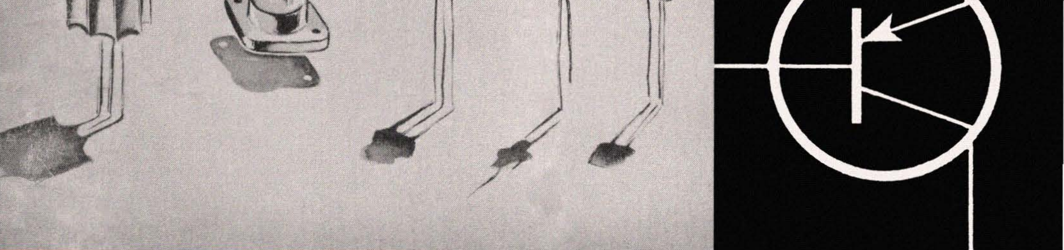
an ALLIED publication

understanding transistors

and how to use them



ALLIED HANDBOOK OF TRANSISTOR FUNDAMENTALS

UNDERSTANDING TRANSISTORS

AND HOW TO USE THEM

Allied's Handbook of Transistor Fundamentals

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UNDERSTANDING TRANSISTORS
and How to Use Them

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PREFACE

Almost everyone is aware that transistors exert a major influence in the field of electronics, but few are truly aware of the "inner workings" of this amazing device. Fortunately, with the simplest of parts and techniques, a considerable number of interesting transistor circuits can be built and understood at home, on a tabletop.

This book is intended for anyone with an interest in the fascinating hobby of electronics. Not only will it provide you with a step-by-step introduction to the transistor theory necessary for an understanding of transistor circuitry, but it shows you how to bring this knowledge to life with a series of experimental and practical projects.

Once you have mastered the "building blocks" in this book you can try your hand at creating original circuits. As innumerable experimenters have already discovered, understanding and using transistors is an engaging hobby—or possibly the beginning of a life-long career in the field of electronics.

Allied Radio Corp.

August, 1962

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CHAPTER 1

WHAT IS A TRANSISTOR?

The development of the transistor in 1948 is destined to be one of the great achievements of 20th Century electronics. The discovery of the triode vacuum tube by Dr. Lee de Forest in 1906 is usually considered as man's first significant advance into the field of communications. The development of the transistor, then, must certainly be heralded as man's second most important step. For here, surely, is as radical a departure from what has heretofore been done as the discovery of the triode.

Examine a transistor closely and you can discover some notable features solely from outward appearances (Fig. 1-1). Most striking is its small size. Conventional vacuum tubes, which the transistor often replaces, are several hundred times larger. If compared on a weight basis, the transistor is far lighter by a factor of approximately 100. Notice the external simplicity, too. The transistor generally has three or more wires emerging from a metal case. In operation, chances are the transistor will be quite cool to the touch. Furthermore, no special vacuum-enclosing envelope is required.

It is upon internal examination that the transistor really exposes the source of its great value. This is not to say that cutting a transistor open reveals the nature of its operation. To the eye, the inside structure consists of a tiny deposit of solid matter to which the outgoing wires are attached. How the transistor achieves its unique operating characteristics is best understood by exploring the nature of this material and how it affects the flow of invisible particles of electrical current.

As the principles unfold, it is extremely helpful to keep in mind the basic reason for placing the transistor in almost any circuit. It helps prevent a common misconception which prevails among some beginning experimenters—that the transistor, in some way, is a *producer* of electrical current. Rather than serving as a generator, the transistor more accurately acts as a current controller. In the greatest number of applications, a small signal is fed into one section; depending on its magnitude and polarity, the transistor draws current from some electrical reservoir (like a battery) to provide the "boosting" power.

Some readers will immediately recognize this concept as amplification, and indeed it is. This is the transistor's most useful task, and a single example points up its worth. Radio waves, which are essentially weak electrical signals, are boosted many thousand times by a receiver before they ultimately provide the power necessary to operate a loudspeaker.

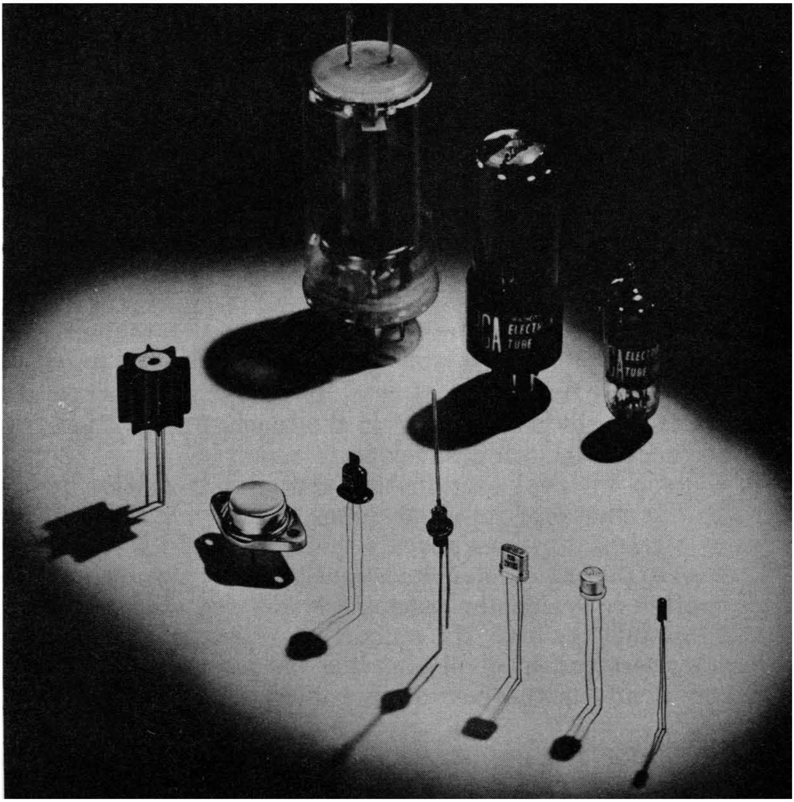


Fig. 1-1. Comparison of transistors and vacuum tubes.

It is this ability to control large current flow on the basis of small input signals that equips the transistor for amplification —and a myriad of other jobs.

How effectively does the transistor fulfill its role? The earlier comparison with the tube was primarily a physical one, but electrical characteristics are perhaps even more significant. The transistor requires a small fraction of the power needed by a vacuum tube to perform a similar function, primarily because a transistor does not need a heater, or filament, whereas a vacuum tube does. For the design engineer this means significant advantages where low-power consumption is important (a space vehicle is one example). The hobbyist also reaps distinct benefits. He can build a variety of small, portable devices that do not need the frequent battery replacement common to tube-operated units. Added to this is the simplicity of the power source. Most often, a single low-voltage battery can serve as the complete power supply.

In effect, the transistor has greatly simplified the whole approach to home experimentation.

THE ELECTRON

Insight into concepts which underlie the transistor's operation best begin by considering the *electron.* It is an invisible particle of electricity found in every known substance. Pinpointing the location of an electron is impossible, but we can illustrate the relation between the electron and nucleus as shown in Fig. 1-2. The electrons circle the *nucleus,* or center portion of the atom. While we are unable to actually view this sub-microsopic structure, the diagram is useful in explaining the behavior of the electron under various conditions. Note that the electron is labeled with a minus (–) sign, indicating the type of electrical charge it bears. Within the nucleus is an-

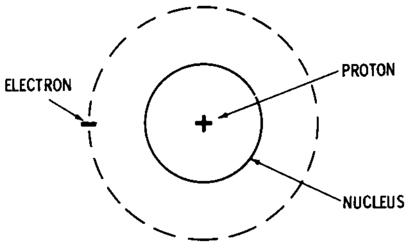


Fig. 1-2. An atom.

other charged particle; the *protron,* marked with a positive sign to indicate a charge opposite to that of the electron. Other particles reside within the atom, but they are not significant here since the interaction occurs between electrons and protons.

The key to understanding the transistor (and the broader field of electronics) is the relationship between the negative electron and positive proton. This relationship is based on the following factors:

> Particles with unlike charges attract each other. Thus, there is a mutual attraction between the electron (–) and proton (+).
>
> Similarly charged particles (two electrons, for example) repel each other.

These factors lead to another relationship which has to do with the movement of the particles. As suggested by Fig. 1-2, electrons circle the atom's nucleus like planets orbiting about the sun. The electron is a light, mobile particle. Protons are nearly 2,000 times heavier. Although a great weight difference exists, the respective electrical charges of the proton and electron remain equal and opposite. However, the weight difference does account for the manner in which electrical current flows in a conventional circuit. Current consists almost entirely of lightweight electrons. The heaviness of the proton and its fixed position within the atom's nucleus tends to keep it stationary. With this picture of the atom, we can probe further into the nature of an electrical current—especially in germanium, the most commonly used element in the production of transistors.

CONDUCTORS AND INSULATORS

The ability of any substance to serve as a pathway for current flow is governed by the distribution of electrons around the atom's nucleus. Although a single electron was shown in the simplified example, atoms of different elements have a number of electron rings. In each case the number of electrons is exactly balanced by a corresponding number of protons in the nucleus. However, it is possible to "dislodge" those electrons which lie in an atom's outermost ring. These are termed *valence* electrons. Their distance from the nucleus makes it possible to subject them to outside forces which can move them out of orbit.

A peculiarity of valence electrons relates to the basic structure of electron rings surrounding the nucleus. No matter how many electrons are contained in a given atom, electron rings attempt to arrange themselves into a specific, stable pattern as shown for five elements in Table 1-1.

TABLE 1-1. ELECTRON DISTRIBUTION

Element	Energy levels						
	K	L	M	N	O	P	Q
OXYGEN	2	6					
ARSENIC	2	8	18	5			
INDIUM	2	8	18	18	3		
XENON	2	8	18	18	8		
GOLD	2	8	18	32	18	1	

The outer or last ring (see XENON) is restricted to a maximum of eight electrons.

It is possible to determine whether a given substance will easily "release" electrons by noting the number of outer, or valence, electrons, and whether they satisfy the stable ring pattern just outlined. Consider a second ring which is nominally complete with 8 electrons. If the atom in question fills out to *less than half* that number, say 3 valence electrons, it can surrender them with relative ease. Even the moderate thermal effects of room temperature impart enough energy to release these electrons and permit them to drift outside the bounds of the atom. They are then known as *free* electrons. Since they are readily available for comprising a current flow, the substance is classified as a *conductor*. Metals such as silver and copper are prime examples.

On the other hand, an element whose atoms have *more than half* the stable complement of electrons in an outer ring will surrender few free electrons. A tighter grip on valence electrons causes the element to be classified as a poor conductor, or *insulator*. Typical of these materials are rubber and glass.

SEMICONDUCTORS

The technology of the transistor is built around the class of substances known as *semiconductors*. It is a material whose resistance value lies somewhere between that of a good conductor and that of an insulator. The actual resistance value is highly dependent upon the purity of the semiconductor substance.

The illustration in Fig. 1-3 shows the atomic structure of germanium, a typical semiconductor material widely used in the manufacture of transistors. Notice how it conforms to the conventional ring pattern for the complement of 32 electrons. Since there are insufficient electrons to satisfy the full number (8) for an outermost ring, four valence electrons reveal the semiconductor nature of the germanium atom.

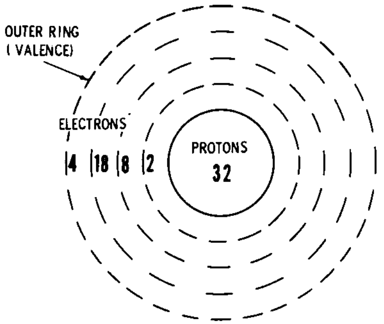


Fig. 1-3. The germanium atom.

In an effort to maintain stability, neighboring atoms of germanium form a working relationship, in which valence electrons are shared. This forms the crystalline structure of Fig. 1-4. (For simplicity, inner rings are not shown.)

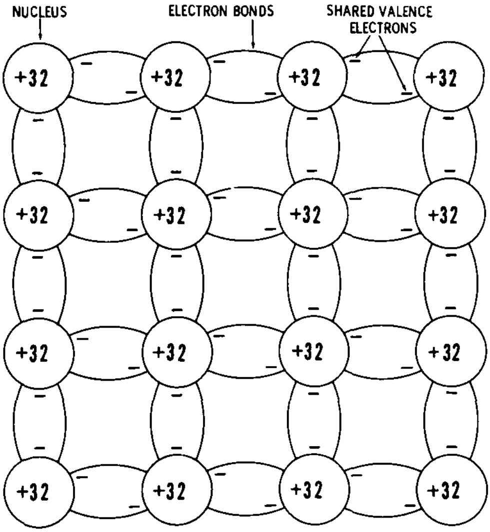


Fig. 1-4. Crystal structure formed by germanium atoms.

If an atom in the center portion of the drawing is viewed, it will be seen that each of its four valence electrons can be "borrowed" by four other atoms of germanium. On this basis, every atom receives a total of four additional electrons on a shared basis from its surrounding neighbors. This satisfies the atom's inclination to have an 8-electron ring and the whole structure achieves stability.

Electrons and Holes

Despite the balance between germanium atoms, it is possible to break the electron bonds established within the structure. This may arise from various sources. A battery, which is essentially an electron "pump" powered by chemical energy, can inject electrons into the semiconductor. The added electrons repel valence electrons contained in the germanium and a flow of current is set up. Also, heating can disturb the stability of the material. Electrons absorb thermal energy and a certain number break their bonds to drift through the crystalline structure.

But once an electron has been freed from its bonds, an unbalance immediately occurs at the point of departure. Recall the basic makeup of the atom and you will see that the nucleus contains positively-charged protons. Unless these protons are exactly balanced, or neutralized, by a similar number of electrons, the atom assumes an electrical charge. Thus, the loss of a valence electron causes a deficiency which imparts a positive charge to the atom. The site of the lost electron is termed a *hole.*

The concept of the hole, or positively charged area, has been given considerable emphasis since the emergence of the transistor in 1948. The reason is that holes are capable of apparent movement through the semiconductor material. At first, the idea of positively-charged areas in motion was thought by many to be quite unconventional, since the source of positive charges is in the relatively fixed nucleus of the atom. However, when hole movement is traced, it becomes evident that the basic concepts remain largely unchanged. This is illustrated in Fig. 1-5.

The action begins as an electron moves out of its valence ring, leaving behind a positively charged hole. It is possible that another electron, located nearby, will fill the hole under the attraction of the newly created positive area. But as the first hole is filled, a second one appears in the area just vacated by

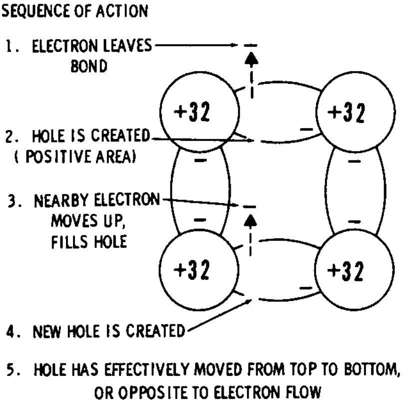


Fig. 1-5. Hole movement in germanium.

the electron. The net effect is that the hole appears to move. The phenomenon occurs repeatedly and it may be assumed that holes, in effect, drift through the germanium structure in much the same manner as free electrons.

Several conclusions may be drawn from electron and hole movement. They reappear in subsequent discussions on the operation of the transistor. First, valence electrons can be made to break their bonds and establish a flow of electrical current which is negative in nature. The creation of holes provides a current flow that is positive. Energy which powers these movements can be heat and light absorbed by the semiconductor material or, as in the majority of cases, the electrical pressures from a battery. When the voltage terminals of a battery are applied across germanium, the flow of electrons and holes ceases to become random. The positive terminal of the battery attracts negatively charged electrons—the negative battery terminal exerts an electrical pull on positively charged holes.

Thus, we have the outlines of a basic system for causing current to flow within the germanium material. Thus far, we have assumed that the substance is absolutely pure and uncontaminated. However, germanium in this form is not suitable for providing the transistor with the raw material required for its special characteristics. New elements are added to differentiate germanium into two important categories.

N-Type Germanium

By introducing traces of the element *arsenic* into a pure piece of germanium, the number of free electrons in the material rises considerably. The source of these additional electrons can be explained by the mechanism already described—the behavior of the outer ring of an atom and its valence electrons. An atom of arsenic has five valence electrons, which is one more than contained in the germanium atom. When the arsenic is within the crystal structure, individual arsenic atoms form valence bonds with neighboring germanium atoms. This is depicted in Fig. 1-6. As before, a sharing process occurs, whereby valence electrons are borrowed to satisfy the stable arrangement of an 8-electron outer ring. However, the arsenic's fifth valence electron is not tightly bonded into the crystal structure. The give-and-take between germanium and arsenic requires an exchange of only four electrons. Thus, the fifth arsenic electron is easily broken away and free to circulate at random.

Although the arsenic is considered an impurity in the germanium substance, it has the desirable effect of enriching germanium with a supply of free electrons, as indicated in Fig. 1-6. Under this condition the germanium is designated *N-type*. The "N" signifies "negative," the characteristic charge borne by the electron. Since arsenic gives up electrons in the process, it is termed a *donor impurity*.

P-Type Germanium

The second major category of germanium needed in the structure of a transistor is *P-type*. As the name implies, it

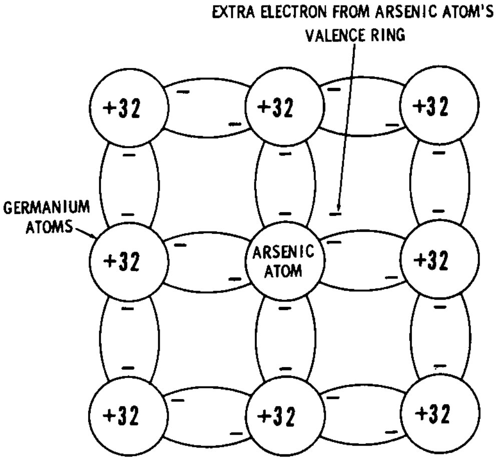


Fig. 1-6. Arsenic atom within germanium-crystal structure.

increases the number of positive charges, or holes, in the germanium. Again, an impurity is added to influence the behavior of the valence electrons in outer rings of the atoms. Unlike arsenic, which donates electrons, the impurity is selected to *extract* electrons from neighboring atoms of germanium. Thus, it is called an *acceptor* impurity. The element *indium* is commonly used for the purpose.

Fig. 1-7 diagrams the relationship set up between germanium and trace amounts of indium atoms. Taking a position within the crystalline structure, the indium atom proceeds to share its valence electrons. They are distributed among neighboring germanium atoms as the total arrangement seeks to maintain the stable 8-electron outer ring for each atom. However, the indium atom has only *three* valence electrons available to share with surrounding germanium atoms. In an effort to satisfy the bonds, which require the interplay of four valence electrons, the indium atom borrows one electron from a nearby germanium bond. This creates a hole at the borrowing point. If another electron is attracted into the newly formed hole, a second hole is created.

Thus, it may be seen that pure germanium can be processed with different types of impurities to achieve the two principle methods of semiconductor current flow—negative electrons and positive holes. The next phase, leading to the over-all structure of the transistor, is joining P- and N-type materials and observing how they interact.

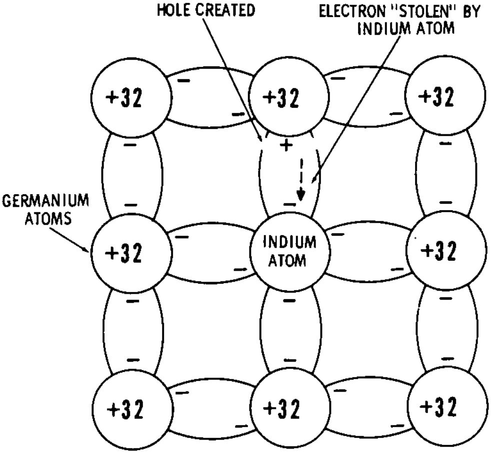


Fig. 1-7. Indium atom within germanium-crystal structure.

FORMATION OF A DIODE

The illustration in Fig. 1-8 shows one piece of P-type germanium butted against a similar-size piece of N-type germanium. This forms a *diode*, or 2-element device, which is actually a practical component presently used in many electronic devices. Although it does not perform the same function as a transistor, it is just one step away in terms of semiconductor theory. The simplicity of the diode is valuable in demonstrating the effects of the PN *junction;* the dividing line between the germanium sections is shown in Fig. 1-8.

Notice that in each section of the diode there are both positive and negative symbols. Consider first the P-type germanium at the left. Negative charges here are circled and represent acceptor atoms. Their effect is to draw electrons from neighboring germanium atoms and create holes, as shown by the positive symbol. As characterized by P-type material, holes are free to move.

The opposite arrangement occurs in the N-type material at the right. The circled positive signs mean donor atoms which have surrendered free electrons. The negative signs shown in the drawing represent those electrons which have mobility in N-type germanium.

According to the rules of like and unlike charges, it would be expected that holes and electrons attempt to join by crossing the junction. A barrier exists, however, which prevents this. It is called a *potential hill,* which can be explained in the following manner: If the electrons in the N-type germanium attempt to migrate across the junction, they encounter the repelling force of the negative acceptors on the P side. (Acceptors and donors remain relatively fixed in the crystal structure.) Similarly, holes in P-type germanium encounter opposition from the positively charged donor atoms on the N side.

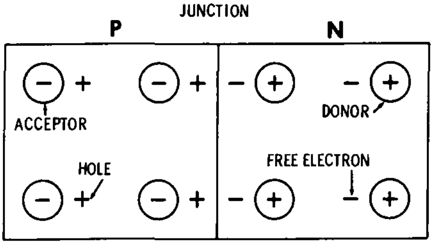


Fig. 1-8. The diode.

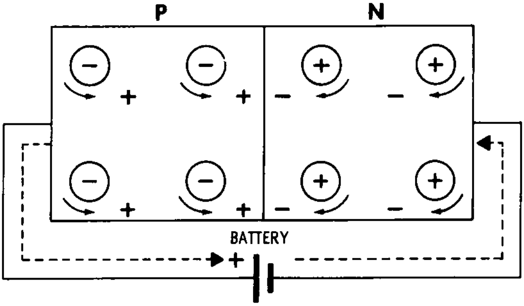


Fig. 1-9. Battery sets up continuous current flow (forward bias).

The free passage of current through the junction is possible only if an external force (e.g., a battery as in Fig. 1-9) is applied to effectively neutralize the potential hill.

The negative terminal of the battery is connected to the N-type germanium, and the positive terminal to the P-type. Again, the attraction and repulsion phenomenon takes place. The battery injects electrons into the N side and electrons contained there are repelled toward the junction. Simultaneously, the holes in the P-type are repelled by the positive connection of the battery. Sufficient energy is provided to overcome the potential hill at the junction, and current (electrons and holes) can cross it.

The process does not cease with the breaking down of the potential hill. A steady flow of electrons travels from the negative terminal of the battery, through the diode, and back into the battery's positive terminal. It is continuous because added electrons are supplied by the battery, and new holes are being created in the semiconductor material. On the P side, a hole that combines with an electron causes a valence bond near the positive battery terminal to break down and surrender an electron to the battery. This action creates a new hole which moves toward the junction.

On the other side of the diode, the N side, the battery supplies an electron for each one that has moved to the junction for combination with a hole.

Note that holes and electrons serve as the current carriers within the diode. However, holes at no time leave the semiconductor material; they can only travel within the crystalline structure of the germanium. The same is not true for electrons. They do not have the same limitation and can move

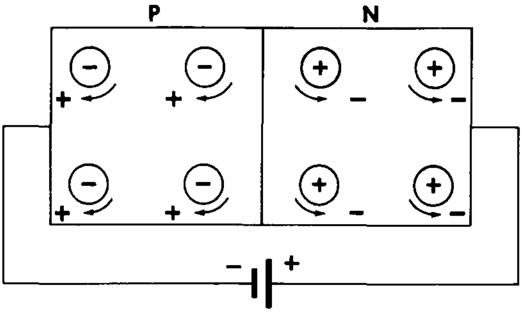


Fig. 1-10. Reverse bias removes current carriers from junction.

through other substances, like the connecting wires and the battery.

The practical application of the diode becomes apparent when the battery terminals are reversed, as shown in Fig. 1-10. An inspection of the forces exerted by the battery reveals that both holes and electrons are attracted *away* from the junction. The negative terminal attracts holes in the P side of the diode, while the positive terminal attracts electrons in the N side. The net effect is that the junction becomes stripped of current carriers, and the external electron flow cannot occur through the diode and battery. This condition is termed *reverse bias.* It creates high resistance to current flow. In the first example, where current could traverse the junction, the diode was under a *forward bias* condition. (The term bias is simply a reference to the voltage polarity of the battery.)

DIODE DEMONSTRATION

As mentioned earlier, not only are the diode's properties useful in illustrating transistor action, but it has practical applications as well. A simple experiment with an actual germanium diode will demonstrate the ability of the component to act as a *rectifier*—a device which changes alternating current (AC) to direct current (DC). In the following experiment, the concept of forward and reverse bias can be clearly demonstrated. Consult the following Parts List and pictorial drawing in Fig. 1-11 for the basic setup.

PARTS LIST

D1—1N34 germanium diode ($ .32)
B—9-volt transistor-type battery (55J650 $ .69)
R1—68-ohm ½-watt resistor (1MM000 $ .12)
M1—#47 pilot lamp (52E312 $ .15)
Misc.—2 alligator clips (45H142 $ .06 ea.); 2 battery clips (55J184 $ .69/pkg. of two); hookup wire (48T457 $ .29 for a 25 foot roll); lamp holder (52E419 $ .39)

Prices subject to change.

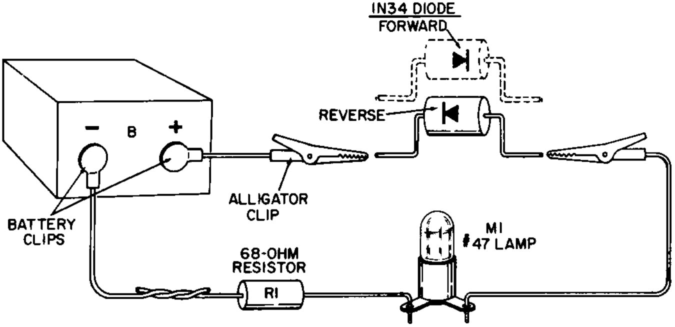
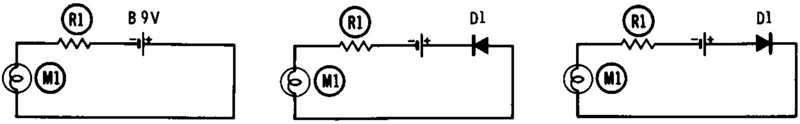


Fig. 1-11. Pictorial of diode demonstration.

The demonstration is a 3-step process, conducted according to the schematic diagrams in Fig. 1-12.

In the first step, the battery is connected to the bulb to observe its effects without the diode in the circuit. (The 68-ohm resistor is used solely to limit the battery current to a safe value for bulb and diode.) Wire the circuit as shown in Fig. 1-12A; the positive battery wire ends in an alligator clip which is connected to one terminal of the pilot lamp holder. The negative wire goes to the other terminal on the lamp holder through the 68-ohm resistor. Once the circuit is complete, the bulb should glow—not brightly, but with adequate illumination. If the battery connections are reversed, an identical glow should be perceived. This reveals that electrons, which travel from the battery's negative to positive terminal, can flow through the bulb in either direction.



(A) No diode. (B) Reverse bias (lamp dark). (C) Forward bias (lamp lights).

Fig. 1-12. Circuit connections.

The circuit is now modified according to Fig. 1-12B. By means of the alligator clips, connect the diode in series with the battery's positive terminal. Your basic setup should resemble that of pictorial Fig. 1-11. It is important to check the polarity markings on the diode; they may not be the same as shown here. A 1N34 may be marked in one of three ways: a bar and arrowhead, as shown; a single color band at one end, or a series of color bands at one end. Various means of indicating diode polarity are shown in Fig. 1-13. The bar or color-band end is the *cathode,* or negative terminal of the diode. It is the side which contains N-type germanium. The other end is the *anode,* the positive end containing P-type germanium. After circuit connections are complete, you should see no glow from the bulb. The reason is that the diode is reverse-biased by the battery. As shown earlier, the junction between P- and N-type germanium is depleted of current carriers, and the diode displays high resistance to current flow. A simple method of noting whether a diode is connected in the reverse bias manner is to observe which terminals of the battery go to the diode's anode and cathode. If the polarity signs disagree, as they do in this case, the diode is in a reverse bias condition.

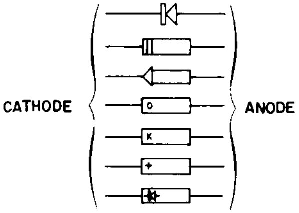


Fig. 1-13. Various means used to designate diode polarity.

The final step is in Fig. 1-12C. Unclip the diode and reverse its hookup in the circuit. The result should be a visible glow in the bulb as the diode's resistance drops and permits current to flow through the circuit. It is now in the forward bias condition. (Note that the positive anode end agrees with the positive battery terminal.) Current carriers consisting of both electrons and holes now overcome the potential hill at the junction between P- and N-type germanium.

The "one-way" effect of the diode equips it to perform as a rectifier in electronic circuits. If house current, which changes direction at the rate of 60 times per second, is applied to a power-type diode, it would change from alternating to direct current. Only portions of the applied voltage which bias the diode in the forward direction would allow current to pass through to the other side. It is a valuable function, since DC is nearly always required in the circuits of electronic devices which operate from house current.

As we have seen, the characteristics of the diode are obtained through the special behavior of semiconductor material. This serves as an excellent bridge toward understanding the transistor, as we'll see in a moment.

CHAPTER 2

TRANSISTOR ACTION

A popular notion often used in the explanation of the transistor is that the device is made of diodes placed "back-to-back." Two diodes cannot be connected to each other to attain transistor action, but there are strong similarities. Both diode and transistor utilize properties of the semiconductor and the effects of forward and reverse bias. The transistor develops its characteristics, chiefly an ability to amplify, by developing the principles found in the simpler diode. Much of the theory developed in Chapter 1 can serve as a convenient starting point.

NPN TRANSISTOR

As shown in Fig. 2-1, the construction of the first basic transistor to be considered resembles that of a sandwich. It is comprised of the same N- and P-type germanium as in the diode. However, notice that a new section has been added. The structure forms the *NPN* transistor, so-called because its germanium layers line up in that order. Another significant difference is that the transistor contains two junctions as compared with the diode's one.

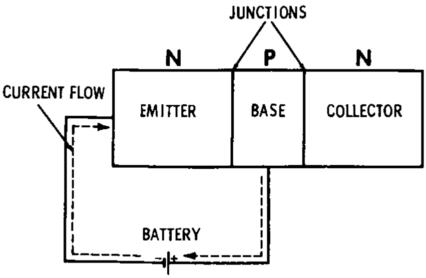


Fig. 2-1. Emitter-base bias in NPN transistor.

At the left side of the drawing, the N-type material is termed the *emitter;* the center P-section is called the *base;* and the remaining N-type germanium is known as the *collector.* The arrangement displays no significant electrical activity until an external source of energy sets holes and electrons into motion through the crystalline structure and across the junctions.

The battery supplies the motivating force. Its negative terminal is applied to the emitter, and its positive terminal to the base. Consider this, for a moment, a simple "diode" with a single junction—ignoring the collector at the right. According to the attraction and repulsion forces from the battery, will a current flow be established through the emitter-base junction? By examining polarities, we find that the diode is biased in a forward direction, so current carriers can proceed across the junction.

The other junction, between base and collector, is normally biased in the reverse direction by the battery shown in Fig. 2-2. Again inspecting the battery polarities, we find that, in this diode section, no current can flow from base to collector and through the battery. Because of the reverse bias, the junction is devoid of current carriers.

The NPN transistor in a complete, though basic, bias arrangement is shown in Fig. 2-3. Current paths adhere to the bias conditions outlined in Figs. 2-1 and 2-2—flowing from emitter to base, with negligible current from base to collector. The heart of the transistor's ability to amplify is centered on a property of the base. Notice in the illustration that it is narrower in width than either the emitter or collector. In an actual transistor, the base is fabricated from exceedingly thin germanium. The net effect is that electrons from the emitter can actually pass through the base and into the

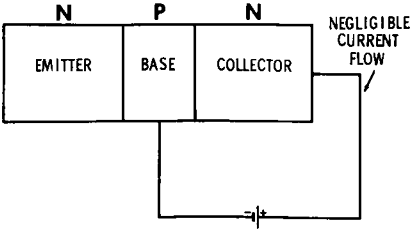


Fig. 2-2. Base-collector bias in NPN transistor.

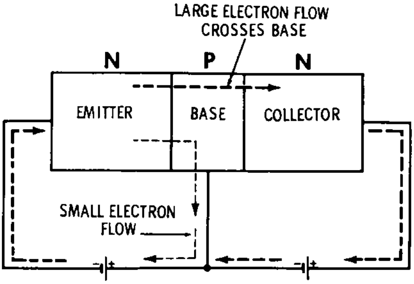


Fig. 2-3. Complete biasing in NPN transistor.

collector. The battery connections aid this passage since the collector is connected to a positive voltage source. This provides the power to attract emitter electrons.

The circulation of current between emitter and collector does not contradict the statement made earlier about reverse bias on the collector. This occurs between base and collector and does not interfere with the free flow of electrons from the emitter.

The role of the base is to exercise control over the emitter-collector flow. Due to its thin construction, few electrons have an opportunity to combine with holes in the base material, and consequently most electrons move on to the collector. However, the base does determine the number of electrons which cross the emitter-base junction. Varying the base-to-emitter bias provides the means of controlling the amount of current flow between emitter and collector.

PNP TRANSISTOR

The second major transistor classification is *PNP*. Fig. 2-4 shows the formation of the germanium sandwich. It differs from the NPN in its order of semiconductor layers—and all battery polarities are reversed. A study of the battery voltages reveals that the biasing arrangement—forward between emitter and base, reverse between base and collector—is identical to that of the NPN unit. However, the key difference between the function of the two transistor types lies in their use of current carriers. In the NPN type, these are electrons, while the PNP utilizes holes as principle carriers. Otherwise, in terms of transistor action, the two perform similar functions.

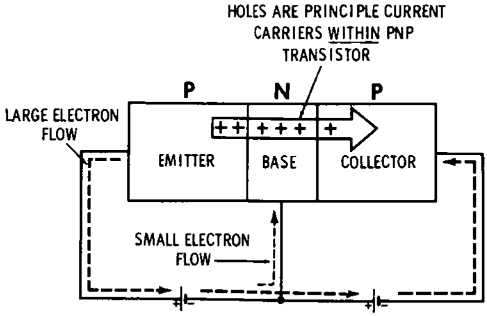


Fig. 2-4. PNP transistor.

Let's examine the migration of current carriers between emitter and base elements of the PNP transistor. The bias battery, at the lower left in Fig. 2-4, provides a positive charge which results in hole travel through the emitter toward the base-emitter junction. Similarly, electrons in the base material are repelled by the negative battery terminal toward the same point. The potential hill or barrier is lowered, and a continuing stream of electrons may flow from the negative battery terminal. However, many of the holes from the emitter fail to combine with electrons from the base (again, due to the thin base construction) and are "attracted" by the strong negative charge at the collector. Holes pouring into the collector combine with electrons from the negative battery terminal at the lower right in Fig. 2-4. Simultaneously, electrons exit from the emitter and ultimately reach the collector by traveling through the two bias batteries.

Note that holes comprise the principle current flow *within* the PNP transistor, but electrons sustain it through the batteries and other portions of the external circuit.

OTHER SEMICONDUCTOR MATERIALS

The emphasis in the preceding discussions has been on germanium as the semiconductor material from which transistors are made. Silicon, whose physical properties closely parallel those of germanium, is also employed for this purpose. Thus, silicon is a semiconductor with four valence electrons and in the solid state, it will form a cubic crystal lattice in which the various atoms are held together by the same mechanism of shared bonds. It is possible to replace some of these atoms by impurities, either the donor or acceptor variety, and form N-type or P-type silicon. By combining suitable P- and N-type sections of silicon, rectifier diodes or complete transistors can be fabricated.

Germanium and silicon have received the greatest amount of research and almost exclusively dominate the commercial transistor field, but considerable interest and investigation is being directed to other semiconductor materials. Among the most promising of the newer types are the *intermetallic compounds.* These differ chemically from such semiconductors as silicon or germanium in that they are formed with two pure elements in place of one. A germanium transistor starts with pure germanium to which is added appropriate impurities to form the required P and N regions. The same is true of silicon. In an intermetallic compound, the basic crystal structure consists of two different metallic elements such as gallium and phosphorus. Combined, they form gallium phosphide (GaP). Suitable impurities are then added to this compound to form the needed P and N regions.

In the introductory discussion on transistors, it was noted that germanium and silicon atoms each have four valence electrons in their outer or chemically active rings. The crystalline structure is then formed by having the atoms share each other's outer electrons to form bonds. In the intermetallic compounds, one of the combining elements has three valence electrons per atom. Equal numbers of the two atoms are used, and these also share each other's valence electrons to form a crystal structure. This structure exhibits many of the same properties as germanium and silicon.

A fundamental electrical property of a semiconductor is the energy needed to free an electron from the bond formed between two atoms. In silicon, more energy is required to liberate electrons. This is a major reason why silicon can be employed at higher temperatures. With intermetallic compounds, by using different combinations of three valence atoms and five valence atoms, we can achieve a very wide range of energy gaps.

The mobility of electrons and holes in semiconductors (i.e., the speed with which these particles or charges move through a crystal) can also be regulated over a fairly extensive range in intermetallic compounds. All these variations make it possible to construct transistors or semiconductor diodes having a wide choice of such properties as current or power-handling capacity, frequency range, and rectification ratio.

Some of the new compounds which are being studied extensively include gallium arsenide, gallium phosphide, indium antominide and indium arsenide. Gallium arsenide, as a semiconductor, can potentially combine the high temperature capacity of silicon (at present 150°C in practical devices) and the high frequency capabilities of germanium. Higher temperature capability will permit higher power applications and levels since the heat energy can be more effectively handled. Gallium phosphide, used in conjunction with gallium arsenide in a device, is expected to extend the upper temperature limit to above 500°C.

Indium phosphide, with an upper temperature limit of approximately 400°C, is considered as a possible "runner-up" to gallium arsenide. Indium antominide and indium arsenide are being experimentally tested in galvanomagnetic devices where frequency and temperature do not play a primary role. Such semiconductors, as opposed to use in transistor or rectifier applications, have potential application in magnetometers, magnetic compasses without moving parts, and gyrators.

Many compounds are under investigation and undoubtedly some of these will be employed commercially. At the present time, fabrication of these substances presents major problems due to difficulty in trying to purify them to the degree necessary and then forming them into suitable transistors or diodes.

TRANSISTOR SYMBOLS

While the drawings thus far conveniently illustrate the various current paths in the transistor, they have not shown standard symbols. In a schematic diagram of a PNP transistor, the symbol would appear as in Fig. 2-5. Often, the symbol will appear in the position shown; however, in many instances it may be rotated for the sake of simplifying the routing of connections to other parts of the circuit.

Note that the base element is a vertical line to which the collector and emitter sections are connected. The entire transistor is normally enclosed within a circle. Any lines outside the circumference of the circle represent the transistor's leads which, in turn, connect to other points in the circuit.

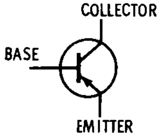


Fig. 2-5. PNP transistor symbol.

In certain transistors, namely the larger power types, there is no lead emerging from the collector; the collector connection is made internally to the metal case. When the transistor is mounted to a chassis plate, necessary contact to the collector is made with the mounting screw. Also in these types, emitter and base leads emerge as short, self-supporting wires or solder terminals. Despite large physical differences between transistors, the symbol remains basically the same.

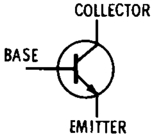


Fig. 2-6. NPN transistor symbol.

The distinguishing characteristic of the transistor symbols is the arrowhead that identifies the emitter element. This serves to indicate whether the transistor is a PNP or NPN type. When the arrow points *toward* the base, the unit is always PNP. The symbol for an NPN transistor has the arrow pointing *away* from the base (Fig. 2-6).

Lead Identification

Few transistors are stamped or printed with letters to identify their terminals. However, physical layouts are fairly well standardized, and these can be used to determine base, emitter and collector connections. The major types are given in Fig. 2-7 for future reference. These basing diagrams show the view of the transistors from the bottom of the case, where the leads emerge. When the transistor in Fig. 2-7A is held with its color dot (usually red) to the left, the terminals are arranged as shown. The transistor in Fig. 2-7B has a large space between base and collector as its identifying feature. A similar arrangement occurs in Fig. 2-7C, but a fourth lead has been added. This is the interlead shield, found in many high-frequency types. The unit in Fig. 2-7D has a

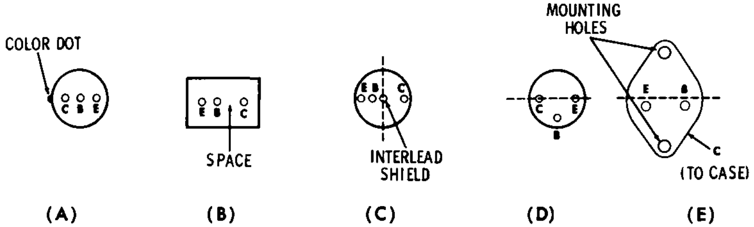


Fig. 2-7. Transistor basing diagrams, showing lead identification.

lead spacing which places the base off-center. Another typical layout is in Fig. 2-7E, commonly found in the diamond-shaped power transistor. Care should be exercised when attempting to identify emitter and base terminals, since their relative locations are not too obvious. Close inspection reveals that they lie below an imaginary center line through the diamond, represented here by a dotted line. When the component is held with the center line *above* the two protruding terminals, the emitter will be to the left, base to the right. The collector is connected internally to the case. It makes contact with the remainder of the circuit after mounting screws have been inserted into the two case holes. Unless the mounting-screw head makes contact with bare metal on the case of the transistor, some paint must be scraped away to assure good electrical connections.

Ohmmeter Check

Once the transistor terminals are properly identified, an ohmmeter is useful to observe some basic effects of forward and reverse bias. But, before proceeding, the function of the ohmmeter should be understood. The instrument reads resistance of a substance by applying a small voltage across it. If resistance is low, the applied voltage can force a relatively high amount of current through the material. The meter indicates this current on a scale calibrated in ohms. For the following tests, the instrument will bias the transistor in both directions. Thus, if forward bias occurs, much current passes and the indicated resistance is low. Since *certain transistors might be damaged by the meter,* perform these tests only on units classified as "general-purpose" audio types; the kind principally used by the hobbyist. (These include the CK722, 2N107, etc.) Further protection is assured by making all measurements with the ohmmeter set to the highest resist-

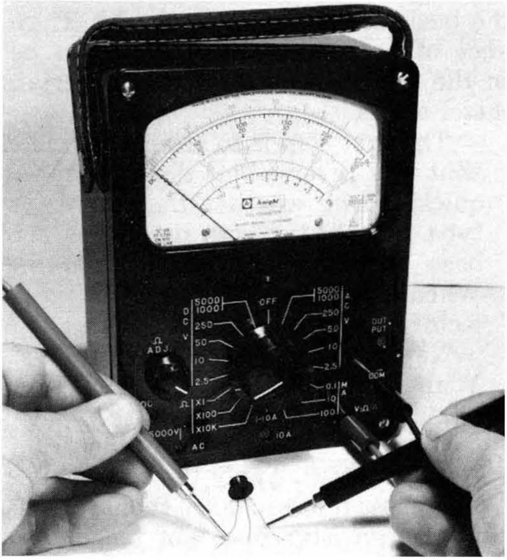


Fig. 2-8. Applying forward and reverse bias with an ohmmeter.

ance range which gives a convenient reading. (This is usually R X 10,000 or R X 100,000.)

Begin by selecting a PNP transistor and using the arrangement illustrated in Fig. 2-8. The leads of the ohmmeter will be clipped to different transistor lead combinations. (The red probe of this meter applies the negative voltage, while the black is positive.) For the first check, connect the positive probe to the collector terminal and the negative probe to the base. Note the meter reading. Now reverse meter connections; the resistance reading should be considerably higher than that obtained for the previous test.

The action of the ohmmeter on the base-collector section of the PNP transistor in the first case illustrates forward bias. Notice that all polarities agree, for both voltage and the type of semiconductor materials in base and collector. Current carriers cross the junction in large numbers and low resistance is indicated on the meter. When meter leads were reversed, the resulting reverse bias depleted current carriers at the junction and resistance was much higher.

The same test may be applied to the junction between the emitter and base. Connecting the ohmmeter in one direction will result in a low resistance reading, while a high reading will be observed when the meter probes are reversed.

A "good-bad" check on a transistor can be devised on the basis of these simple checks. They often reveal the existance of a short or open condition between elements. Begin in the following manner, being certain to use the high ohmmeter scales:

> The first step is to attach the meter leads in a direction that will reverse-bias the collector-base elements. This is quickly done whether the transistor is a PNP or NPN type. Simply try both directions across the collector and base to discover which affords the highest resistance. When you have found it, leave the meter lead to the collector in place.
>
> Next, observe the amount of resistance on the meter. With a screwdriver tip, short the emitter to base; the ohms reading should decrease.
>
> Now remove the meter lead from the base and clip it to the emitter. Apply the screwdriver tip between emitter and base; the resistance should increase.

If a transistor does not respond as described, it may be considered defective. However, weak units, or those which have leakage between elements, might respond satisfactorily. The test is basic, only intended to indicate when a transistor is completely inoperative. Better quality checks on transistors are possible with a number of testers now on the market.

HEAT DISSIPATION

Proper biasing arrangements can prevent transistor overheating resulting from excessive current, but other means must be used to dissipate heat generated during normal operation. This heat is developed at a rate which can be determined by Ohm's law for power, i.e., the power dissipated in the junction of a transistor is the product of the current (squared) through the junction times the junction resistance, or $P = I^2R$. If the heat thus generated is not removed in some way, the transistor may be destroyed. Also, the faster the heat is conducted away greater the efficiency of the transistor becomes. This is the purpose of the "heat sink."

The heat sink acts just as its name suggests—it is usually a large block or plate of metal into which heat can sink—there to be dissipated by conduction, convection, or radiation. The plate or block to be used as a heat sink should be a good heat conductor, such as aluminum. Sometimes the chassis on which the transistor is mounted is used as a heat sink.

CHAPTER 3

TRANSISTOR OPERATION

What happens inside a transistor, as described in the preceding chapters, represents only part of the information needed to place the device into a functioning, useful circuit. Transistors require proper sources of voltage to keep currents at a safe value. Output energy must be coupled into some form of load in order to appear at the correct circuit point. Other components must be chosen so power is efficiently transferred from one section of the circuit to another.

An effective way to gain insight into over-all transistor operation is the construction of a simple one-transistor amplifier. As it is adjusted, varied, and measured, the underlying transistor action may be observed. As stated earlier, this is its ability to utilize a small current flowing between base and emitter to control a much larger flow between emitter and collector. Such an amplifier and its construction details are described in this chapter. As the idea of amplification becomes clear, it is an easy matter to modify the circuit so it performs as an oscillator; an important application evolving from the transistor's inherent ability to amplify.

COMMON-EMITTER AMPLIFIER

The example chosen to demonstrate amplification represents the most widely used circuit configuration; the *common emitter*. This is shown in the schematic of Fig. 3-1. The name is derived from the fact that the emitter is common to both the input (the section of the circuit that receives a signal) and output (the area where amplified energy appears). The transistor itself is a PNP type 2N107, which is typical of the numerous general-purpose units that are popular among experimenters.

To set up a working demonstration, follow the construction details set forth in Fig. 3-2 and the following Parts List.

PARTS LIST

R1—4.7K ½-watt resistor (1MM000 $ .12)
R2—500K potentiometer with switch (30M322 $1.02)
R3—1K ½-watt resistor (1MM000 $ .12)
X1—2N107 transistor ($ .55)
B1—9-volt transistor-type battery (55J650 $ .69)
SW1—Switch for R2 (30M359 $ .60)
Misc.—Perforated board; circuit clips (41H705 $ .10/pkg. of 10); battery clips (55J184 $ .69/pkg. of two)

Prices subject to change.

The chassis is simply a piece of perforated board to which various circuit components are mounted. The leads supported by small metal clips, terminal strips or simply threaded through board holes. The potentiometer control is bracket-mounted in one corner by means of a strip of scrap metal. Two connections in the circuit are purposely incomplete. They provide test points for connecting meter leads to measure current flow at the input and output sides of the transistor. Notice that points 1 and 2 allow current readings to be taken at the base of the transistor; 3 and 4 are in the collector circuit. Whenever the meter is connected to measure current at one set of test points, the other set must be shorted. This is done with a small jumper made by attaching alligator clips to both ends of a piece of hookup wire. The jumper may then be shifted back and forth between collector and base, as is the meter.

Caution: Remember that the meter range switch must be changed to prevent slamming the needle. A recommended procedure is to start with the meter on the highest range and then switch to a lower range that provides the best indication.

The meter is a VOM (volt-ohm-milliammeter). It is the most valuable single instrument used by the electronic hobbyist to analyze, adjust and troubleshoot home-built circuits. While a relatively inexpensive VOM is adequate for checking many transistor circuits, the sensitive 20,000 ohms-per-volt model should be considered if the hobbyist contemplates any significant amount of experimentation.

The basic layout of the amplifier contains various elements already described in terms of theory, plus new components

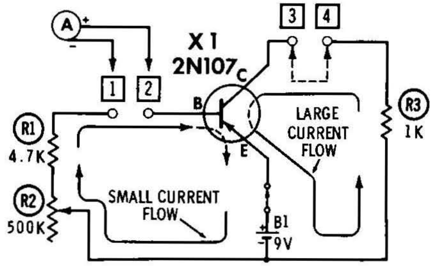
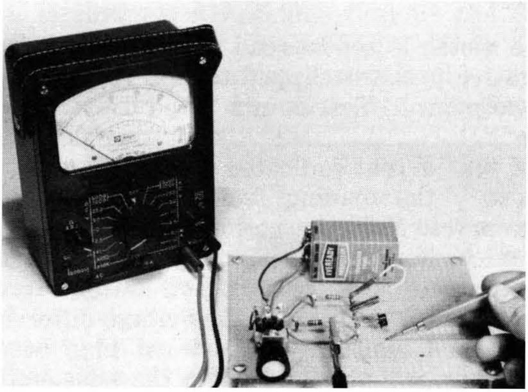


Fig. 3-1. Common-emitter amplifier circuit.



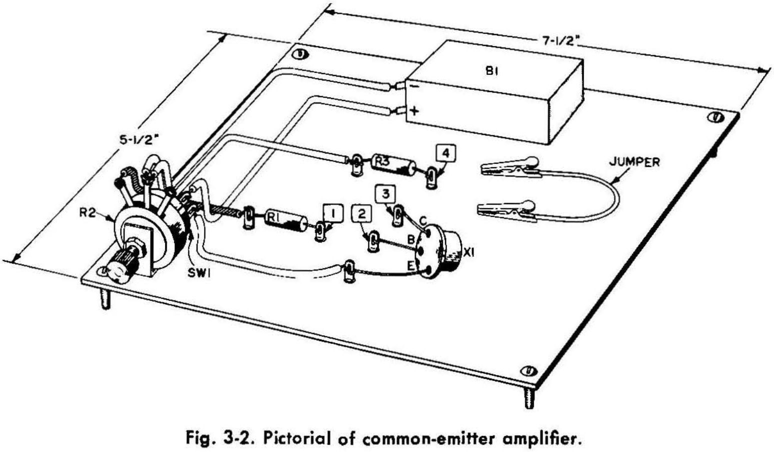


Fig. 3-2. Pictorial of common-emitter amplifier.

which make it a practical circuit. Notice the position of the 9-volt battery in the schematic. The negative terminal can apply voltage to the base through resistor R1, potentiometer R2, and test points 1 and 2. The emitter connects to the positive battery terminal through on-off switch SW1. Thus, the forward bias requirements of a PNP transistor are met. The collector-emitter circuit receives correct bias voltage from the battery. The purpose of the three resistors should become apparent as the circuit is placed into operation. The over-all object is to discover if a small input current to the base circuit will result in a large current flow in the collector circuit. The action may be followed by actually performing the following steps, or tracing out the schematic in Fig. 3-1.

Experiment Tests

First, the meter is set to read at least 100 microamperes, and its negative probe is clipped to test point 1. The positive probe goes to point 2. Test points 3 and 4 are connected with the jumper. Turn on the power by rotating potentiometer R2 and observe the current indicated by the meter. It should be possible to vary the reading from nearly zero up to 90 or 100 microamperes. Note the action of the potentiometer; its slider determines how much resistance, and thus voltage drop, occurs between the base and negative battery terminal. The lower the resistance, the greater the voltage difference there is between base and emitter. As forward bias between these elements is increased, the current in the base-emitter circuit increases. The fixed resistor, R1, serves as a current-limiting device. It keeps a small amount of resistance between base and battery at all times. Otherwise, full battery voltage at the base might cause a current flow beyond the maximum rating of the transistor.

Base currents may now be compared with those flowing in the collector. As a starting point, adjust the potentiometer so 20 microamperes is indicated on the meter. Don't disturb the potentiometer and transfer the meter leads to test points 3 and 4—positive probe to 3 and negative to 4. Shift jumper to points 1 and 2. Collector current should be on the order of .5 milliampere (500 microamperes). This is only an approximate figure, since wide variations between transistors are normal.

One highly significant conclusion may be drawn from these simple steps: If a base current of 20 microamperes causes the collector to conduct .5 milliampere, then the collector current is approximately 25 times greater than that flowing in the base. This represents the DC current gain of the transistor, more precisely termed *DC beta,* and is a measure of the transistor's ability to amplify. As mentioned in an earlier chapter, the original source of current is the battery. The arrows in the schematic of Fig. 3-1 point out the principal directions taken by electrons from the battery.

The demonstration circuit can reveal another major characteristic of the amplifier. This is an ability to recreate the shape of the current being amplified. To prove this for yourself, restore the board to its original setup by returning the jumper to test points 3 and 4 and the meter leads to 1 and 2. Adjust the potentiometer for a reading of 40 microamperes in the base circuit, exactly double that of the earlier step. If collector current is now measured it will be found to be conducting about 1 milliampere, also double the previous value. A third check can be made by adjusting R2 for a base current of 80 microamperes. In this case, collector current should rise to 2 milliamperes. Thus, it may be seen that the 2N107 not only amplifies by a factor of approximately 25, but does this in a *linear* manner. This is true over a range of input currents which fall within the transistor's normal ratings. Linearity in the transistor in many applications is important. For example, if small voice currents from a microphone are to be amplified, the large output currents from the transistor should bear the same basic shape as the input, or distortion will result.

With the existing setup, a characteristic peculiar to the common-emitter amplifier can be examined. Although a signal passing through a transistor wired in this manner is amplified faithfully, the output is actually a mirror image of the input. A process of *phase reversal* occurs. It is easy to demonstrate. Both test points on the board are jumpered, one with the clip lead already made up, the other with a short piece of bare hookup wire. The VOM is adjusted to read 9 volts DC and the probes connected; positive to the positive battery terminal and negative to the transistor collector. When the power is turned on, the meter reads the voltage between emitter and collector—approximately 9 volts. But, as the potentiometer is rotated to increase base current, note that collector voltage proceeds to drop. It reaches nearly zero when the potentiometer is at full clockwise.

Thus, it may be seen that an increase of negative voltage applied to the base causes a corresponding decrease of negative voltage at the collector. In effect, the collector is shifting to an opposite, or in a more positive, direction from that of the

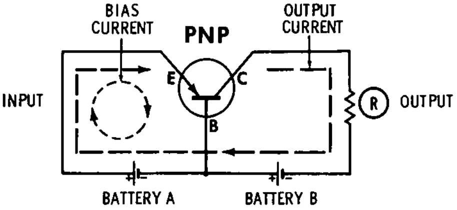


Fig. 3-3. Common-base amplifier circuit.

base. The net effect is that a negative-going signal applied to a common-emitter amplifier creates a positive-going signal at the output.

COMMON-BASE AMPLIFIER

This arrangement is encountered less often than the common emitter, but finds some application in oscillator circuits. There is no phase change in a signal as it is transferred from input to output of a common-base amplifier, *and current gain is always less than one.* This last statement does not mean that the transistor fails to amplify. Although current may be greater at the input, voltage changes are greater at the output than at the input.

The basic action of the common-base connection is shown in Fig. 3-3. Note that the base is common to both emitter and collector circuits. Battery A supplies the necessary current to bias the emitter in the forward direction. The other voltage source, Battery B, provides the reverse bias required by the collector. Bias current, indicated by the light arrows, is a relatively small circulation between emitter and base. Tracing the larger circulation of collector current, we find that it also flows in the input circuit, traveling from collector, through

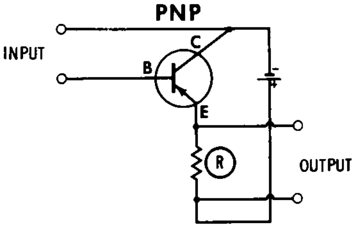


Fig. 3-4. Common-collector amplifier circuit.

the two batteries, to the emitter. Thus, it may be seen that output current also flows in the input. If bias current at the base were made to increase, over-all current would also rise. The load resistor (R) in the collector circuit displays an increasing voltage drop as added current flows through it.

COMMON-COLLECTOR AMPLIFIER

This is the final arrangement in the three basic amplifier connections. The input signal (see Fig. 3-4) is applied between base and collector. As the signal grows increasingly negative, current flow in the output (emitter-collector) also rises. The direction of the signal at the output is the same as for the input which accounts for the lack of phase reversal in the common-collector amplifier.

IMPEDANCE

This term is used often in conjunction with transistor amplifiers. It is a relationship between voltage and current, as determined by the amount of opposition presented to current flow. In general, where relatively large currents flow, impedance is low. The value is measured in ohms and is increasingly significant when signals must be transferred in and out of the transistor amplifier at maximum efficiency. Optimum power transfer occurs when the signal source has the same impedance as the input impedance of the transistor. Of equal importance is the impedance of the load, which should extract maximum energy from the transistor. It, too, must display an impedance as nearly equal to the transistor's output impedance as possible.

This largely accounts for the application of the three different amplifier arrangements just described. In the common-emitter circuit, input impedance is characteristically low, on the order of a few hundred ohms. The reason is that the base is biased in a forward direction and the opposition, or resistance, to current flow is also low. Output impedance is considered to be medium, a few thousand ohms; the collector circuit is reverse-biased and exercises greater opposition.

The other amplifier arrangements, as a consequence of their current flows, display different characteristic impedances. In the common-base, for example, it is extremely low at the input, extremely high at the output. The condition is exactly reversed in the common collector amplifier—very high input impedance, very low output impedance. Through choice of amplifier arrangement, the designer can choose a configuration which best serves the needs of a particular circuit. It must be realized, however, that there is a limitation inherent in this process since voltage and current amplification are also variable factors. This helps to explain the popularity of the common-emitter amplifier; it yields relatively high gain when considered in terms of voltage, current, or power.

AC AMPLIFIERS

For the sake of simplicity, the transistor has been described here as a device capable of amplifying a DC, or direct current, signal. In practice, however, AC amplification is far more commonplace. The input signal often takes the form of a rapidly changing current flow which alternates directions providing positive and negative values. Fig. 3-5 illustrates a typical AC amplifier. Note that it is similar to the earlier version of the common-emitter PNP amplifier, except for the addition of capacitors C1 and C2.

Resistor R1 acts as the base bias resistor. Its value is selected so a nominal amount of current results in the collector and through load resistor R2. Collector current at rest is shown by the dotted line marked "Static Current." Up to this point, we have a basic DC amplifier. The current through it is steady and unchanging. The application of an input AC signal alters this condition. This is shown as a varying current shifting between plus and minus at the left.

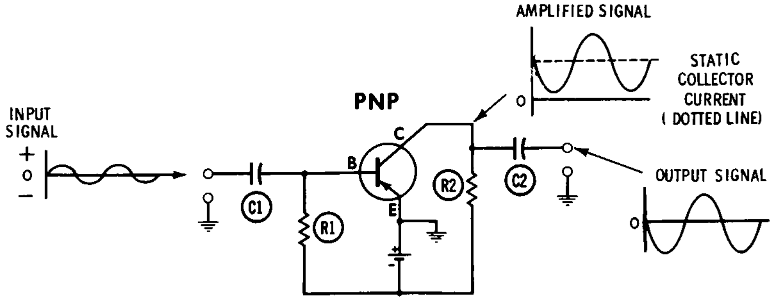


Fig. 3-5. Basic AC amplifier circuit.

As the AC signal reaches the base (through capacitor C1 which offers no opposition to AC), it will oppose or aid base bias current. When the positive part of the AC cycle is applied, it cancels some of the negative-going bias and current in the collector circuit drops. The opposite effect occurs, when the negative-going part of the cycle adds to the base bias; collector current increases. Therefore, collector current is made to vary in strength around its static, or resting, value. Notice that output current is an accurate reproduction of the AC input, though much larger in amplitude, or strength. There is the phase change, which typifies the common-emitter amplifier, but it is of little concern in this application.

The function of the two capacitors in the circuit is to preserve the operating biases applied to the transistor by the battery. Capacitors have the ability to block steady DC, while presenting little opposition to a varying (AC) signal; thus the original biases cannot be lost through the input and output pathways.

An examination of the amplified output reveals an interesting phenomenon. Notice that the waveform of the collector signal lies completely above the zero current line. Although it is a re-creation of the input, it has been changed from AC to pulsating DC. This occurs since the signal is, in effect, a changing of static collector current which can only flow through the transistor collector-emitter circuit in one direction. The output capacitor passes pulsating DC in much the same manner as the original AC input. DC is blocked and the zero reference is preserved.

The next section presents a description of how you can construct a practical amplifier to illustrate these principles just discussed.

Amplifier Classes

The AC amplifier in the foregoing experiment is an example of a major class of amplifier operation commonly found in transistor circuitry—*Class A*. It is the type which renders maximum fidelity in the boosting of an input signal; however, it is also the most inefficient. This is because the base bias is pre-set so the collector conducts an average flow of current throughout the entire application of an input signal. As shown in Fig. 3-5, all portions of the input waveform appear in the output. The factor responsible for inefficiency is the comparatively high level of collector current flow. Many circuits utilize the Class-A mode since current consumption is often insignificant and maximum linearity is achieved.

In the interests of preserving batteries, higher-powered circuits are often operated in the *Class-B* mode. Here, two transistors are combined and base biasing is adjusted for near cutoff current in the collectors. This is shown in the amplifier of Fig. 3-6. It is the push-pull circuit used in the audio output stage of many transistor radios. When no input signal is applied, the stage draws very little current from the battery. When a signal is impressed across the input transformer, according to the polarities shown, current rises in the lower transistor and decreases in the upper one. The amplified signal at the output is a composite of currents flowing in both transistors.

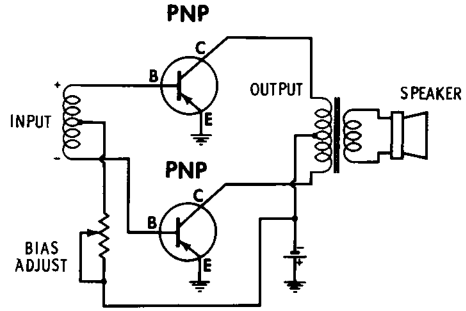


Fig. 3-6. Class-B push-pull amplifier.

The third category is *Class C*, ordinarily reserved for oscillators and frequency multipliers. The transistor is biased so output current can flow only during short periods of the input signal cycle. This leads to greatest operating efficiency, but at the expense of signal distortion. However, fidelity is not important in most radio-frequency work since the wave shape in the output still retains its most important characteristic, which is frequency.

AC Amplifier Experiment

The common-emitter circuit in Fig. 3-1 is readily converted to a demonstration model for AC amplification. The additional items needed are:

(1.) a .1-mfd tubular capacitor

(2.) one earphone, 1000-ohm magnetic type

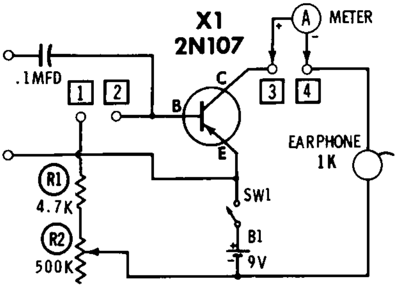


Fig. 3-7. Practical AC amplifier circuit.

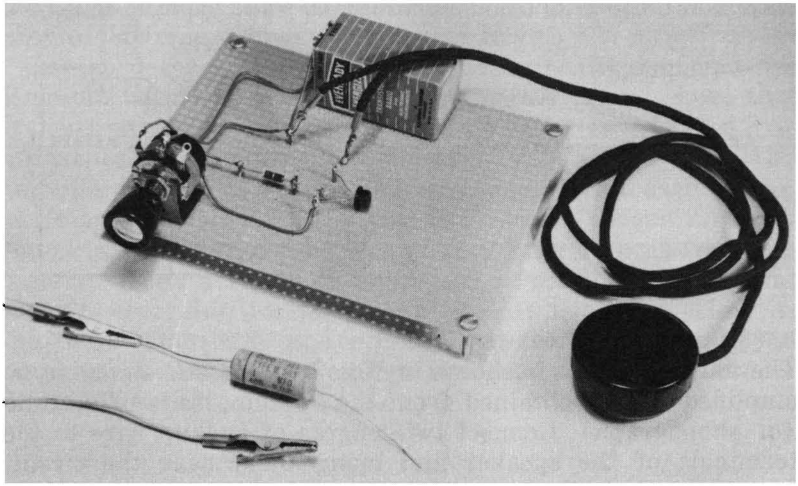
(3.) additional hookup wire

The altered circuit is shown in Fig. 3-7. The AC signal to be amplified can be obtained from the speaker leads of a radio (or phonograph). Connect two lengths of hookup wire to the terminals of the speaker and bring them near the circuit board. As a preliminary test, connect the earphone to the ends of these leads and listen to the signal. The radio volume control should be left at a low level throughout these steps, providing just enough volume to be barely audible in the earphone. If you find it difficult to differentiate between the sound from the radio speaker and that from the earphone, disconnect one speaker lead, being certain that it is rejoined to the piece of hookup wire. This connection is shown in Fig. 3-8, the pictorial drawing of the AC amplifier. The purpose of this step is to provide you with an idea of the strength of the input signal. Later, you will compare it with the boosted output from the transistor.

Next, wire the earphone into the collector circuit of the transistor to serve as a load. (The 1,000-ohm resistor used for the earlier demonstration should be removed completely during this step.)

Set the VOM to read approximately 1 milliampere of current and connect its probes to test points 3 and 4. (Observe the polarity given in the schematic.) Once the on-off switch is turned on, the potentiometer which controls base bias is rotated for a collector current of exactly 1 milliampere. This amount of current establishes a Class-A mode of operation for the transistor.

Now the signal may be applied to the input. Note that this is introduced through the .1-mfd blocking capacitor fastened to the base of X1. The other input connection is the piece of hookup wire to the emitter.



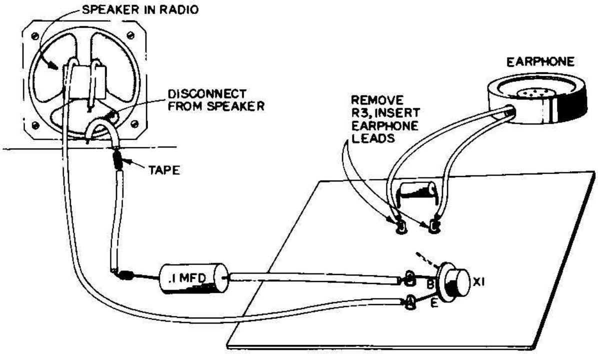


Fig. 3-8. Pictorial of AC amplifier. (See Fig. 3-2 for rest of wiring.)

Listen in the headphone—the volume of the program should sound considerably louder than when it was obtained directly from the radio. If there is distortion, lower the volume control setting on the radio to avoid overloading the transistor input. (This is best accomplished while listening to a voice program.)

In addition to the concept of amplification, the circuit demonstrates other characteristics. Note that the meter needle, which is indicating collector current, remains fixed at 1 milliampere while the program is being amplified. Although the input AC signal is causing a great fluctuation in collector current, this occurs above and below the 1-ma static collector value. The needle cannot move at the rapid audio rate of the program and therefore settles down at the average 1-ma value. This current level remains the same no matter what the level of input signal, as determined by the radio volume control setting. It is, of course, possible to overload the transistor by increasing the input beyond the current-handling ability of the base circuit.

While the amplifier is still set up, press a fingertip to the base lead of the transistor. The presence of hum in the earphone is simply the result of magnetic fields in the room which originate from the house wiring. Your finger enables a small voltage to be introduced at the transistor base and consequently heard in the earphone. It is another example of AC amplification.

OSCILLATORS

The basic function of the oscillator is to generate an AC signal. It is a circuit which draws upon the steady DC source of a battery or other power supply and uses it to produce an AC current. When the frequency is relatively low, the signals fall within the audio range (approximately 20 to 20,000 cycles per second) ; above 20,000 cycles per second they are referred to as radio waves. Transistors readily adapt themselves to the function of oscillators, a direct result of their ability to amplify.

The schematic in Fig. 3-9 is an example of a common-emitter transistor amplifier modified to produce a radio frequency on the order of 600 to 800 kc. This rate of oscillation was chosen so a practical version of the circuit could be assembled and monitored on a table-model radio. These fre-

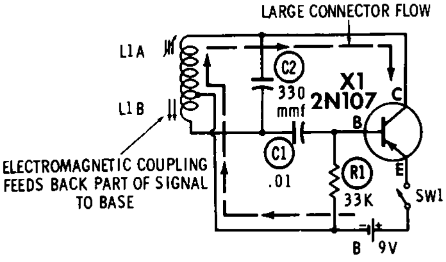


Fig. 3-9. RF oscillator circuit.

quencies will be recognized as falling into the lower end of the standard AM broadcast band.

Virtually any oscillator circuit must contain three prerequisites before it can act as an AC generator. First, it must have some form of *feedback.* This is a circuit link which returns a portion of the output signal back to the input. Also, energy must be traveling in the proper direction. Finally, the circuit must be capable of amplification, to restore energy which is inevitably lost in the circuit. How the transistor fulfills these functions can be explained by tracing the schematic in Fig. 3-9.

Assume that power switch SW, is closed and the battery commences to propel electrons through the large winding L1A. (The direction is given by arrows.) They travel through the turns of the coil and reach the collector, go through the base to the emitter and return into the positive battery terminal. This appears to be the normal route taken by current in the conventional transistor amplifier. However, an important effect occurs as electrons pass through L1A. As with any current-carrying wire, a magnetic field is set up around the turns of the coil. This field expands, cuts across the smaller winding, L1B, and a current flow is induced into the base circuit. In effect, the collector or output side of the circuit has returned energy back to the input, supplying the necessary feedback.

The oscillator must continually repeat its action to produce an AC signal. When power is first applied, the pulse of collector current sets up an oscillation in the tuned circuit of L1 and C1. The oscillator sustains the over-all cycle by amplifying the feedback signal, and thereby replacing energy lost in the tuned circuit.

The construction details for the oscillator are shown in Fig. 3-10, along with a pictorial view. The same board and several of the basic components used in the AC amplifier are used. Note that the coil must have the same basic connections as those shown. The unit specified in the Parts List has three terminals, which are usually identified on a diagram packed in its carton. Just be certain to connect the larger section of the coil between the collector and the negative battery terminal.

After power is applied to the complete circuit, turn on a nearby table radio and tune in a station between 500 and 700 kc on the dial. Now start rotating the coil knob until a strong whistle is heard in the loudspeaker of the radio. This is not

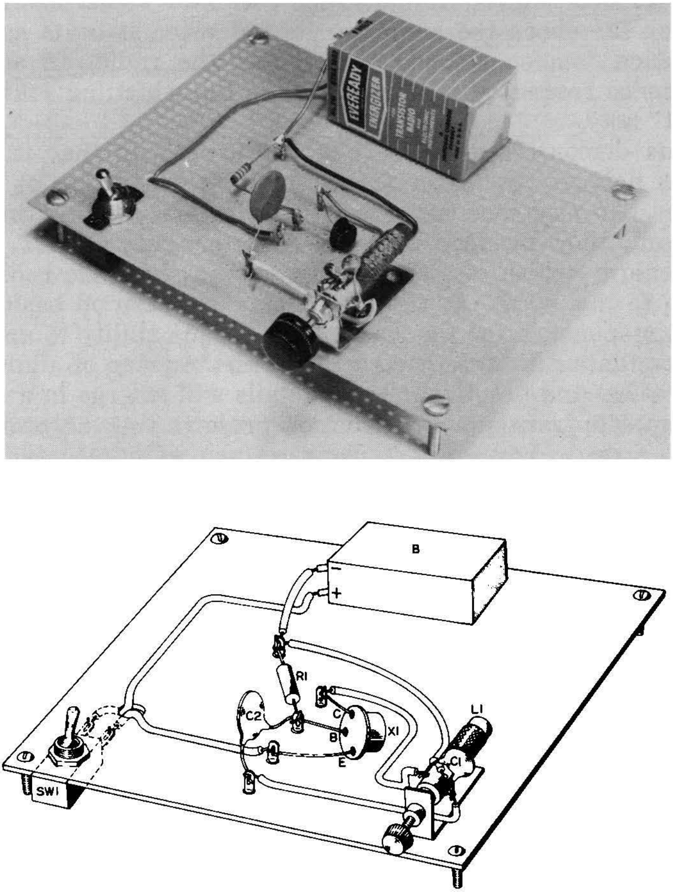


Fig. 3-10. Pictorial of RF oscillator.

PARTS LIST

R1—33K ½-watt resistor (1MM000 $ .12)
C1—330-mmf disc capacitor (16L333 $ .15)
C2—.01-mfd disc capacitor (16L363 $ .18)
L1—Tapped transistor antenna coil (60G895 $1.62)
X1—2N107 transistor ($ .55)
Sw1—SPST toggle switch (34B195 $ .60)
B—9-volt transistor-type battery (55J650 $ .69)
Misc.—Perforated board; circuit clips (41H705 $ .10/pkg. of 10); battery clips (55J184 $ .69/pkg. of two)

Prices subject to change.

the oscillator signal. Actually, the oscillator signal has a frequency far above the audio range, but when it beats against a station frequency being received in the radio, an audible difference frequency is heard. This is the whistling sound, or "beat" note.

This demonstration circuit is noteworthy in that it illustrates not only oscillator action, but the generation of radio waves. As electrons are made to circulate rapidly through the coil, they produce invisible electromagnetic fields. It is this energy which is picked up by the nearby table radio.

Up to this point the chief emphasis has been on basic concepts responsible for the transistor's unique ability to amplify and oscillate. In the following chapters, a myriad of additional theoretical and practical circuit details will emerge in a series of complete transistor construction projects you can build.

COUPLING CONSIDERATION

The method of coupling signals from one transistor stage to another is basically the same as coupling vacuum tube stages. Considerations for both types are: coupling efficiency, stage biasing, gain desired, and component cost. The transformer type of coupling is the most efficient because it is possible to match closely the output impedance of one stage to the input of the next. Transformers are used primarily in RF and IF stages, and to develop the out-of-phase signal necessary to drive push-pull output stages.

The majority of single ended transistor stages are capacitively coupled. The lower efficiency of this method is more than offset by a reduction in weight and cost. The low impedance of the transistor stage requires that a high value of capacitance be used. These coupling capacitors are usually electrolytics—this means the relative polarity of voltages between stages must be observed.

The one type of interstage coupling that differs somewhat from vacuum tube circuitry is the direct coupling made possible by complementary transistors. Direct coupling introduces a temperature drift problem, and is therefore usually reserved for special applications; i.e., preamplifiers, first audio amplifiers in receivers, etc.

CHAPTER 4

GENERAL-PURPOSE AUDIO AMPLIFIER

The three-transistor circuit which makes up the general-purpose amplifier can be used in a variety of ways by the experimenter. It will boost weak audio currents from a microphone until they are strong enough to drive the self-contained loudspeaker. The output of a crystal cartridge is another signal source which may be used to produce audible signals. The amplifier also has application as a signal-tracing test instrument. If you want to check an audio signal at some point in another transistorized project, the signal can be introduced to the amplifier's input terminals and heard in the loudspeaker.

Output power is just a fraction of a watt, but adequate for experimental purposes. At full volume, the speaker can generate enough sound to make extremely low level input signals plainly audible.

CIRCUIT OPERATION

The schematic diagram of the over-all amplifier in Fig. 4-1 appears more complicated than it actually is—close examination will reveal that the three transistors are wired quite similarly. The hookup forms what is commonly known as a *cascade* circuit. The signal is applied to the input terminals and is successively built up as it passes from one transistor to the next.

Notice that all the circuitry lies between the two long horizontal lines representing the positive and negative leads from the battery. The lower, or positive leg, contains a switch to afford a convenient means for controlling the power supply

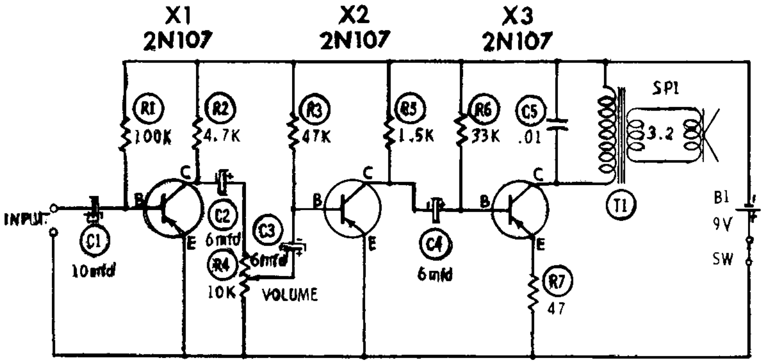


Fig. 4-1. General-purpose audio-amplifier circuit.

(B1). The base of each transistor connects to the negative leg, through a resistor, for operating bias. These are R1, R3 and R6. Other resistors, namely R2 and R5, comprise the loads for the collectors of the first two transistors. However, the load for the final output stage is the primary winding of T1. It transfers energy to the speaker winding.

Tracing of the signal pathway commences at the left side of the schematic at the input terminals. We'll assume that a microphone has been connected to this point and is introducing an AC signal to the base of X1. Capacitor C1 blocks bias arriving through R1, but allows the microphone signal to pass unimpeded. In conventional fashion, the signal adds to or subtracts from the bias, and a corresponding, but larger, current change appears at the collector. The function of load resistor R2 is to cause the amplified energy to appear at the collector terminal. Note that if the load were removed, and a direct connection made from collector to the negative battery terminal, the signal would be lost to the power supply. However, the 4.7K resistor (R2) makes the signal available to C2, a coupling capacitor which transfers the signal to the volume control. C2 provides the same blocking action to DC as did C1. Thus, the negative supply voltage to the collector of X1 is prevented from reaching the next circuit point.

Volume control R4 enables amplifier gain to be varied. Signal energy distributes itself along the resistance element and drops to zero at the lower end of the control. The slider selects the desired level and couples it through capacitor C3 to the base of the second transistor, where additional amplification takes place. The final, or output amplifier, feeds transformer T1. The primary winding presents a load of approximately 1,000 ohms, and permits maximum energy to be transferred by the transistor. As the signal passes through T1, an impedance transformation occurs—from 1,000 ohms down to approximately 3.2 ohms, the load imposed by the speaker. Thus, the function of T1 is that of an impedance-matching device. The speaker voice coil, with an impedance of 3.2 ohms, would receive little power from the transistor if connected directly into the higher-impedance collector circuit.

CONSTRUCTION

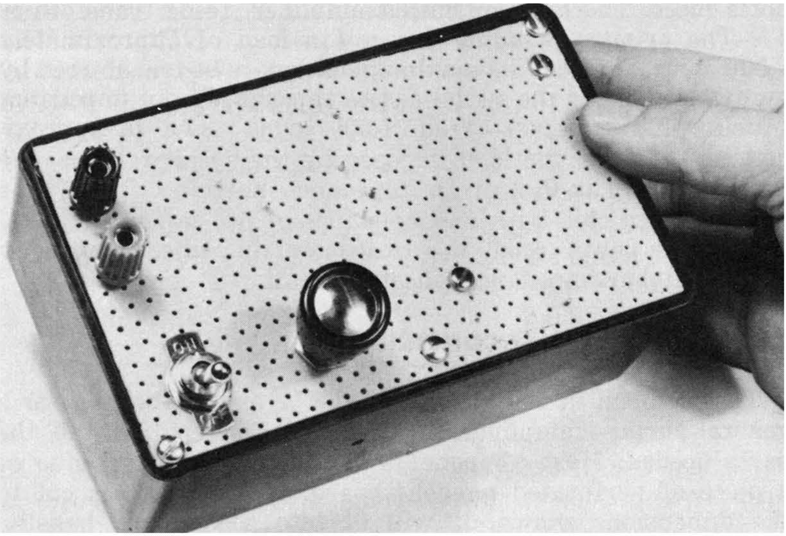
The pictorial in Fig. 4-2 shows the layout and wiring for a general-purpose amplifier.* The Parts List contains all the parts needed. Most components are mounted on one side of a piece of perforated phenolic board. If the board is cut to the dimensions shown, it will fit into a standard bakelite instrument cabinet. Tapped holes in the corners of the cabinet permit the board to be fastened in place by 6-32 x ¼″ machine screws.

PARTS LIST

R1—100K ½-watt resistor (1MM000 $ .12)
R2—4.7K ½-watt resistor (1MM000 $ .12)
R3—47K ½-watt resistor (1MM000 $ .12)
R4—10K carbon potentiometer (30M307 $1.02)
R5—1.5K ½-watt resistor (1MM000 $ .12)
R6—33K ½-watt resistor (1MM000 $ .12)
R7—47-ohm ½-watt resistor (1MM000 $ .12)
C1—10-mfd 15-volt electrolytic capacitor (16L625 $ .84)
C2, C3, C4—6-mfd 15-volt electrolytic capacitor (11L777 $ .84 ea.)
C5—.01-mfd disc capacitor (11L643 $ .21)
X1, X2, X3—2N107 ($ .55 ea.)
T1—Audio output transformer, 1K primary, 4, 8, 16-ohm secondary (63G960 $4.86) transistor type.
SW—SPST toggle switch (34B195 $ .60)
B1—9-volt transistor battery (55J650 $ .69)
SP—Speaker, 3-inch PM-type, 3.2-ohm (59D408 $2.18)
Misc.—Plastic instrument cabinet, 6¼″ x 3¾″ x 1⅞″ (86P286 $ .66); binding posts (41H368 $ .35); clips (41H705 $ .10/pkg. of 10); knob (71H209 $ .39); battery clips (55J184 $ .69/pkg. of two); perforated board.

Prices subject to change.

**Based on material in the Knight-Kit 100-in-1 Lab.*



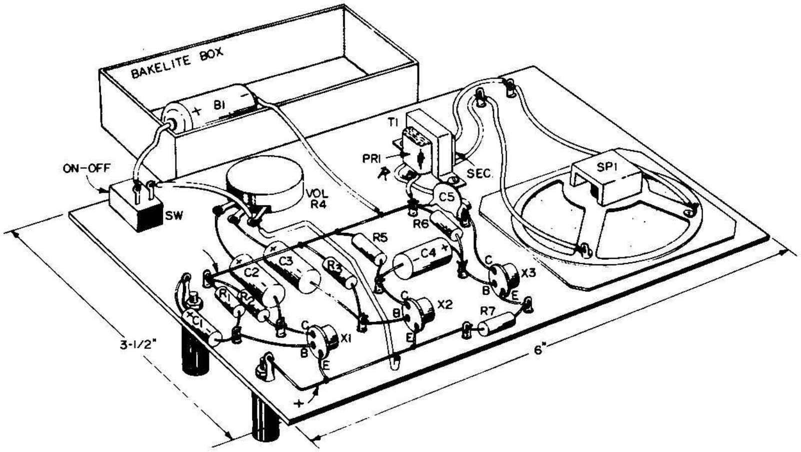


Fig. 4-2. Pictorial of general-purpose amplifier.

Begin assembly by mounting the larger components first. The speaker is held to the underside of the board by two machine screws and nuts. Holes already perforated in the board enable sound to reach the outside. If a solid material, such as hardboard, is chosen for the chassis, be sure to provide these holes before the speaker is finally mounted. Next, the other large components—switch, potentiometer, transformer, and binding posts—are attached. This leaves a small area at the lower left for resistors, capacitors, and transistors. The layout of these parts generally follows that of the schematic. There are two lengths of bare wire which serve as the positive and negative legs from the battery. These may be installed by anchoring their ends to clips or other supports which are pushed into perforations in the board.

With this basic framework completed, the small parts are installed, starting from the left side, at the input terminals. Additional clips are added where necessary to provide tie-points for component leads. Each transistor is mounted with three clips for attaching emitter, base, and collector wires. As assembly progresses, be sure to observe the proper lead connections, especially for the transistors and electrolytic capacitors. The electrolytics are often marked for polarity, with a "+" at one end. If this sign is missing, the side of the capacitor with a small indentation is considered positive. Alternatively, the plus side may have a red marker.

The proper connections for the transformer are given in the instructions which accompany the component. The primary winding, or 1,000-ohm side, must connect between the transistor collector and negative battery lead. (The two leads can be connected in either direction.) Secondary, or 3.2-ohm connections, may similarly be reversed, as long as they terminate at the speaker lugs. (In obtaining a speaker, you are apt to encounter units which have a voice coil rated at 10 or 11 ohms. No great loss in volume will occur if such units are used with a 3.2-ohm transformer winding.)

The final step in construction is mounting the battery. It is the only part which is fastened inside the cabinet. Run 6-inch lengths of hookup wire from the battery clips to the rest of the circuit so the board can be lifted out of the cabinet without removing the battery. A small metal tab cut from a piece of scrap metal is used to hold the battery firmly in place. Drill two holes in the ends of the strap and through the bakelite cabinet for attaching screws and nuts.

TESTING

After all wiring has been checked for errors, the amplifier is ready for trial. First, the over-all current consumption can be measured. Set up your VOM to read approximately 10 milliamperes DC, and connect the probes across the power switch; the positive probe must go to the switch lug which connects to the positive battery terminal. The other meter lead goes to the remaining switch terminal. Be certain that the power switch is in the off position, since the meter completes the circuit and allows the circuit to draw current. If the amplifier is working properly, the meter will indicate somewhere in the vicinity of 9 milliamperes. This represents the total current utilized by the transistors. Mark down the figure you measure for reference. If, at a future date, you suspect the amplifier is not functioning properly, recheck current consumption to see if it is still close to the original value. Several months of operation may cause the battery to weaken, indicated by a lowering of current measured at the switch terminals. Now the meter leads are removed and the power switch turned on for further tests.

A significant test can be conducted by providing an input signal and noting the AC signal level at the output of each transistor. As mentioned earlier, various inputs are possible—microphones, crystal cartridges of the phono type, or the output of a radio tuner. If none of these is immediately available, hook the leads of an earphone to the input and speak into it. Adjust the VOM to read approximately 2.5 volts AC, and attach either probe to the positive leg from the battery. Clip the other probe to a .1-mfd capacitor, which serves to block the flow of DC to the meter as the tests are being performed. The free end of the capacitor will serve as a probe which can be shifted from one circuit point to the next. While you speak loudly into the earphone, touch the probe to the collector lead of the first transistor, X1. The AC signal at this point has undergone only one stage of amplification, but there should be enough energy to give some indication on the meter. With a full-scale setting of about 2.5 volts AC, the meter needle should kick slightly in step with your voice.

Now move the probe to the second collector and note the increase in signal energy. Here, the needle moves much further up the scale. Measuring at the last collector terminal, X3, shows the greatest gain. In some cases, the meter may have to be set to its next higher scale to avoid pinning the needle.

USING THE AMPLIFIER

The general-purpose amplifier has other uses aside from reproducing the output of a microphone or tuner. It can be used in conjunction with other projects. For example, if you want to convert a circuit from earphone to loudspeaker output, the amplifier provides the necessary boost. The circuit change from the original project requires removal of the headphone and substitution of a load having the same ohmic resistance as the earphone impedance. (See Fig. 4-3.) Typically, a 1,000- or 2,000-ohm resistor works in place of the average magnetic-type earphone. Two wires are connected to the ends of the resistor, and these are run to the input posts of the amplifier. The leads should be twisted together along their lengths to cut down hum pickup. Try reversing input connections as an additional hum-reducing measure.

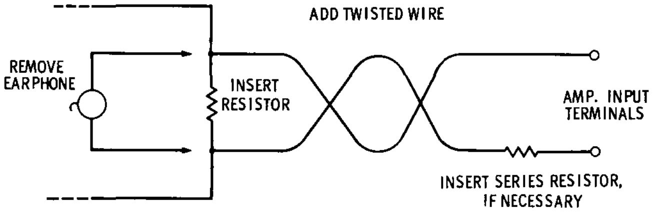


Fig. 4-3. Converting from headphone to speaker output.

Certain inputs are high in level and are likely to overload the first stage of the amplifier. If the sound in the speaker is "mushy" or distorted, the input signal level should be reduced by inserting fixed resistors in series with one of the input wires.

CHAPTER 5

ONE-TRANSISTOR RADIO

Few circuits can compete with the one-transistor receiver when considered on the basis of simple construction and low power consumption. It is a vast improvement over the crystal set, a favorite project of experimenters for several decades. The addition of a single transistor to the crystal receiver significantly improves sensitivity without unduly complicating its circuitry. With reasonably strong broadcast signals, the receiver delivers adequate earphone volume for many months before a battery change is needed. A mere 9 thousandths of a watt is the total power consumption.

CIRCUIT OPERATION

The schematic in Fig. 5-1 shows the addition of some specialized circuits to a single-stage transistor amplifier. The input of the system begins at the antenna. All radio waves in the immediate area cut across the wire and induce exceedingly

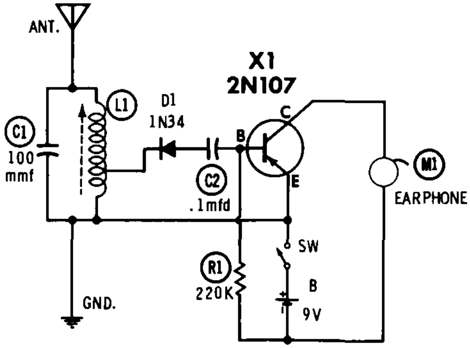


Fig. 5-1. Circuit of a 1-transistor radio.

small current fluctuations. They circulate in the tuned circuit formed by capacitor C1 and coil L1. As in a previous project (the oscillator), a tuned circuit favors one discrete frequency and tends to reject all others. The values of C1-L1 are selected to tune the standard AM broadcast band. The arrow next to L1 indicates the tunable nature of the coil, affording a means of varying its inductance value and thus the desired frequency. Once the signal is selected, it is passed on for further processing, which consists of removing the audio modulation from the radio-frequency signal resonating in the tuned antenna circuit. Note the tap-off point near the bottom of the coil (leading to diode D1). This connection solves the problem of matching impedances. The tuned circuit is typically a high-impedance device rated at many thousands of ohms. If the signal tap-off point were made at the top of L1, and connected to a load of low impedance, a mismatch would occur and little transfer of energy would take place. The load on the tuned circuit in this case is the base of the transistor. As in the case of a common-emitter amplifier, the base is characterized by an impedance of a few hundred ohms. Hooking it to the top of the tuned circuit would have a short-circuiting effect on the signal. Using a tap at a low point on the coil circumvents the problem by coupling the base at a point in the tuned circuit which displays sufficiently low impedance to provide the necessary match.

Signal energy is now transferred through diode D1, the detector section of the circuit. The ability to remove audio energy from the radio wave which carried the program between transmitter and receiver depends largely on the diode's rectifying action. In effect, the diode changes the AC signal to pulsating DC, according to the forward and reverse bias effects discussed earlier.

Coupling capacitor C2 introduces an audio signal to the base of the transistor. The position of the capacitor in the circuit prevents the loss of normal operating bias applied to the base through resistor R1. Amplification occurs and the resulting energy appears as sound in the earphone.

CONSTRUCTION

The radio receiver is built on a piece of perforated board, as shown in Fig. 5-2.* Nine clips, or similar tie points, are

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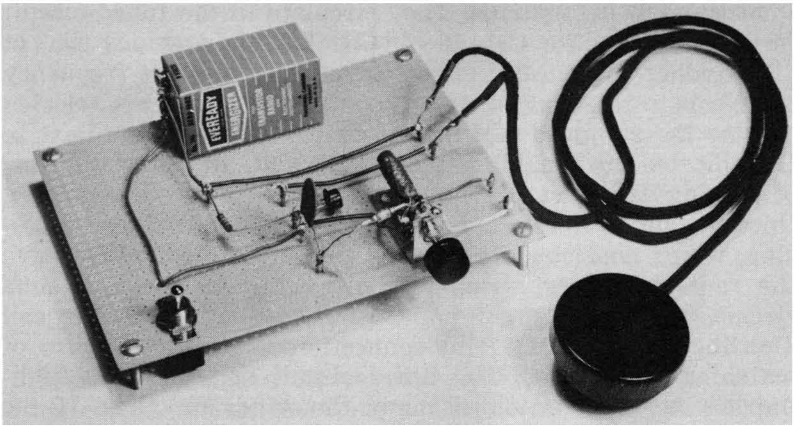
**Based on material in the Knight-Kit 100-in-1 Lab.*



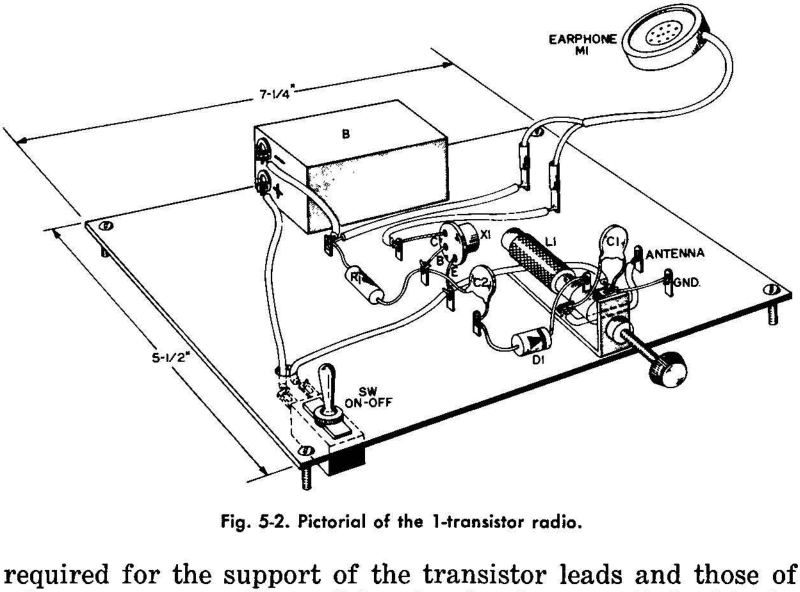


Fig. 5-2. Pictorial of the 1-transistor radio.

required for the support of the transistor leads and those of other components. The coil bracket is often supplied with the coil, but this can be fashioned from a small strip of scrap metal if necessary. Mount the coil firmly in place so its knob can be rotated without causing the whole assembly to shift from a fixed position. Other components are soldered in place by their leads, while hookup wire provides the connections for the longer wiring runs. The only wiring below the top surface of the board goes to the two lugs of the on-off switch, SW. A ¼-inch hole, drilled or reamed in the board, permits these leads to run from the top to the underside area. The Parts List contains all the items necessary for construction.

PARTS LIST

R1—220K ½-watt resistor (1MM000 $ .12)
C1—100-mmf disc capacitor (16L322 $ .15)
C2—.1-mfd disc capacitor (15L999 $ .54)
D1—1N34 germanium diode ($ .32)
X1—2N107 transistor ($ .55)
SW—SPST toggle switch (34B195 $ .60)
M1—1000Ω magnetic-type earphone (59D112 $1.08)
L1—Tapped transistor antenna coil (60G895 $1.62)
B—9-volt transistor-type battery (55J650 $ .69)

Prices subject to change.

The success of the receiver largely hinges on the proper antenna and ground system. At least 30 feet of wire should be attached to the board terminal marked "Antenna." If satisfactory performance is not achieved, the run may be doubled. Any type of wire can serve the purpose—standard hookup wire, or even ordinary lamp cord which has been split down the center and joined end to end for one long length. Install the antenna as high as possible and terminate the far end with a glass or plastic insulator. (The end of the antenna must be kept from direct contact with metal or other materials which would short-circuit the signal.)

The ground connection is also important. This is a wire connected from the board terminal marked "Gnd" and may be the same type of wire used for the antenna. The far end of the wire may be fastened to any of a number of points which will provide the circuit with a good electrical ground. The easiest approach is hooking to the screw which holds the cover plate on an electrical wall outlet. Ordinarily, this provides direct contact with the building electrical ground. Fasten the wire under the head of this screw and tighten. Another ground source is a cold-water pipe. Standard grounding clamps are available, or you can merely wrap a few turns of wire, stripped of insulation, around the pipe.

TESTING

The initial check on the receiver's performance is made with a VOM. Set the meter to read DC milliamperes on a low scale (approximately 10 ma). Clip the meter probes across the switch terminals—red or positive, to the switch lug which connects to the positive battery terminal, and black probe to the remaining switch terminal. Since this hookup energizes the circuit, the switch is placed to the off position during the test. If the receiver is drawing the proper amount of current, a reading of approximately 1 milliampere will be indicated on the meter. Double or half that reading is not unusual due to variations in transistors and the tolerance of other components.

A quick check to determine if the amplifier is functioning is to place a fingertip on the transistor base lead. A fairly strong hum should be heard in the earphone as AC magnetic fields from the house wiring are induced into the circuit.

USING THE RADIO

The receiver can be given an air check by removing the meter leads and turning on the power. The coil knob, used for selecting stations, is slowly rotated over its range while listening in the earphone. Local stations should be heard the loudest, with volume tapering off on those at greater distances. Some overlapping of signals is normal with a simple receiver of this type when station frequencies are fairly close together on the dial.

There is a possibility that stations near the lower end of the broadcast band will not be covered in the tuning range of the receiver. This is a result of different antenna lengths and ground systems which reflect a change in the tuned circuit, L1-C1. However, it is easily possible to alter the frequency coverage. (This should be done after antenna and ground are completed.) Increasing the value of capacitor C1 will shift tuning toward the lower end of the band. The 100-mmf capacitor shown in the Parts List may be replaced with a similar-type capacitor rated at 330 mmf.

CHAPTER 6

CAPACITY-OPERATED RELAY

The transistor version of the capacity-operated relay makes possible a unit that surpasses earlier tube versions. Current consumption is a fraction of former values and the circuit lends itself to small size, if desired. The device has been used for burglar alarms, novel store window displays and other control functions. Its important characteristic is an ability to energize a relay when a hand touches a sensitive antenna wire. In the case of the burglar alarm, the wire is attached to a screen, doorknob, or other surface to be protected. When contact is made, a remote indication such as a lamp or bell is triggered by the relay.

CIRCUIT OPERATION

The heart of the system is a pair of transistors connected as shown in Fig. 6-1. Transistor X1 is wired as an RF oscillator which generates a frequency according to the adjustment of tuning coil L1. The coil forms a tuned circuit with the 150-mmf capacitor, C1. As in any oscillator circuit, there is a feedback path to return a portion of the output energy back to the input. This is the electromagnetic coupling which exists between the large and small sections of the tuning coil. The base of X1 is across the smaller winding and driven by alternating current circulating in the tuned circuit.

The over-all purpose of the oscillator is to establish a signal which is responsive to the touch. If a hand contacts the antenna wire, the capacitance of the human body shunts radiofrequency energy from the tuned circuit to ground. The net result is that oscillations cease; the feedback path to the base of the transistor is discontinued. Instead of coupling into the base circuit, feedback is lost to ground through the hand.

Assume that the oscillator is functioning normally, with no interference from body capacity. The current flow through X1 produces a voltage drop across emitter resistor R4. Note that the base of the other transistor, X2, is also tied to this resistor. Any fluctuations appearing at this point act to change the current flow in X2. As oscillation occurs, the polarity of voltage at the emitter resistor is such that current forward biases the base circuit of X2. Amplification in the second transistor occurs, and the relay coil in its collector circuit is energized. Thus, relay contacts remain closed when the oscillator functions normally.

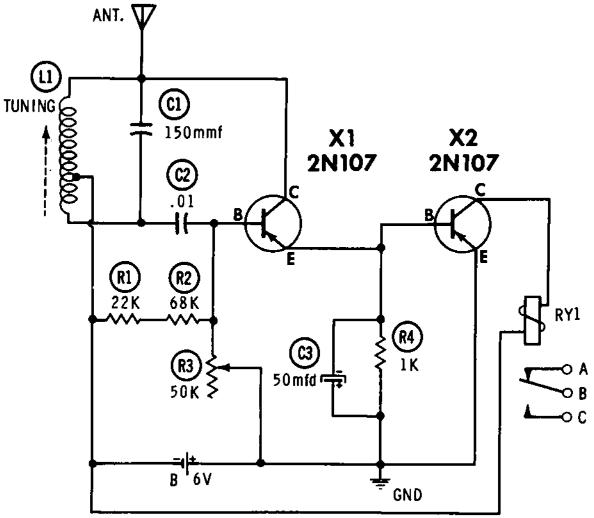


Fig. 6-1. Capacity-operated relay circuit.

However, if the oscillator ceases to operate, the voltage produced across R4 is lost. Transistor X2 loses base bias and its collector current drops sharply. The net result is that the relay is de-energized. Since the relay is a single-pole double-throw type, the proper contacts may be selected to actuate an external alarm circuit.

The capacity relay circuit is refined with the addition of potentiometer R3. This permits oscillator bias to be varied for optimum relay sensitivity. Note its connection between the positive battery terminal and the base of X1.

CONSTRUCTION

As an example of the lab-kit approach to home experimentation, the unit described here was assembled from an Allied *Knight-Kit* "21-in-1" transistor lab kit. After components are soldered to a printed circuit board, a series of projects may be assembled by plugging interconnecting wires into jacks. The correct connections are shown by means of a circuit card placed on top of the board, as shown in Fig. 6-2.

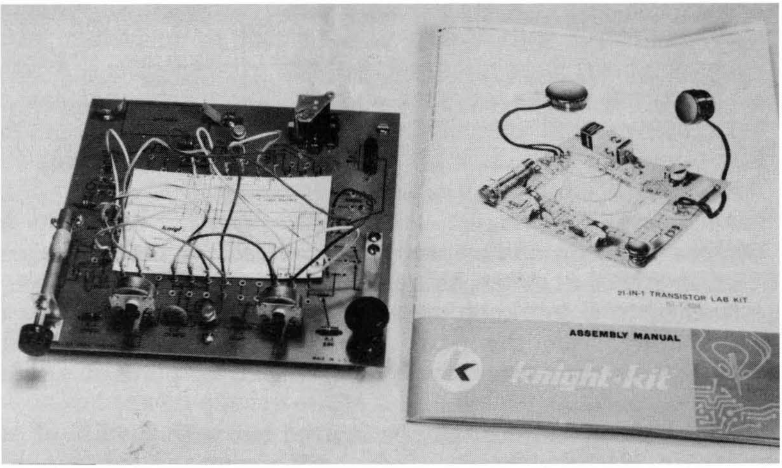


Fig. 6-2. Capacity-operated relay constructed on *Knight-Kit* "21-in-1" transistor lab.

PARTS LIST

R1—22K ½-watt resistor (1MM000 $ .12)
R2—68K ½-watt resistor (1MM000 $ .12)
R3—50K carbon potentiometer (30M314 $1.02)
R4—1K ½-watt resistor (1MM000 $ .12)
C1—150-mmf disc capacitor (16L325 $ .15)
C2—.01-mfd disc ceramic capacitor (16L363 $ .18)
C3—50-mfd 6-volt electrolytic capacitor (16L041 $ .84)
L1—Tapped transistor antenna coil (60G895 $1.62)
B—6-volt transistor-type battery (55J666 $ .69)
X1, X2—2N107 transistor ($ .55 ea.)
RY1—SPDT relay with 500-ohm, 6.5 ma coil (76P260 $6.05)
Misc.—Circuit board; clips (41H705 $ .10/pkg. of 10); battery clips (55J184 $ .69/pkg. of two)

Prices subject to change.

The capacity-operated relay can be assembled as a single project, if desired. The Parts List contains the full complement of components required.

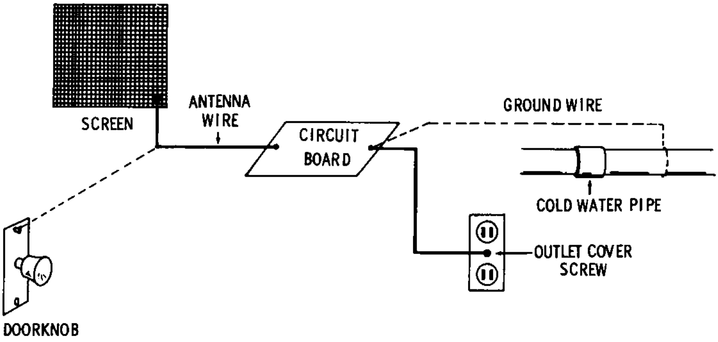


Fig. 6-3. Antenna and ground connections.

Antenna and ground connections required for the device are shown in Fig. 6-3. A length of hookup wire, several feet long, is attached to a doorknob or window screen. The ground is a lead running from the positive battery terminal to a cold-water pipe or the screw which holds the cover plate of a wall outlet.

The relay connections may be figured out with the aid of an ohmmeter if the project is not built from the lab kit, as illustrated here. First, the coil winding is determined by measuring across the various lugs until a resistance of approximately 550 ohms is found. The other three terminals are contacts indicated by the letters A, B and C in the schematic. Place the ohmmeter across various terminals and note which pair displays zero resistance on the ohmmeter. These are the normally-closed contacts. Next, operate the movable contact of the relay by pressing it against the remaining terminal. As this is done, find the terminal pair that indicates zero resistance. These will be the normally-open contacts. The contacts

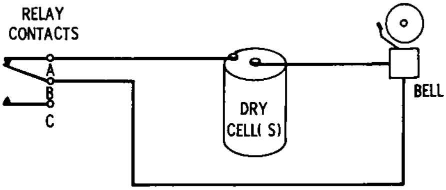


Fig. 6-4. Wiring of alarm circuit.

used for the operation of an alarm device are the normally closed ones. (They correspond to A and B on the schematic.) The use of these contacts with an alarm bell is pictured in Fig. 6-4.

TESTING

The first trial with the completed unit begins by adjusting sensitivity control R3. Start with the knob in the most counterclockwise position and slowly rotate it to the right while watching the movable contact on the relay. (The bell should not be hooked up at this time or it will ring continuously as initial adjustments are made.) Keep turning the knob until you see the relay contact move into its closed position. An audible click should be heard, too. During this process, the knob must be turned very slowly. In fact, best operation will result if you turn the knob a fraction of an inch each time and wait two or three seconds for the relay to react. Once you have discovered the adjustment which just causes the relay to close, touch a finger to the antenna terminal. As this is done, the relay should drop out, then return as the finger is withdrawn.

If the circuit does not respond properly, it may be necessary to readjust the frequency of the oscillator. Try various settings of the coil knob, starting with the knob all the way in.

The functioning circuit may be explored with the aid of a VOM. First, the on-off action of the RF oscillator is examined by opening the collector circuit of X1 and reading current flow under varying conditions. The positive probe of the meter is clipped to the collector terminal, while the negative probe is attached to the disconnected wire. Set the meter range so a few milliamperes can be conveniently read on the scale. Note the amount of current flowing as the oscillator performs undisturbed. Now touch a finger to the antenna terminal; the flow should drop when oscillations cease. Restore collector connections and move the probes to the next test point.

Set the meter on its lowest voltage range, around 1.5 or 2.5 volts DC. Touch the negative probe to the top end of R4, and the positive probe to the lower end of the same resistor. When the oscillator is in operation, a low value of negative voltage should be indicated on the meter. This is the bias applied to the base of X2, and is responsible for its large current flow. When a finger is again touched to the antenna terminal, the voltage should drop. In effect, it goes in a more positive direction and removes operating bias from the base of X2.

Next, the current flow through X2, as controlled by the oscillator, is observed. Insert the meter probes in series with the collector, as before. Set the scale of the VOM to indicate approximately 10 milliamperes. When the oscillator is untouched, the reading should be somewhere near the top of the meter scale, nearly 10 ma. But touch the antenna lead and current drops down to nearly zero. The action of the relay coincides with the change in current flow. It, too, "drops out" under the influence of lowered collector current.

PUTTING THE RELAY TO WORK

Antenna and ground connections are made, as detailed earlier, to place the capacity-operated relay into service. The alarm circuit is connected to the relay terminals and checked as the antenna input to the oscillator is touched. You will notice that increasing the size of the metal object to which the antenna is connected increases sensitivity of the response. This is due to the larger area which exists between the hand and antenna lead. If circuit sensitivity is made very high, through careful adjustment of potentiometer R3, the alarm will "fire" with no actual contact between the hand and pickup point (knob, screen, etc.). Sufficient energy is transferred to ground by the large capacitance developed between the hand and a large metal object.

CHAPTER 7

CODE-PRACTICE OSCILLATOR

The construction of this code-practice oscillator provides a valuable device for learning Morse code while introducing you to some new transistor circuitry. It is built around the *multivibrator,* a two-transistor circuit which can switch itself on and off at a rate that generates an audio tone in the earphone.* A key placed in one of the power leads permits the tone to be "chopped" according to "dits" and "dahs" of individual letters and numbers. The circuit points up the near-instant operation as power is applied to the transistor.

CIRCUIT OPERATION

A descriptive way to view the multivibrator is to liken it to a seesaw. Each of the two transistors alternately unbalance the other, and the result is an alternating flow of current. As you'll see, the multivibrator is actually a variation of the earlier RF oscillator circuits. It contains each of the major elements required to establish oscillations—namely, feedback energy of the proper polarity from output back to input, and an ability to replace energy losses in the circuit. Fig. 7-1 shows the schematic diagram.

When power is applied, a surge of current flows through the base of transistor X1. This is amplified in the collector circuit. A signal appears at the collector and is coupled through capacitor C1. If earlier statements are recalled about the common-emitter connection, we see that a phase reversal occurs. The amplified signal will be going in a direction opposite from that of the input. Assume it is positive-going and applied to the base of transistor X2. Again a phase reversal occurs as

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**Another circuit, utilizing transformer feedback, can be constructed from the Knight-Kit Code Oscillator.*

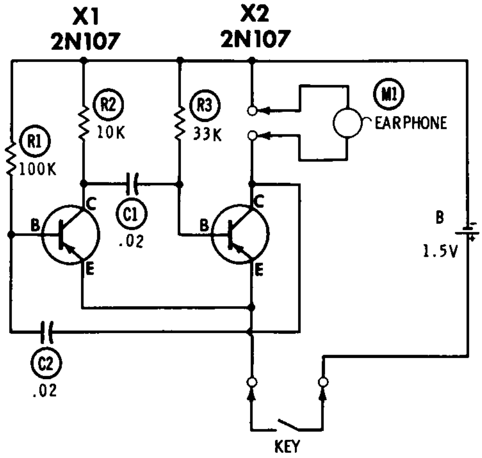
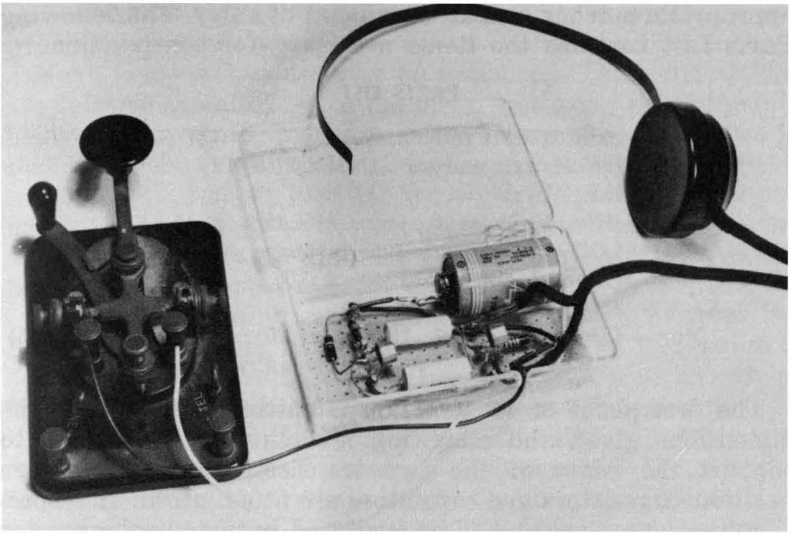


Fig. 7-1. Code-practice oscillator circuit.

the collector circuit re-creates the input as a negative-going signal. Notice the position of capacitor C2 at the collector of X2. It couples a portion of the collector energy back to the base of X1. This is the feedback path needed to sustain oscillation. The whole signal process repeats itself and the circuit generates a steady train of pulses at approximately 500 cycles per second. As a load for the collector of X2, the earphone receives most of the signal energy for conversion to sound waves. Only a small portion of the signal is required for feedback purposes, since both transistors need only be "triggered" into conducting states for short periods. Their amplifying ability provides earphone power and the replacing of signal losses in other circuit components.

CONSTRUCTION

Since over-all size of the circuit is small, the complete code-practice oscillator can be constructed within a plastic box. As shown in the pictorial, Fig. 7-2, a wiring board cut from perforated phenolic will hold all components except key and earphone. The leads of these parts pass into the box through



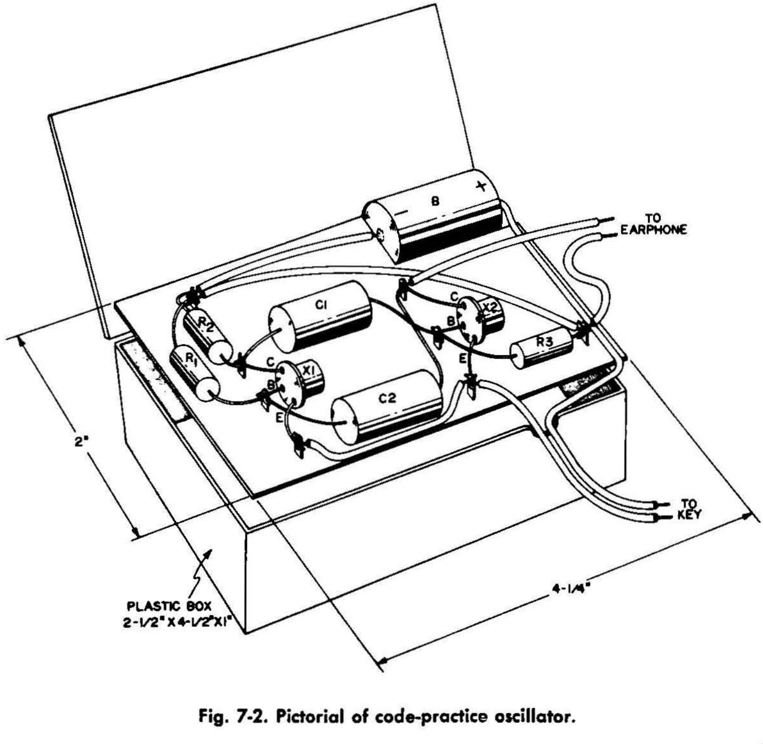


Fig. 7-2. Pictorial of code-practice oscillator.

appropriate notches filed at their point of entry. The following Parts List contains the items necessary for construction.

PARTS LIST

R1—100K ½-watt resistor (1MM000 $ .12)
R2—10K ½-watt resistor (1MM000 $ .12)
R3—33K ½-watt resistor (1MM000 $ .12)
C1, C2—.02-mfd tubular capacitor (15L120 $ .15 ea.)
M1—1,000-ohm magnetic-type earphone (59D112 $1.08)
B—1.5-volt battery (55J340 $ .10)
X1, X2—2N107 transistors ($ .55)
Misc.—Clips (41H705 $ .10/pkg. of 10); key (89S904 $2.25)
Prices subject to change.

The first phase of construction is cutting the board to the dimensions given and mounting six clips, or tie points, to support the wires of the two transistors. Once these are positioned, resistors and capacitors are fitted into their respective locations. Care should be exercised in installing capacitor C2. Its leads run near other bare connections and there is a possibility of a short circuit. This is remedied by covering C2's leads with pieces of "spaghetti" tubing or tape.

The battery is wired to the rest of the circuit through matching clips or a battery holder. There is some range of choice for the battery. The only qualification for this component is that it supply 1.5 volts. You have a choice of three or four sizes, but avoid the use of the standard size D, or common flashlight cell. Its large physical dimensions make it difficult to install within the plastic box. A "penlite" cell is a good choice.

There is no need to install an on-off switch; power is supplied only when the key is down.

TESTING

The presence of a tone in the earphone when the key is closed indicates that the circuit is going into oscillation. It should be possible to key the tone rapidly, with no time lag or shift in tone frequency. Another check is to place the leads of a VOM across the open key leads and measure over-all current consumption. Set the meter on a low DC current scale and connect the positive probe to the key lead which runs to the positive battery terminal. Attach the negative meter lead to the other key lead. Since this hookup turns on the oscillator, an immediate current indication will occur. It should be approximately .4 milliampere.

Next, some AC values may be measured. These indications are relative in nature since the meter tends to load the points being measured. However, they are interesting to observe in that they show where signal energy occurs. During these trials a .1-mfd capacitor should be placed in series with one meter probe to keep power supply voltages from interfering with the readings. Set the meter to read low voltage AC. Its leads may be inserted into the circuit in either polarity.

As the tone is being generated in the earphone, measure the AC value across its two leads. The voltage at this point is approximately .75 volt. Between base and emitter of X1, where feedback energy is occurring, the value is approximately .25 VAC. If the AC signal between base and emitter of X2 is now measured, a reading of about .1 VAC should be found. The fact that the meter partially shorts the circuit is indicated by a tone change in the earphone as the probes are touched.

It may be noticed that the volume of the tone in earphone is uncomfortably loud. This is easily corrected by inserting additional resistance in one leg of the power supply to reduce over-all current consumption of the oscillator. A 1.5K resistor in series with either key lead cuts the current by approximately one-half. The tone intensity also falls as the circuit functions at reduced power. Other resistances may be inserted to achieve a comfortable earphone level when the circuit is keyed.

It is also easily possible to alter the frequency of the oscillator tone by shifting resistance values. As shown in the schematic, R1 is a 100K base bias resistor for transistor X1. By lowering the ohms value of this component, the frequency of oscillation, and thus the tone, will rise. There is a choice of three other resistors to use as substitutes for R1: 68K, 47K and 33K. If the 33K value is used to replace R1, the tone frequency will be highest in pitch. Lowering base bias resistance beyond this point is not recommended since excessive current can flow through the base circuit. On the other hand, raising the resistance much beyond 100K slows the rate of oscillation to the point where a series of slow "ticks" is heard.

USING THE OSCILLATOR

The code-practice oscillator is particularly valuable when used by two persons wishing to learn Morse code. A practical system might work like this: One person operates the key while the other listens to the characters sounded in the earphone. The sender announces a letter, then keys the proper number of "dits" and "dahs." After a while, the person on the receiving end should be able to write an increasing number of characters from the tone sounds alone. While Morse code can be learned in this manner, there are many courses on the market which considerably simplify the teaching process. They make use of phonograph records, tapes, etc.

THE INTERNATIONAL CODE

A	• –	M	– –	Y	– • – –
B	– • • •	N	– •	Z	– – • •
C	– • – •	O	– – –	1	• – – – –
D	– • •	P	• – – •	2	• • – – –
E	•	Q	– – • –	3	• • • – –
F	• • – •	R	• – •	4	• • • • –
G	– – •	S	• • •	5	• • • • •
H	• • • •	T	–	6	– • • • •
I	• •	U	• • –	7	– – • • •
J	• – – –	V	• • • –	8	– – – • •
K	– • –	W	• – –	9	– – – – •
L	• – • •	X	– • • –	0	– – – – –

Question Mark • • – – • •
Period • – • – • –
Error • • • • • • • •
Comma – – • • – –
Wait • – • • •
End of Message • – • – •

CHAPTER 8

WIRELESS BROADCASTER

If voice currents are passed through a coil of wire they set up a magnetic field which travels a few feet through the surrounding air. It may be received by another coil and amplified to form a crude communications system. However, far greater transmission distances are possible by using radio frequencies. In addition to generating a short-range magnetic field, higher radio frequencies establish an electrostatic field which can completely leave a coil and travel outward many hundreds or even thousands of miles. The wireless broadcaster provides a working demonstration of these principles. The range of the device is about ten feet, and its radio energy easily monitored on a nearby table radio tuned to the standard broadcast band. The circuitry is useful in that it demonstrates how the outputs of two transistors can be combined to superimpose audio on a radio-frequency "carrier."

CIRCUIT OPERATION

Upon examining the schematic diagram in Fig. 8-1, it will be seen that transistors form two circuits discussed earlier; X1 is a conventional audio amplifier, X2 is an oscillator capable of generating radio-frequency energy in the broadcast band. Their outputs are combined in a process termed modulation.

Audio frequencies are introduced to the base of X1 by the earphone (M1). (In this application the earphone is made to act as a microphone which converts sound energy into low-level voice currents.) Normal amplification occurs in the transistor and the output appears at the collector.

Next, consider the oscillator, X2. Its tuned circuit, consisting of C4 and L1, plus the feedback of energy through capacitor C3, keeps the transistor in a state of continuous oscillation.

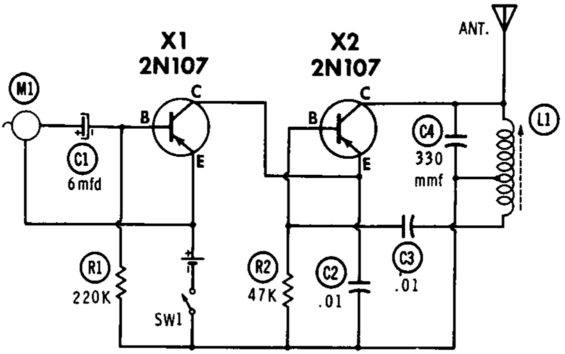


Fig. 8-1. Wireless broadcaster circuit.

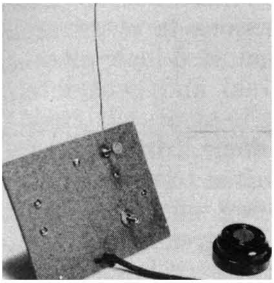
The frequency is high enough to cause a radio wave to be emitted at the antenna.

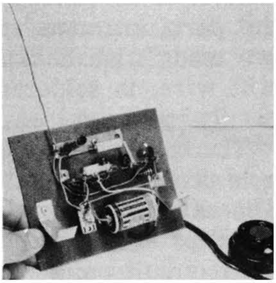
Combining audio- and radio-wave currents for the modulation process occurs at the emitter of X2. Note that the output of the audio amplifier is applied to this point. Audio energy will aid or oppose current flow between emitter and collector of the oscillator. The net effect is a shaping of the radio-wave energy according to the pattern of voice currents. During the process, the frequency of the oscillator does not change; it is the *amplitude* of the oscillations which vary. As characteristic of amplitude modulation, the voice is radiated from the antenna in the form of strength changes in the radio-frequency carrier.

Once the radiated energy is received at the table radio, the wave is "decoded" through the detection process, and the original audio signal is recovered.

CONSTRUCTION

The suggested chassis layout for the wireless broadcaster is in Fig. 8-2. A complete Parts Lists follows. The panel is cut from a piece of hardboard to the dimensions given, and a pair of metal legs are attached for support. Then, the larger components—switch, terminal strip and battery—are fastened in place. The coil is held to the board by means of its metal bracket.





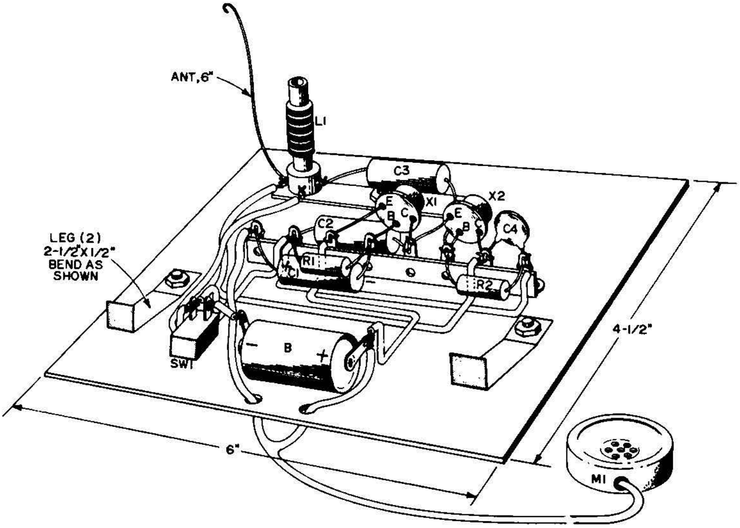


Fig. 8-2. Pictorial of wireless broadcaster.

PARTS LIST

R1—220K ½-watt resistor (1MM000 $ .12)
R2—47K ½-watt resistor (1MM000 $ .12)
C1—6-mfd 15-volt electrolytic capacitor (11L777 $ .84)
C2, C3—.01-mfd tubular capacitor (28L706 $ .15 ea.)
C4—330-mmf disc capacitor (16L333 $ .15)
L1—Tapped transistor antenna coil (60G895 $1.62)
B—9-volt transistor-type battery (55J650 $ .69)
M1—1,000Ω magnetic-type earphone (59D112 $1.08)
X1, X2—2N107 transistor ($ .55 ea.)
Sw1—SPST toggle switch (34B195 $ .60)
Misc.—Hardboard; 8-lug terminal strip (41H693 $ .15); scrap-metal strip; battery clips (55J184 $ .69/pkg. of two); stiff wire, 6″

Prices subject to change.

Most of the wiring is done on an 8-lug terminal strip. After the parts are attached, necessary connections to other areas are made with hookup wire. The antenna, a 6-inch piece of stiff wire, is soldered to one coil terminal and bent into a vertical position.

The battery is fixed to the panel with some drops of household cement, and matching clips are attached to its terminals. The earphone enters the panel through two small drill holes. The tips of the earphone leads may be soldered directly into their circuit points, or phone-tip jacks can be mounted to the panel to provide a plug-in arrangement.

TESTING

Total current consumption of the completed project is measured at the on-off switch terminals. Turn the switch off and attach the probes of a VOM to the terminals—negative meter probe to the terminal which goes to the negative battery terminal. The meter range is selected so 1 milliampere DC can be easily read on the scale. If the circuit is drawing the proper amount of current, the meter will indicate approximately .6 milliampere. The probes are now removed and power switch turned on for the next test.

Audio output from X1 is measured by connecting either meter probe to the collector of this transistor through a .1-mfd isolating capacitor. The other probe hooks directly to the positive leg of the battery. Adjust the VOM for its lowest AC scale, about 2.5 volts. As you speak into the microphone, the meter needle should kick in synchronization with your voice. This is the energy applied to the emitter of the RF oscillator.

To check the radio frequencies, turn on a nearby table radio and set its tuning dial to the lower end of the broadcast band. Then, rotate the knob of tuning coil L1 until a strong rushing sound is heard in the radio speaker. (During this step, no broadcast station should be tuned in.)

USING THE BROADCASTER

The wireless broadcaster is set up according to the checkout in the previous section. By talking into the microphone you should hear a corresponding signal in the radio speaker. It may be necessary to retune the coil knob to find a clear spot on the dial. Another adjustment is finding the coil setting which causes radio speaker reproduction to be as clear and distortion-free as possible. Touching up the tuning of the radio as you speak into the microphone will be helpful during this step.

Next, the range of the radio wave may be determined. Walk around the room as the pickup in the radio is checked, increasing the volume control setting if necessary. Further tests can be conducted by going into an adjoining room and having another person monitor the signal. If no large masses of metal exist between the broadcaster and receiver, the radio waves should easily pass through walls with no apparent loss in strength.

Another application of the broadcaster is the transmission of phonograph record music. The microphone is removed from its connection into the circuit and the output leads of a crystal phono cartridge substituted.

It is possible to increase the range of the wireless broadcaster by lengthening the antenna. However, to keep from interfering with reception on neighboring broadcast receivers, do not extend it by more than a foot or two. There is no limitation, however, on increasing antenna length of the broadcast receiver. This raises the sensitivity of the radio and thus its operating range.

CHAPTER 9

TIMER

This is a practical device for the accurate marking of a time interval. It is the type of circuit which finds application in such fields as dark-room photography and other areas where a need exists for an adjustable timer that can easily be set to denote fractions of a second or periods of up to a minute or so. The indicating signal in this instance is a small pilot lamp. After a key is tapped once, the light remains lit until the end of the selected time interval. The setting of the timer

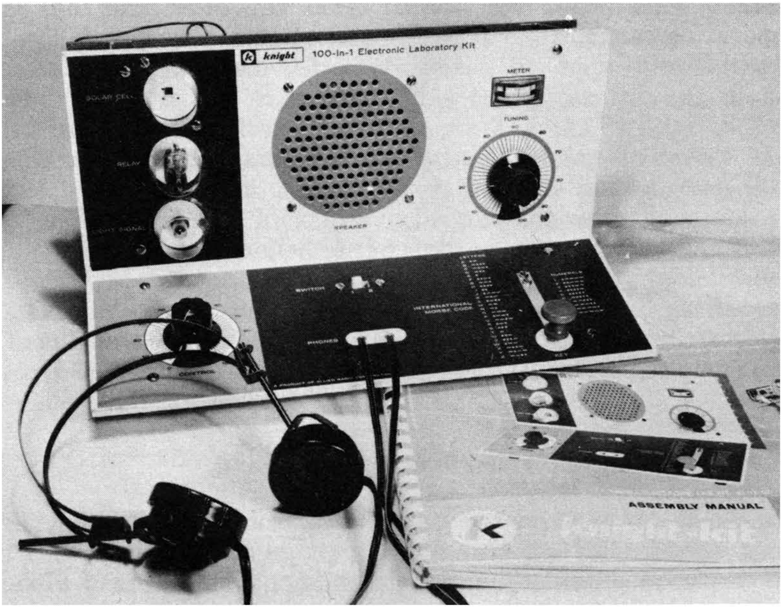


Fig. 9-1. Allied Radio *Knight-Kit* "100-in-1" electronic lab.

is accomplished with a knob-controlled potentiometer on the panel.

The construction of the device, as shown here, is another example of a lab kit available to the home experimenter. Pictured in Fig. 9-1 is the *Knight-Kit* "100-in-1" Electronic Lab. The timer is one of a series of projects which are assembled by means of spring connectors and wires. The approach permits new circuits to be fabricated without damage to the various parts. If the hobbyist wishes to construct the timer independently of the kit, a Parts List follows and a schematic is provided in Fig. 9-2.

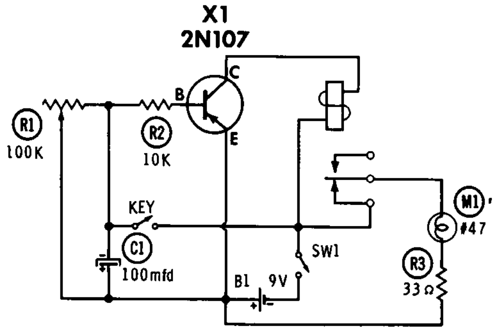


Fig. 9-2. Timer circuit.

PARTS LIST

R1—100K potentiometer (30M318 $1.02)
R2—10K ½-watt resistor (1MM000 $ .12)
R3—33-ohm ½-watt resistor (1MM000 $ .12)
C1—100-mfd 15-volt electrolytic capacitor (16L633 $1.08)
X1—2N107 transistor ($ .55)
M1—#47 lamp (52E312 $ .15)
Sw1—SPST switch (34B195 $ .60)
B1—9-volt transistor-type battery (55J650 $ .69)
RY1—SPDT relay -500Ω 6.5 ma coil (76P260 $6.05)
Misc.—Lamp holder (52E419 $ .39); clips (41H705 $ .10/pkg. of 10); battery clips (55J184 $ .69/pkg. of two); perforated board.

Prices subject to change.

CIRCUIT OPERATION

The sequence of events begins when power switch SW1 is closed. The transistor is unable to conduct since there is no source of forward bias in its base circuit. Thus, no current flows through the relay winding, which is connected in series with the collector terminal, and the lamp remains turned off.

The timing cycle commences as the key is depressed. During this operation the large electrolytic capacitor, C1, is connected directly across the positive and negative terminals of the battery. Charging of the capacitor plates at this time is virtually instantaneous. When the key is opened, the capacitor starts to discharge and sets a flow of current in motion; excess electrons on the negative plate seek a path through R1 and R2 back to a more positive point in the circuit. The rate at which the capacitor spends its energy depends on the resistance encountered in the discharge path. The setting of R1 largely governs this. If the slider of the potentiometer is moved to the right, the pathway to the positive point displays low resistance and discharge of the capacitor is rapid. Conversely, a left-hand position produces a fairly slow leakage rate from the capacitor plates.

Note how the base of the transistor is tied into this current flow. A portion of the negative discharge current acts to forward bias the base-emitter circuit. Thus, any amplified current flow in the collector circuit depends on the time period, or rate of the negative discharge, determined by the adjustment of potentiometer R1.

The relay responds to collector current. It is energized only when adequate discharge current is available from capacitor C1. During this time, relay contacts complete the lamp circuit to the battery and the bulb remains lit. Near the end of the discharge period, the relay drops out and the bulb extinguishes. If the timing cycle is to be repeated, the only action needed is a tap on the key. This recharges C1 and the sequence of events occurs again.

Two resistors in the circuit provide protection against overloading certain components. R2, in series with the base, limits capacitor discharge current through the base-emitter circuit of the transistor. The 33-ohm resistor in series with the bulb reduces the 9-volt battery voltage to a safe value for the pilot lamp.

CONSTRUCTION

As mentioned earlier, the timer is a circuit contained in the *Knight-Kit* "100-in-1" Electronic Lab, as shown in Figs. 9-1 and 9-3. However, it may be assembled by following the schematic and parts list. A perforated board, or other nonmetallic material, can serve as the chassis.

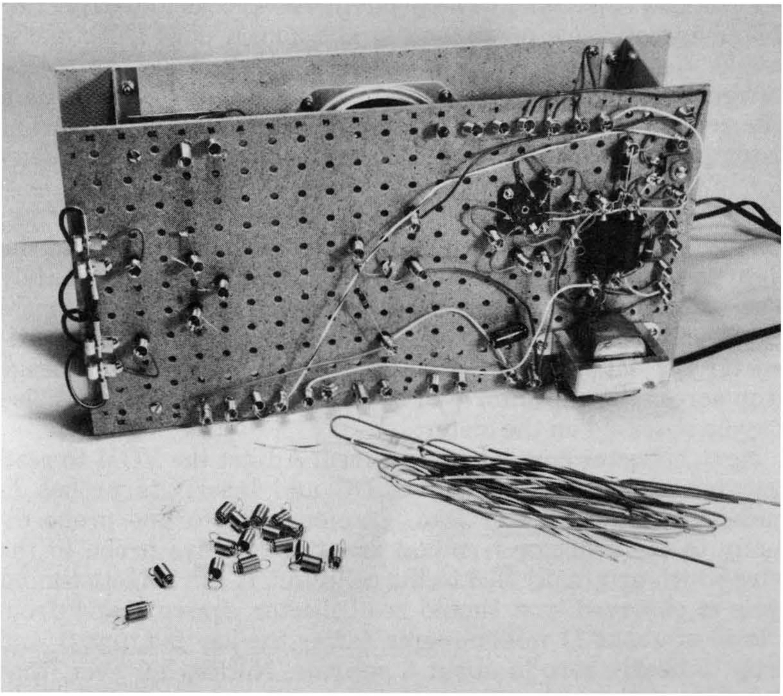


Fig. 9-3. Circuit board of Allied Radio *Knight-Kit* "100-in-1" electronic lab.

The key need not be a telegraph key, but simply a pushbutton switch for applying the initial charge pulse to the capacitor. Alternatively two strips of copper bent apart will provide the necessary contact action.

TESTING

Two significant test points reveal the charge-discharge action of the circuit. The first is in the base circuit, chiefly controlled by C1. A VOM will be used to indicate the voltage across this capacitor as it progresses through the timing cycle. Then, collector current is measured to view the effect of the base circuit on the relay and bulb.

After the unit is completely assembled and functioning, set potentiometer R1 for the longest timing cycle. In the original model, this was fully counterclockwise. Set the VOM to read 10 volts DC and connect the two probes directly across C1, the 100-mfd capacitor. (The polarities of probes and capacitor should agree.) Now press the key and hold it down. The meter should read in the vicinity of –6.5 VDC. This represents charging voltage being applied to the plates of C1. The bulb will remain on during this step since the base of the transistor is being forward biased to the point of current conduction in the collector circuit.

Now release the key and observe the meter. The meter pin follows the discharge curve of the capacitor, dipping from the high point of –6.5 to near zero in a span of approximately 3 seconds. At one point in the cycle the lamp will extinguish. This occurs at approximately the –1-volt level. If the potentiometer is reset for a faster discharge time, the rate of voltage drop across the capacitor will be similarly speeded up and also may be observed on the meter.

Next, collector current is examined. Adjust the VOM to read approximately 15 milliamperes DC and insert its probes in series with the collector lead. Connect the positive probe directly to the collector terminal and the negative probe to the wire which originally tied to the collector. If the longest timing cycle is observed, you should see collector current start from a level of about 11 milliamperes (after the key is tapped) and drop to nearly zero in about 3 seconds. Notice, however, that the relay extinguishes the bulb when collector current is near the 4-milliampere level. This figure represents the dropout current of the relay coil. Shorter timing cycles will be indicated by a correspondingly faster drop of the VOM reading.

It is possible to shift the timing range of the circuit. The most convenient method is to add additional capacity across C1. This effectively increases storage ability and thereby increases the timing cycle. Another 100-mfd electrolytic capacitor in parallel with C1 will approximately double the time period to nearly 6 seconds. All other positions of R1 will provide longer timing cycles than obtained with only one capacitor in the circuit.

USING THE TIMER

Putting the unit into service may follow the procedure outlined above. However, utility value is increased if the potentiometer knob is carefully calibrated in seconds. This is easily performed with the aid of a watch with a sweep second hand. Set the potentiometer for the maximum time period and measure the exact time it takes for the bulb to extinguish. The appropriate timing mark is then written directly on the panel. Other calibrations are added in small steps around the complete travel of the knob.

CHAPTER 10

ELECTRONIC FLASHER

Complete freedom from moving parts, springs, and sparking contacts is possible with this flasher, which is able to switch large currents in a purely electronic fashion. The heart of the circuit is a multivibrator consisting of two transistors—one a small-signal type, the other a large power unit capable of handling relatively high current levels. In operation, a No. 47 lamp is blinked at a nominal rate of one flash every 1.5 seconds. The frequency, as you'll see, can be varied by a small alteration in circuit values.

CIRCUIT OPERATION

The basic theory of operation closely resembles that of the code-practice oscillator already described in an earlier chapter. However, there are several superficial differences and the introduction of new transistor types. Notice that X1, unlike the PNP transistor in the earlier project, is an NPN unit (see schematic in Fig. 10-1). This accounts for its connection into the power supply—emitter to negative, collector to positive through the load resistor. Thus, correct operating biases are provided and the application of a *positive* voltage on the base of X1 will cause it to conduct and amplify. Comparing the X1 arrangement with that of X2, a PNP transistor, reveals the significant reversal in power connections.

In brief, the multivibrator commences to oscillate when power is turned on. A positive-going pulse at the base of X1 is amplified in the collector and undergoes the phase-reversal characteristic of a common-emitter amplifier. The pulse, now negative-going, is applied to the base of X2 and current is drawn through the lamp inserted in the collector lead. To complete the feedback path needed to sustain oscillation, ca-

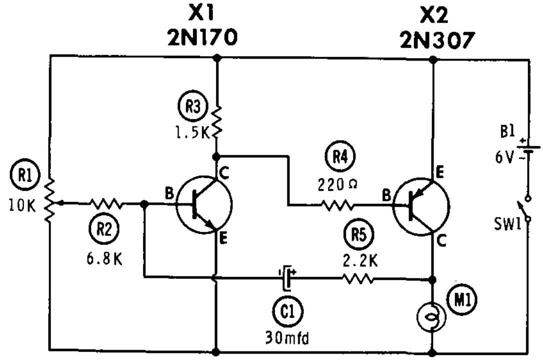


Fig. 10-1. Electronic-flasher circuit.

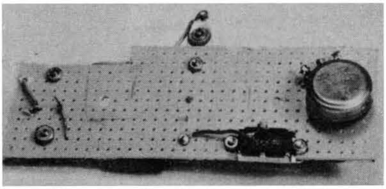
pacitor C1 samples a portion of X2 collector current and returns this to the input, or base, of X1. The capacitor charges and discharges during circuit operation and the bulb is alternately flashed.

Transistor X2 is a good example of a power transistor which enjoys widespread application by experimenters. Unlike small-signal units used in preceding projects, it is capable of handling several watts of power. This is a requirement imposed by the flashing lamp. Approximately 150 milliamperes must be conducted by the transistor to make the bulb reach full brilliance. The 2N307 is actually rated for higher currents but works well in the circuit, is reasonably priced, and needs no elaborate "heat" sink to prevent a damaging rise in temperature.

CONSTRUCTION

A piece of perforated board, cut to the dimensions given in the pictorial drawing of Fig. 10-2, serves as the chassis.* The mounting base will depend on the final use of the flasher. If the unit is to be put into regular service, it will require a rather heavy current supply. This explains the use of a large, lantern-type battery which appears in the original model and the following Parts List. If, however, the flasher is merely built for demonstration purposes, four size-D flashlight batteries may be wired in series to provide a total of 6 volts.

**To facilitate construction, material from the Knight-Kit 100-in-1 Lab may be used.*



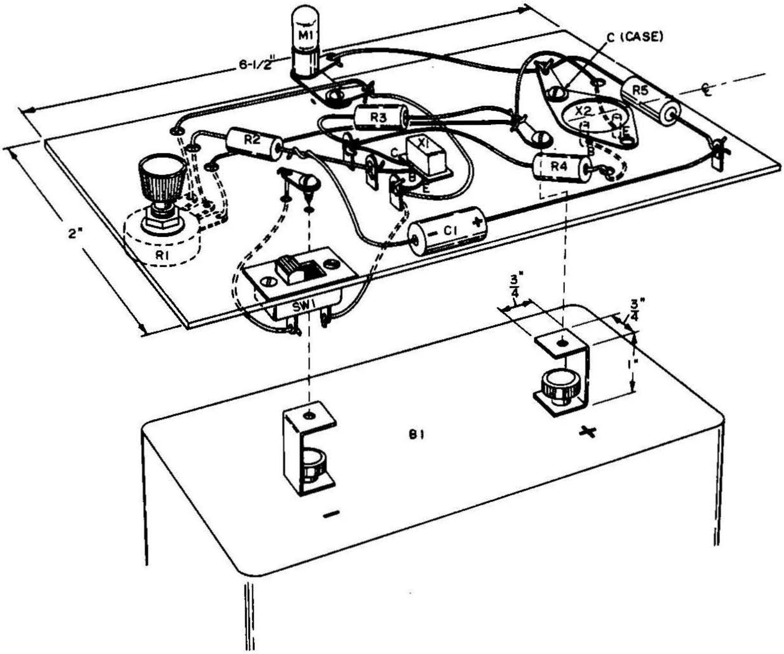


Fig 10-2. Pictorial of electronic flasher.

This arrangement operates the flasher for a reasonable amount of time, but is not recommended if the unit is intended for possible emergency applications.

PARTS LIST

R1—10K potentiometer (30M307 $1.02)
R2—6.8K ½-watt resistor (1MM000 $ .12)
R3—1.5K ½-watt resistor (1MM000 $ .12)
R4—220-ohm ½-watt resistor (1MM000 $ .12)
R5—2.2K ½-watt resistor (1MM000 $ .12)
X1—2N170 transistor ($ .75)
X2—2N307 transistor ($1.49)
C1—30-mfd 15-volt electrolytic capacitor (16L629 $ .90)
M1—#47 lamp (52E312 $ .15)
SW1—SPST slide switch (34B422 $ .10)
B1—6-volt lantern-type battery (55J114 $2.05)
Misc.—Lamp holder (52E419 $ .39); circuit clips (41H705 $ .10/pkg. of 10); metal brackets, 4 solder lugs (44N-607 $ .35/pkg. of 25)

Prices subject to change.

The mounting of the circuit board atop the lantern battery is accomplished by two U-shaped metal brackets. As shown in the pictorial, these are drilled, then held in place by the battery's screw terminals and caps. Nuts and bolts are used to fasten the circuit board to the top ends of the two brackets. Be sure to place solder lugs under the screwheads before the chassis is finally mounted in place.

Other major components are fastened directly to the board. A notch is cut for the switch, and large holes are drilled for potentiometer R1 and transistor X2. Note that one solder lug is fastened under one mounting screw of X2. This is the collector terminal. If the transistor is coated with paint, scrape some off so the screwhead makes adequate electrical contact with bare metal on the transistor case. Transistor X1 is conveniently mounted by three small circuit clips pressed into appropriate holes in the board.

TESTING

Start the checkout with a VOM connected across the terminals of SW1, the on-off switch. With SW1 in an off position, connect the leads of the VOM to two switch lugs—negative probe to the switch terminal which ends at the negative battery terminal. Set the meter to read approximately 200 milliamperes DC. Flashing action begins by locating the correct setting of potentiometer R1. Start with the knob at its most counterclockwise position. If the circuit is functioning properly, this setting will cause the bulb to remain lit and the meter to indicate about 150 milliamperes. Now start turning the knob slowly to the right until you discover the point which just makes the bulb go dark. The flashing action should now proceed at the rate of approximately once every 1.5 seconds, causing a large needle swing on the meter. The meter leads may now be removed and the switch snapped on.

Next, set up the meter to its 10-volt DC range and connect the positive probe to the solder lug which goes to the positive battery terminal. The negative probe is touched to the base of transistor X1. Note the pattern of the needle swing as the bulb flashes. When the light is on, base voltage reads approximately -5 VDC. During dark periods, the potential rises to around -8 VDC. This agrees with the theory of operation; a negative-going pulse, indicated by the voltage rise, is converted to a positive-going pulse in transit through X1. Applied to X2, little collector current results and M1 goes dark.

The source of the -5 VDC, before the pulse appears at X1 base, originates at the potentiometer. Note how it is connected across the power supply. As the slider is moved, the desired amount of operating bias is impressed on the base.

Transfer the VOM negative probe to the collector of X1. When the bulb is on, collector voltage is highest. This displays phase reversal occuring through the transistor. In the previous measurement the bulb was on when base voltage was lowest (-5 VDC).

Now shift the negative meter probe to the collector of X2, the power transistor. Note that collector voltage drops from about -6 VDC to nearly zero when the bulb lights. Again, the phase reversal is evident. When X2 base is driven in a negative direction, the collector voltage shifts in a positive direction—actually toward the zero point in this instance.

A final measurement shows the feedback pulse through capacitor C1. If the probes are placed across the capacitor, the charge and discharge voltage can be read on the meter. (Polarity of the meter probes and the capacitor must agree.)

USING THE FLASHER

If the flasher is to be used outdoors, a suitable weatherproof housing should be constructed. A transparent enclosure is recommended to allow maximum light from the bulb to reach the outside. Although the lamp appears to yield a feeble light during daylight hours, actual tests indicate that the flash is visible for approximately one-half mile.

It is possible to alter the rate of flash, if desired. Slowing it down is best accomplished by adding more capacity across C1. Doubling the 30-mfd value will slow the flashing rate to approximately half the former speed.

Faster rates can be secured by reducing C1 capacity. However, too little capacity at this point in the circuit may cause the cycling action to stop completely. Another approach is a change in the value of R5, the 2.2K resistor which controls the rate of C1 charge. If a smaller resistor is used, flash rate increases. In any case, R5 should have a minimum resistance of 1,000 ohms to prevent the feedback pulse from reaching excessively high intensities.

CHAPTER 11

PHOTOELECTRIC CONTROLLER

The introduction of a photocell into the circuitry of a transistor amplifier creates a device which can perform alarm and control functions according to the intensity of light rays. The model shown here energizes a bell when a beam of light falls upon the sensitive surface of a tiny cadmium sulphide photocell. Other applications are possible. Once the unit is assembled, a relay may be wired to operate a light, buzzer, or other device. The selection of the proper relay contacts determines whether light or darkness will operate the alarm.

CIRCUIT OPERATION

The principle of the controller is based on the behavior of the photocell. It is of the photoresistive type; when light falls upon it, the cell displays a low order of resistance. In strong room light, this is approximately 20,000 ohms. During the dark condition (light source removed) resistance rises to about 1 megohm. Intermediate light intensities produce in-between values of resistance.

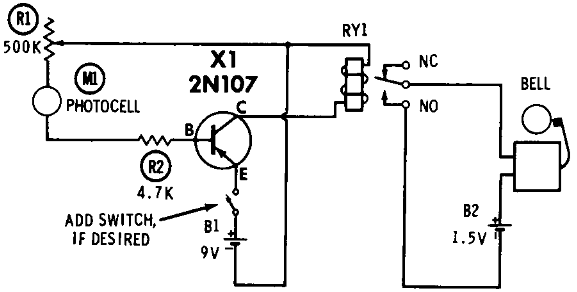
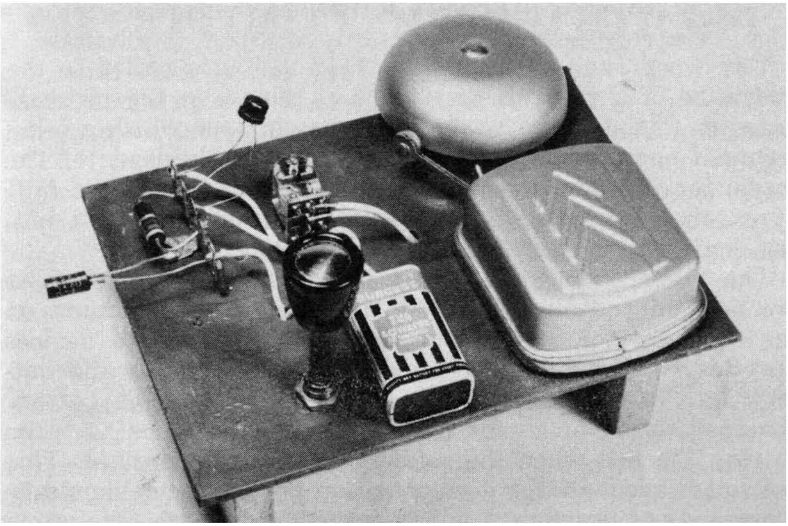


Fig. 11-1. Photoelectric-controller circuit

In the schematic of Fig. 11-1, it may be seen that the photocell is inserted between the base of X1 and a source of negative bias from the battery. Thus, the transistor is permitted to conduct, or is cut off, according to the condition of the photocell.

These variations in the base circuit appear as amplified current fluctuations in the collector. The relay winding, in series with the collector, energizes when sufficient current flows



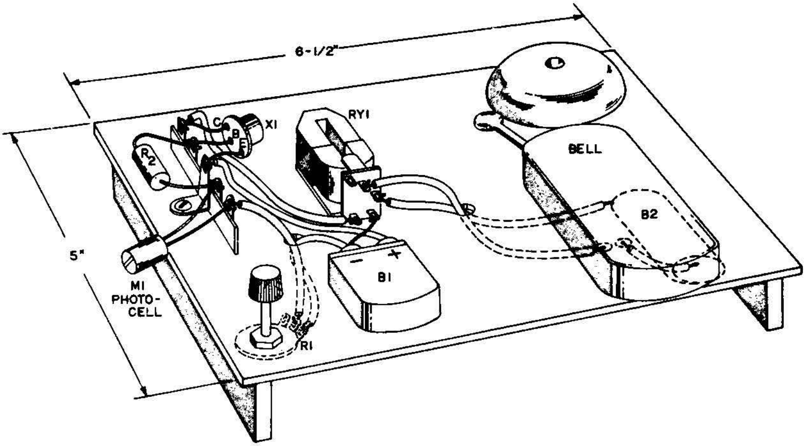


Fig. 11-2. Pictorial of photoelectric controller.

through its coil. The signal device tied to the relay operates accordingly.

Since the controller is used in varying light conditions, an adjustment is provided to calibrate the circuit for different locations. This is the potentiometer, R1, which allows the sensitivity of the base circuit to be pre-set. The fixed resistor, R2, simply limits the maximum current and protects against overbiasing the base circuit.

CONSTRUCTION

Two wood runners measuring 1½″ x 4″ are nailed to the underside of a piece of hardboard as shown in the pictorial drawing, Fig. 11-2.* This forms a chassis upon which a 5-lug terminal strip is bolted. The strip receives the leads of the transistor, R2, and the photocell. Fitted with a pair of stiff wires, the photocell is self-supporting and may be bent into any angle after its wires are soldered in place.

The other components listed in the following Parts List are now added. As illustrated, a household bell mounts on the right side of the chassis. However, other signal devices may be installed by proper choice of relay contacts and battery B2. In this case, B2 is a common flashlight battery strapped to the underside of the panel. It provides 1.5 volts to ring the bell when the relay contacts are energized. This voltage is adequate for demonstration purposes, but should be increased for practical applications. Two or more cells wired in series increases the loudness of ringing.

PARTS LIST

R1—500K potentiometer (30M322 $1.02)
R2—4.7K ½-watt resistor (1MM000 $ .12)
X1—2N107 transistor ($ .55)
RY1—SPDT relay with 5000-ohm 2-ma or less coil (76P379 $6.35)
M1—Cadmium sulphide photocell (4E105 $4.00)
B1—9-volt transistor-type battery (55J650 $ .69)
B2—1.5-volt size-D cell (55J005 $ .20)
Misc.—Hardboard; 5-lug terminal strip (41H690 $ .11); battery clips (55J184 $ .69/pkg. of two); 1.5-volt, battery operated bell; two wood strips.

Prices subject to change.

**To facilitate construction, material from the Knight-Kit 100-in-1 Lab may be used.*

There is no on-off switch shown in the pictorial. If this feature is desired, a single-pole single-throw switch may be added in series with the positive terminal of battery B1. This is the optional arrangement shown in the schematic near the emitter lead of the transistor.

Since there might be some variation in the terminal layout of relay RY1, here is how to identify the proper connections. First find the coil terminals with the aid of an ohmmeter. These are the two lugs which display a resistance of 5000 ohms. The normally-open contacts are the pair which indicate no resistance on the meter; the normally-closed pair will read zero ohms. These measurements are made before the relay is wired into the circuit. The model shown utilizes the normally-open contacts, indicated by the letters "NO" in the schematic. With this hookup, the alarm device sounds when light strikes the photocell and the relay is energized. If you want to reverse the operation of the photoelectric controller—so darkness operates the alarm—connect the leads to the normally-closed contacts of the relay.

TESTING

After the controller is completed, turn the knob of the potentiometer fully counterclockwise. This effectively removes its resistance from the base and the circuit is at maximum sensitivity. Connect a VOM, set to read a few milliamperes DC, between the emitter and the positive battery terminal, or across the open power switch, if one is installed. (The positive probe of the meter must connect to the positive battery terminal.) Now, point the photocell toward a strong source of light. This may be an open window or nearby light bulb. The correct value of current, as indicated on the meter, should be approximately 2 ma. Now cover the photocell and note the drop in current to nearly zero. The relay should pull in and drop out as the hand alternately darkens and exposes the photocell.

By adjusting the VOM for a range of about 2.5 volts DC, the shift in bias voltage at the base of the transistor may be observed. Place the positive probe on the emitter lead, the negative to the base. The transition from dark to light should be accompanied by a change in emitter voltage from about –.3 VDC to –.5 VDC as the resistance of the photocell decreases in value.

USING THE CONTROLLER

The controller can turn on a light as darkness approaches, sound an alarm when a light beam is broken, or be engaged in a variety of other tasks which involve a switching function on the basis of light intensity. Use the potentiometer to cancel the effects of background, or interfering illumination. Only when a light source of sufficient intensity strikes the photocell should the relay operate.

A refinement is the addition of a lens for concentrating a particular light source on the photocell window. This may be an ordinary magnifying glass mounted in front of the photocell. Some experimentation is necessary to reveal the exact distance needed for proper focusing of light. (The spacing is normally a few inches.) Just be careful to avoid concentrating sunlight through the lens; heat buildup might cause damage to the cell's sensitive surface.

GLOSSARY

Acceptor Impurity. The element added to basic transistor material to increase the number of holes.

Amplifier. A device capable of increasing or making larger the input signal.

Base. The portion of the transistor analogous to the grid of a vacuum tube.

Cascade. Circuits connected such that the output of one goes to the input of the next.

Collector. The portion of the transistor analogous to the plate of a tube.

Common-Base Amplifier. A transistor amplifier using the base as the reference terminal.

Common-Collector Amplifier. A transistor amplifier using the collector as the reference terminal.

Common-Emitter Amplifier. A transistor amplifier using the emitter as the reference terminal.

Conductor. An element with many free electrons, allowing easy current flow.

Diode. A two-element device that passes current in one direction only.

Donor Impurity. The element added to basic transistor material to increase the supply of available electrons.

Electron. A particle of negative charge. One of the "building blocks" from which atoms are made. Electrons comprise the greatest portion of current flow.

Emitter. The portion of the transistor analogous to the cathode of a tube.

Forward Bias. The bias voltage polarity that will cause base-emitter conduction.

Hole. The site of a lost electron.

Insulator. An element with few free electrons. Current will not flow easily in an insulator.

N-Type Germanium. Germanium with arsenic added to give it an excess of electrons.

Oscillator. Basically an amplier with feedback from its output to its input to create an AC signal.

PN Junction. The point where a P-type material and a N-type material join.

Potential Hill. The barrier which prevents the joining of unlike charges at the junction.

P-Type Germanium. Germanium with indium added to cause a deficiency of electrons.

Rectifier. The component used to allow current flow in one direction only—usually a heavy-duty form of diode.

Reverse Bias. Bias voltage polarity that will cut off base-emitter current.

Semiconductor. Materials, such as germanium and silicon, whose resistance is greater than a conductor but less than an insulator, and which form the basic material used in the manufacture of transistors.