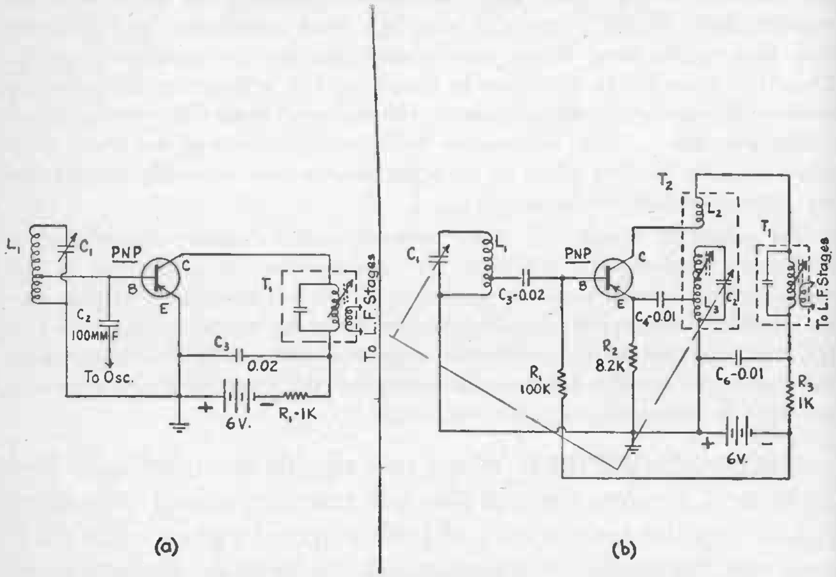


Fig. 6-3

MIXER AND CONVERTER – (a) Basic Mixer; (b) Triode Converter. The grounded-emitter configuration is used in both circuits. The component values specified are for operation at frequencies within the A.M. Broadcast Band and for I.F.s below 500 Kc. different values may be required at higher or lower frequencies. For maximum conversion gain, "high frequency" transistor types should be used.

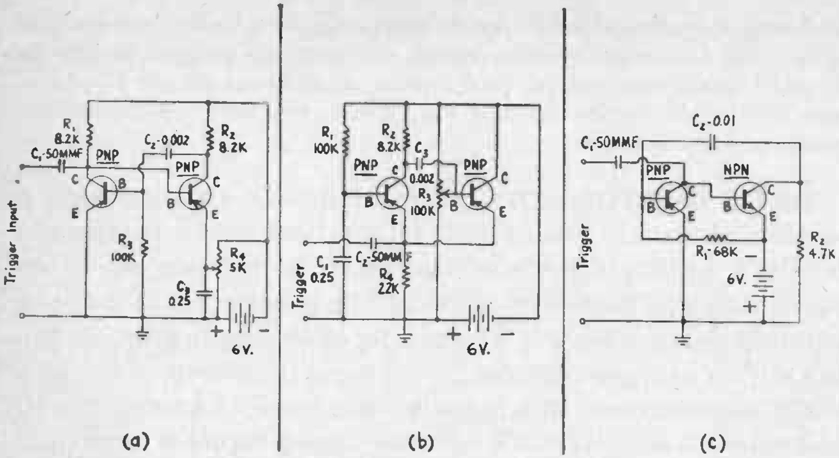
In circuit (a), the input R.F. signal is selected by the L_1-C_1 resonant circuit; L_1 may be an antenna coil, tapped down for proper impedance match to the transistor's input circuit. The signal from the local oscillator is applied to the base through capacitor C_2. Mixing action occurs within the transistor, which is operated without bias. The output I.F. signal appears across the primary of the I.F. transformer T_1.

A typical commercial coil for L_1 is a *MILLER* #2000 Transistor Loop Antenna, for T_1 a *VOKAR* #T-101 I.F. transformer. In circuit (b), a single transistor is used both as an oscillator and as a mixer. A modified "tickler feedback" oscillator circuit is employed, with L_2, in the collector circuit, inductively coupled to L_3, in the emitter circuit. The take-off point on L_3 is tapped down to permit a better impedance match to the transistor and thus to reduce the loading on the L_3-C_2 oscillator tuned circuit. As in the mixer, tuned circuit

L_1-C_1 selects the incoming R.F. signals; tuning capacitor C_1, in the preselector circuit, and C_2, in the oscillator circuit, are generally ganged together in practical circuit applications. In a typical experimental circuit, L_1 and T_1 may be the coils specified for circuit (a), and T_2 may be a *VOKAR* #C-801 oscillator transformer.

GATES AND FLIP-FLOPS: A multivibrator circuit which is unable to sustain oscillation, either because of insufficient feedback or improper bias, can often be thrown out of its stable non-oscillating condition by the application of a strong external signal or *trigger*. Depending on the application and on the circuit arrangement used, two types of operation are generally encountered. In a *gate* or *monostable** circuit, the circuit remains inactive until a strong trigger signal is applied at the proper input point. The circuit then changes from its stable non-oscillating condition to an unstable condition temporarily; after a period of time determined by circuit parameters, the circuit returns to its stable condition. In the majority of applications, the period required for the circuit to return to a stable condition is made equal to one cycle of oscillation, so that a single output pulse is obtained for each input trigger pulse. In a *flip-flop* or *bistable* arrangement, the circuit has two stable conditions, and can be switched from one to the other by the application of appropriate trigger pulses at the proper points. Two input pulses are required to return the circuit to its original stable state, and hence such a circuit may be used as a binary (scale-of-two) counter. Application-wise, monostable circuits are generally used for pulse formation, producing output signals of known waveform, duration and amplitude from varying input signals; bistable circuits are more generally used in counter applications. Because of their small physical size, long life, and minute power requirements, transistors are ideal for use in monostable and bistable circuits, especially where such circuits are used in compact military equipment or in complex computers.

*A *monostable* or *gate* circuit is often called a *"one shot multivibrator"* or *"univibrator."*



(a) (b) (c)

Fig. 6-4

MONOSTABLE CIRCUITS — (a) Collector-Coupled; (b) Emitter-Coupled; (c) "Complementary Symmetry" Collector-Coupled. All three circuits are direct adaptations from corresponding multivibrator circuits.

In circuit (a), the output pulse generally is obtained across the collector load resistor R_2; the input trigger is applied through C_1. The adjustment of R_4 determines the stability of the circuit; with some transistors, R_4 may be adjusted for free-running multivibrator action, in which case there may be two regions of monostable action, one on either side of the adjustment where oscillation takes place. Pulses of opposite polarity are produced, depending on which monostable adjustment is chosen.

In circuit (b), the output pulse appears across collector load R_2; the input trigger is applied through C_2 to the common emitter circuit. The adjustment of R_3 establishes the bias on the second transistor and thus determines whether free-running or monostable action is obtained.

Circuit (c) utilizes the complementary symmetrical characteristics of transistors of different types to permit direct-coupling between stages. The output pulse is obtained across collector load R_2; the input trigger is applied to the common collector-base connection through capacitor C_1. This circuit is quite similar to the multivibrator circuit shown in *Chapter 5* (Fig. 5-10) with but one small change . . . base resistor R_1 is returned to the negative side of the power supply, thus heavily biasing the first transistor and stabilizing the circuit. The circuit remains stable until a trigger pulse is applied, then goes through its cycle of operation and returns to its stable state.

The basic operation of all three circuits is similar in that all three are multivibrators which have been stabilized in a non-oscillating state by the

application of proper bias currents. In circuit (a), adjusting R_4 sets the bias for the second transistor; in circuit (b), adjusting R_3 sets the bias for the second transistor; and in circuit (c), returning the base resistor R_1 to the "hot" side of the power source establishes the bias current for the first transistor. Again, in all three circuits, the application of a trigger pulse initiates a cumulative change in circuit operation which is sustained only by the R-C time constant of the coupling circuits so that the circuits eventually return to their normal stable state.

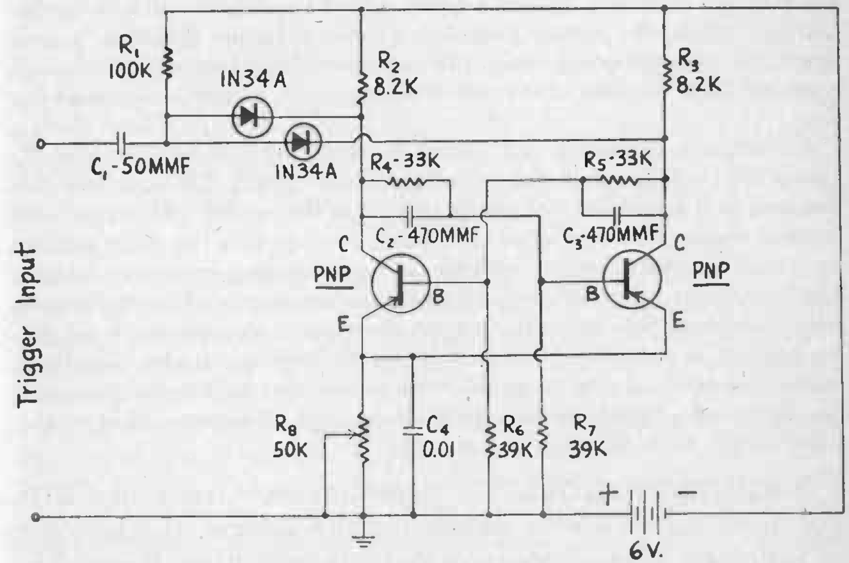


Fig. 6-5

BISTABLE CIRCUIT — This circuit represents a transistorized version of a familiar vacuum tube binary counter. In essence, it is a non-oscillating collector-coupled multivibrator which has two stable states, and which can be transferred from one state to the other by the application of an appropriate trigger pulse. In operation, one or the other of the two transistors starts conducting first.

For purposes of discussion, let us say it is the left-hand transistor. As collector current flows, a voltage drop occurs across the collector load resistor R_2, reducing the potential available for supplying base bias current to the second transistor through voltage divider R_4-R_7. At the same time, the emitter current flowing through resistor R_8 develops a voltage which tends to oppose normal base bias current flow in the right-hand transistor.

Since collector current is limited in the right-hand transistor, due to the lack of proper base bias, comparatively little voltage drop occurs across collector load R_3, and virtually the full source voltage is available to drive bias current through voltage divider R_5-R_6 to the base of the left-hand transistor. This bias current keeps the left hand transistor in a heavily conducting state. If a positive trigger pulse is now applied to the circuit through capacitor C_1, it appears on both collectors. However, since the left-hand transistor is conducting heavily, its collector is close to ground potential and the pulse has little effect. On the other hand, the pulse appearing on the collector of the right-hand transistor is transferred through capacitor C_3 to the base of the left-hand transistor; a positive-going pulse here reduces collector current and thus reduces the voltage drop across collector resistor R_2, which, in turn, develops a negative-going signal. This negative-going signal, applied through capacitor C_2 to the base of the right-hand transistor, intiates collector current flow.

The action is cumulative and, almost instantly, the right-hand transistor is conducting heavily while the collector current in the left-hand unit has dropped to a low value. The circuit remains in this second stable state until another trigger pulse is applied to its input, at which time the circuit switches back to its original operation, with the left-hand transistor conducting heavily. The two diodes are used simply to insure the application of a trigger pulse with the correct polarity to the proper electrode; if desired, the pulse may be applied to the base instead of to the collector electrodes. Adjustable emitter resistor R_8 is used to establish the proper bias for bistable operation. For best results, both transistors, both diodes, and all corresponding components should be reasonably well-matched.

PHOTOTRANSISTORS: The phototransistor is one of a large group of light-sensitive semiconductor devices, the majority of which are photoconductive and self-generating diodes. The phototransistor itself may be manufactured either as a diode junction or as a triode, and even the triode units may be used as diodes in most applications. Photoconductive semiconductor devices are roughly analogous to phototubes and are used in similar applications. Self-generating photo-sensitive semiconductors, on the other hand, may be used in applications in which no vacuum or gas-filled tube will work . . . in self-contained light meters, and even as power sources for transistorized oscillator and amplifier circuits. Circuits featuring the use of light sensitive semiconductors, other than phototransistors, will not be shown in *Chapter 6*; however, typical applications of other photo-semiconductors will be covered in PART III of this volume.

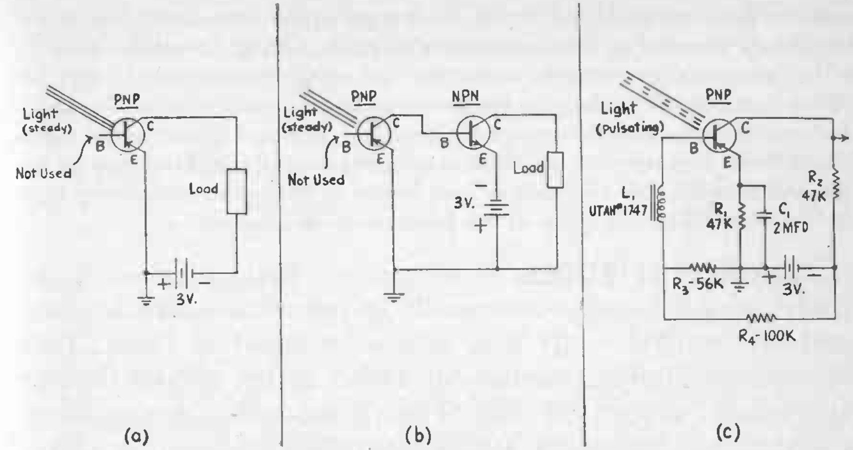


Fig. 6-6

BASIC PHOTOTRANSISTOR CIRCUITS—(a) Simple Diode Circuit; (b) Diode with Direct-Coupled Amplifier; (c) Triode Circuit. The grounded-emitter configuration is used in all three circuits. In circuit (a), the phototransistor is used as a simple photoconductive diode; the *Load* may be a meter or a D'Arsonval type relay.

In operation, as light is allowed to fall on the sensitive portion of the diode, the collector-emitter resistance decreases, allowing a greater current to flow through the load. The current through the load is proportional to the light intensity, up to the limits imposed by the phototransistor's characteristics, the nature of the load, and the source voltage. Circuit (b) is similar to circuit (a) except that the complementary symmetrical characteristics of transistors of different types are utilized to add a direct-coupled amplifier to the basic circuit, thus increasing the over-all sensitivity by a factor of 10 to 50, depending on the gain of the transistor used; the phototransistor itself is still used as a diode. Again, the *Load* may be a meter or sensitive relay. Depending on the characteristics of the phototransistor used, the "dark current" through the load may be considerable.

Where it is necessary to reduce the load current to close to zero when the phototransistor is dark, it may be necessary to supply a "bucking" voltage to the load through an appropriate resistive network. These steps may be necessary with both circuits (a) and (b). Circuit (c) is designed for use with modulated (pulsating) light, so that an A.C. signal is produced across the load; the A.C. signal may then be amplified by a conventional audio amplifier to give almost any desired level of sensitivity. Circuit (c) is D.C. stabilized by voltage divider R_3-R_4 and emitter resistor R_1, bypassed by C_1, all of which establish a fixed base bias current. The output signal is developed across collector load resistor R_2. A choke (L_1) is used in the base circuit, but is not absolutely essential to circuit operation unless R_3 and R_4 have low values.

For maximum sensitivity to a specific light signal, base choke L_1 may be tuned to the light's modulating frequency by an appropriate parallel capacitor, and collector load R_2 may be replaced by a resonant circuit, again tuned to the same frequency. In all three circuits, the overall sensitivity may be increased considerably by using a lens system to concentrate incoming light on the most sensitive portion of the phototransistor's surface.

JUNCTION TETRODES: At the present writing tetrode transistors are produced commercially by just a few manufacturers and are available only in a limited number of types. This limited availability prompts the author to list tetrode circuits as *Special Purpose Circuits* at this time and to group them together in this Chapter. In the future, perhaps even in a later edition of this volume, the author feels that junction tetrode transistors will join their older triode "brothers" as standard devices, and that, at that time, tetrode circuits may be grouped appropriately with corresponding triode amplifiers and oscillators. Currently available tetrode transistors are, in effect, "double-base" triodes, for two connections are made to the base electrode. In most applications the second base is biased with reverse current. This bias, in turn, repels charges traveling from the emitter and narrows the area over which current can travel through the base. Since the major conduction is forced to take place in the region close to the normal base connection, diffusion is kept to a minimum and transistor action is limited to this region. The net effect is to lower the base resistance considerably (in the grounded-base configuration), allowing the transistor to be used at much higher frequencies than would be possible otherwise. Of course, the second base connection may be used for other purposes also . . . for inserting a modulation signal, for gain control, for mixing two signals, and in similar applications. A tetrode may be used as a triode, if desired, simply by allowing one of the base connections to "float." In such cases, different triode characteristics are obtained, depending on which base connection is used.

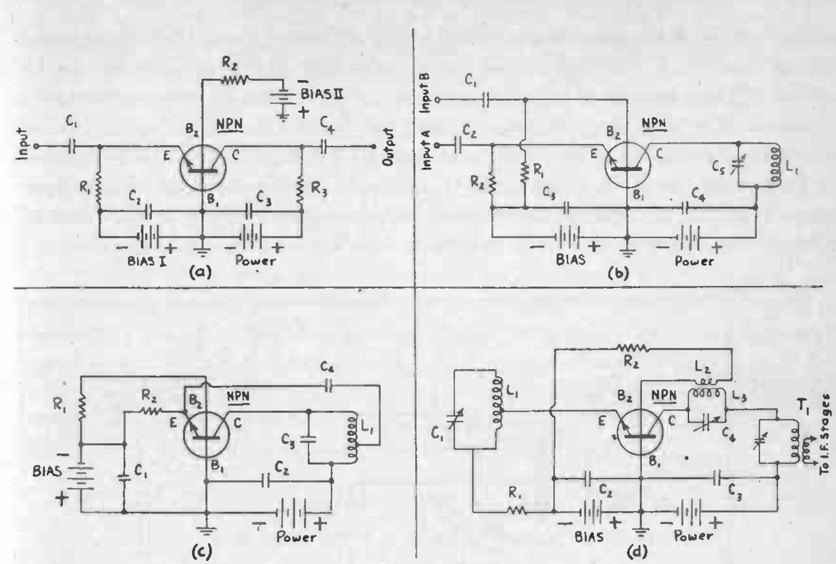


Fig. 6-7

BASIC TETRODE CIRCUITS — (a) Amplifier; (b) Mixer; (c) Oscillator; (d) Converter. The grounded-base configuration is used in all four circuits. Component values are not specified for these basic circuits, for exact values will vary considerably with the types of transistors used and the exact operating conditions desired; however, in most cases, the D.C. operating voltages and currents of the emitter and collector circuits are about the same as for a corresponding triode, while the second base (B_2) current will be on the order of from 0 to 2.0 milliamperes . . . note that the second base is biased with a polarity opposite that of the regular base (B_1).

The basic circuit shown at (a) may be used as a wide-band resistance-coupled amplifier or as an R.F. amplifier; as an R.F. amplifier, the emitter (R_1), and collector (R_3) loads may be replaced by inductive or resonant circuits; as a wide-band resistance-coupled amplifier, the bandwidth may be extended by making collector load R_3 smaller and smaller, but only at the expense of reduced gain at lower frequencies. With presently available transistors, bandwidths of 5 to 10 mc (to 3 db point) are not uncommon, with gains in the neighborhood of 15 to 25 db.

Circuit (b) may be used for mixing two R.F. signals to produce an I.F. signal, which appears across resonant circuit L_1-C_5. One signal is applied to the emitter circuit, the other to the second base.

Circuit (c) is a typical R.F. oscillator arrangement, using a modified Hartley circuit; with presently available transistors, operating frequencies in excess of 100 Mc may be obtained without great difficulty. Circuit (d) combines a "tickler feedback" oscillator and mixer into one circuit to provide an I.F. converter. The feedback signal necessary to start and sustain oscillation is obtained from coil L_2, inductively coupled to L_3, in the collector circuit. Resonant circuit L_1-C_1 is tuned to the incoming R.F. signal, L_3-C_4 to the oscillator frequency, and the primary of T_1 to the I.F. value. R.F. coil L_1 is tapped down to permit an impedance match to the comparatively low input impedance of the stage, and thus to minimize loading on the tuned circuit.

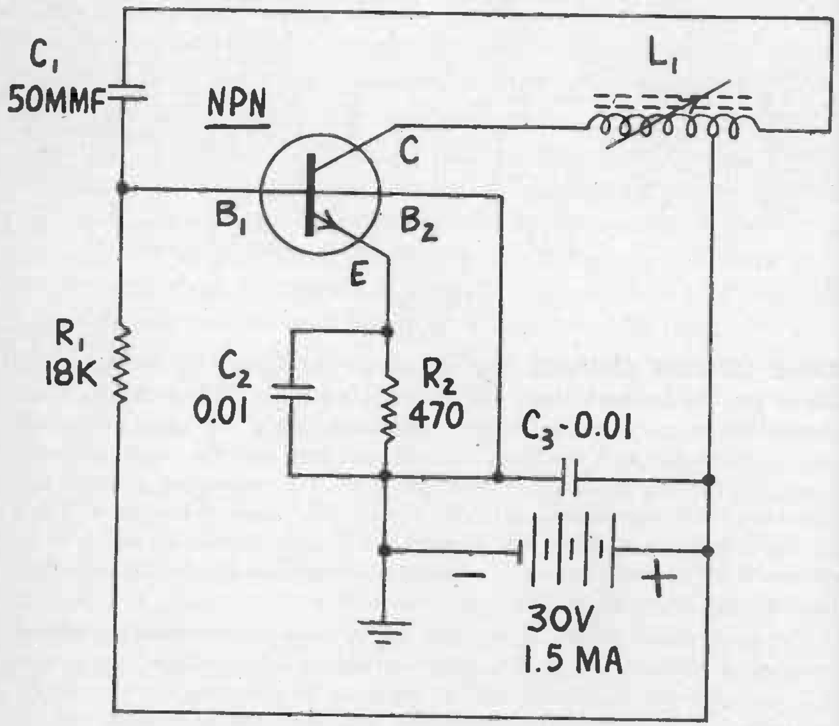


Fig. 6-8

TETRODE OSCILLATOR (Fig. 6-8) — A breadboarded version of the circuit shown gave good results as an R.F. oscillator, operating over the range of 16 to 25 Mc. A *GERMANIUM PRODUCTS CORP.* type 3N23 tetrode junction transistor was used in the author's experimental circuit; L_1 was a standard TV I.F. "transformer" coil to which four turns of #30 insulated copper wire were added for feedback purposes. The circuit is a modified Hartley oscillator arrangement, using a grounded-emitter configuration. In operation, L_1

forms a resonant circuit with its own and circuit distributed capacities; tuning is by means of the coil's (L_1) powdered iron core.

The first base (B_1) is shunt-fed, with the feedback signal applied through capacitor C_1 and bias current supplied through base resistor R_1, which returns to the positive side of the power source. Thus, *the first base is positive with respect to the emitter,* and has the correct polarity for a grounded-emitter *NPN* stage. Emitter resistor R_2, by-passed by capacitor C_2, has a dual purpose; first, it serves to provide a degree of D.C. stabilization; secondly, it serves to provide the proper bias for the second base (B_2). The second base returns directly to ground. The voltage drop across R_2 due to emitter current raises the emitter slightly above ground in a positive direction. *Thus, the second base is negative with respect to the emitter,* and thus is biased with the opposite D.C. polarity of the first base. Capacitor C_3 serves as a by-pass across the power source. This circuit may be modulated by inserting the modulating signal in series with the D.C. supply lead to coil L_1.

TEST CIRCUITS: Techniques and circuits which are useful for testing transistors and transistorized equipment fall into two general groupings . . . (1) those which are basic to laboratory practice and which may be used for testing any type of electronic equipment, whether transistor or vacuum tube operated, and (2) those specifically designed for determining transistor characteristics and performance. As far as a transistor's operation in a specific circuit is concerned, basic information relative to its performance characteristics may be given by indicating *all* D.C. electrode voltages and currents as well as specifying the circuit's performance; D.C. voltages and currents are referred to the common or grounded electrode, whether it be the base, emitter, or collector. Individual transistor characteristics, irrespective of specific circuit operation, may be given by *families* of *characteristic curves;* typical families may be prepared for each basic circuit configuration; for the grounded-base circuit, the following groupings may be used . . . (a) Emitter Voltage vs. Emitter Current for a fixed Collector Current (*Input Characteristic*); (b) Collector Voltage vs. Collector Current for a fixed Emitter Current (*Output Characteristic*); (c) Emitter Current vs. Collector Voltage for a constant Collector Current (*Forward Characteristic*); (d) Collector Current vs. Emitter Voltage for a constant Emitter Current

(*Feedback Characteristic*). Similar families of curves may be prepared for the grounded-emitter configuration, in which case the base electrode is substituted for the emitter in each grouping. Unless special techniques are employed, preparing families of characteristic curves is, at the best, a time consuming process, requiring from scores to hundreds of individual measurements and a final careful plotting of points on appropriate graphs (refer to the section *TESTING TRANSISTORS in Chapter 2—TECHNIQUES)*. For a more rapid evaluation of a transistor's characteristics, two methods may be used . . . (1) the standard "Substitution Test" of the transistor in a desired circuit arrangement as a check on its performance and (2) measurement of its essential gain characteristics (*alpha* and/or *beta*) and its leakage currents.

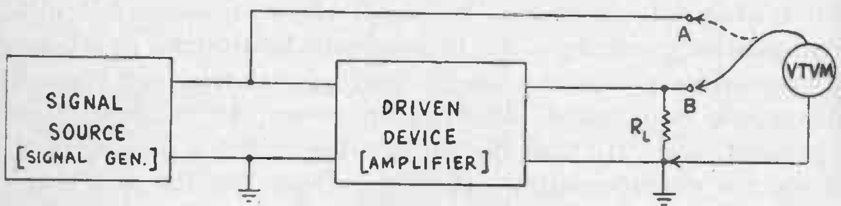


Fig. 6-9

GAIN & FREQUENCY RESPONSE MEASUREMENT — The circuit arrangement shown in block diagram form may be used to check both the overall *gain* and the *frequency response* of virtually any signal handling device, whether vacuum tube or transistor operated. The SIGNAL SOURCE supplies an A.C. voltage of known frequency and amplitude; in most cases, it will be a variable frequency Signal Generator — an Audio Generator is used for checking audio amplifiers, an R.F. Signal Generator for checking radio receivers.

The DRIVEN DEVICE is the piece of equipment to be tested . . . it may be a single amplifier stage, a complete multi-stage amplifier, a radio receiver, or any similar signal handling equipment. Resistor R_L is the normal output load for the DRIVEN DEVICE. The VTVM is used to check both input and output signal amplitudes. *To measure gain*, use the VTVM to check input and output signal amplitudes by transferring the "hot" lead from point "A" to point "B". *Voltage gain* may be determined by dividing the output voltage by the input voltage.

Where *power gain* is desired, its numerical value may be determined by

taking the input and output impedances into account. Assuming that both impedances are resistive, input power may be determined by squaring the input voltage and dividing by the input impedance; output power may be determined by squaring the output voltage and dividing by R_L. In both cases, power is in watts, voltages in volts, and resistances in ohms. The numerical power gain is the output power divided by the input power; however, power gain is generally expressed in db rather than as a numerical ratio. The power gain in db is equal to ten times the logarithm (to the base 10) of the ratio of output to input powers. Simply obtain the logarithm of the numerical value of power gain and multiply by 10.

To measure frequency response, use the VTVM to check input and output signal amplitudes as before. The input amplitude is kept constant as the frequency of the SIGNAL SOURCE is varied over the desired range in discrete steps, and the output signal amplitude is measured and recorded at each point. The set of measurements obtained are then converted into gain figures, using the methods described above, and the results listed in a table or plotted on a graph.

When making either gain or frequency response measurements, care must be taken that the input signal is kept well below the overload point for the DRIVEN DEVICE being tested.

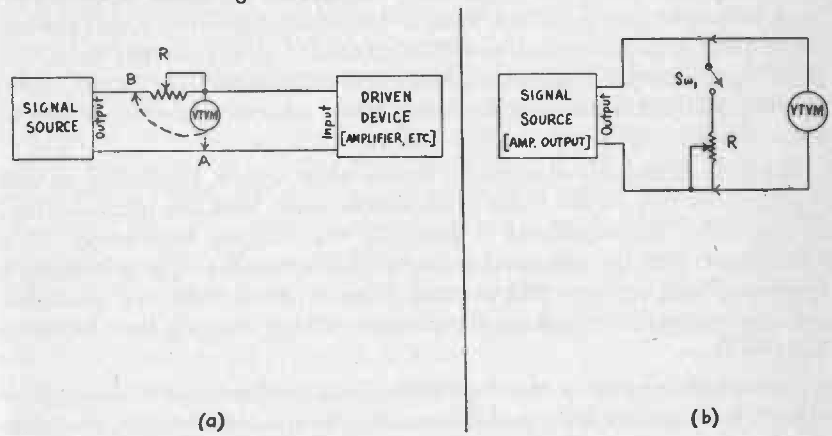


Fig. 6-10

IMPEDANCE MEASUREMENTS — (a) Input Impedance; (b) Output Impedance. Circuit (a) is used to determine the *input impedance* of any DRIVEN DEVICE, such as an audio amplifier, a test instrument, a receiver, or any similar equipment driven by an external signal. The same technique may be used both on single stages and on complete equipments.

A SIGNAL SOURCE, VTVM, and a calibrated, non-inductive variable resistor (R) are the basic instruments needed. If the DRIVEN DEVICE is an amplifier, it should be terminated in its normal load impedance. The SIGNAL SOURCE may be a Signal Generator (either audio or R.F., depending on the equipment to be checked) with a low impedance output. If a calibrated resistor is not available, any non-inductive variable resistor may be used in its place, provided the resistance setting can be checked accurately with an impedance bridge or similar instrument. To measure the *input impedance*, use the SIGNAL SOURCE to apply an appropriate signal to the DRIVEN DEVICE and calibrated resistor (R) connected in series, taking care not to overload the input of the equipment.

Use the VTVM to check the signal voltage across both the calibrated resistor (R) and the input to the DRIVEN DEVICE by transferring its "hot" lead back and forth between points "A" and "B". Adjust the resistor (R) *until these two voltages are equal* . . . the exact readings are not too important. When the voltages at points "A" and "B" are equal, the resistance (R) is equal to the *input impedance* of the DRIVEN DEVICE.

Circuit (b) is used to determine the *output impedance* of any SIGNAL SOURCE, such as a signal generator, or an amplifier driven with an external signal. A VTVM is used to measure the output voltage of the SIGNAL SOURCE under "no-load" conditions (Sw_1 open). A calibrated, non-inductive resistor (R) is connected across the output (Sw_1 closed) and the signal output, under load, measured with the VTVM. Resistor R is adjusted until the output voltage, under load, is equal to one-half the "no-load" voltage. At this point, R is equal to the output impedance of the SIGNAL SOURCE. As before, if the SIGNAL SOURCE is an amplifier driven by an external signal, care must be taken that the equipment is not overdriven.

The *input impedance* of transistor circuits varies widely, depending on both the transistor and on the circuit configuration used. With the *grounded-base* configuration, the impedance is generally low, ranging from about 25 to 1,000 ohms. With the *grounded-emitter* configuration, the input impedance is moderate, ranging from 250 to 2500 ohms or more. With the *grounded-collector* configuration, the input impedance is high, ranging from 50,000 to 500,000 ohms.

The *output impedance* of the *grounded-base* configuration is high, generally between 50,000 ohms and 1 megohm. The *grounded-emitter* configuration has a moderately high output impedance, ranging from 5,000 to 50,000 ohms. Finally, the *grounded-collector* circuit (sometimes called an "emitter-follower") has a moderately low output impedance, ranging from 500 to 25,000 ohms.

These typical values apply only to low-power junction transistors. In general, "hi-power" transistors have both low input *and* low output impedances. Typical input impedances may range from 5 to 25 ohms; output impedances from 20 to 100 ohms.

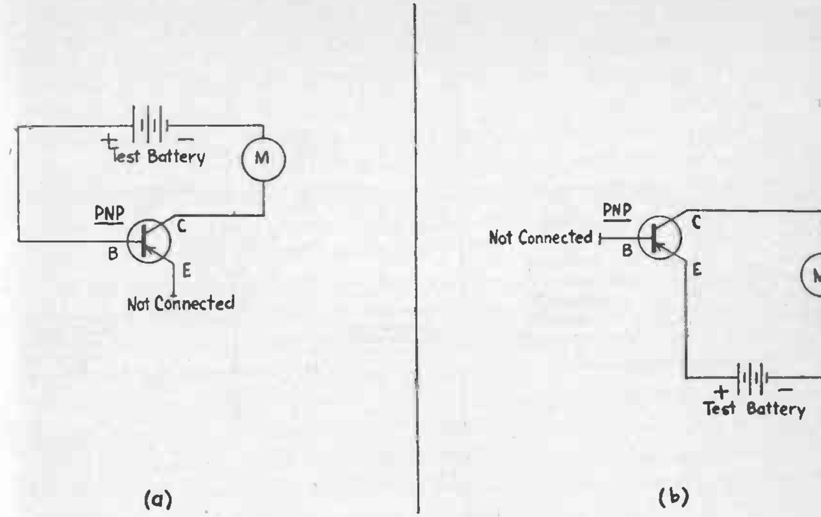


Fig. 6-11

LEAKAGE CURRENTS — (a) Collector-Base (I_{co}); (b) Collector-Emitter (I_{cbo}). In both circuits, meter M is a microammeter of suitable range. The current values measured may be compared with the transistor's published data at the test voltages specified by the manufacturer. In both cases, the smaller the leakage current measured, the better; in addition the currents should not be erratic. Both currents may tend to increase with age and with increases in ambient temperature. Of the two leakage current values, the collector-base current (I_{co}) should be much the smaller, ranging from 0 to around 20 or 25 microamperes; the collector-emitter leakage current may range as high as 100 to 150 microamperes, but should generally be much smaller. If the measured leakage currents are excessively high, or if the readings are erratic, the transistor is probably defective.

With *NPN* transistors, battery polarities and meter connections are reversed. The collector-base leakage current with zero emitter current (I_{co}), as determined with circuit (a), is often called *collector saturation current* and, sometimes, *collector cut-off current.*

Silicon transistors have much lower leakage current values than germanium units. Whereas a good quality germanium transistor may have a *saturation* current value ranging up to 5 microamperes, a silicon transistor may have a *saturation* current of but a *fraction of a microampere*. In most practical work, as long as the *saturation* current is below one microampere, it can be ignored.

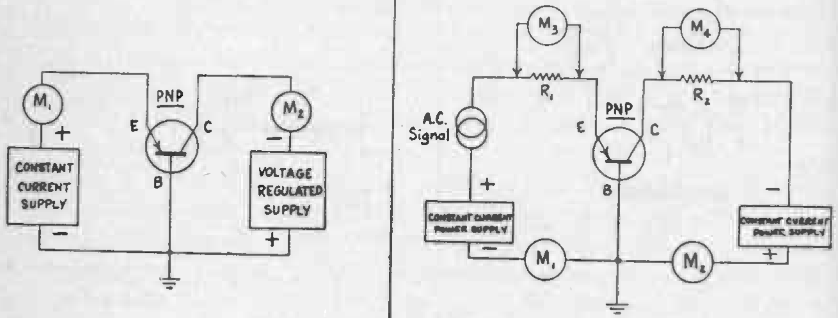


Fig. 6-12

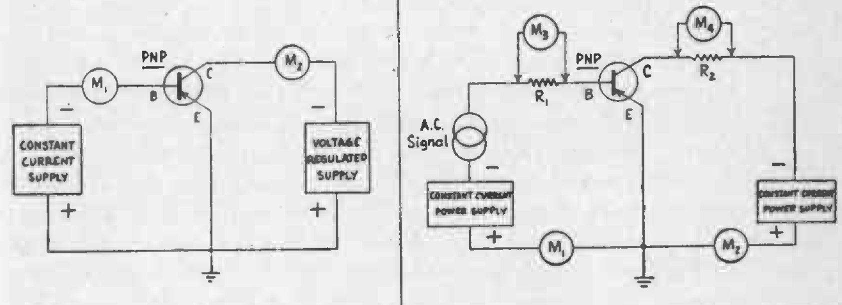
ALPHA MEASUREMENT — (a) Static Measurement; (b) Dynamic Measurement. *Alpha* is the current amplification factor of the transistor in the grounded-base configuration and may be defined as *the ratio of the change in collector current to an incremental change in emitter current at a constant collector potential.* This factor may be determined by either static (D.C.) or dynamic (A.C.) measurements. Both techniques are shown.

In both circuits, M_1 and M_2 are milliammeters and the CONSTANT CURRENT SUPPLIES are either laboratory test units or conventional adjustable voltage supplies with a large value resistor connected in series (see section *TESTING TRANSISTORS, Chapter 2—Techniques).*

In circuit (a), the VOLTAGE REGULATED SUPPLY may be either an A.C. operated circuit or batteries. In circuit (b), series resistors R_1 and R_2 are used simply to develop small A.C. voltages which can be measured by A.C. VTVMs M_3 and M_4 . . . suitable values are from 5 to 50 ohms. R_1 should equal R_2. The power supplies should be heavily by-passed to A.C.; this may be accomplished by connecting high value electrolytic capacitors across their output terminals. The A.C. signal source should have a very low D.C. resistance . . . in general, this will be the secondary of a step-down transformer driven by a Signal Generator. The power supply polarities shown in both circuits (a) and (b) are for *PNP* transistors . . . for *NPN* units, reverse power supply and meter connections.

To measure alpha using the "static" method, as shown at (a), first adjust all D.C. operating voltages and currents to the values suggested by the transistor manufacturer in his specification sheets. Note the values of emitter and collector currents. Next, vary the emitter current a *small amount* (from 0.05 to 0.2 ma), noting the corresponding change in collector current. Alpha is then the ratio of the difference between the two collector current values to the difference between the corresponding emitter current values. Different values of alpha may be obtaind for the same transistor, depending on the initial voltage and current values.

To measure alpha using the "dynamic" method, shown at (b), first adjust all D.C. operating currents to the values suggested by the transistor manufacturer in his specification sheets. Next, apply a small A.C. signal to the emitter circuit, as shown (this signal should be a fraction of a volt for most small transistors). Determine the A.C. voltages appearing across R_1 (M_3) and R_2 (M_4). Alpha is then the ratio of the voltage measured by M_4 to that indicated by M_3. The "dynamic" method for measuring alpha is generally used to determine how alpha varies with frequency and to determine the *alpha cut-off frequency* (fc — frequency at which alpha is 0.707 of its low frequency value . . . that is, the frequency at which the gain is down 3 db from its low frequency value).



(a) (b)

Fig. 6-13

BETA MEASUREMENT — (a) Static Measurement; (b) Dynamic Measurement. *Beta* is the current amplification factor of a transistor in the grounded-emitter configuration and may be defined as *the ratio of the change in collector* *current to an incremental change in base current at a constant collector potential.* This factor, like alpha, may be determined by either static (D.C.) or dynamic (A.C.) measurements; both techniques are shown. In both circuits, M_1 are microammeters, M_2 milliammeters, and the CONSTANT CURRENT SUPPLIES are either laboratory test units or conventional adjustable voltage supplies with a large value resistor connected in series (see section *TESTING TRANSISTORS, Chapter 2—Techniques).*

In circuit (a), the VOLTAGE REGULATED SUPPLY may be either an A.C. operated circuit or batteries. In circuit (b), series resistors R_1 and R_2 are used simply to develop small A.C. voltages which can be measured by A.C. VTVMs M_3 and M_4 . . . suitable values are from 5 to 100 ohms. R_1 should equal R_2. The power supplies should be heavily by-passed to A.C.; this may be accomplished by connecting high value electrolytic capacitors across their output terminals. The A.C. signal source should have a very low D.C. resistance . . . in general, this will be the secondary of a step-down transformer driven by a Signal Generator. The power supply polarities shown in both circuits (a) and (b) are for *PNP* transistors . . . for *NPN* units, reverse power supply and meter connections.

To measure beta using the "static" method, as shown at (a), first adjust all D.C. operating voltages and currents to the values suggested by the transistor manufacturer in his data sheets. Note the value of base and collector currents. Next, vary the base current a small amount (around 5 to 20 microamperes), noting the corresponding change in collector current. Beta is then

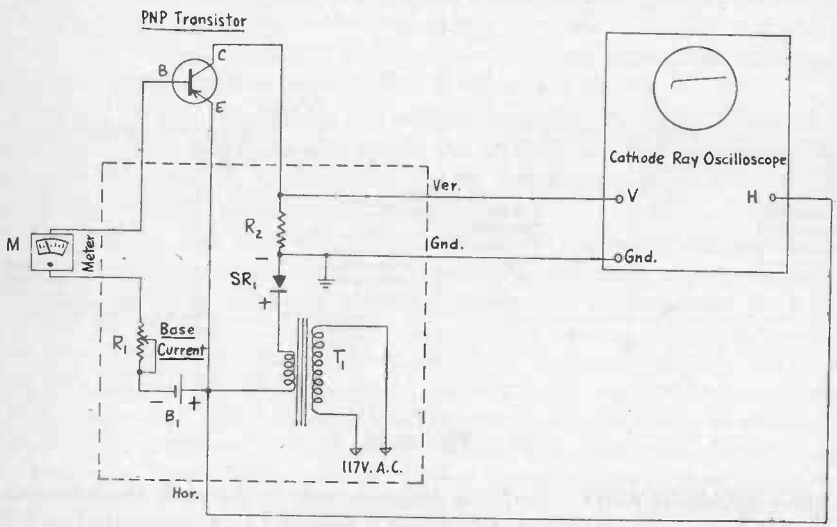


Fig. 6-14

the ratio of the difference between the two collector current values to the difference between the corresponding base current values. Difference values of beta may be obtained for the same transistor, depending on intial voltage and current values.

To measure beta using the "dynamic" method, shown at (b), first adjust all D.C. operating currents to the values suggested by the transistor manufacturer in his data sheets. Next, apply a small A.C. signal to the base circuit, as shown. Determine the A.C. voltages appearing across R_1 (M_3) and R_2 (M_4). Beta is then the ratio of the voltage measured by M_4 to that indicated by M_3. This method of measuring beta is frequently used to determine how beta varies with frequency. This may be accomplished quite easily by making a series of measurements at different applied frequencies.

OBTAINING TRANSISTOR CHARACTERISTIC CURVES (Fig. 6-14) — The customary technique for obtaining a set of characteristic curves, whether for a vacuum tube, a diode, or a transistor, is to assemble the basic circuit using variable output D.C. supplies, then to vary one operating voltage (or current) in discrete steps, recording all other voltage and current changes, and, finally, to plot the resulting data on a graph. This technique is accurate, but quite laborious and time consuming, since scores, and perhaps hundreds, of individual measurements need be made, recorded, and plotted (see section *TESTING TRANSISTORS, Chapter 2—Techniques).* A much more rapid technique is to set up a circuit which permits the display of a complete characteristic curve on the screen of a cathode ray oscilloscope. Such a circuit is illustrated. Typical parts values are: R_1—50K potentiometer, R_2—100 ohm, ½ watt resistor, T_1—6.3 v. filament transformer, B_1—1.5 to 6 v. battery, SR_1—20 Ma. selenium rectifier. The meter (M) may be a 0-500 microampere or 0-1 milliampere unit. The circuit arrangement shown is for a small *PNP* junction transistor such as a *Raytheon* type CK722. For *NPN* transistors, the battery (B_1) and selenium rectifier (SR_1) connections would be reversed.

In operation, R_1 and B_1 form a small "constant current" D.C. supply which is used to establish the base bias current at a fixed value. Each value will give a different characteristic curve. Transformer T_1 and rectifier SR_1 furnish a pulsating D.C. voltage which varies from 0 to a peak maximum value (about 9 volts peak if a 6.3 volt transformer is used). This voltage is applied to the emitter-collector circuit of the transistor and to the *horizontal input* (HOR) of the oscilloscope. A resistor (R_2) is in series with the collector; its value is small so as to minimize its effect on circuit operation. However, a voltage is developed across this resistor (R_2) which is proportional to instantaneous collector current; this voltage is applied to the *vertical input* (VER) of the oscilloscope. Thus, the *vertical* deflection of the cathode ray tube's beam is proportional to instantaneous *collector current,* while the *horizontal* deflection of the beam is proportional to instantaneous *collector voltage,* all with a *fixed base current*. The resulting trace is *an accurate output characteristic curve for the transistor in the grounded-emitter configuration* (i.e., collector voltage vs. collector current for a fixed base current). A similar technique may be used to obtain other types of characteristics curves. The resulting curves may be photographed or traced directly from the screen of the oscilloscope.

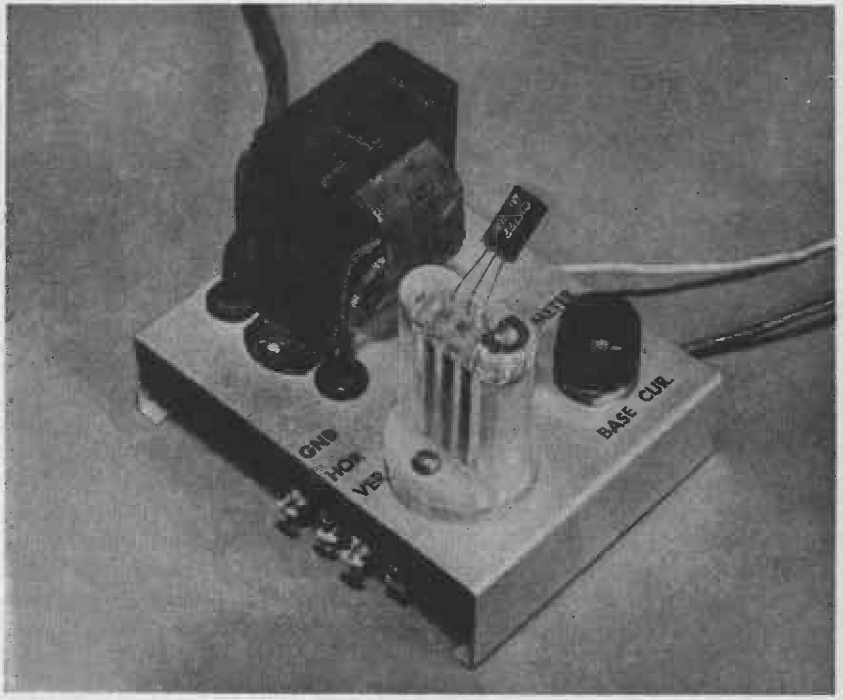


Fig. 6-15

CHARACTERISTIC CURVE GENERATOR — An assembled practical version of the circuit given in Fig. 6-14. The part of the circuit enclosed by the dotted line has been assembled on a small aluminum chassis for experimental lab. work. The battery (B_1) and rheostat (R_1) are self-contained; the meter (M) is external, connected to the chassis through the leads shown in the background. Base current is adjusted by the small knob marked "BASE CUR.", which controls the setting of R_1. Oscilloscope connections are to the terminal strip terminals on one side of the chassis; the terminals marked "GND", "HOR", and "VER" are connected to corresponding terminals of the oscilloscope. The transistor socket used is a special experimental socket of the type used by transistor manufacturers for production testing of transistors.

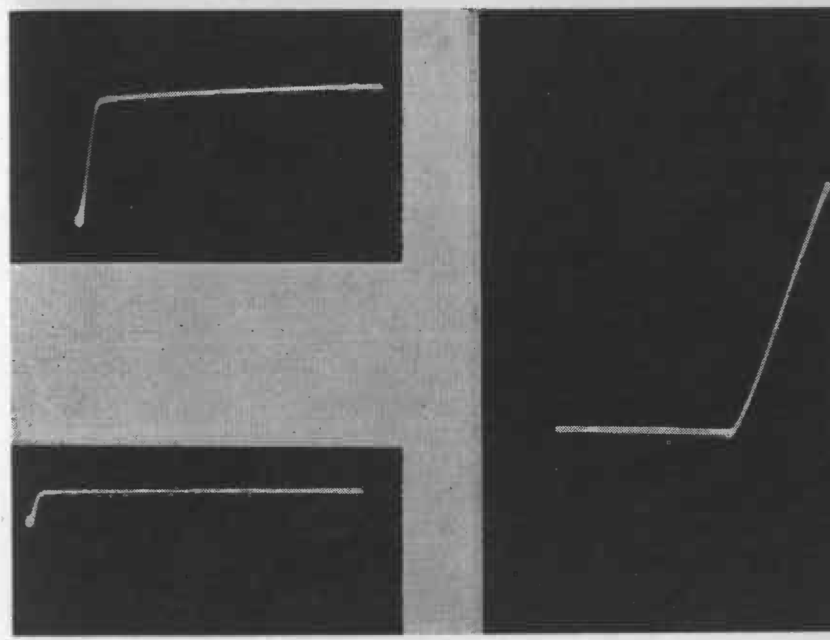


Fig. 6-16

For rapid checking of both *PNP* and *NPN* transistors, a reversing switch may be added to interchange the polarities of the bias battery (B_1) and selenium rectifier (SR_1) . . . see Fig. 6-14.

Commercial Characteristic Curve Generators are available; some of these are capable of displaying a whole "family" of curves on the screen of an oscilloscope at one time. Refer to *Chapter 14* for a list of transistor test equipment manufacturers.

TYPICAL CHARACTERISTIC CURVES — Actual photographs of the oscilloscope presentation of characteristic curves obtained using the characteristic curve generator shown in Figs. 6-14 (schematic) and 6-15 (photo of assembled unit). The two curves to the left are for a *Raytheon* type CK722 *PNP* junction transistor at base currents of 100 (upper curve) and 20 (lower curve) microamperes. The curve to the right represents the characteristic of a type 1N34 germanium diode. It was obtained by connecting the diode in place of the emitter-collector terminals of the transistor.

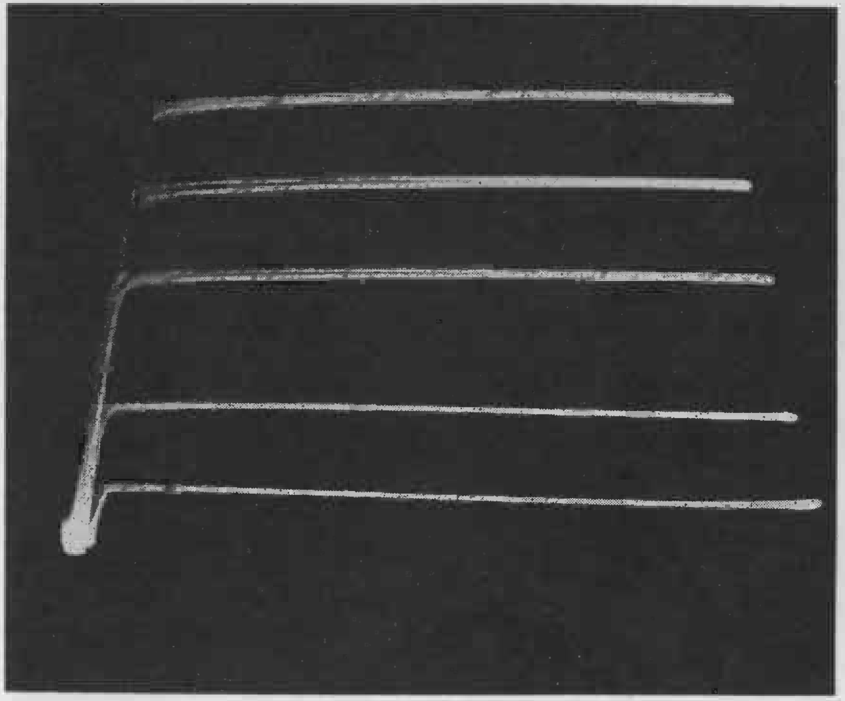


Fig. 6-17

A "FAMILY" OF CURVES — Actual photograph of a "family" of output characteristics curves for a *Raytheon* type CK722 *PNP* junction transistor, obtained using the characteristic curve generator shown in Figs. 6-14 (schematic) and 6-15 (photo of assembled unit). The curves are for base currents of 25, 50, 100, 150, and 200 microamperes, respectively, reading from the bottom to the top.

The "double-trace" effect is due to a slight amount of low frequency phase shift in the oscilloscope used to obtain the curves. Normally, one trace is produced as the collector voltage goes from zero to its peak value, another as the voltage is dropped from its peak back to zero. These traces will overlap and appear as one curve unless there is phase-shift in the oscilloscope used. A family of curves is obtained by making a multiple photographic exposure, readjusting the base current to a new value for each exposure, and recentering the curve on the screen of the oscilloscope.

PART III — CIRCUIT APPLICATIONS

Introduction to PART III

The *Basic Circuits* presented in PART II were intended to be of maximum value to two major groups of workers—*Design Engineers* and *Advanced Students.* The Design Engineer should find the *Basic Circuits* of value as "Building Blocks" in the design of complex equipment. For example, he may combine I.F. and Audio Amplifiers from Chapter 4 with an R.F. Oscillator from Chapter 5 and a Mixer from Chapter 6 to work up the circuit design of a transistorized *superheterodyne receiver.* Or he may combine a D.C. amplifier from Chapter 4 with an R.F. Detector from Chapter 6 to develop a sensitive *R.F. Field Strength Meter.* In both equipments he may use the D.C. stabilizing methods outlined in Chapter 4.

The more advanced Student should find the *Basic Circuits* of value both for experiments and theoretical study, for he should find it more convenient to analyze and to examine single stage circuits than to attempt the analysis of a complete equipment. For the maximum in educational value, the student should combine a theoretical analysis of a circuit with practical laboratory tests.

But technical students and Design Engineers are not the only groups who desire transistor circuit information. There are many others who desire and need such data and, numerically, these groups represent far more individuals. Included in the latter groups are Hams, experimental Audiophiles, electronic hobbyists, servicemen, and, of course, home builders and experimenters. These groups, in general, prefer complete equipment circuit information, including actual construction details. It is to these groups that PART III is dedicated, for in it will be found complete circuits covering the application of transistors to specific items of equipment.

Although PART III, covering *Circuit Applications,* is aimed primarily at the practical experimenters' group, it is felt that others, including Design Engineers, may find this data of value. For example, a factory engineer, presented with a design project involving a piece of transistorized test equipment, may find that one of the circuits shown in Chapter 9, with modifications, may meet his requirements. Or, if unable to find the exact circuit desired, he may be able to get ideas, to stimulate his imagination, and to clarify his thoughts by perusing the circuits illustrated. At the least, he may wish to incorporate some of the features of the circuits shown into his particular project.

The circuits described in PART III, like those in earlier Chapters, have been derived from many sources. A number were adapted from the author's published magazine articles and technical papers. Some were obtained from transistor and component manufacturers. Others were worked up specifically for this volume. *But all the circuits shown have been bench-tested,* and, where model photographs are shown, the circuits have actually been incorporated into finished equipment.

Like the circuits shown earlier, not all have been *Production Engineered.* This does not mean that any particular circuit is critical, however. Rather, it means that variations in component and transistor characteristics, even if due only to broad tolerances, may require minor changes in component values to obtain optimum operation. In addition, it may mean that circuits used under extreme temperature and humidity conditions may require modification to obtain satisfactory operation. In most cases, this modification will include the addition of D.C. Stabilization, as described in Chapter 4.

In extreme cases, the circuit modification may require a switch to a different basic type of transistor or the use of specially selected units. In general, silicon transistors may be used at higher temperatures than germanium units. Although the circuits used with both germanium and silicon transistors may be similar in configuration, small changes in fixed parameters may be necessary to obtain satisfactory operation. Unless otherwise noted, all the circuits shown were checked out with germanium transistors of the type listed.

Method of Presentation: The circuits described in PART III have been grouped in Chapters according to application. However, each circuit is described as an independent *Project.* All component values and manufacturers' type numbers are given, and these are the components used by the author in assembling his test models. Substitutions are possible in most cases, but if different components are used, it is important that the electrical specifications be similar to those given, even if mechanical details differ.

In the case of resistors, the wattage rating may be equal to or greater than that given. In the case of capacitors, the working voltage may be equal to or greater than specified. However, in both cases, the electrical value (in ohms or microfarads) should approximate the listed value.

Layout is not especially important except in the case of R.F. and high frequency circuits, but good wiring practice should be followed throughout. In almost every circuit, transistors of a type other than that specified may be used if appropriate changes are made in component values, and if the general characteristics of the transistor used approximate those of the unit specified.

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PART III — CIRCUIT APPLICATIONS

Chapter 7

AUDIO APPLICATIONS

The first widespread commercial application of transistors was as audio amplifiers. In one field, the Hearing Aid industry, the transistor has completely displaced its older rival, the vacuum tube. Although early transistors, both junction and point-contact, were rather noisy, and the background "transistor hiss" was an accepted characteristic and drawback of transistorized audio circuits, improved production techniques have resulted in units with an inherent noise level even *less* than that of vacuum tubes giving comparative gain.

Since most transistorized audio circuits require so little power that battery operation is actually *more economical* than A.C. line operation, a second source of noise . . . hum . . . has been eliminated. It is no wonder, then, that today the transistor is finding increasing use in other audio applications . . . as Hi Fi Preamplifiers, in remote microphone amplifiers and mixers, and in various types of audio instrumentation.

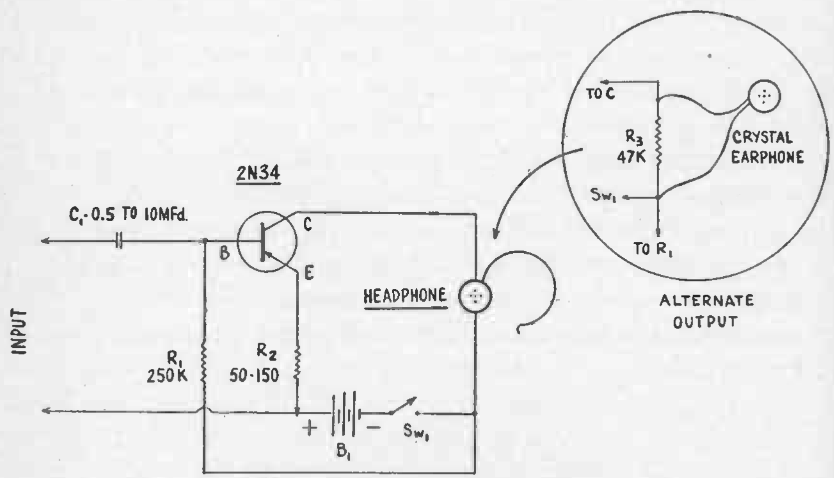


Fig. 7-1.—Simple Headphone Amplifier.

BASIC AUDIO APPLICATIONS

HEADPHONE AMPLIFIER: Non-critical and easy to assemble, the circuit given in Fig. 7-1 represents perhaps the simplest audio application for a transistor. A single unit is used as a one-stage audio amplifier to drive a pair of headphones. By making a slight change in the output load, either crystal or magnetic headphones may be used. Possible applications for the device are numerous . . . it may be used to boost the gain

of a crystal receiver; it may be used to "pull in" weak shortwave stations when used with a Communications Receiver; it may be used with test instruments requiring Headphones as an indicating device . . . impedance bridges, signal tracers, etc.; it may even be used as a "personal" phonograph amplifier when connected to a high output crystal or ceramic phonograph cartridge (through a step-down matching transformer).

CIRCUIT DESCRIPTION: Referring to Fig. 7-1, we see that the *Headphone Amplifier* is a single-stage audio amplifier using a PNP transistor connected in the grounded-emitter configuration. Capacitor C_1 serves as a D.C. blocking and coupling capacitor, R_1 as the base "bias" resistor, and the Headphone (or resistor R_3) as the output load. Resistor R_2, in the emitter circuit, provides degeneration, stabilizing the amplifier both with respect to gain and as far as D.C. characteristics are concerned. Power is supplied by a single battery (B_1), controlled by switch Sw_1.

In operation, audio signals applied to the input are coupled through C_1 to the base-emitter circuit of the 2N34 transistor. Amplification takes place in this stage, with the amplified signal driving the Headphone. If the unit is used with crystal, instead of magnetic, headphones, a resistor (R_3) serves as the output load. The input impedance varies from about 1,000 to as high as 5,000 or 10,000 ohms, depending on the choice of emitter resistor R_2. As R_2 is made larger, the input impedance goes up, but stage gain drops.

PARTS LIST:

C_1 — 0.5 to 10 Mfd.
R_1 — 250K, ½ W. Carbon resistor.
R_2 — 50-150, ½ W. Carbon resistor.
R_3 — 47K, ½ W. Carbon resistor.
2N34 (*Transitron* transistor).
B_1 — 3 to 9 volt battery (penlight cells).
Sw_1 — SPST Switch (toggle or slide).
HEADPHONE — High Impedance Magnetic or Crystal Headset.

MISC. – Case – Plastic Box or small metal box (such as *L.M.B.* No. M00); Transistor socket; solder, wire, misc. Hdwe.

CONSTRUCTION HINTS: The entire *Headphone Amplifier* may be assembled in a small plastic or metal case, with the final case size more dependent on your wiring skill and the type of batteries you use than on anything else. If small mercury batteries are used (such as *Mallory* RM-625), a quite small case will serve. If penlight cells are used, a larger case will be needed. The *Transitron* transistor may be mounted in a socket or soldered in place by means of its leads. If soldered permanently in place, however, be sure the suggestions outlined in Chapter 2 (under *CARE OF TRANSISTORS*) are followed. Battery voltage is not critical . . . use 2, 3, 4 or more cells, as you wish. In some cases, however, R_1's value may have to be changed for optimum operation. You can vary the size of R_2 to obtain the best compromise between gain and stability . . . use from 50 to 150 ohms here . . . or, for maximum gain, leave out this resistor entirely, connecting the emitter (E) directly to the positive side of the battery. Where the assembly is to be connected to a signal source having appreciable D.C.

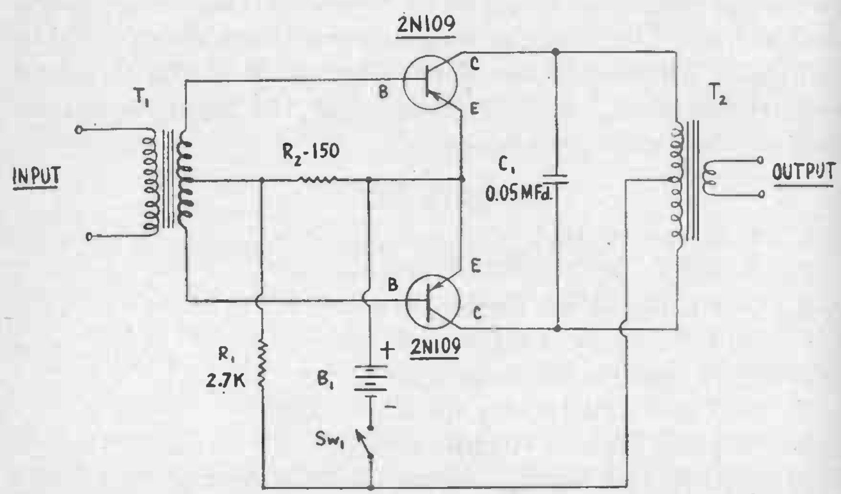


Fig. 7-2.—Basic Push-Pull Power Amplifier.

present, C_1 should be a 200 to 400 volt paper capacitor, with a value of from 0.5 to 2.0 Mfd. If no D.C. is present at the INPUT terminals, C_1 may be an electrolytic, with a value of from 2 Mfd. to 10 Mfd. . . . this will give a better low frequency response.

PUSH-PULL POWER AMPLIFIER: Where a low to moderate amount of audio power is required, the designer has a choice of using either a "High Power" transistor as a single-ended Class A amplifier or a pair of lower power transistors in Class B push-pull. From a power requirement viewpoint, the second choice is the more economical of the two. The circuit given in Fig. 7-2 is typical of the output circuits using two medium power transistors in Class B push-pull. It may be used as the output stage in a phonograph amplifier or in a receiver, or alone as a moderate gain power amplifier. If used as a self-contained instrument, it may be driven by a pre-amplifier, or, if desired, by a high level output phonograph cartridge. If a suitable matching transformer is substituted for T_1, it may be driven by a carbon microphone.

CIRCUIT DESCRIPTION: The amplifier circuit shown in Fig. 7-2 consists of two PNP transistors connected in Class B push-pull, using the grounded-emitter configuration. Transformers T_1 and T_2 serve to match to the transistors' input (base) and output (collector) circuits, respectively. Base bias current is supplied by voltage divider R_1-R_2. Capacitor C_1, across the primary of the output transformer, by-passes high frequency audio signals and thus reduces the effects of any harmonic distortion that may be present. Power is supplied by battery B_1, controlled by switch Sw_1.

The amplifier may be used to drive a higher-powered circuit or to drive a small loudspeaker directly. Power output is between 50 and 100 milliwatts with an efficiency of around 60%. Power gain is approximately 30 db.

PARTS LIST:

R_1 – 2.7K, ½ W. Carbon resistor.
R_2 – 150 ohm, ½ W. Carbon resistor.

C_1 — 0.05 Mfd., 150 volt paper or ceramic capacitor.
T_1 — Input transformer — High Impedance input to 1500 ohms, C.T. (*RCA* type No. XT-8907).
T_2 — Output transformer — Primary Impedance to 400 ohms, C.T. to match loudspeaker (*RCA* type No. XT-8908).
B_1 — 6 volt battery (*Burgess* No. Z4).
Sw_1 — SPST Toggle or Slide type switch.
TRANSISTORS — (2) *RCA* 2N109.
MISC. — (2) Transistor sockets; small chassis; terminal strips; wire, solder, screws, nuts, other small hardware (input and output connectors, etc.)

CONSTRUCTION HINTS: The complete amplifier may be assembled on a small chassis or in an aluminum or plastic box. Use rosin core solder only and follow ordinary good wiring practice. No special precautions must be observed and layout is non-critical. It is necessary that transistor sockets be used, however, since the 2N109 is equipped with short pins instead of the usual long wiring leads. Once the wiring is completed and checked, the battery and transistors may be installed . . . *do not insert or remove the transistors with the power "ON"*, however, for heavy transient currents may result and these, in turn, may damage the transistors.

Suitable miniature loudspeakers for use with this circuit are the *Argonne* No. AR-95, and the *Jensen* P275-Y.

HEARING AID: An individual need not be nearly deaf to find a *Hearing Aid* useful. Slightly impaired hearing may result in embarrassment, job difficulties and, in the case of students, poor grades. Such hearing may be corrected, in some cases, by a *Hearing Aid* of moderate gain. But, unfortunately, most commercial Hearing Aids are designed to have the high gain needed by a nearly deaf person and are priced accordingly. Not so the *Hearing Aid* shown in Figs. 7-3 and 7-4. This circuit is designed to provide only moderate gain, but is both inexpensive and comparatively easy to assemble. It represents a compromise between the factors of circuit complexity, gain, parts cost, and reliability. Since only two transistors are used,

current drain is low and battery life long, resulting in minimum upkeep expense.

But before assembling your own *Hearing Aid,* there is an important point to remember . . . the circuit given in Fig. 7-3 is for educational purposes only. It is *not* suggested as a remedy or cure . . . only *your* Physician, after proper tests, can tell you whether you need a *Hearing Aid.*

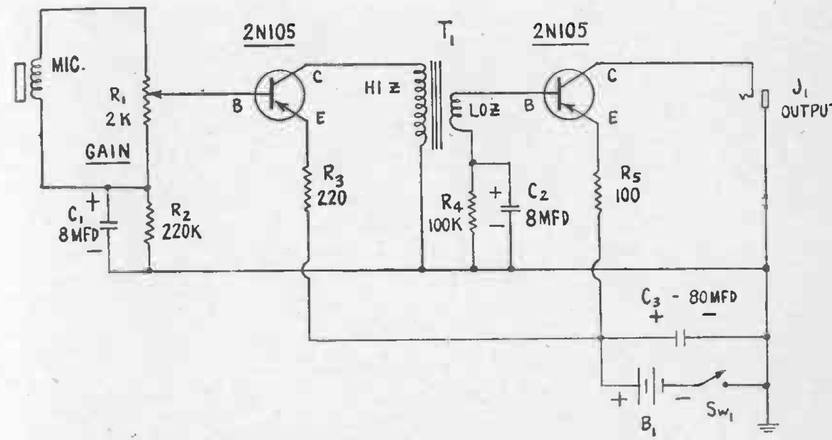


Fig. 7-3.—Compact Hearing Aid Amplifier.

CIRCUIT DESCRIPTION: The *Hearing Aid* circuit given in Fig. 7-3 is a two-stage transformer-coupled amplifier. PNP transistors, connected in the grounded-emitter configuration, are employed. A medium impedance magnetic microphone (MIC.) is used as a pick-up, eliminating the need for an input matching transformer. A high impedance magnetic earset is used in the output.

In operation, audio signals striking the microphone (MIC.) are converted into electrical signals. A portion of the audio signal is applied to the base-emitter circuit of the first 2N105 amplifier stage, depending on the setting of GAIN control R_1. Base bias current for the first stage is supplied through resistor R_2, by-passed by capacitor C_1. An unby-passed emitter resistor, R_3, provides degeneration and helps stabilize this stage.

The amplified signal in the collector circuit of the first stage is coupled through transformer T_1 to the second amplifier stage, another 2N105 transistor. The transformer acts to match the high output impedance of the first stage to the low input impedance of the second stage, insuring an efficient transfer of energy. Bias current for the second stage is supplied through base resistor R_4, by-passed by C_2. Again, an unby-passed emitter resistor, R_5, provides both A.C. and D.C. stabilization.

A high impedance magnetic earphone, plugged into jack J_1, serves as the final output load and converts the amplified audio signal into sound waves. Power is supplied by mercury battery B_1, controlled by Sw_1 (on the GAIN control), and by-passed by capacitor C_3, which, in turn, prevents interstage coupling through the power supply circuit.

PARTS LIST:

R_1 — 2K Miniature potentiometer, with switch (*Centralab* B16-2).
R_2 — 220K, ½ W. Carbon resistor.
R_3 — 220 ohm, ½ W. Carbon resistor.
R_4 — 100K, ½ W. Carbon resistor.
R_5 — 100 ohm, ½ W. Carbon resistor.
C_1, C_2 — 8 Mfd., 6 volt capacitor (*Sprague* No. TE-1068).
C_3 — 80 Mfd., 6 volt capacitor (2 *Sprague* No. TE-1095).
T_1 — Interstage transformer, 20K to 1K (*Chicago Standard* UM-113).
MIC. — 1000 Ohm Magnetic Microphone (*Shure Bros.* MC-20).
Sw_1 — SPST Switch (on R_1).
B_1 — 5 Volt Mercury battery (*Mallory* No. TR-114R).
J_1 — Miniature open circuit jack (*Telex* No. 9240).
TRANSISTORS — (2) *RCA* 2N105 PNP units.
MISC. — Earphone, High Impedance (*Argonne* No. AR-50); Miniature plug (*Telex* No. 9231); Small metal case; wire; solder; Misc. Hdwe.

CONSTRUCTION HINTS: The author's model of the *Hearing Aid,* as shown in Fig. 7-4, was assembled in a small metal case . . . an old *Edgeworth* sliced tobacco can! The case was enameled with a bright finish after machining. You can use a similar case when assembling your own model or, if you prefer, a housing of your own choosing . . . a small plastic box is a good choice. You'll find it easiest to mount the parts on a small *Bakelite* or plastic panel, completing all wiring before final installation in the case proper. Subminiature assembly and wiring requires patience and skill!!!

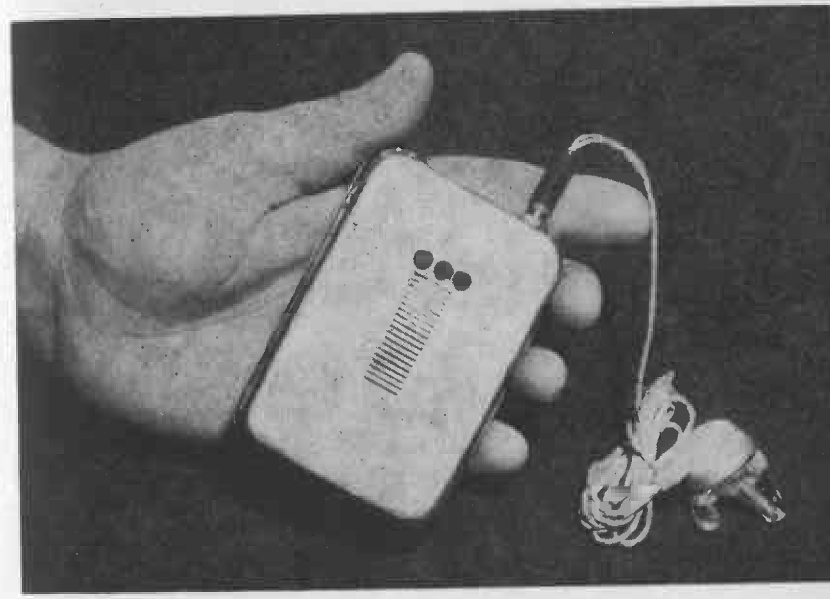


Fig. 7-4.—Hearing Aid assembled in a small metal box.

If you're ambitious, you might prefer to work up an etched circuit layout for the unit. Refer to Chapter 13 for information on *Printed Circuit Techniques.*

But regardless of the method of construction you choose, be sure to observe electrolytic capacitor and battery polarities . . . and, of course, follow the usual precautions when installing the transistors. Although layout is not too critical, you should observe good practice, keeping the "input" and "output" leads well separated. To prevent excessive noise in use, the microphone should be cushioned in a rubber mounting. Use

Rubber-To-Metal Cement (GC No. 35-2*) for making up and mounting this assembly.

SPECIAL PURPOSE AUDIO APPLICATIONS

AN ELECTRONIC "STETHOSCOPE": A Vibration Pick-up-Amplifier or electronic "Stethoscope" is not only an extremely useful instrument, but an intriguing device to use, even in non-technical work. With it, an operator can listen to virtually inaudible sounds in machinery, or can hear the tumblers of combination locks falling into place like heavy blocks. With practice, he can often listen through walls and doors, overhearing conversations in closed rooms. The transistorized instrument shown in Figs. 7-5, 7-6, and 7-8 is fairly easy to assemble, inexpensive, and easy to use. It should be of value to locksmiths, mechanics, detectives, and repairmen.

CIRCUIT DESCRIPTION: The transistorized electronic "Stethoscope" consists of three elements . . . (a) an "input" transducer which converts mechanical vibrations into electrical signals, (b) an audio amplifier, and (c) an "output" transducer which converts electrical signals into sound. In the author's model, a crystal phonograph cartridge serves as the "input" transducer and a magnetic earset as the "output" transducer. The amplifier is a three-stage transistorized circuit.

Referring to Fig. 7-5, we see that the amplifier uses two PNP transistors and one NPN unit, with direct coupling between stages. The direct coupling insures a good low frequency response characteristic and also minimizes the need for trans-

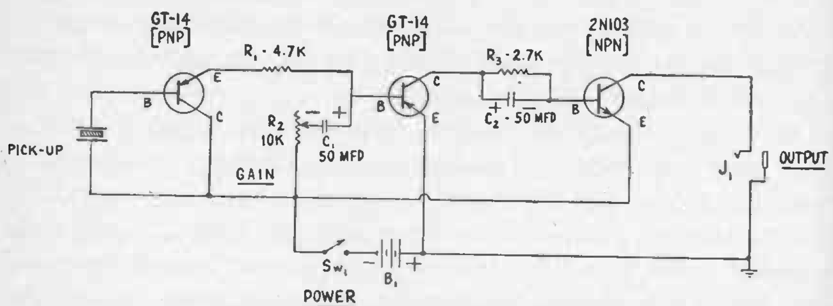


Fig. 7-5.—A transistorized electronic "Stethoscope".

Fig. 7-6.—Exterior view of the electronic "Stethoscope".

formers or other special parts. The first stage is a grounded-collector amplifier, and is used to provide an impedance match between the high output impedance of the crystal pick-up and the low input impedance of the succeeding transistor stage. Following the grounded-collector stage, which provides little or no gain, is a cascaded two-stage complementary amplifier.

In operation, R_1, C_1 and R_2 form the GAIN control network, with R_1 and R_2 acting as a simple voltage divider. Capacitor C_1 is used for coupling and D.C. blocking purposes only. Resistor R_3, by-passed by C_2, is used in the direct-coupled complementary amplifier simply for protective purposes . . . that is, to limit D.C. flow and to protect the transistors. They are not otherwise essential to circuit operation . . . and, in fact, somewhat greater gain will be obtained if these two components are replaced by a direct connection. Power is supplied by battery B_1, controlled by slide switch Sw_1.

PARTS LIST:

R_1 — 4.7K, ½ W. Carbon resistor.
R_2 — 10K Potentiometer, Audio Taper (*Centralab* No. B-18).
R_3 — 2.7K, ½ W. Carbon resistor.
C_1, C_2 — 50 Mfd., 6 volt capacitors (*Sprague* No. TE-1100).
Sw_1 — SPST Slide switch.
B_1 — 5 volt mercury battery (*Mallory* No. TR-114R).
J_1 — Open circuit 'phone jack.
PICK-UP — High output crystal phonograph cartridge (*Astatic* L-70-A).
TRANSISTORS — (2) *General Transistor* type GT-14 (PNP). (1) *Germanium Products* type 2N103 (NPN).
MISC. — (3) Transistor sockets; Small metal case (*ICA* No. 29435); Control Knob; Magnetic Earphone and Plug (*Telex* No. 4680); Metal spike; wire, solder, screws, nuts, Misc. Hdwe.

CONSTRUCTION HINTS: With care, the entire electronic *"Stethoscope"*, including both the amplifier and pick-up cartridge, may be assembled into the standard 2¾" x 2⅛" x 1⅝" aluminum box specified in the *Parts List* and shown in the photographs. Controls may be labeled with *Tekni-Label* decals, protected, after application, with at least two coats of clear plastic spray. Neither layout nor lead dress are critical, but you should follow the usual practice of keeping input and output leads well separated. Be sure to observe all polarities, both of electrolytic capacitors and battery. Finally, do not install the transistors until after you have double-checked for wiring errors and accidental shorts.

A detailed view of the pick-up's mounting is given in Fig. 7-7. The crystal phonograph cartridge used is mounted on the

case so as to bear against a 4" to 8" long metal spike which, in turn, serves as a test-probe. An old ice-pick point, a hardened nail, or anything similar may serve as the probe. Other than bearing against the phono cartridge's case, there is no mechanical or electrical connection between the test probe and the rest of the circuit.

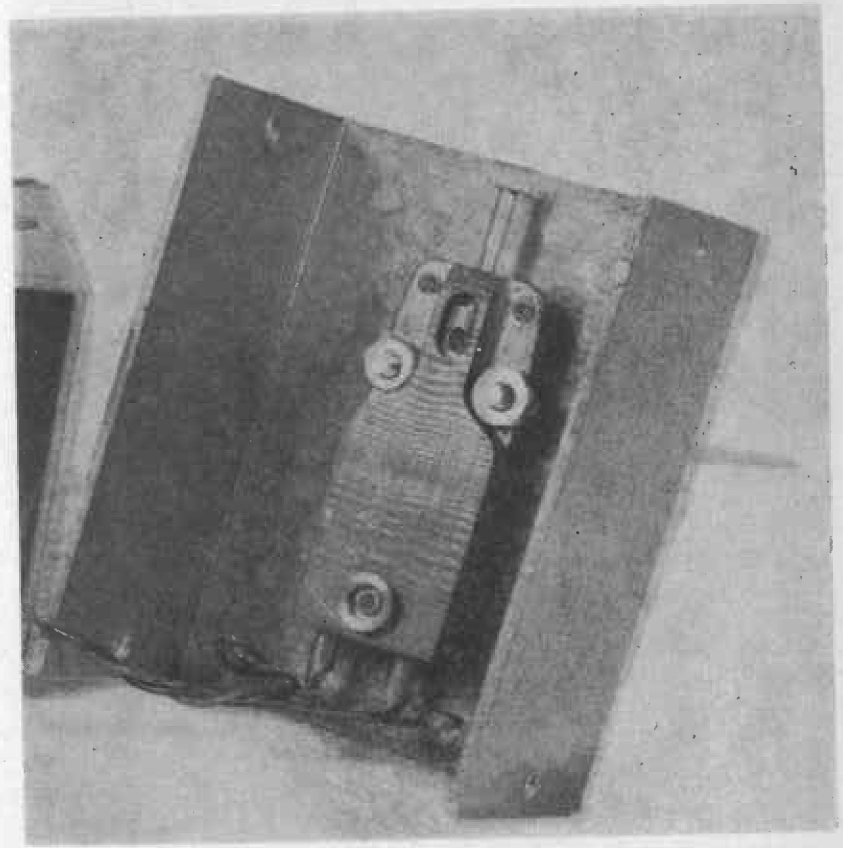


Fig. 7-7.—Detail of crystal cartridge mounting.

To use the electronic *"Stethoscope"*, plug in the earset (into jack J_1), close switch Sw_1, and hold the probe against the object to be checked. *Gradually* adjust the GAIN control (R_2) until the desired volume level is obtained . . . avoid overloading the amplifier, as severe distortion may result. Proper use of the instrument is shown in Fig. 7-8.

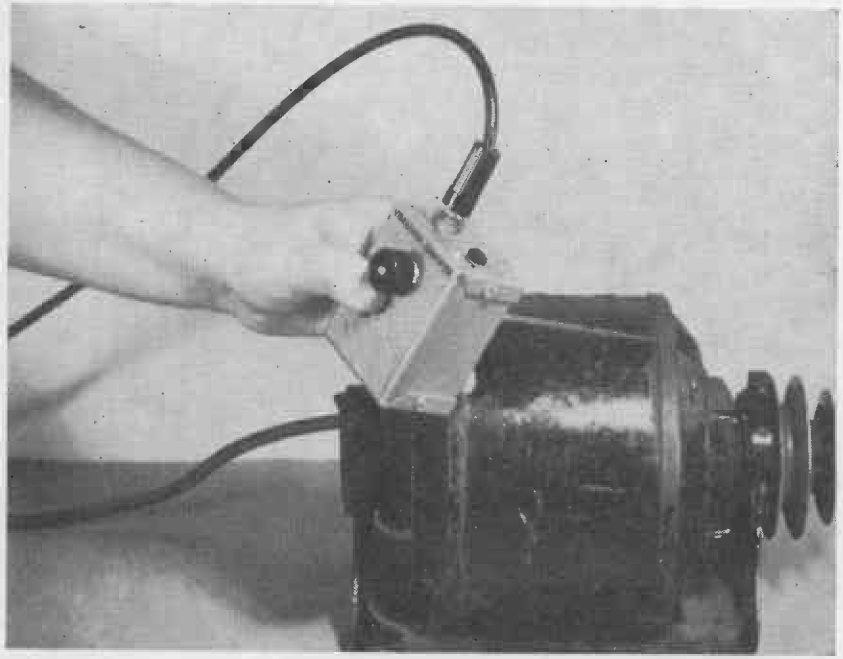


Fig. 7-8.—Using a transistorized electronic "Stethoscope" to listen to the vibration of an electric motor.

SELECTIVE AUDIO AMPLIFIER: Although most audio amplifiers are designed to have a more or less "flat" frequency response, it is possible to assemble a unit which, like a radio receiver, is "tuned" to give maximum gain at a single frequency, with little or no gain at other frequencies. The circuit for such an amplifier is given in Fig. 7-9. This unit may be used advantageously wherever a single audio frequency is of interest . . . for example, when used with a Communications Receiver to listen to CW (code) signals, it is effective in reducing background noise and interference; a *Selective Audio Amplifier* is also useful for "nulling" the output of Impedance Bridges or other test instruments giving an audible indication.

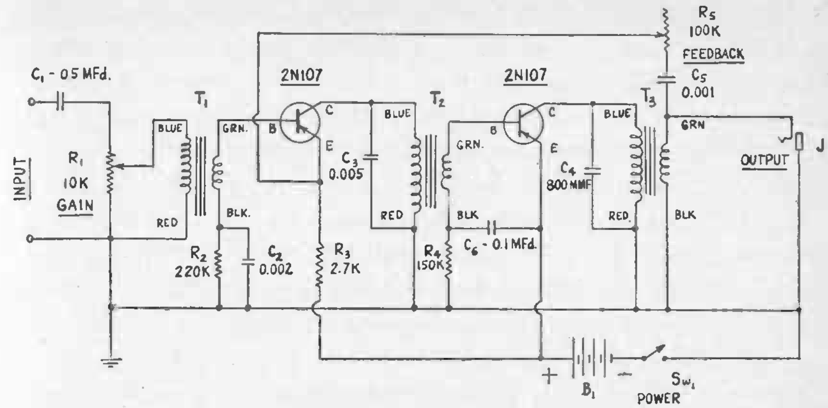


Fig. 7-9.—A Selective Audio Amplifier.

CIRCUIT DESCRIPTION: Referring to Fig. 7-9, we see that a two-stage transformer-coupled circuit is employed, using PNP transistors in the common-emitter configuration. A peaked response characteristic is obtained by modifying the basic circuit in several ways. First, the primaries of coupling transformers T_2 and T_3 are tuned by capacitors C_3 and C_4, respectively. Secondly, considerable negative feedback is introduced in the first stage by unby-passed emitter resistor R_3. This degeneration would normally reduce amplifier gain at all frequencies, but is cancelled *at one frequency* by a positive feedback signal obtained from the secondary of T_3 and coupled back to the emitter through C_5 and R_5. Finally, by-pass capacitors C_2 and C_6 are chosen to be effective only at higher frequencies, providing additional degeneration in the base circuit on the low frequency side of the peaked or "resonant" frequency.

The *Selective Audio Amplifier* has a moderately high input impedance, provided by input transformer T_1, and a moderate output impedance. The author's model provided an overall gain of approximately 40 db at the peaked frequency of 860 cycles, falling off to 20 db at 700 and 1500 cycles. The output level may be adjusted by GAIN control R_1, the "peaking" by FEEDBACK control R_5. If desired, R_5 may be adjusted to throw the circuit into oscillation. Power is supplied by a 6-volt battery, B_1, made up of four penlight cells in series, and controlled by POWER switch Sw_1.

PARTS LIST:

R_1 — 10K, Potentiometer, Audio Taper (*Centralab* No. B-18).
R_2 — 220K, ½ W. Carbon resistor.
R_3 — 2.7K, ½ W. Carbon resistor.
R_4 — 150K, ½ W. Carbon resistor.
R_5 — 100K Potentiometer, Linear Taper (*Centralab* No. B-40).
C_1 — 0.5 Mfd., 400 V. Paper capacitor.
C_2 — 0.002 Mfd., ceramic (*Centralab* No. DM-202).
C_3 — 0.005 Mfd., ceramic (*Centralab* No. DM-502).
C_4 — 800 Mmf. mica capacitor.
C_5 — 0.001 Mfd., ceramic (*Centralab* No. DM-102).
C_6 — 0.1 Mfd., ceramic capacitor (*Centralab* No. DF-104).
T_1, T_2, T_3 — Interstage transistor transformers (*Chicago Standard Transformer Co.* No. UM-113).
J_1 — Open circuit 'phone jack.
Sw_1 — SPST Toggle switch.
B_1 — 6-volt battery (4 *Burgess* type Z).
TRANSISTORS — (2) *GE* type 2N107.
MISC. — (2) Transistor sockets; (2) Knobs; High Impedance Magnetic Headphones; Battery Box for 4 penlight cells (*Austin-Craft*); Small cabinet (*L.M.B.* No. 108); (2) Binding posts; Wire, solder, screws, nuts, terminal strips, misc. Hdwe.

CONSTRUCTION HINTS: Although layout and lead dress are not extremely critical, you'll find it best to devote some thought to parts arrangement before starting construction. A clean, "in-line" circuit arrangement is preferred, with the cores of adjacent transformers at right angles to each other. Pay especial attention to the location of capacitors C_2, C_3, C_4, C_5, and C_6, as you may wish to change the values of these components during final test and adjustment. The transistors may be mounted in sockets or wired permanently in place . . . the usual precauations should be followed if you decide to solder to the transistor leads, however.

When the wiring is completed and double-checked for possible errors, make sure the POWER switch Sw_1 is in the OFF position before inserting the transistors. Double-check, too, on the polarity of battery connections. Note that four penlight cells are connected in series to provide a 6-volt battery.

ADJUSTMENT AND USE: Capacitors C_2, C_3, C_4, C_5 and C_6 are chosen experimentally to give a peaked output at the desired frequency. The values given in Fig. 7-9 were those used in the author's model . . . which peaked at about 860 cycles/second. Another model may peak at a different frequency, even with capacitors of the same (marked) value due to differences in wiring capacities, tolerances of components, and other factors. These capacitor values should be determined with the Headphone plugged into the OUTPUT jack J_1 . . . high impedance headphones are preferred to minimize circuit loading.

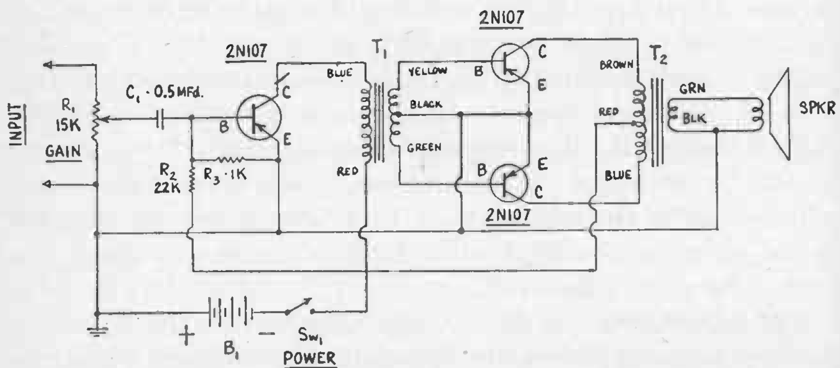
With the circuit wired and checked, try adjusting FEEDBACK control R_5, listening to the Headphone . . . you should be able to throw the circuit into oscillation. If not, reverse the connections to the secondary of T_3. In operation, the sharpest tuned action is obtained when R_5 is adjusted to a point just below the oscillation level.

THE GEIGAMP: Low cost Geiger Counters, of the type used by most amateur prospectors, are generally designed for Headphone operation only. While this type of design keeps initial cost low, the resulting gear may be bothersome to use, for Headphones can be mighty uncomfortable if worn for hours at a stretch . . . as may occur during a prospecting trip. Loudspeaker operation is much to be preferred, if available.

The *Geigamp* (short for *Geig*er *Amp*lifier) is a self-contained unit designed especially as an accessory for low cost Geiger Counters. It provides loudspeaker operation when its INPUT leads are connected to the "PHONE" jacks of a Counter; no modification of the Counter itself is needed.

This instrument is a good example of a "Special Purpose" transistor circuit design. It is not a "good" *general purpose* audio amplifier, for its frequency response is limited and its distortion level is intolerably high for use in amplifying music or voice. However, it does an excellent job of amplifying Geiger Counter clicks, and is quite economical of operation . . . a set of batteries should last around 200 hours. The circuit is simple, straightforward, and reliable.

CIRCUIT DESCRIPTION: Referring to the schematic diagram given in Fig. 7-10, we see that three PNP transistors are employed in this circuit. One is connected as a Class A single-ended "gain" amplifier and serves to drive two transistors connected in Class B push-pull. The grounded-emitter configuration is employed in both stages and transformer coupling is used throughout. The Class B push-pull stage serves as the power amplifier and drives the loudspeaker.



Courtesy Popular Electronics

Fig. 7-10.—Circuit of the Geigamp . . . a Geiger Counter amplifier.

In operation, an audio signal applied to the INPUT leads appears across GAIN control R_1. A portion of this signal, depending on the setting of R_1, is applied through coupling capacitor C_1 to the base of the first transistor. Base bias current for this stage is supplied by voltage divider R_1-R_2.

The amplified signal in the collector circuit of the first transistor stage is coupled through transformer T_1 to the push-pull output stage, which is operated without bias current, and thus as a Class B stage. Transformer T_1 serves the dual function of matching the high output impedance of the first stage to the

low input impedance of the output stage and of providing a push-pull "drive" signal.

Further amplification occurs in the push-pull stage, with the final output signal coupled through transformer T_2 to drive the loudspeaker. Since the output stage operates without base bias current, its D.C. power requirements are low except when a signal is being amplified. Average current drain, of the entire circuit, is only about 5 Ma.

Power is supplied by a "battery" made up of four mercury cells connected in series, controlled by POWER switch Sw_1.

PARTS LIST:

R_1 — 15K Potentiometer, Audio Taper (*Centralab* No. B-20).
R_2 — 22K, ½ W. Carbon resistor.
R_3 — 1K, ½ W. Carbon resistor.
C_1 — 0.5 Mfd., 200 V. metallized paper capacitor.
T_1 — Transistor driver transformer, 10K to 2K C.T. (*Argonne* No. AR-109).
T_2 — Output transformer, 500 ohms C.T. to 3.2 ohms (*Argonne* No. AR-119).
Sw_1 — SPST Slide Switch.
B_1 — Battery—(4) *Mallory* RM-1R mercury cells in series.
SPKR — 2½″ PM Loudspeaker, 3.2 ohm voice coil.
TRANSISTORS — (3) *GE* type 2N107.
MISC. — Cabinet (cut down from *ICA* No. 29077); 36″ Lamp cord; (2) 'phone tips; rubber grommet; wire, solder, nuts, screws, Misc. Hdwe., etc.

CONSTRUCTION HINTS: An exterior view of the *Geigamp*, alongside a commercial Geiger Counter is given in Fig. 7-11, while an interior view is shown in Fig. 7-12. A standard aluminum chassis was cut down to make the small metal cabinet and a scrap piece of aluminum bent to make a back cover. Belt loops were fitted on the back cover for ease in carrying.

The battery is made up by fitting four *Mallory* RM-1R mercury cells into a piece of plastic tubing and clamping the ends.

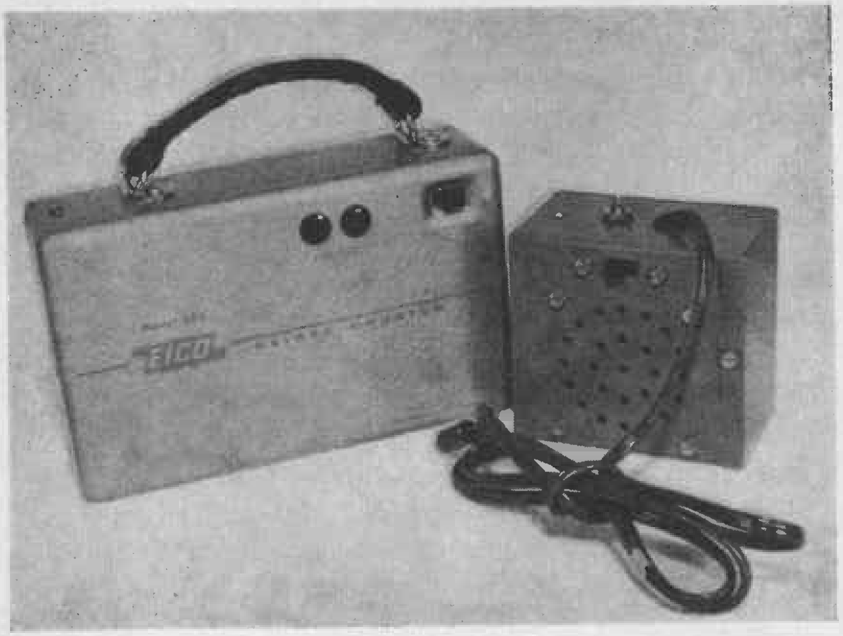
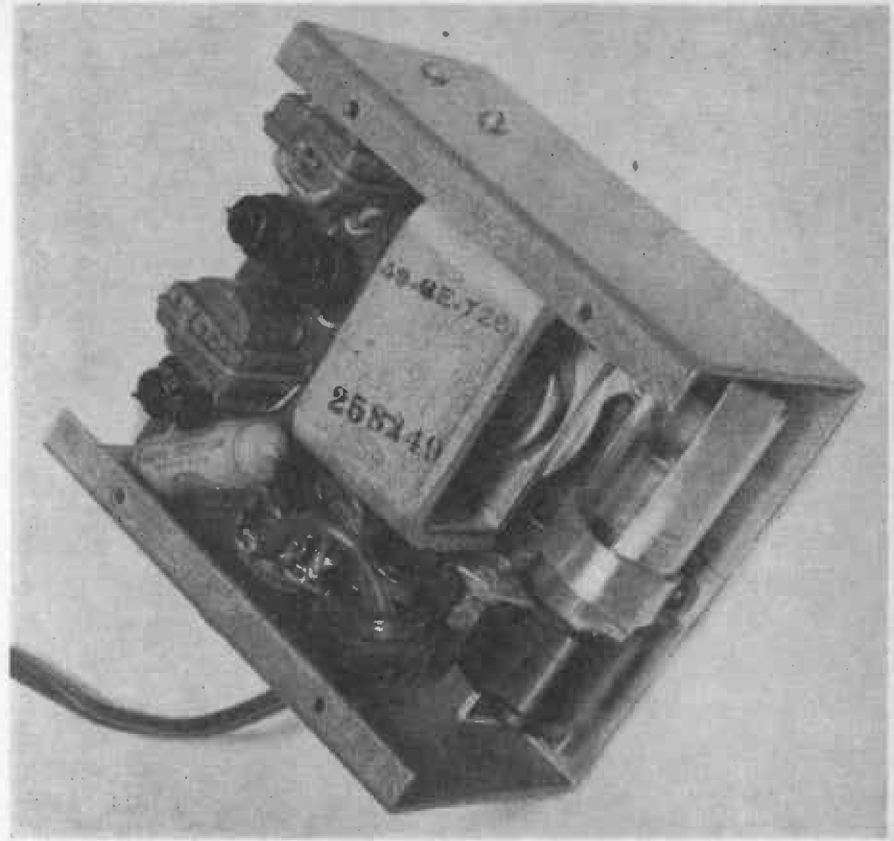


Fig. 7-11.—The Geigamp alongside a commercial Geiger Counter with which it can be used.

This assembly is visible in Fig. 7-12 as the tube-like device on one side of the loudspeaker. You may wish to substitute a five or six volt mercury battery for this assembly . . . a suitable choice is the *Mallory* type TR-134R (5 volt) or TR-135R (6.5 volt).

In the author's model, as shown in the photographs, the amplifier proper has been assembled on an etched circuit board (see Chapter 13—*Special Techniques*) but conventional construction techniques may be employed if preferred by the builder. Where an etched circuit board is used, the transistors are soldered permanently in place . . . if you use this procedure, be sure to follow the usual precautions (see Chapter 2—*Care of Transistors*).

A length of twin-conductor lamp cord may be used for connecting the *Geigamp* to the Geiger Counter with which it is used. This cord should be terminated in 'phone tips, a 'phone



Courtesy Popular Electronics

Fig. 7-12.—Interior view of the Geigamp.

plug, or whatever type of connector is appropriate to fit the HEADPHONE terminals of the Geiger Counter. 'Phone tips were used in the author's model.

GENERAL AUDIO APPLICATIONS

TWO-STATION INTERCOM: Two-way intercommunication systems are widely used by industry, business and the professions. A manufacturer will use such a system to maintain contact between executives and various departments. A business house finds such systems valuable for rapid communication between offices. And professional men . . . doctors, dentists, engineers and lawyers, find such equipment indispensable for daily contact between themselves and their secretaries or receptionists.

Most commercial *Intercoms* (short for *Intercom*munication) are vacuum-tube operated and suffer the usual disadvantages of such equipment . . . excessive heating, tendency to develop hum and noise, frequent servicing as tubes burn out, and a dependence on nearby line receptacles. This last characteristic renders the majority of such systems impractical for field or portable use as well as limiting their application to localities where line voltage is readily available.

The transistorized *Intercom* shown in Figs. 7-13 and 7-14 offers all the advantages of a two-way intercommunication system without the disadvantages inherent in vacuum-tube operated equipment. It is compact, self-contained, lightweight, and completely independent of line voltage requirements. Nor is it subject to inherent hum or tube failure problems.

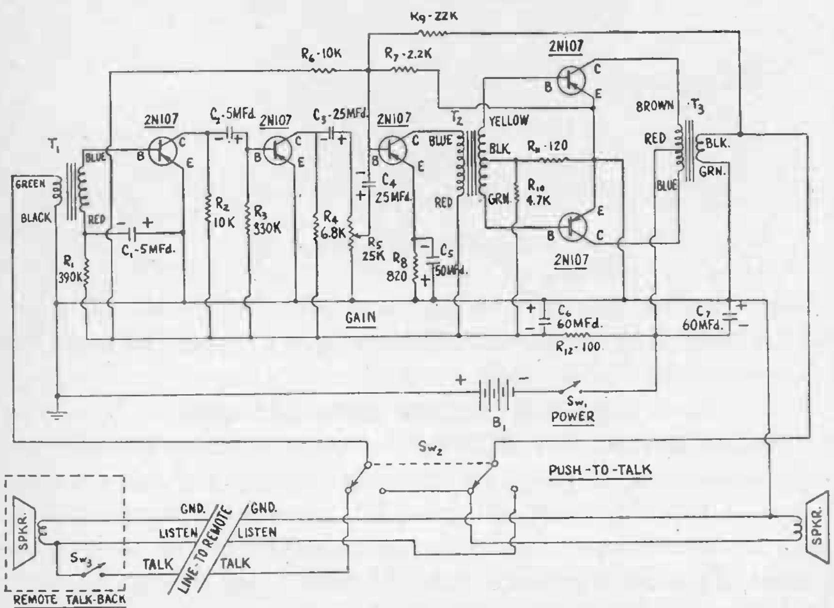


Fig. 7-13.—A transistorized two-station Intercom.

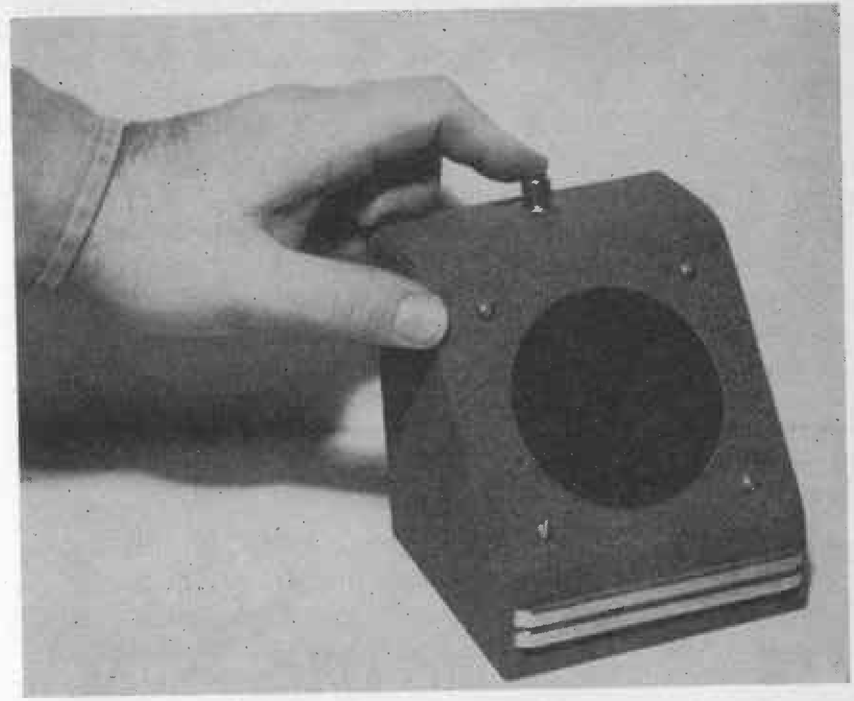


Fig. 7-14.—Using the transistorized Intercom.

CIRCUIT DESCRIPTION: Referring to the schematic diagram (Fig. 7-13), we observe that five PNP transistors are employed, three as voltage amplifiers (or "gain" stages) and two in push-pull as a power amplifier. Resistance-capacity coupling is used between the first three stages and transformer coupling between the last "gain" stage and the power amplifier. PM loudspeakers are used both as sound reproducing devices and as microphones, with an input transformer (T_1) used to match the low voice coil impedance (3.2 ohms) to the moderate input impedance of the first stage, and an output transformer (T_3) used to match the push-pull power stage to the output loudspeaker's voice coil. Resistor R_5 serves as the GAIN control; switch Sw_1 as the POWER switch; switch Sw_2 as the PUSH-TO-TALK switch at the "Master" unit (housing the amplifier); and, finally, switch Sw_3 as the PUSH-TO-TALK switch at the remote location. Inverse (degenerative) feedback is provided across the last two stages to minimize distortion, with resistor R_9 serving as the feedback path.

In operation, PUSH-TO-TALK switch Sw_2 serves to interchange the connections of the two PM loudspeakers between the "Input" and "Output" of the transistorized amplifier . . . permitting either to serve as a microphone while the other serves as a sound reproducing device. With the switch in the position shown in Fig. 7-13, the "Remote" speaker serves as a microphone *when Sw_3 is depressed,* and the built-in speaker in the "Master" serves its normal function as a loudspeaker. When Sw_2 is depressed, the speaker in the "Master" becomes a microphone, while the remote unit is driven as a loudspeaker. With Sw_2 depressed, switch Sw_3 has no effect on circuit operation.

Power is supplied by a single six-volt battery, controlled by Sw_1. Battery life is reasonably long due to the low power requirements of the transistor stages.

PARTS LIST:

R_1 — 390K, ½ W. Carbon resistor.
R_2, R_6 — 10K, ½ W. Carbon resistors.
R_3 — 330K, ½ W. Carbon resistor.
R_4 — 6.8K, ½ W. Carbon resistor.
R_5 — 25K Potentiometer, Audio Taper (*Centralab* B-27).
R_7 — 2.2K, ½ W. Carbon resistor.
R_8 — 820 ohm, ½ W. Carbon resistor.
R_9 — 22K, ½ W. Carbon resistor.
R_{10} — 4.7K, ½ W. Carbon resistor.
R_{11} — 120 Ohm, ½ W. Carbon resistor.
R_{12} — 100 Ohm, ½ W. Carbon resistor.
C_1, C_2 — 5 Mfd., 6 volt electrolytic (*Sprague* No. TE-1084).
C_3, C_4 — 25 Mfd., 6 volt electrolytic (*Sprague* No. TE-1091).
C_5 — 50 Mfd., 6 volt electrolytic (*Sprague* No. TE-1100).
C_6, C_7 — 60 Mfd., 6 volt electrolytic (*Sprague* No. TE-1101).
T_1 — Transistor Input transformer (*Argonne* AR-125) . . . 3.2 ohms to 4K.

T_2 — Transistor Driver trans. (*Argonne* AR-109) . . . 10K to 2K, C.T.
T_3 — Transistor Output trans. (*Argonne* AR-119) . . . 500 C.T. to 3.2 ohms.
Sw_1 — SPST Slide or Toggle switch.
Sw_2 — DPDT Spring Return, Push-button or lever switch.
Sw_3 — SPST Spring Return Push-button switch.
B_1 — 6 volt battery (*Burgess* No. Z4).
SPKR — 3″ PM Loudspeaker, 3.2 ohm voice coil (2 needed).
TRANSISTORS — (5) *GE* type 2N107.
MISC. — (2) Cabinets (*ICA* No. 3996); (1) Chassis (*ICA* No. 29082); Spkr. grill screen; (5) transistor sockets; Battery box (*Austin-Craft* No. 110); Knob; Wire, solder, machine screws, nuts, terminal strips, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The transistorized *Intercom* may be assembled quite easily in a commercial cabinet, as shown in Fig. 7-14, giving the completed instrument a professional "factory-built" appearance. Two cabinets are needed, one of which houses a PM *Spkr,* the battery (B_1), the amplifier, and PUSH-TO-TALK switch Sw_2 . . . this unit is the "*Master*". The second cabinet houses the other PM loudspeaker and switch Sw_3 and serves as the REMOTE TALK-BACK or "*Slave*" unit. The *Master* and *Slave* are connected together with a length of 3-conductor intercom wire.

The amplifier proper may be built on a small sub-chassis, to be installed in the cabinet and connected to the *Spkr,* Sw_2, and the battery, after being checked out for possible wiring errors. Be sure to observe electrolytic capacitor and battery polarities, as indicated in Fig. 7-13. Do not insert or remove the transistors with the power "ON".

Layout is not critical, although the usual practice of keeping "Input" and "Output" circuits well separated should be observed. Mount nearby or adjacent transformers so their cores are at right angles to each other. The transistors may be mounted in sockets or wired permanently in place. If you solder these components in place, follow the usual precautions. Since the GAIN control, R_5, is adjusted only during initial installation, it can be mounted on the back of the chassis or cabinet. The POWER switch, Sw_1, is generally turned "OFF" and "ON" only once each day . . . in normal use . . . and, therefore, it, too, can be mounted on the back of the unit. The PUSH-TO-TALK switch, Sw_2, should be readily accessible, however, and may be mounted either on the top or side of the cabinet . . . in the model this switch is mounted on the top.

In a few instances, you may find that readjustment of bias currents will improve gain, give greater power output, or reduce distortion. The values of resistors R_1, R_3, R_6, and R_{10} may be adjusted to change bias currents in their respective stages.

INSTALLATION AND USE: With the construction completed and all wiring checked, install the battery and transistors. Connect the *Master* and *Slave* units together with a length of 3-conductor cable. Close the POWER switch, and depress the PUSH-TO-TALK switch (Sw_2), speaking into the *Master's* loudspeaker and listening for a sound from the *Slave* unit. Readjust the GAIN control if necessary. As a final test, release Sw_2 and depress Sw_3 (on the *Slave* unit), speaking into the *Slave's* loudspeaker and and listening for a sound from the *Master* unit.

To install the two-way *Intercom* system, place the *Master* at one location, the *Slave* at the other. Run a length of 3 -conductor intercom cable between the two locations and connect to appropriate terminals on the *Master* and *Slave* units. Such cable is generally color-coded, so identifying leads should be easy. The cable should be wired neatly in place . . . you can use insulated staples to tack the connecting cable around baseboards. Finally, turn the system "ON" and adjust the GAIN control to the desired level, with a helper at the *Slave's* location to use the talk-back switch (Sw_3).

POWER MEGAPHONE: With both low input and output impedances, the "high power" type of transistor is especially adaptable to direct-drive by a carbon microphone and to direct-driving a moderate impedance "paging" type trumpet loud-

speaker . . . with neither input nor output transformers needed. Such an assembly makes a simple, compact, light-weight, inexpensive, but effective electronic *Power Megaphone*. The circuit for such an instrument is given in Fig. 7-15, while an actual model is shown in Fig. 7-16.

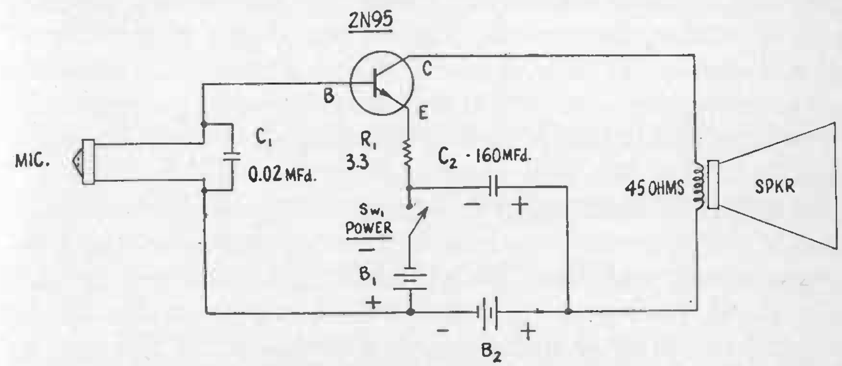


Fig. 7-15.—An electronic Power Megaphone.

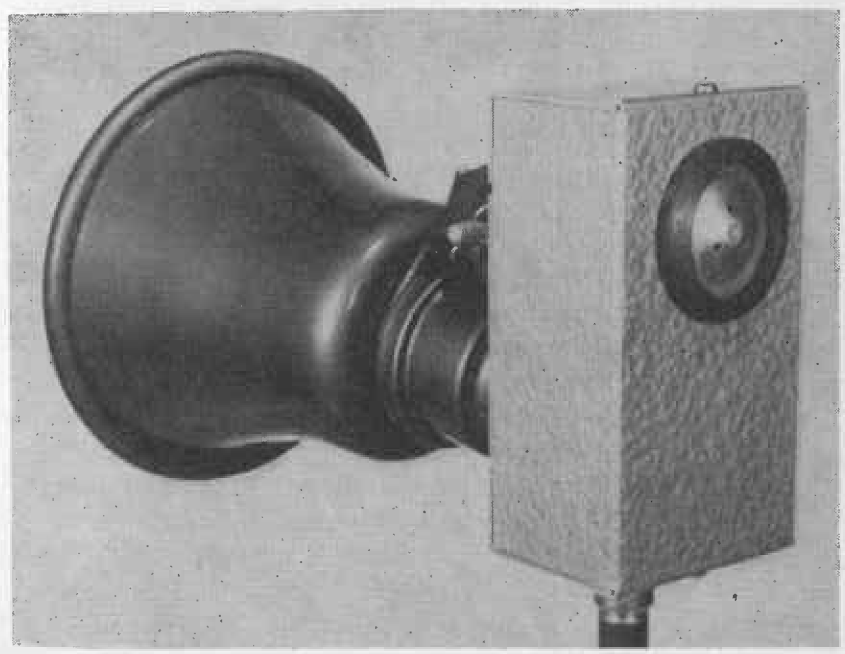


Fig. 7-16.—Exterior view of the transistorized Power Megaphone.

A *Power Megaphone* has applications in many fields . . . policemen, firemen, athletic coaches, traffic directors, Civil Defense workers, construction foremen, yachters, cheerleaders, drill instructors, pitchmen and announcers are but a few of the people who can use such an instrument to advantage. Even the typical housewife should find such a device handy . . . for calling the children home or for giving instructions to the milkman, iceman, or bread delivery man. And since the instrument *directs* as well as *amplifies* the voice, the housewife would probably find it handy for asking the next door neighbor for an extra cup of sugar or flour!

CIRCUIT DESCRIPTION: Referring to Fig. 7-15, we see that a single NPN power transistor is used, connected in the common-emitter amplifier configuration. A carbon microphone (MIC.) serves both to establish D.C. base bias current and to supply the driving audio signal. The voice coil of a paging type trumpet loudspeaker (SPKR) completes the collector circuit and serves as the collector load impedance. Power is supplied by four 1.5 volt cells, connected in series to supply 6 volts (B_1 and B_2), with a tap at 3 volts to supply current to the microphone circuit.

In operation, a steady base bias current flows through the base-emitter circuit, with its value determined by the static D.C. resistance of the microphone, the internal resistance of the transistor, and R_1. A corresponding current flow takes place in the collector-emitter circuit, but of greater magnitude,due to the gain of the transistor . . . and the higher voltage available in this circuit. When sound waves strike the microphone, its resistance varies, changing the base bias current, and causing the collector current to vary in the same manner. Collector current variations are greater than the base current variations, however, due to the amplification provided by the transistor. This changing collector current flow is reproduced as sound waves by the loudspeaker.

Capacitor C_1, across the microphone, acts to by-pass higher frequency signals and thus to reduce microphone "hiss" (a characteristic of carbon microphones). Unby-passed emitter

resistor R_1 is included for A.C. and D.C. stabilization purposes and provides a slight amount of degeneration. Capacitor C_2, across the battery supply and POWER switch Sw_1, serves to absorb current surges when the unit is turned "ON" and "OFF".

The operation of the instrument is controlled by a push-button power switch, Sw_1, so that maximum current drain takes place only when the *Power Megaphone* is in actual use.

PARTS LIST:

R_1 — 3.3 Ohm, 3 Watt resistor (see *"Construction Hints"*).
C_1 — 0.02 Mfd., paper capacitor, 150 to 400 volts.
C_2 — 160 Mfd., 6 volt electrolytic (*Barco* No. P6-100).
Sw_1 — SPST push-button switch.
B_1, B_2 — (4) Flashlight Cells (Size C or D) in series.
MIC. Single Button carbon Microphone (*Shure Bros.* No. R10).
SPKR — "Paging" type trumpet loudspeaker, 3 Watts, *45 ohm* impedance, similar to *University* type MIL-45.
TRANSISTOR — *Sylvania* type 2N95.
MISC. — (2) Double battery boxes (*Austin-Craft* No. 144 or 145, depending on dry cells used); Small metal case (*L.M.B.* No. 136); Microphone stand adaptor (*Atlas* No. AD-11); Wire, solder, machine screws, nuts, terminal strips, Misc. Hdwe, etc.

CONSTRUCTION HINTS: Since the circuit of the *Power Megaphone* is so simple and straightforward, there are no problems of layout or lead dress to give the builder difficulty. A housing is needed for the amplifier, of course. In the author's model, the one-stage amplifier was assembled in a small aluminum box which, in turn, was attached to the trumpet loudspeaker's mounting bracket. An *Atlas* microphone adaptor was attached to the bottom of the case, to permit mounting the completed unit on a microphone stand. When hand-held, the entire case or housing serves as a handle.

The power transistor used is supplied with a tapped hole to permit mounting it directly to a metal chassis, using a single screw. Such a mounting insures maximum heat dissipation.

The collector electrode is internally connected to the transistor's case, however. Therefore, if you mount the transistor on the case, *do not ground* other parts of the circuit. On the other hand, you may prefer to insulate the transistor, using thin insulating washers . . . for details, refer to *Chapter 4*, Fig. 4-13.

Two adjustments should be made for optimum performance after wiring is completed and checked. First, R_1 may have a value of from 2.5 ohms to as high as 10 ohms. As R_1 is increased in value, gain drops but stability improves. About 3.3 ohms seems to be optimum (3 ten ohm resistors in parallel). An easy way to determine the best value for R_1 in your particular unit is to connect four 10 ohm resistors in parallel . . . using one, two, three or four units as needed to give best performance. The second adjustment needed is the microphone current . . . in the author's model, best results were obtained with the tap at 3 volts; as shown in Fig. 7-15, but you may wish to try taps at 1.5, 4.5, or 6 volts (one, three and four dry cells, respectively).

OPERATION: The *Power Megaphone* is designed to be used for close-talking in a moderately loud voice. To use the unit, hold the *Mike* within a few inches of your lips, depress the POWER switch Sw_1, and speak in a raised voice, "aiming" the trumpet loudspeaker in the direction in which you wish to project your voice. Keep Sw_1 depressed only as long as you are talking in order to conserve battery life.

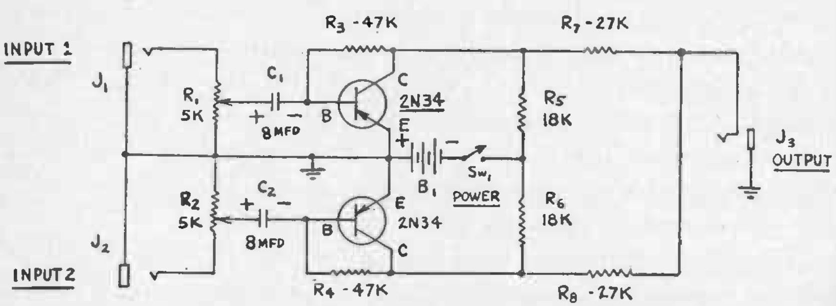


Fig. 7-17.—A transistorized 2-Channel Audio Mixer.

AUDIO MIXER: Low cost amplifiers and recorders generally have a single microphone input jack. This places a definite limit on the applications of the instrument, for the operator cannot, for example, pick up music at one location and a singing voice at another. Such a limitation may be overcome by adding the transistorized accessory shown in Figs. 7-17 and 7-18. This *Audio Mixer* combines two signal inputs into

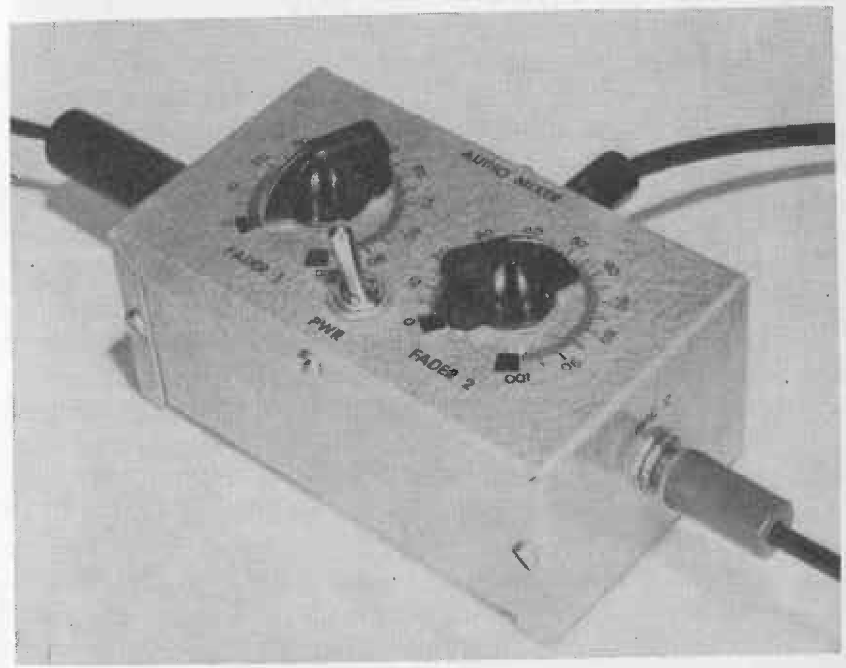


Fig. 7-18.—Exterior view of the Audio Mixer, showing the unit in use.

one, while, at the same time, providing separate GAIN or "FADER" controls over each input. By adjusting the controls, the operator can bring both inputs to full volume, can reduce both to "zero", can operate the two inputs at different levels, or can "fade" one signal in and the other out, as he chooses. The entire instrument is simple to construct, reliable, and comparatively inexpensive.

CIRCUIT DESCRIPTION: Basically, the *Audio Mixer* consists of two independent amplifier stages, with separate inputs, but with the outputs combined through a resistive isolating network. Two PNP transistors are employed, connected in the common-emitter configuration. Referring to Fig. 7-17, R_1 and R_2 serve as the input GAIN or FADER controls, R_5 and R_6 as the output load resistors, and R_7 and R_8 as the output network, isolating the two channels. Capacitors C_1 and C_2 serve both as coupling capacitors and D.C. isolating capacitors, preventing the bias current from being shorted to ground when the FADER controls are turned down. Bias currents for the two transistors are provided by resistors R_3 and R_4. Power for the entire circuit is supplied by a single battery, controlled by POWER switch Sw_1.

The bias arrangement used deserves some comment. When the base resistors are returned to the collector electrodes instad of to the power source or to ground, the circuit is D.C. stabilized. At the same time, some degenerative feedback is introduced, increasing the amplifier's input impedance and, at the same time, improving the A.C. stability, thus minimizing differences between transistors. The arrangement used is essentially that shown in *Chapter 4,* Fig. 4-4(c), and discussed under the topic of D.C. STABILIZATION AND TEMPERATURE COMPENSATION.

PARTS LIST:

R_1, R_2 – 5K Potentiometers, Audio Taper (*Centralab* No. B-12).
R_3, R_4 – 47K, ½ W. Carbon resistors.
R_5, R_6 – 18K, ½ W. Carbon resistors.
R_7, R_8 – 27K, ½ W. Carbon resistors.
C_1, C_2 – 8 Mfd., 6 volt electrolytic (*Barco* No. P6-8).
J_1, J_2, J_3 – Open circuit 'phone jacks.
Sw_1 – SPST Toggle switch.
B_1 – 5 volt mercury battery (*Mallory* type TR-164R).
TRANSISTORS – (2) *Transitron* type 2N34.
MISC. – (2) Transistor sockets; (2) Control Knobs; Case (*ICA* No. 2944); Wire, solder, machine screws, nuts, terminal strips, ground lugs, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The author's model is shown in Fig. 7-18. The average builder should have no difficulty assembling a duplicate unit in two or three evenings or on a weekend. Neither parts layout nor lead dress are critical, so you can follow your own inclinations when building the unit . . . but you will find it worthwhile to observe good wiring practices. If you wish, you can replace the 'phone packs (J_1, J_2, and J_3) used in the model and specified in the *PARTS LIST* with other types of connectors . . . Microphone receptacles, phono jacks, tip jacks, or coaxial connectors, as may be most convenient for your audio equipment. The professional "Factory-Built" appearance of the model shown in Fig. 7-18 was obtained by applying *Tekni-Label* decals to the case . . . after machining, but before mounting parts. The decals were protected with two coats of clear acrylic plastic spray.

APPLICATION AND USE: The *Audio Mixer* has a moderate input impedance (about 5,000 ohms) and thus is well-suited to use with magnetic or dynamic microphones. If high-impedance microphones are to be used with it (such as crystal units) a step-down transformer should be used between the microphone and the appropriate INPUT jack. In operation, the two signals to be mixed are applied to the two INPUT jacks, and a cable connected between the OUTPUT jack (J_3) and the audio equipment (amplifier or recorder) with which the *Audio Mixer* is to be used. Use shielded cables for all inter-equipment connections. Controls R_1 and R_2 are used to control the individual inputs, while the GAIN or VOLUME control of the audio amplifier (or recorder) serves as the "MASTER" gain control.

PUBLIC ADDRESS AMPLIFIER: While the *Power Megaphone* described earier is useful for many applications, its power output is definitely limited because a single power transistor, operating essentially as a Class A amplifier, is used. Where greater power is needed, two transistors may be operated in a push-pull Class B power amplifier. Using commonly available transistors, it is possible to obtain around 5 watts audio output from such an arrangement. This is ample power for applica-

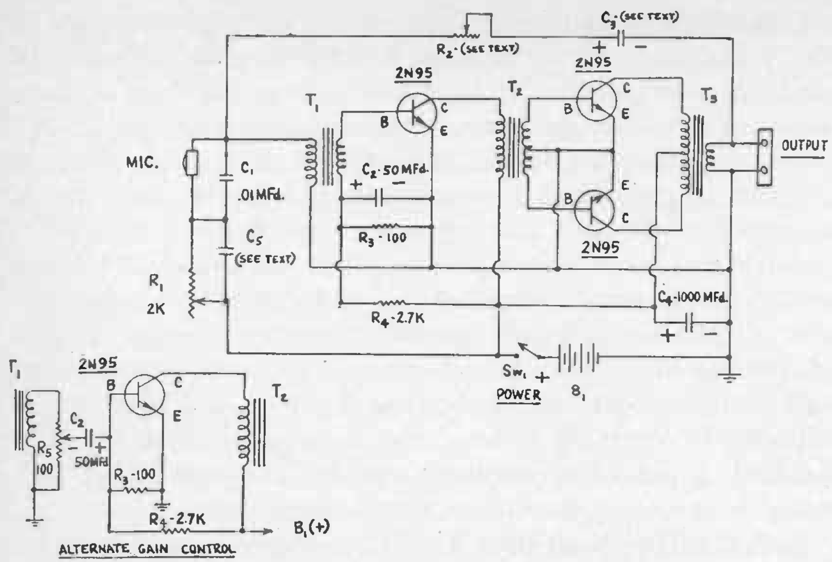


Fig. 7-19.—A transistorized P.A. System.

tions in small auditoriums, at club and committee meetings, in school rooms, with limited outdoor gatherings, and, when used to drive trumpet type loudspeakers, in mobile P.A. work. The circuit for such an amplifier is given in Fig. 7-19, while an assembled model is shown in Fig. 7-20. Since the amplifier is intended for use with a 12 volt automobile battery, it is especially well-suited to portable and outdoor applications.

CIRCUIT DESCRIPTION: Referring to the schematic diagram given in Fig. 7-19, we see that three NPN power transistors are used in a two-stage amplifier. A Class A "gain" stage is used to drive a Class B push-pull power output stage. The common-emitter configuration is used in both stages, and transformer coupling employed throughout. To minimize the need for pre-amplifier stages, a carbon microphone (supplying a relatively high level signal) is used with the amplifier.

In operation, a steady D.C. flows through the microphone circuit, including R_1, the microphone (MIC.), and the primary of input transformer T_1. When sound waves strike the microphone, its resistance varies, varying the D.C. in the same

manner. The audio portion of this pulsating D.C. signal is transferred through T_1 to the base-emitter circuit of the first stage. Microphone current is determined by rheostat R_1, by-passed by C_5. Capacitor C_1, across the microphone terminals, is included to minimize "hiss".

Bias current for the first stage, to insure Class A operation, is obtained from voltage divider R_3-R_4, by-passed by C_2. The amplified signal in the collector circuit is coupled to the push-pull output stage through transformer T_2, which serves the dual function of matching impedances *and* providing a push-pull drive signal.

Further amplification takes place in the push-pull stage, with the final output signal coupled to the loudspeaker through transformer T_3. Negative (degenerative) feedback across the entire amplifier is provided by C_3 and R_2 to reduce distortion and to stabilize gain. By making R_2 adjustable, the feedback

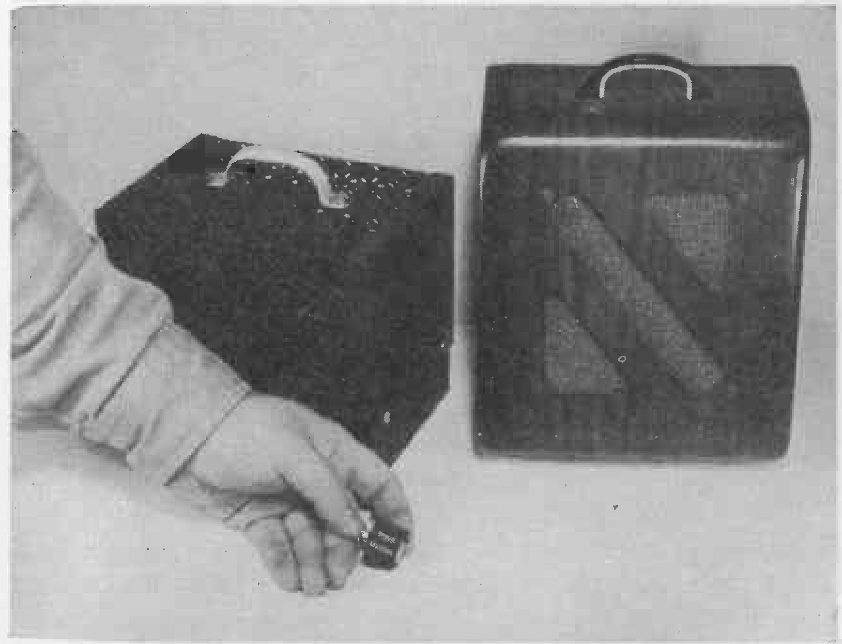


Fig. 7-20.—The transistorized P.A. System, less microphone. The loudspeaker is in the floor baffle to the right, the amplifier itself in the case to the left. The type of power transistor used is shown.

may be varied to control gain . . . and R_2 can then serve as a GAIN control. If desired, however, a conventional type of GAIN control (R_5) may be used, with R_2 left at a fixed value.

Power for the amplifier is supplied by a single battery, B_1, controlled by POWER switch Sw_1. A large by-pass capacitor, C_4, is connected across the power source to minimize current surges when the amplifier is turned "ON", and also to prevent possible interstage coupling through the power supply circuit.

PARTS LIST:

R_1 – 2K Carbon potentiometer (*Centralab* No. B-6).
R_2 – 25K Carbon potentiometer (*Centralab* No. B-37).
R_3 – 100 ohm, 1 W. Carbon resistor.
R_4 – 2.7K, 1 W. Carbon resistor.
R_5 – 100 ohm Carbon potentiometer.
C_1 – 0.01 Mfd., 200 volt paper capacitor.
C_2 – 50 Mfd., 25 volt electrolytic (*Barco* No. P25-50).
C_3 – (See *CONSTRUCTION HINTS*).
C_4 – 1000 Mfd., 25 volt electrolytic (*Sprague* No. TVL-1230).
C_5 – 25 Mfd., 25 volt electrolytic (*Barco* No. P25-25) see text.
T_1 – Line to Voice-Coil transformer.
T_2 – Transistor Driver transformer (*UTAH* No. 1744).
T_3 – High Power transistor output transformer (*UTAH* No. 1743).
Sw_1 – SPST Toggle switch.
B_1 – 12 Volt storage battery (or two *Burgess* No. F4P1 in series).
MIC. Single button carbon microphone.
TRANSISTORS – (3) *Sylvania* type 2N95 . . . *two should be matched pair.*
MISC. – Cabinet (*Bud* No. CA-1754); Control Knob; Terminal strips; Wire, solder, machine screws, nuts, Misc. Hdwe., etc.
ACCESSORY – PM Loudspeaker(s) in baffle or trumpet type loudspeaker.

CONSTRUCTION HINTS: Although the circuit appears relatively simple, the transistorized *P.A. System* is definitely *not* a project for the rank beginner. It should be undertaken only by someone who has had experience working with transistor circuits and who can trouble-shoot in cases of trouble . . . and can make minor modifications in the circuit to obtain optimum performance.

For minimum distortion, it is essential that the two transistors used in the Class B push-pull stage be a *matched pair* . . . the manufacturer can often supply such pairs on special order. All three power transistors are mounted directly to the metal chassis to insure maximum heat dissipation. Use machine screws which fit the tapped holes in the transistors, installing thin insulating and shoulder washers to prevent a direct electrical connection to the chassis. Remember that the collector electrode is connected directly to the transistor's outer case in these units.

Although the microphone is shown wired directly into the circuit in Fig. 7-19, you may wish to provide a jack and plug arrangement for this component. The input transformer (T_1) should also be chosen to match the microphone used . . . a nominal unit will be a "Line-to-Voice-Coil" transformer, designed to match a 500 or 600 ohm line to an 8 ohm voice coil . . . low impedance to base.

Degenerative feedback is provided by R_2 and C_3, connected between the secondary of the output transformer T_3 and the primary of the input transformer T_1. Two connections to T_3 are possible, depending on which of the secondary leads are grounded . . . one connection will provide the desired degenerative feedback, the other connection will provide regenerative (positive) feedback, which can result in oscillation. Therefore, if oscillation occurs, reverse T_3's secondary leads. Feedback capacitor C_3 may have a value of from 0.5 Mfd to as high as 50 Mfd., depending on the operating characteristic desired. As smaller capacities are used, degeneration becomes effective only at higher frequencies.

With the circuit shown, gain is varied by adjusting the amount of degenerative feedback, and R_2 becomes the GAIN (or VOLUME) control. With this arrangement, control range is limited and some builders may prefer to use a more conventional type of GAIN control, as shown in the inset drawing, retaining R_2 as a semi-fixed adjustment instead of as a control.

Although layout is not too critical, good wiring practice should be followed. The audio transformers should be mounted so that alternate cores are at right angles with respect to each other. The "input" and "output" circuits should be kept well separated. And, finally, the usual precautions relating to transistor wiring, as outlined earlier, should be observed.

ADJUSTMENT AND USE: With the wiring completed and checked for errors, a loudspeaker may be connected to the OUTPUT terminals and the power source attached. Assuming the feedback connections are correct, open the microphone's circuit and insert a current meter. Close the power switch and adjust the "Mike" current (by adjusting R_1) for the value recommended by the microphone's manufacturer. The meter may then be removed.

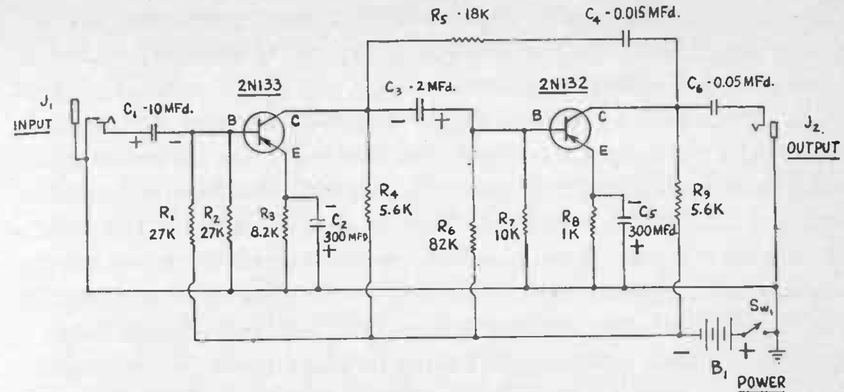
As a final adjustment, if you've used the ALTERNATE GAIN CONTROL arrangement, have someone speak into the microphone and adjust the FEEDBACK control (R_2) for the best compromise between over-all gain and quality of voice reproduction.

Depending on the microphone used, and thus the final adjustment of R_1, some change in the value of C_5 may be necessary. If most of R_1 is used in the circuit, a value of 25 Mfd. should be satisfactory for C_5. If R_1 is turned near minimum resistance, however, you may wish to use as much as 100 Mfd., or more, for the by-pass capacitor.

In extreme cases, some variation in the size of bias resistor R_4 may be needed. If you find that distortion is too high (or gain too low), regardless of the amount of degenerative feedback (as R_2 is adjusted) try experimenting with the value of R_4.

HI FI PREAMP

HI FI AMPLIFIER: In High Fidelity audio work, hum and noise must be kept to an absolute minimum, especially at low



Courtesy Raytheon

Fig. 7-21.—Circuit of a transistorized Hi Fi Preamplifier

Fig. 7-22.—Model of the Hi Fi Preamp assembled by the author.

signal levels. For such applications, some transistors are actually superior to vacuum tubes. A typical transistorized *Hi Fi* phongraph *Preamp* is shown in Figs. 7-21 and 7-22. This circuit, developed by *Raytheon,* is designed for use with reluctance type pick-up cartridges and has a RIAA response characteristic. Compared to a twin-triode vacuum tube preamplifier using a 6SC7 tube, this unit offers 44 db gain against the tube's 32 db, an output signal level of 1.6 volts against the tube's 0.4 volts, and a Signal/Noise ratio of 78 db against the tube's 72 db, when both are driven with a 10 millivolt signal from a reluctance type cartridge. The input impedance is low, matching the magnetic cartridge, while the output impedance is moderately high, matching the typical input impedance of an audio amplifier.

CIRCUIT DESCRIPTION: The *Hi Fi Preamp* is a two-stage resistance-coupled amplifier using special low-noise PNP transistors in the common-emitter configuration. Capacitors C_1, C_3, and C_6 serve as the input, interstage, and output coupling capacitors, respectively. Power is supplied by a single 6.5 volt battery, B_1, controlled by SPST switch Sw_1.

In operation, base bias current for the first stage is determined by voltage divider R_1-R_2 along with emitter resistor R_3, by-passed by capacitor C_2, providing a D.C. stabilized circuit. Resistor R_4 serves as the collector load for the first stage, with the amplified signal appearing across it applied to the input of the second stage through capacitor C_3. The second stage is also D.C. stabilized, with base bias determined by voltage divider R_6-R_7 in conjunction with emitter resistor R_8, by-passed by capacitor C_5. R_9 serves as the collector load for the second stage.

A degenerative (negative) feedback signal is coupled between the output of the second stage and the output of the first stage through R_5 and C_4. This establishes the response characteristic of the amplifier.

PARTS LIST:

R_1, R_2 — 27K, ½ W. Carbon resistors.
R_3 — 8.2K, ½ W. Carbon resistor.

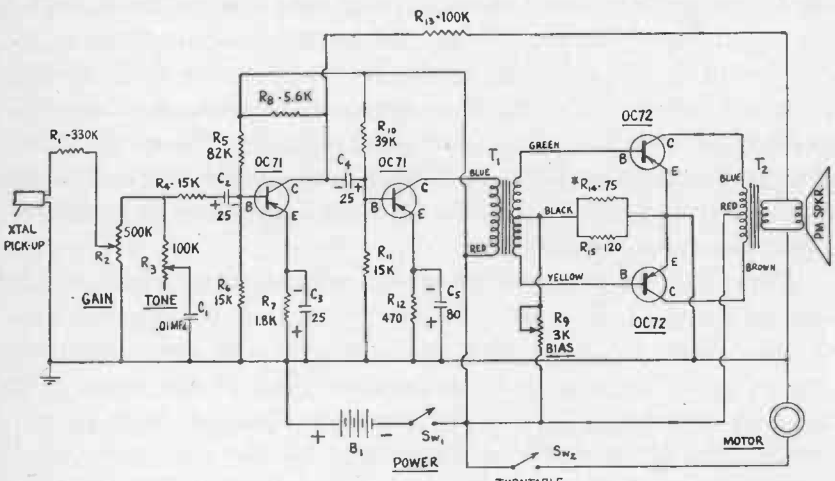
R_4, R_9 — 5.6K, ½ W. Carbon resistors.
R_5 — 18K, ½ W. Carbon resistor.
R_6 — 82K, ½ W. Carbon resistor.
R_7 — 10K, ½ W. Carbon resistor.
R_8 — 1K, ½ W. Carbon resistor.
C_1 — 10 Mfd., 6 volt electrolytic (*Sprague* No. TE-1087).
C_2, C_5 — 300 Mfd. electrolytic, 6 volts or higher (*Sprague* No. TVL-1434).
C_3 — 2 Mfd., 6 volt electrolytic (*Sprague* No. TE-1081).
C_4 — 0.015 Mfd., 200 volt paper capacitor.
C_6 — 0.05 Mfd., 200 volt paper capacitor.
J_1 — Closed circuit 'phone jack (see Text).
J_2 — Open circuit 'phone jack (see Text).
Sw_1 — SPST Toggle switch.
B_1 — 6.15 volt mercury battery (*Mallory* No. TR-135R).
TRANSISTORS—(1) *Raytheon* type 2N132; (1) *Raytheon* type 2N133.
MISC.—Small chassis; (2) transistor sockets; terminal strips, wire, solder, machine screws, nuts, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The *Hi Fi Preamp* may be assembled on a conventional metal chassis, like the author's model shown in Fig. 7-22, or laid out for assembly on an etched circuit board . . . for information on *Printed Circuit Techniques,* refer to Chapter 13. Good wiring practice should be observed, neither lay-out nor lead dress are critical. However, care should be taken to keep the *Input* and *Output* circuits well separated, and, of course, electrolytic capacitor and battery polarities must be observed.

There are a number of changes in construction details which the individual builder may be interested in making in his own model. First, he may wish to substitute the more popular *phono* jacks for the more expensive Headphone type jacks used by the author (J_1 and J_2). Secondly, he may wish to substitute tubular electrolytic capacitors for the 150 volt "can" type units used by the author and specified in the *PARTS LIST* (C_2 and C_5) . . . voltage rating is not critical, but should be over 6 volts, capacity may be from 250 to 400 Mfd. Finally, he may wish to substitute a zinc-carbon dry battery for the mercury battery specified . . . a suitable replacement is a *Burgess* type Z4.

With the wiring completed and double-checked for errors, a lead may be run from the *INPUT* jack to the phonograph's cartridge and from the *OUTPUT* jack to the amplifier with which the *Hi Fi Preamp* is to be used. Be sure to use shielded cables for these connections. After checking the *Preamp's* operation, it should be permanently mounted at some location near the record player . . . many builders will prefer to mount it directly in the record player's base, if room is available.

PHONOGRAPH AMPLIFIER: Because of their low power requirements, transistors are ideally suited to the design of battery-operated portable entertainment equipment . . . radio receivers, phonographs, Guitar amplifiers, etc. We'll discuss transistorized radios in a later Chapter; the schematic diagram for a high quality *Phonograph Amplifier* is given in Fig. 7-23. This circuit, developed by the *Amperex Electronic Corporation,* is fully temperature compensated, and is designed to give maximum performance with only four transistors. Although



Courtesy Amperex

Fig. 7-23.—Circuit of a high quality transistorized Phonograph Amplifier. This unit might also be used as a Guitar or similar "Music" amplifier, or even as a low power P.A. system.

designed primarily for use in a portable record player, the amplifier is also suitable for use as a musical instrument amplifier if a suitable pick-up is substituted for the phonograph cartridge. It might also serve as the *audio section of* a transistorized receiver or as a "loudspeaker booster" for a crystal set.

CIRCUIT DESCRIPTION: The *Phonograph Amplifier* shown in Fig. 7-23 uses four PNP junction transistors . . . two are resistance-coupled as "gain" stages and two are connected as a push-pull Class B power amplifier. Audio power output is approximately 200 milliwatts under normal operating conditions. D.C. operating power is supplied by a single six volt battery, controlled by switch Sw_1.

In operation, the audio signal is obtained from a high output crystal or ceramic phonograph cartridge and fed through matching resistor R_1 to GAIN control R_2. Although considerable signal is lost in R_1, this is offset by the high output of the cartridge and the gain of the amplifier. From the GAIN control, the signal is coupled through R_4 and C_2 to the input of the first amplifier stage. Potentiometer R_3 and capacitor C_1 form a simple "losser" type tone control . . . as R_3 is reduced in value, more and more high frequency signals are by-passed to circuit ground through C_1. Stabilized operation of the first stage is assured by the base bias current arrangement, consisting of voltage divider R_5-R_6 and emitter resistor R_7, by-passed by capacitor C_3.

The amplified audio signal appearing across collector load resistor R_8 is coupled through capacitor C_4 to the second stage. This stage, too, is D.C. stabilized by the base bias current circuit . . . in this case consisting of voltage divider R_{10}-R_{11} and emitter resistor R_{12}, by-passed by capacitor C_5.

Additional amplification takes place in the second stage. The collector load for this stage is the primary of transformer T_1, which serves both to match the output of the gain stage to the input of the power output stage and to provide the push-pull drive signal needed.

The power output stage consists of a *matched* pair of transistors operated as Class B push-pull amplifiers, with D.C.

stabilization assured by a bias network consisting of R_9, R_{15}, and *thermistor* R_{14}. The power stage is matched to the loudspeaker load by transformer T_2. Degenerative (negative) feedback to the input of the second stage is provided to insure distortionless operation . . . R_{13} serves to couple the negative feedback signal from the secondary of T_2 back to the earlier stage.

PARTS LIST:

R_1 – 330K, ½ W. Carbon resistor.
R_2 – 500K, Carbon potentiometer, Audio Taper (*Centralab* B61).
R_3 – 100K, Carbon potentiometer (*Centralab* B41).
R_4, R_6, R_{11} – 15K, ½ W. Carbon resistors.
R_5 – 82K, ½ W. Carbon resistor.
R_7 – 1.8K, ½ W. Carbon resistor.
R_8 – 5.6K, ½ W. Carbon resistor.
R_9 – 3K, Carbon potentiometer (*Centralab* B8).
R_{10} – 39K, ½ W. Carbon resistor.
R_{12} – 470 ohm, ½ W. Carbon resistor.
R_{13} – 100K, ½ W. Carbon resistor.
R_{14} – 75 ohm thermistor (@ 25°C), negative temperature coefficient.
R_{15} – 120 ohm, ½ W. Carbon resistor.
C_1 – 0.01 Mfd., disc ceramic capacitor (*Centralab* No. DD6-103).
C_2, C_3, C_4 – 25 Mfd., 25 volt electrolytics (*Barco* No. P25-25).
C_5 – 80 Mfd., 6 volt electrolytic (*Barco* No. P6-80).
T_1 – Transistor driver transformer (*Argonne* No. AR-109).
T_2 – Transistor output transformer (*Argonne* No. AR-139).
Sw_1, Sw_2 – SPST Toggle or Slide switches.
B_1 – 6 volt battery . . . *Burgess* No. Z4, *Mallory* No. TR-135R, or four *Burgess* No. 2 flashlight cells in series.
PICK-UP – Tone arm with crystal or ceramic cartridge with high output (0.5 volt or higher output).
MOTOR – 6 volt D.C. motor and turntable (see *CONSTRUCTION HINTS*).

PM SPKR – 6″ to 10″ PM Loudspeaker, 8 ohm voice coil.
TRANSISTORS – (2) *Amperex* type 0C71; Matched pair *Amperex* type 0C72.
MISC. – Small chassis or etched circuit board; (2) control knobs; Cabinet; Terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe.

CONSTRUCTION HINTS: The *Phonograph Amplifier* may be assembled either on a conventional chassis or on an etched circuit board, depending on the individual builder's preference (for details on *Printed Circuits,* see Chapter 13). It is necessary to solder the transistors in place, since these particular units are not well suited to mounting in standard transistor sockets. Observe the usual precautions against overheating when installing the transistors. And, of course, be sure to double-check electrolytic capacitor and battery polarities.

You may have some slight difficulty locating a phonograph turntable and motor combination requiring six volts D.C.—although several have been made for commercial applications, the author knows of no "across-the-counter" sources of such units. If you have a machine shop available, and are skilled in mechanical design, you might wish to design and build your own turntable-motor around one of the commonly available miniature battery-operated model motors. Or, as an alternative, you might wish to substitute a spring-driven motor and turntable for the electric unit.

Average current drain for the amplifier proper is only about 30 milliamperes at 6 volts, or about 0.18 watts (180 milliwatts). Therefore, the total current drain will depend more on the phonograph motor used than on the amplifier. For maximum battery life, the spring-driven motor-turntable suggested above is recommended. If the spring-driven motor is used, either the *Burgess* Z4 or the *Mallory* TR-135R batteries may be used. If an electric motor is employed, four large (*Burgess* No. 2) flashlight batteries should be used as a power source . . . the flashlight cells are connected in series and may be mounted in two *Austin-Craft* No. 145 Battery Boxes.

After the wiring is completed and double-checked for errors, check the connection of feedback resistor R_{13} to transformer T_2. With one connection oscillation may occur, due to positive feedback. If this happens, reverse the secondary leads (T_2). *BIAS* control R_9 should be set about mid-way in its range during this test. As a final step, R_9 is set so that the 0C72's draw about 1.5 milliamperes under "no signal" conditions. This should be between 1000 and 3000 ohms. Use a milliameter (connected between the *Red* transformer lead of T_2 and Sw_1) to check collector current during this adjustment.

CONCLUSION

The projects described in this Chapter represent only a small sampling of the possible applications of transistors to Audio circuits, but they should give the reader a definite "feeling" for the potentialities of these *mighty mites.* The author hopes the reader will feel encouraged to "carry on" from this point and work up new applications of his own.

In later Chapters additional audio applications will be covered . . . and circuits will be shown for control circuits, code practice oscillators, toys, and other transistorized devices operating at audio frequencies.

Chapter 8

R.F. APPLICATIONS

Early point-contact transistors could be used at both audio and radio frequencies; not so the early junction units, which were suitable for use at audio frequencies only. For a long time, the expressions "R.F. Transistor" and "Point-Contact Transistor" were almost interchangeable. However, with improvements in design, modifications in construction, and refinements in manufacturing methods, the upper frequency limit of junction transistors has been extended higher and higher until, today, units are available which will operate in the tens of megacycles. In addition, new techniques have produced transistors which are useable at hundreds, and even thousands, of megacycles. It is reasonably safe to predict that in the future the upper frequency limit of transistor operation will continue to be pushed ever higher.

The majority of the projects described in this Chapter are based on the use of transistors operating at AM Broadcast Band frequencies (550-1500 KC) and lower. In most instances, however, the circuits given will work at higher frequencies if proper changes are made in the tuned circuit parameters and if a suitable transistor type is employed. The "criteria" for choosing an R.F. transistor is its *alpha cutoff frequency* (or *beta cutoff frequency*). This is the frequency at which the gain of the transistor is 0.707 of its low frequency value. Most transistors may be used as oscillators at frequencies greater than their cutoff frequency, however. In critical circuits, additional factors to consider are the *base resistance,* which should be low, and the interelectrode capacities, which should also be low.

When working with tuned circuits, the experimenter should remember that the transistor, in most configurations, has a *low* input impedance, and only a moderately high output impedance. If connected directly across a parallel resonant circuit, it may cause considerable loading, resulting in poor selectivity and relatively low gain. For best results, it is a good idea to "tap down" to match the transistor's impedance.

RECEIVERS

SIMPLE RECEIVER: Radio receivers are by far the most popular projects with students, with home builders, and with gadgeteers. Even the more advanced worker will sometimes

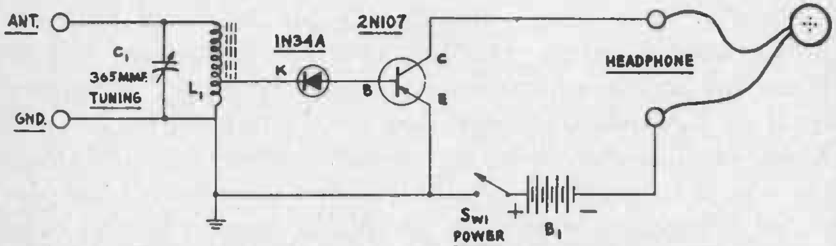


Fig. 8-1.—Simple transistorized Receiver using a diode detector.

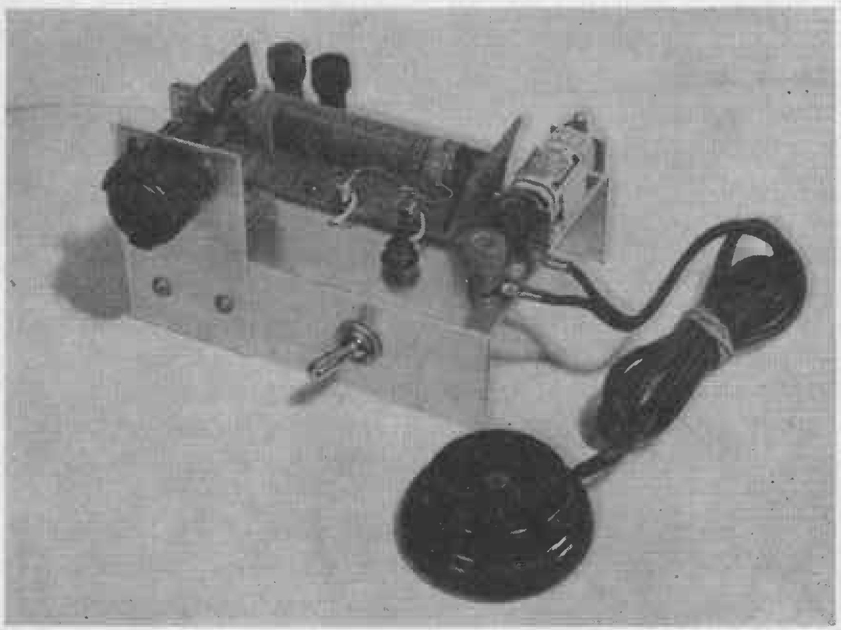


Fig. 8-2.—Overall view of the Simple Receiver.

get the urge to assemble a receiver . . . if for no other purpose than to demonstrate to his family and friends. The transistorized receiver shown in Figs. 8-1 and 8-2 is an excellent project for the beginner. It is non-critical, inexpensive, and easy to assemble. The average worker should have no difficulty duplicating the author's model in a single evening. When used with a good ground and a moderate sized antenna, it is satisfactory for reception of most local stations with adequate Headphone volume. Under favorable conditions, distant stations may be "pulled in".

CIRCUIT DESCRIPTION: As can be seen by reference to Fig. 8-1, the *Simple Receiver* consists of little more than a tuned circuit, a diode detector, and a transistor amplifier. A PNP transistor is used, connected in the grounded-emitter configuration. Power is supplied by a 15 volt "Hearing Aid" battery, B_1, controlled by a SPST Toggle switch, Sw_1.

In operation, radio signals picked up by the Antenna-Ground system are selected by a tuned circuit made up of variable tuning capacitor C_1 and high Q coil L_1. A tap is provided on the coil to match the high-impedance tuned circuit to the comparatively low input impedance of the detector-amplifier circuit. The selected R.F. signal supplied from the tap on L_1 is fed to the detector, consisting of a 1N34A diode and the base-emitter circuit of the 2N107 transistor. The audio portion of the detected signal is amplified by the transistor and used to drive the *Headphone,* which serves as the collector load impedance for the transistor.

PARTS LIST:

C_1 — 365 Mmf. variable capacitor.
L_1 — Transistor antenna coil (*Lafayette* No. MS-166).
Sw_1 — SPST Toggle switch.
B_1 — 15 Volt Hearing Aid battery (*Burgess* No. Y10).
Diode — 1N34A germanium diode.
Transistor — (1) *GE* type 2N107.
MISC. — (1) transistor socket; (4) binding posts; Battery box (*Austin-Craft* No. 136); Control knob; High impe-

dance magnetic Headphone; Wire, solder, machine screws, nuts, small chassis, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The author's model of the *Simple Receiver,* as shown in Fig. 8-2, was assembled on a small aluminum chassis. However, the circuit is well adapted to "breadboard" assembly, if the individual builder prefers this type of construction. Neither layout nor lead dress are critical. Of course, the transistor should not be installed until *after* the wiring is completed and double-checked for errors . . . and care should be taken to observe correct polarity when installing the battery.

Several changes may be made in the basic circuit and these may, in some cases, improve sensitivity and selectivity. First, if a long antenna is used, a 50 Mmf. capacitor should be connected in series with the antenna lead to minimize detuning effects. Secondly, good results are sometimes obtained if the *1N34A* is replaced by a 0.05 Mfd. capacitor . . . detection then takes place solely in the transistor's input circuit. Finally, somewhat higher gain may be obtained by biasing the transistor . . . to do this, connect a 0.1 Mfd. between the *anode* of the *1N34A* and the base of the 2N107. Connect a 470K, ½ W. Carbon resistor between the base of the 2N107 and the negative terminal of B_1. Finally, connect a 27K, ½ W. Carbon resistor between the *anode* of the diode and circuit ground.

REGENERATIVE RECEIVER: A receiver's sensitivity depends on the gain of the amplifier stages used. When more gain is

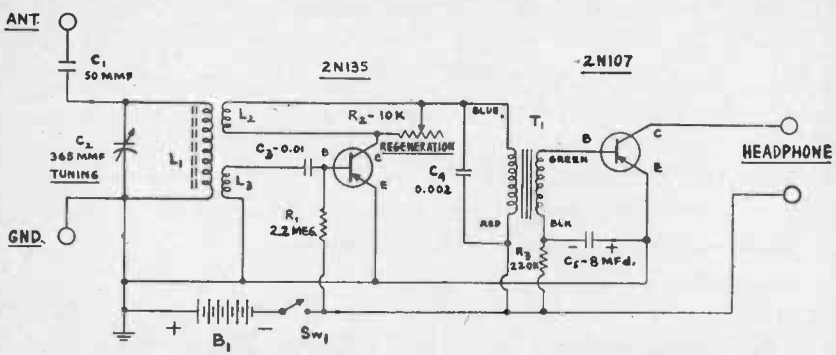


Fig. 8-3.—Transistorized Regenerative Receiver with audio stage added.

needed than can be obtained from a single transistor, two or more stages may be used. In the receiver shown in Figs. 8-3 and 8-4 good sensitivity has been obtained by combining a sensitive *regenerative* detector stage with a transformer-coupled audio amplifier. This radio, only slightly more complex than the *Simple Receiver* described earlier, nevertheless has con-

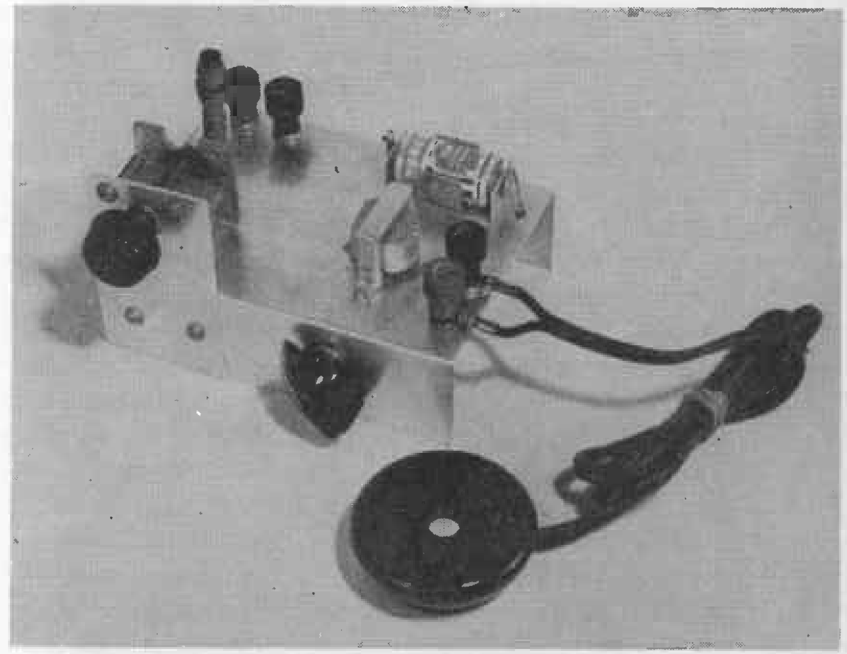


Fig. 8-4.—Author's model of the Regenerative Receiver. Transistors are mounted below chassis.

siderably more sensitivity . . . it will bring in local stations with increased volume and permit picking up more distant stations. It is a good project for the worker who wants a circuit with more "hop" but who is not yet ready to tackle a superheterodyne assembly job.

CIRCUIT DESCRIPTION: Basically, the *Regenerative Receiver* consists of an R.F. transistor connected as a regenerative detector, with its audio output signal transformer-coupled to a single stage audio amplifier which, in turn, drives the Headphone. Both transistors are PNP units, connected in the grounded-emitter configuration. Power is supplied by a single 15 volt "Hearing Aid" battery, controlled by SPST switch Sw_1.

In operation, R.F. signals picked up by the ground-antenna system are coupled through C_1 to tuned circuit L_1-C_2, where the desired signal is selected by adjusting C_2, a variable capacitor. Two secondary windings are provided on L_1 . . . L_2 is the "feedback" winding and L_3 is a "step-down" winding to match to the low input impedance of the transistor.

The R.F. signal obtained from L_3 is coupled through C_3 to the base-emitter circuit of the 2N135 R.F. transistor, where detection takes place. Both an R.F. and the detected audio signal, amplified, appear in the collector circuit of this stage. Feedback coil L_2 acts as practically a short circuit as far as A.F. is concerned, so the audio signal feeds directly to the primary of transformer T_1, but the R.F. portion of the signal is coupled by L_2 back to L_1 and L_3, increasing the signal level in these coils and thus boosting the available signal and the gain of the stage. REGENERATION control R_2, across L_2, serves to by-pass part of the R.F. signal and thus to determine the degree of feedback or regeneration. When this control is turned to minimum resistance, virtually no regeneration takes place and gain is at a minimum. When turned to maximum resistance, full regeneration occurs and the circuit may break into oscillation. Maximum gain is obtained just below the oscillation point. A small base bias current for the 2N135 is supplied through R_1.

Any R.F. signal passing L_2 is by-passed around T_1's primary by capacitor C_4. This transformer serves to match the high output impedance of the 2N135 to the low input impedance of the 2N107 audio amplifier, insuring the most efficient transfer of energy and thus maximum gain. The audio signal appearing across the secondary winding is fed to the input of the 2N107, where additional amplification occurs, with the final output signal driving the *Headphone*. Base bias current for the amplifier stage is supplied by R_3, by-passed by C_5.

PARTS LIST:

R_1 – 2.2 Megohm, ½ W. Carbon resistor.
R_2 – 10K Carbon potentiometer (*Centralab* B15, with switch).
R_3 – 220K, ½ W. Carbon resistor.
C_1 – 50 Mmf. tubular ceramic capacitor (*Centralab* No. D6-500).
C_2 – 365 Mmf. variable tuning capacitor.
C_3 – 0.01 Mfd., disc ceramic capacitor (*Centralab* No. MD-103).
C_4 – 0.002 Mfd., 200 volt, tubular paper capacitor.
C_5 – 8 Mfd., 25 volt electrolytic (*Barco* No. P25-8).
L_1 – Tuning coil (*Superex* Vari-Loopstick).
L_2 – Feedback winding, 12 turns No. 30 enameled wire, close-wound on L_1.
L_3 – Secondary coil, 8 turns No. 30 wire, close-wound on L_1.
T_1 – Transistor interstage transformer (*Argonne* No. AR-129).
Sw_1 – SPST switch, on R_2.
B_1 – 15 volt Hearing Aid battery (*Burgess* No. Y10).
Transistors – (1) *GE* type 2N135; (1) *GE* type 2N107.
MISC. – Small metal chassis; (2) Control knobs; (4) binding posts; battery box (*Austin-Craft* No. 136); High impedance magnetic Headphone; Machine screws, nuts, wire, solder, terminal strips, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The *Regenerative Receiver* is suited to assembly in any of several ways . . . depending on the individual builder's choice . . . it may be assembled in a small plastic box as a self-contained receiver, may be wired in "breadboard" fashion, or, like the author's model shown in Fig. 8-4, may be assembled on a small metal chassis. Neither layout nor lead dress are especially critical, but good wiring practice should be followed. In the author's model, the transistors were wired permanently in place . . . if you follow this procedure, be sure to observe the usual precautions against accidental overheating; otherwise, provide sockets for these components. Do not install the battery until all wiring is completed and double-checked for accuracy . . . and make sure both battery and electrolytic capacitor (C_2) polarities are observed.

The connections to feedback winding L_2 are critical . . . with one connection, the feedback signal will tend to cancel the original signal, resulting in a *loss* of gain. If trouble is encountered, try reversing the lead connections to this coil.

Although the circuit is non-critical, maximum performance can be obtained by adjusting the bias currents to give optimum performance with the individual transistors used. To change the bias current values, adjust the sizes of R_1 (for the 2N135) and R_3 (for the 2N107).

To use the *Regenerative Receiver,* connect a good ground to the GND. terminal and an antenna to the ANT. terminal. Connect a high impedance magnetic headset to the HEADPHONE terminals and turn up the REGENERATION control, closing switch Sw_1. Adjust R_2 near its maximum resistance value . . . if an audio tone or "putt-putt" sound is heard in the Headphone, turn back R_2 until this sound just disappears. Finally, adjust TUNING control C_2 to pick up the desired station . . . *tune slowly,* as the setting may be critical. Readjust R_2, "if necessary", as C_2 is adjusted and as stations are received.

POCKET RECEIVER: Because of their small size, transistors are ideally suited to the design of miniaturized equipment,

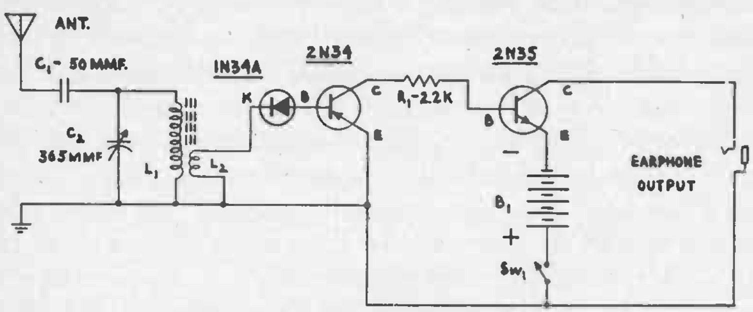


Fig. 8-5.—Schematic diagram of a Pocket Receiver using a two-stage complementary amplifier.

but no attempt has been made to miniaturize the design of the radio receivers described thus far in this Chapter. However, a skilled worker, using standard, commercially available components can assemble a moderate gain transistorized receiver in a box *smaller* than a package of cigarettes! Such a *Pocket Receiver* is shown in Fig. 8-6, while the schematic circuit diagram

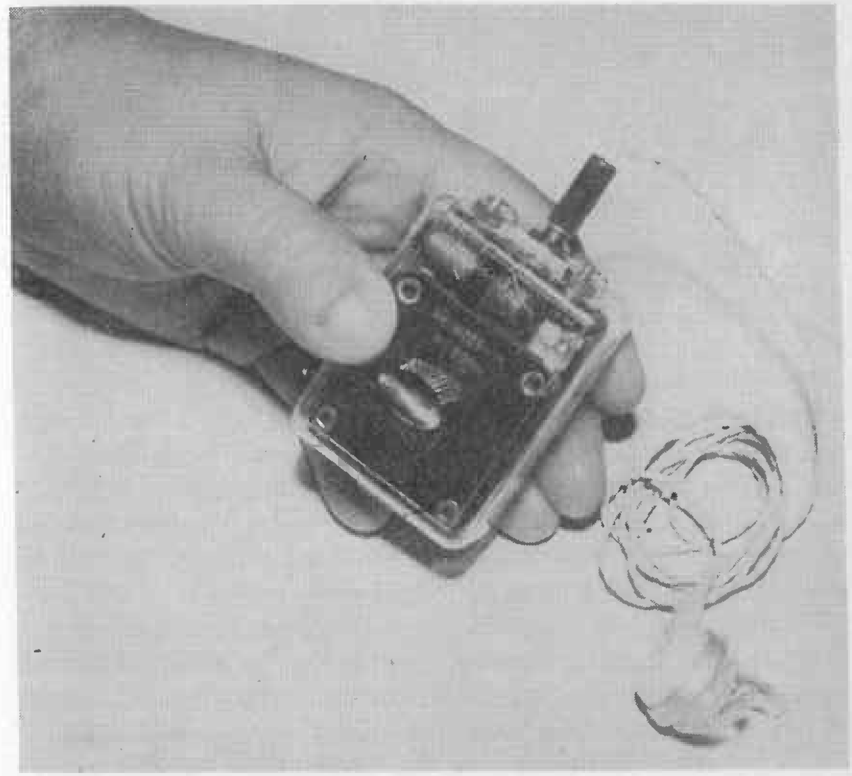


Fig. 8-6.—Exterior view of the Pocket Receiver . . . assembled in a small plastic box!

is given in Fig. 8-5 and an interior view of the model in Fig. 8-7. This tiny receiver operates from its own self-contained battery and drives a small magnetic earset. While an external antenna and ground are needed for best reception, strong nearby stations can sometimes be received directly.

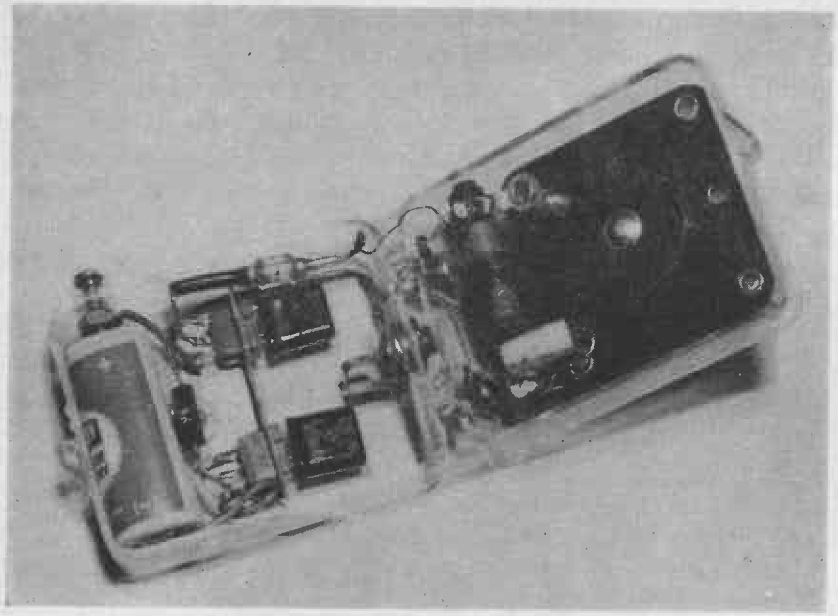


Fig. 8-7.—Interior view of the Pocket Receiver.

CIRCUIT DESCRIPTION: Referring to Fig. 8-5, we see that the *Pocket Receiver* consists of a tuned circuit, a diode detector, and a two-stage complementary amplifier, using both PNP and NPN transistors. The common-emitter configuration is used in the amplifier stages. Power is supplied by a small 15 volt Hearing Aid battery, controlled by a SPST switch Sw_1. The output drives a high impedance magnetic earphone.

In operation, radio signals picked up by the antenna-ground system are coupled through C_1 to tuned circuit L_1-C_2 where the desired station is selected by adjusting variable capacitor C_2. Secondary winding L_2, on L_1, couples R.F. energy to the 1N34A diode detector and serves to match the low input impedance of the detector-amplifier stage, minimizing loading of the L_1-C_2 tuned circuit, and thus insuring good gain and reasonable selectivity.

The detected audio signal, in the base-emitter circuit of the first stage, a 2N34 PNP transistor, is amplified by this stage and direct-coupled through R_1 to the base-emitter circuit of

the second stage, a 2N35 NPN transistor. R_1 serves simply to limit base current flow in the second stage and thus to protect the transistors against overloads on strong stations . . . it is not otherwise essential to circuit operation. Further amplification occurs in the second stage, with the output audio signal used to drive a high impedance magnetic earphone, connected to OUTPUT jack J_1.

PARTS LIST:

R_1 – 2.2K, ½ W. Carbon resistor.
C_1 – 50 Mmf. tubular ceramic capacitor (*Centralab* No. D6-500).
C_2 – Miniature tuning capacitor, 365 Mmf. (*Lafayette* No. MS-215).
L_1 – R.F. Antenna coil (*Superex* Ferri-Loopstick cut down).
L_2 – Approx. 15-20 turns No. 30 enameled wire on L_1.
B_1 – 15 Volt Hearing Aid battery (*Eveready* No. 504ER).
Sw_1 – SPST switch (see *CONSTRUCTION HINTS*).
Diode – 1N34A germanium diode.
Transistors – (1) *Sylvania* type 2N34; (1) *Sylvania* type 2N35.
MISC. – Open circuit jack, J_1 (*Telex* No. 9240); High impedance magnetic earphone (*Argonne* No. AR50); Miniature 'phone plug (*Telex* No. 9231); (2) transistor sockets; control knob; small plastic case; Machine screws; nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: While neither circuit layout nor lead dress are critical, some care must be exercised in assembling and wiring the *Pocket Receiver* if the small size of the author's model is to be retained. Make up a "mock" layout or two before drilling holes in the plastic case or attempting to mount components.

The layout and construction used by the author is clearly evident in the exterior and interior photos of his model, given in Figs. 8-6 and 8-7, respectively. The 15 volt battery is held firmly against the plastic case by a small "L" bracket; the two transistor sockets are mounted on another small bracket, cut from a scrap piece of thin aluminum. Both the battery and socket brackets are held in place by a single machine screw and nut. Simple "Lap" joints were used for soldering all connections.

The SPST switch, Sw_1, consists of a small machine screw, a small coil spring, and a hex nut. A lead is soldered directly to

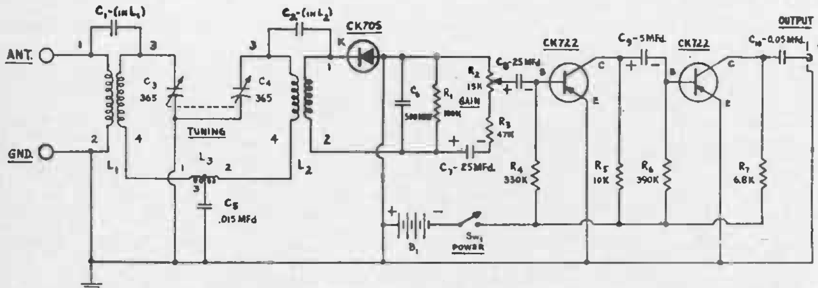


Fig. 8-8.—Diagram of a Hi Fi AM Tuner featuring a transistorized preamplifier.

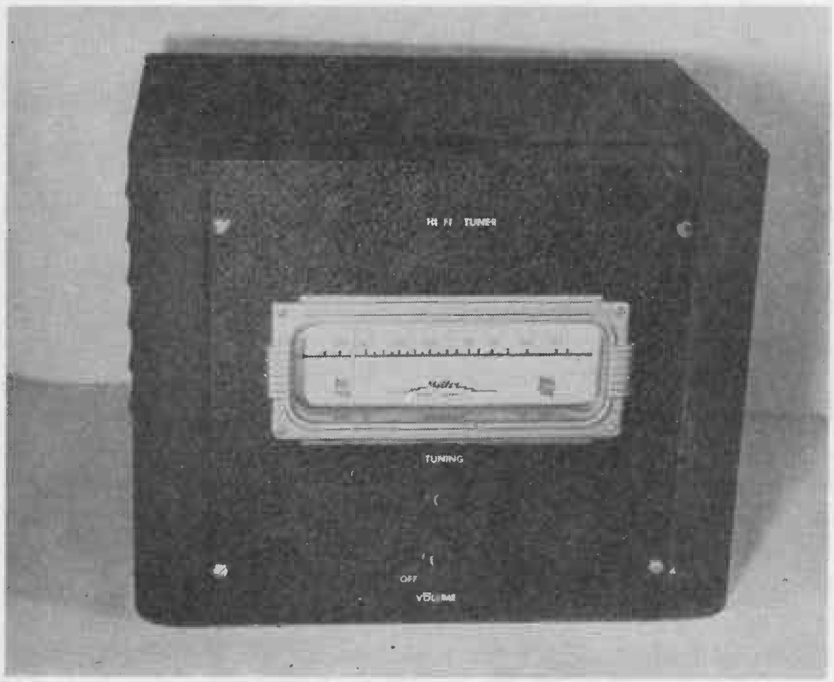


Fig. 8-9.—Exterior view of the Hi Fi Tuner in its cabinet.

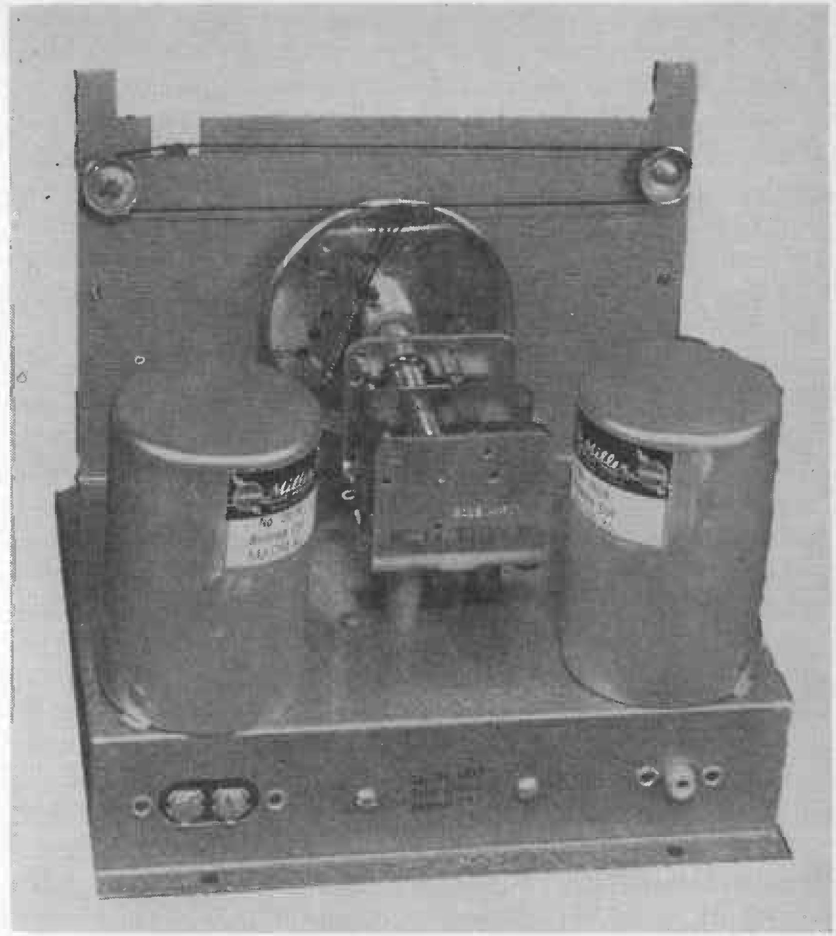


Fig. 8-10.—Rear view of the Hi Fi Tuner's chassis.

the nut. In operation, depressing and releasing the screw gives a "push-button" action, while a permanent closure can be made by turning the screw in until it bears against the positive terminal of the battery. Switch construction is clearly shown in Fig. 8-7.

HI FI AM TUNER: High Fidelity enthusiasts or *audiophiles* are naturally interested in how transistors may be applied to their pet hobby. In Chapter 7, we discussed the circuit of a

Hi Fi Phonograph Preamplifier (Figs. 7-21 and 7-22). A transistorized *Hi Fi Tuner* covering the AM Broadcast Band is shown in Figs. 8-8, 8-9 and 8-10. When used with a high quality audio amplifier and loudspeaker, and conected to a good Antenna-Ground system, this tuner will give results that should please even a discriminating "Golden Ear". In addition to its ability to deliver a high quality audio signal, the *Hi Fi AM Tuner* is free of the hum and noise often associated with A.C. line operated equipment, for, being transistorized and battery-powered, it is completely independent of power line connections.

CIRCUIT DESCRIPTION: The *Hi Fi Tuner* consists of a broad band, but selective, R.F. tuned circuit, a diode detector, and a two-stage resistance-coupled transistor amplifier, featuring PNP transistors connected in the grounded-emitter configuration. Power is supplied by a single 6 volt battery, controlled by SPST switch Sw_1, mounted on the GAIN (VOLUME) control, R_2. Due to the small power requirements of the transistors, battery life should be quite long under normal operating conditions.

Refer to Fig. 8-8. In operation, R.F. signals picked up by the Antenna-Ground system are fed directly into the primary of transformer L_1. R.F. transformers L_1 and L_2, coil L_3, tuning capacitors C_3 and C_4, and coupling capacitors C_1, C_2 and C_3 form a double-tuned bandpass tuning arrangement which serves to select the desired station. Although this circuit has a bandwidth of 25 KC at the 2 db points, it is able to select adjacent stations without difficulty, because of the high Q of the coils specified.

The selected radio signal is detected by the CK705 diode, with the audio signal appearing across diode load resistor R_1. Capacitor C_6 serves to by-pass any R.F. remaining after detection. From here the audio signal is coupled through capacitor C_7 to the GAIN (VOLUME) control, consisting of fixed resistor R_3 and potentiometer R_2.

A portion of the available audio signal, depending on the setting of R_2, is coupled through C_8 to the base-emitter circuit

of the first amplifier stage. Base bias current for the first stage is supplied through resistor R_4. Amplification takes place in the first stage, with the audio signal appearing across collector load resistor R_5 coupled through capacitor C_9 to the input of the second stage. Additional amplification takes place in the second stage, with the output signal, appearing across collector load resistor R_7, coupled through C_{10} to OUTPUT jack J_1. Bias current for the second stage is supplied by base resistor R_6.

PARTS LIST:

(1) MILLER No. 585 Tuner Kit, including the following components:

L_1, L_2 – T.R.F. Ant. coils (*Miller* No. 242-A).
L_3 – Mutual coupling coil (*Miller* No. EL-55).
C_1, C_2 – Coupling capacitors (included in coils L_1 and L_2).
C_3, C_4 – 2-Gang tuning capacitor, 365 Mmf. each.
J_1 – Phono type jack (OUTPUT).

Plus hardware items . . . including the following:

(1) 2-Terminal screw-type ANT.-GND. terminal strip.
(1) Chassis, 7"x5"x1½" (*Miller* No. 855-1).
(1) Slide rule dial assembly (*Miller* No. 152-H).
Assorted mounting hardware, screws, nuts, etc.

In addition to the *MILLER* kit, the following items are needed:

R_1 – 100K, ½ W. Carbon resistor.
R_2 – 15K Carbon Potentiometer, Audio Taper (*Centralab* B20), with switch.
R_3 – 47K, ½ W. Carbon resistor.
R_4 – 330K, ½ W. Carbon resistor.
R_5 – 10K, ½ W. Carbon resistor.
R_6 – 390K, ½ W. Carbon resistor.
R_7 – 6.8K, ½ W. Carbon resistor.
C_5 – 0.015 Mfd., 200 volt tubular paper capacitor.
C_6 – 500 Mmf., tubular ceramic capacitor (*Centralab* No. MD-501).
C_7, C_8 – 25 Mfd., 6 volt electrolytics (*Barco* No. P6-25).
C_9 – 5 Mfd., 8 volt electrolytic (*Barco* No. PS8-5).

C_{10} — 0.05 Mfd., 200 volt, tubular paper capacitor.
Sw_1 — SPST switch, on R_2.
B_1 — 6 volt battery (*Burgess* No. Z4).
Diode — *Raytheon* type CK705.
Transistors — (2) *Raytheon* type CK722.
MISC. — (2) Control knobs; Cabinet (*Bud* No. C-1789); Battery box; Ground lugs, machine screws, nuts, wire, solder, terminal strips, other Misc. hdwe.

CONSTRUCTION HINTS: With a moderate amount of care in assembly, even a builder of limited experience can assemble a *Hi Fi Tuner* which equals the author's model (shown in Figs. 8-9 and 8-10) and thus rivals professional "factory-built" equipment in appearance. Neither parts layout nor lead dress are especially critical but, of course, good wiring practice should be followed.

Machine work is minimized by the pre-drilled and punched chassis furnished as part of the *MILLER* kit specified in the *PARTS LIST*, although not eliminated altogether. The basic *MILLER* kit is made up as a crystal receiver and thus there is no provision, on the chassis, for the transistorized audio amplifier. A few additional holes will be needed for this circuit . . . or, if you prefer, you can employ the technique used by the author. He assembled the entire transistor amplifier on a small "sub-chassis" and mounted it, in turn, under the main tuner chassis.

The transistors may be wired permanently in place or installed in the common "in-line" subminiature sockets. If soldered in place, the usual precautions to avoid overheating should be observed. In any case, the battery should not be installed until after all wiring is completed and double-checked for possible errors. Be sure to observe battery and electrolytic capacitor polarities.

With the wiring completed and checked, install the battery, the transistors, and connect an ANTENNA and GROUND to the proper terminals. Use a shielded cable to connect the *Hi Fi Tuner's* output to your audio system. Next, with the tuning capacitor plates fully meshed, adjust the dial pointer

to the extreme low frequency end of the dial. Now, tune to the high frequency end of the dial, picking up a station somewhere from 1200 to 1600 KC. Check the dial reading where the station is tuned to see if it corresponds with station's known operating frequency.

If dial reading does not correspond with station frequency, readjust the small trimmer capacitors on the sides of C_3 and C_4 . . . *both at the same time* . . . using an insulated alignment tool. Recheck the dial reading, and keep adjusting until dial reading corresponds with station frequency. The *Hi Fi Tuner* is then aligned and ready for use . . . you can install it in the cabinet specified in the *PARTS LIST* or one of your own choosing.

SUPERHETERODYNE RECEIVER: If a High Fidelity system is considered the "Queen" of audio amplifiers, then the "superhet" receiver must certainly be considered the "King" of radio receivers, for this general type of circuit offers the maximum in gain and selectivity combined with ease of operation and reliability. The circuit for a simplified four-transistor superhet is given in Fig. 8-11. This particular receiver covers the AM Broadcast Band (500-1500 KC) and uses commercially available components. It has been designed primarily for ease in

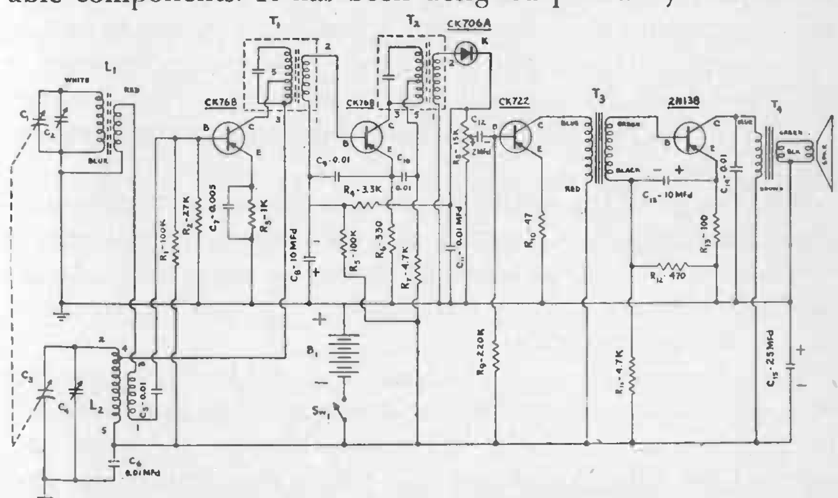


Fig. 8-11.—Schematic diagram of a four-transistor Superheterodyne Receiver.

home construction and, while adequate for all normal use, has neither the audio power ouput nor the sensitivity of commercially built 6, 7 and 8 transistor receivers. Although it is an excellent "first superhet" project for the student or home experimenter . . . it is not a suitable project for a beginner in electronics. The beginner will find it advisable to tackle two or three of the simpler projects described elsewhere in this Chapter before starting on a superhet receiver.

CIRCUIT DESCRIPTION: Referring to Fig. 8-11, the *Superhet Receiver* consists of five stages; four of the stages use PNP transistors in the common-emitter configuration, and the detector stage uses a germanium diode. Power is supplied by a single 9 volt battery, B_1, controlled by SPST switch Sw_1. The set has a built-in "loop" antenna and, therefore, requires no external antenna or ground for receiving local stations. It features loudspeaker output.

In operation, signals are picked and selected by "loop" antenna coil L_1, which has a low impedance secondary winding to match to the low input impedance of the transistor stage. The selected R.F. signal is fed to the first CK768 transistor, wired as a *converter* stage, thus serving both as *local oscillator* and *mixer*. The oscillator coil, L_2, like the antenna coil L_1, is also equipped with a step-down secondary winding to match the transistor's low input impedance. The *converter* stage is D.C. stabilized by providing its bias current from voltage divider R_1-R_2, working in conjunction with emitter resistor R_3, by-passed by C_7.

The design of the oscillator and antenna tuned circuits, and tuning capacitor C_1-C_3, is such that the difference frequency is 455 KC, and this serves as the I.F. value for the receiver. Intermediate frequency (I.F.) transformers T_1 and T_2 are fixed tuned to this frequency.

Both the picked up R.F. signal and the locally generated R.F. signal are combined in the converter stage and their difference frequency of 455 KC is amplified by the stage and selected by I.F. transformer T_1, which also rejects the two original frequencies as well as the sum frequency. (*When two R.F. signals are combined in a mixer stage, the output normally contains both original frequencies, plus the sum and difference frequencies . . . in this case, only the difference frequency is of interest.*)

Transformer T_1 serves a dual purpose . . . not only does it select the desired I.F. signal, but it also acts to match the high impedance of its tuned circuit to the low input impedance of the I.F. amplifier stage, a second CK768 R.F. transistor. The I.F. signal is amplified in the second stage, with its output appearing across the second I.F. transformer T_2. The gain of the I.F. stage is varied in accordance with relative signal strength to provide *Automatic Volume Control* (AVC) action. This is accomplished by establishing the bias of the stage with the D.C. component of the detected I.F. signal, obtained from the diode detector stage and fed back through a filter and decoupling network consisting of C_8, C_9, C_{11}, R_4 and R_5. Stable operation is insured by emitter resistor R_6.

The amplified I.F. signal obtained from the secondary winding of the second I.F. transformer T_2 is detected by the CK706A diode, with both an audio and a D.C. component appearing across diode load resistor R_8. The diode load also serves as the VOLUME or GAIN control. The D.C. portion of the detected signal is coupled back to the base of the I.F. amplifier stage to provide AVC control. This control voltage has a *positive* polarity and thus tends to cancel the *negative* bias supplied through R_5, reducing the gain of the I.F. stage when strong signals are received. The stronger the signal received, the larger the D.C. voltage developed, and thus the greater the control. The net result is to maintain the I.F. stage's gain more or less constant.

The audio portion of the detected signal is coupled through C_{12} to the first audio stage, a type CK722 transistor. Bias for this stage is supplied through R_9, with stabilization obtained by means of emitter resistor R_{10}. The amplified audio signal is then coupled through interstage matching transformer T_3 to the power output stage, a type 2N138 medium power transistor.

Additional gain is obtained from the output stage, with the final audio signal coupled to the PM loudspeaker through output transformer T_4. The power output stage is stabilized by means of emitter resistor R_{13} and the voltage divider network used to supply base bias current . . . R_{11} and R_{12}, with R_{12} by-passed by C_{13}. Capacitor C_{14}, from the 2N138's collector to ground, serves to by-pass higher frequency signals and thus to reduce the effect of harmonic distortion.

PARTS LIST:

R_1, R_5 – 100K, ½ W. Carbon resistors.
R_2 – 27K, ½ W. Carbon resistor.
R_3 – 1K, ½ W. Carbon resistor.
R_4 – 3.3K, ½ W. Carbon resistor.
R_6 – 330 ohm, ½ W. Carbon resistor.
R_7, R_{11} – 4.7K, ½ W. Carbon resistor.
R_8 – 15K Carbon potentiometer, Audio Taper (*Centralab* B20).
R_9 – 220K, ½ W. Carbon resistor.
R_{10} – 47 ohm, ½ W. Carbon resistor.
R_{12} – 470 ohm, ½ W. Carbon resistor.
R_{13} – 100 ohm, ½ W. Carbon resistor.
C_1, C_3 Subminiature dual superhet tuning capacitor (*Argonne* No. AR-93).
C_2, C_4 Trimmer capacitors . . . part of C_1-C_3.
C_5, C_6, C_9, C_{10}, C_{11}, C_{14} – 0.01 Mfd. Disc ceramics (*Centralab* MD-103).
C_7 – 0.005 Mfd. Disc ceramic (*Centralab* MD-502).
C_8, C_{13} – 10 Mfd., 12 volt electrolytic (*Sprague* No. TE-1128).
C_{12} – 2 Mfd., 6 volt electrolytic (*Sprague* No. TE-1081).
C_{15} – 25 Mfd., 10 volt electrolytic (*Sprague* No. TE-1118).
L_1 – "Loop" Antenna coil (*Argonne* No. AR-97).
L_2 – Superhet Oscillator coil (*Argonne* No. AR-98).
T_1, T_2 – I.F. Transformers, 455 KC (*Argonne* No. AR-60).
T_3 – Transistor interstage transformer, 20K to 1K (*Argonne* No. AR-104).

T_4 – Output transformer 400 ohms to 11 ohms (*Argonne* No. AR-120).
SPKR – Miniature PM Loudspeaker, 10 ohm V.C. (*Argonne* No. AR-95).
Sw_1 – SPST Switch, on R_8.
B_1 – 9 volt battery (*RCA* No. VS300).
Diode – (1) *Raytheon* type CK706A.
Transistors – (2) *Raytheon* type CK768; (1) *Raytheon* type CK722; (1) *Raytheon* type 2N138.
MISC. – (4) transistor sockets; battery clips; (2) control knobs; plastic case or cabinet; terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: While parts layout and wiring lead dress are not especially critical, the builder should exercise care in laying out the receiver if trouble is to be avoided in mechanical assembly and electrical operation, The accepted "rules" of good wiring practice should be observed . . . that is signal leads should be kept reasonably short and direct, "input" and "output" circuits of each stage should be kept well separated, and exposed leads should be protected with insulating spaghetti tubing.

The 4-transistor *Superhet Receiver* is suited to either conventional metal chassis construction or to assembly on an etched circuit board, depending on the individual builder's preference. For information on *Printed Circuit Techniques* refer to Chapter 13. However, regardless of whether conventional construction or etched circuitry is employed, the final receiver should be housed in a plastic or wooden case (cabinet), for a metal case will tend to shield the "loop" antenna coil L_1.

Although the transistors specified in the *PARTS LIST* are equipped with wire leads suitable for permanent soldering into the circuit, the author recommends the use of sockets, with the transistor leads cut off to an appropriate length. The advantages are two-fold . . . there is less chance of heat damage to the transistors since they are installed *after* wiring is completed and checked, and, secondly, the builder can experiment with different transistors. Although the circuit is non-critical and should not require "selected" transistors for operation, it is an accepted fact that *maximum* performance of a transistor circuit may be obtained with selected units.

Once the wiring is completed, re-check the circuit for possible wiring errors or accidental shorts *before* installing the transistors or the battery. Pay especial attention to the polarity of electrolytic capacitor connections.

The final step is alignment. With the transistors and battery installed, turn the unit "ON" and turn the VOLUME control (R_8) to its full volume position. Turn the TUNING control (C_1-C_3) until the plates are fully meshed. *Loosely* couple a standard *R.F. Signal Generator* to the antenna coil L_1 . . . often, you can do this simply by placing the "hot" Signal Generator lead near this coil. Set the instrument to supply a modulated R.F. signal at 455 KC. Next, using the proper type of insulated alignment tool, carefully adjust I.F. transformers T_1 and T_2 for maximum signal output . . . use the minimum signal from the Signal Generator which will allow you to hear a tone from the loudspeaker of the receiver. Reduce the Signal Generator's output during alignment if necessary to keep signal level to a minimum. This is necessary to avoid AVC action.

With the I.F. transformers peaked, adjust the TUNING control for minimum capacity and set the Signal Generator at 1575 KC. Adjust trimmer capacitors C_2 and C_4 (on the back of the tuning capacitor) for peak output. Again, use the minimum signal level which permits a useable signal from the loudspeaker. If you've used a calibrated dial, C_4 may be set to make the dial reading correspond with actual frequency, while C_2 may be used to "peak" the output at about 1500 KC.

If trouble is encountered with the completed model, it may indicate either an error in wiring or one or more defective parts. Oscillation may indicate poor layout in the R.F. and I.F. circuit sections. Distortion may indicate either defective parts or the need for readjustment of bias currents in the audio section . . . resistors R_9 and R_{11} may be changed to adjust bias in their respective changes. Finally, if the receiver responds to the I.F. signal, but appears "dead" at R.F. during alignment,

it may indicate that the local oscillator is not functioning . . . again, check parts and lead connections also try interchanging the two CK768 transistors.

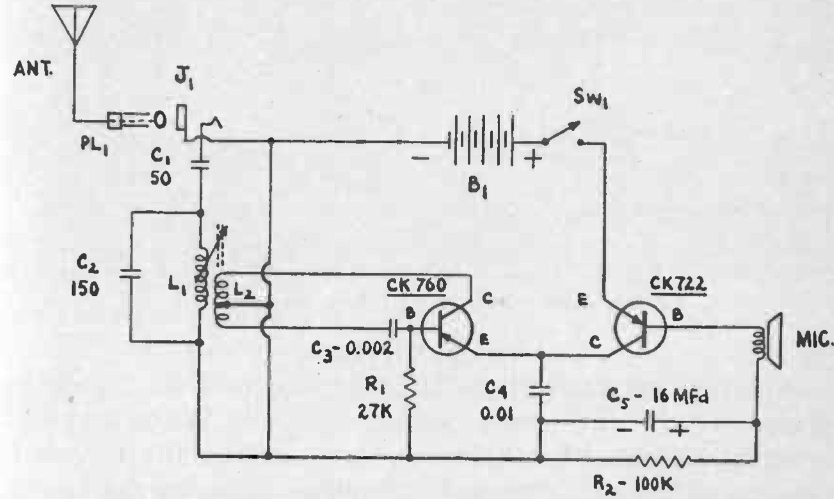


Fig. 8-12.—A miniature Wireless Microphone or "Home Broadcaster".

Fig. 8-13.—Exterior of the "Home Broadcaster"—smaller than a package of cigarettes!!

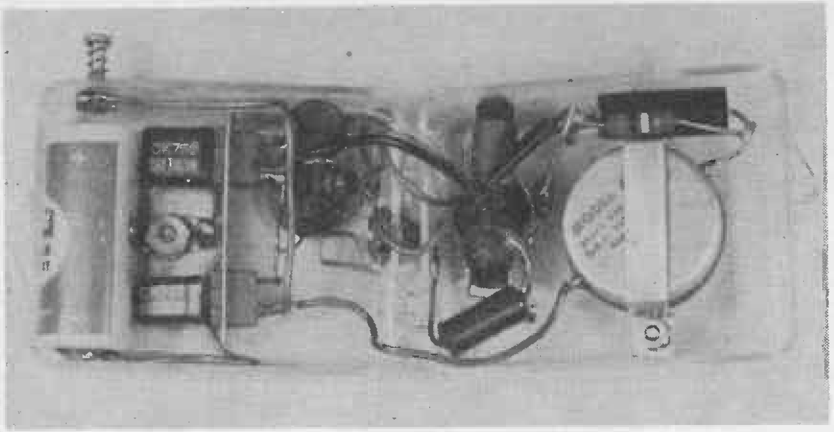


Fig. 8-14.—Interior view of the "Home Broadcaster".

TRANSMITTERS

WIRELESS MICROPHONE: Although smaller than a package of cigarettes, the instrument shown in Figs. 8-12, 8-13 and 8-14 is actually a miniature *Home Broadcaster* . . . a type of self-contained "Broadcast Station" which an operator can use to broadcast his voice through any standard AM Broadcast Receiver within its range. It uses standard components and may be assembled quite easily by a worker of moderate skill. Although its range will depend on the receiver with which it is used, the unit is designed to have a maximum range of 8 to 15 feet to insure operation well within the legal limits established by the FCC. It makes an excellent toy for children, and may also be used for "party fun" at adult get-togethers.

CIRCUIT DESCRIPTION: The *Wireless Microphone* uses two PNP transistors in a rather unique *series* circuit arrangement, although the basic circuit used with both transistors is essentially the common-emitter configuration. A type CK760 R.F. transistor is used as an R.F. oscillator; a type CK722 unit as an audio amplifier. Power is supplied by a single 15 volt Hearing Aid battery, controlled by a simple SPST push-button switch, Sw_1.

Refer to Fig. 8-12. In operation, the CK760 oscillates at a radio frequency determined by tuned circuit C_2-L_1. The feedback necessary to start and sustain oscillation is determined by secondary coil L_2, coupled to L_1. Coil L_2 serves a triple function . . . it couples to the tuned circuit, it matches the high impedance of the tuned circuit to the input impedances of the transistor, and, by virtue of its tap, it supplies the necessary feedback between collector and base electrodes to insure oscillation. Base bias current for the R.F. oscillator is supplied through resistor R_1. Capacitor C_3 serves simply as a D.C. blocking capacitor to avoid applying the full supply voltage to the base.

The R.F. oscillator is modulated by varying its emitter current in accordance with an audio signal. This is accomplished by the CK722 transistor, which is connected *in series with* the CK760's emitter electrode and the power supply, B_1. The CK722 thus serves the dual purpose of modulating the R.F. oscillator and acting as an audio amplifier for the signal obtained from the low impedance magnetic microphone (MIC.). Base bias current for the CK722 is supplied by R_2, by-passed by C_5. Capacitor C_4, connected between the CK760's emitter and circuit "ground", by-passes R.F. signals at this point, insuring the operation of the CK760 as a common-emitter oscillator, but does not affect the audio signal delivered by the CK722.

The modulated R.F. signal is fed through C_1 to "output" jack J_1, into which the antenna wire is plugged. This capacitor serves simply to reduce the capacitive loading of the antenna and is not otherwise essential to circuit operation.

PARTS LIST:

R_1 — 27K, ½ W. Carbon resistor.
R_2 — 100 K, ½ W. Carbon resistor.
C_1 — 50 Mmf., tubular ceramic capacitor (*Centralab* D6-500).
C_2 — 150 Mmf. tubular ceramic . . . see text (*Centralab* D6-151).
C_3 — 0.002 Mfd., disc ceramic (*Centralab* DD-202).
C_4 — 0.01 Mfd., disc ceramic (*Centralab* DD-103).

C_5 – 16 Mfd., 12 volt electrolytic (*Barco* No. P12-16).
L_1 – R.F. Antenna coil, cut down (*Superex* Ferri-Loopstick).
L_2 – About 20 turns of No. 30 enameled wire, close-wound on L_1, with tap about 4 or 5 turns from "base" end.
J_1 – Miniature open circuit jack (*Telex* No. 9240).
PL_1 – Miniature plug (*Telex* No. 9231).
B_1 – 15 volt Hearing Aid battery (*Eveready* No. ER505E).
Sw_1 – SPST switch (see text).
MIC. – Miniature magnetic microphone (*Shure Bros.* No. MC-11).
Transistors – (1) *Raytheon* CK760; (1) *Raytheon* CK722.
MISC. – (2) transistor sockets; small plastic case; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The construction details of the author's model of the *Wireless Microphone* are clearly visible in the exterior and interior views of the unit, given in Figs. 8-13 and 8-14, respectively. Good wiring practice should be followed, of course, but no special precautions are necessary in regard to parts layout and lead dress. Since the working area is rather confined . . . at least if the builder attempts to duplicate the author's model as far as size is concerned . . . it is suggested that "lap" joints be used for all soldered connections.

Mechanically, the two transistor sockets are mounted in a small bracket cut from scrap aluminum, and this bracket, together with the small "L" bracket used to hold the battery (B_1) in place, are mounted on the plastic case with a single machine screw and hex nut. The small microphone is held in place by a simple "U" bracket, made from a strip of sheet metal, and two machine screws and nuts.

Push-button switch Sw_1 is made up from a small machine screw, a small coil spring which just fits the screw, and a hex nut. The lead connection is made by soldering a flexible wire to the hex nut. This switch is arranged on the side of the plastic case, as shown in Fig. 8-14. When depressed, it makes contact with one terminal of B_1 (a wire is soldered to the opposite terminal of the battery). A "permanent" connection can be made by turning the screw in, against the pressure of the spring, until firm contact is made with the battery. This switch is thus identical to that described in Chapter 7 (*Pocket Receiver*).

Coils L_1 and L_2 deserve some mention. Coil L_1 is made up from a commercial antenna coil by cutting away all the cardboard form except the short portion on which the coil proper is wound, retaining only the coil and the iron "slug". If the iron "slug" is tapped, it may be mounted on the plastic case with a machine screw . . . otherwise, it can be cemented in place. Coil L_1 consists of about 20 turns of fine enameled wire, close-wound right on top of L_1, and with a tap about 4 or 5 turns from the "base" end . . . or 15 or 16 turns from the end connected to the transistor's collector electrode.

If you fail to obtain proper operation when you try the completed *Wireless Microphone*, you may want to experiment with L_2. Moving the tap towards the center will increase feedback (if you don't get oscillation). In some cases you may wish to increase or decrease the number of turns to obtain optimum operation with your particular coil and transistor combination.

Several modifications in the basic design are possible, depending on the individual builder's inclinations. The "plug-in" type of antenna used in the author's model may be replaced by a permanently soldered length of hook-up wire, eliminating $J_1$and PL_1, thus reducing cost slightly. Switch Sw_1 may be replaced with a toggle or slide switch. The microphone may be replaced with a PM loudspeaker, together with a matching "output" transformer . . . connect the high impedance primary winding of the transformer to the transistor and R_2, the low impedance winding to the speaker's voice coil terminals.

With the wiring completed and checked, the transistors may be installed and the unit tried. Connect the antenna . . . this should be from 2 to 5 feet long and may be ordinary hook-up wire. Turn on an AM Broadcast receiver, and, standing close to the receiver, depress switch Sw_1 and start counting slowly, holding the microphone within a few inches of your lips. With the receiver's volume turned up, tune *slowly* over the Broadcast Band until you pick up your voice.

For proper operation, the tuning of the *Wireless Microphone* should be such that the signal is picked up at a "dead spot" on the Receiver's dial . . . that is, where no station is heard. To change the tuning of the unit, you can slide L_1 along its core or, for a major shift in frequency, you can replace C_2 with another capacitor. If C_2 is made smaller, operating frequency is increased . . . as C_2 is made larger, frequency is decreased. Best results are generally obtained when the frequency is adjusted near the middle or low frequency end of the band . . . below 1000 KC.

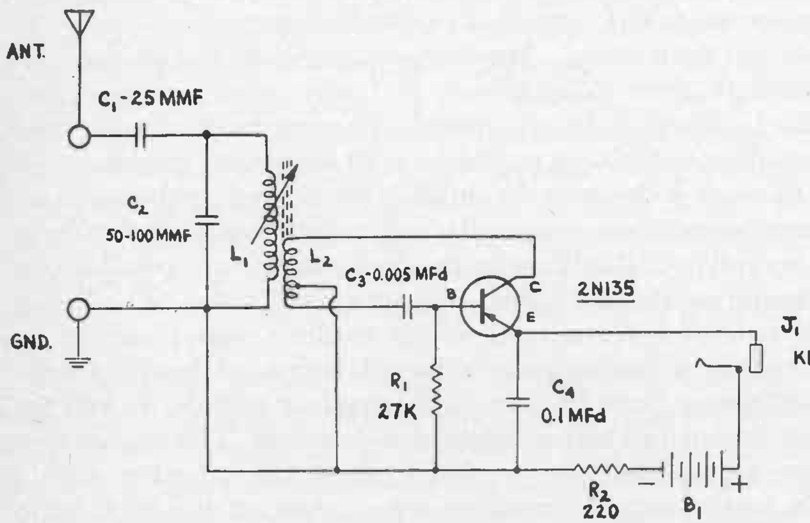


Fig. 8-15.—Circuit for a Wireless Code Practice Oscillator.

WIRELESS CODE PRACTICE OSCILLATOR: Prospective shipboard radio operators, "hams", and military communications workers are just a few of the individuals who need to know the Radiotelegraph Code. To learn the code, most beginners work with audio frequency "Code Practice Oscillators" . . . instruments which sound an audio tone in a pair of Head-

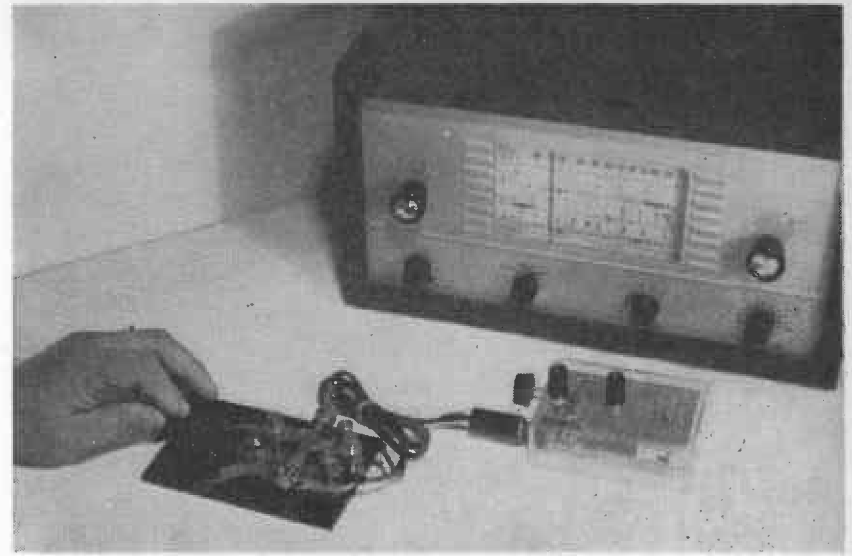


Fig. 8-16.—Using the Wireless C.P.O.

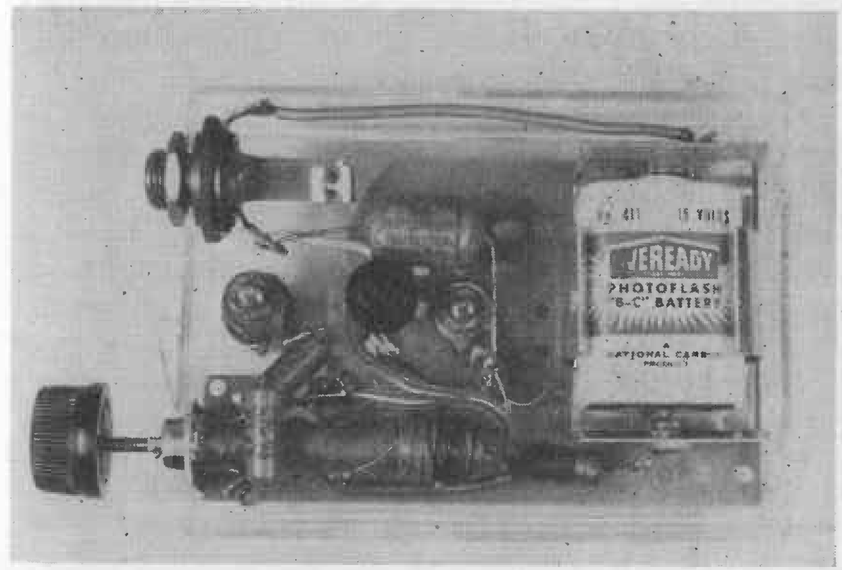


Fig. 8-17.—Interior view of the Wireless C.P.O.

phones or in a loudspeaker each time a sending key is depressed. We'll show and describe transistorized versions of such devices in a later chapter. The code practice oscillator (C.P.O.) shown in Figs. 8-15, 8-16, and 8-17 is *not* an audio unit and, therefore, uses no Headphones or speaker in its design. Instead, this device permits true "on the air" practice when used with a standard Communications Receiver. The *Wireless C.P.O.* is actually a miniature self-contained CW transmitter with a limited range . . . no connection to the receiver with which it is used is needed!

CIRCUIT DESCRIPTION: Referring to Fig. 8-15, we see that the *Wireless C.P.O.* uses a single PNP R.F. type transistor connected as an R.F. oscillator, using the common-emitter configuration.

In operation, the frequency is determined by the tuned "tank" circuit L_1-C_2. Secondary coil L_2, coupled to L_1, serves both to match the input and output impedances of the transistor and to provide the feedback necessary to start and sustain oscillation. L_2 is connected directly to the transistor's collector electrode and through capacitor C_3 to the base. Base bias current is supplied through resistor R_1.

Power is supplied by a single 15 volt Hearing Aid type battery, controlled by the sending KEY, which is normally plugged into jack J_1. A series resistor, R_3, prevents current surges which could damage the transistor as the circuit is keyed rapidly. By-pass capacitor C_4, from emitter to circuit ground, serves both as a "key-click" filter and to prevent degeneration which R_2 might introduce.

The output CW radio signal is coupled to the antenna binding post (ANT.) through capacitor C_1, which serves to reduce the loading and detuning effect of the antenna lead. For convenience in operation, and to minimize possible body capacity effects, a ground binding post (GND.) is also provided . . . this permits an external ground to be connected to circuit ground.

PARTS LIST:

R_1 — 27K, ½ W. Carbon resistor.
R_2 — 220 ohm, ½ W. Carbon resistor.
C_1 — 25 Mmf. tubular ceramic capacitor.
C_2 — Tuning capacitor, tubular ceramic . . . from 50 to 100 Mmf.
C_3 — 0.005 Mfd., disc ceramic (*Centralab* DD-502).
C_4 — 0.1 Mfd., 200 volt paper capacitor.
L_1 — R.F. Antenna coil (*Superex* Vari-Loopstick).
L_2 — 18 turns #30 enameled wire, close-wound on L_1, tap about 4 to 6 turns from end connected to transistor's base.
J_1 — Open circuit 'phone jack.
B_1 — 15 Volt Hearing Aid Battery (*Eveready* No. 411).
Transistor — (1) *GE* type 2N135.
MISC. — (2) Binding posts; (1) Small control knob, 3/16″ hole; transistor socket; battery box (*Austin-Craft* No. 134); small plastic box; small piece of perforated *bakelite* board; Hand Key; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The layout used in the author's model is evident in the interior view of the *Wireless C.P.O.*, given in Fig. 8-17. The individual builder may follow this layout when assembling his model, or may make up a new one to suit his own inclinations, as he chooses, for neither layout nor lead dress is critical. In the author's model, most of the circuit is assembled on a small piece of perforated *bakelite* which, in turn, is mounted in the plastic box serving as a case. The transistor socket is cemented to the *bakelite* using *General Cement* No. 45-2 "All-Purpose" Cement; other parts are mounted with small machine screws and hex nuts.

Coil L_2 is hand-wound on L_1, using No. 30 enameled wire. Specifications for this coil are given in the *PARTS LIST*, but neither the exact number of turns nor the exact location of the tap are critical. Some builders may wish to experiment with this coil to get maximum performance with their transistor.

When wiring is completed and double-checked for possible errors, the transistor and battery may be installed and the Hand Key connected to jack J_1. Place the completed unit near your Communications Receiver, as shown in Fig. 8-16. Make sure the Receiver has had time to "warmp up", then turn on its B.F.O. (Beat Frequency Oscillator) . . . the B.F.O. must be used to obtain an audio tone in the speaker, just as if a code signal from a radio station were being received, for the *Wireless C.P.O.* works just like a CW transmitter.

Depress the Hand Key (or close its switch) and try tuning the receiver over the range from 1000 to 2000 KC. Tune slowly and listen for a beat note. When the signal is received, you can try your hand at sending code!

For best results, the *Wireless C.P.O.* should be adjusted to an operating frequency slightly above the AM Broadcast Band (above 1600 KC). Its operating frequency may be changed by adjusting L_1's iron "slug" or by changing fixed tuning capacitor C_2. The capacitor may be changed for a "coarse" frequency adjustment, with the "slug" adjusted for "fine tuning".

When an antenna lead and ground wire are attached to the proper binding posts, the operating frequency may shift slightly, requiring retuning of either the Receiver or the *Wireless C.P.O.* With a moderate length antenna wire and a good ground connection, the device has a transmitting range of 25 to 50 feet, when used with the average Communications Receiver.

CRYSTAL CALIBRATOR: A crystal-controlled R.F. oscillator, operating at a frequency of 100 KC and supplying a signal rich in harmonics, can be an extremely valuable tool in the radio-electronics lab. or home electronics workshop. It can be used for such jobs as calibrating the dial of a Communications Receiver or checking the accuracy of an R.F. Signal Generator. Vacuum-tube operated versions of this instrument have been available for a number of years, but, like most vacuum-tube devices, they lack the portability, compact size, and ease of use which characterizes transistorized equipment.

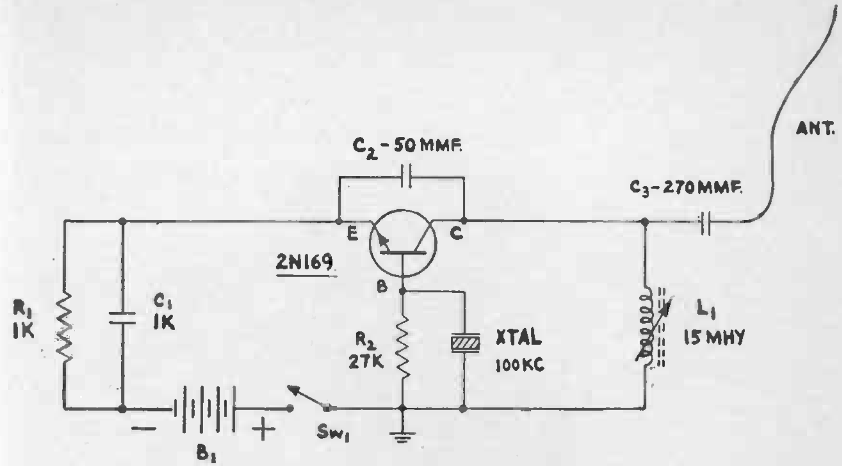


Fig. 8-18.—Diagram of a 100 KC crystal-controlled Calibrator.

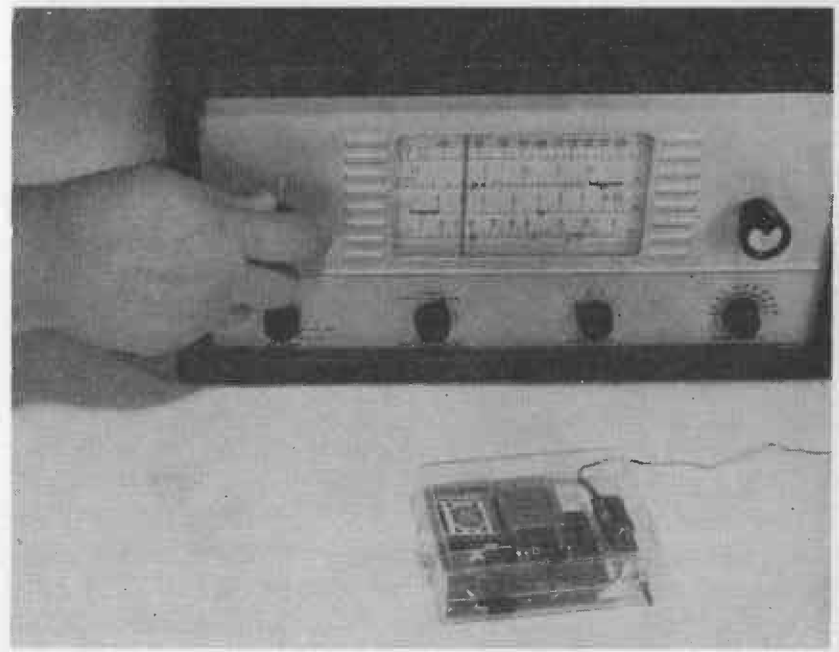


Fig. 8-19.—Checking the dial calibration of a communications receiver.

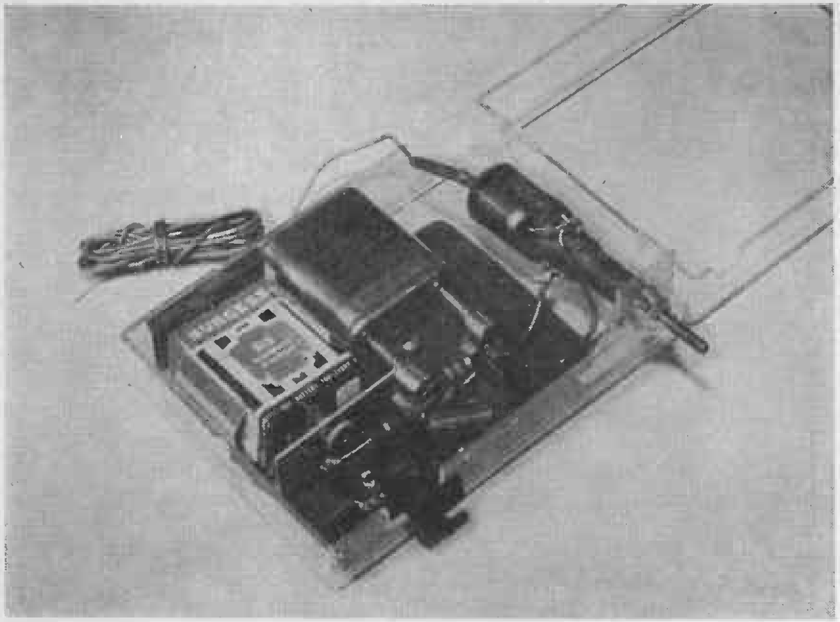


Fig. 8-20.—Interior view of the Crystal Calibrator.

The *Crystal Calibrator* shown in Figs. 8-18, 8-19 and 8-20 is a reliable and accurate 100 KC oscillator which is completely self-contained, requiring no power line connection or external batteries, yet is housed within a case hardly larger than a package of cigarettes. It is completely portable and thus ideal for both lab. and field work; and, with only one control and one adjustment, it is extremely easy to use.

CIRCUIT DESCRIPTION: The schematic wiring diagram of the *Crystal Calibrator* is given in Fig. 8-18. This instrument uses a single NPN transistor in a modified common-base circuit configuration. It is powered by a 15 volt Hearing Aid battery, controlled by a SPST miniature slide switch (Sw_1).

In operation, adjustable choke coil L_1 serves as the collector load impedance and resistor R_1 as the emitter load. Feedback between the collector and emitter circuits is provided by a capacitive voltage divider C_1-C_2, which also serves as an impedance matching network, matching the relatively high im-

pedance of the collector circuit to the low "input" impedance of the emitter.

The base is "floated" above circuit ground by resistor R_2. This resistor would normally introduce enough degeneration to prevent oscillation, but it is "by-passed" by the 100 KC crystal (XTAL). Since the crystal acts effectively like a series resonant circuit, *offering a low impedance at its resonant frequency,* it serves to "short" the base to ground, permitting the transistor to work as a common-base amplifier at this one frequency. Oscillation can then take place due to the feedback supplied by the C_1-C_2 network. For proper operation, signal phase relationships must be correct, and this is insured by making L_1 adjustable.

PARTS LIST:

R_1 — 1K, ½ W. Carbon resistor.
R_2 — 27K, ½ W. Carbon resistor.
C_1 — 100 Mmf. tubular ceramic capacitor (*Centralab* D6-102).
C_2 — 50 Mmf. tubular ceramic capacitor (*Erie* GPIK).
C_3 — 270 Mmf. tubular ceramic capacitor (*Centralab* D6-271).
L_1 — 15 MHy adjustable choke coil (*Superex* No. V-25).
Sw_1 — SPST slide switch.
B_1 — 15 Volt Hearing Aid battery (*Burgess* No. U10).
XTAL — 100 KC Quartz Crystal (*Hupp Electronic Corp.* Type 44).
Transistor — (1) *GE* type 2N169.
MISC. — Transistor socket; battery box (*Austin-Craft* No. 134); Small plastic box; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: Most workers should have no difficulty assembling and wiring the *Crystal Calibrator* for neither parts layout nor lead dress are critical. Only standard, readily available components are used. Even when assembled in a small plastic box, like that used in the author's model, wiring is not crowded and no special skills are required.

Construction details and general layout used by the author are clear in the exterior and interior views of his model, shown in Figs. 8-19 and 8-20, respectively. In the author's model, all parts were mounted on a small *bakelite "sub-chassis"* which, in turn, was mounted in the plastic case. The transistor socket was cemented in place, other parts were mounted with small machine screws and hex nuts. The adjustable coil, L_1, was mounted using a small "L" bracket made up from a scrap piece of aluminum. The antenna (ANT.) is a 20″ to 30″ length of flexible hook-up wire.

ADJUSTMENT AND USE: Once wiring is completed and checked, the transistor and battery may be installed. Remember that a NPN transistor is used, and pay especial attention to battery polarity.

To use the *Crystal Calibrator,* simply spread out the ANT. lead near your Communications Receiver and close the power switch Sw_1. For maximum output, the ANT. lead may be connected directly to the ANTENNA post of the receiver . . . no ground connection is needed. Coil L_1 must be adjusted initially until oscillation occurs; afterwards, it serves as a "vernier" control on frequency . . . however, since the operating frequency is controlled primarily by the crystal, don't expect to be able to shift frequency appreciably by adjusting L_1!

The *Crystal Calibrator* supplies a CW (unmodulated) signal. Therefore, to hear its signal in your receiver, you'll have to turn on the B.F.O. . . . just as if you were receiving code signals. When both the set and the instrument are on and properly adjusted, you'll get audio "beat" notes at 100 KC intervals across the dial. The author's model gave strong beats to 36 MC, the upper frequency limit of his Communications Receiver. When used to check the calibration of a R.F. Signal Generator, both the Signal Generator and the *Crystal Calibrator* are connected to the receiver . . . the B.F.O. is not needed in this case, for the "beat" note is obtained between the two R.F. signals.

HAM GEAR

HAM STATION MONITOR: Some amateur radio operators like to monitor their CW transmissions. One way they can do this is to tune their Communications Receiver near their station frequency and to use it as a "Monitor". This system has several drawbacks . . . not only is there a chance of overloading the Receiver, due to the close proximity of a powerful signal source, but two-way communications are more difficult to carry on, since the Receiver must be retuned to the incoming station's frequency after each transmission. A simpler and more satisfactory approach is to assemble a compact *Station Monitor* . . . the circuit for a transistorized version of such a device is given in Fig. 8-21. This unit provides an audio note in the Headphones whenever the transmitter is "sending".

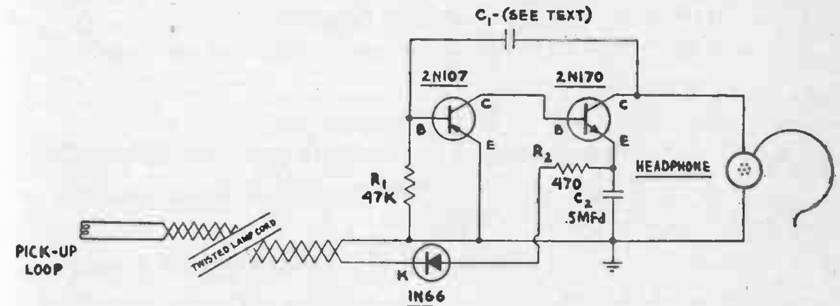


Fig. 8-21.—Schematic of an easily built Ham Station Monitor.

CIRCUIT DESCRIPTION: The *Station Monitor* is basically a two-stage complementary oscillator, using direct-coupled PNP and NPN transistors in the common emitter configuration. Power is supplied by R.F. energy obtained from the station's transmitter, after appropriate rectification and filtering. Since power is supplied *only* when the transmitter is working, the oscillator can operate only at this time, and since only a small fraction of a watt is needed by the transistorized oscillator, there is no detrimental effect on the station's power output.

In operation, the type 2N107 PNP transistor is direct-coupled to the type 2N170 NPN unit, forming a two-stage amplifier. A pair of magnetic Headphones serves as the collector load impedance for the second stage. Resistor R_1 serves as the base resistor for the first stage. Since direct-coupling is employed, the second stage requires no base resistor. Capacitor C_1 is connected between the "output" and the "input" of the two-stage amplifier to convert it into an audio oscillator . . . this capacitor serves as the feedback path.

R.F. power is picked up by a small loop near the transmitter and tranferred to the *Station Monitor* over a simple transmission line. Here, a 1N66 diode is used as a half--wave rectifier which, together with filter network R_2-C_2, forms the D.C. power supply for the audio oscillator.

PARTS LIST:

R_1 – 47K, ½ W. Carbon resistor.
R_2 – 470 ohm, ½ W. Carbon resistor.
C_1 – 0.001 to 0.01 Mfd. (see text), ceramic or paper capacitor.
C_2 – 0.5 Mfd., 200 volt paper capacitor.
LOOP – Approximately 3 turns hook up wire, about 2½" to 3" diameter, *loosely* coupled to the transmitter.
Diode – (1) *GE* type 1N66.
Transistors – (1) *GE* type 2N107 PNP transistor; (1) *GE* type 2N170, NPN.
MISC. – (2) Transistor sockets; high impedance magnetic headphone; twisted pair lamp cord; small plastic box; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The entire *Station Monitor* may be assembled in a small plastic or metal box. Good wiring practice should be observed, but neither layout nor lead dress are critical. The *Pick-up Loop* consists of about three turns of insulated hook up wire, wound on a form about two to three inches in diameter. It is connected to the *Station Monitor* with a short length of twisted pair lamp cord and *loosely* coupled to the transmitter. You may have to experiment to determine the best location for the pick-up coil.

When assembling the *Station Monitor* pay particular attention to the polarity of transistor and diode connections. If desired, the NPN and PNP units may be interchanged, *provided*

the diode is reversed to insure proper power supply voltage polarity.

Capacitor C_1 is chosen experimentally to give the audio note desired. Generally, its value should be between 0.001 and 0.01 Mfd., but its final value will depend on the audio frequency desired and on the impedance of the Headphone used.

Circuit values are not especially critical, but you may find it worthwhile to experiment somewhat, to obtain optimum performance with your particular assembly . . . and under your special operating conditions. You can try varying the values of R_1, R_2 and C_2.

R.F. FREQUENCY METER: If there is any one instrument that is found almost universally in "Ham Shacks", it is probably the Absorption Frequency Meter. Used for quick transmitter frequency checks, this instrument may take many forms. In its simplest form it consists of an inductance coil and variable capacitor, connected as a tuned circuit in series with a small flashlight bulb which serves as an indicating device. In use, the instrument is held near the transmitter and tuned through resonance . . . at the resonant frequency the circulating current, induced by the proximity of the transmitter, reaches a maximum, and the small bulb glows. Such an instrument requires a fair amount of power for operation. Some Hams use a more sensitive form, substituting a diode detector and D.C. meter for the lamp bulb indicator . . . these instruments give a peak in meter reading at resonance, and require less power than the simpler circuit.

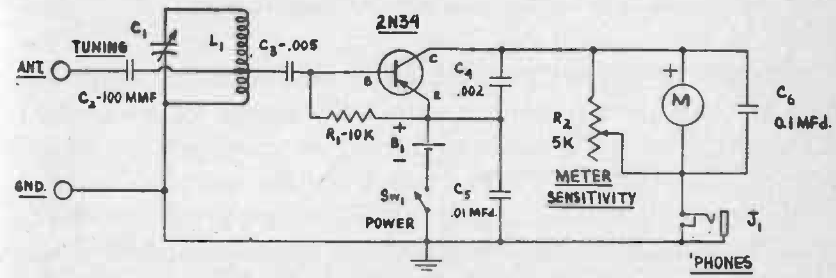
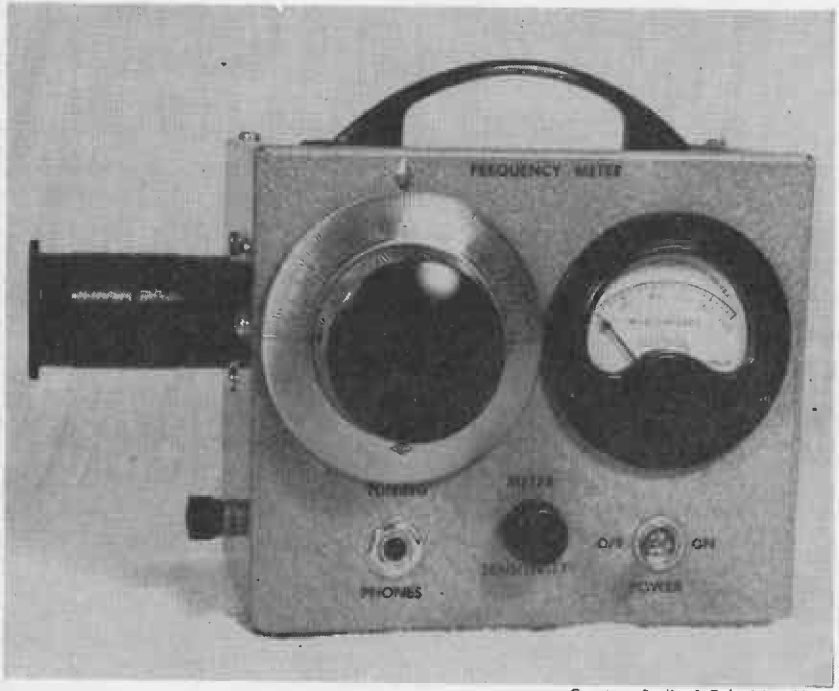


Fig. 8-22.—Circuit for a transistorized R.F. Frequency Meter.

By combining the detection and D.C. amplifying characteristics of the transistor with the basic circuitry of the absorption frequency meter, we can develop an instrument that is more sensitive than either of the simpler forms, yet is still easy to assemble and to use. The circuit for a transistorized *R.F. Frequency Meter* is given in Fig. 8-22, while an exterior view of the author's model of the instrument is shown in Fig. 8-23.



Courtesy Radio & Television News

Fig. 8-23.—Exterior view of the R.F. Frequency Meter.

CIRCUIT DESCRIPTION: Referring to Fig. 8-22, tuned circuit L_1-C_1 is used to pick up the R.F. signal to be checked. Normally, pick-up is made by inductive coupling to the coil proper, but provision has been made for the use of an antenna and ground, if desired. A tap on L_1 matches the low input impedance of the PNP transistor and minimizes the loading effect of the transistor on the tuned circuit.

The R.F. signal is coupled through C_3 to the base-emitter circuit of the transistor, connected in the common-emitter configuration and operated without bias current so as to serve as a detector-amplifier. Resistor R_1 serves as the base resistor.

The collector current of the transistor varies with the amplitude of the applied R.F. signal and this current, in turn, is indicated on the meter (M). Thus, the meter reading indicates when there is a peak in the tuning of C_1-L_1 and therefore the resonance of this circuit. The meter is shunted by potentiometer R_2, which serves as a SENSITIVITY control, and thus prevents possible overloading of the meter on strong signals. The meter is by-passed by capacitor C_6, which prevents attenuation of the audio signal when a modulated R.F. signal is being received, and when Headphones are plugged into jack J_1 for monitoring purposes. Capacitors C_4 and C_5 serve as R.F. by-pass capacitors. Power is supplied by a single penlight cell, B_1, controlled by SPST toggle switch Sw_1.

PARTS LIST:

R_1 — 10K, ½ W. Carbon resistor.
R_2 — 5K, Carbon potentiometer, Linear Taper (*Centralab* B10).
C_1 — Variable capacitor, Tuning (*Hammarlund* HF-140 . . . 140 Mmf.).
C_2 — 100 Mmf., tubular ceramic (*Centralab* D6-101).
C_3 — 0.005 Mfd., disc ceramic (*Centralab* MD-502).
C_4 — 0.002 Mfd., disc ceramic (*Centralab* MD-202).
C_5 — 0.01 Mfd., disc ceramic (*Centralab* MD-103).
C_6 — 0.1 Mfd., 200 volt tubular paper capacitor.
L_1 — Tapped inductance coil—*see text*.
B_1 — 1.5 volt penlight cell (*Burgess* No. Z).
Sw_1 — SPST toggle switch.
J_1 — Closed circuit 'phone jack.
M — Meter, 0-200 Microamperes.
Transistor—(1) *Transitron* type 2N34.
MISC.—Transistor socket; control knob; coil socket; (2) binding posts vernier tuning dial (*National* AM-2); small

metal case (*L.M.B.* No. 140); Battery box (*Austin-Craft* No. 127); small handle; terminal strips; Machine screws, hex nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The assembly of the *R.F. Frequency Meter* is a relatively simple job and no special skills or tools are required. Neither parts layout nor lead dress are critical; however, good R.F. wiring practice should be observed in the signal circuits . . . that is, signal leads should be kept short and direct. For best results, the entire circuit should be wired in a small metal case such as the aluminum box specified in the *PARTS LIST*. The final unit may be given a professional touch by labeling all controls with *Tekni-Label Decals*. These decals should be applied *after* all machine work is finished, but *before* parts are mounted, and should be protected, after application, with two or three coats of clear plastic spray.

Data on the inductance coil L_1 is not given in the *PARTS LIST* as the specifications will vary with the tuning capacitor used and with the desired frequency coverage. Full coil winding data may be found in standard reference sources, such as *THE RADIO AMATEUR'S HANDBOOK* (ARRL). The impedance matching tap should be from 1/10 to 1/4 the total number of turns used from the "ground" end of the coil. The exact location of the tap is not critical. In the author's model, L_1 consisted of 72 turns of No. 26 enameled wire on a standard 1¼" diameter 4-prong form; the tap was at 13 turns . . . frequency coverage was approximately 1.2 to 4.0 MC. Although a permanently installed fixed coil may be used, the author recommends the use of plug-in coils, permitting the frequency range to be changed at will.

CALIBRATION AND USE: To be of value as a frequency measuring device, the *R.F. Frequency Meter* must be accurately calibrated. This may be done by using a Grid Dip Meter or R.F. Signal Generator of known accuracy to provide check points as the calibrated dial is rotated. These points may then be plotted on a *Calibration Chart* or graph scale . . . a separate curve will be needed for each coil used.

If you have a signal source (Signal Generator, for example) available, but are not sure of its accuracy, you can check it by "zero beating" against known Broadcast and Short-wave Stations, using a standard Communications Receiver as a detector.

In use, the inductance coil, mounted on the *outside* of the instrument's case, is inductively coupled to the transmitter (or other device) being checked. C_2 is adjusted for a peak reading on the meter M. If the pointer tends to go off-scale, the sensitivity may be reduced by adjusting R_2 . . . but this adjustment should be made only after the inductive coupling has been brought to a minimum. After "peaking" C_2, the dial reading is noted and checked against the previously prepared *Calibration Chart* to determine frequency. To monitor an AM signal, Headphones (moderate impedance magnetic type) are plugged into jack J_1.

Use of an antenna and ground, connected to terminals *ANT.* and *GND.* respectively, will improve sensitivity, but will also change the dial calibration. For maximum accuracy, you may wish to prepare two *Calibration Charts* for each coil . . . one when the coil is used alone, and another when an antenna and ground are used with the instrument. For the calibration to be valid, the *same* antenna and ground must always be used.

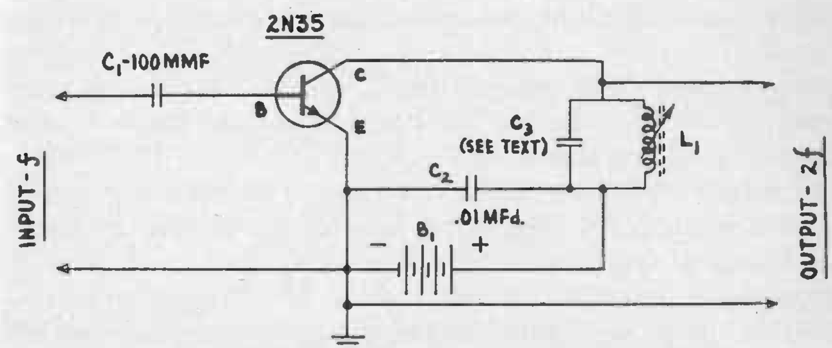


Fig. 8-24.—Diagram of a basic transistorized R.F. Frequency Doubler.

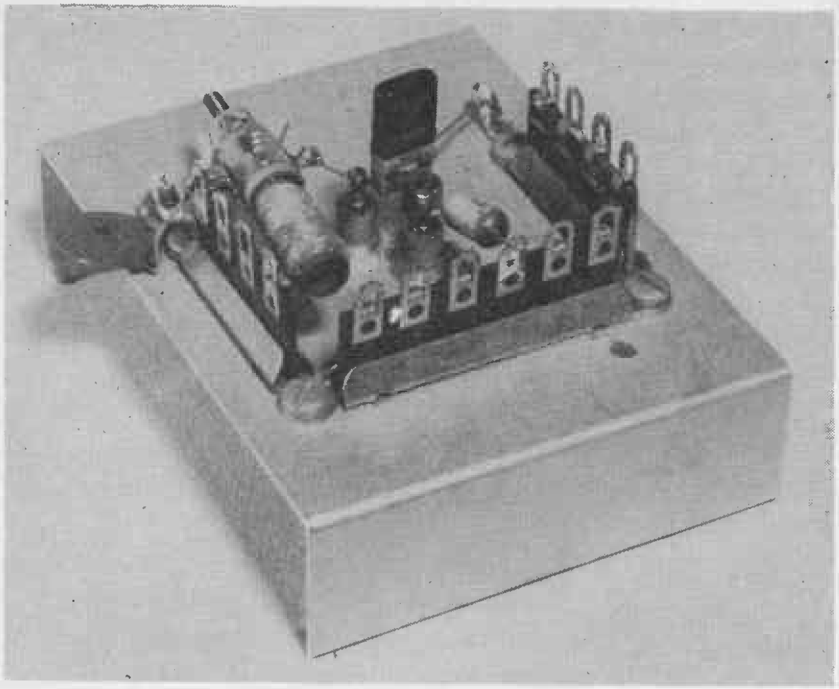


Fig. 8-25.—Breadboarded Frequency Doubler.

SPECIAL R.F. CIRCUITS

FREQUENCY DOUBLER: Where practical considerations make it difficult to design and build an oscillator to deliver a desired signal frequency, it is common practice to use a *Frequency Doubler*. In its simplest form, this is a non-linear amplifier which drives a resonant circuit tuned to twice the input signal frequency. Transistors are well suited to the design of such devices. The circuit for a transistorized *Frequency Doubler* is given in Fig. 8-24, while an assembled "breadboard" model is shown in Fig. 8-25.

CIRCUIT DESCRIPTION: As we can see by referring to Fig. 8-24, a single NPN transistor is used in this device, connected as a tuned amplifier in the common-emitter configuration. Power is supplied by a single battery. Since this is an experimental circuit, no controls or switches are provided or needed.

In operation, the input signal is coupled to the base-emitter

circuit through capacitor C_1. Since no base resistor is used, the transistor is operated without bias current and thus acts to "detect" or "clip" the incoming signal, feeding amplified pulses to its collector load . . . tuned circuit L_1-C_3. These pulses "shock-excite" the tuned circuit at its resonant frequency, producing an output signal at this value. For frequency doubling, resonant circuit L_1-C_3 is tuned to *twice* the frequency of the applied signal.

Capacitor C_2 serves simply as an R.F. by-pass across the power source, battery B_1, and is not essential to circuit operation.

PARTS LIST:

C_1 — 100 Mmf. tubular ceramic capacitor (*Centralab* D6-101).
C_2 — 0.01 Mfd. disc ceramic (*Centralab* MD-103).
C_3 — (*See Text*).
L_1 — Adjustable inductance coil (see text).
B_1 — Battery . . . from ½ to 12 volts.
Transistor — (1) *Sylvania* type 2N35 (see text).
MISC. — Transistor socket; small chassis; terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The author's model of the *Frequency Doubler* shown in Fig. 8-25 was assembled on the small single circuit "breadboard chassis" described in *Chapter 2* (Figs. 2-4, 2-5 and 2-6). Coil L_1 and capacitor C_3 are chosen to resonate at the desired output frequency. Battery voltage is not critical, as long as the maximum rating of the transistor is not exceeded.

A Sylvania type 2N35 transistor is specified and shown in the illustrations. This transistor is suitable for output frequencies up to about 1.5 to 2.0 M.C. For higher frequencies, R.F. type transistors should be employed . . . suitable types are *Sylvania's* 2N94 and 2N94A, *Raytheon's* CK760 series, *GE's* 2N135, 2N136 and 2N137, *RCA's* 2N139 and 2N140, and *General Transistor's* GT-760 series. Where PNP transistors are used, the battery polarity *must* be reversed.

Although described as a *Frequency Doubler,* the circuit given in Fig. 8-24 may also be used as a *Frequency Tripler* or *Frequency Quadrupler* simply by adjusting tuned circuit L_1-C_3 to the appropriate frequency. This is possible because the transistor shock-excites the tuned circuit. If loading is kept to a minimum, to prevent damping, even higher frequency multiplication is possible.

HIGH FREQUENCY OSCILLATOR: Except for the circuit values employed, and the types of transistor used, High Frequency transistor oscillators are quite similar to their lower frequency counterparts. A typical circuit, featuring a *Surface Barrier* transistor, is shown in Fig. 8-26. This circuit is suitable for use in such applications as in an R.F. Signal Generator, in a low-powered transmitter, or as the local oscillator in a transistorized "short-wave" Superhet radio receiver. Operating frequencies up to about 50 MC are possible with the proper choice of tuned circuit components, and good layout and wiring.

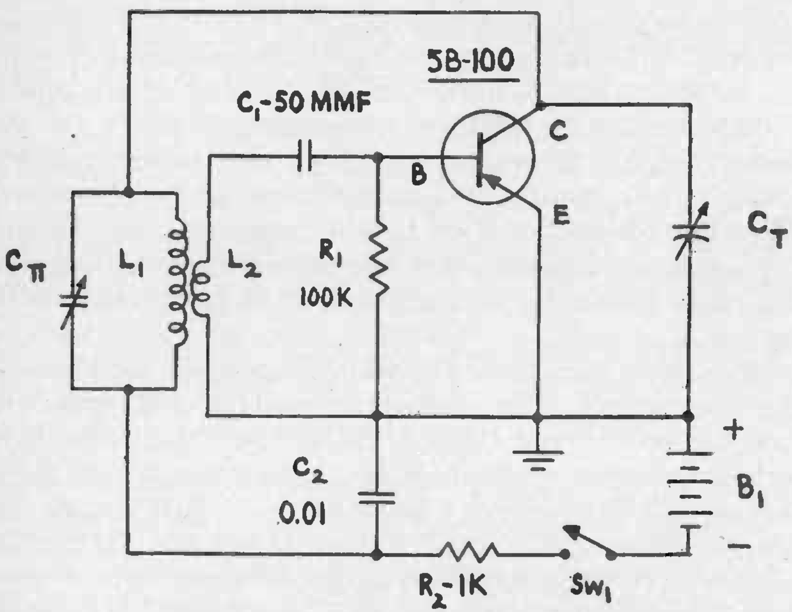


Fig. 8-26.—Schematic of a High Frequency Oscillator featuring a "Surface Barrier" transistor.

CIRCUIT DESCRIPTION: The *Surface Barrier* transistor is wired in a "tickler feedback" arrangement, using a common-emitter circuit configuration. In operation, tuning capacitor C_T, together with inductance coil L_1 and trimmer capacitor C_{TT}, form the tuned circuit which serves as the collector load. Feedback between the collector and base circuits is provided by coil L_2, inductively coupled to L_1 . . . generally, these two coils are wound on the same form. Capacitor C_1 and resistor R_1 are the base coupling capacitor and "base return" resistor, respectively. Power is supplied by a 6 volt battery, B_1, controlled by SPST switch Sw_1.

Resistor R_2 and capacitor C_2 form a simple "L" type filter network which has a dual function. This serves as a decoupling filter to keep R.F. out of the power supply circuit and also acts to absorb the initial shock when power switch Sw_1 is thrown "ON" . . . the *Surface Barrier* transistor is extremely sensitive to electrical shock and may be ruined quite easily by a switching transient.

PARTS LIST:

R_1 – 100K, ½ W. Carbon resistor.
R_2 – 1K, ½ W. Carbon resistor.
C_1 – 50 Mmf. tubular ceramic capacitor (*Centralab* D6-500).
C_2 – 0.01 Mfd., disc ceramic (*Centralab* MD-103).
C_T, C_{TT}, L_1, L_2 – Tuned circuit and feedback coil, *see text.*
B_1 – 6 volt battery (*Burgess* No. Z4).
Sw_1 – SPST Toggle switch.
Transistor – (1) *Philco* type SB-100.
MISC. – Small chassis; battery box (*Austin-Craft* No. 110); terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: Other than the usual "rules" of good wiring practice in regard to R.F. circuits, no special steps are needed in laying out and wiring the circuit itself . . . signal leads should be kept short and direct, "ground" leads should go directly to chassis ground and, if possible, all grounds should be made at a common point, etc. *Wiring the transistor into the circuit calls for special care, however, since the Surface Barrier transistor is easily damaged by transient currents.* Any test equipment to be connected to the circuit should be bonded together and connected to a good "earth" ground. The soldering iron used should connect to an isolation transformer rather than directly to the power line, and should have its shell connected to ground . . . a soldering "gun" is preferred to a conventional iron, if available. If experimental changes are to be made in the circuit, a meter should be used to monitor collector current, making sure it never exceeds the transistor's maximum ratings at the supply voltage used.

The tuned circuit components (CT, CTT, L_1, and L_2) are chosen to operate at the desired frequency. Where several ranges are desired, a standard Band-Switch may be used to change coils and the trimmer capacitor, with CT left permanently connected to the transistor's collector. Data on coil design will be found in any standard text . . . such as *THE RADIO AMATEUR'S HANDBOOK*. In general, coil L_2 will consist of fewer turns than coil L_1, to provide a "step-down" ratio. Both coils are close-wound on the same form. At lower frequencies L_2 may have from 1/6 to 1/4 the turns of L_1 (chosen to operate at the desired frequency with the tuning capacitor used). At higher frequencies, the ratio may start to approach 1:1, as more feedback is required to start and sustain oscillation. In some instances, it may even be necessary to interwind L_1 and L_2 . . . at least for a couple of turns . . . to insure adequate coupling.

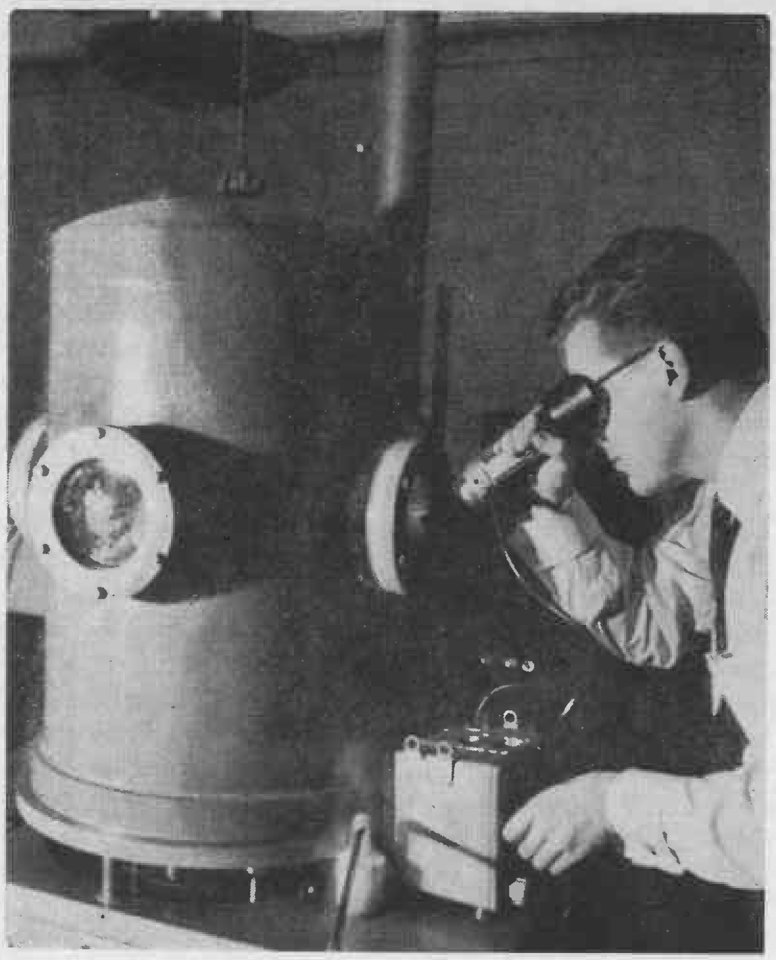
The completed *High Frequency Oscillator* may be checked by listening for it with a Communications Receiver, using the built-in B.F.O. If the circuit does not oscillate, try interchanging the connections to L_2. Make sure there are no errors in wiring and that all parts are good. Finally, if difficulty is still encountered, experiment with turns ratio of L_1 and L_2, as well as with the coupling between these two coils. In a few instances, it may be advisable to "bias" the transistor by returning a resistor from the base to the neg. side of B_1 . . . a good

"starting" value would be 3.3 Megohms. Start with this value, and, checking collector current constantly, try lower values.

CONCLUSION

In this Chapter we have tried to "highlight" typical R.F. Applications of transistors. Our major emphasis has been on receiver circuits, since these are generally the most popular . . . with both experimenters and students. Additional R.F. Applications will be found in later Chapters.

The circuits given by no means exhaust the possible uses of transistors in R.F. work. Many additional instruments and devices are possible if the individual reader wishes to exercise his ingenuity and skill . . . for example, the four-transistor *Superhet Receiver* might be modified to become a six-transistor set by adding an additional stage of I.F. amplification and by changing the audio output stage to a push-pull circuit. The simple Broadcast Band receivers might be used as Long or Short-wave Receivers by changing the tnned circuits employed and by using other transistors. By changing the crystal frequency and adding a *Frequency Doubler,* the *Crystal Calibrator* could be changed into a low-power Ham Band CW transmitter. Undoubtedly, the reader can think of many other applications and circuit modifications. It is the author's hope that the reader considers the suggested circuits as a "guide" rather than as a rigid set of inflexible projects.



Credit: Bell Telephone Laboratories

C. A. Lee, Bell Telephone Laboratories physicist, peers into vacuum oven and adjusts gauge to determine temperature in diffusion chamber where a new germanium transistor is made. Gas and chemical impurities are introduced to give material unique electrical properties. Transistor performs at high frequencies.

Chapter 9

TEST INSTRUMENTS

Compared to equipment using vacuum tubes, transistorized test instruments offer the user many advantages from an operational view-point. Instant working, there are no problems of "warm-up" time, with attendant drift in characteristics. And, since most transistorized instruments are battery powered, the problems brought about by line fluctuations are eliminated, along with hum and line noise. In addition, battery operation, coupled with light weight and compact size, gives such instruments complete portability, making them ideal for field use. Reliability is another important advantage offered by transistorized test instruments, for transistor life is, for practical purposes, virtually infinite . . . there is no danger of a "filament burn-out" occurring in the midst of important tests. Finally, since transistorized equipment is likely to be simpler, circuit-wise, than corresponding vacuum tube operated gear, it may be less costly, both to acquire and to maintain.

Electronic instrumentation includes so many different types of equipment that even an attempt at complete descriptive coverage would require several books the size of this volume. Therefore, to conserve space, we will cover only basic instruments that might find usage in the typical laboratory or maintenance shop. Nonetheless, in describing transistorized test equipment, we will try to give a cross-sectional view of potential applications to all types of instrumentation. Thus, the individual reader, by applying his own ingenuity and knowledge, should be able to modify and to adopt most of the instruments shown to his own specific needs and requirements. At the very least, the instruments shown should stimulate the reader's thinking and should serve as a guide in helping him to devise new instruments and test devices.

SIGNAL GENERATORS

AUDIO SINE WAVE GENERATOR: A single frequency audio signal generator can be extremely valuable in the hands of a skilled technician. It may be used for such jobs as checking "weak" and "dead" audio circuits in TV, FM, and Broadcast Band radio receivers, and for servicing P.A. Systems, Hi Fi Amplifiers, and Intercom installations. The transistorized audio generator shown in Figs. 9-1 and 9-2, although small in

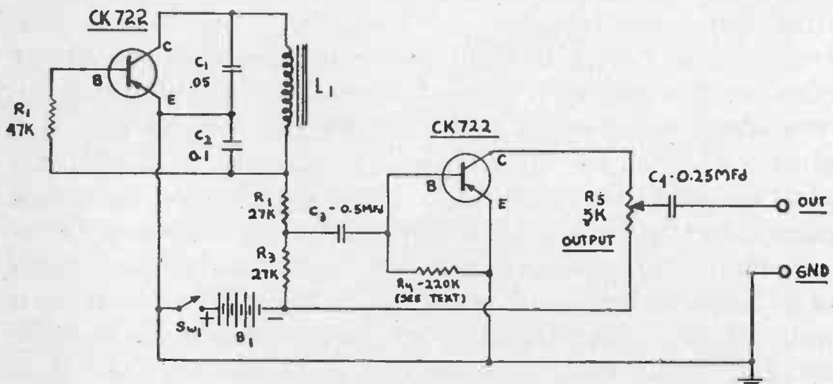


Fig. 9-1.—Circuit for the transistorized Audio Sine Wave Signal Generator.

size and completely self-contained, can be adjusted to give an almost perfect sine wave signal (Fig. 9-3) of sufficient amplitude for all general servicing and test applications. The good quality sine wave delivered by the instrument makes it suitable for distortion checks as well as for signal injection tests.

CIRCUIT DESCRIPTION: The *Audio Sine Wave Generator* shown in Fig. 9-1 uses two PNP transistors—one as an oscillator, the second as a "buffer" amplifier. The common-emitter configuration is employed in both circuits. Power is supplied by a single 15 volt Hearing Aid battery (B_1), controlled by a SPST witch Sw_1, which is mounted on the OUTPUT control R_5. The total current drain is quite small so that battery life, under typical operating conditions, should approximate the "shelf life" of the unit.

The first transistor is connected as a "Colpitts" audio oscillator, with the feedback necessary to start and sustain oscillation furnished by capacitive voltage divider C_1-C_2. Operating frequency is determined by the tuned circuit made up of L_1,

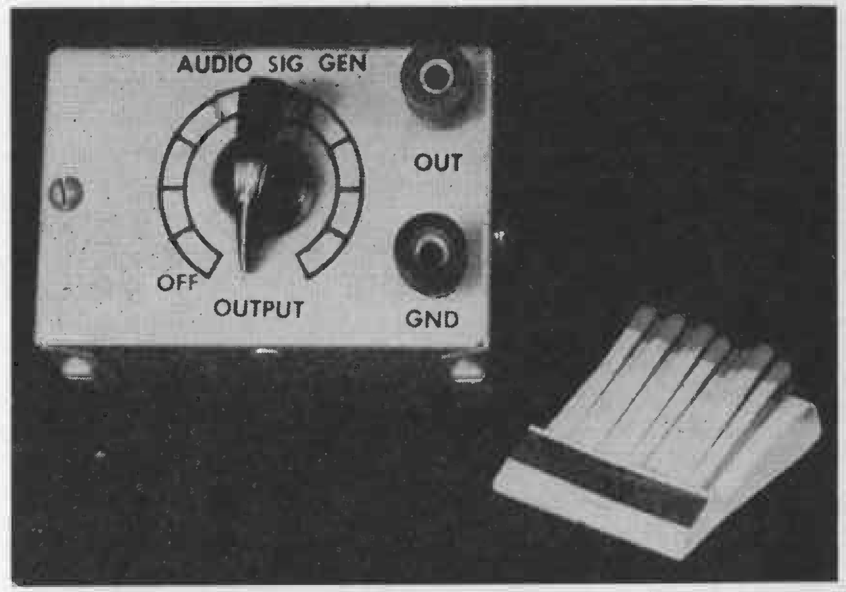


Fig. 9-2.—Exterior view of the Audio Sine Wave Generator—book matches show size.

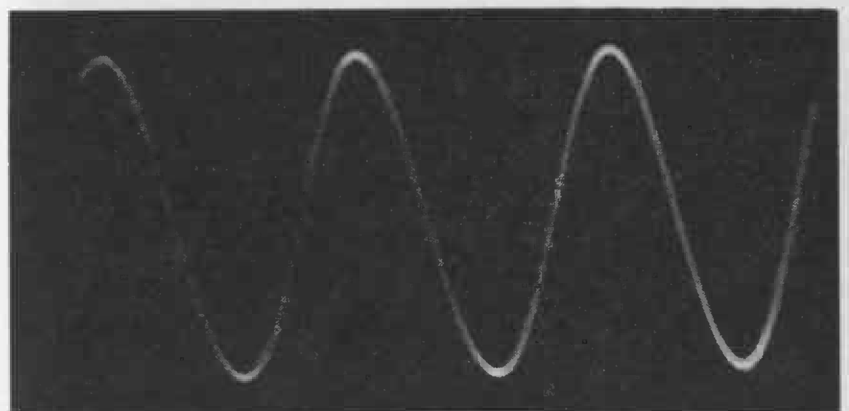


Fig. 9-3.—The nearly perfect sine wave signal obtained from the Audio Generator.

together with C_1 and C_2 in series. Base bias current is furnished through R_1.

Resistors R_2 and R_3 form an output voltage divider network, with the signal appearing across R_3 coupled through C_3 to the "buffer" amplifier stage. The use of a buffer stage provides greater output while, at the same time, minimizing the effect of external loads on the output frequency, amplitude or signal waveform. R_4 serves as the base resistor for the buffer stage. A 5,000 ohm potentiometer, R_5, serves as the collector load for the buffer amplifier, with the signal appearing across it coupled through D.C. blocking capacitor C_4 to the output binding post. Thus, R_5 also serves as the OUTPUT control.

PARTS LIST:

R_1 — 47K, ½ W. Carbon resistor.
R_2, R_3 — 27K, ½ W. Carbon resistors.
R_4 — 220K, ½ W. Carbon resistor.
R_5 — 5K Carbon potentiometer, Linear Taper (*Centralab*).
C_1 — 0.05 Mfd., 200 volt, paper tubular capacitor.
C_2 — 0.1 Mfd., 200 volt, paper tubular capacitor.
C_3 — 0.5 Mfd., 200 volt, paper tubular capacitor.
C_4 — 0.25 Mfd., 400 volt, paper tubular capacitor.
L_1 — Small audio choke (primary of audio output transformer).
Sw_1 — SPST switch (on R_5).
B_1 — 15 volt Hearing Aid battery (*Burgess* No. Y10).
Transistors — (2) *Raytheon* type CK722.
MISC. — (2) transistor sockets; Battery Box (*Austin-Craft* No. 136); (2) binding posts; control knob; small metal case (*ICA* No. 29436); terminal strips; machine screws, hex nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The average builder should have no difficulty in duplicating the author's model, shown in Fig. 9-2. Neither parts layout nor lead dress are especially critical, so the builder may arrange parts within the small metal box used as a "cabinet" to suit his own inclinations. For a professional "touch", the instrument may be labeled with decals.

These should be protected, after application, with at least two coats of clear plastic or lacquer.

If the usual precautions against overheating are observed, the transistors may be permanently wired into the circuit. This type of construction will result in the most compact assembly, but should be followed only where the worker is skilled. Otherwise, small transistor sockets should be employed.

The frequency of operation is determined by choke L_1, together with capacitors C_1 and C_2. In the author's model, L_1 is the primary of a small audio output transformer, salvaged from an old portable radio receiver. Almost any small audio choke may be used in this application, but the ratio of C_1 and C_2, as well as their total capacity, may have to be varied to give optimum performance.

After assembly and test, the output waveform should be observed on an Oscilloscope. If a good quality sine wave is not obtained, the feedback ratio should be checked (by adjusting the values of C_1 and C_2) as well as the size of base resistor R_1. In some cases it may be desirable to change R_1 to a larger or smaller resistance value.

Output drive depends on the ratio of R_2 and R_3 while the performance of the "buffer" amplifier depends, to a large extent, on base resistor R_4. These resistors can be adjusted, experimentally, for optimum results. Occasionally, it may be desirable to "bias" the output stage by returning R_4 to the negative terminal of B_1 instead of to circuit ground.

OPERATION AND USE: As designed, and shown in Fig. 9-1, the *Audio Sine Wave Generator* supplies a single frequency. If several output frequencies are desired, a selector switch may be provided to select different capacitors (C_1-C_2) or choke coils (L_1). The output level is controlled by R_5.

To use the instrument to isolate "dead" or "weak" stages in an audio amplifier, connect its output to the input of each stage, starting at the *output stage* of the amplifier and working back towards the first or "pre-amp" stage. There should be an increase in the audio level (as indicated by either the amplifier's loudspeaker or a separate *Output Meter*) as additional gain stages are added . . . it should be necessary to reduce the output of the *Audio Sine Wave Generator* as the first stage is approached. Where there is either a loss of the output signal, or a decided drop in signal level, the defective stage has been isolated . . . further checks in that stage should enable the worker to identify the defective part.

For distortion tests, use the instrument in conjunction with an Oscilloscope. Check the waveform at the input and output of each stage of the amplifier, comparing it with the signal supplied by the generator. A change in the waveform indicates distortion in the stage being checked. A flattening of the positive half-cycle, in a vacuum tube amplifier, generally indicates insufficient bias, a weak tube, or low screen or plate voltages. A flattening of the negative half-cycle generally indicates excessive bias. If both sides of the signal are flattened, it generally indicates an overload condition.

R.F. ALIGNMENT GENERATOR: Three frequencies are needed for the proper alignment of AM Broadcast Radio Receivers. A signal at about 455 KC is needed for peaking the I.F. transformers; a 500 KC signal is needed for "padder" capacitor or coil "slug" adjustment at the low frequency end of the band; and a 1500 KC signal is needed for adjusting the local ocillator and R.F. pre-selector at the high frequency end

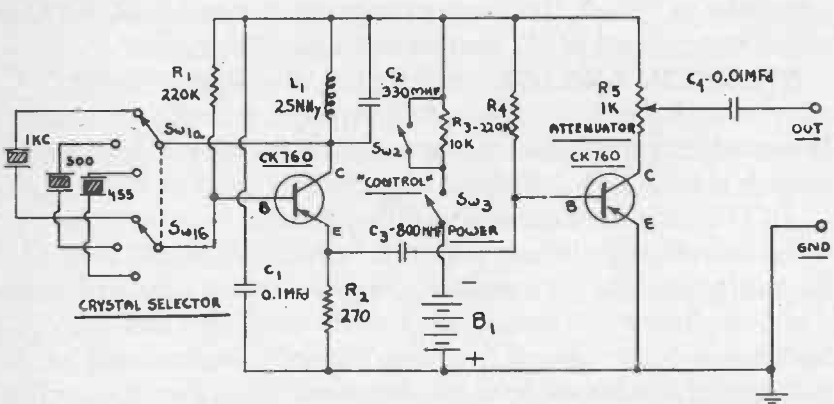


Fig. 9-4.—Schematic diagram of an R.F. Alignment Generator.

Fig. 9-5.—Author's model of the R.F. Alignment Generator.

of the band. For a final check, a 1000 KC signal may be used to check tuning near the center of the band. Multiples of a 1000 KC signal are useful for checking the alignment at higher frequencies if the receiver is provided with one or more Short-Wave bands. The transistorized instrument shown in Figs. 9-4, 9-5 and 9-6 supplies signals at all of these basic frequencies.

The *R.F. Alignment Generator* is crystal-controlled and, therefore, supplies signals of greater frequency accuracy than those obtained, say, from an instrument using L-C resonant

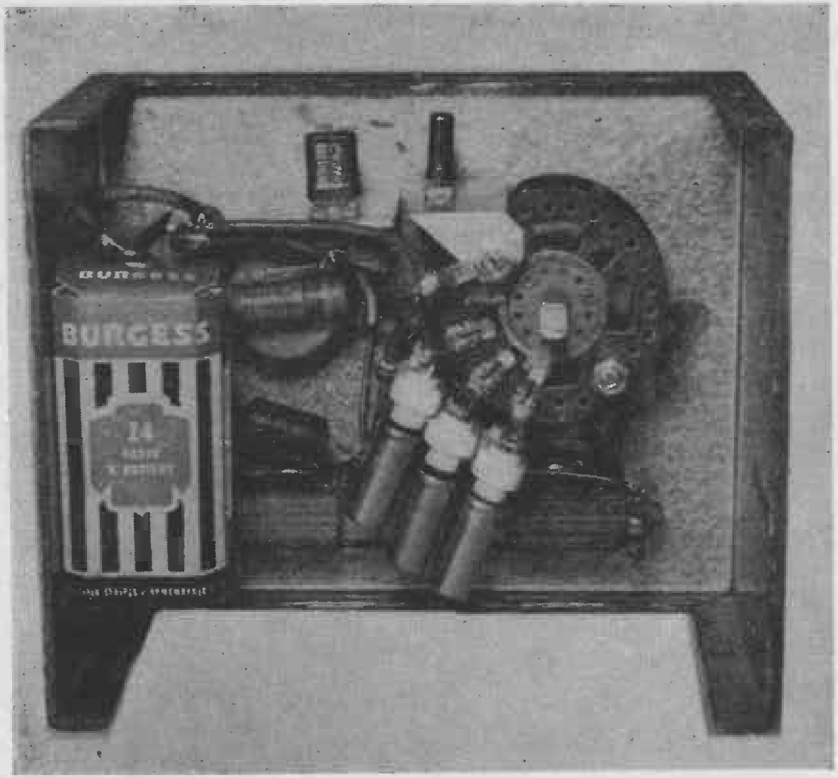


Fig. 9-6.—Interior view of the R.F. Alignment Generator—note crystal mounting.

circuits to determine operating frequencies. It is completely self-contained, operating from a built-in battery power supply. Hence, there are no problems of "warm-up" time or short term frequency drift to limit its application. Further, the instrument supplies an output signal of sufficient amplitude to align even a weak receiver, with strong harmonics available to the upper frequency limit of most Communications Receivers.

CIRCUIT DESCRIPTION: The instrument uses two R.F. type PNP transistors; one serves as a crystal-controlled oscillator and is connected in a modified common-emitter configuration; the second transistor serves as a "buffer" or output amplifier and uses a standard common-emitter circuit arrangement. Power is supplied by a single 6 volt battery (B_1), controlled by

a SPST toggle switch (SW_3). Output impedance is approximately 1000 ohms at full output.

In operation, R.F. Choke coil L_1, shunted by loading capacitor C_2, forms the collector load for the oscillator stage. The feedback necessary to start and sustain oscillation is supplied through one of three quartz crystals, selected by switch Sw_1. The feedback is between collector and base circuits, with base current established by resistor R_1. The crystal selected by Sw_1 determines the frequency of operation.

R.F. output is obtained from the oscillator across unbypassed emitter resistor R_2, and is coupled through C_3 to the base of the buffer amplifier. Extracting an R.F. signal from the oscillator in this fashion minimizes circuit loading and assures maximum frequency stability. Base bias current for the output stage is supplied through R_4.

Carbon potentiometer R_5 serves as the collector load for the output stage, with the amplified R.F. signal appearing across it coupled through D.C. blocking capacitor C_4 to the OUTPUT binding post. The setting of this control determines the output signal level.

Two other circuit components are of interest. Resistor R_3, shunted by switch Sw_2, can be used to reduce the D.C. applied to the oscillator and amplifier circuits and thus to acts as a "Coarse" control on output level. Capacitor C_1 serves as a general by-pass across the power supply.

PARTS LIST:

R_1, R_4 — 220K, ½ W. Carbon resistors.
R_2 — 270 ohm, ½ W. Carbon resistor.
R_3 — 10K, ½ W. Carbon resistor.
R_5 — 1K Carbon potentiometer, Linear Taper (*Centralab*).
C_1 — 0.1 Mfd., 200 volt paper capacitor.
C_2 — 330 Mmf. tubular ceramic capacitor (*Centralab* No. D6-331).
C_3 — 800 Mmf. disc ceramic capacitor (*Centralab* No. DD-801).
C_4 — 0.01 Mfd., 600 volt tubular paper capacitor.

L_1 — 2.5 MHy R.F. Choke (*Superex* No. F-25).
Sw_{1a}, Sw_{1b} — 2 Pole, 3 Pos. Rotary switch (*Centralab* No. PA-1005).
Sw_2, Sw_3 — SPST toggle switches.
B_1 — 6 volt battery (*Burgess* No. Z4).
Crystals — Quartz crystal, 455 KC, 500 KC, 1000 KC (*Hupp Electronic Corp.* Type 20).
Transistors — (2) *Raytheon* type CK760/2N112.
MISC. — (2) transistor sockets; (2) control knobs; (2) binding posts; (3) Crystal sockets; small plastic handle; aluminum case (*ICA* No. 29440); *Tekni-Label* decals; (4) rubber feet; machine screws, hex nuts, terminal strips, wire, solder, Misc. Hdwe.

CONSTRUCTION HINTS: Typical construction is clearly shown in the exterior and interior views of the author's model, given in Figs. 9-5 and 9-6, respectively. Although the entire instrument is assembled in an aluminum box measuring only 3″ x 4″ x 5″, there is no crowding of parts, nor any need to use subminiature components. An external "factory-built" appearance is obtained by using decals to label all controls. These are applied after all machine work (drilling, etc.) is finished, but before parts are mounted, and are protected, after application, with two coats of clear plastic spray.

Although the transistor sockets are mounted on small subchassis, bent from scrap pieces of sheet metal, the crystal sockets are soldered directly to lugs on the CRYSTAL SELECTOR switch (Sw_1). The battery (B_1) is held in place by a simple "Z" bracket fastened to the side of the case with a single machine screw and nut.

After the wiring is completed, re-check all connections *before* installing the transistors. Make sure there are no wiring errors, nor accidental shorts between bare leads. Pay especial attention to the battery connections . . . remember that polarity is important.

OPERATION AND USE: The transistorized *R.F. Alignment Generator* is somewhat easier to use than a conventional R.F. Signal Generator for two reasons . . . first, with no "warm-up" time required, the instrument can be turned "ON" and "OFF" as often as is needed; secondly, frequency is selected simply by turning the CRYSTAL SELECTOR switch instead of by setting a hard-to-read dial. The ATTENUATOR (R_5), is used as a fine or "vernier" control on the output level, while the CONTROL switch (Sw_2) is used as a "coarse" control. Maximum output is obtained when R_3 is shorted out by Sw_2 . . . a peak signal of about 6 volts is available, or considerably more than is furnished by the usual service instrument. This *reserve* is valuable for checking sets that are far out of alignment.

The instrument furnishes an *unmodulated* (CW) signal. This means that a receiver's AVC voltage should be used as an indication of output rather than an audio signal level. When checking the calibration of a Short-Wave or Communications Receiver, the set's B.F.O. must be "ON".

To use in alignment, connect a shielded lead from the OUTPUT terminals to the receiver. Use a "dummy" antenna of the type recommended by the receiver manufacturer. Connect a VTVM or high resistance D.C. voltmeter across the receiver's detector load resistor. Set the *R.F. Alignment Generator's* CRYSTAL SELECTOR switch to 455 KC and turn up the ATTENUATOR control until a reading is obtained on the voltmeter; switch the CONTROL to "HI" output if necessary. Next, using an insulated alignment tool, adjust the I.F. transformers of the receiver for maximum output reading. Use the minimum signal necessary to obtain a good voltmeter reading to avoid overloading the receiver. Turn back the ATTENUATOR control if necessary.

With the I.F. transformers peaked, switch to the 500 KC crystal and set the receiver's dial to 1500 KC. Adjust the receiver's local oscillator trimmer capacitor (usually located on the tuning capacitor section with the *smaller* plates) for a peak voltmeter reading. Adjust the pre-selector trimmer capacitor for a peak reading. Next, tune the receiver to the 500 KC position and, "rocking" the dial, adjust the "padder" capacitor (or oscillator coil's "slug") for a peak output. Recheck the 1500 KC adjustment.

To use the instrument for checking the calibration of a Communications Receiver, set the CRYSTAL SELECTOR switch to the 1000 KC crystal. Turn "ON" the receiver's B.F.O. With the *R.F. Alignment Generator* set to near maximum output, you should pick up "beats" at 1 megacycle (1 MC) intervals up to as high as your receiver will tune . . . generally from 30 to 50 MC. If the receiver is properly calibrated *and aligned* these beat signals should be obtained at exact dial settings . . . that is, 1 MC, 2 MC, 3 MC, 4 MC, 5 MC, 6 MC, etc.

THE SIGNAL SQUIRTER: By far the majority of electronic test instruments are designed primarily for general purpose applications, even though special models may be manufactured for the radio-electronic repair and servicing trades. Not so the instrument shown in Figs. 9-7 and 9-8 and shown in use in Fig. 9-9. This instrument, named *The Signal Squirter* by the author, has been designed *specifically* for use as a servicing tool. It is intended to simplify the application of the "Signal Injection" diagnostic method in servicing amplifiers, broadcast receivers, TV sets, and similar equipment.

The "Signal Injection" test method is generally applied to "dead" or "weak" receivers or amplifiers. Normally, an audio or R.F. test signal is obtained from a conventional Signal Gen-

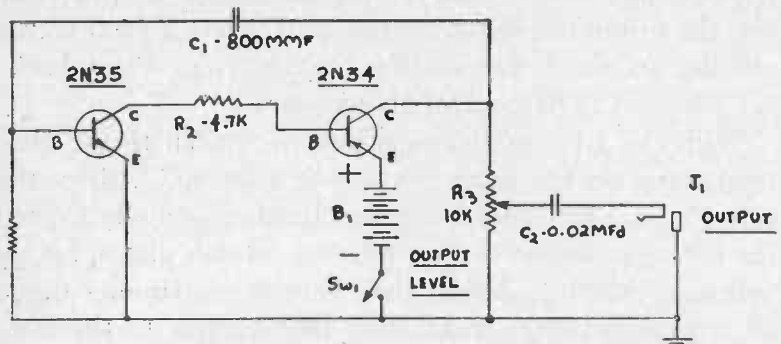


Fig. 9-7.—Circuit for The Signal Squirter.

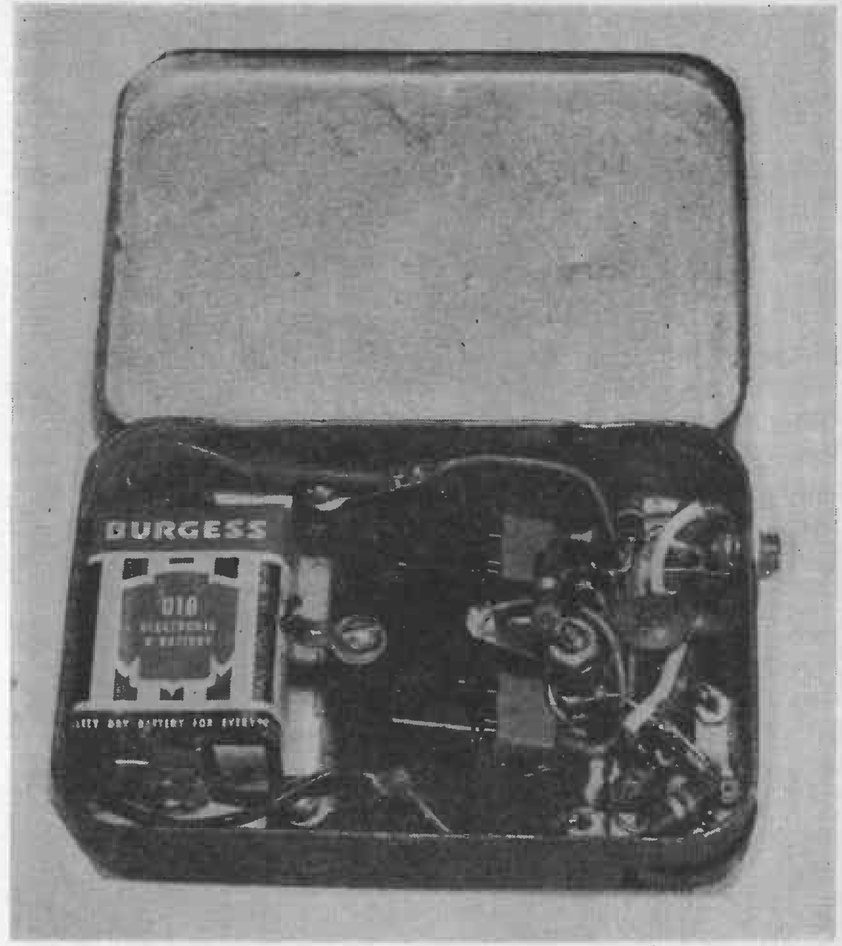


Fig. 9-8.—Interior view of The Signal Squirter.

erator and applied to various stages in the defective equipment, starting at the "output" stage and working back towards the first or "input" stage. The type of signal used, whether A.F. or R.F., as well as its frequency, is changed in accordance with the equipment being tested and the stage checked. When servicing a typical radio receiver, the technician would find it necessary to change his signal several times . . . for an audio signal is used for checking the audio stages, a modulated R.F.

Fig. 9-9.—Using The Signal Squirter to service a transistorized receiver.

signal at the I.F. value for checking the I.F. amplifiers and detector, and, finally, a modulated R.F. signal at a broadcast frequency for checking the R.F. and converter stages. Simply changing frequencies and leads can require as much time as the tests themselves.

The Signal Squirter permits the "Signal Injection" test method to be applied *without* changing test leads, *without* changing frequencies, and *without* changing instruments. It supplies a complex signal which is basically an A.F. signal, but which contains rich harmonics through the AM Broadcast Band. *In practice, it may be used to inject a signal at any point in a typical AM receiver or audio stage.* Its probe is simply touched to the input of the stage to be checked. From its application, it is easy to see how the author derived the instrument's name.

This instrument, working from its own self-contained battery, requires no line cord, meter, or auxiliary equipment for its operation. And it works equally well with both vacuum-tube operated and transistorized equipment. What's more, the instrument is so small that it can be slipped easily into a tool box . . . or even into the serviceman's shirt pocket . . . making it a truly portable instrument!

CIRCUIT DESCRIPTION: Referring to Fig. 9-7, we see that *The Signal Squirter* is basically a two-stage direct-coupled complementary amplifier, with capacity coupling between the "input" and "output" to convert the amplifier into an audio frequency multivibrator. The common-emitter circuit configuration is used in both stages. Power is supplied by a single 15 volt Hearing Aid battery (B_1), controlled by a SPST switch (Sw_1).

In operation, a type 2N35 NPN transistor is direct-coupled to a type 2N34 PNP unit through resistor R_2. This resistor serves simply to limit D.C. current flow between stages and thus to protect the transistors. It is not essential to circuit operation. Resistor R_1 serves as the base resistor for the first stage; because of the direct-coupling, no base resistor is needed for the second stage.

A potentiometer is used as the collector load for the second stage and also serves as the OUTPUT control (R_3). The "output" of the second stage is coupled back to the base of the first stage through capacitor C_1, changing the amplifier into a multivibrator.

The output signal, appearing across R_3, and coupled through C_2 to OUTPUT jack J_1, is a sharp pulse, recurring at an audio rate. The pulse type of waveform is a complex signal and contains higher frequency harmonics of considerable amplitude. In this case, the harmonics extend into, and through, the AM Broadctst Band (above 1600 KC), even though the basic pulse repetition rate is at an audio frequency. Thus, in effect, the circuit supplies both Audio and Modulated R.F. signals over a wide frequency range *simultaneously*.

PARTS LIST:

R_1 — 47K, ½ W. Carbon resistor.
R_2 — 4.7K, ½ W. Carbon resistor.
R_3 — 10K, subminiature potentiometer (*Centralab* No. B16-2—).
C_1 — 800 Mmf., disc ceramic (*Centralab* DD-801).
C_2 — 0.02 Mfd., disc ceramic (*Centralab* DD-203).
Sw_1 — SPST switch, on R_3.
B_1 — 15 volt Hearing Aid Battery (*Burgess* No. U10).
J_1 — Subminiature open circuit jack (*Telex* No. 9240).
Transistors—(1) *Sylvania* type 2N35; (1) *Sylvania* type 2N34.
MISC. — (2) transistor sockets; Subminiature plug (*Telex* No. 9231); Small metal case; Ground lugs, machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The circuit is simple and non-critical and, therefore, subject to straightforward construction. No special precautions need be observed regarding either layout or lead dress. Of course, the builder should follow the usual "rules" of good wiring practice as far as transistor circuitry is concerned . . . battery polarity should be observed, care should be taken not to overheat the transistor leads, and the wiring should be double-checked for errors before the transistors are installed.

Mechanically, the *Signal Squirter* may be housed in either a plastic or a metal case, but, from an electrical viewpoint, the metal housing is preferred because of its shielding characteristics. The author's model, shown in the photographs, was housed in a flat metal case. Some builders may prefer to use a cylindrical housing, however, to give the completed instrument a conventional "Probe" appearance.

The output lead is a short length of fairly heavy bus bar, attached to the "hot" (center) terminal of a plug fitting jack J_1. In use, the instrument is held in one hand and this lead used as a test probe. For some work, a ground lead may be desirable . . . for such applications, a short length of flexible hook-up wire attached to the metal case, and with a clip at the far end, should be satisfactory.

OPERATION AND USE: The average technician should require relatively little practice to become skillful in using *The Signal Squirter*. Typical usage is illustrated in Fig. 9-9. The instrument may be held in either hand, with one finger used to manipulate the OUTPUT control and "ON-OFF" switch. The test probe is simply touched to the point at which the signal is to be "injected" into the equipment under test. In some cases, depending on the type of equipment being serviced and the defect encountered, a "ground" lead connected between the instrument's case and the chassis of the equipment being tested will increase the signal level. This should be needed only in rare cases, however.

When servicing a piece of "dead" or "very weak" equipment, the *Signal Squirter* is used is inject a signal into each stage, starting at the output stage and working back towards the input. The output level should increase as each stage adds its gain. Where the output signal first drops appreciably, or disappears entirely, the defective stage has been located! Further tests in that stage, using a conventional VoltOhmmeter, should isolate the defective part or parts.

The OUTPUT control is used to set the desired signal level. In most work, the control is first set for maximum output, then gradually turned back as the signal is injected into earlier stages. Care must be taken not to overload any one stage for this, in itself, may cause improper operation of the equipment and lead to false conclusions.

SQUARE-WAVE GENERATOR: A symmetrical rectangular waveform, or "square-wave", is made up of a fundamental sine wave signal, plus odd harmonics of gradually decreasing amplitude. Since the signal's waveshape depends on higher frequency harmonic content, as well as their relative amplitude, any loss or deterioration of higher frequency signals, or any increase in their amplitude, will result in a change from the normal square-wave signal. Because of this characteristic, one of the quickest ways to determine the approximate frequency response of a non-tuned amplifier is to apply square-wave signals at selected frequencies and to note any changes in waveform.

A "flat" amplifier will pass square-wave signals without changing the waveshape. An amplifier with limited high frequency response, poor low frequency response, or a peak in its characteristics, will distort the square-wave signal. The type of distortion varies with the frequency response of the amplifier. A skilled technician, by observing both the "input" and "output" square-wave signals of an Oscilloscope, can draw valid conclusions about the characteristics of the amplifier under test.

The circuit of a transistorized *Square-Wave Generator,* supplying signals at four different frequencies, and designed primarily for testing audio and instrument amplifiers, is given in Fig. 9-10. The instrument is shown connected to a *Heathkit* Oscilloscope in Fig. 9-11, while an interior view is given in Fig. 9-12.

CIRCUIT DESCRIPTION: Three transistors are used in the instrument . . . one PNP and two NPN units. A type 2N34 PNP transistor and a type 2N35 NPN unit are connected to form a direct-coupled complementary multivibrator. A second

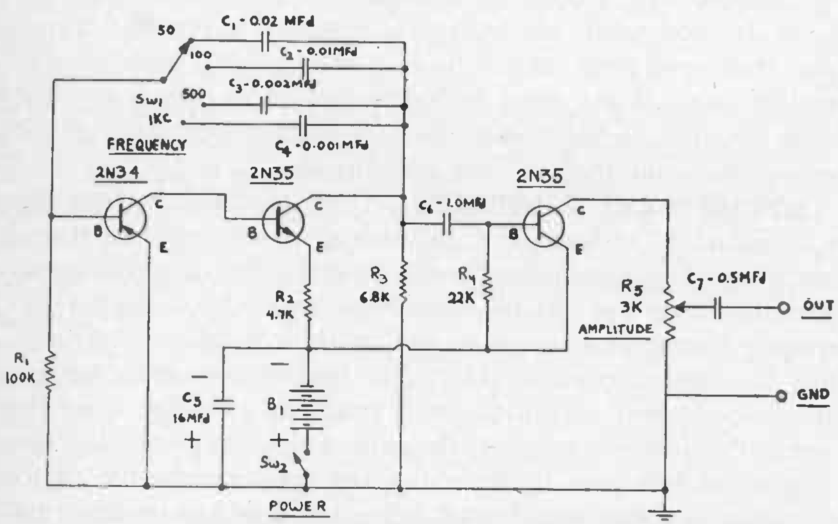


Fig. 9-10.—Schematic of a simple 4-frequency Square-Wave Generator.

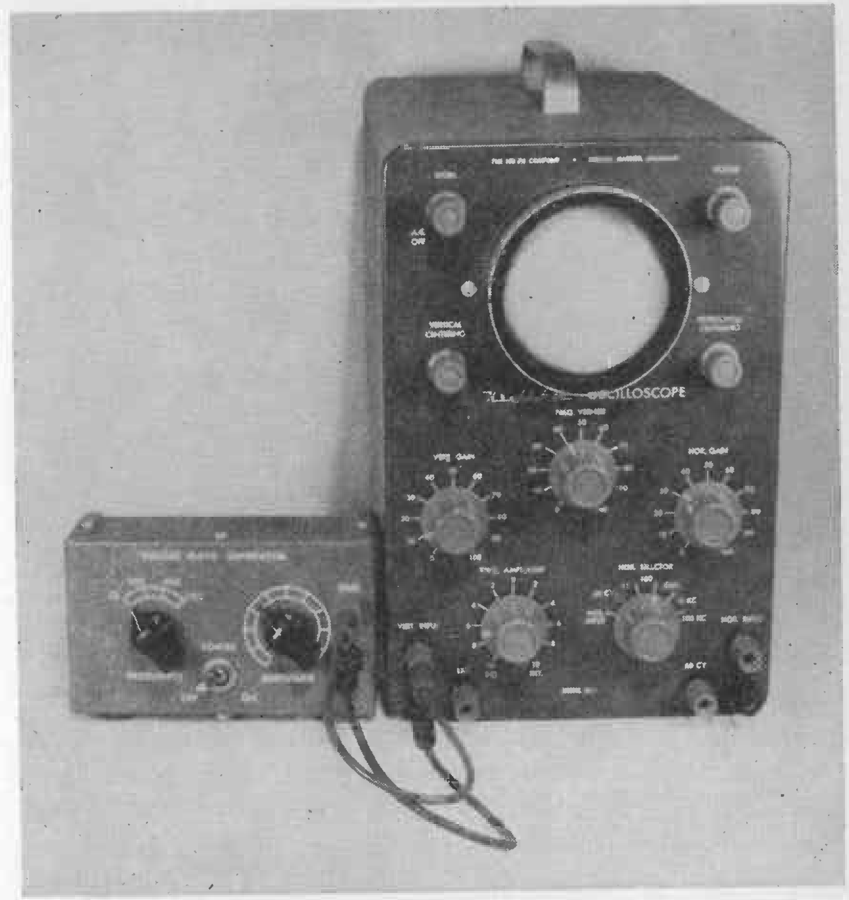


Fig. 9-11.—The Square-Wave Generator connected to an Oscilloscope.

type 2N35 is used as an output amplifier-clipper. Operating Power is supplied by a single 15 volt Hearing Aid battery (B_1), controlled by SPST toggle switch Sw_2.

Refer to Fig. 9-10. A 2N34 and 2N35 transistor are direct-coupled in a complementary multivibrator very similar to that used in the *Signal Squirter* described in an earlier project. But there are several important differences. First, a selector switch, Sw_1, is used to choose any one of several feedback capacitors (C_1, C_2, C_3, C_4), thus providing a simple control on operating

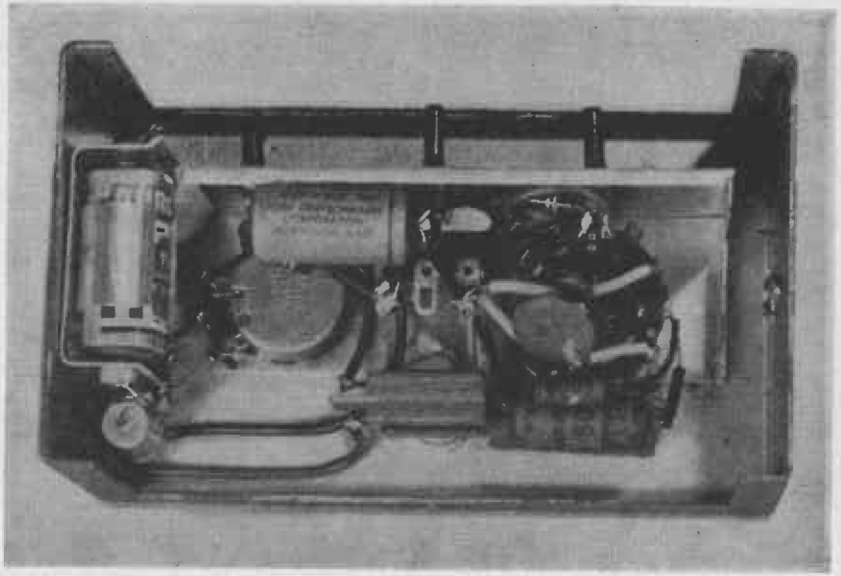


Fig. 9-12.—Interior view of the transistorized Square-Wave Generator.

frequency. Secondly, an unby-passed emitter resistor, R_2, has been added to the second stage; this resistor changes the output from a narrow pulse to a symmetrical rectangular wave. The use of R_2, in the emitter circuit of the second stage, eliminates the need for an interstage current limiting resistor, so the collector of the first stage is connected *directly* to the base of the second stage. R_1 serves as the base resistor for the first (2N34) stage, while R_3 serves as the output load.

The signal appearing across R_3 is coupled through capacitor C_6 to the base input of the output stage, a common-emitter amplifier operated without bias current in order to obtain "clipping" action, further "squaring" the signal waveform. R_4 serves as the base resistor for this stage, with potentiometer R_5 serving the dual function of collector load and AMPLITUDE control. The final output signal is coupled through C_7 to the OUTPUT terminal.

PARTS LIST:

R_1 — 100K, ½ W. Carbon resistor.
R_2 — 4.7K, ½ W. Carbon resistor . . . *see text.*
R_3 — 6.8K, ½ W. Carbon resistor . . . *see text.*
R_4 — 22K, ½ W. Carbon resistor.
R_5 — 3K Carbon potentiometer, Linear Taper (*Centralab* No. B-8).
C_1* — 0.02 Mfd., 200 volt tubular paper capacitor.
C_2* — 0.01 Mfd., disc ceramic capacitor (*Centralab* DD-1032).
C_3* — 0.002 Mfd., 200 volt tubular paper capacitor . . . or disc ceramic.
C_4* — 0.001 Mfd., disc ceramic capacitor (*Centralab* DD-102).
**Frequency determining capacitors . . . see text.*
C_5 — 16 Mfd., 40 volt electrolytic capacitor (*Barco* No. P40-16).
C_6 — 1.0 Mfd., 200 volt tubular paper capacitor.
C_7 — 0.5 Mfd., 400 volt tubular paper capacitor.
Sw_1 — One Pole, 4 Position rotary switch.
Sw_2 — SPST Toggle switch.
B_1 — 15 volt Hearing Aid battery (*Burgess* No. Y10).
Transistors—(1) *Sylvania* type 2N34; (2) *Sylvania* type 2N35.
MISC. — (3) transistor sockets; (2) control knobs; (2) binding posts; Battery box (*Austin-Craft* No. 136); metal case (*ICA* No. 29441); (4) rubber feet; terminal strips, machine screws, hex nuts, ground lugs, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The construction details of the author's model are clearly evident in the exterior and interior views of his instrument, given in Figs. 9-11 and 9-12 respectively. The entire circuit, including battery, is easily assembled into the 3″ x 5¼″ x 2″ aluminum box specified in the *PARTS LIST;* there is no crowding of parts. A small aluminum sub-chassis, bent from scrap metal, supports the three transistor sockets. For a final professional "touch", the completed instrument was labeled with white decals.

Since neither lay-out nor lead dress are critical, a prospective builder may either follow the author's model or make up a new arrangement to suit his specific requirements. Care should be taken to keep signal leads short and direct to minimize circuit distributed capacities, however. And, of course, special attention should be paid to battery and electrolytic capacitor polarities.

Although circuit *lay-out* is not critical, the electrical values may need some adjustment for optimum performance. These adjustments can be made best *after* wiring is completed and double-checked and *after* the instrument has been given a preliminary test by checking its output with an Oscilloscope. Specifically, adjustment must be made for output *frequency, symmetrical waveform,* and *best quality waveshape.*

The output frequency is changed by changing the values of capacitors C_1, C_2, C_3 and C_4. The frequencies of 50, 100, 500, and 1,000 (1 KC) C.P.S. used in the author's model were chosen arbitrarily for audio applications. To obtain *exact* frequencies at any specific value, it may be necessary to use selected capacitors, due to normal parts tolerances. As an alternative, each capacitor may be shunted with smaller units to "trim" to exact frequency.

A complementary multivibrator of the type used in this instrument normally delivers a narrow output pulse. To obtain a symmetrical output waveform or true "square" wave, emitter resistor R_2 has been added to the circuit. The ratio of R_2 and R_3 will determine the symmetrical qualities of the output waveform . . . that is, whether the *positive* and *negative* half-cycles of the signal are of equal time duration. Adjust these two resistors experimentally . . . a *Resistance Substitution Box* is handy for this job . . . until the desired waveform is obtained. Remember that all values listed in Fig. 9-10 and the *PARTS LIST* are *nominal* only . . . final values are determined experimentally to match the individual transistors used.

The final check is for the *quality* of the output waveform. The signal should have straight sides and a flat top. If the signal is distorted, it may be that adequate clipping is not obtained in the output stage. Try interchanging the two 2N35 transistors . . . some of these work better as clippers than others. Also try varying the bias on this stage. Although normally operated without bias, a small bias current may be added by conecting a resistor from the base terminal to circuit ground . . . this may have a value ranging from as low as 12K to as high as 220K. Determine the best value experimentally.

OPERATION AND USE: The transistorized *Square-Wave Generator* has three controls and two output terminals. The instrument is turned "OFF" and "ON" by the POWER switch (Sw_2); no warm-up time is required. The square-wave repetition rate or frequency is set to specific values by the FREQUENCY switch (Sw_1). The output level is adjusted by the AMPLITUDE control (R_5); normally, the minimum signal level needed to obtain observable results is used, to avoid possible overload of the equipment under test. An Oscilloscope is a *required* accessory.

To check the response of an amplifier, connect the OUTPUT terminals of the *Square-Wave Generator* to the INPUT of the unit. Use short, direct leads to minimize distributed capacities. An Oscilloscope is used to check *both* the output of the generator *and* the output of the amplifier and the waveforms are compared. Poor low frequency response and phase shift is indicated by a "tilt" of the top of a 50 cycle signal. Poor high frequency response is indicated by a "rounding" of the forward square edge of a 1 KC signal. A peak in amplifier response may cause either a small "pip" or upward swelling on the top of the square wave (which should be flat) or, in extreme cases, may cause a small "wiggle" in the output signal, due to transient oscillation brought about by shock excitation.

For a fairly thorough test, use all four output frequencies, noting the response of the amplifier to each. Try varying the AMPLITUDE control to make sure there is no overload in the amplifier . . . output waveform should remain the same, except for height, regardless of the AMPLITUDE control's setting, up to the point where overload occurs.

Generally speaking, it is possible, with practice, to determine an amplifier's approximate response characteristics to about the 10th or 20th harmonic of the square-wave signal used. Thus, a 1KC square-wave serves as a check to about 10,000 or 20,000 C.P.S., depending on the skill of the operator.

PULSE GENERATOR: While all of the test instruments described thus far in this Chapter have had important applications as radio-electronic servicing and repair aids, even if not designed expressly for such work, the instrument shown in Figs. 9-13 and 9-14 finds little, if any, application in the main-

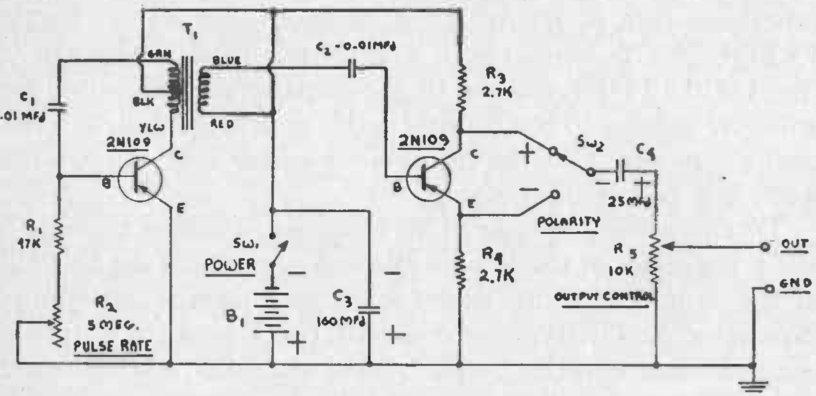


Fig. 9-13.—Circuit of a transistorized Pulse Generator delivering both positive-going and negative-going pulses.

tenance field. Its primary use is in the experimental laboratory. The *Pulse Generator* supplies a repetitive signal of relatively short time duration, of variable output amplitude, and with either a positive-going or negative-going characteristic.

Since the *Pulse Generator* serves as a source of a special type of signal waveform, its applications vary considerably with the needs and interests of the individual user. Typical applications include . . . checking of delay lines and special circuit networks, use as a timing marker, triggering sweep circuits, transient response tests of wide-band amplifiers, shock-excitation of "ringing" circuits, and tests of electronic counter circuits.

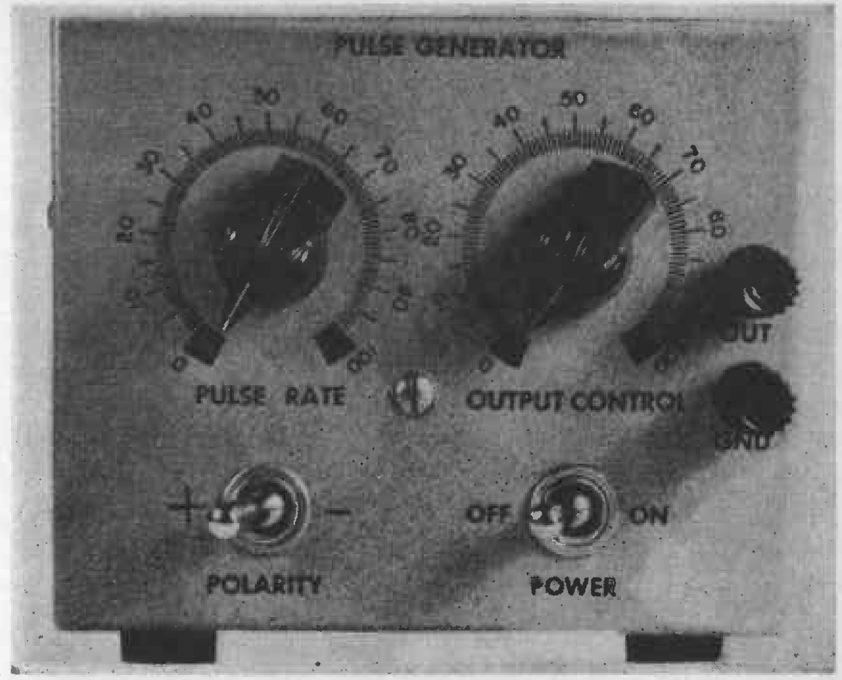


Fig. 9-14.—Exterior view of the Pulse Generator.

CIRCUIT DESCRIPTION: As we can see by reference to the schematic diagram given in Fig. 9-13, the transistorized *Pulse Generator* uses two PNP transistors. One is connected as a blocking oscillator, using a common-emitter circuit configuration; the other serves as an output amplifier, and uses a split-load circuit arrangement to obtain signals with opposite polarity characteristics. Operating power is supplied by a single 6 volt battery, B_1, controlled by a SPST switch (Sw_1) and bypassed by a capacitor (C_3) to minimize interstage coupling as well as to absorb switching transients.

In operation, transformer T_1 serves a dual purpose. Its center-tapped primary winding supplies the feedback necessary to start and sustain oscillation in the first stage, while its secondary winding serves to couple the oscillator's signal to the output amplifier stage. While the signal's waveshape is determined primarily by the characteristics of the oscillator transformer (T_1), the frequency or *Pulse* repetition *Rate* is determined by the R-C time constant in the base circuit of the oscillator . . . . that is, by coupling capacitor C_1 and base resistors R_1 and R_2. By making R_2 variable, we can provide a smooth control over PULSE RATE. The upper frequency limit is determined by R_1 and C_1, the lower limit by the total value of R_1 and R_2, plus C_1.

The pulse signal obtained from the blocking oscillator stage is coupled through D.C. blocking capacitor C_2 to the output amplifier. This stage serves to provide signals of both positive and negative polarity, and to act as a "buffer" to isolate the oscillator from the output, but provides little or no signal gain. Positive-going signal pulses are developed across collector load R_3; negative-going pulses across emitter load R_4. A SPDT switch, Sw_2, determines which signal is coupled through capacitor C_4 to the OUTPUT CONTROL, potentiometer R_5.

PARTS LIST:

R_1 – 47K, ½ W. Carbon resistor.
R_2 – 5 Megohm Carbon potentiometer, Linear Taper (*Centralab* B-87).
R_3, R_4 – 2.7K, ½ W. Carbon resistors (*see text*).
R_5 – 10K Carbon potentiometer, Linear Taper (*Centralab* B-14).
C_1, C_2 – 0.01 Mfd., disc ceramic capacitors (*Centralab* DD6-1032).
C_3 – 160 Mfd., 6 volt electrolytic (*Barco* No. P6-160).
C_4 – 25 Mfd., 25 volt electrolytic (*Barco* No. P25-25).
T_1 – Transistor input transformer, 100K to 1500 ohms (*Argonne* AR-102).
Sw_1 – SPST Toggle switch.
Sw_2 – SPDT Toggle switch.
B_1 – 6 volt battery (*Burgess* No. Z4).
Transistors – (2) *RCA* type 2N109.
MISC. – (2) transistor sockets; (2) control knobs; (2) binding posts; aluminum case, 3″ x 4″ x 5″ (*L.M.B.* No. 140); (4) rubber feet; Machine screws, hex nuts, wire, solder, terminal strips, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The author's model of the *Pulse Generator* was assembled in a standard aluminum box measuring 3″ x 4″ x 5″, with plenty of room to "spare". A careful builder should have no difficulty assembling the instrument in an even smaller case . . . although any reduction in panel space might crowd the controls. Signal leads should be kept short and direct to minimize distributed capacities, but, otherwise, circuit lay-out and wiring are not critical. Of course, battery and electrolytic capacitor polarities should be observed.

The "factory-built" appearance of the author's model, as shown in Fig. 9-14, is due almost entirely to the use of commercially available decals for labeling the instrument and controls, plus the use of an aluminum case pre-finished with a gray hammerloid enamel.

There is only one point that might give the builder some trouble . . . output resistors R_3 and R_4 may have to be adjusted. In most cases, these two resistors can have the same value. However, where the builder wishes the positive-going pulse and the negative-going pulse to have *exactly the same amplitude* for a given setting of R_5, then the final values of these two resistors may have to be determined experimentally. As an alternative, a 5K potentiometer may be substituted for *either* R_3 or R_4. After construction and testing, this control is adjusted so that the two output pulses are of equal amplitude.

OPERATION: Typical positive-going output pulses, as supplied by the transistorized *Pulse Generator,* are shown in Fig. 9-15. As can be seen, the pulses are reasonably narrow and have a sharp leading edge. Except for polarity, the positive-going and negative-going pulses are virtually identical.

The instrument is equipped with four controls and two output binding posts, one of which serves as the GND terminal. The POWER switch and POLARITY control are simple toggle switches. No warm-up time is required. The pulse frequency, or repetition rate, is set by the PULSE RATE control; in the author's model, coverage was from 40 PPS to 400

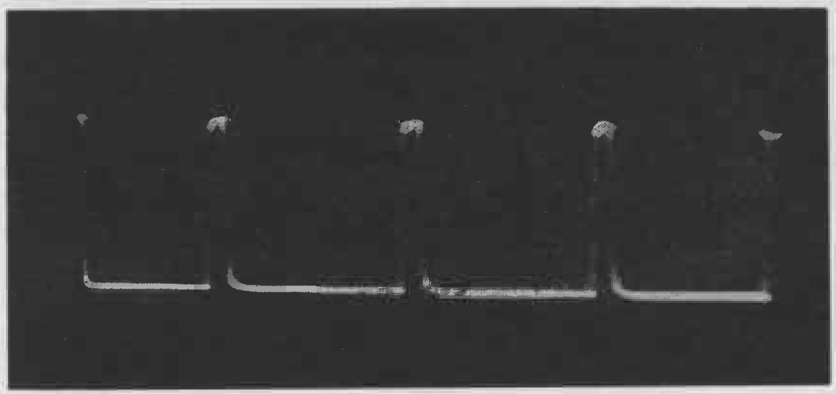


Fig. 9-15.—Positive-going pulses obtained from the instrument shown in Fig. 9-14.

PPS as R_2 was adjusted. The output amplitude is set by the OUTPUT CONTROL (R_5); maximum output of the author's model was approximately 1.5 volts peak . . . an ample signal level for low power and small signal testing. Current drain is very low, so battery life should equal the normal "shelf life" of the battery used . . . measured power consumption of the author's model was *50 microamperes* at 6 volts.

SPECIAL INSTRUMENTS

SINE WAVE CLIPPER: A clipped sine wave may be used as a substitute for a square-wave signal for many basic tests. Thus, an electronics worker who does not feel that his need for a *Square-Wave Generator* is great or pressing enough to justify his purchase or construction of such an instrument may prefer

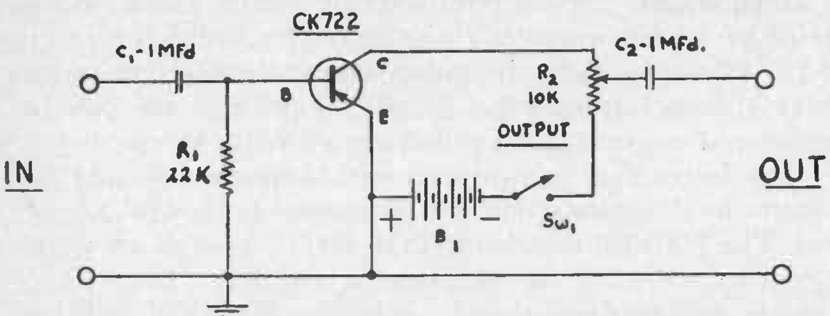


Fig. 9-16.—Schematic of a simple, but useful, test instrument—a Sine Wave Clipper.

to assemble a simple *Sine Wave Clipper* to use in conjunction with his standard A.F. Sine Wave Generator. The circuit for such an instrument is given in Fig. 9-16, while an assembled model is shown in Fig. 9-17 . . . the instrument is so small that it can be held comfortably in the palm of the hand!

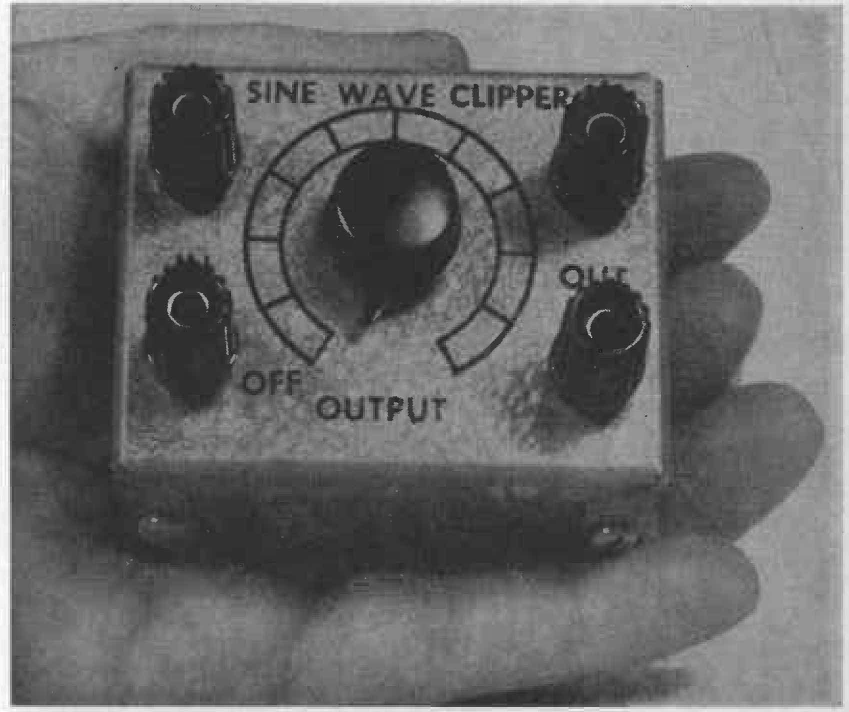


Fig. 9-17.—The Sine Wave Clipper fits easily into the palm of your hand.

CIRCUIT DESCRIPTION: The circuit used is extremely simple, as can be seen by reference to the schematic diagram given in Fig. 9-16. Basically, the *Sine Wave Clipper* is a single stage amplifier using a PNP transistor in the common-emitter configuration, and operated without base bias current. Power is supplied by a 15 volt Hearing Aid battery, B_1, controlled by a SPST switch (Sw_1) mounted on the OUTPUT control.

In operation, capacitors C_1 and C_2 serve as input and output D.C. blocking capacitors, respectively. R_1 serves as the base resistor and OUTPUT control R_2 as the collector load resistor. When a transistor amplifier is operated without bias at fairly high signal levels, it becomes essentially a Class B amplifier, and converts applied signals into relatively narrow pulses with rounded tops. Since some amplification occurs, the output signal level will be greater than the input signal.

If the amplifier has a resistive load (R_2), the collector current can increase with increasing applied signal level only a limited amount . . . that is, to the point where the *entire* supply voltage is dropped across the load resistor. At this point, the rounded tops of the output pulses are clipped off and the output signal becomes a rectangular pulse, with straight sides and flat tops and bases . . . for practical purposes, an unsymmetrical square-wave, and it may be used as a square-wave for quick circuit tests!

Thus, when properly driven, the *Sine Wave Clipper* supplies pulse signals.

PARTS LIST:

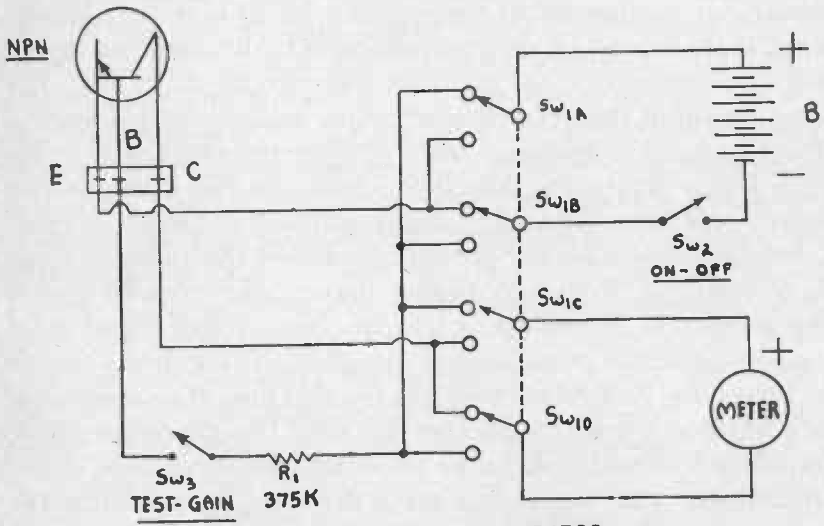
R_1 — 22K, ½ W. Carbon resistor.
R_2 — 10K Carbon potentiometer, Linear Taper (*Centralab* B-14).
C_1, C_2 — 1.0 Mfd., 200 volt metallized paper capacitors.
Sw_1 — SPST switch, on R_2.
B_1 — 15 volt Hearing Aid battery (*Burgess* Y10).
Transistor — (1) *Raytheon* type CK722.
MISC. — Transistor socket; control knob; (4) binding posts; battery box (*Austin-Craft* No. 136); aluminum case (*ICA* No. 29435); Terminal strips, ground lugs, machine screws, hex nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The average builder should have little or no difficulty assembling the *Sine Wave Clipper* into the small case shown in the photograph and specified in the *PARTS LIST* if he takes time to plan component arrangement *prior* to starting assembly and wiring. Layout is noncritical, but all signal leads should be kept short and direct. The "factory-built" appearance of the model was obtained by labeling the instrument with black decals. Available through most radio parts distributors, these decals are applied *after* machine work is finished, but *before* parts are mounted and wiring started. The decals should be protected by at least two coats of clear lacquer or Acrylic plastic for maximum life.

OPERATION: A standard A.F. Sine Wave Generator is connected to the INPUT terminals and the OUTPUT terminals are connected to the equipment to be tested. Fairly short leads should be used to minimize high frequency signal loss due to distributed capacities. For proper drive and clipping, an input signal of between three and six volts is needed (from a standard 600 ohm source). The transistorized *Audio Sine Wave Generator* described earlier in this Chapter can supply sufficient drive *only* if an auxiliary amplifier is used. Good quality signals may be obtained over the range of from 30 to 30,000 C.P.S., with proper drive. Maximum output is approximately 15 volts peak-to-peak, but a lower signal level is easily obtained by adjusting the OUTPUT control.

To use the *Sine Wave Clipper* for checking the response of an amplifier, simply connect its OUTPUT to the input of the amplifier. Use an Oscilloscope to observe the waveshape of the clipped sine wave signal applied to the amplifier as well as the outut signal obtained from amplifier. Note any deterioration of signal waveform. A "rounding" of the sharp leading edge of the pulse indicates poor high frequency response. A "tilt" in the flat base (or top) of in the signal indicates poor low frequency response or severe phase shift. Use a 50 to 100 C.P.S. signal for checking the low frequency response . . . a 5 to 10 KC signal for checking high frequency response. Basic waveform analysis is similar to that used in tests with a *Square-Wave Generator* (which see).

TRANSISTOR CHECKER: Experimenters and servicemen alike need some simple method for checking their transistors, at least until such time that their work can justify the purchase of a laboratory type tester, such as the instrument shown and described in Chapter 13. From a practical viewpoint, there are three things a worker should know for a simple qualitative (*Good* or *Bad?*) evaluation of a transistor: Is the transistor "leaky" (or shorted)? Is the unit "open"? Does the transistor give reasonable gain? The circuit for a simple *Transistor Checker* which will answer these three questions is given in Fig. 9-18, while exterior and interior views of an assembled model are given in Figs. 9-19 and 9-20, respectively. This in-



Courtesy Lafayette Radio

Fig. 9-18.—Circuit for a simple Transistor Checker.

strument uses no expensive precision parts and requires no difficult-to-make calibrations and, therefore, is an excellent project for the student or home experimenter. It is suitable for checking both PNP and NPN junction triode transistors.

CIRCUIT DESCRIPTION: Refer to the schematic diagram given in Fig. 9-18. The *Transistor Checker* makes a *static* (D.C.) test of the transistor's characteristics. Power is supplied by a self-contained 15 volt Hearing Aid battery (B_1), controlled by SPST toggle switch Sw_1, while a D.C. Milliammeter serves as an indicating device.

In operation, the four-pole-two-position SELECTOR switch Sw_1 acts to reverse the battery and meter polarities, to permit testing both PNP and NPN units. In the "TEST" position

Fig. 9-19.—Author's model of the Transistor Checker.

(Sw_3 open), a D.C. voltage is applied to the transistor's emitter and collector electrodes, with the meter in series to read resulting current flow; the transistor's base electrode is left "floating" (open) during this test. If the transistor is "Good", current flow should be low, with its value proportional to the transistor's *collector cut-off current* (I_{co}). A small up-scale meter reading may be expected of some units, but if more than

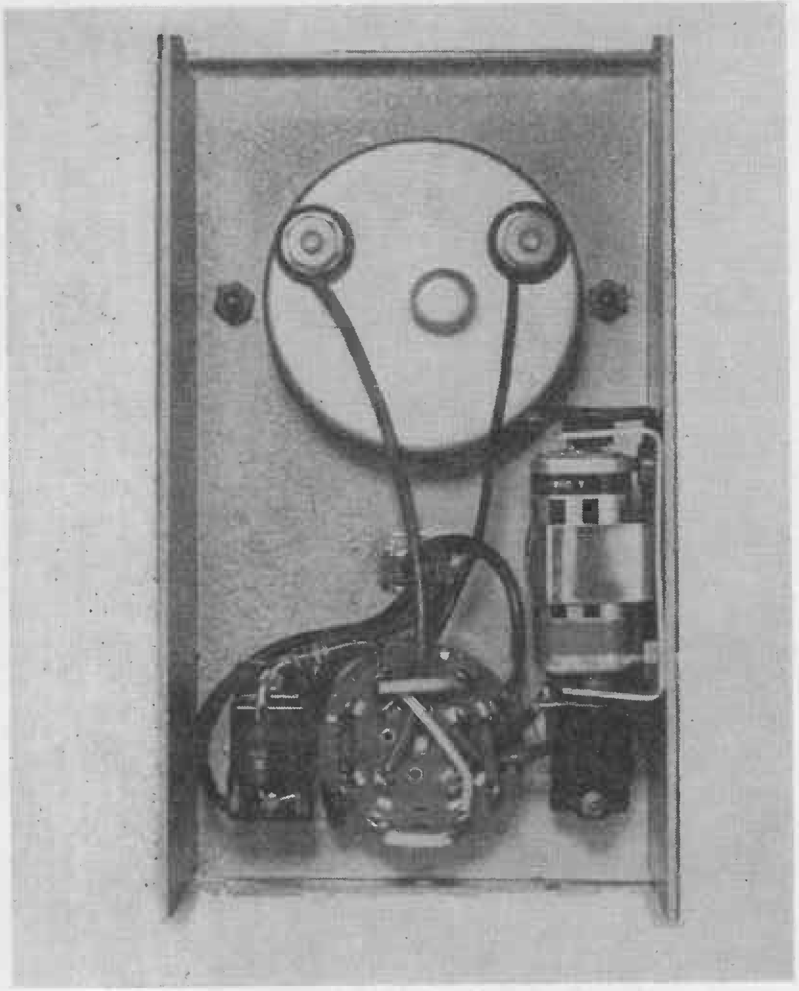


Fig. 9-20.—Interior view of the Transistor Checker.

a quarter-scale reading is obtained, it indicates that the transistor is "leaky" (has high I_{co}). A greater than full-scale reading indicates that the transistor is probably shorted.

When switch Sw_3 is thrown to the GAIN position (closed), a small base bias current is applied through resistor R_1, permitting an increase in collector-emitter current flow. An *upscale* meter reading should be obtained, with the reading pro-

portional to the transistor's gain (*beta*). If there is no current flow indicated on the meter, the transistor is "open". A small reading indicates low gain, a high reading good gain (assuming the "leakage" current to be low).

PARTS LIST:

R_1 – 375K, 1 W. Carbon resistor, 5% tolerance (made up 360K, ½ W. and 15K, ½ W. resistors in series).
Sw_{1A}, Sw_{1B}, Sw_{1C}, Sw_{1D} – 4P-2Pos. Rotary switch
Sw_2, Sw_3 – SPST Toggle switches.
B_1 – 15 volt Hearing Aid battery (*Burgess* No. Y10).
METER – 0-2 Milliamperes D.C. Milliammeter, high resistance coil (*Sterling* No. 835, Type 68N).
MISC. – Transistor socket; Battery box (*Austin-Craft* No. 136); control knob; metal case (*L.M.B.* No. 136); (4) rubber feet; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

(NOTE: Lafayette Radio, 100 Sixth Ave., New York 13, N. Y. offers a "kit" for assembling an instrument of this type.)

CONSTRUCTION HINTS: The lay-out and construction of the author's model is clear from the exterior and interior views given in Figs. 9-19 and 9-20. Black decals were used to label the instrument and controls. Since only D.C. circuits are involved, neither parts arrangement nor lead dress are critical, and since no semiconductors are used in the circuit proper, no special precautions against heat damage are needed. The individual builder may either follow the author's lay-out or make up a new one to suit his own inclinations. After assembly is completed, however, all wiring should be double-checked for accuracy, with special attention to battery and meter polarities.

OPERATION AND USE: Testing a transistor with the *Transistor Checker* is simplicity itself. First, determine the type of transistor to be tested (NPN or PNP), referring to the table given in *Chapter 11* if necessary, and set the SELECTOR switch (Sw_1) accordingly. With Sw_3 in the TEST position, close the ON-OFF switch (Sw_2) and insert the transistor in its socket. A "Good" transistor should cause little, if any, meter deflection . . . the maximum reading should not exceed 0.5 milliamperes (¼ scale deflection). Readings in excess of this value indicate that the transistor has a high cut-off current (I_{co}) and may be considered excessively "leaky" . . . if a greater than full scale reading is obtained, the transistor may be considered "shorted".

To check for gain, throw Sw_3 to the GAIN position (closing it) and again note meter reading. *An up-scale reading should be obtained,* with the reading proportional to transistor gain. If a "zero" meter reading was obtained in the first test, then the transistor's *beta* may be approximated by multiplying the actual meter reading by 25. Thus, if a reading of 1.2 milliamperes is obtained, *beta* is approximately 30. If a greater than "zero" reading was obtained in the first test, this multiplying factor does not hold. High gain transistors may give a greater than full-scale reading . . . this does not indicate a defective unit. On the other hand, if "zero" meter readings are obtained with both the leakage and gain tests, the transistor is open.

In addition to its application in basic transistor tests, the *Transistor Checker* is also valuable for *selecting* transistors with special characteristics. For example, it might be used to select the highest gain transistor out of a group of similar units. Or it might be used for obtaining a "matched pair" of transistors for push-pull applications. Or it could be used for selecting a unit with low D.C. leakage for D.C. amplifier applications.

Several modifications in the basic circuit may be made, if desired by the individual builder. First, since current is drawn *only* when a transistor is inserted in the socket, ON-OFF switch Sw_2 may be left out of the circuit . . . simply connect the battery direct to switch Sw_1B. A second modification, which may appeal to some builders, is the substitution of a push-button switch for Sw_3 in place of the Toggle switch specified in the *PARTS LIST* and shown on the model.

TEST METERS

METER AMPLIFIERS: Some types of technical and scientific work require the measurement of extremely small direct currents—on the order of several microamperes, or less. Meters for measuring such small currents, while available, are generally very expensive and quite delicate, hardly suitable for the comparatively rough usage encountered in a typical laboratory. Fortunately, the sensitivity of a D.C. meter may be increased considerably by adding a direct-coupled transistor amplifier. The overall sensitivity of the combination depends both on the sensitivity of the basic meter movement and on the gain (*beta*) of the transistor used. Gain multiplying factors of 10 to 50 are fairly easy to achieve with commonly available transistors. For higher gains, two or more transistors may be used in cascade.

Two typical *Meter Amplifier* circuits are given in Fig. 9-21. The circuit shown in Fig. 9-21(a) uses a single transistor to drive a meter. The circuit given in Fig. 9-21(b) uses two transistors in cascade to achieve higher gain; in addition, calibra-

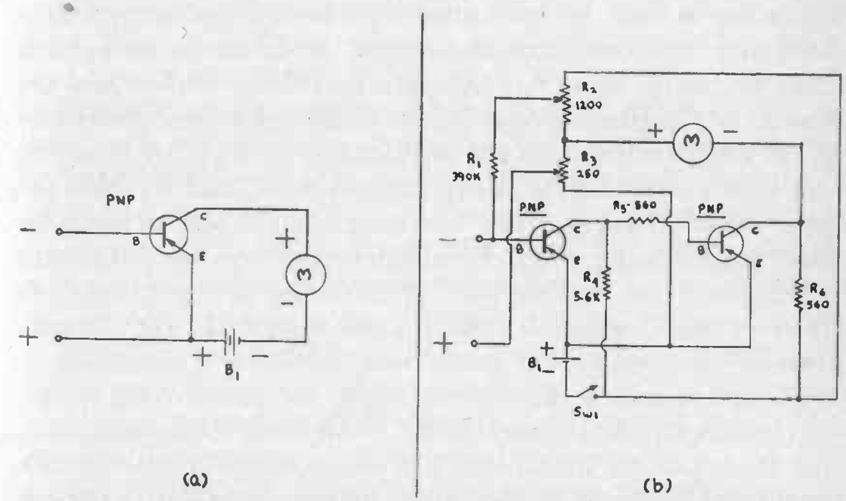


Fig. 9-21.—Circuits for two transistorized Meter Amplifiers—(a) Single Stage and (b) Cascaded Stages.

tion and zero adjustment provision has been added to the latter circuit.

CIRCUIT DESCRIPTION: With junction transistors, the common-emitter circuit is used almost universally for D.C. amplification, except where impedance matching considerations or other factors dictate the use of the common-collector or common-base configurations. The circuit shown in Fig. 9-21(a) represents the *basic* D.C. amplifier. In operation, the transistor is operated without base bias current and meter current is essentially the "leakage" current of the transistor. With a good quality transistor, the "zero input" meter reading should approximate zero. When the amplifier is connected into a D.C. circuit, current flowing through the circuit becomes, essentially, the base "bias" current of the transistor. A flow of bias current allows collector current to flow, giving an up-scale meter reading. Collector current is of much greater magnitude than base current, of course, due to the gain of the transistor. Thus, the gain of this circuit is directly proportional to the *beta* of the transistor used.

Greater gain is obtained when two transistors are connected in cascade, as shown in Fig. 9-21(b). The common-emitter configuration is used in both stages. Although operating essentially like the basic circuit, several refinements have been made to insure more linear operation. First, both stages are biased . . . the bias current for the first stage is determined by R_1, in conjunction with the adjustment of R_2. The bias current of the second stage is determined by R_4 and R_5, plus the "zero input" current of the first stage (and hence, to some extent, on the setting of R_2). Finally, a bridge type output circuit is employed . . . the "upper" arms of the bridge circuit are collector load resistor R_6 and Potentiometer R_2, the "lower" arms of the bridge are potentiometer R_3 and the emitter-collector circuit of the second stage; the meter (M) is connected directly across the bridge. Since bias adjustment control R_2 is part of the output circuit, it contributes a certain amount of feedback to the input, helping to stabilize the circuit with variations in transistor characteristics.

PARTS LIST—Fig. 9-21(a):

B_1 – 1.5 volt to 6 volt battery.
M – Meter . . . 100 microamperes to 2 milliamperes (*see text*).
Transistors – Any small signal PNP type . . . examples, *GE* 2N107, 2N45; *Raytheon* CK722, CK721; *Sylvania* 2N34; *Transitron* 2N34; *Germanium Products* 2N103, 2N98; etc.
MISC. – Small meter case; (2) binding posts; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

PARTS LIST—Fig. 9-21(b):

R_1 – 390K, ½ W. Carbon resistor.
R_2 – 1200 Ohm, Carbon or wirewound potentiometer.
R_3 – 250 Ohm, Carbon or wirewound potentiometer.
R_4 – 5.6K, ½ W. Carbon resistor.
R_5,R_6 – 560 Ohm, ½ W. Carbon resistors.
Sw_1 – SPST Toggle switch.
B_1 – 1.5 to 4.5 volt battery.
M – Meter . . . 100 microamps. to 2 milliamps. (*see text*).
Transistors – See text.
MISC. – Small meter case; (2) binding posts or tip jacks; (2) control knobs; Battery box; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: Construction of either of the two *Meter Amplifier* circuits shown should be simple and straightforward. With only D.C. circuits involved, both lay-out and lead dress are non-critical. There are a few points which the builder should keep in mind, however. First, since most circuit currents are on a low order of magnitude, it is important that circuit resistances be kept low; for this reason, it is recommended that the transistors be wired permanently into the circuit, to avoid the resistances developed in the pressure contacts used in sockets. The usual precautions to avoid overheating of transistor leads should be observed.

Almost any D.C. meter may be used in either circuit, depending on the overall sensitivity desired. Maximum sensitivity will be obtained if an 0-50 or 0-100 Microamperes meter is used, but a more rugged instrument will result if an 0-500 Microamperes or 0-1 Milliampere meter is used. Meters with a full-scale range up to 5 milliamperes are satisfactory, but, for most work, the author suggests the use of meters with a full-scale sensitivity not exceeding 2 Milliamperes.

The builder can follow his own inclinations regarding a choice of transistor types. Almost any low power PNP unit will work in either circuit, although the components values listed for Fig. 9-21(b) are based on the use of medium gain transistors . . . some change from the listed values may be necessary for optimum results. Typical transistor types are . . . *GE's* 2N43, 2N44, 2N45, 2N107; *Raytheon's* CK721, CK722, 2N133; *Transitron's* 2N34, 2N44, 2N45; *Sylvania's* 2N34; *General Transistor's* GT-14, GT-20; *Amperex's* OC-70; *RCA's* 2N104, 2N105; etc. If desired, NPN units may be used in the circuits, *provided* that meter, battery, and input polarities are reversed. Typical NPN types are . . . *GE'S* 2N169, 2N170; *Sylvania's* 2N35; *Germanium Products'* 2N97, 2N98, 2N103; etc. Overall sensitivity of the completed instrument will vary with the gain (*beta*) of the transistors used, of course. If the builder has a choice of units, he should pick transistors having a low collector cut-off current (low I_{co}) . . . such units generally give the best results in D.C. amplifier service.

After the wiring is completed and checked, the instruments must be calibrated against known standards. Either of two methods may be used . . . (a) A calibration "chart" may be prepared, giving actual meter readings versus true reading, and (b) a new meter scale may be drawn and installed in the instrument. Of the two, method (a) is the easiest to carry out, but method (b) results in an easier-to-use instrument.

One further point . . . with the circuit given in Fig. 9-21(a), there is no provision for balancing out the "leakage" current of the transistor, so the *zero input* reading may represent a small up-scale movement of the meter's pointer. This initial reading becomes the new "zero reading".

OPERATION AND USE: With either circuit, application of a D.C. signal to the input terminals with the polarity shown should cause an up-scale movement of the meter's pointer. With the circuit given in Fig. 9-21(a), no preliminary adjustments are necessary. However, if the circuit given in Fig. 9-21(b) is used, potentiometers R_2 and R_3 must be adjusted before measurements are made. The following procedure may be used: (1) ZERO the meter by adjusting R_2; (2) "Short" the input terminals with a 100K resistor and ZERO again; (3) Recheck both adjustments.

D.C. VOLTMETER: Where voltage measurements are to be made with a minimum of circuit loading, it is common practice to use a VTVM or *Vacuum-Tube Voltmeter*. This type of meter has, over a period of years, become almost a "standard" instrument in electronic laboratories. From an operational viewpoint, a VTVM is simply a high impedance meter. Basically, it consists of a high resistance voltage divider, a direct-coupled vacuum tube amplifier, and a sensitive meter movement. The high impedance input is made possible, in part, by the D.C. amplifier used to increase the effective sensitivity of the basic meter. It follows, then, that a transistorized D.C. amplifier, added to a meter, can make possible the semiconductor equivalent of a VTVM. The circuit for such an instrument is given in Fig. 9-22.

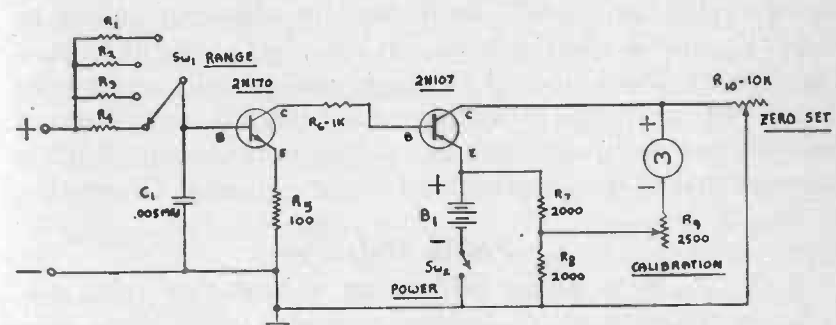


Fig. 9-22.—Schematic of a high impedance transistorized D.C. Voltmeter.

CIRCUIT DESCRIPTION: The transistorized high impedance *D.C. Voltmeter* uses a two-stage amplifier, employing PNP and NPN transistors in a direct-coupled complementary amplifier circuit. The common-emitter circuit configuration is used in both stages. Operating power is supplied by a single 6 volt battery, controlled by SPST switch Sw_2.

Referring to Fig. 9-22, resistors R_1, R_2, R_3 and R_4, selected by selector switch Sw_1, together with the moderate input impedance of the type 2N170 NPN transistor, form a simple series network which limits the maximum base current for a given D.C. voltage applied to the input terminals. These resistors thus serve to determine the different voltage ranges of the instrument. Capacitor C_1, from base to circuit ground, serves to by-pass any A.C. components in the applied D.C. voltage and, otherwise, is not essential to circuit operation. The unby-passed emitter resistor R_5 serves the dual function of helping to stabilize the first stage and of increasing its effective input impedance.

D.C. amplification occurs in the first (NPN) stage, with its output direct-coupled to the second (PNP) stage through current limiting resistor R_6. After additional amplification, the final output is used to drive a simple bridge circuit consisting of the emitter-collector impedance of the 2N107 transistor, R_7, R_8, and potentiometer R_{10}. The indicating meter (M), together with its series calibrating resistor, R_9, is connected directly across the bridge. The bridge circuit is initially balanced under "no signal" conditions by adjusting one of its arms (R_{10}). This effectively cancels the effect of any D.C. passing through 2N107 due to "leakage" and permits zeroing the meter. When a signal is received, the bridge is thrown out of balance and an up-scale meter reading is obtained, which is proportional to the amplitude of the amplified D.C. signal.

PARTS LIST:

R_1, R_2, R_3, R_4 – Range calibrating resistors (*see text*).
R_5 – 100 ohm, ½ W. Carbon resistor.
R_6 – 1K, ½ W. Carbon resistor.

R_7, R_8 – 2K, ½ W. Carbon resistors.
R_9 – 2500 ohm Carbon potentiometer, Linear Taper (*Centralab* B-7).
R_{10} – 10K Carbon potentiometer, Linear Taper (*Centralab* B-14).
C_1 – 0.005 Mfd., disc ceramic (*Centralab* MD-502).
Sw_1 – Rotary selector switch, 1 pole (*see text*) . . . (*Centralab* PA-2001).
Sw_2 – SPST Toggle switch.
B_1 – 6 volt battery (*Burgess* No. Z4).
M – Meter . . . 0-100 Microamperes to 1 Milliamperes (*see text*).
Transistors – (1) *GE* 2N170; (1) *GE* 2N107.
MISC. – (2) Binding posts; (3) control knobs; Battery box (*Austin-Craft* No. 110); metal case (*ICA* No. 29442); (4) rubber feet; small handle; terminal strips; Machine screws, nuts, wire, solder, ground lugs, Misc. Hdwe., etc.

CONSTRUCTION HINTS: With neither parts lay-out nor lead dress critical, this instrument is well suited to assembly using either "conventional" metal chassis construction or the newer etched circuit techniques. An etched circuit board might very well be designed to mount on the back of the meter itself (M). For information on *Printed Circuit Technique*, refer to Chapter 13. Although transistor sockets may be installed, the author feels it is best to wire these components in place in an application of this type. Exercise care in protecting these components against heat damage during installation.

Meters with a full scale sensitivity of from 100 microamperes to 1 milliampere may be used in this circuit. The average builder will probably prefer to use the popular 1 MA meter, but, of course, the more sensitive the meter movement, the greater the overall sensitivity of the instrument. The number of range resistors required (R_1, R_2, R_3, R_4, etc.), as well as their individual values and the number of positions on the rotary RANGE switch (Sw_1), will depend on the number of ranges the builder wishes in his own instrument, on their maximum value, and on the basic meter movement used (and hence on overall sensitivity). If desired, a conventional "tapped" voltage divider resistor multiplier network may be substituted for the individual resistors shown in Fig. 9-22. For maximum accuracy in setting up the basic ranges, subminiature "trimmer" potentiometers may be used in place of fixed resistors for each range (R_1, R_2, R_3, etc.). These may be arranged in a "bank" in the final instrument . . . a typical arrangement of such units is illustrated in Fig. 9-23.

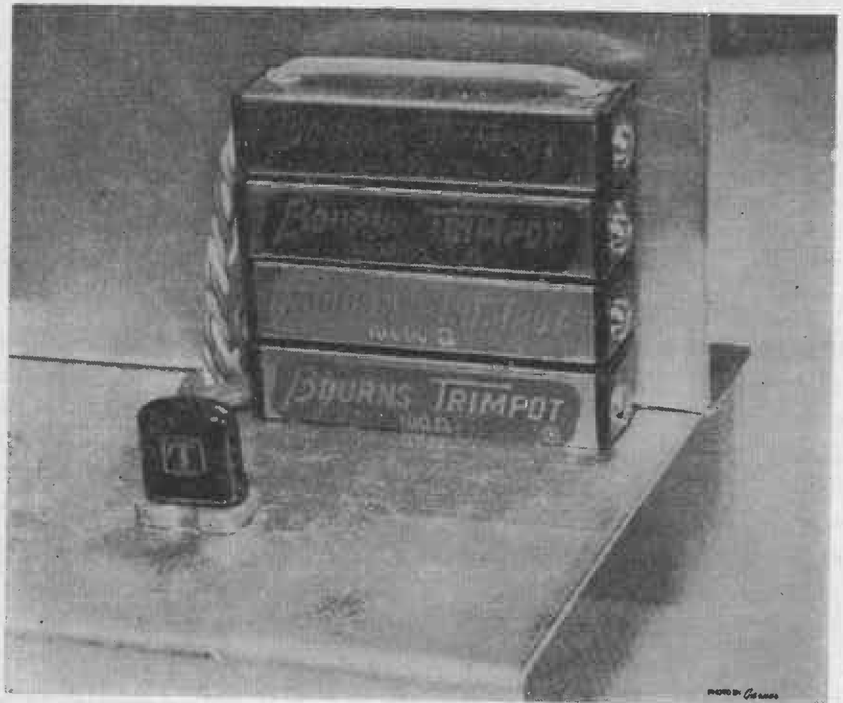


Fig. 9-23.—Range calibration potentiometers used in a transistorized meter circuit.

After the wiring is completed and checked, the instrument must be calibrated. Generally, the range resistors (R_1, R_2, R_3, etc.) are chosen to give full-scale meter deflection when the maximum voltage of each range is applied to the "input" terminals. CALIBRATION rheostat R_9 may be set to from 50 to 500 ohms, depending on the resistance of the meter movement used; after the range resistors are chosen and installed,

R_9 is used as a vernier control for setting the full-scale reading . . . this is done by setting the instrument to its lowest range and, after adjusting R_{10} for a "zero" reading with no input, applying an accurate test voltage equal to full-scale reading of that range. The CALIBRATION control is then readjusted to give a full-scale reading.

Either of several methods may be used for making up the final scale calibrations. First, of course, known D.C. voltages are applied and the actual meter readings noted, enabling the worker to prepare a "table" correlating actual meter readings with applied voltages. If desired, the table may be used alone, with the operator interpolating in-between values. Or these readings may be plotted on a smooth curve, using regular graph paper . . . the resulting curve is then used as a *Calibration Chart* for the instrument. Finally, a new dial may be made up for the instrument, giving actual voltage readings instead of current values.

OPERATION: The instrument is used in much the same manner that any voltmeter is employed, except for the initial "setting" up. Turn the instrument "ON" by closing POWER switch Sw_2. No warm-up time is needed. Set the RANGE switch to its lowest range. Adjust ZERO SET control R_{10} to "zero" the meter. Apply a known D.C. voltage to the input terminals, observing polarity. This voltage should be equal to the full-scale reading of the range to which Sw_1 is set. Adjust CALIBRATION control R_9 for a fullscale reading. Finally, re-check the ZERO SET control. The instrument is now ready for use.

In general, the ZERO SET and CALIBRATION controls should hold their settings reasonably well. Readjustment should be necessary only with aging of the battery and changes in the transistors' characteristics due to changing ambient temperatures.

Like any sensitive meter, care must be taken not to overload the instrument. When making voltage measurements, start with the *highest* range unless you are reasonably sure of the approximate voltages in the circuit under test.

LIGHT METERS: Architects, electrical engineers, educational advisors, office managers, illumination engineers, industrial psychologists, efficiency specialists, interior designers and industrial engineers are but a few of the groups who may use *Light Meters* in their work. Applications range from determining the relative illumination levels in schools, offices, shops and factories, to the analysis of the reflectivity characteristics of paints, draperies, wall paper, or other wall and ceiling coverings. Photographers, both amateur and professional, are large users of these instruments.

The simplest *Light Meter* is a self-generating photocell (or "sun battery") connected to a sensitive meter movement. Such instruments have limited sensitivity, due to the limited output of the photocells; and, because of the sensitive meter movement used, are subject to shock and vibration damage. Semiconductor photocells are used in most of these instruments, supplying essentially a D.C. output.

Since the transistor, itself a semiconductor device, makes an excellent D.C. amplifier, a logical move would be a "marriage" of a photocell and a transistor amplifier into one instrument.

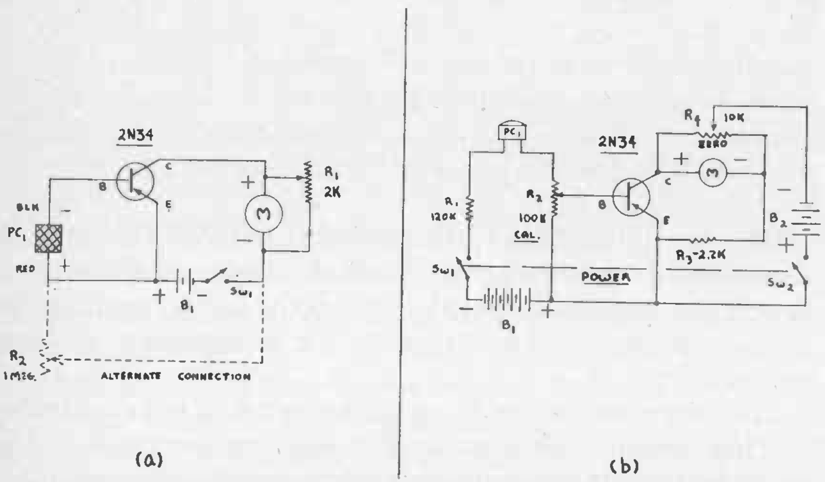


Fig. 9-24.—Two Light Meter circuits—(a) Basic circuit using a selenium photocell and (b) Basic circuit using a Cadmium Sulfide photocell.

Such an arrangement will provide an instrument of greater sensitivity; in addition, ruggedness should be greater, since the gain of the transistor will permit the use of an indicating meter less delicate than the one required with a photocell alone.

Circuits for three different transistorized *Light Meters* are given in Figs. 9-24 and 9-25. Basic circuits, using a single tran-

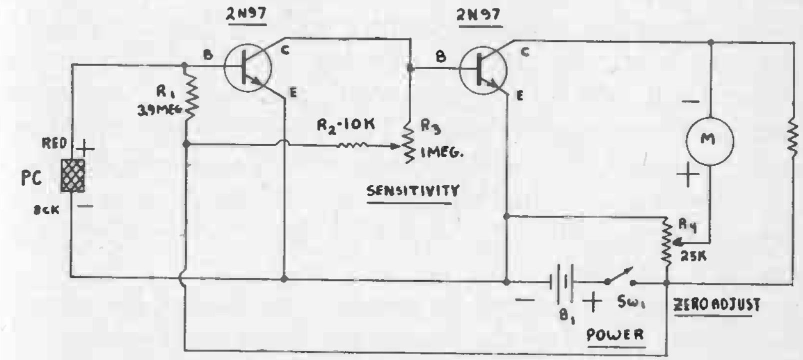


Fig. 9-25.—A very Sensitive Light Meter circuit featuring a cascaded complementary amplifier.

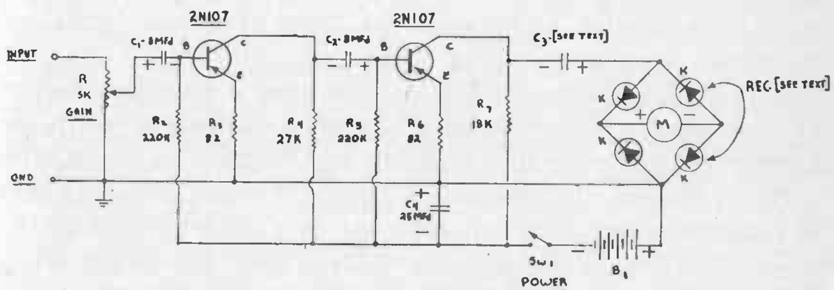


Fig. 9-26.—Schematic of an easily built Audio Level Meter.

sistor, are given in Fig. 9-24, while a more sensitive circuit, using two transistors in cascade, is shown in Fig. 9-25. The two circuits given in Fig. 9-24, while basically similar, illustrate the use of two different types of photocells.

CIRCUIT DESCRIPTION: Referring to Fig. 9-24(a), a PNP transistor serves as a one-stage direct-coupled amplifier. The common-emitter configuration is used. Power is supplied by a single battery, B_1, controlled by SPST switch Sw_1. In operation, with no light falling on the photocell (PC_1), base current is virtually zero, and hence collector current, as indicated by meter M, is at a minimum value. When light falls on the self-generating photocell, a small current is produced. This becomes the base bias current for the transistor and permits a considerably larger collector current to flow, due to the gain of the transistor, and gives an up-scale reading on the meter. As more light falls on the photocell, base current, and thus collector current, both increase. The meter (M) is shunted by a simple rheostat, R_1, which serves as the *Sensitivity* control. As R_1 is reduced in value, more of the collector current can be by-passed around the meter, reducing the meter reading for a given light intensity.

An alternate connection for the *positive* lead of the photocell is shown dotted in the schematic diagram. Instead of returning to the positive terminal of the power supply, it is returned, through R_2, to the negative side of the circuit. This provides a small bias on the photocell and increases circuit sensitivity slightly. Optimum bias, for a given photocell and transistor, is determined by making R_2 adjustable.

The circuit shown in Fig. 9-24(b) uses a *photoconductive* rather than a "self-generating" type of photocell. With the former, no current is developed by light falling on its sensitive surface; instead, its resistance changes. To utilize this change of resistance, the photocell is biased by a separate battery, B_1, which, in turn, is controlled by switch Sw_1. The bias current is limited by series resistor R_1 and CALIBRATION control R_2. This circuit, like the first one, also uses a single PNP transistor as a common-emitter amplifier. Transistor operating power is supplied by a second battery, B_2, controlled by switch Sw_2, which, in practice, is ganged with the "bias" switch Sw_1.

In addition to using a different type of photocell, the circuit given in Fig. 9-24(b) differs from the first one in another important respect . . . the simple series meter circuit has been replaced by a bridge arrangement, to permit "balancing" out any steady collector current which may flow due to inherent "leakage" (high I_{co}) in the transistor. The upper arms of the bridge are made up by ZERO adjustment potentiometer R_4. The lower arms of the bridge consists of the emitter-collector circuit of the transistor and resistor R_3. The meter (M) is connected across the bridge.

Greater sensitivity is obtained by cascading two NPN transistors in a direct-coupled amplifier in the circuit given in Fig. 9-25. A "self-generating" photocell (PC) is used with this circuit so only one battery (B_1) is needed for operation; it is controlled by POWER switch Sw_1. Base bias for the first stage is furnished both by the photocell PC and through resistor R_1, which has a relatively high value. Both stages use the common-emitter configuration. The first stage is direct-coupled to the second stage, with the base bias current for the second stage determined by the collector current of the first stage, as well as by SENSITIVITY control R_3 and fixed resistor R_2.

The amplified output of the second stage is coupled to the indicating meter M through a bridge network, permitting the "dark" (no signal) current of the output transistor to be balanced out. The upper arms of the bridge are made up of fixed resistor R_5 and part of ZERO ADJUST potentiometer R_4. The lower arms of the bridge are made up of the emitter-collector impedance of the output transistor and the remaining part of potentiometer R_4. The meter is connected directly across the bridge.

In operation, light falling on the photocell (PC) results in an increase in the base current of the first stage. This, in turn, causes a much larger change in the collector current, due to the gain of the transistor. As the collector current of the first stage changes, the base bias current of the second stage changes in a similar manner, with its amplified output changing the balance of the bridge circuit and permitting an up-scale reading on the meter.

PARTS LIST—Fig. 9-24(a):

R_1 — 2K, Carbon or wirewound potentiometer.
R_2 — 1 Megohm Carbon potentiometer (*alternate circuit*).
PC_1 — "Self-generating" selenium photocell (*International Rectifier Co.* type B2M).
M — Meter . . . 0-100 microamperes to 0-1 milliamperes (*see text*).
Sw_1 — SPST Toggle switch.
B_1 — 3 volt battery (Two *Burgess* No. Z in series).
Transistor — (1) *Transitron* type 2N34.
MISC. — Transistor socket; aluminum or plastic case; control knob; battery box (*Austin-Craft* No. 124); terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

PARTS LIST—Fig. 9-24(b):

R_1 — 120K, ½ W. Carbon resistor.
R_2 — 100K Carbon potentiometer (*Centralab* B-40).
R_3 — 2.2K, ½ W. Carbon resistor.
R_4 — 10K Carbon potentiometer (*Centralab* B-14).
PC_1 — Cadmium Sulfide photocell (*RCA* No. 6694).
M — Meter . . . 0-100 microamperes to 0-1 milliamperes (*see text*).
Sw_1, Sw_2 — DPST Toggle switch.
B_1 — 22½ volt Hearing Aid battery (*Burgess* No. U15).
B_2 — 6 volt battery (*Burgess* No. Z4).
Transistor — (1) *Transitron* type 2N34.
MISC. — (2) transistor sockets; aluminum or plastic case; (2) control knobs; (2) battery boxes (*Austin-Craft* No. 113 for 22½ volt battery, No. 110 for 6 volt battery); lens (optional); terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

PARTS LIST—Fig. 9-25:

R_1 — 3.9 Megohm, ½ W. Carbon resistor.
R_2 — 10K, ½ W. Carbon resistor.
R_3 — 1 Megohm Carbon potentiometer (*Centralab* B-69).
R_4 — 25K Carbon potentiometer (*Centralab* B-26).

R_5 — 22K, ½ W. Carbon resistor.
PC — "Self-generating selenium photocell (*International Rectifier Co.* type B2M).
M — Meter . . . 0-100 microamperes to 0-1 milliamperes (*see text*).
Sw_1 — SPST Toggle switch.
B_1 — 6 volt battery (*Burgess* No. Z4).
Transistors — (2) *Germanium Products* type 2N97.
MISC. — (2) transistor sockets; aluminum or plastic case; (2) control knobs; battery box (*Austin-Craft* No. 110); lens (optional); terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The same construction techniques may be applied to any of the three transistorized *Light Meter* circuits. Either "conventional" or *Printed Circuit* wiring methods may be employed (see Chapter 13). Good wiring practice should be followed, of course, but neither parts arrangement nor lead dress are critical.

Although PNP transistors are specified for the circuits given in Fig. 9-24 and NPN units for the circuit given in Fig. 9-25, the opposite types may be used in either circuit, provided all D.C. polarities are reversed. The transistor used in the simple circuit given in Fig. 9-24(a) should be selected for a low collector cutoff current (I_{co}) to avoid too high a "dark" reading on the meter. However, since the other two circuits employ a bridge balancing arrangement in their output, this factor is not as important.

The selenium photocells specified for the circuits given in Figs. 9-24(a) and 9-25 are equipped with small mounting brackets and color-coded leads. The Cadmium Sulfide photocell used in the circuit shown in Fig. 9-24(b) mounts in a standard transistor socket. In all three circuits, however, the photocell must be mounted so that the light being measured can fall on its sensitive surface. For maximum sensitivity, a small lens may be used to concentrate light on the photocell. If desired, a darkened filter may be mounted so that it can be swung in front of photocell—a mechanical "sensitivity" control.

Meters with full scale sensitivities ranging from 100 microamperes to 1 milliampere may be used in any of the three circuits. The more sensitive the meter movement used, the greater the overall sensitivity of the complete instrument. Of course, where an instrument is intended for considerable "field" use, it should be remembered that, in general, the less sensitive meters are more rugged from a mechanical viewpoint.

After assembly and wiring is completed and checked, the finished instrument should be calibrated. If the *Light Meter* is to be used for relative tests only, such as comparing the reflectivity characteristics of two types of material, chances are an arbitrary calibration . . . or none at all (except the meter scale) . . . will be satisfactory. If it is to be used for absolute measurements, it may be calibrated by checking its readings against a known standard . . . such as an *Exposure Meter* borrowed from a photographer friend.

OPERATION: The operation of the three instruments is self-evident from the schematic circuit diagrams. With any *Light Meter,* the instrument is held so that the light to be measured, whether direct or reflected, falls on the sensitive surface of the photocell. The unit is turned "ON" and, after any necessary adjustments are made, the meter is read.

If the instrument has been assembled according to the circuit given in Fig. 9-24(a), two adjustments are possible, depending on whether the alternate *construction* shown is followed. Generally, R_1 is set for the desired full-scale sensitivity. If the *alternate arrangement* is used, R_1 is first set to maximum sensitivity (full resistance), then R_2 is set for the best compromise between the "dark" reading (photocell covered), which should be as close to "zero" as possible, and maximum sensitivity, when the photocell is lighted. This adjustment is made when the instrument is first calibrated, then left fixed.

If the circuit given in Fig. 9-24(b) has been followed, the ZERO adjustment (R_4) is used to "zero" the meter with the photocell dark. The CAL. (*calibrate*) adjustment is used to set the full-scale reading for the maximum light level to be measured. The ZERO (R_4) and CAL. (R_2) adjustments should be checked out two or three times during initial calibration. Afterwards, it should only be necessary to adjust the ZERO control just prior to taking a reading.

Finally, if an instrument is assembled according to the circuit given in Fig. 9-25, the procedure followed is similar to that employed with the circuit given in Fig. 9-24(b), except that the SENSITIVITY control (R_3) serves to set the full-scale reading. If desired, calibrations may be made for several settings of the SENSITIVITY control, providing the operator with two or more ranges.

AUDIO LEVEL METER: The *Meter Amplifiers* and the *D.C. Voltmeter* described earlier in this Chapter were designed specifically for D.C. measurements. While A.C. or R.F. signals could be measured with any of the circuits shown simply by adding an appropriate rectifier (detector) and filter network, all amplication would still take place at a D.C. level. On the other hand, the circuit given in Fig. 9-26 is for an instrument designed for A.C., or, more specifically, A.F. measurements only; all amplification takes place at the frequency of the signal being measured, with rectification occurring just prior to the application of the signal to a D.C. meter.

Such an instrument has many potential applications, depending on its final calibration and the type of input device used. If equipped with a sensitive microphone or similar pickup, it could be used as an *Audio Noise Meter.* If connected to a tape or wire recorder, it could be used as a *Recording Level Indicator.* Supplied with test leads and a D.C. blocking capacitor on its input, it could serve the Radio-Electronics Serviceman as an *Audio Output Meter.* And if the user were inclined to "Show Business", he might connect it to a P.A. system for use as a *Monitoring Meter . . .* or, on another occasion, he might attach a microphone and use the device as an *Applause Meter.* The reader can probably think of many additional applications for this simple meter.

CIRCUIT DESCRIPTION: Referring to Fig. 9-26, we see that the *Audio Level Meter* consists of a two-stage resistance-coupled amplifier using PNP transistors, followed by a bridge rectifier which, in turn, drives a D.C. meter. The common-emitter circuit configuration is used in both stages. Operating power is supplied by a single 6 volt battery (B_1), controlled by SPST switch Sw_1.

In operation, an audio signal applied to the INPUT appears across GAIN control R_1. The setting of this control determines what portion of the available signal is applied through coupling capacitor C_1 to the input of the first stage. Base bias current for this stage is supplied through resistor R_2. Stability is assured by unby-passed emitter resistor R_3.

After amplification in the first stage, the signal appearing across collector load resistor R_4 is coupled through C_2 to the second stage, where additional amplification occurs. Base bias current for the second stage is furnished through resistor R_5. Again, an unby-passed emitter resistor (R_6) is included in the circuit to improve A.C. and D.C. stability.

The final amplified signal, appearing across collector load resistor R_7, is coupled through D.C. blocking capacitor C_3 to a bridge rectifier consisting of four diode elements. The D.C. output of the bridge rectifier drives a standard D.C. meter, which gives an up-scale reading proportional to the amplitude of the amplified audio signal applied through C_3. Capacitor C_4, across the power supply, is included both for de-coupling purposes and to reduce the effect of switching transients.

PARTS LIST:

R_1 — 5K Carbon potentiometer (*Centralab* B-10 or B-12).
R_2, R_5 — 220K, ½ W. Carbon resistors.
R_3, R_6 — 82 ohm, ½ W. Carbon resistors.
R_4 — 27K, ½ W. Carbon resistor.
R_7 — 18K, ½ W. Carbon resistor.
C_1, C_2 — 8 Mfd., 6 volt electrolytic (*Barco* P6-8).
C_3 — Electrolytic or paper capacitor (*see text*).
C_4 — 25 Mfd., 6 volt electrolytic (*Barco* P6-25).
M — Meter — 0-200 Microamperes.
Sw_1 — SPST Toggle or Slide switch.
B_1 — 6 volt battery (*Burgess* No. Z4).

Diodes — Instrument rectifier (*Conant* Series 160, type B), or (4) diodes, such as *Raytheon* type CK705 or *Sylvania* type 1N34.
Transistors — (2) *GE* type 2N107.
MISC. — (2) transistor sockets; control knob; small aluminum case (*L.M.B.* No. 140); battery box (*Austin-Craft* No. 110); terminal strips; Machine screws, hex nuts, ground lugs, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The *Audio Level Meter* should be assembled in a small metal case to minimize stray noise and hum pick-up. Although parts lay-out and wiring arrangement are not critical, the builder should remember that the instrument is essentially an audio amplifier and should be guided accordingly . . . signal leads should be kept short and direct, and the "input" and "output" circuits should be kept well separated.

If an Oscilloscope is available, the builder will find it worthwhile to make a check of the completed circuit, applying a sine-wave signal to the INPUT. The bias resistors (R_2, R_5) as well as the collector load resistors (R_4, R_7) should be adjusted to give the best compromise between gain and minimum distortion. The values listed for these components on the schematic diagram are nominal only.

Although an 0-200 microampere meter is specified as an indicating device (M), a more (or less) sensitive meter may be used in the circuit . . . for greater sensitivity, a 0-50 or 0-100 microammeter may be used; for less sensitivity, and lower cost, an 0-500 microammeter or 0-1 milliammeter may be preferred.

A number of modifications are possible in the basic circuit, depending on the intended application of the completed instrument and the needs of the individual builder. For example, if intended for use as an *Audio Output Meter,* a D.C. blocking capacitor (1.0 Mfd., 400 volts) should be connected in series with the INPUT terminal. If intended for *gain* measurements, the continuously variable GAIN control may be replaced by a tapped voltage divider and selector switch, permitting the establishment of precise full-scale ranges. Finally, the selection of coupling capacitor C_3 will depend on intended use. For higher frequency tests, a moderately small paper capacitor might be used here (0.1 to 0.5 Mfd., 100 volts). If the entire audio spectrum is of interest, a larger electrolytic capacitor (8 to 25 Mfd., 6 volts) should be used to prevent loss of low frequencies. Adjusting C_3 will permit an operator to "weigh" the response characteristic of the instrument.

The output bridge rectifier may be either a standard miniature instrument rectifier, as specified in the PARTS LIST, or four individual diodes, connected as shown in the diagram. Similar results will be obtained with either arrangement, but the instrument rectifier is both less costly and smaller.

Final calibration will depend on intended use. For relative tests, such as may be made with an *Audio Output Meter* or an *Applause Meter,* the meter scale calibration may be satisfactory. For more precise measurements, the builder may wish to calibrate the instrument against a known standard, such as an A.C. Voltmeter, expressing the results in db. A *Calibration Chart* may be prepared, correlating meter readings with db values, or a new scale for the meter may be drawn, as preferred by the individual builder.

OPERATION AND USE: Final operational procedure will depend, of course, on the intended application of the instrument and on the modifications which the individual builder may make. In general, however, the instrument is turned "ON" and the GAIN control (or switch) set to the desired full-scale range. The audio signal to be measured is applied to the INPUT terminals and the meter read.

SERVICING INSTRUMENT

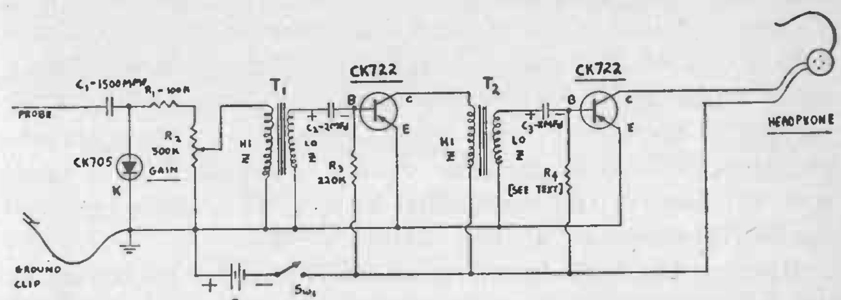
SIGNAL TRACER: In the first section of this Chapter, devoted to SIGNAL GENERATORS, we discussed *The Signal Squirter,* an instrument designed specifically for use in the *Signal Injection* servicing technique. With this method, as you may recall, a signal is injected into different stages of a "dead" or "weak" receiver (or amplifier), starting at the final stage and working back towards the first (or "input") stage.

The effect on equipment operation is noted at each point. Where the output signal, whether indicated on a meter or heard in a loudspeaker, first dropped in level or was "lost", the defective stage had been isolated. After stage isolation, checks in the defective stage with a volt-ohmmeter were used to isolate the defective part.

There is another powerful servicing technique which is similar, yet complementary to the *Signal Injection* method . . . *Signal Tracing.* Like the other method, stage-by-stage tests are involved. With the *Signal Tracing* technique, a fixed signal is applied to the input of the equipment, and this signal is traced, stage-by-stage, *from* the first (input) stage to the last (output) stage. Defective stages are easily isolated, for the signal will be present at the input of the stage and either lost or very weak at the output.

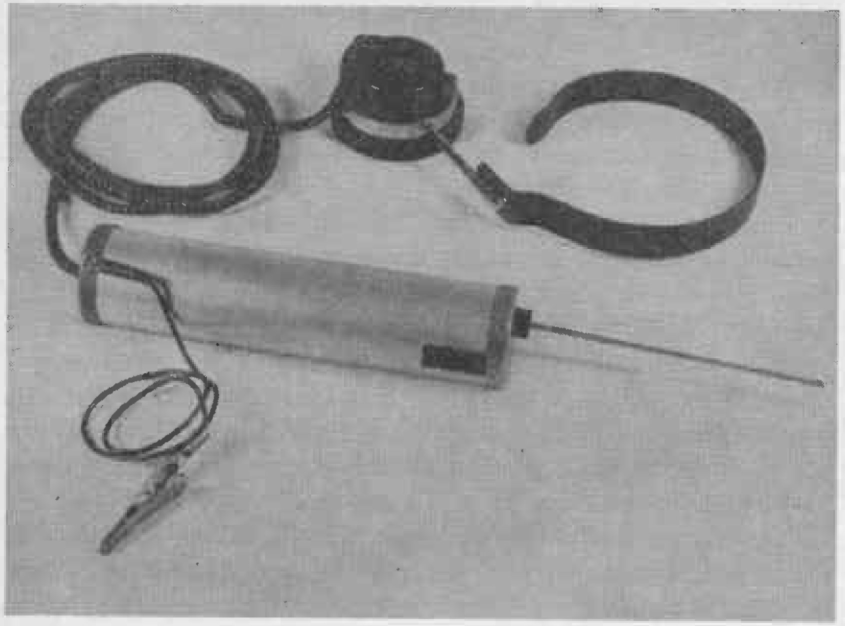
Although *Signal Injection* and *Signal Tracing* may accomplish similar results, the well-trained serviceman will take pains to be familiar with *both* techniques, and to have suitable instruments for carrying out both types of tests. Generally, the *Signal Tracing* technique may be used if the serviceman suspects trouble in the R.F. stages of, say, a receiver, and the *Signal Injection* technique used if he suspects trouble with the audio section. Of course, either method may be used throughout all stages of a piece of equipment, if desired.

A transistorized *Signal Tracer,* designed primarily for tracing through R.F. circuits, is shown in Figs. 9-27 and 9-28 . . .



Courtesy Radio & Television News

Fig. 9-27.—Schematic diagram of a transistorized Signal Tracer.



Courtesy Radio & Television News

Fig. 9-28.—Author's model of the Signal Tracer.

and in use in Fig. 9-29. This instrument, although not appreciably larger than a conventional meter probe, is completely self-contained . . . including its own GAIN control, ON-OFF switch, and power supply. It is easy to construct at comparatively low cost, and may be carried easily in a tool box . . . or even in a coat pocket.

CIRCUIT DESCRIPTION: Basically, the transistorized *Signal Tracer* consists of an R.F. diode detector, followed by a GAIN control (R_2) and a two-stage transformer-coupled transistor audio amplifier driving a magnetic headphone. PNP transistors are used in both stages, connected in the common-emitter circuit configuration. Power is supplied by a small mercury battery (B_1) controlled by a SPST switch (Sw_1) on the GAIN control.

Refer to Fig. 9-27. In operation, an R.F. signal picked up by the *Probe* is applied through coupling capacitor C_1 to a CK705 detector. After detection, the audio signal is applied to a gain

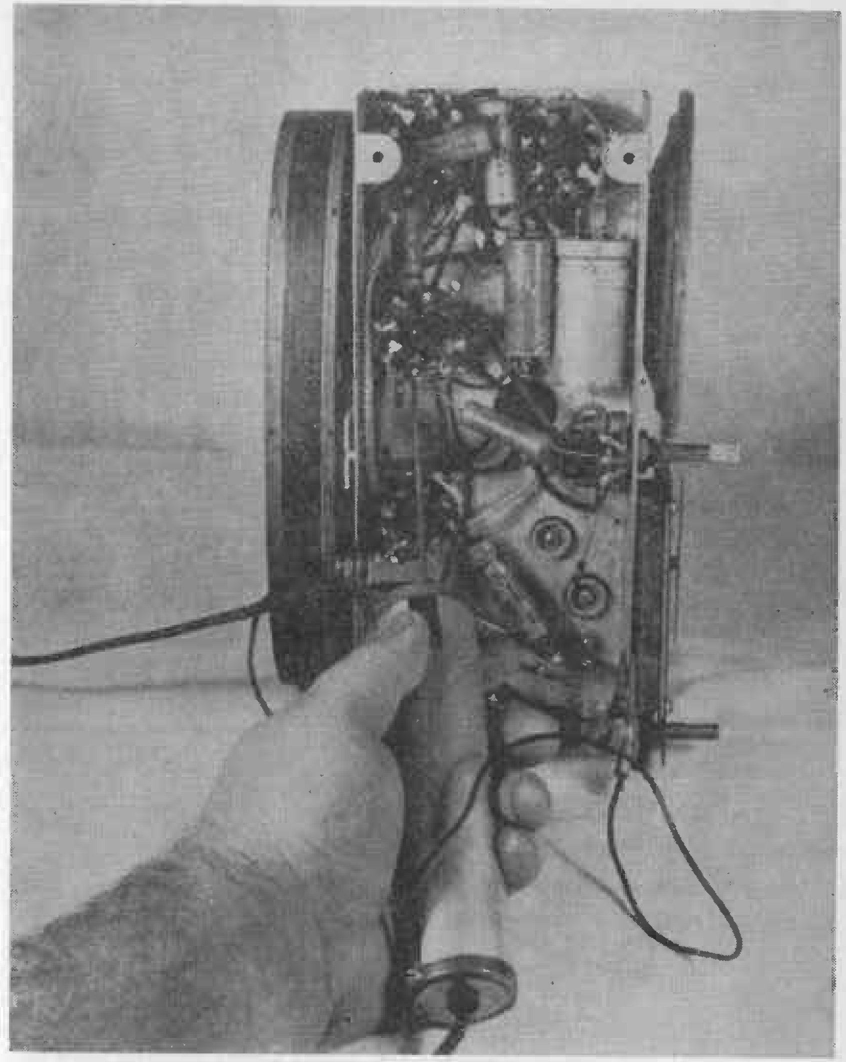


Fig. 9-29.—Using the Signal Tracer to service a broadcast receiver.

control network consisting of fixed resistor R_1 and potentiometer R_2. A portion of the available signal, depending on the adjustment of R_2, is applied to transformer T_1, which serves to match the high impedance of the GAIN control and detector circuit to the low input impedance of the transistor amplifier.

The audio signal, transferred through T_1, is applied to the base-emitter circuit of the first stage through capacitor C_2, which serves to keep the low D.C. resistance of the transformer's secondary from shorting out the base bias current, applied through resistor R_3. After amplification by the first stage, the audio signal is coupled to the second stage through interstage matching transformer T_2. Again, a coupling capacitor (C_3) prevents a short of base bias current to ground; bias current for the second stage is supplied through R_4. After additional amplification by the second stage, the audio output signal drives the magnetic headphones serving as the final collector load.

PARTS LIST:

R_1 — 100K, ½ W. Carbon resistor.
R_2 — 500K Subminiature Carbon potentiometer, with switch (*Centralab* No. B16-218).
R_3 — 220K, ½ W. Carbon resistor.
R_4 — ½ W. Carbon resistor . . . 100K to 330K (see text).
C_1 — 1500 Mmf., disc ceramic (*Centralab* No. MD-152).
C_2, C_3 — 2 Mfd., 6 volt electrolytic (*Barco* No. P6-2).
T_1,T_2 — Interstage transistor transformers (*UTC* No. SO-3 or *Argonne* No. AR-129).
Sw_1 — SPST switch (on R_2).
B_1 — 2.69 volt battery (*Mallory* type TR-132).
HEADPHONE—Magnetic headset, 2000 ohms impedance.
Diode — (1) *Raytheon* type CK705.
Transistors — (2) *Raytheon* type CK722.
MISC. — Probe . . . short piece of No. 12 Bus Bar; alligator clip (2) transistor sockets; tip jack; short length of 1½" diam. aluminum tubing; Machine screws, hex nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: This circuit is well-suited to an "in-line" type of construction — that is, with all stages in a direct line across the chassis or wiring board. As long as good wiring practice is observed, no difficulties with lay-out or lead dress should be encountered. In the author's model, shown in Fig. 9-28, the "chassis" consists of a small piece of fiber board, to which the transistor sockets and transformer are cemented. The final construction is very similar to that used with *Printed Circuit* techniques (see Chapter 13).

Although the model is shown assembled in an aluminum tube, giving the entire instrument a "probe-like" appearance, this type of housing is not mandatory. If preferred by the individual builder, the instrument might very easily be housed in a small metal box . . . perhaps similar to that used in assembling *The Signal Squirter,* described earlier in this Chapter.

The base resistor for the final stage (R_4) is chosen after the instrument is completed and ready for test. The value of this resistor will vary somewhat with the type of Headphones used and with the characteristics of the transistor used in the final stage. Determine the correct value experimentally, choosing a resistance which gives the best compromise between overall gain and minimum distortion. The final value will probably be in the range of from 100K to 330K.

Several modifications in the basic circuit may be made. If higher gain transistors (such as *Raytheon* type CK721) are substituted for the units specified in the *PARTS LIST,* the instrument will be more sensitive. Crystal headphones may be substituted for the magnetic headset specified, provided a 10K, ½ W. carbon resistor is connected from the collector of the final stage to the "set" side of switch Sw_1 . . . that is, so that the resistor serves as an output load. Higher or lower operating voltages may be used (1.5 to 6 volts) if the bias resistors (R_3 and R_4) are adjusted for optimum operation.

OPERATION AND USE: The *Signal Tracer* is designed for "one-hand" operation, as shown in Fig. 9-29. The GAIN control (ON-OFF switch) is operated with the extended thumb.

To use the instrument for servicing a "dead" or "weak" receiver, first apply a modulated R.F. signal to the input (antenna) of the set. Connect the *Signal Tracer's* "ground" lead to the receiver's chassis. With the HEADPHONE on, turn up the GAIN control and touch the *Probe* to the input and output (grid and plate) of each stage, starting at the antenna, and working towards the detector stage. There should be a steady increase in signal strength, as each stage adds its gain. When the signal level first drops appreciably . . . or disappears . . . as a particular stage is checked, the defective stage has been isolated!

There are a few important things to remember when using the *Signal Tracer*. First, since headphones are used as an indicating device, a *modulated* R.F. signal must be supplied to the receiver . . . this can be obtained from a standard R.F. Signal Generator or by tuning in a strong local broadcast station, or even from *The Signal Squirter,* if this instrument is available. The *Signal Tracer* and the *Signal Squirter,* together, make a handy pair of servicing instruments. Secondly, there may be a slight drop in signal level when the *Probe* is touched to a particular stage . . . this is due primarily to the de-tuning and loading effect of the instrument . . . however, as long as this de-tuning is expected, it should cause no trouble. Finally, since the outer shell or case of the instrument is made of metal for shielding purposes, and since this shell is connected to circuit ground, it should be used to check A.C.-D.C. equipment *only where an isolation transformer is used between the equipment and the power line* . . . otherwise, accidental shocks are possible.

CONCLUSION

The transistorized test instruments described in this Chapter represent a fair cross-section sampling of typical applications. They do not, however, represent even a good percentage of the possible circuits that may be developed around transistors. As the individual worker becomes familiar with transistor circuitry, he will, undoubtedly, see many modifications of the described instruments. At the same time, he will probably be able to devise many new and different instruments . . . based on his special needs, and upon his ability to adapt standard circuits to other applications. In addition, as new and better transistors are developed and offered to the user, the possible circuits will continue to expand in scope and variety.

Chapter 10

CONTROLS AND GADGETS

In discussing transistor circuit applications, it is often well to remember that the transistor is basically an amplifying device. Its great versatility lies in how its amplifying characteristics can be utilized by the circuit designer and how other circuit elements can be combined with the transistor to achieve the desired end results. The transistor, alone, is of little practical value. But when combined with batteries, resistors, capacitors, coils, resonant circuits, transformers, relays or meters, it can serve in a wide variety of important jobs.

In the preceding three Chapters, we've discussed transistor circuit applications to Audio Amplifiers, to R.F. equipment, and to Test Instruments. But transistor applications are by no means limited to these three general fields. While Audio Amplifiers, Radio Receivers and Transmitters represent, perhaps, the major fields of application for transistors as far as the lay public is concerned, to the "dyed-in-the-wool" gadgeteer, *control circuits* offer far more experimental possibilities. And if we add to these the practical applications of transistors and other semiconductor devices to gadgets and toys, the potentialities become truly enormous.

CONTROL CIRCUITS

TIMERS: Devices for closing electrical circuits for specific time intervals have been popular for many years and have been used extensively in the commercial, industrial and scientific fields. Typical applications have included operating electrical mixers (stirrers), controlling electric heaters, switching exhaust fans or blowers, operating refrigeration devices, controlling solenoid valves, and switching recording instruments. Even hobbyists . . . particularly home chemists and amateur photographers . . . have found such devices useful; chemists have used them for controlling mixing and heating processes, photographers have found them valuable for operating their Print Boxes and Enlargers.

Most commercial timing devices are either electronic, using vacuum tubes, electro-mechanical, using an electric motor, or mechanical, using a spring-driven clockwork. The electronic timers generally use one to three vacuum tubes and an electro-magnetic relay. Electro-mechanical timers use a slow-speed electric motor, fitted with a cam which, in turn, operates an electric switch. Mechanical timers are similar to the electro-mechanical units, except that the electric motor is replaced by a spring-driven clockwork, but with the cam and switch arrangement retained.

All three types have limitations which restrict their applications. The electronic and electro-mechanical types usually require line voltage for operation, even though the controlled equipment may be battery operated. Electronic types are prone to tube failure. Mechanical types, whether electrical or

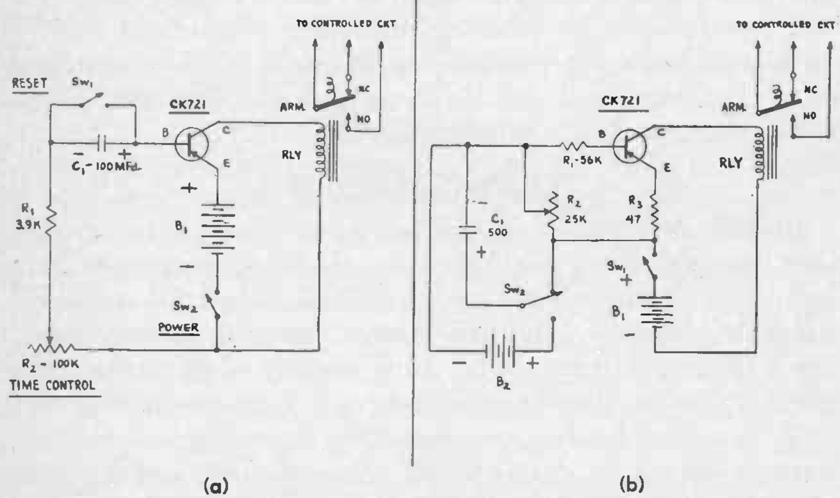


Fig. 10-1.—Two simple transistorized Timers: Circuit (a) operates on the "charge" cycle of a capacitor, circuit (b) on the "discharge" cycle.

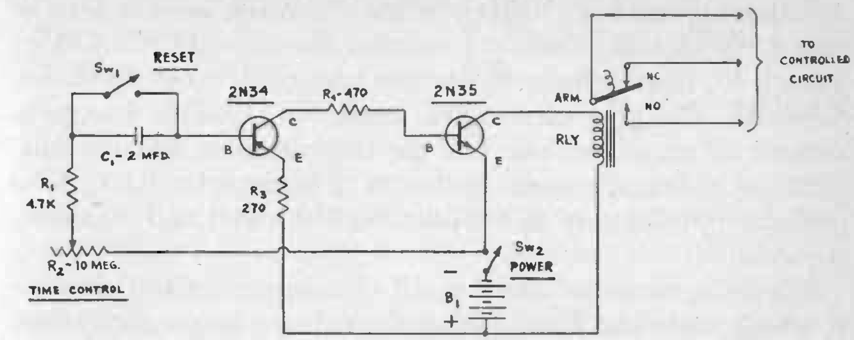


Fig. 10-2.—A "Precision" transistorized Timer circuit—no electrolytic capacitors are used.

spring driven, are subject to the usual mechanical failures brought on by friction. And, of course, spring-driven types require regular rewinding.

A transistorized *Timer* offers the user the advantages of electronic operation without the disadvantages usually associated with vacuum-tube operated equipment . . . frequent filament "burn-out", dependence on line voltage for operation. and execessive heat generation. Three transistorized *Timer* circuits are given in Figs. 10-1 and 10-2. All three circuits are relatively simple and easy-to-assemble, even for a worker of moderate skill. And all three use commercially available components.

CIRCUIT DESCRIPTION: A study of the schematic diagrams reveals that all three *Timer* circuits use transistors in the common-emitter circuit configuration. The two circuits given in Fig. 10-1 use PNP transistors; the circuit given in Fig. 10-2 uses both PNP and NPN units in a direct-coupled complementary amplifier arrangement. All three circuits utilize the *time constant* of a resistor-capacitor network to determine their timing intervals, with the resistor made variable to serve as a TIME CONTROL. The circuits given in Figs. 10-1(a) and 10-2 utilize the "charge" time of a R-C network to determine range, while the circuit given in Fig. 10-1(b) uses the "discharge" time of its R-C network.

Referring to Fig. 10-1(a), when POWER switch Sw_2 is closed, there is a "rush" of current through TIME CONTROL R_2, fixed resistor R_1 and the base-emitter circuit of the transistor, charging electrolytic capacitor C_1. This charging current serves as the base bias for the transistor and permits sufficient collector current to flow to close the relay RLY. The power supply battery B_1 supplies both the bias and collector currents.

The relay remains closed until C_1 approaches full charge, at which time the base bias current drops below the value necessary to maintain collector current at a level needed to hold the relay "in". The relay drops "out" (opens) and the circuit is ready for use. Depressing the RESET switch Sw_1 discharges C_1 by shorting it, and re-establishes the base bias current, closing RLY. Again, the relay remains closed until C_1 charges, with its "charging time" determined by its value and the total series resistance . . . for practical purposes, the combined value of R_1 and R_2. Since R_2 is variable, it can be used to change the R-C time constant and thus to vary the timing range.

The circuit given in Fig. 10-1(b) depends on the "discharge" time of an R-C network to determine its timing range. In operation, timing capacitor C_1 is charged by battery B_2 when RESET switch Sw_2 is depressed. When Sw_2 is released, C_1 discharges through R_2 and through the circuit in parallel with R_2, consisting of R_1, the base-emitter circuit of the transistor, and emitter resistor R_3. Unby-passed emitter resistor R_3 is included simply to increase the effective input impedance of the base-emitter circuit. The portion of the discharge current flowing over the parallel path (R_1, base-emitter, and R_3) establishes the base bias current for the transistor, allowing a greater collector current to flow (due to the gain of the transistor) and closing the relay, RLY. Collector current is furnished by a separate battery, B_1, controlled by switch Sw_1.

The relay (RLY) remains closed until C_1 is nearly discharged and base bias current drops too low to maintain the transistor's collector current at a value which will hold the relay "in", Since R_2 has a lower resistance than the R_1-base-emitter-R_3 path, its value has the greatest effect on C_1's discharge time and this resistor thus serves as the TIME CONTROL. The timing cycle may be repeated whenever desired simply by depressing and releasing Sw_2.

Both of the circuits shown in Fig. 10-1 use large value electrolytic capacitors in order to obtain a reasonable timing range with the comparatively small series resistors used. The small series resistors, in turn, were made necessary by the minimum base current needed by the transistor to insure relay closure. Such circuits can not be made too accurate because of the tolerances of electrolytic capacitors, plus their tendency to change value with aging.

In contrast to the first two circuits, the arrangement shown in Fig. 10-2 may be considered almost a *Precision Timer*. In this circuit, the "timing" capacitor has been replaced by a smaller value paper capacitor (C_1) and a larger series resistance used to re-establish the timing range. This is made possible by the use of a two-stage direct-coupled transistor amplifier, using PNP and NPN transistors in a complementary circuit. The two-stage amplifier, has considerably more gain than the one-stage circuits shown in Fig. 10-1 and hence requires considerably less input current to effect and maintain relay closure.

Except for the use of the two-stage circuit, the operation of the *Precision Timer* is almost identical to that of the one-stage basic Timer shown in Fig. 10-1(a). Timing capacitor C_1 is charged through TIME CONTROL R_2, through fixed resistor R_1, through the base-emitter circuit of the 2N34 transistor, and through emitter resistor R_3; the capacitor is discharged when RESET switch Sw_1 is depressed. The relay closes when Sw_1 is depressed and remains closed while C_1 is charging, depending on the adjustment of R_2. Unby-passed emitter resistor R_3 serves to raise the input impedance of the first stage. Interstage coupling resistor R_4 serves simply to limit the current between stages, protecting the transistors. Power is supplied by a single battery, B_1, controlled by SPST switch Sw_1.

PARTS LIST — Fig. 10-1(a):

R_1 — 3.9K, ½ W. Carbon resistor.
R_2 — 100K Carbon potentiometer (*Centralab* B-40).
C_1 — 100 Mfd., 15 volt electrolytic (*Sprague* No. TVA-1160).
Sw_1 — SPST, spring return push-button switch.
Sw_2 — SPST Toggle switch.
B_1 — 6 volt battery (*Burgess* No. Z4).
RLY — Relay, 3500 ohm coil (*Advance* No. SV/1C).
Transistor — (1) *Raytheon* type CK721.
MISC. — Transistor socket; Control knob; Battery box (*Austin-Craft* No. 110); Metal case (*ICA* No. 29440); (4) Rubber feet; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

PARTS LIST — Fig. 10-1(b):

R_1 — 56K, ½ W. Carbon resistor.
R_2 — 25K Carbon potentiometer (*Centralab* B-26).
R_3 — 47 ohm, ½ W. Carbon resistor.
C_1 — 500 Mfd., 15 volt electrolytic (*Sprague* No. TA-1162).
Sw_1 — SPST Toggle switch.
Sw_2 — SPDT, spring return push-button switch.
B_1 — 6 volt battery (*Burgess* No. Z4).
B_2 — 22½ volt Hearing Aid battery (*Burgess* No. U15).
RLY — Relay, 3500 ohm coil (*Advance* No. SV/1C).
Transistor — (1) *Raytheon* CK721.
MISC. — Transistor socket; control knob; Battery boxes (*Austin-Craft* No. 110 for 6 volt battery, No. 113 for 22½ volt battery); Metal case (*ICA* No. 29440); (4) Rubber feet; Machine screws, nuts, wire, solder, terminal strips, Misc. Hdwe., etc.

PARTS LIST — Fig. 10-2:

R_1 — 4.7K, ½ W. Carbon resistor.
R_2 — 10 Megohm Carbon potentiometer (*Centralab* B-98).
R_3 — 47 ohm, ½ W. Carbon resistor.

R_4 — 470 ohm, ½ W. Carbon resistor.
C_1 — 2 Mfd., 200 volt metallized paper capacitor.
Sw_1 — SPST, spring return push-button switch.
Sw_2 — SPST Toggle switch.
B_1 — 6 volt battery (*Burgess* No. Z4).
RLY — Relay, 3500 ohm coil (*Advance* No. SV/1C).
Transistors — (1) *Sylvania* 2N34; (1) *Sylvania* 2N35.
MISC. — Transistor sockets; control knob; battery box (*Austin-Craft* No. 110); Metal case (*ICA* No. 29440); (4) Rubber feet; Machine screws, nuts, terminal strips, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The author's model of a transistorized *Timer* is shown in Fig. 10-3. It has been assembled in a standard 3″ x 4″ x 5″ aluminum case, as specified in the *PARTS LIST* for all three circuits, and labeled with black decals to give it a professional "factory-built" appearance. Any of the circuits may be assembled in a similar sized case . . . with room to spare!

With neither parts layout nor wiring arrangement critical, the builder is free to follow his own inclinations regarding construction. There are a few points he should remember, however. First, special attention must be paid to battery and electrolytic capacitor polarities. The transistors should not be installed until *after* all construction is completed and double-checked for possible errors. It is *extremely* important that the electrolytic capacitors used in the two circuits given in Fig. 10-1 have *low* leakage . . . only "fresh" stock should be used. And, finally, the relay specified in the *PARTS LIST, or its exact electrical equivalent,* must be used . . . substitution of a "plate sensitive" relay in this circuit will not give satisfactory results.

After wiring is completed and the circuit's operation checked, the unit should be calibrated. This can be done by setting the TIME CONTROL knob to various positions and measuring the *time delay* obtained, using either a Stop Watch or a standard Wrist Watch with a sweep-second hand. If a different range is desired, or if more than one range is needed,

Courtesy Radio & Television News

Fig. 10-3.—Author's model of a transistorized Timer.

different capacitors may be used in place of the "timing capacitor" (C_1 in all three circuits). In general, substituting a larger capacitor will increase the maximum range, while a smaller unit will reduce range.

RAIN ALARM: Here's a handy electronic control that should find uses in almost every household . . . a transistorized *Rain Alarm* or *Moisture Detector*. With such a unit installed, the "lady of the house" can hang her wash out to dry and settle down for a well-earned nap, without the fear that she'll awake

to find her almost dry clothes drenched by an unexpected shower; the *Rain Alarm* will awaken her with the first few drops of moisture, and in plenty of time to save her wash. The "man of the house" might install the control in his basement workshop . . . to warn of water seepage or excessive condensation, so he can take steps to protect his valuable tools. And, with the control installed in a home, the entire household can retire on sultry summer evenings, with the windows left open for night breezes, but without the worry that they'll sleep through a sudden summer shower which might otherwise soak the house.

As can be seen by reference to the schematic diagram given in Fig. 10-4, the *Rain Alarm* uses a relatively simple circuit, requiring just a few parts. There is nothing "tricky" in either its construction or operation. A typical householder who is "handy with tools" should have little or no difficulty assembling his own control in one or two evenings . . . even if he has not had extensive experience wiring electronic circuits.

CIRCUIT DESCRIPTION: The *Rain Alarm* uses but one NPN transistor as a single-stage direct-coupled amplifier to drive a sensitive relay. The common-emitter circuit configuration is

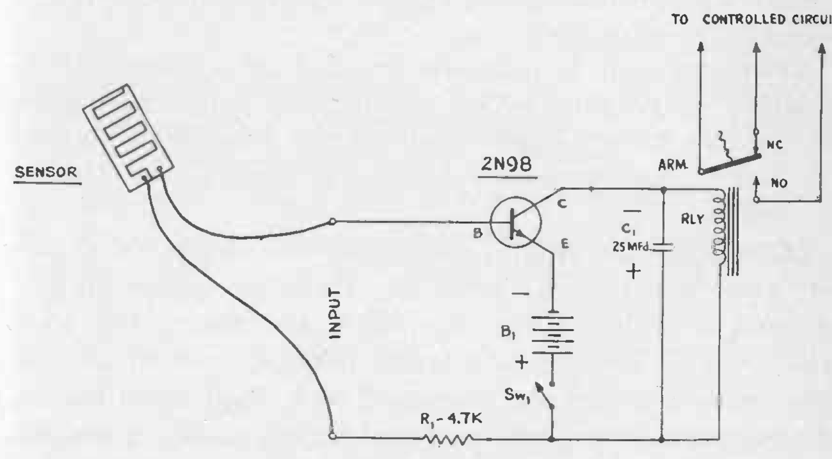


Fig. 10-4.—"Rain Alarm" circuit.

employed. Power is supplied by a long-life battery made up of four flashlight cells in series (B_1) and controlled by a SPST switch (SW_1).

In operation, the base circuit of the transistor is normally "open" and the unit operates without bias current. The only collector current flowing is that due to the normal "leakage" of the transistor and this is too low to close the relay RLY. When moisture falls on (or condenses on) the two-electrode SENSOR plate, it closes the base circuit, allowing base bias current to flow through limiting resistor R_1. The flow of bias current permits sufficient collector current to flow to close the relay (RLY), operating the light, buzzer, or other signal that is controlled by it. Capacitor C_1, across the relay, serves to prevent transient voltage or current peaks due to the inductive effects of the relay's coil, as well as to minimize possible "chattering" in case of intermittent contact across the SENSOR plate.

PARTS LIST:

R_1 — 4.7K, ½ W. Carbon resistor.
C_1 — 25 Mfd., 6 volt electrolytic (*Barco* P6-25).
Sw_1 — SPST Toggle or Slide switch.
B_1 — 6 volt battery (four flashlight cells . . . *Burgess* No. 2).
RLY — Sensitive relay, 3500 ohm coil (*Advance* SV/1C).
SENSOR — *See Text.*
Transistor — (1) *Germanium Products* type 2N98.
MISC. — Transistor socket; (2) Binding posts; Small chassis; (2) battery boxes (*Austin-Craft* No. 145); terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: Except for care in observing battery and capacitor D.C. polarities, there are no special precautions to follow when assembling and wiring the *Rain Alarm* circuit. Neither parts layout nor lead dress are critical. The author's model was assembled on a small metal chassis, but a duplicate unit could be assembled in a plastic or wooden case, if preferred by the individual builder.

The *SENSOR* plate is essentially two conductors mounted on an insulating base. It may be made up out of aluminum foil, cemented to a *bakelite, lucite* or *polystyrene* board . . . or etched from copper-clad phenolic, using *Printed Circuit Techniques* (see Chapter 13). A grid-like arrangement is used to expose the maximum conducting area between the two insulated electrodes. A drop of moisture bridges this gap and closes the circuit. The *SENSOR* used with the author's model, shown in Fig. 10-5, was made up by mounting two metal "pet" combs on a plastic base. The comb's teeth intermesh, but do not touch.

If desired, a PNP transistor may be substituted for the NPN unit shown in the diagram and specified in the *PARTS LIST*. Typical types are the *Raytheon* CK722, *GE* 2N107, *RCA* 2N109, and *Transitron* 2N43. If a PNP unit is used, reverse both battery and electrolytic capacitor lead connections.

With the wiring completed and double-checked, and the transistor and battery installed, the unit is ready for test. Close switch Sw_1 and touch a moistened finger across the INPUT terminals. The relay (RLY) should close. To install the *Rain Alarm,* connect the two electrodes of the *SENSOR* plate to the

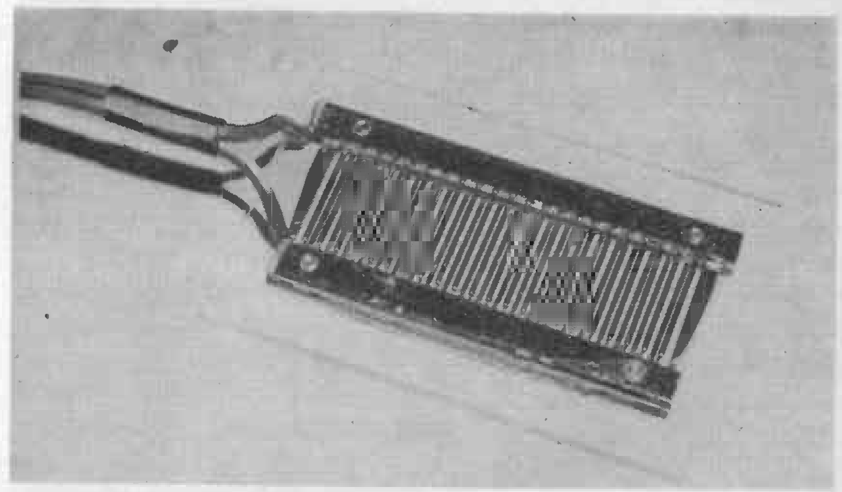


Fig. 10-5.—Sensor Plate used with the Rain Alarm.

INPUT terminals using insulated twin-conductor cable. The *SENSOR* is placed outside . . . or wherever appropriate . . . so that moisture can fall on its surface. The relay (RLY) terminals are connected to control the alarm circuit, whether a buzzer, light, bell, or other device is used. Use the armature (ARM.) and *normally open* (NO) terminals as a simple switch.

"ELECTRIC EYE" RELAYS: From both industrial and commercial viewpoints, instruments using photoelectric cells or "electric eyes" as their sensing element are by far the most popular type of electronic controls. These instruments are used for such widely diversified tasks as automatically opening doors, counting patrons to an exhibit or show, comparing colors of processed materials, protecting workers operating heavy machinery, inspecting cleaned bottles for foreign matter, and even protecting rooms and entire buildings against intrusion by spies, thiefs, or saboteurs.

Hobbyists and experimenters, like industry, also find that "electric eye" controls rank high as interesting and useful projects. A Home Owner might use such a device as a simple burglar alarm, as an automatic light switch, to control a "trick" doorbell, as an annunciator, or for the remote control of Audio Amplifiers, TV Receivers, or other electrically operated devices. Transistors are well-suited to the design of "electric eye" controls; circuits for three transistorized *Electric Eyes*

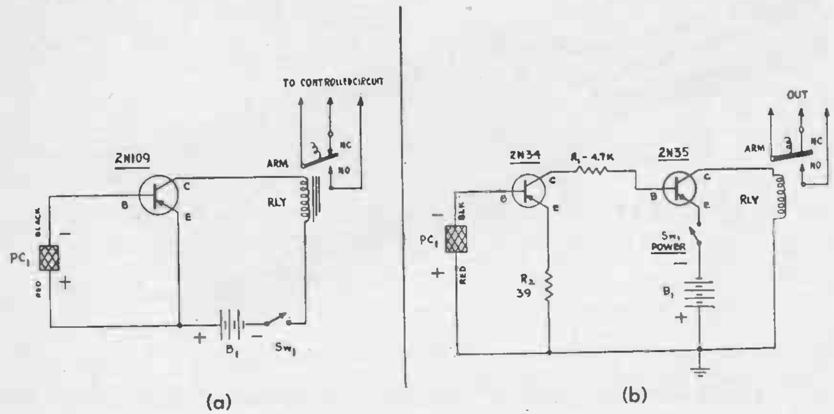


Fig. 10-6.—Two "Electric Eye" relay circuits (a) Basic circuit; (b) Sensitive version.

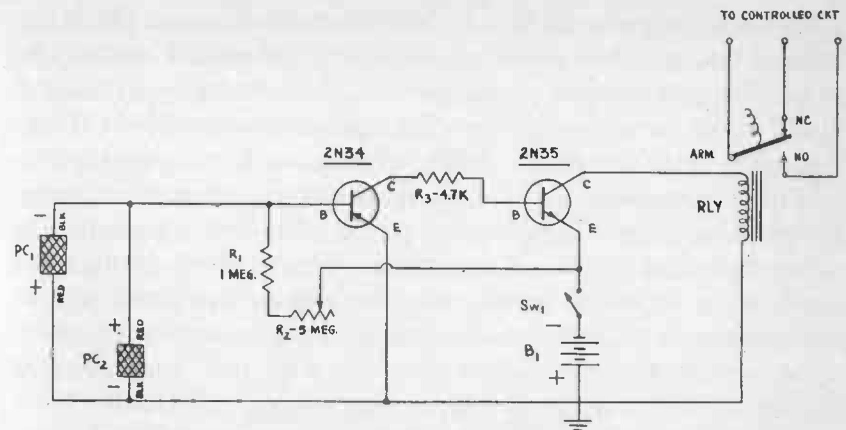


Fig. 10-7.—Schematic of a transistorized "ON-OFF" Light Control circuit.

are given in Figs. 10-6 and 10-7. A basic circuit, using a single transistor, is given in Fig. 10-6(a), while a more sensitive two-stage circuit is shown in Fig. 10-6(b). Finally, a special *locked-in "ON-OFF" Light Control* circuit is given in Fig. 10-7.

CIRCUIT DESCRIPTION: While details differ, all three of the transistorized light control circuits share certain features in common. All three use "self-generating" selenium photocells; all three use transistors in the common-emitter circuit configuration; and all three require but a single battery in their power supply. The circuit given in Fig. 10-6(a) uses a single PNP transistor, while the circuits given in Fig. 10-6(b) and 10-7 use both PNP and NPN units.

Referring to Fig. 10-6(a), the 2N109 PNP transistor serves as a direct-coupled D.C. amplifier between the selenium photocell PC_1 and the relay RLY. In operation, when the photocell is dark, there is no base bias current supplied to the transistor and collector current is very small . . . the relay remains open. When light strikes the photocell, a small voltage is developed and this, in turn, drives bias current through the base-emitter circuit of the transistor. This base current permits a much larger collector current to flow, due to the gain of the transistor, and the collector current, passing through the relay, closes it and operates the external circuit.

The circuit given in Fig. 10-6(b) operates in much the same fashion, except that two transistors are connected in cascade to obtain considerably more gain . . . and hence to provide a much more sensitive circuit. In operation, the 2N34 PNP transistor and the 2N35 NPN unit form a complementary amplifier. Coupling resistor R_1 serves simply to limit current flow between stages and thus to protect the two transistors; it is not essential to circuit operation. Unby-passed emitter resistor R_2 is included to increase the input impedance of the first stage and to improve stability by its degeneration action.

At first glance, the circuit given in Fig. 10-7 appears very similar to the circuit shown in Fig. 10-6(b). Actually, both circuits use essentially the same basic two-stage complementary amplifier, but the second circuit has been modified in two important ways . . . *two* photocells are used (PC_1 and PC_2) and a small fixed bias has been applied to the first stage through fixed resistor R_1 and rheostat R_2. The two photocells are connected "back-to-back" . . . that is, with opposite polarity. The net effect of these changes is to provide a "locked-in" operation . . . the relay *stays* open or closed.

In operation, the circuits given in Fig. 10-6 close the relay *only* while their photocells are lighted. When the light is removed, the relay opens. In contrast, the circuit in Fig. 10-7 holds the relay *either* open or closed, depending on which photocell is illuminated last. This permits the unit to be used for remote control switching without the need of using a steady light source.

Refer to Fig. 10-7. The small base bias current supplied to the first stage through R_1 and R_2 results in a larger collector current flow in the last stage (due to the gain of the amplifier). This final current, through the relay (RLY), *is enough to hold the relay closed, but not to close it, if open. (NOTE: More current is required to close a relay than to hold it closed).* The correct current is determined by adjustment of R_2, with *both* photocells dark.

Suppose, now, that photocell PC_1 is lighted. Due to the polarity of its connections, this tends to *increase* bias current in the first stage, increasing final collector current, and *closing* the relay. The relay stays closed even when the light is removed from PC_1 due to the steady collector current established by the fixed bias of the first stage.

To open the relay, photocell PC_2 is lighted. Since it is connected with reverse polarity, it tends to oppose and to partially cancel the fixed bias current. The *reduced* bias current results in a corresponding drop in final collector current, *opening* the relay. The relay stays open even when the light is removed from PC_2 since the steady state collector current is *not* enough to close it.

PARTS LIST — Fig. 10-6(a):

Sw_1 — SPST Toggle or Slide switch.
B_1 — 6 volt battery (*Burgess* No. Z4).
RLY—Sensitive relay, 3500 ohm coil (*Advance* No. SV/1C).
PC_1 — Selenium photocell
(*International Rectifier Corp.* No. B2M).
Transistor — (1) *RCA* 2N109.
MISC.—Transistor socket; small metal case; lens (optional); battery box (*Austin-Craft* No. 110); terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

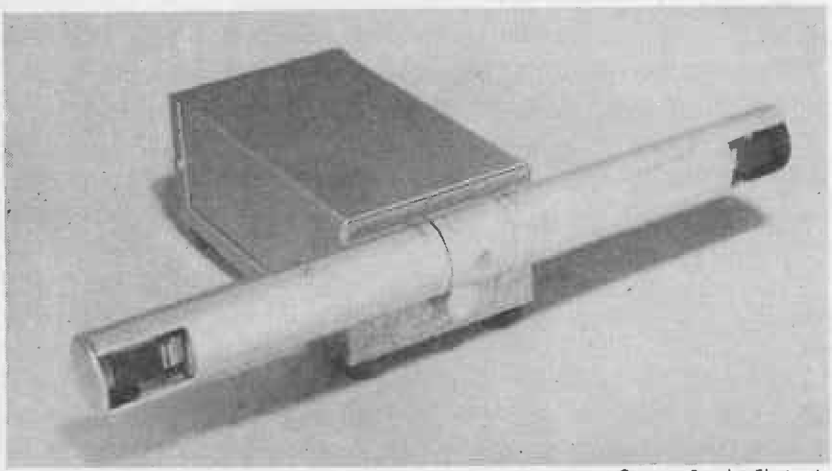
PARTS LIST — Fig. 10-6(b):

R_1 — 4.7K, ½ W. Carbon resistor.
R_2 — 39 ohm, ½ W. Carbon resistor.
Sw_1 — SPST Toggle or Slide switch.
B_1 — 6 volt battery (*Burgess* No. Z4).
RLY—Sensitive relay, 3500 ohm coil (*Advance* No. SV/1C).
PC_1 — Selenium photocell
(*International Rectifier Corp.* No. B2M).
Transistors — (1) *Sylvania* 2N34; (1) *Sylvania* 2N35.
MISC. — (2) Transistor sockets; small metal case; lens (optional); battery box (*Austin-Craft* No. 110); terminal strips; Machine screws, hex nuts, wire, solder, Misc. Hdwe., etc.

PARTS LIST – Fig. 10-7:

R_1 – 1 Megohm, ½ W. Carbon resistor.
R_2 – 5 Megohm Carbon potentiometer (*Centralab* B-87).
R_3 – 4.7K, ½ W. Carbon resistor.
Sw_1 – SPST Slide switch.
B_1 – 6 volt battery (*Burgess* No. Z4).
RLY–Sensitive relay, 5500 ohm coil (*Advance* No. SV/1C).
PC_1 PC_2 – Selenium photocells (*International Rectifier* No. B2M).
Transistors – (1) *Sylvania* 2N34; (1) *Sylvania* 2N35.
MISC. – (2) Transistor sockets; small aluminum case (*ICA* No. 29441); small control knob; (4) rubber feet; length 1″ O.D. alumiunm tubing; Machine screws, nuts, ground lugs, terminal strip; wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: Except for the usual care to observe battery polarity and to avoid accidental overheating of the transistors, no special precautions need be observed when assembling and wiring either of the three light-controlled relay circuits. Neither layout nor lead dress are critical, so the builder can exercise his own judgment about parts arrangement. If desired, a small lens may be mounted to concentrate light on the photocell; this will increase sensitivity somewhat.



Courtesy Popular Electronics

Fig. 10-8.—Author's model of the "ON-OFF" Light Control.

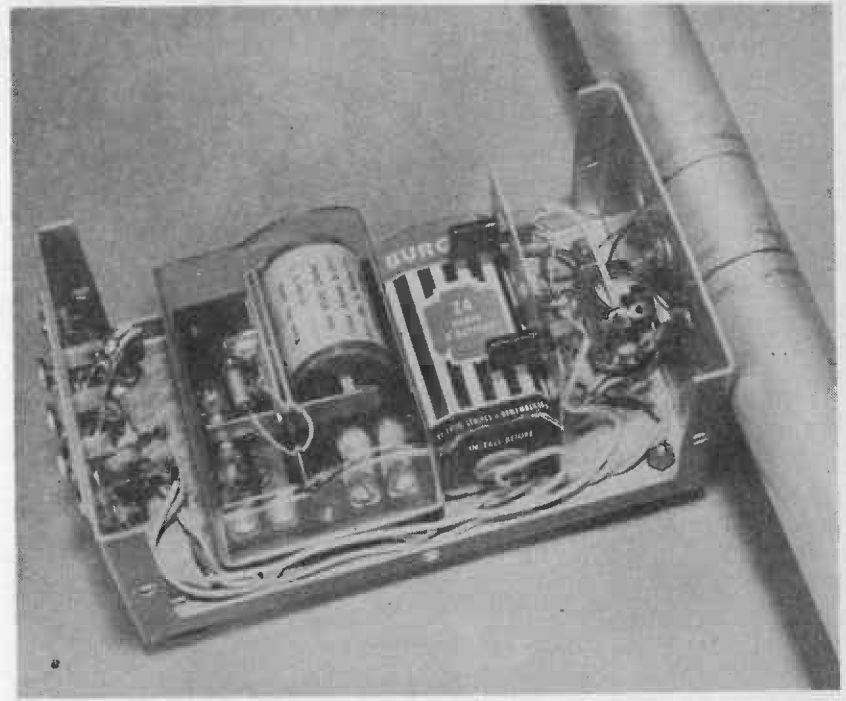


Fig. 10-9.—Interior view of the "ON-OFF" Light Controlled Relay.

The construction of the author's model of the *"ON-OFF" Light Control* unit is clear from the exterior and interior views given in Figs. 10-8 and 10-9, respectively. The photocells (PC_1 and PC_2) are mounted at opposite ends of a "control arm" so that the light beam used for operation will strike only one photocell at a time. Since the mounting bracket provided for these photocells is part of the electrical circuit, care must be taken to provide adequate insulation; in the model this was accomplished by mounting the photocells on a *wooden dowel inside the aluminum tube* making up the "control arm". Other points of interest in the model . . . the relay contact terminals are brought to a terminal strip on the back of the aluminum case; the POWER switch (Sw_1) is also mounted on the back of the case; the battery (B_1) is held in place by contact pressure between the relay (RLY) and the small chassis on which the transistor sockets are mounted . . . with electrical connections made by soldering leads directly to its terminals.

The final installation procedure, once the completed control circuit has been checked and tested, will vary considerably with the intended application. In general, however, a *focused* light source will be set up at one location and the *Light Control Relay* placed at another, with the light beam centered squarely on the photocell. Maximum range, or "throw", will depend on which circuit has been used (single or two-stage), on whether a lens is employed to concentrate the light beam, and on the intensity and sharpness of focus of the light beam. The relay's contact terminals are conected as a switch to actuate the electrical circuit to be operated when the light beam is broken . . . this may be a signal buzzer, bell, or light, a solenoid lock or valve, or a control motor of some sort, depending on the specific application.

Fig. 10-10.—The "ON-OFF" Light Controlled Relay used as a TV Commercial Killer.

An interesting application of the *"ON-OFF" Light Control* circuit given in Fig. 10-7 is shown in Fig. 10-10. Here, the unit has been placed on a TV receiver and wired as a "TV Commercial Killer". A twin lead is connected to the receiver's loudspeaker voice coil and to the armature (ARM.) and normally open (NO) contacts of the relay. In use, whenever a "commercial" comes on, the viewer switches on a small, sharply focused flashlight and flashes it momentarily on PC_1. The relay closes, shorting out the speaker voice coil and "killing" the sound. When the "commercial" is over, as evidenced by the picture content, the viewer again flashes a beam of light at the control, this time striking PC_2 and opening the relay . . . restoring the sound.

SOUND SWITCH: To the average layman, an *Electric Eye,* or light-controlled relay, is almost a commonplace device. Although he might not consider such units exactly "old hat", he is sufficiently familiar with their operation that he is not particularly impressed by them. But his reaction to a *Sound Switch,* or voice-controlled relay, is likely to be far different. To him, the operation of an electrical or mechanical device "on command" may be so unusual as to smack of science-

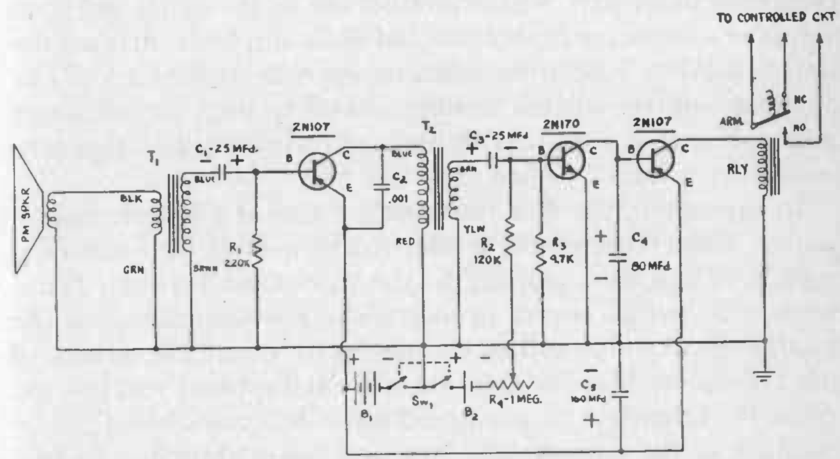


Fig. 10-11.—Circuit of a transistorized Sound Switch or voice-controlled relay.

fiction. Yet a basic *Sound Switch,* electronically, is no more complicated than the more commonplace *Electric Eye.*

The circuit for relatively simple three-transistor *Sound Switch* is given in Fig. 10-11. Basically, the instrument consists of an audio amplifier coupled to a detector and D.C. amplifier which, in turn, drives a standard electromagnetic relay. The relay performs the actual switching operation.

An experimenter with a slight touch of the practical joker in his nature can have considerable fun with this device. For instance, he might connect it to a Radio or TV Receiver. When a particularly obnoxious program comes on, he could glance in the direction of the receiver, and, raising his voice a little, tell it to "shut up" . . . with the receiver obeying him! Visiting friends are sure to be amazed. Or, on another occasion, he might connect it in place of a lamp switch at a party. During the festivities, he might raise his voice and shout "Lights out!" . . . with the light obeying! The reader can undoubtedly think of many other possibilities.

CIRCUIT DESCRIPTION: Referring to Fig. 10-11, we see that the *Sound Switch* uses three transistors. The first stage consists of a PNP unit serving as a single stage transformer-coupled amplifier. The output of the first stage drives a NPN-PNP complementary pair, which rectifies the audio signal and then serves as a two-stage direct-coupled D.C. amplifier, driving the output device, a sensitive electromagnetic relay (RLY). The common-emitter circuit configuration is used in all three stages. Power is supplied by two batteries (B_1 and B_2), controlled by a DPST switch, Sw_1.

In operation, the PM loudspeaker acts as a simple microphone, converting sound waves which strike it into electrical signals. These are coupled to the first stage through transformer T_1, which serves to match the low impedance of the loudspeaker's voice coil to the moderate input impedance of the transistor. Bias for the first stage is supplied through resistor R_1. Capacitor C_1 permits the audio signal from T_1 to be coupled to the base circuit, but prevents a short of the bias limiting resistor R_1 by T_1's secondary winding.

The audio signal is amplified by the first stage and coupled through interstage matching transformer T_2 to the input of the two-stage complementary D.C. amplifier. Capacitor C_2 serves to by-pass higher frequency signals and to prevent possible interstage coupling which could result in oscillation at an ultrasonic frequency.

Battery B_2 supplies a small bias current to the complementary stage through a voltage divider consisting of rheostat R_4, fixed resistor R_2 and base resistor R_3. D.C. blocking capacitor C_3 prevents a short of the bias current to ground through the secondary of T_2. This bias current is very small, but with a reverse polarity to insure non-linear operation. As a result, the first stage acts to rectify the applied audio signal and to pass a D.C. signal to the final stage which is proportional to the level of the audio signal. C_4 serves as a filter and provides time delay.

This D.C. signal, amplified further by the last stage, actuates the relay (RLY). Capacitor C_5, across power supply battery B_1, serves as a decoupling filter.

PARTS LIST:

R_1 — 220K, ½ W. Carbon resistor.
R_2 — 120K, ½ W. Carbon resistor.
R_3 — 4.7K, ½ W. Carbon resistor.
R_4 — 1 Megohm Carbon potentiometer (*Centralab* B-69).
C_1, C_3 — 25 Mfd., 6 volt electrolytic (*Barco* P6-25).
C_2 — 0.001 Mfd. disc ceramic capacitor (*Centralab* DD-102).
C_4 — 80 Mfd., 6 volt electrolytic (*Barco* P6-80).
C_5 — 160 Mfd., 6 volt electrolytic (*Barco* P6-160).
T_1 — Transistor output transformer, 400 ohms to 11 ohms (*Argonne* AR-120).
T_2 — Transistor interstage transformer, 10,000 ohms to 2K (*Argonne* AR-109).
Sw_1 — DPST Toggle switch.
B_1 — 6 volt battery (*Burgess* No. Z4).
B_2 — 1.5 volt penlight cell (*Burgess* No. Z).

PM SPKR – PM Loudspeaker, 10 ohm voice coil (*Argonne* AR-95).

RLY – Sensitive relay, 5500 ohm coil (*Advance* SV/1C).

Transistors – (2) *GE* type 2N107; (1) *GE* type 2N170.

MISC. – (3) Transistor sockets; Small metal Box (*L.M.B.* No. 142); battery boxes (*Austin-Craft* No. 110 for 6-volt battery, No. 127 for 1.5 volt cell); small control knob; terminal strips; Machine screws, hex nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The *Sound Switch* may be assembled in a small metal or plastic case. For convenience in wiring, the author suggests the use of a small sub-chassis, on which are mounted the transistor sockets, the transformers, and similar small components. Although layout is not especially critical, signal leads should be kept short and direct, and the "input" and "output" circuits should be kept well separated to avoid possible overall oscillation. Battery and electrolytic capacitor polarities must be observed. And bare leads should be covered with spaghetti tubing to avoid accidental shorts.

With the wiring completed and double-checked, the transistors and batteries may be installed and the device tested. Close the power switch, Sw_1, and try speaking in a moderately loud voice within two or three feet of the PM loudspeaker. The relay should close and should stay closed for a second or so, due to the "time delay" introduced by capacitor C_4. If the relay fails to close, or fails to drop out after a short time delay (*after the actuating sound is stopped*), R_4 should be adjusted. If further trouble is encountered, the wiring should be re-checked and components tested.

Installation methods will vary with the desired use. In general, the *Sound Switch* itself is located in a concealed location so that the controlling sound, whether voice or music, is close enough to operate it, but so that extraneous sounds and background noise will not initiate operation. The unit's sensitivity, and therefore maximum range, will vary from three to ten feet, depending on the level of the initiating sound and on the adjustment of the relay (RLY). The relay contacts are used as

a simple switch to actuate the equipment or circuit to be controlled by the device.

GADGETS

CODE PRACTICE OSCILLATORS: In an earlier section (*Chapter 8*), we described and discussed a simple *Wireless Code Practice Oscillator*. While the prospective Ham would find such an instrument extremely valuable for simulated "on-the-air" practice, its usefulness depends on the availability of a standard Communications Receiver equipped with a B.F.O. Some learners may not have a Communications Receiver . . . others may prefer a self-contained instrument that they can use anywhere. For these groups, as well as for others who may prefer to work with A.F. rather than R.F. circuits, the *Audio Code Practice Oscillator* provides a good answer to the problem of learning code.

Circuits for two *Code Practice Oscillators* are given in Fig. 10-12, while assembled models are shown in Figs. 10-13 and 10-14. A single transistor provides headphone operation in the model shown in Figs. 10-12(a) and 10-13. For more con-

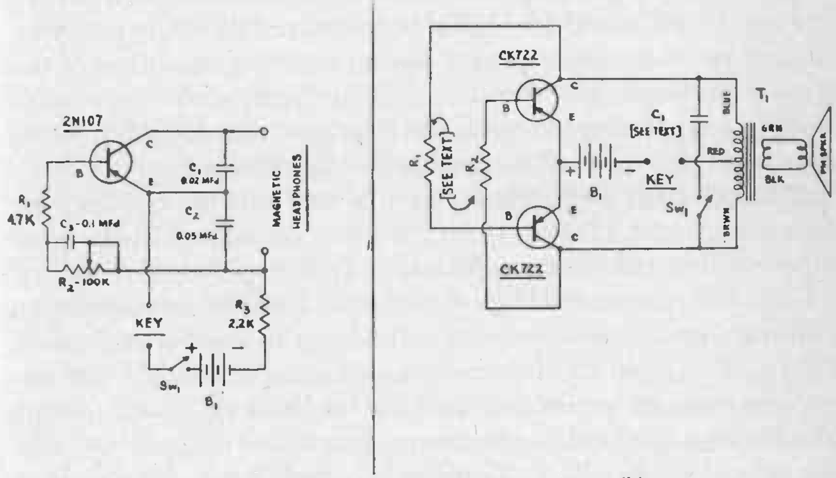


Fig. 10-12.—Diagrams for two easily built Code Practice Oscillators—(a) Headphone type; (b) Loudspeaker type.

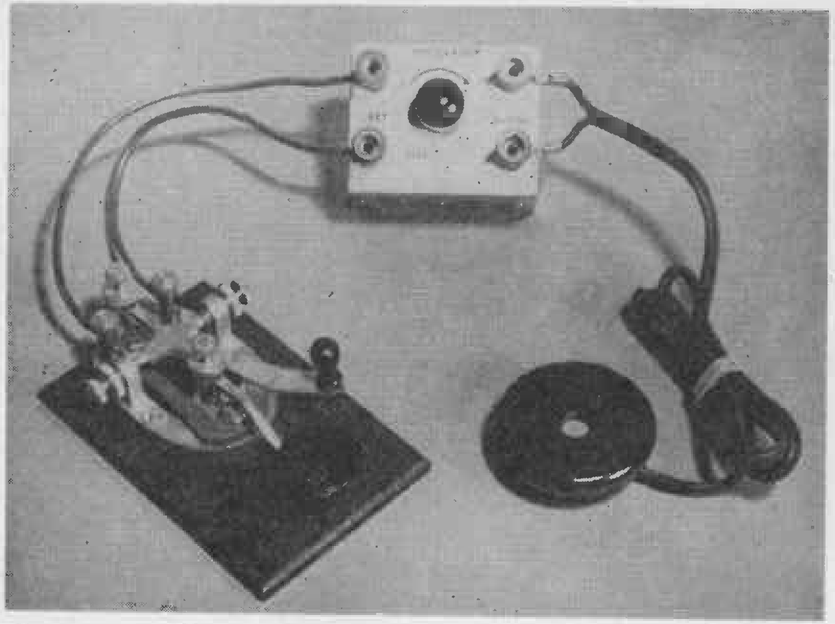


Fig. 10-13.—Headphone type Code Practice Oscillator.

venient use, or group practice, the two-transistor unit shown in Figs. 10-12(b) and 10-14 will be preferred by many builders, since it provides Loudspeaker operation. But regardless of the circuit preferred, the builder will find that either is easy to build, inexpensive, cheap to operate, and simple to use. Only standard, readily available components are used.

CIRCUIT DESCRIPTION: Referring first to Fig. 10-12(a), we see that a single PNP transistor is used, connected in the common-emitter circuit configuration. In operation, the inductance of the magnetic Headphones used with the unit forms an audio frequency resonant (tuned) circuit in combination with capacitors C_1 and C_2. These two capacitors also form a voltage-divider network which provides the feedback necessary to start and sustain oscillation. Because capacitive feedback is used, the unit is essentially a "Colpitts" type oscillator. The ratio of C_1 and C_2 determines feedback.

Base bias current is supplied through fixed resistor R_1 and

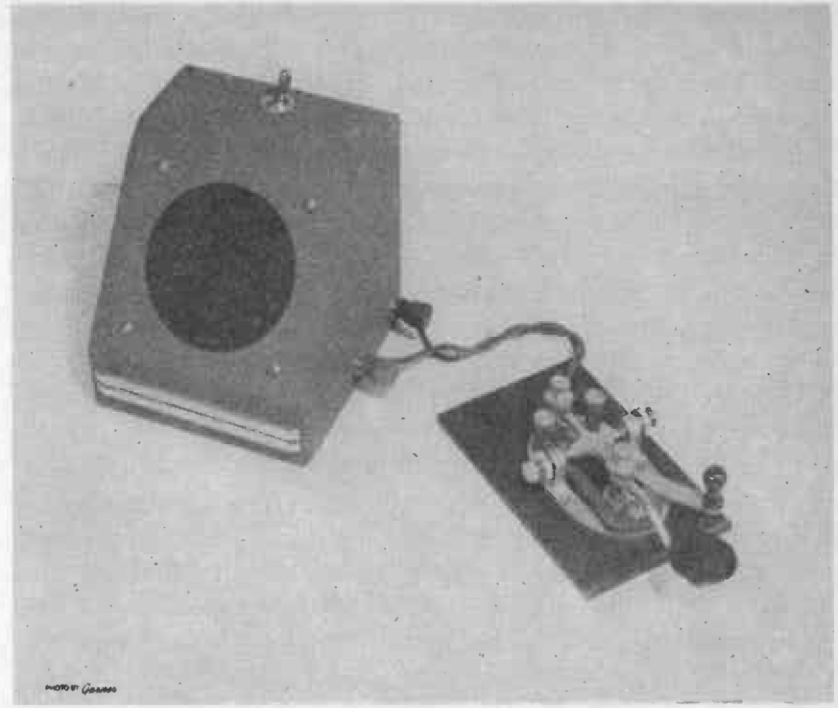


Fig. 10-14.—Loudspeaker type Code Practice Oscillator.

potentiometer R_2, by-passed by C_3. Resistor R_3 serves to isolate the battery (B_1) used as a power supply from the tuned circuit and thus prevents an A.C. "short" across C_2. The circuit is controlled by switching the battery "ON" and "OFF" by means of the Handkey (KEY), which is effective only after POWER switch Sw_1 is closed. This switch may be omitted, if desired, and was included in the author's model (and shown in the circuit) simply because it was available on control R_2

Good loudspeaker volume is obtained with the circuit given in Fig. 10-12(b) by using two PNP transistors in a push-pull oscillator circuit. In operation, transformer T_1 serves the dual purpose of matching the transistors to the low impedance loudspeaker voice coil and of providing the feedback necessary to start and sustain oscillation. The operating frequency is determined by the transformer used and by the sizes of base resistors R_1 and R_2, serving both to establish base bias current and to determine the ratio of the feedback signal. A further control on frequency is provided by capacitor C_1, which may be switched across the transformer's primary winding by SPST switch Sw_1, effectively changing its "natural" resonant frequency. Power is supplied by a single battery (B_1), controlled by the Handkey (KEY). This circuit, like the first, also uses the common-emitter circuit configuration, even though the transistors are connected for push-pull operation.

PARTS LIST — Fig. 10-12(a):

R_1 — 4.7K, ½ W. Carbon resistor.
R_2 — 100K Carbon potentiometer, with switch (*Centralab* B-40-S).
R_3 — 2.2K, ½ W. Carbon resistor.
C_1 — 0.02 Mfd., 200 volt, metallized paper capacitor.
C_2 — 0.05 Mfd., 200 volt, metallized paper capacitor.
C_3 — 0.1 Mfd., 200 volt, metallized paper capacitor.
Sw_1 — SPST switch (on R_2).
B_1 — 3 to 6 volt battery (penlight cells in series).
Transistor — (1) *GE* type 2N107.
MISC. — Transistor socket; control knob; small metal case (*ICA* No. 29435); (4) binding posts; terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.
ACCESSORIES — Handkey; Magnetic Headphone(s) . . . 1000 to 2000 ohms impedance.

PARTS LIST — Fig. 10-12(b):

R_1,R_2 — ½ W. Carbon resistors (*see text for values*).
C_1 — Tone control capacitor, optional (*see text*).
T_1 — Transistor Push-Pull Output transformer (*Argonne* No. AR-119).
B_1 — 9 volt battery (*RCA* VS300).
PM SPKR — 3″ Loudspeaker, 3.2 ohm voice coil.
Transistors — (2) *Raytheon* CK722.
MISC. — (2) Transistor sockets; (2) binding posts; small chassis; battery clips; small cabinet (*ICA* No. 3996); terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.
ACCESSORY — Handkey.

CONSTRUCTION HINTS: The author's models, shown in Figs. 10-13 and 10-14, should serve to suggest typical construction to a prospective builder. Relatively few parts are used in either the Headphone or the Loudspeaker model, so the basic circuits may be assembled in quite small metal or plastic boxes. In the case of the Loudspeaker model, shown in Fig. 10-14, the size of the loudspeaker used will probably be the determining factor on case size . . . if a 3″ loudspeaker is used, a standard *Meter Case* (specified in the *PARTS LIST*) makes an attractive housing. Neither parts arrangement or lead dress are critical, so the builder can follow his own inclinations regarding layout.

If the Headphone model is assembled (Figs. 10-12(a) and 10-13), the frequency of operation may be changed by changing capacitors C_1 and C_2. In rare instances it may be necessary to change component values in this circuit to obtain optimum operation with the particular pair of Headphones employed. And, of course, other PNP transistors may be used if component values are adjusted for best operation.

Assembly of the *Loudspeaker C.P.O.*, shown in Figs. 10-12(b) and 10-14, requires that certain values be determined experimentally. First, base resistors R_1 and R_2 are chosen to give the best compromise between desired tone and output volume. These two resistors should have the same value. They may be determined either by using a rheostat in each circuit or temporarily connecting a *Resistance Substitution Box* in place of the resistors. Typical values should fall between 10K and 100K. If *two* output frequencies are required, C_1 may be added to the circuit. Again, this value is determined experimentally for the tone desired . . . typical values run between 0.001 and 0.02 Mfd.

Regardless of which model is assembled, the transistors and battery should *not* be installed until *after* all wiring has been double-checked for possible errors and accidental shorts. If desired, NPN transistors with similar gain characteristics may be used in either circuit, *provided* battery polarities are reversed.

LIGHT BEAM RECEIVER: The "dits" (dots) and "dahs" (dashes) of the International Morse Code may be transmitted both as an interrupted Radio Signal and as a flashing Light Beam. Generally speaking, faster communication is possible with Radio than with Light, however, since the average trained operator can recognize and record messages which he hears as tones faster than he can recognize and record messages received as flashing lights. But if the instrument shown in Fig. 10-15 is used, *Light Beam signals can be received as audio tones.*

This instrument, which employs two transistors and a selenium photocell, converts light into an audio signal which can be heard in the *Headphone*. The frequency of the audio signal produced depends, to some extent, on the *intensity* of the light beam striking the photocell. This fact permits the unit to be used as an *Audible Light Meter* in addition to its application as a *Light Beam Receiver*. A switch is provided to cut out the "tone generation" characteristic, permitting it to be used to

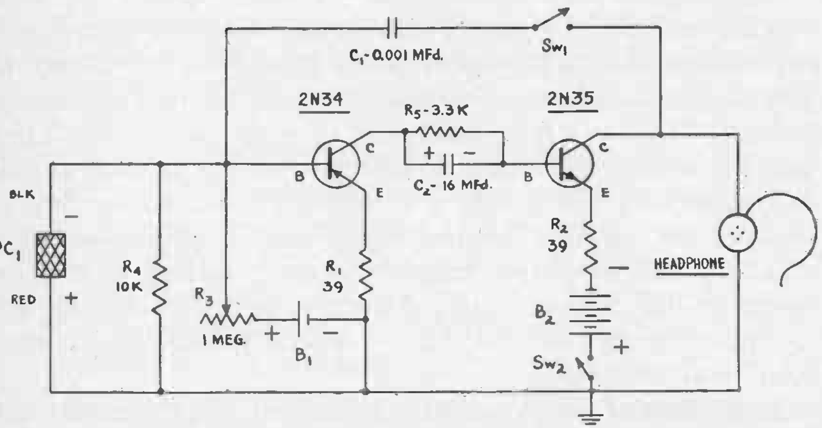


Fig. 10-15.—Circuit for a Light Beam Receiver or Audio Photometer.

receive *modulated* light, thus increasing its versatility even further.

CIRCUIT DESCRIPTION: Referring to the schematic diagram (Fig. 10-15), the *Light Beam Receiver* uses a type 2N34 and a type 2N35 NPN transistor in a modified direct-coupled complementary amplifier circuit. The common-emitter configuration is used in both stages. The basic amplifier is converted into an audio frequency multivibrator by feedback between the "output" and "input" circuits through capacitor C_1, controlled by switch Sw_1.

In operation, oscillation is prevented by a "reverse" bias applied to the base of the first (PNP) stage. This bias current is obtained from battery B_1, with voltage divider R_3-R_4 determining the exact bias level. The self-generating selenium photocell PC_1 is also connected to the base-emitter circuit, *but with a polarity which tends to cancel the bias current supplied through R_3*. Thus, when light strikes the photocell, the current produced by it cancels the bias and allows oscillation to take place . . . this is heard as a tone in the *Headphone* serving as the collector load for the second (NPN) stage.

Unby-passed emitter resistors R_1 and R_2 are included to improve circuit stability and to increase the input impedances of their respective stages. Interstage coupling resistor R_5, by-passed by C_2, is included to limit maximum current between stages and thus to protect the transistors; other than serving for current limiting purposes, R_5 (and C_2) is not essential to circuit operation. Power is supplied by B_2, controlled by SPST switch Sw_2.

PARTS LIST:

R_1, R_2 — 39 ohm, ½ W. Carbon resistors.
R_3 — 1 Megohm Carbon potentiometer (*Centralab* B-69).
R_4 — 10K, ½ W. Carbon resistor.
R_5 — 3.3K, ½ W. Carbon resistor.
C_1 — 0.001 Mfd. disc ceramic (*Centralab* DD-102) . . . *see text.*
C_2 — 16 Mfd., 12 volt electrolytic (*Barco* No. P12-16).
Sw_1, Sw_2 — SPST Toggle switches.

B_1 — 1.5 volt penlight cell (*Burgess* No. Z).
B_2 — 6 volt battery (*Burgess* No. Z4).
PC_1 — Selenium photocell (*International Rectifier Corp.* No. B2M).
Transistors — (1) *Sylvania* 2N34; (1) *Sylvania* 2N35.
Headphone — Magnetic Headphone, 1000 to 3000 ohms impedance.
MISC. — (2) Transistor sockets; control knob; small metal case; lens (optional—*see text*); terminal strips; Machine screws, hex nuts, wire, solder, Misc. Hdwe., etc.
ACCESSORY — Light Beam Transmitter . . . spotlight controlled by Handkey, *see text*.

CONSTRUCTION HINTS: The instrument may be assembled in a small aluminum or steel case of the type offered by most Radio Parts Distributors. Although parts layout is not critical, there are a few points relative to final assembly which the builder should keep in mind if possible trouble is to be minimized. First, the mounting bracket attached to the photocell specified is connected, electrically, to the unit . . . for best results, this bracket should be insulated from chassis or circuit ground. Of course, photocell lead as well as battery and electrolytic capacitor polarities *must* be observed. For maximum sensitivity, mount a small lens in front of the photocell so as to concentrate light on it . . . the larger the lens and the better its light-gathering ability, the greater the increase in sensitivity. Whether or not a lens is used, a small "hood" or tube should be provided to keep extraneous light from striking the photocell . . . the inside of the hood should be finished with *flat black* paint.

The *Light Beam Transmitter* used with the *Receiver* can be any strong, sharply focused light source that can be controlled with a standard Handkey. A *Burgess* "Radar-Lite" is a suitable unit. Wire the Handkey in parallel with the normal ON-OFF switch so that either may be used to control the light. Operating range will depend primarily on the intensity and sharpness of focus of the light source used. With a small flash-light, the range may be under 10 feet . . . with a more powerful unit, range may be up to 50 or 100 feet, or more.

With the wiring completed and checked for errors, the transistors and batteries may be installed, and the unit adjusted for operation. Set up the *Light Beam Transmitter* and the *Receiver* so that the beam falls squarely on the photocell's sensitive surface. Close switches Sw_1 and Sw_2. With the light beam *ON*, adjust R_3 until a tone is heard in the *Headphone*. Turn the beam *OFF* . . . if the tone doesn't disappear, try readjusting R_3. When R_3 is properly adjusted, the audio tone is heard only when the beam is *ON*. This preliminary adjustment should be made at short range . . . some slight readjustment will be necessary as the *Light Beam Transmitter* is backed away to full range, but this should be minor.

The audio tone (frequency) will depend both on the intensity of the light source and on the value of feedback capacitor C_1. If you find that the pitch is too high (or too low), change this capacitor. A smaller capacity here will *raise* the operating frequency; a larger unit will *lower* the pitch. The final choice of a capacitor should be made with the *Light Beam Transmitter* set at *normal* operating range, whether this is maximum range or some shorter distance.

The basic *Light Beam Receiver* may be changed into an *Audio Light Meter* simply by mounting the photocell so that the light to be measured falls on its surface. Tone (frequency) will indicate light intensity . . . with extremely strong (or weak) light, the unit may stop oscillating. In such a case, readjust R_3. If the instrument is to be used to receive *modulated light* . . . open switch Sw_1, removing the feedback.

MUSICAL GADGETS

METRONOME: Student musicians have used mechanical *Metronomes* for many, many years. Basically, these units consist of a spring-driven clockwork which, in turn, is coupled to a movable pendulum arm. As the pendulum swings back and forth, it sounds distinctive repetitive "clicks" which serve to establish timing. The timing rate may be changed by moving a sliding weight along the arm and thus changing its operating period. More recently, electronic *Metronomes,* using vacuum tubes, have been developed and manufactured commercially. Operating a small loudspeaker, in which periodic "clicks" or "plops" are sounded, these units have proven moderately popular. However, although a vacuum tube *Metronome* does not have to be rewound regularly, it has certain disadvantages . . . it requires a source of line power for operation; it requires "warm-up" time before it can be used; it develops excessive heat; and frequent filament "burn-out" and tube replacement brings up a maintenance problem.

A transistorized electronic *Metronome,* on the other hand, offers all the advantages of electronic operation with none of the disadvantages. Except for a rather infrequent replacement of an inexpensive battery, maintenance is virtually "nil". Compact, light-weight, and completely self-contained, a transistorized *Metronome* may be used anywhere . . . requiring neither "warm-up" time nor a source of line power. A suitable

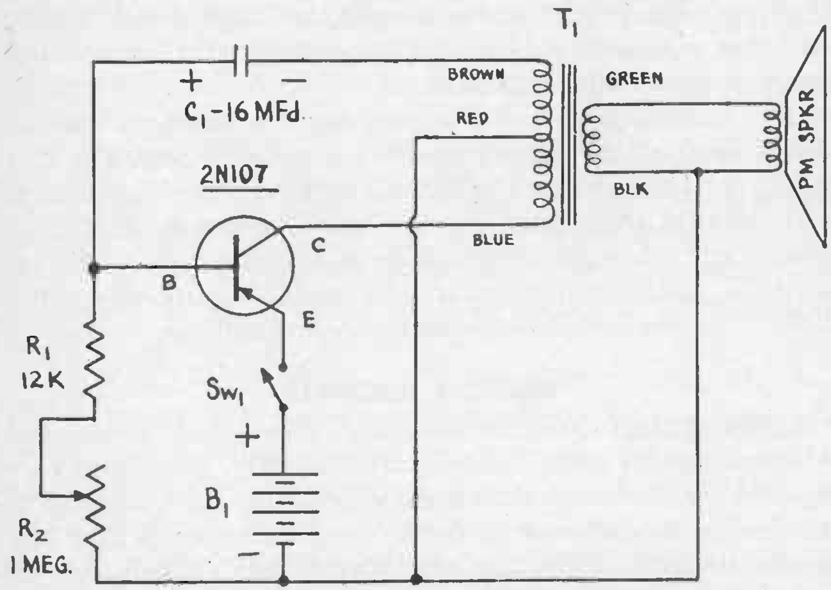


Fig. 10-16.—Schematic diagram of a transistorized Metronome.

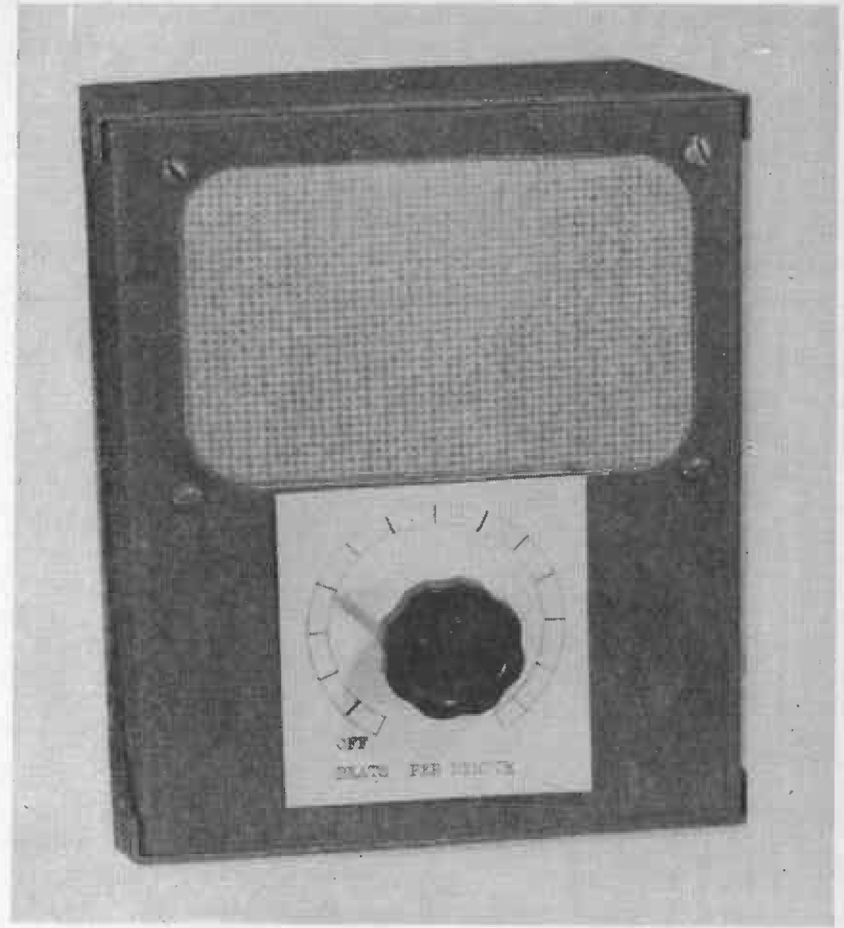


Fig. 10-17.—Author's model of the Metronome.

Metronome circuit, requiring but a single transistor and battery, is shown in Fig. 10-16, while an assembled model is shown in Fig. 10-17. Only standard, commercially available components are used, with construction simple and straightforward, requiring, at the most, only two or three evenings or a spare week-end for a person of moderate skill.

CIRCUIT DESCRIPTION: The transistorized *Metronome* employs a PNP transistor in a "blocking oscillator" circuit, using the common-emitter configuration. Power is supplied by a single battery, B_1, controlled by SPST switch Sw_1.

In operation, transformer T_1 serves the dual purpose of providing the feedback necessary to start and sustain oscillation and of matching the transistor's high impedance output to the low impedance of the loudspeaker's voice coil. To accomplish this dual purpose, a push-pull output transformer is employed. The repetition rate is determined by the R-C time constant of coupling capacitor C_1 and the base resistor, made up of fixed resistor R_1 and the "beat rate" control R_2. Adjusting R_2 changes the R-C time constant and thus changes the operating rate (frequency).

PARTS LIST:

R_1 — 12K, ½ W. Carbon resistor.
R_2 — 1 Megohm Carbon potentiometer (*Centralab* B-69).
C_1 — 16 Mfd., 12 volt electrolytic (*Barco* P12-16).
T_1 — Transistor output transformer (*Argonne* No. AR-138).
Sw_1 — SPST switch, on R_2.
B_1 — 9 volt battery (*RCA* No. VS300).
PM SPKR — 4″ PM Loudspeaker, 3.2 ohm voice coil.
Transistor — (1) *GE* type 2N107.
MISC. — Transistor socket; control knob; battery clips; metal case (*L.M.B.* No. 142); (4) rubber feet; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: The exterior view of the author's model, given in Fig. 10-17, might be used as a guide by the worker assembling his own unit. However, since parts layout is not at all critical, the builder can follow his own inclinations. Even the metal case can be changed, since it is not needed for shielding purposes . . . a plastic, or even a wooden case is equally satisfactory for housing this circuit. The only points to watch are the transformer connections and the battery (B_1) and electrolytic capacitor (C_1) lead polarities. Other PNP transistors may be substituted for the unit specified and, in most cases, no component changes need be made. Even a

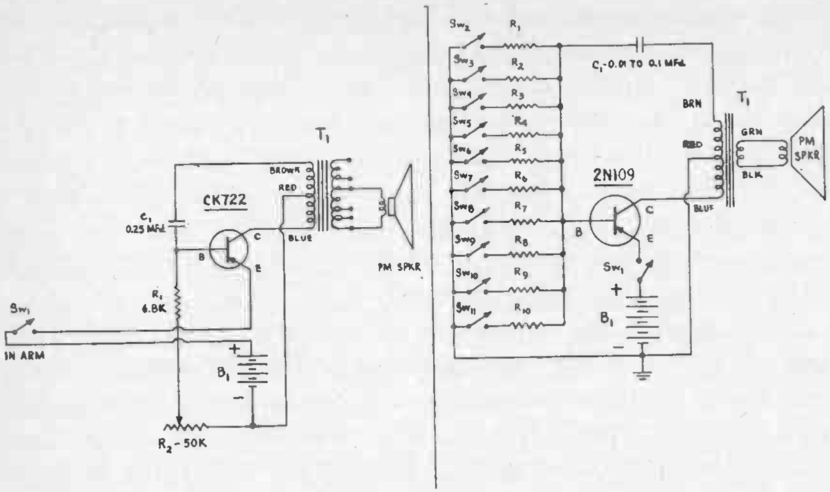
NPN transistor may be used, *provided* the battery and electrolytic capacitor leads are reversed.

Once the wiring is completed and checked, the transistor and battery should be installed and the instrument tested. As a final step, the "rate" control (R_2) should be calibrated in *Beats Per Minute*. This may be done by using another *Metronome* as a standard or by actually counting the individual beats, using a stop watch (or watch with a sweep-second hand) to determine the timing interval.

If the operating range is not satisfactory, it may be changed quite easily by changing capacitor C_1. A larger capacitor here will lower the maximum beat rate, while a smaller unit will give a higher repetition rate. The *minimum* rate (frequency) is determined by fixed resistor R_1 plus the maximum value of R_2; the *maximum* rate is determined by R_1 alone, for a given value of C_1. If desired, R_1 may be changed to vary the *maximum* rate, but, in general, should not be lower than 10K.

"MUSICAL TOYS": Transistors, because of their small size, light weight, ruggedness, and low cost, are almost ideally suited to the construction of electronic toys. In addition to their desirable physical characteristics, their minute power requirements make battery operation feasible and this, in turn, permits the design of a self-contained and completely portable toy. More important, the use of low battery voltages insures complete freedom from possible shock.

A basic approach to electronic toy design is to assemble a standard circuit into a special or "gimmick" package. For example, one of the Receiver circuits described in Chapter 8 might be assembled as a *Wrist Radio, Spaceman's Set,* or *Police Receiver,* depending on the housing used. Using this approach, a *"Musical"* type of toy might be developed around a simple audio oscillator driving a loudspeaker. By changing the housing, the same circuit might become, in turn, a *Banjo,* an *Organ,* a *Violin,* a *Guitar* or almost any other type of electronic toy. Typical circuits that might be used in such applications are given in Fig. 10-18, while an assembled electronic *Banjo* is shown in Fig. 10-19.



(a) (b)

Fig. 10-18.—Two transistorized Musical Toys—(a) an electronic "Banjo"; (b) an electronic "Organ".

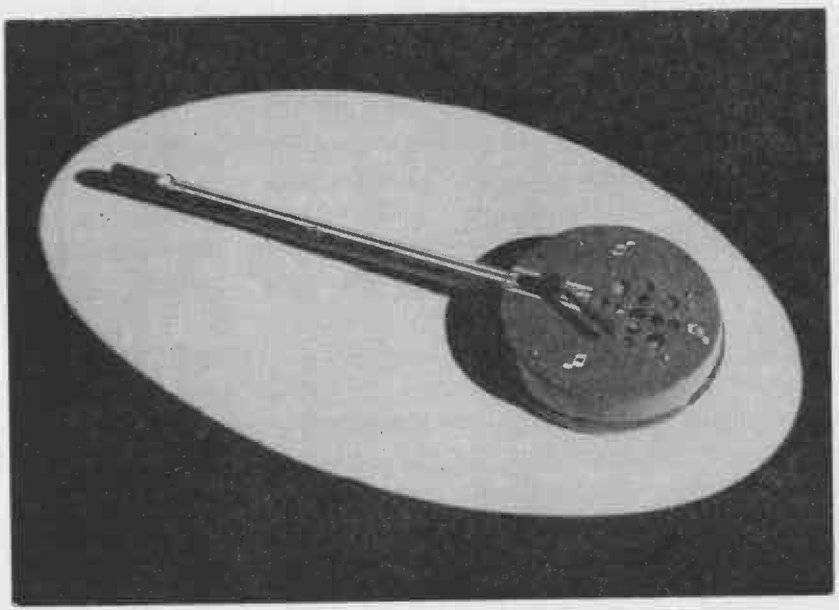


Fig. 10-19.—Author's model of a transistorized electronic "Banjo".

CIRCUIT DESCRIPTION: To be useful in a *Musical Toy,* an audio oscillator must be easily adjusted over a moderate frequency range. This is necessary to permit sounding different notes, and thus the playing of simple tunes. A conventional L-C oscillator is not suitable for such an application because the physical size and high cost of large value variable L and C elements render them impractical for a toy. To avoid the need for such components, a "blocking oscillator" circuit arrangement may be used; in such circuits, the repetition rate (frequency) depends on an R-C time constant . . . and variable resistors are both compact and inexpensive.

The two circuits given in Fig. 10-18 are basically alike, even though they differ in details. Both are blocking oscillators; both use PNP transistors in a common-emitter configuration; both are powered by a single battery; the operating frequency of both is varied by changing the resistance in the base circuit; and, finally, both use a push-pull transformer to provide feedback and to match the transistor to a loudspeaker's voice coil.

Referring first to Fig. 10-18(a), the operating frequency is determined by the R-C time constant of coupling capacitor C_1 and base resistors R_1 and R_2. A potentiometer is used for R_2, permitting a continuous adjustment of frequency from the minimum to maximum value. A specific note is sounded by pre-setting R_2, as determined by a calibrated scale or by "feel" and then depressing Sw_1. The switch is held depressed for the time needed to sound an eighth, quarter, half or full note. To "slide" from one note to another, Sw_1 is held depressed as R_2 is shifted in value.

The circuit given in Fig. 10-18(b) is almost identical in operation, except that the continuously variable base resistance has been replaced by a series of individual resistors (R_1 to R_{10}), any one of which can be switched into the circuit by depressing an appropriate SPST switch (Sw_2 to Sw_{11}). Again, the operating frequency is determined *both* by the coupling capacitor (C_1) and the resistor chosen. A specific note is sounded by depressing the frequency (note) selector switch *and* the POWER switch (Sw_1) *simultaneously.*

PARTS LIST — Fig. 10-18(a):

R_1 — 6.8K, ½ W. Carbon resistor.
R_2 — 50K Carbon potentiometer (*Centralab* B-31).
C_1 — 0.25 Mfd., 200 volt tubular paper capacitor.
T_1 — Audio output transformer (*Merit* A-2900).
Sw_1 — SPST Push-button switch, normally open.
B_1 — 22½ volt Hearing Aid battery (*Burgess* No. U-15).
PM SPKR — 4″ to 6″ PM Loudspeaker, 6-8 ohm voice coil.
Transistor — (1) *Raytheon* CK722.
MISC. — Transistor socket; battery box (*Austin-Craft* No. 113); Bar knob or control lever; housing (*see text*); terminal strips; Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

PARTS LIST — Fig. 10-18(b):

R_1 - R_{10} — ½ Watt Carbon resistors (*see text*).
C_1 — 200 volt paper capacitor (0.01 Mfd. to 0.1 Mfd., *see text*).
Sw_1 - Sw_{11} — SPST Push-button switches, normally open.
B_1 — 9 volt battery (*RCA* VS300).
T_1 — Transistor output transformer (*Argonne* No. AR-139).
PM SPKR — 4″ to 8″ PM Loudspeaker, 8 ohm voice coil.
Transistor — (1) *RCA* 2N109.
MISC.—Transistor socket; battery clips; housing (*see text*); Machine screws, nuts, wire, solder, Misc. Hdwe., etc.

CONSTRUCTION HINTS: Except for the usual care to observe battery polarity and to avoid overheating transistor leads, no special precautions need be observed when assembling either of the circuits shown in Fig. 10-18. Neither parts layout nor wiring arrangement are critical. More important than the wiring technique employed is the type of housing and ruggedness of assembly . . . all components and leads should be secure to prevent damage from the bouncing and jiggling which a toy is likely to receive; and the circuit itself should be well covered by the housing, to keep out prying and inquisitive fingers.

The type of housing chosen, as well as its material of construction, will depend on the type of instrument to be simulated by the toy. Metal, wood, or plastic are all suitable for the housing, provided a reasonably rugged construction is employed. The circuit given in Fig. 10-18(a) is best for toys which simulate instruments providing a more or less *continuous* variation of tone . . . in general, most string and wind instruments. Typical housings might simulate a *violin*, a *banjo*, a *cello*, a *guitar*, or any similar instrument. The circuit given in Fig. 10-18(b), on the other hand, is best suited for toys which simulate key-operated instruments, such as *pianos*, *organs*, or *accordions*.

A toy electronic *banjo*, using the circuit given in Fig. 10-18(a), is shown in Fig. 10-19. This home-made instrument was assembled from a round cake pan and a length of aluminum tubing, painted, then decorated with commercial decals. The control switch (Sw_1) is mounted near the end of the arm, while the tone control (R_2) is operated by a control lever. A pattern of small holes were made in the pan for the loudspeaker. In use, this toy is held like a conventional banjo, with one hand operating the push-button and the other adjusting the frequency control.

Since the circuit given in Fig. 10-18(a) provides a continuous control of frequency, any note within its range may be sounded by adjusting R_2. The circuit given in Fig. 10-18(b), on the other hand, depends on fixed resistors to determine individual notes (R_1 to R_{10}) . . . although ten resistors are specified, any number may be used, depending on the number of notes required. These resistor values are determined experimentally to give the desired note with the particular coupling capacitor (C_1) employed. Typical values range from 12K to about 220K. Capacitor C_1 is chosen to place emphasis on either the low-pitched or the high-pitched notes . . . the larger C_1, the lower the operating frequency, for a given base resistance.

GENERAL SEMICONDUCTOR APPLICATIONS

As discussed in the INTRODUCTION (Chapter 1), transistors are a group within a general class of semiconductor components, with the larger class including diodes, photocells, and other types of devices. Thus far, we have emphasized transistor circuits; this is proper, of course, in a TRANSISTOR CIRCUIT HANDBOOK. Although diodes, photocells, and other semiconductor devices have been shown in a number of instrument diagrams, their application was generally incidental to the transistor circuitry itself. However, the author feels that the treatment of general semiconductor applications, if done briefiy, would not be completely out-of-place in this volume . . . any more than the treatment of diode, phototube, and thyratron applications would be out-of-place, say, in a general volume on vacuum tube circuits. It is with this thought in mind, then, that we devote the next few pages to circuits using semiconductor devices other than transistors.

Typical circuits are given in Figs. 10-20, 10-21, 10-24, 10-26, and 10-27, while photos of assembled models are shown in Figs. 10-22, 10-23, 10-25, 10-28, and 10-29. In order to keep our discussion of each circuit application brief, we shall use an approach intermediate between that employed in discussing the BASIC CIRCUITS in Part II and the detailed descriptions employed in the previous sections and Chapters of Part III.

RECTIFIER CIRCUITS: A diode is a non-linear device, passing current better in one direction than in the other. This characteristic makes it useful as a *detector* or as a *rectifier*. In practice, both *detector* and *rectifier* circuits are similar in appearance, differing primarily in their specific application and in the additional components used with the basic diode. A *detector* circuit is generally used either to *mix* two signals, to *modulate* one signal with another, or to *separate* a modulated signal into component parts . . . as, for example, separating the R.F. and A.F. components of a modulated R.F. carrier. A *rectifier,* on the other hand, is generally used to convert A.C. into pulsating D.C., which, in turn, can be changed into pure D.C. by appropriate filtering.

Typical *rectifier* circuits are given in Fig. 10-20. In any of

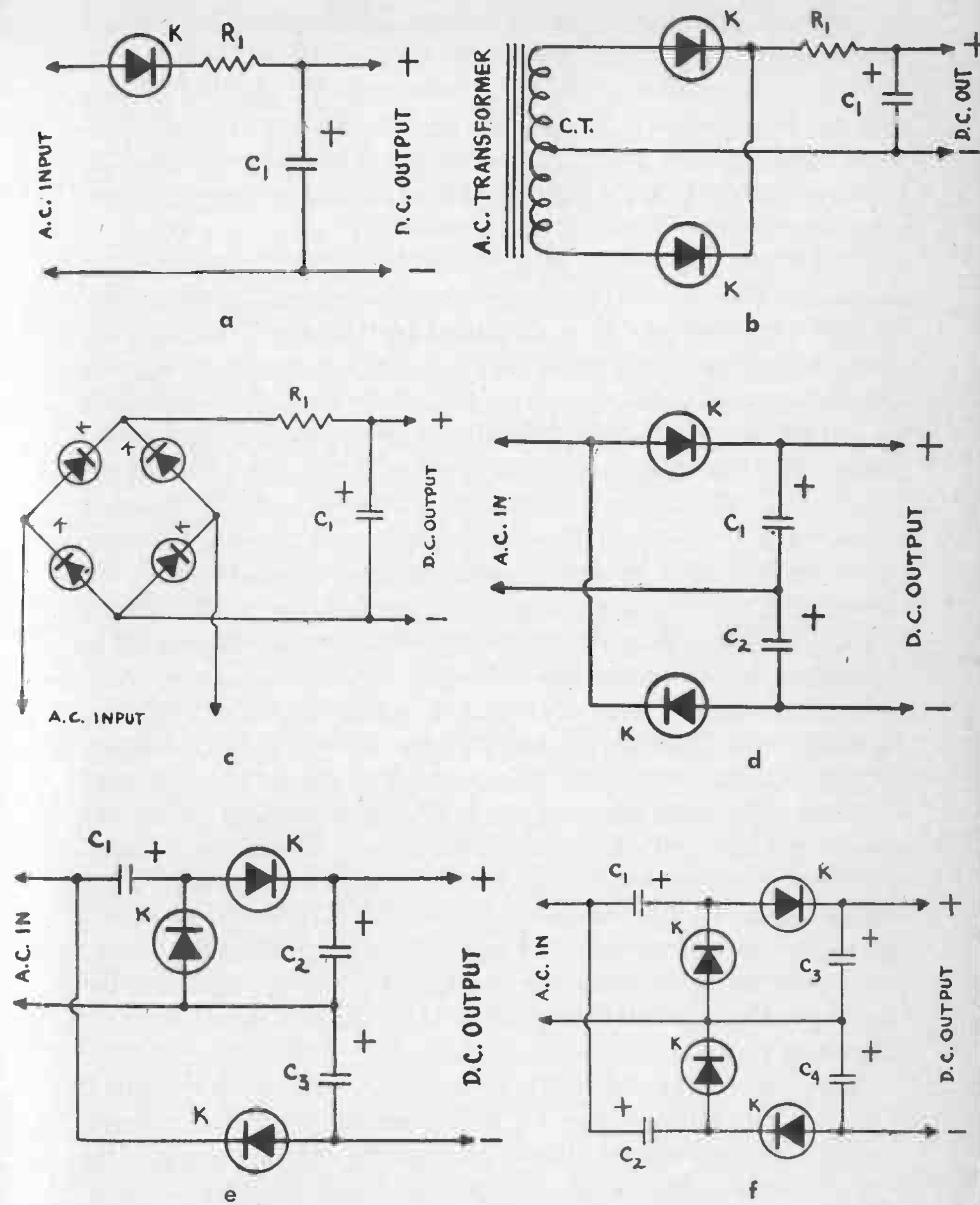


Fig. 10-20.—Basic semiconductor diode Rectifier circuits: (a) Half-Wave; (b) Full-Wave; (c) Full-Wave Bridge; (d) Voltage-Doubler; (e) Voltage-Tripler; (f) Voltage-Quadrupler.

the circuits, the diode may be a selenium, germanium, or silicon power rectifier, or a small signal level diode, either junction or point-contact. These circuits may be applied to low voltage, high current, or to high voltage, high current, and to high voltage, low current applications, depending on the type of diode used. If suitable capacitor values are chosen, these circuits may also be used as *detectors*.

Half-wave, full-wave, and full-wave bridge rectifiers are shown in Figs. 10-20(a), 10-20(b), and 10-20(c), respectively. In each case, resistor R_1 is included for current limiting purposes, to protect the diode from a damaging current surge in case the applied A.C. voltage is at a peak when input capacitor C_1 is discharged. Whether included or omitted in a specific circuit, this small series resistor (generally less than 100 ohms) should be included as a matter of good engineering practice wherever a low impedance diode feeds a high value capacitor. The full-wave bridge rectifier shown in Fig. 10-20(c), although requiring more diode elements than the circuit given in Fig. 10-20(b), offers the advantage that a center-tapped driving source is *not* needed for full-wave rectification.

Voltage multiplying circuits are given in Figs. 10-20(d), 10-20(e), and 10-20(f). These circuits supply a D.C. output voltage that is a multiple of the peak applied A.C. voltage. Where a sine wave input is used, the peak applied voltage is approximately 1.41 times the RMS value. Thus, the *voltage doubler* circuit shown in Fig. 10-20(d) supplies a no-load D.C. voltage equal to 2.82 times the applied A.C. voltage; the *voltage tripler* circuit shown in Fig. 10-20(e) supplies a D.C. output equal to 4.23 times the input; the *voltage quadrupler* shown in Fig. 10-20(f) supplies a D.C. output equal to 5.64 times the input.

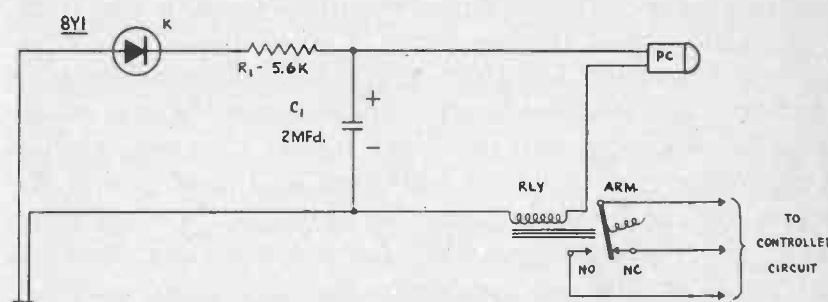
Referring to Fig. 10-20(d), on one half-cycle of the applied A.C. voltage, either C_1 or C_2 is charged to peak line voltage through its appropriate diode. Discharge, except through the output load, is prevented by the high back resistance of the diode. On the succeeding half cycle, the other capacitor is similarly charged to peak line voltage. As far as the D.C. load

is concerned, the two capacitors, C_1 and C_2 are in series aiding, so that their respective D.C. charges add, resulting in the high output voltage.

In the *voltage tripler* circuit, Fig. 10-20(e) C_1 and C_3 are charged to peak line voltage on one half cycle. On the next, the charge of C_1 adds to the line voltage to charge C_2, through its diode, to twice peak line voltage. Thus, C_2 is charged to twice line voltage, C_3 to line voltage, with the result that the D.C. voltage impressed across the output load is three times the peak applied A.C. voltage . . . that is, the sum of the D.C. voltage charges across C_2 and C_3 in series aiding. The *voltage quadrupler,* Fig. 10-20(f), operates in much the same manner, with C_1 and C_2 charged to peak line voltage, and the series output capacitors, C_3 and C_4, each charged to twice the peak applied A.C. voltage.

In practice, the useful D.C. output voltage is generally less than the maximum possible due to the effect of the D.C. load, except where current requirements are almost negligible . . . as in Geiger Counter and Cathode Ray applications.

In any case, with any of the rectifier circuits shown, a standard filter network is used between the *D.C. Output* terminals indicated and the final load. Where current drains are low, R-C filter networks may be used to reduce ripple content. Where the D.C. drain is heavy, L-C networks are used.



Courtesy Radio & Television News

Fig. 10-21.—Circuit of a Cadmium Sulfide (CdS) Photocell Relay.

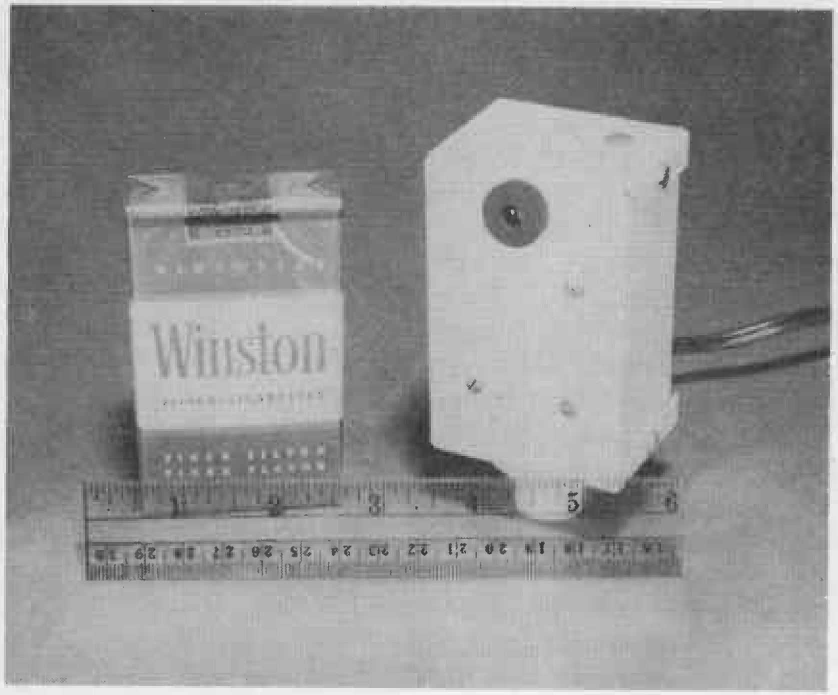
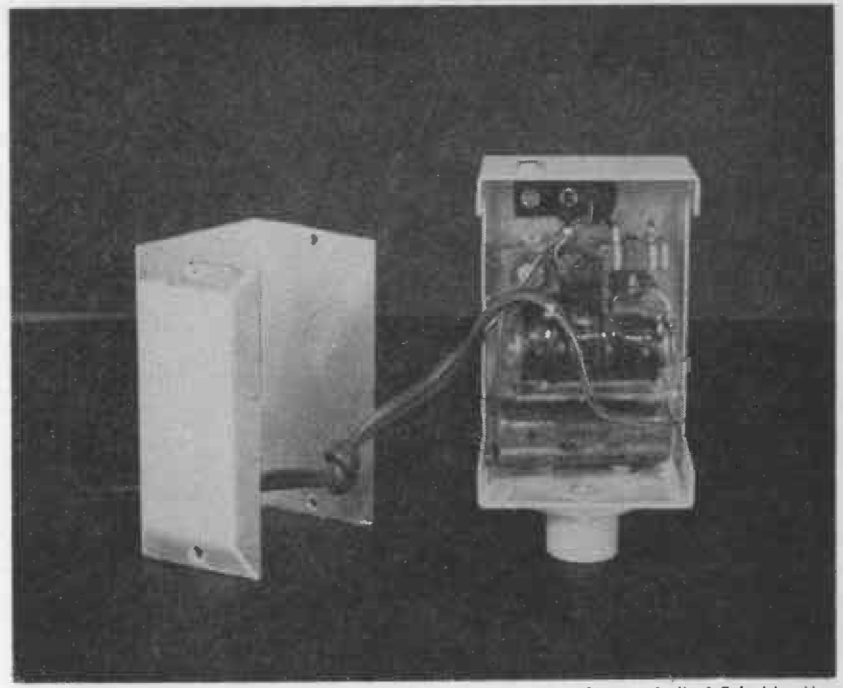


Fig. 10-22.—Author's model of the CdS Photocell Relay.

CdS PHOTOCELL RELAY: A moderately sensitive *Light Controlled Relay* may be assembled by using a Cadmium Sulfide photoconductive cell, a D.C. power source, and a sensitive electromagnetic relay. A typical circuit is given in Fig. 10-21, while exterior and interior views of an assembled model are given in Figs. 10-22 and 10-23, respectively. The entire circuit has been assembled in a small aluminum box, with the photocell (PC) itself mounted in a thick rubber grommet. Typical components are as follows: Line cord and plug; *Radio Receptor* type 8Y1 selenium rectifier; 5.6K, ½ W. Carbon resistor (R_1); *Clairex* type CL-2 Cadmium Sulfide photocell (PC); 2 Mfd., 200 volt paper capacitor (C_1); *Potter & Brumfield* type SS5D relay, 10,000 ohm coil (RLY); aluminum case, Misc. Hdwe., etc.



Courtesy Radio & Television News

Fig. 10-23.—Interior view of the CdS Photocell Relay.

The resistance of a photoconductive cell varies with the amount of light falling on its sensitive surface. The greater the light, the lower its resistance. In operation, the diode rectifier, together with R_1 and C_1, form a simple D.C. power supply. The photocell (PC) and the relay (RLY) are in series across this D.C. source. When the photocell is "dark", its resistance is high and insufficient current can flow to close the relay. When the photocell is exposed to a moderately strong light, its resistance drops, the current goes up, and the relay closes.

60 CYCLE STROBOSCOPE: The word *stroboscope* is derived from the Greek words meaning—"twisting or turning around" and "to see or view" . . . literally, an instrument for viewing a rotating object. In practice, a stroboscope may be used to observe either rotating or vibrating machinery. It accomplishes this by apparently "stopping" the motion of the object. An

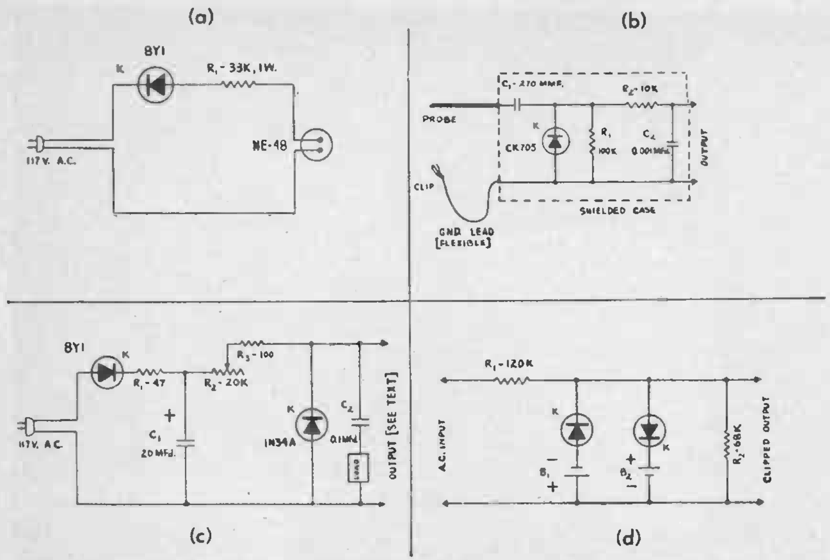


Fig. 10-24.—General semiconductor applications: (a) 60 Cycle Stroboscope; (b) Signal Tracing Probe; (c) Zener Oscillator; (d) Clipper.

electronic stroboscope "stops" motion by illuminating the object periodically *at the same position in its cycle of movement.* Since the object is always seen in the same position, no matter how rapidly it is actually moving, it *appears* to be standing still.

The circuit for a simple *60 Cycle Stroboscope* is given in Fig. 10-24(a). This instrument uses a semiconductor device (a diode) to supply pulsating D.C. to a neon bulb, which, in turn, flashes periodically at 60 cycles per second. It may be used to "stop" the motion of rotating or vibrating objects moving at this rate (or multiples thereof).

Only four electrical components are required . . . a line cord, a *Radio Receptor* type 8Y1 selenium rectifier, a 33K, 1 W. current limiting resistor (R_1), and a type NE-48 neon bulb. The entire instrument is easily assembled in a small plastic vial. A completed model is shown in Fig. 10-25, along with a stroboscopic disk with which it can be used to check the speed of record players . . . these small disks are available from most Radio Parts Distributors.

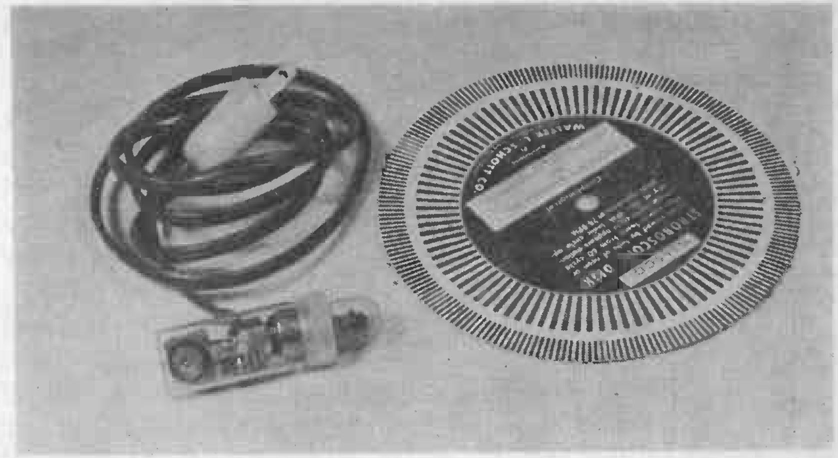


Fig. 10-25.—A 60 Cycle Stroboscope . . . shown with the disk with which it is used.

SIGNAL TRACING PROBE: Modulated R.F. signals may be traced through a Radio Receiver by using a R.F. Detector together with a high gain Amplifier. The circuit for a suitable instrument is given in Fig. 10-24(b). This *Signal Tracing Probe* features the use of a small *Raytheon* type CK705 diode as a detector and incorporates, in its design, a simple R-C filter network . . . consisting of R_2 and C_2. For best results, this instrument should be assembled in a closed metal tube to provide over-all shielding.

In use, the OUTPUT leads are connected to an Audio Amplifier and the flexible GND. LEAD connected to the chassis of the Receiver under test. The PROBE is touched to the input and output of various R.F. and I.F. stages in the Receiver to check for the presence of a signal at these points, as well as its relative amplitude. If used on an A.C.-D.C. receiver, an isolation transformer should be employed between the Receiver and the line receptacle to avoid accidental shocks.

ZENER OSCILLATOR: When a D.C. voltage is applied to a diode in its non-conducting direction, very little current will flow until the applied voltage reaches a specific value. At this point, a type of "break-down" occurs, and the reverse current flow will increase appreciably. The voltage at which this condition occurs is called the *Zener voltage*. This characteristic may be utilized in a simple relaxation oscillator. A suitable circuit is shown in Fig. 10-24(c).

The *Zener Oscillator* requires a D.C. power supply, made up from a small selenium rectifier (*Radio Receptor* type 8Y1), a 47 ohm, ½ W. Carbon resistor (R_1), and a 20 Mfd., 150 volt electrolytic capacitor (C_1). This power supply may be replaced by a 160 volt battery, if desired. The oscillator portion of the circuit includes a voltage adjustment potentiometer (R_2), a 100 ohm, ½ W. (R_3) limiting resistor, a 0.1 Mfd., 200 volt paper capacitor (C_2), and a type 1N34A germanium diode. The output "Load" may be a moderate impedance pair of Headphones (1000 ohm magnetic headset) or a small output transformer, and is connected in series with C_2. The signal waveform may be observed by connecting an Oscilloscope across C_2 . . . the 'scope should have a high impedance input, preferably 5 Megohms or more, to prevent undue loading of the circuit.

In operation, the D.C. power supply charges capacitor C_2 slowly through resistors R_2 and R_3. As long as the voltage across the capacitor is less than the *Zener voltage* of the diode, the diode acts as a high impedance . . . almost an open circuit. As soon as the voltage across C_2 approaches the *Zener voltage*, the diode acts like a low impedance device, passing a comparatively heavy current, and discharging C_2. When the voltage across C_2 drops sufficiently, due to its being discharged, the diode again becomes a high impedance device, and the charging action starts again. The frequency of operation depends on the value of C_2, on the available voltage, on the individual diode used, and on the value of the series resistors, R_2 and R_3.

When using this circuit, set R_2 at its *maximum* value, reducing it slowly until the circuit breaks into oscillation. Then turn it back slightly from this point. The *Zener Oscillator* may be used as a simple audio oscillator for demonstration purposes, for code practice, or as a signal source. It is not suitable for continuous use, however, for extended operation of the

diode at its *Zener voltage* rating will result in permanent damage.

SIGNAL CLIPPER: When a voltage is applied to a diode in its conducting direction, its acts like a very low resistance. This characteristic may be used to "clip" the peaks of an applied signal. A typical circuit is shown in Fig. 10-24(d). Referring to this diagram, almost any diodes may be used in the circuit . . . suitable types are *Raytheon's* CK705 and 1N66 or *Sylvania's* 1N34; batteries B_1 and B_2 set the "clipping" level . . . normally, single penlight cells will be used here. Resistors R_1 and R_2 may be ½ W. Carbon units.

In operation, an applied A.C. signal is clipped at the voltage level determined by batteries B_1 and B_2. Considering, first, the negative half-cycle of the applied signal, there is no attenuation of the signal, except that caused by the voltage-divider action of R_1 and R_2, until the signal level exceeds the voltage of B_1. Up to this point, the first diode is biased in its non-conducting region. When the applied signal voltage becomes greater than B_1, the diode can conduct and acts like a low resistance, forming a voltage-divider with fixed resistance R_1 and sharply attenuating the signal. The second diode is non-conducting during this period due to the polarity of the applied signal; on the positive half-cycle, however, the first diode does not conduct, and the second diode (biased by B_2) acts as a clipper. If only one side of the applied A.C. signal is to be clipped, the appropriate diode (and its biasing battery) may be left out of the circuit. To clip *only* the negative half-cycle, remove the second diode; to clip *only* the positive half-cycle, remove the first diode . . . the remaining diode is left in either case. If clipping is desired at the "zero" signal level, the biasing battery may be removed, and the diode connected directly across the line.

R.F. APPLICATIONS: A *bridge modulator* circuit is shown in Fig. 10-26(a). Four R.F. diodes are used . . . *Raytheon* type CK705 diodes are satisfactory. This unit may be used to combine an audio (A.F.) and a radio (R.F.) signal to provide a *Modulated* R.F. output. The A.F. signal is fed into the circuit

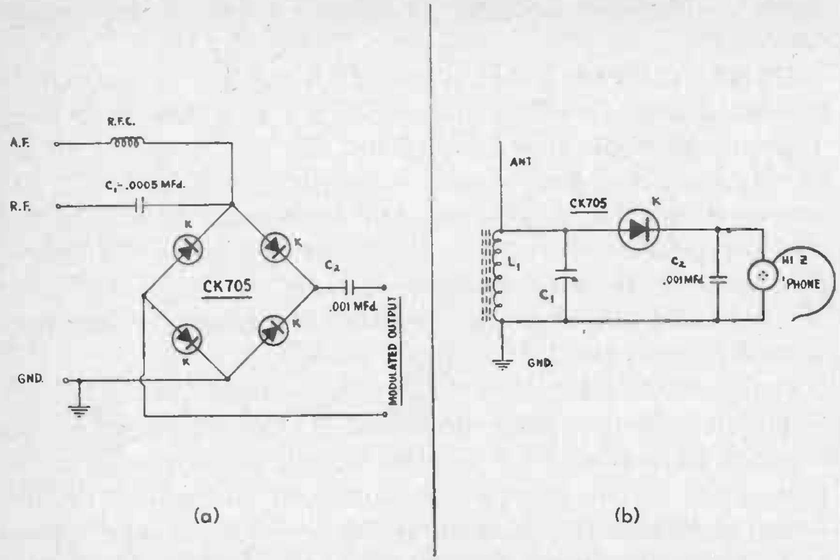


Fig. 10-26.—R.F. Semiconductor Diode applications: (a) Bridge Modulator; (b) Simple Crystal Receiver.

through a small R.F. choke (R.F.C.) . . a typical value is 2.5 MHy (*Superex* No. F-25). The R.F. signal is coupled into the circuit through a small mica or ceramic capacitor (C_1—0.0005 Mfd.), which serves to block the A.F. signal. The modulated output is obtained through a 0.001 Mfd. ceramic capacitor (C_2). A typical application of this circuit would be to combine an R.F. signal from a small *R.F. Signal Generator* (such as the unit shown in Chapter 9, Fig. 9-4) with the output from an *Audio Oscillator* (such as the unit shown in Chapter 9, Fig. 9-1) to provide a *Modulated R.F.* signal. The circuit may be assembled in a small metal box and used as an accessory with other instruments . . . or it may be used as a "built-in" feature of another piece of equipment.

A simple *crystal receiver* is shown in Fig. 10-26(b). Since no gain is provided, a good antenna and ground system must be used with the unit. Tuning coil L_1 and variable capacitor C_1 are chosen to cover the desired frequency range. Capacitor C_2, a 0.001 Mfd. mica or ceramic unit, is used as a simple R.F.

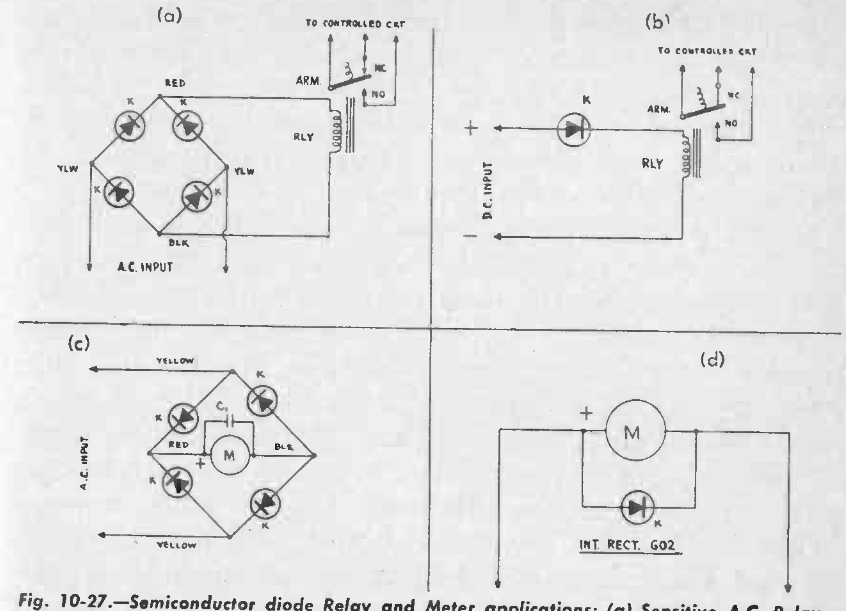


Fig. 10-27.—Semiconductor diode Relay and Meter applications: (a) Sensitive A.C. Relay; (b) Polarized Relay; (c) A.C. Meter; (d) Meter Protection Circuit.

filter. Best results are obtained when high impedance magnetic headphones are used in this circuit. In this application, a semiconductor diode serves as a simple R.F. *detector*.

RELAY CIRCUITS: Typical semiconductor diode applications to relay circuits are illustrated in Figs. 10-27(a) and 10-27(b). In Fig. 10-27(a), a bridge rectifier is used to convert a D.C. unit into an *A.C. Relay*. Separate diode elements may be used to make up the assembly or, if preferred, a pre-assembled "bridge" instrument rectifier may be used. A suitable type is the *Conant* Series 500, Type M. This circuit arrangement is often used with sensitive relays, such as the *Advance* type SV/1C.

If a diode is connected in series with a D.C. relay, as shown in Fig. 10-27(b), the assembly becomes a *Polarized Relay*. That is, the relay will work on *either A.C.* or on *D.C. of the correct polarity*. Such a circuit permits two different relays to be controlled independently over the same line. A diode is connected so that one operates with a positive voltage, as shown in the diagram. A reversed diode is used with the second relay, permitting its operation on a negative voltage only. By applying the proper voltage to the line, either relay may be closed at will . . . or both may be closed simultaneously by applying an A.C. voltage. This general arrangement is quite popular in certain types of remote control work.

METER APPLICATIONS: Semiconductor diodes are often used as rectifiers to permit the operation of D.C. Meters on A.C. Almost any of the basic rectifier circuits given in Fig. 10-20 may be used, but the *bridge* circuit is probably the most popular. This arrangement is shown in Fig. 10-27(c). The meter (M) is connected directly across the bridge and, often, is by-passed with a small capacitor (C_1) to minimize ripple. This capacitor is more important at low frequencies, but, on occasion, may be used in R.F. work. Typical values, at power frequencies and A.F. are .05 to 1.0 Mfd., at R.F. from .001 to .02 Mfd. Either four individual diodes or a single bridge rectifier assembly may be used. Typical units are the *Conant* Series 500, Type M, Series 160, Type B, and the Series 160-C, Type B-C, or the *Bradley* Types CX2E4U and CX4D4U.

An interesting application for a shunt diode is shown in Fig. 10-27(d), where a semiconductor diode is connected in parallel with a basic meter movement (M). The diode is one of a series of *Meter Protection Diodes* developed by *The International Rectifier Corporation* (1521 East Grand Ave., El Segundo, California). These units are designed to protect relatively sensitive meters against accidental overloads. In operation, they exhibit a very high resistance within the meter's calibrated range, but have a comparatively low resistance when the voltage drop across the meter (due to current flow through it) passes a certain minimum value, acting to shunt, and to protect, the movement.

SUN BATTERIES: The "self-generating" photocells specified in a number of earlier projects are, in reality, low power *Sun Batteries* . . . that is, semiconductor devices capable of converting light energy into electrical power. Many semiconductor materials exhibit these photoelectric characteristics, but the

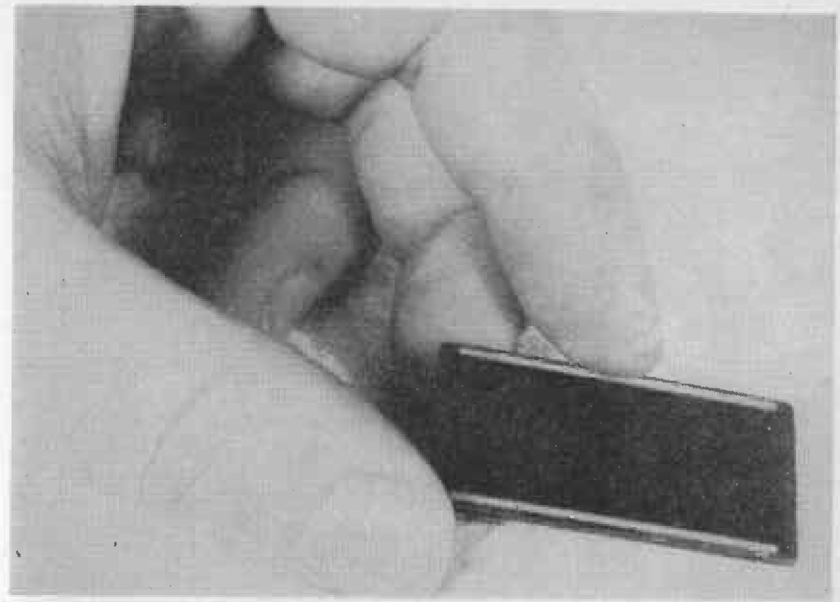


Fig. 10-28.—A single selenium Photocell.

majority of commercial *Sun Batteries* are manufactured from either silicon or selenium. A typical selenium cell is shown in Fig. 10-28.

Silicon cells are offered by a number of manufacturers, but one of the leading suppliers of "across-the-counter" units which experimenters and gadgeteers may be able to obtain and use is *NATFAB (National Fabricated Products,* 2650 West Belden Avenue, Chicago 47, Illinois). Their type S-1 cell, a round unit approximately 1½" in diameter, can supply up to 10 milliwatts in full sunlight under optimum conditions.

Selenium photocells have been available commercially much longer than silicon units and have been used for many years in Photographers' *Exposure Meters.* A leading producer of units for experimenters is *The International Rectifier Corporation* (1521 East Grand Ave., El Segundo, California). Their popular type B2M unit, with an active area of approximately 0.26 square inches, will develop as much as 0.5 volts under "no-load" conditions in average sunlight, or will drive

Fig. 10-29.—Easily assembled "Sun Battery" . . . will power a simple receiver, an audio amplifier, or a Code Practice Oscillator, or even a low-power transmitter in full sunlight.

a current of 2.0 MA through a 10 ohm load under similar conditions.

Where greater currents, or voltages, are required than can be delivered by a single cell, whether silicon or selenium, groups of cells may be mounted in "batteries" and connected in series or parallel combinations. A series arrangement is used to obtain higher *voltages,* a parallel arrangement to obtain higher *currents,* and a series-parallel arrangement where both higher voltages and currents are needed. A typical bank, or battery, of photocells is shown in Fig. 10-29; six *International Rectifier* type B2M units are used, with their leads brought to individual terminals, permitting a choice of either series, parallel, or series-parallel connections, as needed for a particular experiment. Large banks of *Sun Batteries* can supply sufficient power to operate small motors.

Because transistors require so little power for operation, it is only natural to think of combining a transistorized circuit with a *Sun Battery* power supply. This is a fairly easy job to accomplish, for many of the receiver, amplifier, and oscillator circuits given in the last few Chapters may be powered by one or more Sun Batteries. In most cases, it is only necessary to adjust component values (generally the base resistors) for optimum operation.

The experimenter choosing a *Sun Battery* may be guided by both electrical specifications and economic considerations. At this writing, silicon units are much more efficient than selenium units having the same sensitive area, but are many, many times more expensive. For commercial and military applications, where efficiency, ruggedness, and similar factors are of prime importance, and economic considerations of secondary interest, silicon units will probably be preferred. But the home hobbyist, with his pocketbook and budget to consider, will probably prefer to work with the selenium photocells.

CONCLUSION

With the end of this Chapter, we reluctantly conclude Part III and our discussion of practical transistor *Circuit Applications.* Throughout the four Chapters making up Part III, we have attempted to describe a wide variety of equipment circuits, not only to supply the experimenter, gadgeteer, student, Ham, and home-builder with actual construction information, but, in a larger sense, to illustrate how the many, many *Basic Circuits* discussed in Part II could be applied to every-day equipment design. At the risk of being repetitious, we have described each equipment circuit as a more or less independent "project". While this has certainly called for some slight duplication of material, particularly in the *CONSTRUCTION HINTS,* we feel that the advantages to this approach far outweigh any possible disadvantages that might accrue. We have felt that the average reader would prefer to have the various circuits arranged and described in "project" fashion, for it permits him to refer to those equipments which are of especial interest to him without the need of reading through an entire Chapter or section. As mentioned earlier, the author intends that this volume shall serve as a true *Handbook* rather than as a text or "story".

Again, we must repeat that the reader should consider these construction projects in the same light that the earlier circuits were described . . . that is, as a *guide* to transistor application, rather than as a complete listing. He should not hesitate to adapt the circuits to his own special needs, nor to work up completely new circuits, based on combinations and modifications of both the *Basic Circuits* given in Part II and projects described in this section (Part III).

PART IV — REFERENCE DATA

Introduction to PART IV

There are a number of topics which are useful to transistor circuit design and test but which cannot be classified as circuit information. Such topics include data on transistor characteristics, definitions of technical terms, basic design formula, laboratory techniques and related supplementary information. For the convenience of the reader, all of these topics, except those the author felt would be more helpful as introductory material, have been grouped together in PART IV *(Reference Data)*. The introductory topics were discussed in PART I *(Laboratory Practice)*. Like the circuit data given in PARTS II and III, the reference material in PART IV is not intended to be read as a novel nor studied as a textbook. Rather, the technical data should be referred to as needed.

The material in PART IV has been divided into four relatively independent chapters. *Chapter 11* covers *Transistor Characteristics* and is based partially on material abstracted from a chart appearing in a well known trade publication and partially on material obtained by the author in response to inquiries sent to every known transistor manufacturer. *Chapter 12* covers basic *Definitions* and *Design Formulas.* Of necessity, the amount of design information given has been limited, in keeping with the stated purpose of this volume. The author feels that detailed design information falls more within the provinces of textbooks and Design Manuals. *Chapter 13* covers *Special Techniques* not discussed elsewhere as well as *New Developments* in the field. In referring to *Chapter 13,* the reader should remember that the art is still in a highly fluid state, with new developments announced by research laboratories and manufacturers almost on a day-to-day schedule. In a semi-permanent work like this volume, as contrasted to a monthly publication, it is possible to cover only those developments which have crystallized sufficiently to permit examination and discussion. For the latest information on new developments in the field, the reader should use the material discussed in *Chapter 13* as supplemental to material found in current issues of the various trade publications, professional journals, and popular technical magazines.

A portion of the material in PART IV, especially the information dealing with techniques and new developments in *Chapter 13*, was touched upon briefly in PART I of this volume. The author felt that a more exhaustive treatment of the subject matter would have been out-of-place in PART I, but that a more detailed discussion was desirable in view of the state of the art. Hence the inclusion of the material on printed circuits, on a transistor tester, and on "field effect" transistors in *Chapter 13*.

Finally, *Chapter 14* is a basic *Bibliography*, included for the convenience of the reader in obtaining more detailed information on specialized topics. A few words concerning the *Bibliography* may be in order. The author makes no claim that the listing of sources is complete or exhaustive. A complete bibliography of all available transistor and semiconductor literature could easily fill a volume. Moreover, such a complete listing would duplicate existing information, for most of the subject papers that could be listed have already been listed in other, easily available, bibliographic works. Therefore, in the interests of conserving space, the author has tried to limit the bibliography to those technical papers, books, and magazine articles which he found especially helpful. However, he has included a listing of all transistor bibliographic and reference lists with which he is familiar. Most of these lists are currently available. The reader planning exhaustive literary research on any phase of transistor work will find it worthwhile to consult copies of the bibliographic works listed.

In addition to books, magazines, professional journals, and similar conventional sources of circuit data, a good deal of valuable reference material will be found in the literature published by transistor and component manufacturers. Some of this material is in the form of reprints of technical papers and magazine articles originally written by members of the manufacturers' staff. However, considerable original material is available and the reader is advised to check such sources for circuit suggestions and application data relative to specific types or circuit components.

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PART IV—REFERENCE DATA

Chapter 11

TRANSISTOR CHARACTERISTICS — MANUFACTURERS

SECTION A: Transistor Characteristics

The table given on the following pages lists commercially available transistors and their characteristics. Transistor manufacturers are identified by a coded list at the end of the table. This table has been abstracted from a longer *Transistor Data Chart* appearing originally in the July, 1955 issue of *ELECTRONIC DESIGN* and is reprinted here with the kind permission of the Copyright holder, the Hayden Publishing Co., Inc., of N. Y. The author has modified the original *Data Chart* to some extent, principally by excluding a number of suppliers given in the earlier list. Before listing any manufacturer as a transistor supplier, the author made a sincere effort to contact that manufacturer, either by personal call, by telephone, or by correspondence. Several of the firms mentioned in the original list indicated that they were producing transistors in experimental quantities only and did not foresee mass production in the immediate future; on this basis, the author did not feel it would be germane to list them as current suppliers. At least one firm *(Radio Receptor)* has suspended transistor production temporarily. Another firm *(Hydro-Aire)* sold its transistor manufacturing facilities. Still others failed to respond to correspondence and personal contacts, thus indicating that they were not actively in business. The only firms retained in the final list are those who were in current production and who could deliver sample or production quantities of transistors on order.

Due to the present extremely fluid state of the field, any table listing commercially available transistors and their characteristics is obsolete almost before it is published. However, the following table covers the transistor types used in proving out the *Basic Circuits* given in *PART II* and the *Equipment Circuits* given in *PART III* of this volume, unless otherwise noted. Nonetheless, the author hastens to caution the reader to use the following table for general reference only, not as a final guide. For full information on the latest available transistor types and their electrical and mechanical specifications, write directly to the manufacturers listed.

The majority of the junction transistors listed are *PNP* units. These have no special identification. The *NPN* transistors are identified by an asterisk (*) next to their type number. The column headings at the top of the chart stand for the following parameters:

V_c ..... Collector voltage
I_c ...... Collector current
W_c ..... Collector dissipation (Where available, the temperature at which W_c was measured is given in parentheses.)
α ...... "alpha" or current amplification factor (listed value less unity).
β ...... base current amplification factor (listed value more than unity).
PG .... Power gain
PO .... Power output
Z ...... Source impedance at which *PG* and *PO* measured
R_L ..... Load resistance at which *PG* and *PO* measured
NF .... Noise factor

F_{co} ..... Cutoff frequency
C ...... Type of circuit for which the characteristics are listed. "GE" being grounded emitter; "GB" being grounded base; "GC" being grounded collector; "CE" being common emitter connection.

A..... Amperex Electronic Corp., 230 Duffy Ave., Hicksville, N. Y.
CBS.... CBS-Hytron, Division of Columbia Broadcasting System, Danvers, Mass.
GE..... General Electric Co., Electronics Park, Syracuse, N. Y.
G...... General Transistor Corp., 95-18 Sutphin Blvd., Jamaica 35, N. Y.
GP..... Germanium Products Corp., 26 Cornelison Ave., Jersey City 4, N. J
MH..... Minneapolis-Honeywell Regulator Corp., 2747 Fourth Ave. S., Minneapolis, Minn.
P...... Philco Corp., Government & Industrial Div., 4700 Wissahickon Ave., Philadelphia 44, Pa.
RCA.... Radio Corporation of America, Tube Dept., Harrison, N. J.
RAY.... Raytheon Manufacturing Co., 55 Chapel St., Newton, Mass.
S...... Sylvania Electric Products Co., 1740 Broadway, New York 19, N. Y.
TI..... Texas Instruments, Inc., 6000 Lemmon Ave., Dallas 9, Texas
TR..... Transitron Electronic Corp., 403 Main St., Melrose 76, Mass.
TS..... Tung-Sol Electric Inc., 95 Eighth Ave., Newark 4, N. J.

Footnotes

* n-p-n
(a) Available in matched pairs. Power output (PO) indicated is for a pair.
(b) Measured with $Z_s = 1000$ ohms; $R_L = 20{,}000$ ohms; $f = 1000$cy.
(c) Push-pull, Class B.
(d) These types have the same electrical characteristics, but the higher number units are in a smaller case.
(e) Measured with $Z_s = 1000$ ohms; $R_L = 20{,}000$ ohms, and $f = 1500$cy.
(f) Measured at 455kc.
(g) As limited by dissipation.
(h) Frequency maximum.
(i) Per transistor.
(j) Per base connection.
(k) Per collector.
(l) Measured with $R_L = 5000$ ohms and a high Z_s.
(m) With heat sink.
(n) Measured with $R_s = 25$ and $R_L = 1500$ ohms.
(r) Measured at 5Mc.
(s) Oscillation frequency.

Made By	Type No.	Maximum Ratings V_c (volts)	I_c (ma)	W_c (mw)	Typical Operation I_e (ma)	V_c (volts)	I_c (ma)	a or β	PG (db)	PO (mw)	Z_B (kilohm)	R_L (kilohm)	NF (db)	F_{co} (Mc)	C	Application
Junction Transistors—Triodes																
A	OC70	−5	−10	25		−2	0.5	30					10	0.4	GE	Audia
	OC71	−5	−10	25		−2	3	47					10	0.4	GE	Audia
	2-OC72 (a)	−6.5	−45	45 (45°C)		−6	60		27	200				0.01	GE	Audia aut.
CBS	2N38A	−20	−8	50(50°C)		−3	−0.5	18	34				27(b)			Hearing aid
	2N80	−25	−2	20(75°C)		−6	−1	80							GE	High temp.
	2N82	−20	−15	35(71°C)		−6	−1	60								High temp.
	2N108(a)	−20	−15	50(25°C)		−3.5	27		13	58(c)	2	100	27(b)		GB(c)	Audia aut.
	2N116	−20	−8	50(25°C)		−3	−0.5	18	34		0.5	3.1	27(b)			Low noise
	HA1-HA8(d)	−20	−8	50(50°C)		−3	−0.5	40	40		1	30	12(e)		GE	Hearing aid
	HA2-HA9(d)	−20	−8	50(50°C)		−3	−0.5	30	37		1	30	27(e)		GE	Hearing aid
	HA3-HA10(d)	−20	−12	50(50°C)		−3	−2.5	35		3	1	1.2			GE	Hearing aid
	HC1	−20	−8	50(50°C)	1	−6		45	40		1	30		0.7	GE	Computer
	HD-197	−40		500(25°C)		−10	−50	10	30		0.1	5		0.15	GE	Power
G	2N34	−25		70(50°C)	1	−6		40	40		0.5	30			GE	
	2N36	−25		70(50°C)	1	−6		45	40		1	30			GE	
	2N37	−25		70(50°C)	1	−6		30	36		1	30			GE	
	2N38	−25		70(50°C)	1	−6		15	32		1	30			GE	
	2N39	−30		50(50°C)	1	−4.5	1		39		0.5	30	24		GE	
	2N40	−30		50(50°C)	1	−4.5	1		38		0.5	30	24		GE	
	2N42	−30		50(50°C)	1	−4.5	1		36		0.5	30	24		GE	
	2N43	−45	−50	150(25°C)	1	−5			39		0.6	4	22	1	GE	
	2N44	−45	−50	150(25°C)	5	−20			33		0.22	4.5	22	1	GE	
	2N45	−45	−50	150(25°C)	5	−20			30		0.125	4.5	22	1	GE	
	2N63	−22	−10	33(30°C)	1	−6		22	39		0.8	20	25	0.8	GE	Audia
	2N64	−22	−10	33(30°C)	1	−6		45	41		1.5	20	22	0.8	GE	Audio
	2N65	−22	−10	33(30°C)	1	−6		90	42		2.7	20	20	0.8	GE	Audia
	GT-14	−25	(g)	70(50°C)	1	−4.5		28	36		1	30	16		GE	Audia
	GT-20	−25	(g)	70(50°C)	1	−4.5		45	40		1	30	16		GE	Audio
	GT-24	−6	(g)	40(50°C)	1	−1.5		45	40		1	30	16		GE	Hearing aid
	GT-34	−25	(g)	70(50°C)	1	−4.5		15	32		1	30	16		GE	Audio
	GT-38	−6	(g)	40(50°C)	1	−1.5			28	1	0.5	0.35			GE	Hearing aid
	GT-81	−25	(g)	70(50°C)	1	−4.5		65	42		1	30	16		GE	Audio
	GT-81h	−6	(g)	40(50°C)	1	−1.5		90	42		1	30	12		GE	Hearing aid
	GT-83	−25	(g)	70(50°C)	1	−4.5		45	40		1	30	16	0.7	GE	Computer
	GT-87	−25	(g)	70(50°C)	1	−4.5		28	36		1	30	16	0.5	GE	Computer
	GT-88	−25	(g)	70(50°C)	1	−4.5		65	42		1	30	16	1	GE	Computer
	GT-760	115		40(50°C)	1	−6		40	30(f)					5	GE	Comp. & i-f
GE	2N43	−45	−50	150(25°C)	1	−5	−1	0.98	39		1	30	22	1	GE	Hi-gain amp.
	2N43A	−45	−50	150(25°C)	1	−5	−1	0.977	39		1	30	10	1	GE	Med. power
	2N44	−45	−50	150(25°C)	1	−5	−1	0.95	38		0.7	30	22	1	GE	Med. pawer
	2N45	−45	−50	150(25°C)	1	−5	−1	0.92	36		0.45	30	22	1	GE	Med. pawer
	2N76	−20	−10		1	−5	−1	0.95	38		1	30	18	1	GE	Gen. purpose
	2N78*	15	20	50	−1	5	1	0.95	22(f)		1.5	10	14	4	GE	r-f/i-f amp.
	2N123	−20	−20	75	1	−5	−1		25(f)				11	6.5	GE	r-f/i-f amp.
GP	2N97*	30	−10	50(25°C)	−1	4.5	1	0.93	38		0.4	100	20	1	GE	Med. gair.
	2N98*	40	−10	50(25°C)	−1	4.5	1	0.975	47		0.85	100	20	2.5	GE	Hi-gain amp.
	2N99*	40	−10	50(25°C)	−1	4.5	1	0.975	47		0.85	100	15	3.5	GE	Computer
	2N100*	25	−5	25(25°C)	−1	4.5	1	0.993	53		3.5	100	20	5	GE	Computer
	2N103*	35	−10	50(25°C)	−1	4.5	1	0.80	33		0.225	100	22	0.75	GE	Computer
P	2N47	−35	−20	50(25°C)	1	−5	−1	0.975	40		1	20	15	0.8	GE	Hearing aid
	2N49	−35	−20	50(25°C)	1	−5	−1	0.975	40		1	20	15	0.8	GE	Lo-noise audia
	SB-100	−4.5	−5	10(40°C)	1	−3	−1	0.95	33(f)		1	20	12	45(h)	GE	Computer, r-f
RCA	2N77	−25	−15	35		−4	−0.7	55	41		1.98	95	6.5	0.7	CE	Lo-power audio
	2N104	−30	−50	150		−6	−1	44	41		1.05	68	12	0.7	CE	Lo-power audio
	2N105	−25	−15	35		−4	−0.7	55	42		1.75	100	4.5	0.75	CE	Lo-power audio
	2N109	−20	−50	50		−4.5	−13	70	30(c)	75(i)	.375(j)	0.1(k)			CE	Large signal

Made By	Type No.	Maximum Ratings V_c (volts)	I_c (ma)	W_c (mw)	Typical Operation I_e (ma)	V_c (volts)	I_c (ma)	α or β	PG (db)	PO (mw)	Z_B (kilohm)	R_L (kilohm)	NF (db)	F_{co} (Mc)	C	Application
RAY	CK-721	−15	−10	180(25°C)	1	−6		45	41				22	0.8	GE	Gen. purpose
	CK-722	−22	−10	180(25°C)	1	−6		22	39				25	0.7	GE	Gen. purpose
	CK725	−12	−10	180(25°C)	1	−6		90	42				20	0.9	GE	Hi-gain
	CK727	−6	−10	180(25°C)	0.5	−1.5		25	36				10	0.8	GE	Low noise
	2N63	−22	−10	100(25°C)	1	−6		22	39				25	0.7	GE	Gen. purpose
	2N64	−15	−10	100(25°C)	1	−6		45	41				22	0.8	GE	Gen. purpose
	2N65	−12	−10	100(25°C)	1	−6		90	42				20	0.9	GE	High gain
	2N106	−6	−10	100(25°C)	0.5	−1.5		25	36				10	0.8	GE	Low noise
	2N112	−6	−5	100(25°C)	1	−6		40	32(f)					5	GE	Hi-frequency
	2N113	−6	−5	100(25°C)	1	−6		45	33(f)					10	GE	Hi-frequency
	2N114	−6	−5	100(25°C)	1	−6		65						20	GE	Hi-frequency
S	2N34	−25	−8	50(25°C)	1	−6		40	40		0.5	30	18	0.6	GE	Amp.
	2N35*	25	8	50(25°C)	−1	6		40	40		0.5	30	16	0.8	GE	Amp.
	2N94*	20	10	50(25°C)	−0.5	6			32		0.5	25	15	3	GE	Switching
	2N94A*	20	10	50(25°C)	−0.5	6			35		0.5	25	15	6	GE	Switching
TI	200*	30	5	50(25°C)	−1	5		9	37	2.15(l)	0.5	20	26	0.9	GE	Hi-gain audio
	201*	30	5	50(25°C)	−1	5		19	40	2.30(l)	0.5	20	23	1.1	GE	Hi-gain audio
	202*	30	5	50(25°C)	−1	5		49	43	2.38(l)	1.25	20	20	1.3	GE	Hi-gain audio
	210*	30	5	50(25°C)		22.5	2		39	12	0.5	10			GE	Audio
	220*	30	5	50(25°C)		22.5	0.7		31						GE	i-f amp.
	221*	30	5	50(25°C)		22.5	0.7		33						GE	i-f amp.
	222*	30	5	50(25°C)		22.5	0.7		35						GE	i-f amp.
	223*	30	5	50(25°C)		22.5	0.7								GE	Osc.-mixer
	300	−30	−10	50(25°C)	1	−5		9					25		GE	Audio
	301	−30	−10	50(25°C)	1	−5		19					20		GE	Audio
	350(a)					12			20	500		0.5			CE	Aud. output
	X-2*	35	75	350(50°C)(m)		22.5	40		9.5	500		1			GB(c)	Med. power
	X-59*	10	8	50(75°C)				12-200	T_r = 1 µsec; Tc = 2 µsec					5	GE	Switching
TR	2N34	−25	−20	125	1	−6	−1	55	41		1	30	20	0.8	GE	Hi-gain amp.
	2N36	−25	−20	125	1	−6	−1	60	41		1	30	20	0.8	GE	Hi-gain amp.
	2N37	−25	−20	125	1	−6	−1	38	37		1	30	22	0.6	GE	Medium gain
	2N38	−25	−20	125	1	−6	−1	22	35		1	30	24	0.5	GE	Gen. purpose
	2N43	−45	−50	375 (m)	1	−6	−1	50	40		1	30	20	0.7	GE	Hi-gain amp.
	2N43A	−45	−50	150(25°C)	1	−6	−1	45	40		1	30	10	1	GE	Hi-gain amp.
	2N44	−45	−50	375	1	−6	−1	22	37		1	30	22	0.5	GE	Medium gain
	2N45	−45	−50	375	1	−6	−1	19	33		1	30	22	0.4	GE	Gen. purpose
	2N63	−45	−20	125	1	−6	−1	22	38		1	30	18	0.5	GE	Gen. purpose
	2N64	−25	−20	125	1	−6	−1	45	39		1	30	16	0.7	GE	Medium gain
	2N65	−25	−20	125	1	−6	−1	90	42		1	30	15	1	GE	High gain
	2N76	−20	−10	125(25°C)	1	−6	−1	20	36				18	0.5	GE	Gen. purpose
	2N85	−45	−100	750(25°C)(m)	10	−12	−10	45	33	1000(c)	2	0.8	20	0.8	GE	Med. power
	2N86	−60	−100	750(25°C)(m)	10	−12	−10	25	30	1400(c)	2	1.2	20	0.8	GE	Med. power
	2N87	−30	−100	750(25°C)(m)	10	−12	−10	25	30	500(c)	2	0.8	20	0.8	GE	Med. power
	2N88	−12	−10	25(25°C)	0.5	−1.3	−0.5	35	39		.025	1.5	10	0.5	GE	Subminiature
	2N89	−12	−10	25(25°C)	0.5	−1.3	−0.5	35	39		.025	1.5	20	0.5	GE	Subminiature
	2N90	−12	−10	25(25°C)	0.5	−1.3	−0.5	50	30	1.5	1	0.6	20	0.5	GE	Subminiature
	2N91	−15	500	500(25°C)(m)	1	−6	−1	40							GE	Switching
	2N92	−25	200	500(25°C)(m)	1	−6	−1	50							GE	Switching
TS	DR-126	−10	8	50(25°C)		−1.5	0.01	0.96	33		1	30	14		GE	Hearing aid
	DR-128	−10	8	50(25°C)		−1.5	5	0.975	26	2.5	0.2	0.2	18		GE	Hearing aid
	DR-129	−25	8	50(25°C)		−1.5	0.01	0.97	35		1	30	18	0.9	GE	Gen. purpose
	DR-130	−25	8	50(25°C)		−1.5	0.01	0.93	27		1	30	21	0.5	GE	Gen. purpose
	DR-131	−25	8	50(25°C)		−1.5	0.01	0.87	24		1	30	24	0.4	GE	Gen.pur pose
	DR-154	−25	8	50(25°C)		−1.5	0.01	0.99	35		1	30	28	0.7	GE	High gain
	DR-155	−25	8	50(25°C)		−1.5	0.01	0.97	35		1	30	28	1.4	GE	R-F
Silicon Transistors—Triodes (Silicon power types are listed under power transistors.)																
TI	903*	30	10	75(150°C)	−1	5		.90-.95					23	3	GB	Hi-gain, lo-level
	904*	30	10	75(150°C)	−1	5		.95-.975					23	3	GB	Hi-gain, lo-level
	905*	30	10	75(150°C)	−1	5		≥.975					23	3	GB	Hi-gain, lo-level
	904A*	30	10	75(150°C)	−1	5		≥.95					23	≥8	GB	Hi-gain, lo-leve.

Made By	Type No.	Maximum Ratings V_c (volts)	I_c (ma)	W_c (mw)	Typical Operation I_e (ma)	V_c (volts)	I_c (ma)	α or β	PG (db)	PO (mw)	Z_g (kilohm)	R_L (kilohm)	NF (db)	F_c (Mc)	C	Application
Power Transistors (units with an output of one watt or higher. W_c and PO given in watts, R_L and Z_g in ohms. All rated with a heat sink.)																
A	2N115	−16	2000	3(60°)		−12	636	25	27	6	Class B, push-pull			0.3	GE	
MH	2N57	−60	1000	20(70°F)	550	28	500	0.86	16	6.25	23	56		0.2	CE	
	H1	−60	800	20(70°F)	460	28	400	0.8	15	5	20	70		0.15	CE	
	H2	−60	1400	20(70°F)	635	28	600	0.92	20	7.5	26	47		0.385	CE	
	H3	−60	350	5(70°F)	170	28	150	0.82	16	1.9	50	187			CE	
	H4	−60	500	5(70°F)	160	28	150	0.90	21	1.9	60	87			CE	
	P-11	−60	5000	60(70°F)	2130	28	2000	0.82	20	24	3.4	11		0.1	CE	
S	2N68	−25	1500	4(25°C)		−12	−550		15	5	50	12(k)			GE(c)	
	2N95*	25	1500	4(25°C)		12	550		15	5	50	12(k)			GE(c)	
	2N101	−25	1500	4(25°C)		−12	−550		15	5	50	12(k)			GE(c)	
	2N102*	25	1500	4(25°C)		12	550		15	5	50	12(k)			GE(c)	
TI	951*	50	60	1(25°C)		28			20	0.45	1	1.5			CE	(Silicon)
	952*	80	50	1(25°C)		45			21	0.6	1	4			CE	(Silicon)
	953*	120	40	1(25°C)		67.5			23	1	1	8			CE	(Silicon)
TR	2N83	−45	−1000	10(25°C)	100	−20	−100	20	30(n)	2.5(c)	100	600		0.2	GE	
	2N84	−30	−1000	10(25°C)	100	−20	−100	20	32(n)	2.0(c)	100	400		0.2	GE	
Tetrode Transistors																
GP	3N23	30	— 5	50(25°C)	2	22.5	1.3		12(r)		.025	9		15(s)	GB	H-F osc., amp.
	3N23A	30	— 5	50(25°C)	2	22.5	1.3		14(r)		.025	9		30(s)	GB	H-F osc., amp.
	3N23B	30	— 5	50(25°C)	2	22.5	1.3		15(r)		.025	9		40(s)	GB	H-F osc., amp.
	3N23C	30	— 5	50(25°C)	2	22.5	1.3		17(r)		.025	9		60(s)	GB	H-F osc., amp.
TI	700*	30		50(25°C)	−1	5		0.95							GE	A-G-C circuit

SECTION B: Transistor Test Equipment and Manufacturers

The tables below, like the *Transistor Data Chart* given on the preceding pages, are reprinted here with the permission of the Hayden Publishing Co., Inc., N. Y., publishers of *ELECTRONIC DESIGN*. These tables appeared in the July, 1955 issue of the magazine. Manufacturers' addresses are given on page 346.

Transistor Test Equipment

Name	Description	Manufacturer
Small Signal Analyzers		
Test Set, Model GP	Measures directly all h and equiv. t resistances. Measures α, β, C_c, $f\alpha_o$, I_{co}, voltage feedback ratio and channel effect voltage	Baird Assoc.
Test Set, Type 210	Measures h parameters including r_{11}, , y_{22}, α, I_{co}	Owen Labs
Test Set, Model T-62	Measures h_{11}, h_{12}, h_{22}, α, $1-\alpha$, and static values	Scientific Specialties
Analyzer, Model JHI	Measures h_{21}, I_{co} for various biases	Quantum
	See Transistor Analyzers Models TA-1 and TA-4 below	
Curve Tracers		
Dynamic Analyzer	Provides swept current gain, collector, transfer, and emitter characteristic measurements	Fairchild Engine
Curve Plotter	Plots input, transfer, and output on X-Y pen recorder	Kay Electric
Curve Tracer	Plots family of collector or feedback transfer curves	Magnetic Amplifier
Analyzer, Model TA-1A	Measures α, β. Plots α vs. I_e and β vs. I_b	Polyphase Instr.
Analyzer Model TA-2	Traces neg. resistance of point contact types. Traces collector, transfer, emitter characteristics	Polyphase Instr.
Analyzer Model TA-3	Displays r_{12}, r_{22}, h_{12}	Polyphase Instr.
Analyzer Model TA-4	Presents α and β vs. frequency	Polyphase Instr.
Testers		
Semi-Conductor Tester, Model JR1	Determines conductivity (n or p) of sample	Baird Assoc.
Transistor Tester	Tests current gain. Includes 270cy osc.	Devenco
Comparison Tester, Model TT-11A	Compares r_e, r_b, r_c, gain and stability with standard transistor	Electronic Research
Alpha Tester, Model AT-10	Direct reading of α and β and α cut-off vs. bias	Electronic Research
Noise Figure Meters		
N F Meter, Model NFC-1A	Automatically measures noise figure, 5 to 65 db	Electronic Research
Noise Figure Test Set	Shows noise figure directly on 5-25 or 25-45 db range. Agc.	Radio Receptor
Miscellaneous		
Semi-Conductor Minority Carrier Life-time Test Set, Model JJ1	Measures exponential increase as carriers recombine when pulse of light is removed	Baird Assoc.
Semi-Conductor Resistivity Test Set, Model JN1	Measures resistivity of semi-conductor in range of 0.1-100 ohms/cm.	Baird Assoc.

Power Supplies for Transistors

Name	Description	Manufacturer
Power Unit, Model 212-A	0-100v d-c output at 100 ma. Regulated output can be regulated	Electronic Measurements
Power Supply, Model 210	Adjustable constant voltage and constant current	Electronic Research
High Current P. S., Model 30	1.5 amp max., 30va capacity. Tubeless supply	Electronic Research
Dual Supply, Model 110	Dual d-c output for any combination of emitter or collector bias	Electronic Research
Voltage Regulated P. S., Model 4500	Two identical regulated d-c outputs. Regulated	Kepco Laboratories
Power Supply, Model UHR-220	Ultra-high regulation at low voltages. Low internal impedance	Krohn-Hite Instr.
Power Supply, Model DV60-1	0-60v d-c. Stable at low voltages	Model Rectifier
Twin Power Supply, Model TR-200AF	Dual output precision regulated	Universal

TRANSISTOR TEST EQUIPMENT MANUFACTURERS:

BAIRD ASSOCIATES, INC.
33 University Road
Cambridge 38, Massachusetts

DEVENCO, INC.
150 Broadway
New York 38, N. Y.

ELECTRONIC MEASUREMENTS CO., INC.
Lewis Street & Maple Avenue
Eatontown, N. J.

ELECTRONIC RESEARCH ASSOCIATES, INC.
Box 29
Caldwell, N. J.

FAIRCHILD ENGINE & AIRPLANE CORPORATION
Guided Missle Division
Wyandanch, N. Y.

KAY ELECTRIC COMPANY
14 Maple Avenue
Pine Brook, N. J.

KEPCO LABS.
131-38 Sanford Avenue
Flushing 55, N. Y.

KROHN-HITE INSTRUMENT COMPANY
580 Massachusetts Avenue
Cambridge 39, Massachusetts

MAGNETIC AMPLIFIERS, INC.
632 Tinton Avenue
New York 55, N. Y.

MODEL RECTIFIER CORPORATION
557 Rogers Avenue
Brooklyn 25, N. Y.

OWEN LABORATORIES
412 Woodward Building
Pasadena 10, California

POLYPHASE INSTRUMENT COMPANY
705 Haverford Road
Bryn Mawr, Pennsylvania

QUANTUM ELECTRONICS, INC.
1921 Virginia Street, NE
Albuquerque, New Mexico

RADIO RECEPTOR COMPANY, INC.
251 W. 19th Street
New York 11, N. Y.

SCIENTIFIC SPECIALTIES CORPORATION
Snow & Union Streets
Boston 35, Massachusetts

SECTION C: Transistor Component Manufacturers

Transistor component manufacturers and/or suppliers are identified by code letters in the tabular listing given below in order to conserve space and to minimize repetition. The manufacturers' names and addresses are given in a separate list following the table. The majority of the suppliers listed can supply subminiature transistor components, but this has not been the primary criteria used for choosing these firms. Rather, the listed firms have been chosen on the basis of their ability to supply low voltage, low current, low power components, such as are used in transistor circuitry, whether subminiaturized or not. In additon to the component manufacturers, suppliers of products supplemental to circuit wiring, such as tools, are listed for the convenience of the reader. The author makes no claim that the list is complete or all-inclusive. New manufacturers are entering the field almost daily. However, the author has contacted all of the firms listed, either directly or through their representatives, and has been assured that the listed firms are currently supplying the products specified.

Component	Manufacturers/Suppliers
Batteries	
Zinc-Carbon	BB, NC, RCA
Mercury	NC, MAL
Solar	IREC
Battery Boxes	AC
Breadboard Chassis	
Transistor & P-C	EC
Cabinets and Small Chassis	
Metal	BR, ICA
Plastic	LR
Capacitors	
Low Voltage Ceramic	MU
Aluminum Electrolytic	BI, SPR
Tantalum Electrolytic	GE, MAL, SPR
Metallized Paper	AS, CD, GU, SPR
Subminiature Variable	AM, LR, MCE, RC
Coils (R.F.)	
Antenna & Local Osc.	AEM (LR), MIC, V
I-F Transformers	AEM, (LR), AM, MIC, V
Miniature R.F. Chokes	W
Connectors (Jacks & Plugs)	
Subminiature	SWI, TE
Crystals (Quartz)	MCE, SED
Photocells (Semiconductor)	
Cadmium Sulfide	CC, RCA, SED
Selenium	IREC

Component	Manufacturers/Suppliers
Printed Circuits	
To Order	PC
Kits	KEPRO, TEC
Repair Kits	GC
Relays	
Sensitive	AD, PB
Miniature & Subminiature	AD, PB
Resistors	
Fixed, subminiature	AB, FL
Controls, subminiature	CEN, FL
Precision Adjustable	BL
Sockets	CM, EBY
Switches (Miniature)	
Rotary	CEN, GH
Other	CEN, SWI
Tools (Miniature)	
Hand Tools (Pliers, etc.)	KCO
Screwdrivers, etc.	GC, ICA, MMP
Soldering Instruments	O, UET
Transducers	
Earphones	FL, LR, TE
Loudspeakers	J, RCA, URP
Microphones (Lo Z)	SHB
Transformers & Chokes	
Audio	AEM, (LR), CTC, FL, RCA, TE, TI, UTC, URP
Transistor Kits	GTC, LR, SUT, SYL
Wire (Subminiature)	TEN

MANUFACTURERS

AB—Allen Bradley Co.
136 W. Greenfield Avenue
Milwaukee 4, Wisconsin

AC—Austin-Craft
431 S. Victory Boulevard
Burbank, California

AD—Advance Electric and Relay Co.
2435 North Noami Street
Burbank, California

AEM—Argonne Electronics Mfg. Corp.
27 Thompson Street
New York 13, N. Y.
(Distributed by Lafayette Radio —See Below).

AM—Automatic Manufacturing Corp.
65 Gouverneur Street
Newark 4, N. J.

AS—Astron Corp.
255 Grant Avenue
East Newark, N. J.

BB—Burgess Battery Co.
Freeport, Illinois

BI—Barco, Inc.
Milwaukee 1, Wisconsin

BL—Bourns Laboratories
6135 Magnolia Avenue
Riverside, California

BR—Bud Radio, Inc.
2118 E. 55th Street
Cleveland 3, Ohio

CC—Clairex Corporation
50 West 26th Street
New York 10, N. Y.

CD—Cornell Dubilier Elec. Corporation
South Plainfield, N. J.

CEN—Centralab,
Division of Globe-Union, Inc.
900 East Keefe Avenue
Milwaukee 1, Wisconsin

CM—Cinch Mfg. Corp.
10265 Homan Avenue
Chicago 24, Illinois

CTC—Chicago Standard Transformer Corp.
3580 Elston Avenue
Chicago 18, Illinois

EBY—Hugh H. Eby Co.
4700 Stenton Avenue
Philadelphia 44, Pa.

EC—The Electratomic Co.
P. O. Box 827
Wheaton, Maryland

FL—Fortiphone, Ltd.
247 Regent St., W 1,
London, England

GC—General Cement Mfg. Co.
919 Taylor Avenue
Rockford, Illinois

GE—General Electric Co.
Capacitor Department
John Street
Hudson Falls, N. Y.

GH—Grayhill
537 Hillgrove Avenue
La Grange, Illinois

MANUFACTURERS

GTC—General Transistor Corporation
130-11 90th Avenue
Richmond Hills 18, N. Y.

GU—The Gudeman Co.
340 West Huron Street
Chicago 10, Illinois

ICA—The Insuline Corporation of America
186 Granite Street
Manchester, N. H.

IREC—International Rectifier Corporation
1521 East Grand Avenue
El Segundo, California

J—Jensen Mfg. Co.
6601 S. Laramie Avenue
Chicago 38, Illinois

KCO—Kraeuter & Co., Inc.
Newark, N. J.

KEPRO—Keil Engineering Products
4536 Duncan
St. Louis 10, Missouri

LR—Lafayette Radio (Distributor)
100 Sixth Avenue
New York 13, N. Y.

MAL—P. R. Mallory & Co., Inc.
3029 E. Washington Street
Indianapolis 6, Indiana

MCE—McCoy Electronics Co.
Mt. Holly Spring, Pa.

MIC—J. W. Miller Co.
5917 S. Main Street
Los Angeles 3, California

MMP—Moody Machine Products, Inc.
Providence, R. I.

MU—Mucon Corporation
9 St. Francis Street
Newark 5, N. J.

NC—National Carbon Co.
30 E. 42nd Street
New York 17, N. Y.

O—Oryx Soldering Instruments
Distributor: Television Accessories Co.
P. O. Box 368
Scottsdale, Arizona

PB—Potter & Brumfield
Princeton, Indiana

PC—Photocircuits Corporation
New Street
Glen Cove, New York

RC—Radio Condenser Co.
Camden, N. J.

RCA—Radio Corporation of America
Harrison, N. J.

SED—Formerly Standard Electronics Division
Now Hupp Corporation
P. O. Box 513
Carlisle, Pa.

SHB—Shure Bros.
222 Hartrey Ave.
Evanston, Illinois

SPR—Sprague Electric Co.
North Adams, Massachusetts

MANUFACTURERS

SWI—Switchcraft, Inc.
1320 N. Halsted Street
Chicago 22, Illinois

SUT—Sutton Electronic Co., Inc.
Lexington, Kentucky

SYL—Sylvania Electric Products, Inc.
1100 Main Street
Buffalo 9, N. Y.

TE—Telex, Inc.
Telex Park
St. Paul, Minnesota

TEC—Techniques, Inc.
135 Belmont Street
Englewood, N. J.

TEN—Tensolite Insulated Wire Co., Inc.
198 Main Street
Tarrytown, N. Y.

TI—Texas Instruments, Inc.
6000 Lemmon Avenue
Dallas 9, Texas

UTC—United Transformer Co.
150 Varick Street
New York 13, N. Y.

URP—Utah Radio Products, Inc.
1123 E. Franklin Street
Huntington, Indiana

UET—Ungar Electric Tools, Inc.
P. O. Box 312
Venice, California

V—Vokar Corporation
7300 Huron River Drive
Dexter, Michigan

W—Wilco Corporation
546 Drover Street
Indianapolis 21, Indiana

PART IV—REFERENCE DATA

Chapter 12

DEFINITIONS & DESIGN FORMULA

Absolute Maximum Ratings: The operating limits of a device which, if exceeded, may result in permanent damage. Typical ratings are maximum operating voltages and currents, maximum power dissipation, and maximum operating temperatures. Some manufacturers specify a maximum storage temperature for semiconductor devices as well as maximum operating temperatures.

Acceptor: A substance (impurity) which, when added to a pure semiconductor material, results in an increase in the number of *holes* so that major conduction through the material takes place as a transfer of the hole structure from molecule to molecule. Since this is equivalent to the transfer of a positive charge, the resulting alloy is called a P-TYPE semiconductor. Typical acceptor materials for germanium are indium, aluminum and gallium.

AFC: Automatic Frequency Control.

AGC: Automatic Gain Control.

Alpha (α): The current amplification factor of a transistor when connected in a *grounded-base* configuration. Essentially, the ratio of the incremental change in collector current to an incremental change in emitter current at a constant collector potential.

Amplifier: A device for changing (increasing) the amplitude of a signal without altering its quality. An *amplifier* is generally used to increase the amount of power associated with a signal, but may be used for impedance matching purposes.

Amplifier, Class of Operation: An amplifier's *Class* is determined by the relation between operating bias and input signal. A *CLASS A* amplifier is biased in such a manner that *all* of the input signal has a control on the output; this generally means that the operating point is fixed near the center of the linear portion of the amplifier's operating characteristic curve. A *CLASS B* amplifier is biased in such a manner that only the positive (or negative) going half of an applied signal has a control on the output; this generally means that the operating point is fixed near the bottom of the amplifier's characteristic curve, or at the D.C. "cutoff" point. A *CLASS C* amplifier is biased in such a manner that only the peaks (positive or negative) of an applied signal have control on the output; this generally means that the operating point is fixed *beyond* D.C. output current cutoff. A *CLASS AB* amplifier is intermediate between *CLASS A* and *CLASS B*. In general, the higher the *class* of operation, the more power required to drive the amplifier. Thus, a *CLASS B* amplifier requires greater drive than a *CLASS A* amplifier. Also, the higher the *class* of operation, the more efficient the device; a *CLASS C* amplifier is the most efficient.

Audio (A.F.): Signals with a frequency which falls within the audible range, generally taken to be from 20 to 20,000 c.p.s.

AVC: Automatic Volume Control.

Base: One of the electrodes in a transistor. Roughly analogous to the *grid* or "control electrode" of a vacuum tube. In a junction transistor, the *base* is the intermediate layer of semiconductor material; in a point-contact transistor, the *base* is the block of semiconductor material upon which the point electrodes rest.

Beta (β): The current amplification of a transistor when connected in the *grounded-emitter* configuration. Essentially, the ratio of the incremental change in collector current to an incremental change in base current at a constant collector voltage.

Bias: The steady (D.C.) operating voltage or current applied to an electrode to establish the basic operating conditions of a device. A bias *voltage* is applied to the grid of a vacuum tube to establish its operating conditions. A bias *current* establishes the operating conditions of a transistor.

Breadboard: An experimental circuit set up for test purposes.

Characteristics: The electrical specifications of a device, sometimes given as a table or curve showing the variation of one electrical quantity with respect to another.

Collector: One of the electrodes in a transistor. Roughly analogous to the *plate* of a vacuum tube. A *collector* junction is generally biased in a reverse direction.

Compensation: The techniques employed to correct for shortcomings in circuit design or operation. *High frequency compensation* is the technique used to extend the frequency response of an amplifier by reducing the effects of distributed wiring capacities and other detrimental factors. *Temperature compensation* is the technique used to minimize changes in circuit operation with changes in ambient temperatures.

Complementary Symmetry: The term applied to circuits utilizing the similar (symmetrical) but opposite (complementary) characteristics of PNP and NPN junction transistors. The current flowing through each electrode of a PNP transistor is exactly the opposite of that flowing through the corresponding electrode of a NPN unit as far as D.C. is concerned, and assuming normal circuit configurations and power supply connections.

Configuration: The circuit arrangement. There are three basic configurations used in transistor circuitry . . . (a) *grounded-base*, (b) *grounded-emitter*, and (c) *grounded-collector*.

Constant Current Supply: A D.C. power supply in which the output current is relatively independent of load impedance. In general, a high impedance supply. A battery or conventional D.C. power supply may be used as a *constant current supply* by connecting a high value resistor in series with the supply leads. The series resistance should be from ten to one thousand times the expected load resistance. *Constant current supplies* are used to study transistor characteristics.

Converter: Referring to transistor circuitry, a combination oscillator and mixer. A *converter* is used in the "front end" of a receiver to change an incoming R.F. signal to a different frequency . . . the intermediate frequency (I.F.). Sometimes called a *first detector,* a term also applied to mixers.

Coupling Methods: The techniques used to connect together two or more stages in a multi-stage amplifier. With *direct-coupling* there is a direct (resistive) electrical connection between the output of one stage and the input of the succeeding stage; such an amplifier will pass a D.C. signal. With *capacitive-coupling* a capacitor is connected between stages, allowing the A.C. signal to pass, but blocking D.C. With *transformer-coupling* a transformer is used between stages; its primary winding is connected to the output of one stage, its secondary winding to the input of the following stage. In general, *direct-coupled* and *capacitive-coupled* transistor amplifiers have less gain but better frequency response than *transformer-coupled amplifiers. Transformer-coupling* gives greater gain as it allows the output impedance of one stage to be matched to the input impedance of the following stage, permitting maximum transfer of energy.

Cutoff Frequency: Generally taken as the frequency at which the gain of a device is 3 db below its low frequency value. Used when referring to the variation of *alpha* or *beta* with respect to frequency.

Decibel (db): Originally, one-tenth of a *bel,* the fundamental unit for expressing the relationship between two signal power levels and to give a quantitative measure of the differences in sound-sensation levels. Although used originally only for sound measurements, it is now used as the basic logarithmic unit for indicating power relationships. Mathematically, a change in power level, in decibels, is equal to ten times the logarithm (to the base 10) of the ratio of the two powers, or

$$db = 10 \log_{10} (P_1/P_2).$$

The decibel is also used to express the logarithmic relationship between two voltages or currents, and is equal to twenty times the logarithm (to the base 10) of the ratio of the two voltages or currents. The db should be used to indicate voltage and current ratios only where the two points where the levels are taken have identical impedances. Since the db indicates the ratio of two power levels, the gain of an amplifier or the attenuation of a network may be expressed in decibels. Where the power ratio is less than unity (that is, a loss occurs), the fractional ratio is inverted and the loss indicated by giving the db value a negative sign. In audio work, a level of *zero* (0) db is equal to an absolute value of 0.006 watts (6 milliwatts). Power levels below this value are expressed as negative, above as positive.

Derate: To reduce the rating of a device. Generally used in referring to the power dissipation of a transistor. When a power transistor is used at high ambient temperatures, it is customary to *derate* the unit to prevent excessive heating with resulting damage.

Detector: An electrical circuit or device used to remove the modulation from a carrier signal.

Diode: An electrical device having two electrodes . . . cathode and anode. May be either a semiconductor or a vacuum tube.

Dissipation: A loss of energy. Generally used to indicate the amount of electrical energy converted into heat by a device. Expressed in watts. A transistor may be rated by its collector dissipation in watts . . . this is the maximum amount of electrical power that the transistor can convert into heat at its collector electrode without damage. This value may be reduced (derated) at high ambient temperatures. In general, the higher the rated power dissipation of a device, the greater the power it can handle, assuming normal efficiencies.

Donor: A substance (impurity) which, when added to a pure semiconductor material, results in an increase in the number of free electrons so that major conduction through the material takes place as a movement of electrons. Since this is equivalent to the transfer of a negative charge, the resulting alloy is called a N-TYPE semiconductor. Typical donor materials for germanium are phosphorus, arsenic and antimony.

Efficiency: The ratio of useful power output to power input. Generally expressed as a percentage. A "perfect" device would be 100% efficient. Since the difference between power output and power input to a device represents a loss of energy, the more efficient a device, the lower the internal losses. A "perfect" device would have zero losses.

Emitter: One of the electrodes in a transistor. Roughly analogous to the *cathode* of a vacuum tube. An *emitter* junction is generally biased in a forward direction.

Feedback: In a mechanical or electrical system, returning a control signal from one part of the system to an earlier stage. The signal is "fed back," hence the term.

Feedback, Degenerative: Also termed *negative* or *inverse* feedback. A feedback signal that is out-of-phase with the forward moving signal at the point at which it is injected into the system, thus tending to cancel a portion of the normal signal. Degenerative feedback thus tends to neutralize or to cancel changes in the signal, reducing distortion, reducing gain (in an amplifier), and extending the frequency response of the system. Degenerative feedback is often used in audio amplifiers as a means of reducing distortion. It is also used in R.F. amplifiers to prevent oscillation, where it is termed *neutralization* (which see).

Feedback, Regenerative: Also termed *positive* feedback. A feedback signal that is in-phase with the forward moving signal at the point at which it is injected into the system, thus tending to increase the amplitude of that signal. Regenerative feedback thus tends to continue changes in the signal in the same direction, increasing the system's gain. Regeneration is sometimes used to increase the gain of an R.F. amplifier. Where enough regenerative feedback is used to overcome circuit losses, *oscillation* may take place.

Fieldistor: A type of transistor in which the current through the semiconductor is controlled by an electric field from an electrode near to, but not in contact with, the semiconductor. Either a point-contact or junction *diode* is used, with the field electrode added. A fieldistor has a high input impedance. As of this writing only experimental units have been made . . . not now in commercial production.

Field Effect: The influence of an electrical field. Used for control purposes in the *fieldistor* and in the *field effect* or *unipolar* transistor, which see.

Forward Current: The D.C. flow resulting when a semiconductor junction is biased in its low resistance direction . . . or, its "conducting" direction.

Frequency: The periodic rate at which a quantity changes. Generally expressed in cycles per second (c.p.s.), in thousands of cycles per second (kilocycles, or simply Kc), or in millions of cycles per second (megacycles, or Mc) in electronics work.

g (symbol): Acceleration due to gravity. Approximately 32 feet per second. Used for measuring the shock that a system can stand. The acceleration due to gravity (g) has become the standard unit for determining both acceleration and deceleration, permitting a deceleration drop or shock to be expressed as "so many g."

Gain: The amount of amplification which a system gives to a signal. If the system reduces (attenuates) the signal, the gain is said to be less than unity (one). In electrical systems, voltage and current gains are often expressed as simple numerical ratios of output to input signal amplitudes. Power gain, on the other hand, is more generally expressed in decibels.

Ground: In circuit work, a common connection point, either a metal chassis, a common terminal, or a *ground bus.* If a point has zero voltage with respect to ground, it is said to be at "ground potential."

Grounded-Base: Also *common-base* or GB. A transistor circuit configuration in which the base electrode is common to both the input and output circuits. The base need not be connected directly to circuit ground, however. A *grounded-base* transistor circuit is roughly analogous to a *grounded-grid* vacuum tube circuit.

Grounded-Collector: Also *common-collector* or GC. A transistor circuit configuration in which the collector electrode is common to both the input and output circuits. The collector need not be connected directly to circuit ground, however. A *grounded-collector* transistor circuit is roughly analogous to a *grounded-plate* or *cathode-follower* vacuum tube circuit.

Grounded-Emitter: Also *common-emitter* or GE. A transistor circuit configuration in which the emitter electrode is common to both the input and output circuits. The emitter need not be connected directly to circuit ground, however. A *grounded-emitter* transistor circuit is roughly analogous to a *grounded cathode* vacuum tube circuit.

Hall Effect: The influence of crossed electric and magnetic fields in a conductor or semiconductor, developing a potential difference (Hall voltage) between the edges of the material.

Heat Sink: As applied to transistor work, a mass of metal or other good heat conductor which serves to quickly absorb and to dissipate quantities of heat energy. Used to prevent overheating of a transistor or semiconductor's electrodes.

Hole: In semiconductor work, the absence of an electron in the atomic or molecular structure of a material resulting in

a net positive charge which can be transferred through the material by the exchange of valence bonds. In effect, the "hole" acts more or less like a particle with the mass and size of an electron, but with a positive charge.

I.F. (Intermediate Frequency): The frequency of the signal to which all incoming R.F. signals are converted in a superheterodyne receiver. In general, it is a fixed frequency *intermediate* in value between the incoming R.F. signal and the final demodulated (audio or video) signal, hence its name.

Impedance: The opposition which a circuit or component offers to the flow of electric current. It is expressed in ohms and is equal to the ratio of the effective value of the voltage applied to the circuit to the resulting current flow. In A.C. circuits, the impedance is a complex quantity including both resistance and reactance. In D.C. circuits, the impedance is purely resistive.

Impurity: In transistor work, a substance which, when added to a pure semiconductor, gives it specified electrical properties. See *acceptor* and *donor.*

Junction: An area or point of contact between two dissimilar metals or materials. In semiconductor work, a *junction* may be formed by pressure contact of a point electrode, by welding, by alloying, by plating, and by "growing" a single crystal containing alternate layers of dissimilar materials. In most transistor work a junction is between *P-type and N-type* semiconductor materials.

Kilo-: Metric prefix used to indicate "thousand." Examples . . . *kilo*cycles, thousand cycles; *kilo*volt, thousand volts; *kilo*watt, thousand watts.

Load: In general, a device or circuit that absorbs or uses power from a generator or other source. A resistor connected across a battery acts as a load on the battery, absorbing electrical energy and converting it into heat. In electrical circuits, the *lower* the resistance or impedance of a loading device, the greater the energy absorbed and hence the greater the load. Since transistors, in general, have a low input impedance, they act to *load* circuits to which they are connected.

Matching: Coupling two circuits or devices in such a manner that maximum energy transfer can take place. In general, this means making the input impedance of the *driven* device match the *output* impedance of the *driving* device. Since transistors, in the usual circuit configurations, have a low input, but high output impedance, maximum gain can be obtained from multistage circuits only when coupling transformers or similar devices are used to *match* impedances.

Meg-: Prefix meaning "million." Example . . . *meg*ohm, million ohms.

Micro-: Prefix meaning one-millionth of a quantity. Examples . . . *micro*watt, one-millionth of a watt; *micro*ampere, one-millionth of an ampere. Due to the low powers required by transistor circuits, currents are often expressed in microamperes.

Milli-: Prefix meaning one-thousandth of a quantity. Examples . . . *milli*watt, one-thousandth of a watt; *milli*ampere, one-thousandth of an ampere. The maximum power dissipation of low power transistors is generally expressed in milliwatts.

Mixer: An electrical circuit used to combine two signals. Generally refers to that stage in a superheterodyne radio receiver where the incoming R.F. signal and the signal supplied by the local oscillator are combined to produce the I.F. signal. Often called the *first detector*. A non-linear amplifier or a detector are good mixers.

Modulate: To change or vary . . . such as varying the amplitude *(amplitude modulation)* or frequency *(frequency modulation)* of a signal. The circuit which *modulates* a signal is called a modulator. The reverse of modulation is de-modulation or *detection*. A *mixer* circuit (above) may also serve as a modulator.

Neutralization: Generally used with reference to R.F. amplifier circuits. The technique used to cancel the effects of feedback between the input and output terminations of a stage due to interelectrode coupling, which, in a transistor, is both resistive and capacitive. *Neutralization* improves the stability of an R.F. amplifier, reducing any tendency to oscillate and making its alignment (tuning) less critical. The general technique is to use degenerative (out-of-phase) feedback to cancel the energy fed back due to interelectrode coupling.

Noise Factor: At the present writing, a number of methods are used to express the *Noise Factor* of a transistor, with the result that a certain degree of confusion exists in the field. The best definition is probably that given in Military Standards MIL-T-12679A, as follows: "For a linear system at a selected input frequency, the noise factor is the ratio of the total noise power per unit bandwidth (at a corresponding output frequency) available at the output terminals, to the portion thereof engendered at the input frequency by the input termination, whose noise temperature is standard (290°K) at all frequencies." The best junction transistors have a noise factor approximating *or less than* the best vacuum tubes.

Oscillator: In general, an electrical circuit which converts a D.C. supply voltage into an A.C. signal by means of a self-sustaining action. A basic oscillator is an amplifier with sufficient regenerative feedback to overcome circuit losses.

Parameter: A constant corresponding to and expressing some electrical characteristic or property of a device or network. If a transistor is considered as a four-terminal network (two input, two output terminals), its parameters may be given in any of three forms. The R-PARAMETERS are resistance or impedance values obtained when the transistor is considered as an *open-circuit* network. The G-PARAMETERS are conductance or admittance values obtained when the transistor is considered as a *short-circuited* network. In practice, the R-PARAMETERS are most convenient for describing point-contact transistors, the G-PARAMETERS for describing junction transistors. Both systems are in use. However, there is an increasing tendency for engineers to refer to the *hybrid* or H-PARAMETERS, which combine the features of both systems. For additional information on this subject, refer to SECTION B of this chapter.

Photodiode: A two-electrode light sensitive device. In general, the resistance between the two electrodes varies inversely with the amount of light falling on the light sensitive surface.

Phototransistor: A light sensitive transistor. May have two or three electrodes, although a two electrode device is more properly called a *photodiode*.

Power: In semiconductor work, the rate at which electrical energy is fed to or taken from a device. Expressed in watts, milliwatts, or microwatts. In general, in resistive circuits, the power, in watts, is equal to the product of the voltage across the circuit in volts and the current through the circuit in amperes, or, *Power* (watts) = *Voltage* (volts) × *Current* (amps.)

Rectifier: A device that permits greater current flow in one direction than in the other. A "perfect" rectifier would have zero resistance to the flow of current in the *forward* direction, infinite resistance to the flow of current in the *reverse* direction. Most diodes may be used as rectifiers. A rectifier may be used to convert A.C. into pulsating D.C.

Reverse Current: The D.C. flow resulting when a semiconductor junction is biased in its high resistance direction . . . or, its "non-conducting" direction.

R. F. (Radio Frequency): Signals with a repetition rate (frequency) above the audible range, but below the frequencies associated with heat and light. Generally taken to

be from 20,000 c.p.s. (20 Kc) to 30,000,000,000 c.p.s. (30,000 Mc).

Runaway, Collector Current: A condition that may occur when a power transistor is operated without D.C. stabilization at high ambient temperatures. The collector current increases the collector junction temperature, reducing the collector resistance and allowing a greater current to flow. The increased current increases collector junction heating still more, resulting in a further drop in collector resistance and still greater increase in current. The action may continue until the transistor is destroyed.

Saturation Current: The collector current flowing with zero emitter current. Sometimes called *leakage* current or *collector cutoff current*. Abbreviated I_{co}. May be determined by applying a reverse bias to the collector-base junction, with the emitter circuit open. In general, the lower the saturation current, the better the transistor. A high quality transistor may have a saturation current of less than 5 microamperes. An excessively high saturation current indicates a defective transistor.

Semiconductor: In general, a material, usually crystalline in structure, with electrical resistivities intermediate between those of a conductor (metal) and an insulator. Often, the resistivity may be changed by the application of various physical forces, such as heat, light, or electrical and magnetic fields. Semiconductors may be grouped into three general classes. An *intrinsic* semiconductor is one in which the concentration of acceptors and donors is zero, so that current flow is by means of both holes and free electrons in equal quantities. A *P-type* semiconductor is one with a majority of acceptors, so that current flow is primarily by means of hole migration. An *N-type* semiconductor is one with a majority of donors, so that current flow is primarily by means of free electrons.

Stability: The ability of a circuit or device to maintain its operating characteristics constant despite changes in temperatures, humidity, power supply voltages (or currents), etc.; or, the ability of a circuit to be completely independent of changes of any nature as far as its operating characteristics are concerned. Often used with respect to a particular characteristic, such as *frequency stability*, when referring to oscillators, *gain stability*, when referring to amplifiers, etc. The techniques used to increase the stability of a circuit are *stabilization* methods.

Stability Factor: A mathematical quantity relating the variation in output current to the variation of *saturation current* in a transistor. In its basic form, the stability factor is a partial differential equation.

Tantalytic: (Trade Mark) The name applied to tantalum electrolytic capacitors manufactured by the *General Electric Company*.

Tetrode: A device having four electrodes.

Transducer: A device by means of which energy may flow from one type of transmission to another type of transmission system. Sometimes taken to be a device used for converting energy from one form to another. For example, a *loudspeaker* is a transducer, converting electrical energy into sound energy, a *microphone* is a tranducer, used for converting sound energy into electrical energy. In a true transducer, the wave characteristics of the energy are maintained in the flow from one system to another.

Transient: A temporary, non-periodic, current flow (or voltage) induced in a circuit or device by a change in loading or applied voltages. It generally exists only while the circuit is readjusting itself to a new set of conditions. It may be in the form of a narrow pulse, or, sometimes, a damped oscillatory wave train.

Transistor: A device which depends for its essential action on the movement and control of charges in a semiconductor material. In general, a semiconductor device having several electrodes in which the resistance between two electrodes

is controlled by the current supplied to another electrode. The name is coined from the expression *TRANS*fer res*ISTOR*.

Transistor, Analog: A theoretical transistor type analogous to a vacuum tube in construction and operation, except that current flow is through a semiconductor material instead of through a vacuum. A central emitter serves as a "cathode". This, in turn, is surrounded by an area of intrinsic semiconductor material in which are located "grid" electrodes of a semiconductor material of a type opposite that of the emitter. Completely surrounding the entire structure is another layer of semiconductor material of a type similar to that of the central emitter. The outer layer is analogous to the plate of a vacuum tube. In practice, the analog transistor should have a high input impedance.

Transistor, Coaxial: A special type of point-contact transistor in which the base consists of a thin disk of semiconductor material mounted in a small cartridge. The emitter and collector connections are point electrodes making pressure contact on either side of the thin disk, and mounted coaxially to the cartridge body (hence the name). The coaxial transistor should have good stability, should be fairly simple to produce, and offers the advantage of shielding between input and output connections, where the *grounded-base* configuration is employed.

Transistor, Junction: A transistor in which the electrodes consist of alternate layers of semiconductor material, generally of opposite types. It may be a single crystal containing alternate layers developed during the growing process or a crystal of one type of material with the outer layers formed by a welding or plating process. The basic construction is indicated by a letter terminology which identifies the tran--sistor. Thus, a *NPN* transistor consists of two *N-type* semiconductor layers with a *P-type* semiconductor layer in-between. Basic types are *NPN* and *PNP*. More recently, four layer types have been introduced, including *NPIN*, *PNIP*, and *PNPN* transistors. The *"I"* indicates a layer of *intrinsic* semiconductor material.

Transistor, PN Hook: A junction type transistor in which the collector electrode has been replaced by an additional junction. Generally, a *PNP* transistor with the collector electrode *(P-type material)* replaced by a *PN* junction, forming a *PNPN* transistor. A theoretical type, its gain should be many times greater than that of a conventional junction transistor.

Transistor, Point-Contact: A transistor in which the base consists of a small pellet of *N-type* or *P-type* semiconductor material and the collector and emitter electrodes consist of small wire "cat's whiskers" in pressure contact on the surface of the semiconductor and in close proximity to each other. May be identified as *N-base* or *P-base* point-contact transistors, depending on the semiconductor material used.

Transistor, Surface-Barrier: A junction type transistor manufactured by the *Philco Corporation*. The base consists of a wafer of semiconductor material which has been etched thin by an electrolytic process, with the emitter and collector electrodes consisting of small metal dots electroplated on opposite sides of the etched area. This type of transistor is characterized by an excellent high frequency response.

Transistor, Unipolar: Also called a *Field Effect* transistor, occasionally termed a *"transtrictor."* A transistor differing from point-contact and junction transistors both in construction and operation. In its basic form, it consists of a slab of semiconductor material with a junction formed around its center and with two electrical contacts in the vicinity of, but on opposite sides of, the junction. If the slab is *N-type* material, a *P-type* junction is formed. The junction serves as one electrode, the two electrical contacts as the other electrodes. The junction is termed a "gate," the other two electrodes are called the "source" and "drain." In operation, the current flow between the source and drain is controlled by an electric field set up by the gate electrode. Thus, the operation depends on the influence of an electric field, hence the name *"field effect."* The unipolar transistor is characterized by good high frequency response and a high input impedance. As of this writing, it is not avaialble as a commercial device, but has been built in experimental quantities by a number of laboratories.

Transistor, Tetrode: A four-electrode transistor. May be either point-contact or junction type. The most common type that is currently available is a junction tetrode which is essentially a junction triode with two base connections. It is characterized by an excellent high frequency response, both as an amplifier and as an oscillator. With two base connections, it is valuable as a modulator or mixer. Experimental units have been manufactured which operate at frequencies in excess of 1,000,000,000 c.p.s. (1,000 Mc).

Triode: An electrical device having three electrodes. The majority of transistors that are currently available as commercial devices are triodes.

Valence: A measure of the ability of atoms of an element to combine with other atoms to form molecules. When atoms are combined in molecular structures, the forces holding the structure together are *valence bonds*.

Zener Voltage: If a voltage is applied to a semiconductor junction in its high resistance or "non-conducting" direction, very little reverse current will flow until the applied voltage reaches a specific value. At this point, the reverse current will suddenly increase appreciably. In general, the voltage at this point is the maximum reverse voltage that can be safely applied to the junction and is termed the *Zener voltage*.

Section B: DESIGN FORMULA

Transistor Parameters: For analysis and design purposes, the transistor is generally considered to be a four-terminal network with one input and one output terminal common, as shown in Fig. 12-1. The characteristics of this network may be

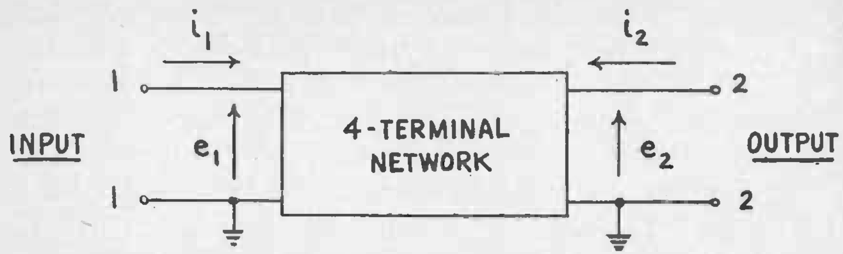


Fig. 12-1.—Basic four-terminal network representation shown as a "black box." Input and output terminals and input and output voltages and currents are identified. Arrows show conventional flow.

expressed in terms of measurements made between the various terminals, assuming voltages (e_1, e_2) and currents (i_1, i_2) as shown in the diagram. If the resistances between the various terminals are specified, we have the basic *r-parameters* of the transistor; these values are given in ohms. If the conductances between the network terminals are specified, we have the basic *g-parameters* of the transistor; these values are given in mhos or micromhos. It is also possible to use a combination of both *r* and *g* parameters, in which case the characteristics of the transistor are expressed as *hybrid* or *h-parameters.* The last system is rapidly becoming the most popular among design engineers.

Some engineers prefer to use the more general form of *r* and *g* parameters, substituting impedance *(z)* values in place of resistances and admittance *(y)* values in place of conductances. In such cases, the *r-parameters* become *z-parameters* and the *g-parameters* become *y-parameters.* For purposes of our discussion, we will use *r, g* and *h-* terminology, but the reader should remember that the more general terms may be substituted in the equations if desired.

The *r-parameters* may be defined as follows . . . the subscript numerals indicate the terminals at which the values apply, referring to Fig. 12-1:

(1) r_{11}—*input resistance with open-circuit output terminals, equal to* e_1/i_1, *with* $i_2 = 0$.

(2) r_{22}—*output resistance with open-circuit input terminals, equal to* e_2/i_2, *with* $i_1 = 0$.

(3) r_{12}—*feedback or reverse transfer resistance, with the input open, equal to* e_1/i_2, *with* $i_1 = 0$.

(4) r_{21}—*forward transfer resistance with open-circuit output terminals, equal to* e_2/i_1, *with* $i_2 = 0$.

The *g-parameters* may be defined as follows . . . again, the subscript numerals indicate the terminals at which the values apply, referring to Fig. 12-1:

(5) g_{11}—*input conductance with the output terminals shorted, equal to* i_1/e_1, *with* $e_2 = 0$.

(6) g_{22}—*output conductance with the input terminals shorted, equal to* i_2/e_2, *with* $e_1 = 0$.

(7) g_{12}—*feedback or reverse transfer conductance with the input terminals shorted, equal to* i_1/e_2, *with* $e_1 = 0$.

(8) g_{21}—*forward transfer conductance with the output terminals shorted, equal to* i_2/e_1, *with* $e_2 = 0$.

Finally, the *h-parameters* are defined as follows . . . again, the subscript numerals indicate the terminals at which the values apply, referring to Fig. 12-1. Note that the *h-parameters* combine features of the *r-* and *g-parameters,* and also include new terms indicating circuit gain or amplification:

(9) h_{11}—*input resistance (impedance) with the output terminals shorted, equal to* e_1/i_1, *with* $e_2 = 0$.

(10) h_{22}—*output conductance (admittance) with the input terminals open, equal to* i_2/e_2, *with* $i_1 = 0$.

(11) h_{12}—*input to output voltage ratio with open-circuit input terminals, equal to* e_1/e_2.

(12) h_{21}—*output to input current ratio with shorted output terminals, equal to* i_2/i_1, *with* $e_2 = 0$. *Given a negative sign by convention.*

The *r-parameter* values, as well as h_{11}, are given in ohms. Note that h_{11} is *not* equal to r_{11}, however, for one measurement is made with an open-circuit output, the other with a shorted output. The *g-parameter* values, as well as h_{22}, are given in mhos or micromhos. Note that h_{22} is *not* equal to g_{22}, however, for one measurement is made with the input terminals shorted, the other with the input terminals open. The last two parameter values, h_{12} and h_{21}, are pure numbers, since they represent ratios. The last parameter, h_{21}, is the *current* *amplification factor* for the transistor and is equal to minus *alpha* where the *grounded-base* circuit configuration is considered or to *beta* where the *grounded-emitter* configuration is used. In practice, the actual values of the parameters, whether the *r-*, *g-* or *h-* terminology is used, will depend not only on the individual transistor but upon which of the basic circuit configurations are used to represent the four-terminal network. In general, the *grounded-base* configuration is employed. Thus, h_{21} is equal to minus *alpha,* and *beta* is determined by the following relationships . . .

(13) $\beta = \frac{\alpha}{(1-\alpha)}$, *or* (14) $\alpha = \frac{\beta}{(1+\beta)}$.

If desired, the *r-* and *g-parameters* may be converted into *h-parameters* by using the following relationships:

(15) $$h_{11} = r_{11} - \left(\frac{r_{12}r_{21}}{r_{22}}\right) = \frac{1}{g_{11}}.$$

(16) $$h_{22} = \frac{1}{r_{22}} = g_{22} - \left(\frac{g_{12}g_{21}}{g_{11}}\right).$$

(17) $$h_{12} = \frac{r_{12}}{r_{22}} = -\left(\frac{g_{12}}{g_{11}}\right).$$

(18) $$h_{21} = -\left(\frac{r_{21}}{r_{22}}\right) = \frac{g_{21}}{g_{22}} = -\alpha.$$

Equivalent Circuits: The basic four-terminal network shown in Fig. 12-1 is useful for setting up and describing the relationships given thus far. But if the described parameters are to be used in practical circuit design work, it is necessary to relate them to the electrical properties of the transistor itself. This is most conveniently accomplished by means of an equivalent circuit . . . an electrical network whose components represent the electrical components of the transistor. A wide variety of electrical networks may be represented as four-terminal systems, and many of these will serve as equivalent to a transistor if the correct assumptions are made. The three

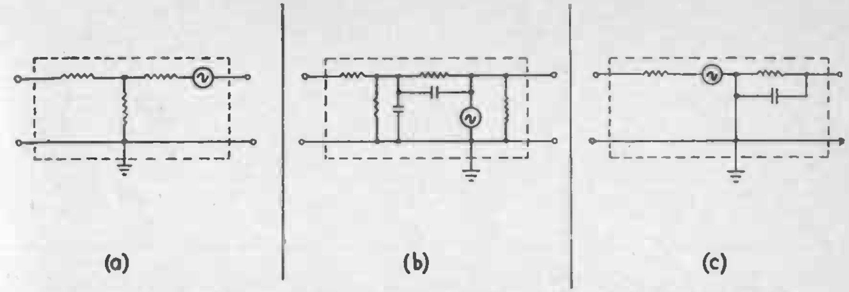


Fig. 12-2.—Three basic equivalent circuits which may be represented as four-terminal networks. (a) T Network; (b) Pi Network; (c) H Network.

equivalent circuits most often used to represent transistors are shown at (a), (b) and (c) in Fig. 12-2. In all three cases, the equivalent circuit is assumed to be an *active* network, [i.e., to include a voltage (current) generator] as this more nearly duplicates the actual transistor in use. The *T network* shown in Fig. 12-2(a) is generally used with the *r-parameters,* hence some engineers refer to the relationships given above as *r-parameters* as *T-parameters,* designating them by network rather than by electrical property. The *pi network* shown in Fig. 12-2 (b) is more often used in connection with the *g-parameters.* Again, some engineers identify the circuit relationships as *pi-parameters* instead of *g-parameters.* Finally, the equivalent circuit shown in Fig. 12-2(c) is used with the *h-parameters.* We will use the *T-network* and *r-parameters* in the remainder of this discussion.

Referring to Fig. 12-3, the three basic transistor circuit configurations are shown at (a), (b) and (c), with the three corresponding *T network* equivalent circuits shown at (d), (e) and (f), respectively. The *grounded-base* configuration is shown in Fig. 12-3(a), with *T network* equivalent circuit shown directly below it in Fig. 12-3(d). The *grounded-emitter* configuration and its *T network* equivalent circuit are shown at Fig. 12-3(b) and 12-3(e), respectively. The *grounded-collector* configuration and its *T network* equivalent circuit are shown at Fig. 12-3(c) and 12-3(f), respectively. All three circuits are drawn so as to correspond, in general form, to the

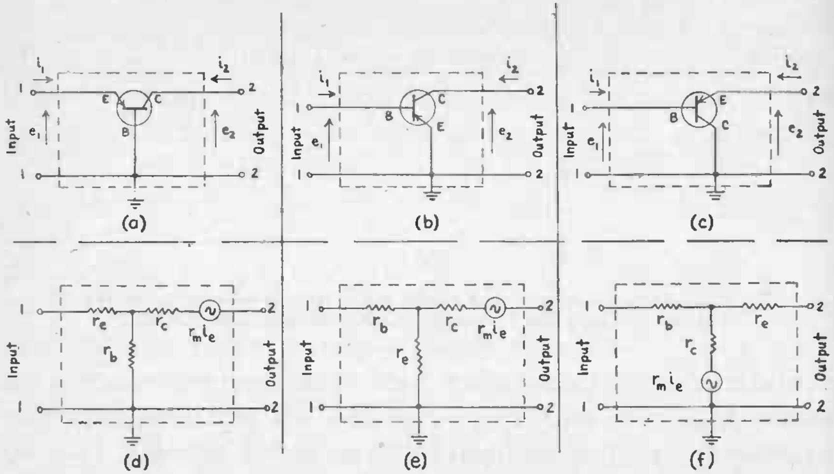


Fig. 12-3.—The three fundamental transistor circuit configurations together with their T network equivalent circuits. The grounded-base configuration is shown at (a) and (d); the grounded-emitter configuration is shown at (b) and (e); the grounded-collector configuration is shown at (c) and (f).

four-terminal network given in Fig. 12-1. The components making up the *T network* equivalent circuits are identified as follows:

- r_e—emitter resistance.
- r_b—base resistance.
- r_c—collector resistance.
- $r_m i_e$—internal generator (voltage source), with
- r_m—mutual resistance for the network, and
- i_e—emitter current (through r_e).

Referring back to Fig. 12-1 and to the *r-parameter* definitions (1) to (4), the *T network* equivalent circuit components are related to the *r-parameters* as follows:

I. In the *grounded-base circuit,* Figs. 12-3(a) and 12-3(d):

(19) $r_{11} = r_e + r_b.$

(20) $r_{22} = r_c + r_b.$

(21) $r_{12} = r_b.$

(22) $r_{21} = r_m + r_b.$

II. In the *grounded-emitter circuit,* Figs. 12-3(b) and 12-3(e):

(23) $r_{11} = r_b + r_e.$

(24) $r_{22} = r_c + r_e - r_m.$

(25) $r_{12} = r_e.$

(26) $r_{21} = r_e - r_m.$

III. In the *grounded-collector* circuit, Figs. 15-3(c) and 15-3(f):

(27) $r_{11} = r_b + r_c.$

(28) $r_{22} = r_c + r_e - r_m.$

(29) $r_{12} = r_c - r_m.$

(30) $r_{21} = r_c.$

Approximate Amplifier Design Formula: *Typical* operating transistor *T network* equivalent circuits are given in Fig. 12-4. These are similar to the circuits given in Fig. 12-3, but with the addition of a load resistance (R_L) and a signal voltage source (E_G) having an internal resistance (R_G). Impedances (Z) may be substituted for resistances if desired. D.C. supply sources are omitted for reasons of clarity. If a few simple, but legitimate, assumptions are made, it is possible to describe each of the three circuits in terms of relatively simple design formulas. These formulas are given below and hold true for most circuit design work involving standard junction transistors. For more exact design equations, and for the derivation of the formulas given below, the reader should refer to the very excellent references listed in the *Bibliography*

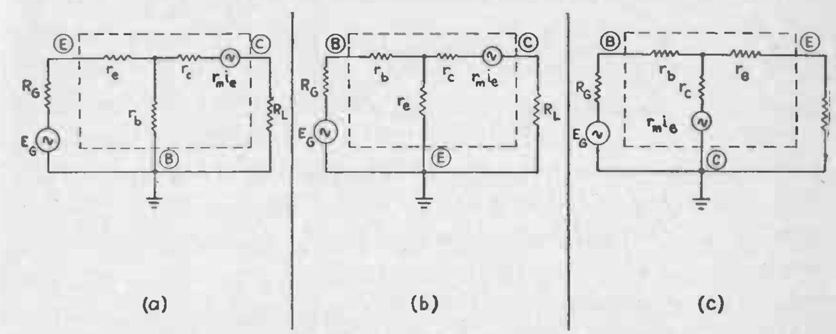


Fig. 12-4.—The three fundamental transistor circuit configurations shown as their operating T network equivalent circuits. The emitter, base, and collector connections are identified outside the dotted box, which represents the transistor proper. The grounded-base configuration is shown at (a), the grounded-emitter configuration at (b), and the grounded-collector configuration at (c).

(Chapter 14). In the following formulas it is assumed that the sum of the emitter resistance (r_e) and the base resistance (r_b) is much less than the load resistance (R_L) and that this value, in turn, is much less than the network's mutual resistance (r_m); it is also assumed that the sum of the emitter and base resistances ($r_e + r_b$) is much less than the signal source's internal impedance (R_G) and that this value, in turn, is much less than the collector resistance (r_c):

I. In the *grounded-base* circuit, Fig. 15-4 (a):

(31) $\text{Input Impedance} = r_e + r_b(1 - \alpha).$

(32) $\text{Output Impedance} = r_c.$

(33) $\text{Voltage Amplification} = \dfrac{\alpha R_L}{r_e + r_b(1 - \alpha)}.$

(34) $\text{Current Amplification} = \alpha.$

(35) $\text{Power Gain} = \dfrac{\alpha^2 R_L}{r_e + r_b(1 - \alpha)}.$

II. In the *grounded-emitter* circuit, Fig. 15-4 (b):

(36) $\text{Input Impedance} = r_b + \dfrac{r_e}{1 - \alpha}.$

(37) $\text{Output Impedance} = r_c(1 - \alpha).$

(38) $\text{Voltage Amplification} = \dfrac{-\alpha R_L}{r_e + r_b(1 - \alpha)}.$

(39) $\text{Current Amplification} = \beta.$

(40) $\text{Power Gain} = \dfrac{\alpha^2 R_L}{r_e(1 - a) + r_b(1 - a)^2}.$

III. In the *grounded-collector* circuit, Fig. 15-4 (c):

(41) $\text{Input Impedance} = (\beta + 1)R_L.$

(42) $\text{Output Impedance} = R_G(1 - \alpha).$

(43) $\text{Voltage Amplification} = 1.$

(44) $\text{Current Amplification} = \beta + 1.$

(45) $\text{Power Gain} = \beta + 1.$

In all of the above formulas, the current amplification factors, *alpha* (α) and *beta* (β) are as defined earlier. See SECTION A of this chapter.

PART IV—REFERENCE DATA

Chapter 13

SPECIAL TECHNIQUES – NEW DEVELOPMENTS

SECTION A: Special Techniques

Printed Circuits: Transistors and printed circuit techniques are related from an historical viewpoint. Both became important parts of the American Industrial Scene at about the same time. But there are other relationships — the majority of currently available transistorized equipment has been manufactured using printed circuits; transistors, because of their small physical size, long life, and low power requirements, are ideal components for the assembly of subminiature equipment . . . and printed circuit techniques are ideal as manufacturing methods for such equipment. Because of these close relationships, as well as the growing importance of printed circuit techniques, the author felt it would be germane to discuss printed circuits as a part of this volume. However, he hastens to point out that printed circuits are not confined to transistor circuitry, nor must all transistor equipment be assembled using printed circuit techniques. Printed circuits are applicable to *all* types of wiring, even including non-electronic electrical applications. And transistors may be used in circuits wired using older "conventional" techniques.

Basically, *printed circuits* are electrical circuits in which individual wire lead connections have been replaced by a two-dimensional conductive pattern bonded to an insulating base material. The name itself is derived from one of the score or more techniques that are used for producing such circuits. Although there are many different techniques that may be used to manufacture printed circuits, most of these may be classed as belonging to one of two major systems. Where *deposit* methods are used, the conductive pattern is deposited directly upon the insulating base material. Where *stripping* techniques are used, the insulating base is covered with the conductive material (usually metallic, such as copper, brass, aluminum or silver); the final circuit is made by removing excess material to leave the desired pattern. Either chemical etching or electrical or mechanical methods may be used to strip away the unwanted conductor.

Among the *deposit* methods are *printing, painting, spraying, plating* and *hot-die stamping*. Two or more of these methods may be combined; for example, a thin conductive pattern may be *printed* on an insulating base, then later built up with metallic layers deposited by an *electroplating* process. Conducting (metallic), insulating and resistive inks or paints may be used with the first three methods, permitting components (resistors and capacitors) as well as conducting leads to be formed. A metallic foil is generally used with the *hot-die stamping* process, with the foil imbedded slightly in the base material by the die. Where *hot-die stamping* is used, the base may be paper, plastic, laminated phenolic, rubber, or similar materials. All of these materials may be used with the *printing, painting,* and *spraying* methods, as well as glass and various ceramics. If a glass or ceramic base is used, the printed circuit may be fused in place by high-temperature firing, assuring an extremely strong and stable bond. If the conductive material is applied by *painting,* a brush or pen may be used "freehand" for individual jobs, or a stencil or silk screen pattern employed for production runs. A stencil or mask is employed when the conductive material is to be *sprayed* onto the insulating base. *Deposit* techniques are widely used in the production of small components (resistors and capacitors) and compact network and single stage assemblies, although, at this writing, these techniques are not used extensively in the production of complete equipment circuits.

The more popular *stripping* methods include *stamping, embossing,* and *etching*. In most cases, where *stripping* techniques are employed, the raw material is a metal-clad laminate. Copper-clad phenolics are used extensively. Both the *stamping* and *embossing* methods use dies. With the *stamping* technique, the metallic foil is cut out by a die having the shape of the desired circuit. After stamping, the unwanted foil is stripped away from the base, leaving the finished circuit. Where the *embossing* method is used, the metallic foil is pressed into the surface of the insulating base material by the pressure of a die having the proper shape for the desired circuit. After pressing, the embossed surface is cut away, using either a milling device or abrasive action. This operation removes all the exposed metallic surfaces except those pressed into the insulating material and beyond the reach of the cutting device. The finished circuit pattern is actually embedded in the base material. Where the *etching* technique is employed, a special *resist* material is deposited on the metallic foil in the pattern of the desired circuit. The metal-clad laminate is then exposed to the etching ("eating away") action of a chemical solution which attacks all the exposed foil but is held back by the *resist* wherever it covers the metal. After all the excess foil is etched away, the *resist* is removed and the final *etched circuit* is ready for further processing. All three *stripping* techniques have been used in the manufacture of printed circuits, but *etching* is by far the most popular and is worthy of more detailed discussion. *Stripping* techniques are used most often in the preparation of complete equipment circuits, but have been used in the preparation of components, principally inductance coils, small capacitors, and switch assemblies.

As mentioned above, the *etching* method is currently the most popular process for producing printed circuits. A majority of manufacturers use this technique, with copper-clad laminate (usually phenolic base) serving as the basic material and ferric chloride solution serving as an etchant. Actual manufacturing techniques vary widely, however, principally in the type of *"resist"* used, in the way the *resist* is applied, and in the way the etchant is applied. The principal methods now used are outlined briefly below:

Ink and Paint Resists—An acid resistant ink or paint is applied to the metallic surface of the laminate in the pattern of the desired circuit. For small "custom" jobs, the paint may be applied with a brush or pen. For short production runs, a silk-screen or similar stencil may be employed.

Photoengraving—The copper-clad laminate is coated with a light-sensitive enamel. The prepared laminate is then exposed to strong light through a negative of the circuit drawing and the enamel developed to obtain an acid resist pattern. The unexposed material is removed during the developing process, leaving a protective covering only where light struck the surface of the laminate.

Offset printing—The circuit pattern is printed on the copper-clad laminate using a plate prepared, photographically, from an original circuit drawing. While the ink is still wet, asphalt powder is dusted onto the ink and fused at a moderately high temperature to form an acid resistive pattern.

Plated resists—A *reverse* of the circuit pattern is printed on the copper-clad phenolic. The laminate is then electroplated with a metal that is unaffected by the ferric chloride used to etch the copper (silver, solder, hard nickel or rhodium may be used). The plating is deposited only where the circuit pattern appears for the reverse ink pattern prevents the plating from taking place on other areas. After plating, the ink is removed using an appropriate solvent, leaving exposed copper except where the plated pattern covers the surface.

Etching—After the copper-clad laminate has been covered with a *resist* in the desired circuit pattern, the board is etched in a ferric chloride or similar acid solution. The unprotected copper is eaten away, leaving a conductive pattern only where the copper is protected by the resist. Several etching techniques are employed. *Still* etching is the slowest and consists simply of immersing the laminate in a tray or tank

of the etchant solution. A somewhat more rapid method is to use a deep tank of etchant, agitated with air bubbles supplied from a compressor. *Air-agitated* baths are suitable for mass production. Even more rapid etching may be accomplished by using a *splash etching* process. A machine is used in which small paddles splash the etchant against the prepared copper-clad laminate boards. The most rapid and most efficient etching method is that employing a *spray* process. Small nozzles direct the etchant solution against the laminate boards in a steady spray.

When the etching is completed, the boards are washed and cleaned. Ink or photographic *resists* are removed with appropriate solvents or by mechanical abrasion. Mounting holes are drilled or punched in the *circuit boards,* small components are mounted by passing their leads through the holes, and the completed circuit finished by soldering all connections simultaneously by dipping the board in a tank of molten solder.

The methods just described are especially well suited to the mass production of electronic circuits, and it is in quantity production that printed circuit techniques find their greatest application at the present time. To the manufacturer, the use of printed circuits offers a great reduction in labor costs over "hand-wiring," which may represent as much as 50% of the production costs of "conventionally-wired" electronic equipment. In addition, when compared to hand-wired circuits, printed circuits are less costly from a materials viewpoint, more compact, faster to assemble, and consistently alike, assuring better quality control and more consistent operation of the final product. Finally, since wiring errors are eliminated, final inspection processes are simplified and less costly.

Printed circuits may offer the advantages of simplified circuit layout, compact construction, and better circuit performance to the laboratory worker as well as to the manufacturer. Recognizing this fact, several manufacturers have made up basic "kits" containing the materials necessary to the production of printed circuits and have offered these kits to laboratory workers, home experimenters, and prototype equipment designers. Two such kits are shown in Figs. 13-1 and 13-2.

Any one of several different methods may be used by the laboratory worker in making up a "one-shot" etched circuit. The chief difference in the various methods is in the type of *resist* used. The three most popular methods are illustrated in Fig. 13-3. Shown are a tape resist, an ink resist, and a negative such as might be used with the photographic process. Regardless of the type of resist used, essentially the same step-by-step process is followed in making up a complete printed circuit assembly. The important steps are as follows:

(1) Initial circuit *layout* to scale.
(2) *Preparation* of the copper-clad laminate board.

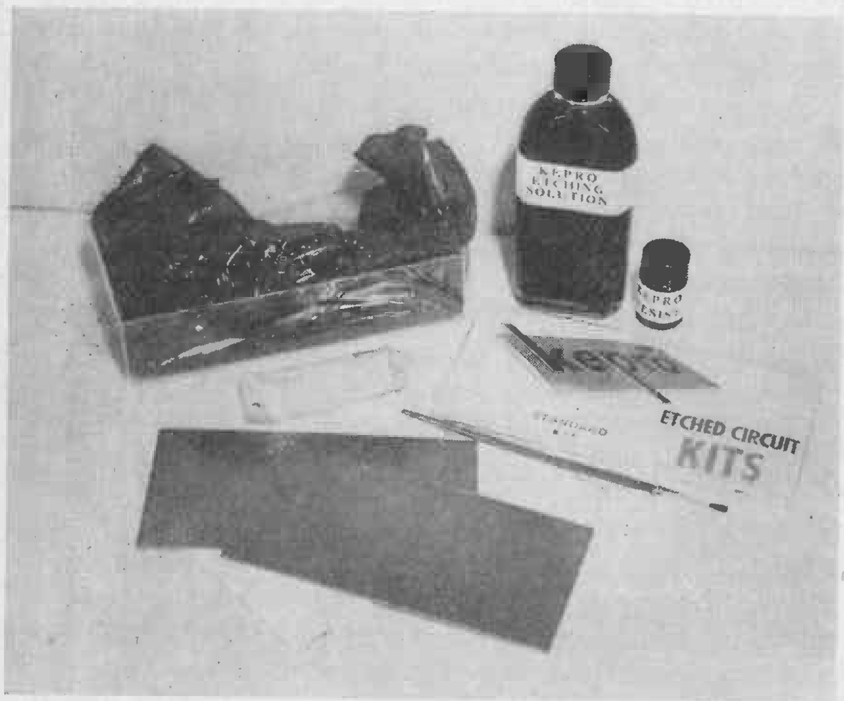


Fig. 13-1.—A KEPRO Etched Circuit Kit. The kit includes copper laminate, ink resist, etching solution, steel wool, an etching tray, a small brush, and full instructions.

(3) *Transfer* of the layout to the board as a pattern of resist.
(4) *Etching* the laminate.
(5) *Removing* the resist.
(6) *Machining* the board.
(7) *Final assembly.*

Let us discuss each of these steps in turn.

(1) *Initial layout:* Before work on the circuit board itself can be started, a scale layout of the desired circuit must be prepared. The layout shows the location of all components and the position of all conductors on the final board. If tape or ink resists are to be used, the layout may be full-sized. If a photographic process is to be used, it is customary to make the initial layout *four times* full size, then to reduce to full

Fig. 13-2.—A TECHNIQUES Printed Circuit Kit. Designed for small laboratories, this kit includes copper laminate, tube sockets, ink resist, tape resist, a small drill, eyelets, and packets of etching powder, together with full instructions.

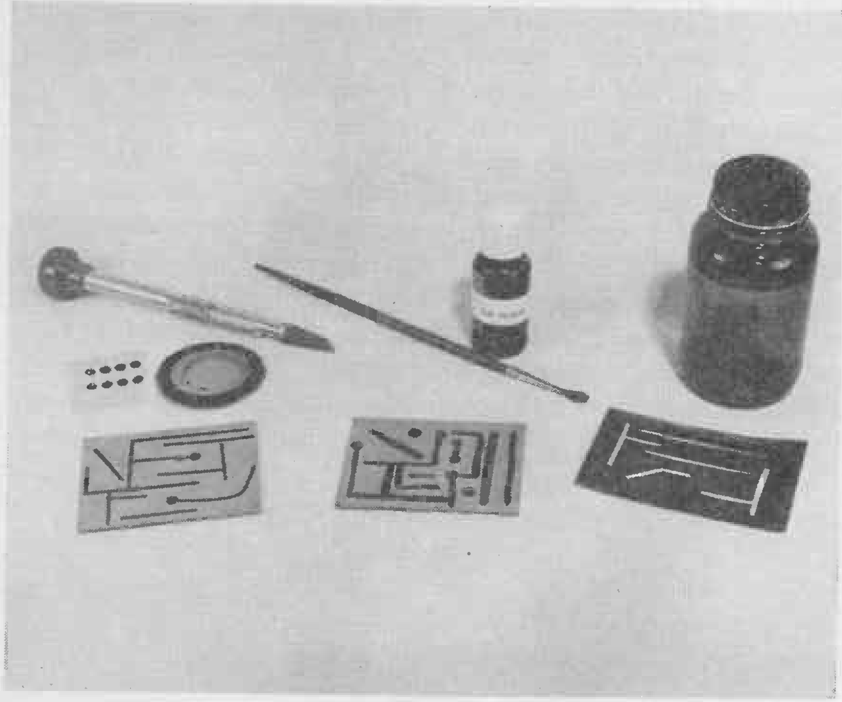


Fig. 13-3.—Three popular techniques used for making up "one-shot" etched circuits in the laboratory. Reading from left to right, the methods shown include tape resist, ink resist, and a photographic negative for a printed circuit layout.

size photographically. Such reduction of the initial layout minimizes errors and insures a finer finished job.

(2) *Board preparation:* Once the layout is completed, the overall dimensions of the final board can be determined and a piece of copper-clad laminate cut to size. A fine hacksaw, scroll saw, or jigsaw may be used for this operation. Once cut to size, the copper foil surface is carefully cleaned and washed to remove dirt and grease, then scrubbed with pumice or an abrasive household cleanser to develop a slightly roughened surface. Etching is much faster if the surface of the copper is roughened slightly. If a photographic process is to be used, the light sensitive solution is flowed evenly across the surface of the board and allowed to dry.

(3) *Transferring the layout:* If tape or ink resists are to be used, the full-scale layout is transferred to the surface of the copper foil in any manner desired by the individual worker. Many workers prefer to *trace* the layout pattern on the copper foil, using the layout drawing and stencil carbon. Others prefer to transfer the layout drawing using dividers and similar means. Regardless of the method used, once the pattern is on the board, the paths of conductors are covered with the resist, whether *Scotch* tape or acid resistant ink. The tape is simply pressed into place and burnished flat with a smooth tool. The ink may be flowed on using a pen or fine brush. If several identical boards are to be prepared, a paper or silk screen stencil of the layout may be prepared and the ink applied through the stencil. If a photographic process is to

Fig. 13-4.—After the desired layout has been transferred to the copper-clad laminate as a pattern of resist, the board is etched in an enamel or plastic tray.

be used, the prepared board is simply exposed to a strong light through the previously prepared full-size negative. A strong white or ultra-violet light is generally used. The exposure time varies with the light, but is generally on the order of several minutes. Once exposed, the board is developed. The exact development technique will depend on the chemicals used . . . follow the manufacturers' recommendations here.

(4) *Etching:* With the pattern of resist on the board, a warm solution of ferric chloride is placed in an enamel, plastic, or glass tray, and the board placed in the tray so that it is completely covered by the etchant. See Fig. 13-4. The solution is agitated during the etching process. The board may be removed from time to time for inspection. Don't allow the etchant to touch bare skin . . . use rubber gloves and tongs. When all excess copper has been etched away, wash the board in clear water. Remove all traces of etchant.

(5) *Removing the resist:* With the etching completed and the board washed, the resist must be removed. Tape resist is simply stripped off. Ink or photographic resist is removed by scrubbing with fine steel wool.

(6) *Machining:* Small holes are drilled through the board where leads are to pass through and where components are to be mounted. Special care must be taken not to crack the board. In general, it is best to drill from the copper foil side.

(7) *Final assembly:* Small brass or copper eyelets may be mounted in holes where connections are likely to be removed often. Parts are mounted simply by passing their leads through appropriate holes. Large components, such as tuning capacitors, may be held in place by small machine screws, nuts, and brackets. "One-shot" circuits are usually hand-soldered (as opposed to the *dip-soldering* technique employed in mass production). Use a small tip (1⅛") hot soldering iron and a low melting point solder (such as G-C No. 9131). Complete the soldering as quickly as possible. Too much heat will result in the copper foil separating from the insulating base. Although components may be mounted on both sides of an

etched circuit board, it is customary to mount all the components on the side opposite that of the conductors. A typical etched circuit board, seen from the "wiring" side, is shown in Fig. 13-5.

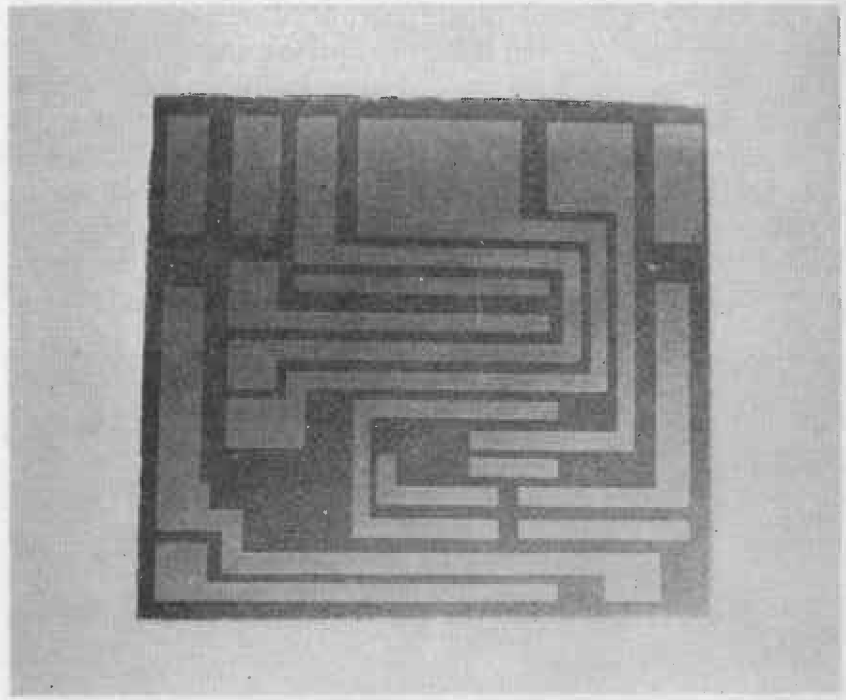


Fig. 13-5.—A typical etched circuit board.

Potting: Another technique often used with, but not confined to, transistor circuits, is that of *"potting"* a completed circuit. *Potting* is simply encapsulating a circuit or component in a plastic-like material that completely surrounds it and serves to enclose and protect it. The basic idea of potting is not new. Transformers, capacitors, electrical networks, and similar components have been potted since the early days of radio. Pitch and various hard waxes were used in the past but, more recently, various resins have been employed. Potting is most often applied to circuits or components intended for military applications or severe commercial applications where unusual environmental conditions may be encountered.

Commercial Breadboard Chassis: The use of a "breadboard" experimental chassis was discussed in *Chapter 2* (TECHNIQUES) and a hand assembled unit described and shown; see Figs. 2-4 and 2-5. An experimental transistor circuit is shown assembled on a commercially available breadboard chassis in Fig. 13-6. The chassis shown, a product of *The Electratomic Co.,* P. O. Box 827, Wheaton, Maryland, was originally designed for the assembly of printed circuit prototypes, but the author has found it to be especially well suited to testing transistor circuits. The "chassis" consists of a rectangular insulating board in which are mounted a grid-

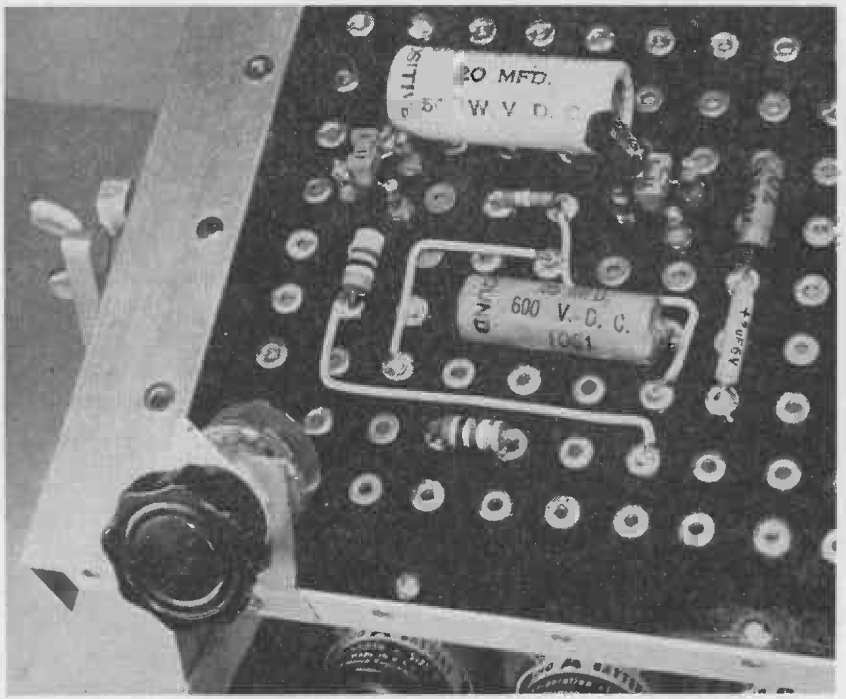


Fig. 13-6.—An experimental transistor circuit wired on a commercial "Breadboard" Chassis. Photo Courtesy The Electratomic Company, Wheaton, Md.

like arrangement of brass or copper eyelets. The board itself is universally mounted over a metal base and may be adjusted to any desired angle by means of thumb-nuts. The metal base serves to hold batteries, a power supply, or other auxiliary equipment. There is provision for mounting brackets to hold potentiometers, meters, loudspeakers, variable capacitors or similar bulky components. In use, each eyelet is filled with solder and serves as a connection point. Individual leads are connected simply by heating the appropriate eyelet with a soldering iron and inserting the lead. Assembly and disassembly of individual circuits is quite rapid. In most cases it is unnecessary to cut leads of components or to make mechanical connections.

Commercial Transistor Tester: As of this writing, most commercially available transistor test sets are fairly complex devices, intended more for a detailed study and analysis of all transistor characteristics than for a rapid evaluation of a transistor's overall quality. As experience is gained in working with transistor circuits, the worker soon comes to recognize that the values of just a few parameters are fairly indicative of a transistor's relative quality. A "good" junction transistor of a given type will have an emitter current (I_e) which is steady at fixed bias levels, will supply a minimum gain (the actual value of which depends on the type of transistor) for a given set of operating conditions, and will have a low saturation current (I_{co}). If I_e is unsteady, if the gain *(beta)* is unusually low, or if I_{co} is high, the transistor may be considered defective. Of the various transistor test sets that are currently available, the only instrument with which the author is familiar that will quickly determine all three of these essential values is the transistor tester shown in use in Fig. 13-7. The instrument shown is a Junction Transistor Analyzer manufactured by *Quantum Electronics, Inc.,* 1921 Virginia St., NE, Albuquerque, N. M. Using this instrument, the author found it was possible to check triode junction transistors as quickly as vacuum tubes could be checked using

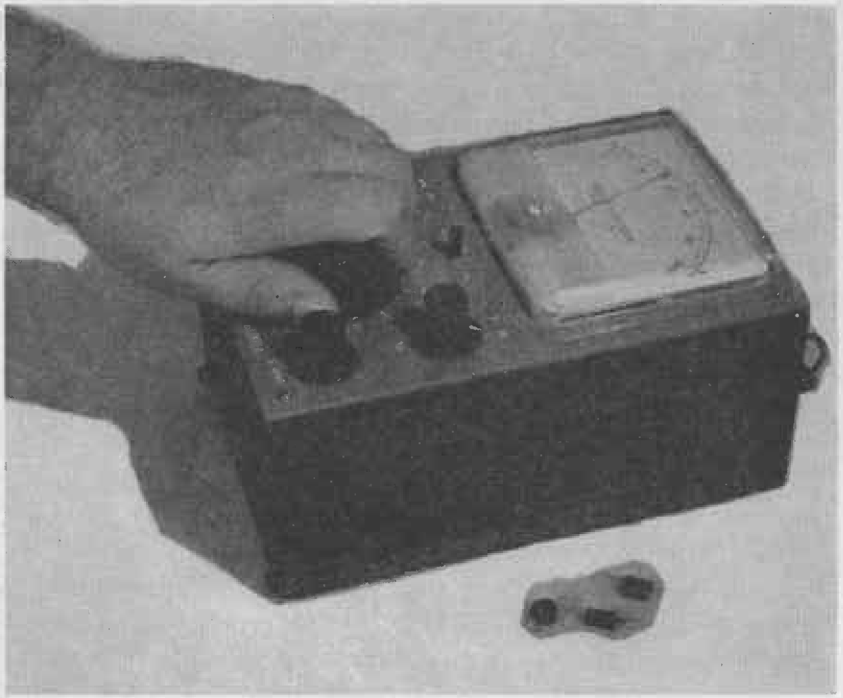


Fig. 13-7.—Using a QUANTUM Junction Transistor Analyzer to check transistors.

a "service" type emission tube tester. The *Quantum* transistor tester is, itself, transistorized and completely self-contained, with its own built-in power supply. It includes a built-in oscillator supplying an A.C. signal for checking *beta* as well as appropriate switches and controls for establishing I_e and for checking I_{co}. It handles both *NPN* and *PNP* junction transistors. Self-calibration is provided to compensate for long term drift and unusual ambient temperature conditions.

In operation, only five switches or controls are adjusted. One switch is set for the type of transistor being tested *(NPN* or *PNP),* another for the measurement desired (I_e, *beta,* or I_{co}), and another for the *beta* range to be used. *Betas* of 0-50 or 0-100 may be measured. One control is used for initial calibration for any given set of tests and another is used to set I_e to a fixed level for *beta* measurements.

SECTION B: New Developments

The Melt-Back Process: A new method of transistor manufacture developed by *General Electric* in which wire-shaped crystals rather than sliced semiconductor ingots are used. Because of the small size of the crystals, the melted semiconductor material cools rapidly and there is less intermixing or contamination between adjacent semiconductor layers. The process may be used to produce semiconductor crystals in which the layer of impurities is as thin as 1/5000″. The transistors produced by this process have extremely high gains and are usable at frequencies much higher than transistors produced using older processes. As of this writing, transistors made by the new process are not available on the commercial market.

Zone Melter: A device developed by the *Bureau of Standards* to obtain high-purity semiconductor materials. In operation, the solid material to be purified is placed in a fused slicia or carbon *boat* within a glass tube. A water-cooled induction coil, coaxial with the tube, is passed slowly along the length of the tube. The semiconductor is rapidly heated to melting point by eddy currents induced by the R.F. energy flowing through the inductance coil. This melting takes place only in a narrow *zone,* however, which is within the direct influence of the coil. As the coil moves along, the molten zone moves along with it. Impurities tend to separate at the zone boundaries, so after the material has been melted a number of times, impurities tend to concentrate at one end of the bar . . . which may then be cut off.

Diffusion Techniques: Relatively new methods used in the manufacture of high frequency, low to medium power transistors. Three procedures for manufacturing transistors by diffusion are in current use. The *diffused-base* and *double-diffusion* techniques were developed by *Bell Telephone Laboratories,* the *grown-diffused* method by *Texas Instruments.* All three techniques are based on the solid-state diffusion of impurity atoms through semiconductor material under precisely controlled conditions involving the accurate control of temperature, chemical purities, and other factors.

In the *diffused-base* method, small bars of one type of semiconductor material are cut, lapped, polished, and given a slight etch. These bars eventually serve as the collector layer. Where *PNP* transistors are to be made, the bars might be cut from P-type germanium. After washing, the bars are placed in an oven where a small amount of impurity is diffused onto the surface to form a thin base layer. Again, to make a *PNP* transistor, arsenic-doped germanium could be used as a source of N-type impurity. Next, a thin film of metal (aluminum in the example) is evaporated onto a small masked area, then alloyed to the bar with heat, forming the emitter area. As a final step, the bar may be masked again and additional metallic deposits made for electrode connections. *Diffused-base* techniques have been used to make germanium transistors with an alpha-cutoff frequency of 400-600 Mc and a collector dissipation of 150 milliwatts.

Double-diffused transistors may be made in any of several ways, but one common technique relies on differences in the diffusion rates of various semiconductor impurities. In practice, selected *donor* and *acceptor* impurities may be diffused simultaneously into a prepared bar of, say, N-type semiconductor, which eventually serves as the collector. One impurity diffuses faster into the semiconductor, getting ahead of the other, and forming a base layer of opposite characteristics. For example, a N-type semiconductor bar may be used, together with a fast-diffusing acceptor and a slow-diffusing donor impurities. The acceptor impurity, diffusing faster than the donor, gets ahead of it and forms an intermediate P-type layer between the inner and outer N-type layers, resulting in a *NPN* transistor. After diffusion, the semiconductor bar is *completely* covered with diffused N-type and P-type layers, with the central bar forming the collector, the intermediate layer the base, and the outer layer the emitter. Final base contact is made by alloying directly through the outer emitter area. Connection to the central collector is made by masking the unit and etch-

ing away the unwanted layers in a limited area. The *double-diffusion* technique has been used to make silicon transistors with alpha-cutoff frequencies of 100-120 Mc and collector dissipations of 500 milliwatts.

The *grown-diffused* method developed by *Texas Instruments* utilizes solid-state diffusion techniques while the crystal is being grown, resulting in an ultra-thin base region. Silicon transistors produced with this technique give good gains up to 30Mc, or more, while maintaining useful power outputs to temperatures of 150°C. Germanium units have been produced with cutoff frequencies of 200 Mc, and collector dissipation ratings of 25 milliwatts at 75°C.

Prior to the application of diffusion techniques to the production of transistors, similar methods were used to produce high power semiconductor rectifiers with extremely high efficiencies. As an example, two pea-sized units mounted on a cooling fin are able to furnish better than 20 amperes at 100 volts, with only 20 watts lost in heat dissipation. It would appear that similar techniques might one day result in truly "high-power" transistors.

Special Purpose Transistors: A number of specialized transistors and related semiconductor devices have been designed and manufactured, both in the laboratory and in pilot plant quantities. These units are different from the usual "special transistors", such as junction tetrodes, R.F. units, low-noise adio transistors, sub-miniature units, and "hi-power" transistors, both in construction and in application. Among the types that have been made are the *Field-Effect transistor,* the *Tandem transistor,* the *"Thyratron" transistor,* and the *Double-based diode.* It is expected that other special units will be developed by manufacturers and offered in the future.

The *Field-Effect transistor* is a unipolar semiconductor device which differs from junction transistors in that current flow is predominantly by one type of carrier (electrons or "holes") and that this current flow is caused by field drift rather than slow diffusion, a relatively high electric field intensity (voltage) being employed between electrodes. This unit features a high input and high output impedance, and has moderately good frequency response. Pilot plant units have been used as oscillators up to 10 or 12 Mc.

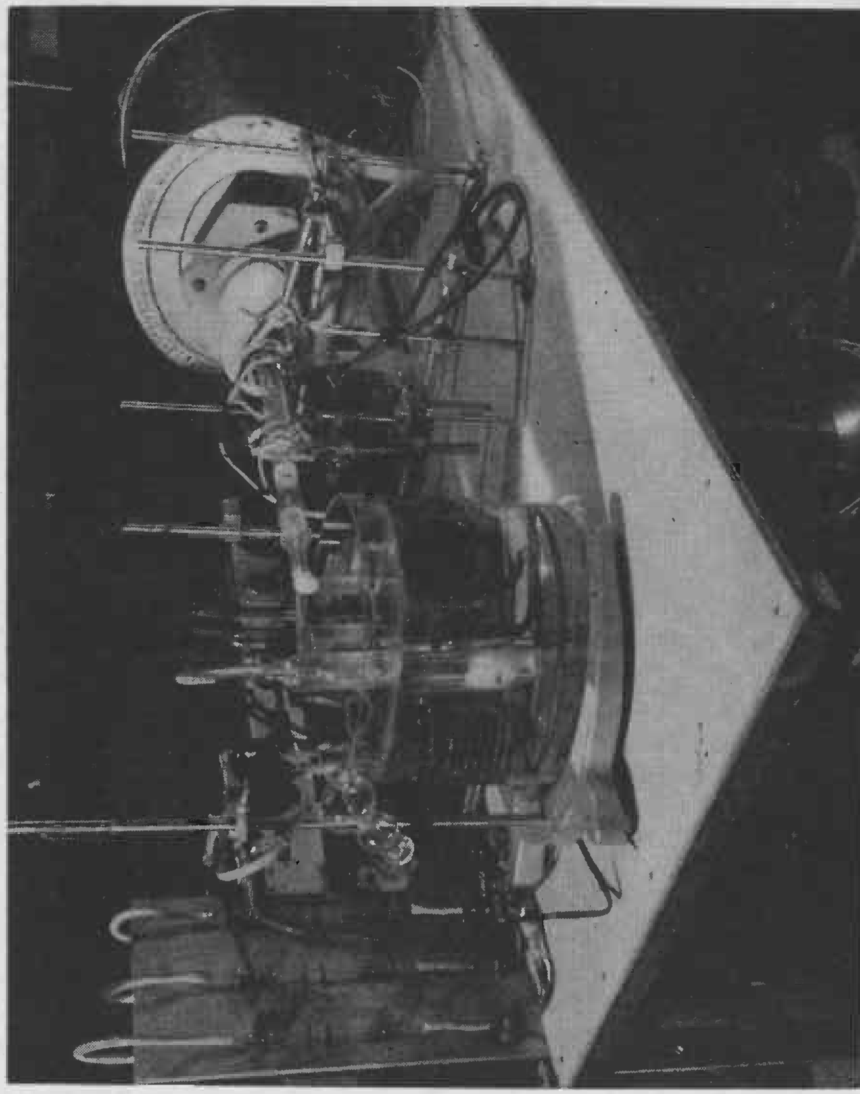
The *Tandem transistor* is essentially two junction triode transistors in a single housing, with a direct internal connection between the emitter of one transistor and the base of the second unit. It is roughly analogous to a "multi-purpose" vacuum tube which consists of two separate tubes in a single envelope. In operation, the unit acts like a *grounded-collector* amplifier stage direct-coupled to a *grounded-emitter* stage. The first unit serves as the "base leak" of the second stage. It is used as a self-contained cascade amplifier and features high input as well as good output impedances. In addition, varying the input base bias current varies the gain considerably, permitting the unit to be used as a variable gain device . . . roughly similar to a variable *mu* vacuum tube. *MARVELCO* introduced these units.

The *"Thyratron" transistor,* developed by *IBM,* and produced in experimental quantities, is a unique unit with a *junction emitter* and *point-contact collector.* It has the "all or nothing" characteristic which is analogous to a thyratron thermionic tube and, for this reason, is named after the earlier device. In operation, in the *grounded-emitter* configuration, a small base current will keep the collector load current low. If the base current is removed, however, the emitter-collector impedance drops and a high load current can flow . . . the transistor is "on". To turn the unit "off", the base current must be returned and the collector voltage dropped to a low value. Since the semiconductor material used (germanium) is sensitive to light, the unit can also be switched with a light signal.

The *Double-based diode* provides an action very similar to that of a *"thyratron"* transistor, in that it may be used as a switching device with an "off" and an "on" state. The basic unit consists of a rectifying junction made to a bar, the ends of which are terminated in ohmic connections. It is called a *double-based diode* because it is similar in construction to an ordinary crystal diode having two bases and, in fact, if the two

connections are tied together electrically, the unit will operate as a conventional diode. The *double-based diode* is thus similar to a *junction tetrode transistor,* but without the collector electrode and connection. Under some operating conditions the *double-based diode* exhibits a negative-resistance input characteristic, permitting its use in astable, monostable, and bistable multivibrators, as well as in counters, oscillators, and phase detectors, in addition to its basic switch operation. Pilot production of *double-based diodes* has been started by *General Electric* but, as of this writing, test samples were not available for circuit investigation.

The author hopes to include circuits for many of these special purpose semiconductor devices in future additions of the TRANSISTOR CIRCUIT HANDBOOK . . . as well as circuits for other, as yet undeveloped, units. Among the possible future devices could be a *"complementary-symmetry" tandem transistor* . . . essentially a cascaded NPN-PNP transistor pair in a single hermetically sealed container, with the collector of one direct-coupled, internally, to the base of the second unit. Still another possibility would be a *push-pull complementary-symmetry tandem transistor* . . . again, a NPN-PNP pair, but with matched characteristics and with the collector electrodes direct-coupled internally . . . a type of self-contained single-ended push-pull amplifier.



Credit: Bell Telephone Laboratories

Apparatus used at Bell Telephone Laboratories to control, automatically, diffusion process used in making new high frequency transistors. Panel at left controls flow of chemical impurities and gas through the tubes coiled in tank of water in center. From tubes, impurities are introduced into oven at the right, where, under gas and at carefully regulated temperatures, they are diffused into material. An attendant can easily check the progress of the diffusion process.

PART IV—REFERENCE DATA

Chapter 14
BIBLIOGRAPHY

Published transistor literature is running a course similar to that followed by literature in any new technical field. Starting as a small trickle, it has progressed to a veritable flood and now covers the gamut of literary effort . . . from popular accounts to the most profound technical papers. A complete and comprehensive listing of all transistor literature would require more space than can be allotted to the subject in this volume. Therefore, the author has had to exercise considerable discretion in choosing items to be listed. The selection of any article, book or paper over some other does not imply it is in any way superior to an unlisted work. In many cases, the author's guiding rule has been availability. Unfortunately, some of the most valuable published works have had a limited distribution. For the convenience of the reader, the author has subdivided the Bibliography into types of publications, with separate listings of books, trade publications, magazine articles, and similar topics. The section on *Magazine Articles* and *Technical Papers* has been further subdivided into subject coverage. In each section, the works are listed in numerical order. This listing is sometimes arbitrary and sometimes chronological. In no case is the listing order intended to indicate the relative importance of the individual works.

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33. TRANSISTORIZED WRIST-RADIO, *U. S. Department of Commerce, Office of Technical Services*, Washington 25, D. C. (No. PB 111461, 25c).
34. BUILD THIS TRANSISTOR RECEIVER, *R. K. Dixon*, Pgs. 35-37, 132, Radio & Television News, February, 1953.
35. POCKET RADIO, *H. G. McEntee*, Pgs. 205-207, 264, Popular Science Monthly, September, 1954.
36. TRANSISTOR PORTABLE GETS ALL THE STATIONS, *H. G. McEntee*, Pgs. 209-214, Popular Science Monthly, September, 1955.
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TRANSMITTERS AND HAM GEAR:

40. SOLARIZED QSO, *E. Laird Campbell*, Pgs. 11, 110, CQ, September, 1955.

41. A TRANSISTORIZED AUDIO FILTER FOR AMATEUR RECEPTION, *Raytheon Mfg. Co.*, 55 Chapel Street, Newton 58, Massachusetts.

42. TRANSISTOR FREQUENCY STANDARD, *P. G. Sulzer*, Pgs. 206, 208, 210, 212, 214, Electronics, May, 1953.

43. A NEW, SENSITIZED GRID-DIP ADAPTOR, Pgs. 3-7, C-D Capacitor, August, 1955.

44. SENSITIVE TRANSISTORIZED FIELD STRENGTH METER, *Aerovox Research Worker*, Part I, July, 1955; Part II, August, 1955.

TEST INSTRUMENTS:

45. TRANSISTOR POWER SUPPLY FOR GEIGER COUNTERS, *A. R. Pearlman*, Pgs. 144, 145, Electronics, August, 1954.

46. VEST-POCKET TRANSISTOR ALPHA METER, *B. P. Kerfoot*, Pgs. 216, 218, 220, 222, 224, Electronics, December, 1953.

47. TRANSISTORIZED VOLTMETER, *R. P. Turner*, Pgs. 54-55, Radio-Electronics, December, 1954.

48. A TRANSISTOR OPERATED LIGHT METER, *L. E. Garner, Jr.*, Pgs. 93-96, Popular Electronics, March, 1955.

49. TRANSISTORIZED SINE-WAVE GENERATOR, *L. E. Garner, Jr.*, Pgs. 43-45, Popular Electronics, September, 1955.

50. A number of transistorized test instruments are described in *Raytheon's* TRANSISTOR APPLICATIONS book . . . see item No. 3 under BOOKS AND BOOKLETS in this Bibliography.

PATENTS

The U. S. Patents listed below represent only a fraction of the total number of patents issued covering transistors and transistor circuits. These were chosen because they have been referred to or reviewed in trade literature and, therefore, may be considered to be of more than casual interest. In order to conserve space, only the last names of the inventors have been given. The titles listed may not be the "official" title in every case . . . liberties have been taken in a few instances to provide a more descriptive listing. In most cases, the firms to which the patents are assigned are shown in parentheses in abbreviated form. "RCA" refers to the Radio Corporation of America; "BTL" to the Bell Telephone Laboratories, Inc. The "basic" transistor patent is generally considered to be U.S. Pat. No. 2,524,035 (BTL).

1. FILAMENT TYPE TRANSISTOR, No. 2,502,479, *Pearson and Shockley* (BTL).

2. N-P JUNCTION TRANSISTOR, No. 2,502,488, *Shockley* (BTL).

3. TRANSISTOR HAVING HIGH IMPEDANCE INPUT, No. 2,524,033, *Bardeen* (BTL).

4. FIELD CONTROLLED TRANSISTOR, No. 2,524,034, *Brattain and Gibney* (BTL).

5. TRANSISTOR MICROPHONE, No. 2,549,550, *Shockley* (BTL).

6. JUNCTION TRANSISTOR, No. 2,569,347, *Shockley* (BTL).

7. MAKING SEMICONDUCTOR DEVICES, No. 2,629,672, *Oliver* (BTL).

8. LINE CONTACT TRANSISTOR, No. 2,580,027, *Johnson* (RCA).

9. SEMICONDUCTOR TRANSLATING DEVICE, No. 2,651,831, *Bond, Sparks, Teal* (BTL).

10. TRANSISTOR AMPLIFIER CIRCUITS, No. 2,652,460, *Wallace* (BTL).

11. ELECTRIC SEMICONDUCTOR, No. 2,653,374, *Matthews and White* (International Standard Electric Company of New York).

12. MAKING SEMICONDUCTOR DEVICES, No. 2,654,059, *Sparks* (BTL).

13. SEMICONDUCTOR SIGNAL TRANSLATING DEVICE, No. 2,655,610, *Ebbers* (BTL).

14. FOUR-ELECTRODE TRANSISTOR MODULATOR, No. 2,657,360, *Wallace* (BTL).

15. INVERTED GROUNDED EMITTER TRANSISTOR AMPLIFIER, No. 2,659,773, *Barney* (BTL).

16. BIDIRECTIONAL TRANSISTOR AMPLIFIER, No. 2,659,774, *Barney* (BTL).

17. TWO-WAY TRANSISTOR ELECTRICAL TRANSMISSION SYSTEM, No. 2,662,122, *Ryder* (BTL).

18. TRANSISTOR "FOLLOWER," No. 2,663,796, *Raisbeck and Wallace* (BTL).

19. FREQUENCY CONTROLLED TRANSISTOR OSCILLATOR, No. 2,663,800, *Herzog* (RCA).

20. SEMICONDUCTOR SIGNAL TRANSLATING DEVICES, No. 2,663,806, *Shockley* (BTL).

21. TRANSISTOR SIGNALING, No. 2,666,812, *Kircher* (BTL).

22. TRANSDUCER, No. 2,666,861, *Campbell* (Reed Research, Inc.).

23. REGENERATIVE TRANSISTOR AMPLIFIER, No. 2,670,445, *Felker* (BTL).

24. SEMICONDUCTOR TRANSLATING DEVICE, No. 2,672,523, *Shockley* (BTL).
25. TWO-TERMINAL SINE WAVE OSCILLATOR, No. 2,675,474, *Eberhard* (RCA).
26. TRANSISTOR BIAS CIRCUIT, No. 2,680,160, *Yaeger* (BTL).
27. TRANSISTOR OSCILLATOR, No. 2,681,996, *Wallace* (BTL).
28. SEMICONDUCTOR CURRENT CONTROL DEVICE, No. 2,689,930, *Hall* (General Electric Co.).
29. TRANSISTOR SYSTEM FOR TRANSLATING SIGNALS IN TWO DIRECTIONS, No. 2,691,073, *Lowman* (Hazeltine Research, Inc.).
30. TRANSISTOR AMPLIFIER FOR LOW DISTORTION, No. 2,691,077, *Koros* (RCA).
31. OSCILLATION GENERATOR, No. 2,692,337, *Hanson* (BTL).
32. PUSH-PULL SINE-WAVE OSCILLATOR, No. 2,698,386, *Eberhard and Endres* (RCA).
33. SEMICONDUCTOR FREQUENCY CONVERTER, No. 2,701,-302, *Giacoletto* (RCA).
34. SEMICONDUCTOR OSCILLATION GENERATOR, No. 2,701,309, *Barney* (BTL).
35. TRANSISTOR MODULATION SYSTEM, No. 2,702,316, *Friend* (RCA).
36. VARIABLE PROFILE TRANSISTORS, No. 2,702,361, *Seiler and Fedotowski* (International Standard Electric Corporation).
37. PN JUNCTION TRANSISTOR, No. 2,705,767, *Hall* (General Electric Co.).
38. COAXIAL TRANSISTORS, No. 2,707,310, *Conrad* (Stromberg-Carlson Co.).
39. TRANSISTOR MULTIVIBRATOR, No. 2,707,752, *Gabler* (North American Aviation, Inc.)
40. TRANSISTOR TRIGGER CIRCUIT, No. 2,708,720, *Anderson* (BTL).
41. CONSTANT VOLTAGE SEMICONDUCTOR DEVICE, No. 2,709,780, *Kircher* (BTL).
42. HETERODYNE CONVERTER, No. 2,713,117, *Haegele* (Sylvania Electric Products, Inc.
43. SELF-POWERED SEMICONDUCTOR DEVICES, No. 2,713,644, *Rappaport* (RCA).

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