THE TRANSISTOR
RADIO HANDBOOK

- *Theory*
- *Circuitry*
- *Equipment*

THE TRANSISTOR
RADIO HANDBOOK

(First edition)

– *Theory*

– *Circuitry*

– *Equipment*

by Donald L. Stoner and L. A. Earnshaw

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THE
TRANSISTOR
RADIO HANDBOOK

1st EDITION

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FOREWORD TO THE FIRST EDITION

In all probability this is the first transistor manual written by two authors in two widely separated countries. Transistors are transistors the world over, and in each country they function the same.

Different environments engender different ideas, however. One cannot imagine an Eskimo inventing a plow, a Bolivian inventing a kayak, or an American inventing a set of chopsticks. However, if one gave an American a set of chopsticks and said "Improve on these," no doubt he would.

Through the medium of amateur radio, the authors have discussed the subject of transistors back and forth across the Pacific ocean. We sincerely hope that the synthesis of our ideas have produced worthwhile results. While we make no claim to having invented a new kind of plow or a better kayak, we do feel that by adding small bowls to the ends of the chopsticks and calling them spoons, we have improved on something. Bowls are not new, nor are chopsticks, but a combination of both is a very useful tool.

The authors particularly wish to thank the following individuals and companies who have provided assistance and encouragement in this project.

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Mr. Ed. King	*Amperex Semiconductors*
Mr. John Vadja	*Motorola Semiconductors*
Mr. William Wilson	*International Rectifier Corp.*
Mr. C. D. Simmonds	*Philco Semiconductors*
Mr. Frank O'Brien	*Pacific Semiconductors*
Mr. John Fischer	*Radio Corporation of America*
Major Gilbert	*Texas Instruments*

Inside Semiconductors

The reader need not understand all the mysteries pertaining to holes, covalence bonds, etcetera, to construct transistor circuits and equipment. All that is needed is a good magazine article and a few clear photos. However, this basic information is essential either to troubleshoot equipment properly or to design circuits yourself. If you are content to follow the leader, omit this chapter.

Before delving into the operation of a transistor, it would be useful to review a bit of high school chemistry regarding the nature of *matter*.

1.1   What is Matter?

That's simple. Matter is just about everything! Typical examples are the air we breathe, the water we drink, and the food we eat. These examples also illustrate the three basic forms of matter: gaseous, liquid, and solid. Matter may be found in these forms as either *elements* or *compounds*. An element is defined as a basic structure which cannot be separated into substances of other kinds. Scientists have been able to isolate over 100 elements. Some of the more familiar ones are copper, aluminum, hydrogen, and oxygen. Lesser known elements, which we shall study later, including silicon and germanium.

A compound, on the other hand, is a pure substance which contains two or more elements and has a constant composition. It usually exhibits properties different from the elements of which it is composed. A very abundant compound is water. It is composed of two parts hydrogen and one part oxygen and is known by chemical shorthand as H_2O.

The Molecule   Elements are thought to be composed of *molecules*. A molecule is the smallest physical part of an element or compound. If one divides a piece of copper many times into the smallest part possible and still has copper, this small part would be a molecule.

The Atom   Scientists believe that molecules are constructed of various arrangements of atoms. The molecule may contain one or more like atoms in an element or two or more different atoms in a compound. Figure 1.1-A shows the relationship between the atom and the molecule. Two of the simple hydrogen atoms combine with a single atom of oxygen to form one molecule of the compound water.

Since there are over 100 elements, it is reasonable to expect that there exist the same number of atomic structures which correspond to these elements. As will

TWO ATOMS OF HYDROGEN PLUS ONE OXYGEN ATOM = H2O

Figure 1.1-A
THE RELATIONSHIP BETWEEN ATOMS AND MOLECULES

soon be shown, the atom is made up of *subatomic particles*. The same particles make up all the atoms in the universe. Only the manner in which they are arranged varies, and it is the arrangement which gives each atom its own characteristics. This may be easier to comprehend if one compares the atom to a fingerprint. The fingerprint is composed of simple loops and whirls, but they can be combined in an infinite number of ways, and no two fingerprints are alike! Criminologists are convinced that all the fingerprint types in the world have *not* been discovered. Similarly, scientists assume that there are more elements which have not been identified.

1.2 Building Blocks of the Universe

For the purpose of illustration, let the reader equip himself with a more powerful microscope than exists in the world. With the microscope, examine a piece of aluminum. Aluminum is usually associated with chassis and panels. It is smooth and

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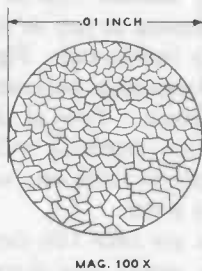
Figure 1.2-A
CRYSTALLINE SURFACE OF ALUMINUM

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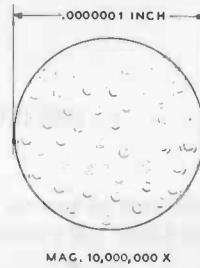
Figure 1.2-B
VAGUE OUTLINE OF THE ATOMIC STRUCTURE OF ALUMINUM

shiny, and may be drilled, punched and formed into angles. If, however, the surface is magnified 100 times, it becomes obvious that the aluminum is not smooth, but actually has a rough crystalline surface as shown in figure 1.2-A.

If the surface is magnified 10 million times, one begins to see vague outlines of roughly spherical shape. These tiny blobs are the atoms of aluminum, and may be "seen" in figure 1.2-B.

No one has seen an atom. However, with X-ray techniques and advanced mathematics, it is possible to make some rather accurate guesses about their appearance. Scientists believe the atom looks like the drawing in figure 1.2-C. It consists of a central core with one or more tiny particles orbiting around it as planets orbit the sun in the solar system.

To simplify explanations and drawings,

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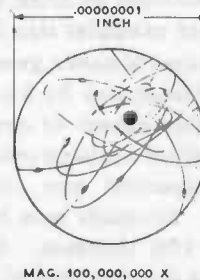
Figure 1.2-C
SCIENTISTS BELIEVE THE ATOM LOOKS LIKE THIS.

the atom is usually depicted as shown in figure 1.2-D; in this case it is the "chemical schematic" of an atom of aluminum. Notice that this atom of aluminum is more complex than the hydrogen atom shown in figure 1.1-A.

Composition of the Atom Referring to figure 1.2-D, the central core of the atom is termed the *nucleus*. If it were possible to examine the nucleus of the aluminum atom under the imaginary microscope, one would see something similar to figure 1.2-E. The nucleus is composed of *neutrons* with *no charge* and *protons* which have a positive *charge*. These components make up the heart of the atom. Note in figure 1.2-D that the nucleus of the atom consists of 13 protons and 14 neutrons.

Each of the tiny particles orbiting the nucleus is a negatively charged *electron*. The electrons whirl at tremendous speeds around the nucleus in orbits or *rings*, as they are more commonly called. Note further that the aluminum atom has two electrons in the first ring, eight in the second, and three in the outer ring, for a total of 13 electrons.

Size It might be helpful to describe these particles in definite terms. The diameter of an electron is believed to be 0.00000000000022 or 22×10^{-14} inches and is about three times the size of the proton. Despite its smaller size, the mass of the proton is about 1,850 times that of the electron. The comparison is something like a cubic foot of lead to a cubic foot of feathers.

1ST RING, 2 ELECTRONS —

NUCLEUS CONTAINING 13 PROTONS AND 14 NEUTRONS.

2ND RING, 8 ELECTRONS —   — 3RD RING, 3 ELECTRONS
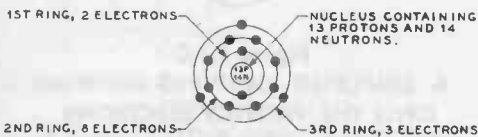
Figure 1.2-D
A SINGLE ATOM OF ALUMINUM
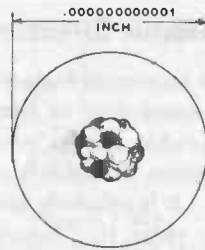
.000000000001 INCH

MAG. 1,000,000,000,000 X

Figure 1.2-E
THE NUCLEUS OF THE ATOM IS BELIEVED TO LOOK LIKE THIS
It contains both positive protons, and neutrons which have no charge.

If you can comprehend a copper penny being enlarged to the size of the earth's orbit around the sun, then you would be able to visualize the electrons in the copper. They would be roughly the size of baseballs and might be spaced approximately three miles apart! The nucleus, the central "sun," would be composed of a group of neutrons and protons about the size of walnuts!

All matter is composed of atoms. By the same token, all atoms are built up from electrons, neutrons, and protons. Only the way in which the parts are arranged and their quantities will differ. Thus, these particles may be considered the fundamental building blocks of the universe.

Charges The positive charge on the proton and the negative charge on the electron are exactly equal in the aluminum atom discussed earlier. The 13 protons equal the 13 electrons, and this aluminum atom is said to be *electrically balanced*.

These charges are believed to be the smallest that exist, and therefore they are considered the fundamental unit of electrical charge. However, this quantity is much too small to deal with, and the coulomb is commonly used in its place. One coulomb of electricity contains more than six million, million, million, or 6.28×10^{18} electrons!

1.3 Atomic Structure

The most important feature of the atom is the fickle outer ring of electrons. The atom is somewhat similar to the common household onion in that it is composed of many rings. It is relatively easy to remove pieces of the outer ring simply by peeling them off. The inner rings do not fall off, for the outer rings hold them in place.

The inner rings of the atom are tightly bound to the nucleus, but the outer ring may be stripped off. More commonly, subtle modifications are made to change its characteristics.

It is also known that the electrons in the outer ring may skip from one atom to another in a random manner due to thermal agitation (heat). Also, electrons may be added or removed from the outer ring. Electrons able to move in this manner are known as *valence electrons*. Any matter with a large number of valence electrons is known as a *conductor*, and matter which has few loosely held electrons is termed an *insulator*. Materials referred to as *semiconductors* lie somewhere between these two extremes. Germanium and silicon are two excellent examples of semiconductors. These two elements are not very good conductors in their pure states. When properly modified they can be made to conduct electricity, much the same as a piece of wire.

The atomic schematics for germanium and silicon are shown in figure 1.3-A and 1.3-B, respectively. For simplicity, the neutrons found in the nucleus are not shown. Since neutrons have no charge, they do not affect our discussion. Note also the similarity between the germanium and sili-
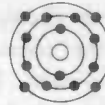
1ST RING – 2 ELECTRONS
2ND RING – 8 ELECTRONS
3RD RING – 4 ELECTRONS

Figure 1.3-B
SILICON ATOM (Si)

con atoms. Each atom has four valence electrons in the outer ring. Since the action occurring in the atom takes place in the valence ring, the atomic schematic may be further simplified by showing only the valence electrons, as in figure 1.3-C. When reduced to this form, both germanium and silicon appear to be identical, and as a matter of fact they are equally useful in manufacturing transistors.

The reader should understand that different materials may contain a different number of valence electrons. However, just because two atoms contain the same number of valence electrons, they do not necessarily constitute the same material. Note that in aluminum the valence ring contains three electrons, as does gallium, which is also used in manufacturing semiconductor products. Two other elements useful in preparing semiconductors are antimony and arsenic, each having five valence electrons.

1.4 Crystal Lattice Structures

Most substances when examined under a microscope will exhibit a crystalline structure, even though the surface may appear smooth to the eye. All crystalline sub-
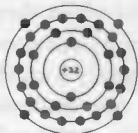
1ST RING – 2 ELECTRONS
2ND RING – 8 ELECTRONS
3RD RING – 18 ELECTRONS
4TH RING – 4 ELECTRONS

Figure 1.3-A
GERMANIUM ATOM (Ge)

Figure 1.3-C
A SIMPLIFIED DRAWING SHOWING ONLY THE VALENCE ELECTRONS
This could be either the germanium or silicon atom since they both have four valence electrons.

stances have an identifying characteristic. The most common example would be the elusive snowflake, which is composed of an infinite number of geometric patterns made up of 60° angles. Common household salt will form tiny cubes, while some materials form needles, rhomboids, or variations of hexagonal or rectangular structures.

By scientific deduction, it appears that the rotation of the valence electrons in one atom is closely coordinated to the electron motion in adjacent atoms. The coordinated rotation forms **an** *electron pair bond* or a *covalence bond*. This bond is countermanded by the repulsion of the positively charged nucleus and a state of equilibrium exists, forming a single crystal of the material.

The lattice structure of a single germanium crystal is shown in figure 1.4-A. For simplicity, only one "layer" of the structure is shown. Although it is not possible to illustrate the fact with two dimensional drawing, each germanium atom is bonded by electron pairs to *four* adjacent atoms (or would be if an infinite number could be illustrated). This is due to the fact that each atom contains four electrons in the outer or valence ring.

In the element copper, the valence electrons are not tightly bound as just described, but are free to move about. Thus, when subjected to an electric potential, the valence electrons move in an orderly manner. Such material is said to be a good conductor. On the other hand, material
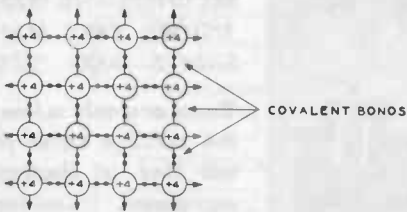
Figure 1.4-A
A STABLE LATTICE STRUCTURE CON-
TAINING ONLY GERMANIUM OR
SILICON ATOMS.
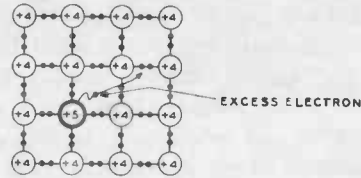
Figure 1.5-A
A "DONOR" IMPURITY HAS BEEN
ADDED TO THE PURE GERMANIUM
INTRODUCING AN EXCESS ELECTRON

like polystyrene is a poor conductor, and examination shows that its valence electrons are very tightly bound together.

1.5   Impurities

Earlier it was stated that silicon and germanium could be made into conductors by modifying their structure. These structures were considered to be *pure*, that is, containing nothing but germanium or silicon atoms. To be usable in semiconductors, germanium and silicon must be *refined* to the point where only one impurity will be found in 10 billion parts of the pure material.

When this state of purity is achieved, a controlled amount of *impurities* may be added to modify the structure in a desired manner. Such impurities might be antimony, arsenic, aluminum, or the gallium mentioned earlier.

A typical example might be the pure germanium structure discussed in section 1.4. Impurities "dope" the element by adding one part antimony (five valence electrons) to 10 million parts of germanium. An examination of the germanium structure now will show an extra atom in the group (figure 1.5-A0, a single atom of antimony. A closer look will show that the atom is accompanied by an excess electron. Remember that germanium has four valence electrons, while antimony has five. Since there can be no more than four electrons in any of the valence rings, this excess electron must drift through the structure

looking for a gap to occupy. Fortunately for the transistor industry it never finds one! The excess electron may combine with one of the valence rings, but it will always drive out an electron, leaving one extra electron in the structure for each excess electron added.

The impurity that has donated the extra electron is logically called a *donor impurity*. Arsenic could also be the donor since it has one extra electron when compared to germanium or silicon. Although the discussion has dealt with single structures and a single excess electron, the reader should be aware that millions of these excess electrons are present in millions of lattices, even in a piece of germanium too small to be seen with the naked eye.

Germanium to which a donor impurity has been added is called *N-type* germanium, since it contains an excess of electrons which carry a negative charge.

Acceptors Just as we have added the antimony and arsenic impurities, it is possible to "contaminate" pure germanium with aluminum or gallium. As mentioned earlier, these two im-
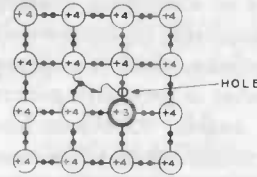
Figure 1.5-B
AN "ACCEPTOR" IMPURITY IS SHOWN ADDED TO PURE GERMANIUM
Valence electrons try to fill this space, but a gap always remains in the structure.

purities have only three valence electrons. What happens to the atomic structure when these impurities are combined with the germanium or silicon? There is no longer an excess of electrons, but rather a lack of them. Thus, this impurity is able to accept electrons from the germanium, leaving a *hole* in the valence rings. This type of impurity is referred to as an *acceptor impurity*.

To illustrate what might happen in a single crystal of germanium when "doped" with acceptor impurities, refer to figure 1.5-B. The impurity atom might withdraw an electron from the adjoining germanium atom in a futile effort to neutralize the
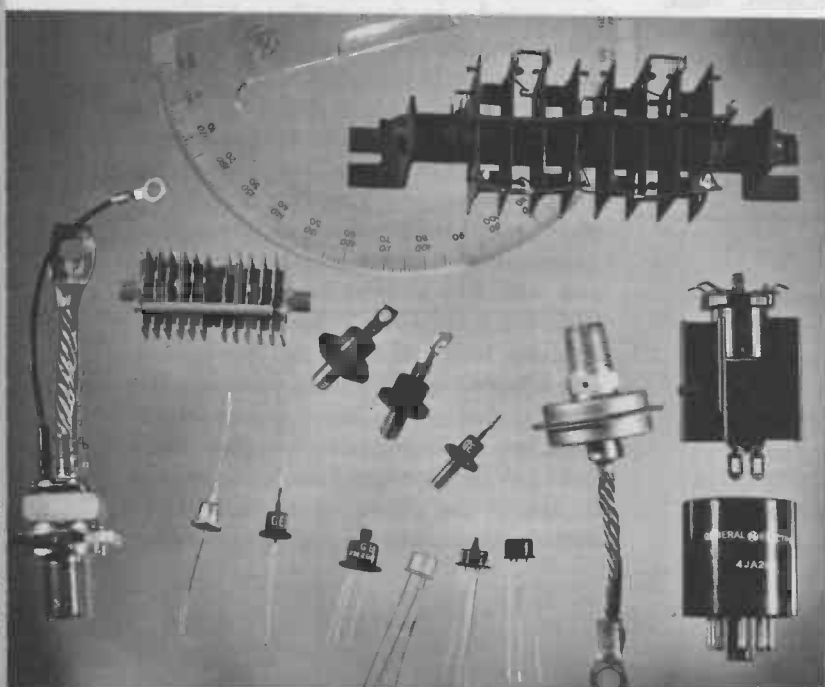
SEMICONDUCTOR RECTIFIERS AND TRANSISTORS TAKE MANY SHAPES AND SIZES.

These are only a few of the package styles you will find in electronic equipment. (Courtesy, General Electric Company)

structure. However, this leaves a gap in the adjacent atom's valence ring which might be filled. Our incomplete atom is compelled to become whole again and it, in turn, withdraws an electron from another atom. This occurs continuously, and in a random manner. The hole is simply a gap in a valence ring, which has no electron to fill it. Since there is continuous agitation in the structure (due to ever-present heat) the gap or hole is continuously changing position. As before, there are millions of these impurity atoms in a tiny speck of germanium, and, consequently, there are also millions of holes seeking an electron. Although the holes are moving, they are evenly distributed and never leave the confines of the germanium. A piece of germanium doped in this manner is called *P-type* germanium, since it lacks electrons and therefore must carry a positive charge.

An analogy which might help clarify the function of the hole is the classic garage full of cars illustration. As shown in figure 1.5-C, the 12-car garage is nearly filled to capacity with 11 automobiles. Naturally, the only empty space is at the rear of the garage. When one drives up to 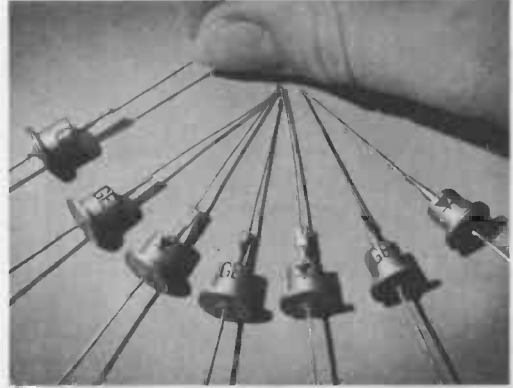store a car, the attendant moves the front car forward into the space. He then moves the second car up a space. Finally, after moving each car up a space, he makes way for the 12th car. Although the attendant has only moved cars forward, in effect, he has moved the

THESE POWER DIODES WILL DO THE SAME JOB AS A 5U4 RECTIFIER
But they will provide more output voltage for an indefinitely long time.
(Courtesy, General Electric Company)

space (the hole) toward the entrance.

When a potential is applied to the P-type germanium, the holes will move in a very orderly fashion and in one direction, which constitutes an electric current. In N-type germanium, the electrons move from the negative to the positive source while in P-type material, the holes traverse from positive to negative. The holes (P) or electrons (N) are termed the *majority carriers* since they make up the majority of moving particles.

1.6   Junctions

The reader with a fair imagination should be able to visualize what happens inside a piece of impurity-doped germanium or silicon, whether type N or type P.

Consider now what happens when blocks of N-type and P-type materials are "sandwiched" together to from a *P-N junction* (figure 1.6-A.) The situation produced by joining of P and N type material is somewhat complex. Remember that when manufactured, P-type material is elec-
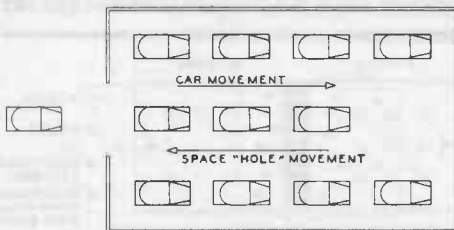
Figure 1.5-C
CLASSIC EXAMPLE SHOWING MOVE-MENT OF HOLES
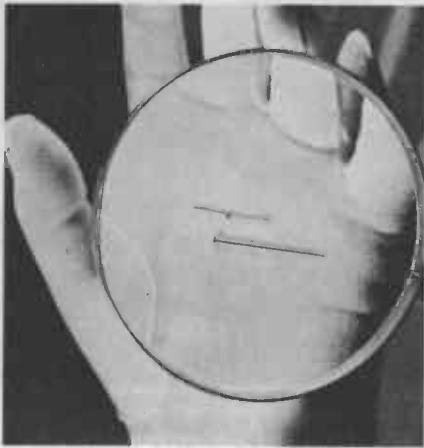
**PROBABLY THE WORLD'S SMALLEST
SEMICONDUCTOR DIODE**
The "Tiny Tim." That's not a 16-penny
nail; it's a common household pin!
(Courtesy, Pacific Semiconductors, Inc.)

DEPLETION
REGION
SHOWING
RECOMBINATIONS

**Figure 1.6-A
TWO "BLOCKS" OF GERMANIUM ARE
JOINED TO FORM A JUNCTION**

trically neutral, as is also the N-type material. Because the atoms in each are sharing electrons or holes, there is no actual surplus of electrons or holes. A surplus or a deficiency of electrons would mean that the germanium (or silicon) was electrically charged. When the two types of germanium are placed together the reader might immediately assume that the excess electrons in the N-type material would join the holes in the P-type material. This is not the case. Although a few *recombinations* do occur, these are caused by thermal agitation. The two sides actually set up a *barrier*, preventing total recombination. If an electron crosses from the N zone to the P zone, both electrically neutral pieces will now take on a charge. The N zone will have lost an electron and the P zone will have gained an electron. The P zone will thus become negative with respect to the N zone. Thus, the negative P zone will now repel the entry of further negative particles. Remember that like poles repel and unlike poles attract. In fact, a barrier is set up between the two junctions, and it takes a potential from a

battery to force reluctant electrons across the barrier.

The physical width of the barrier is rather indefinite and is usually measured in terms of the voltage necessary to drive an electron across the depletion region. With no external potential applied, the barrier width may be as high as 0.6 volts. This is called the *barrier potential*.

**Forward
Bias**   If electrons can be made to traverse the barrier with an applied potential, it is reasonable to assume that the P-N junction will conduct a current.

To obtain *forward bias*, the positive terminal of a battery is connected to the P-type germanium and the negative terminal of the battery is connected to the N-type germanium. If one could examine the inside of these slabs of germanium (figure 1.6-B) it would be seen that the holes are being repelled from the positive terminal and the
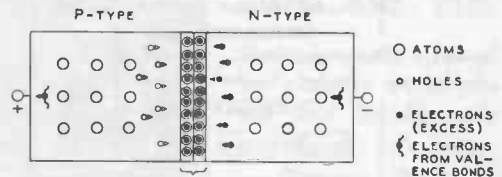
**Figure 1.6-B
A GERMANIUM JUNCTION WITH FOR-
WARD-BIAS APPLIED**

electrons repelled from the negative terminal. This electric pressure against the depletion region greatly reduces it, allowing large quantities of holes and electrons to recombine. For each recombination that occurs, an electron from the negative terminal of the battery enters the material. Similarly, an electron breaks its bond and enters the positive terminal of the battery. At the same time an electron from the negative terminal enters the junction to repair the bond. The action is continuous. Recombination about the depletion region occurs so long as the battery is across the junction. Connected in this manner, an electric current flows in the external circuit.

Reverse Bias   An entirely different effect takes place when the battery is reversed. For a *reverse bias* condition, the positive battery terminal is conected to the N-type germanium and the negative terminal is connected to the P-type germanium.

Once again inspecting the interior of the germanium (figure 1.6-C), one finds that the holes in the P-type germanium are attracted to the negative end of the structure, while the electrons are drawn to the positive end. This has the effect of stretching the depletion region, which increases the potential needed to overcome this barrier. In actual practice, the barrier width increases to the potential of the applied voltage and conduction does not occur.

The reverse-biased junction may be thought of as having a very high resistance.
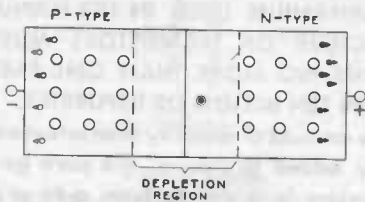
Figure 1.6-C
A GERMANIUM JUNCTION WITH RE-VERSE-BIAS APPLIED
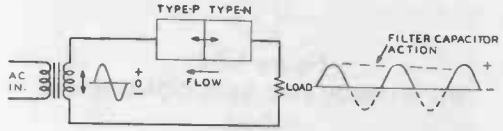
Figure 1.7-A
SINGLE P-N JUNCTION USED AS A RECTIFIER

Actually the resistance does not go to infinity, for a small amount of recombination does occur. This represents a tiny reverse *leakage current* caused by the minority current carriers. With a small voltage applied, the leakage current will be only a few microamperes. If excessive voltage is applied, the atomic stability of the lattice may be impaired, which breaks down the junction. This effect does not damage the junction unless excessive heat is generated due to heavy current flow.

1.7   Diode Action

From the preceding explanation the reader can see that the diode will conduct when the applied potential is in the forward direction and (for all practical purposes) will not conduct when reverse biased.

If connected as shown in figure 1.7-A, the junction becomes a *rectifier* when an a.c. signal is applied. During the positive half-cycle the depletion region is almost nonexistent (once the barrier potential is overcome), and current flows virtually unopposed. During the negative half-cycle the conditions are identical to reversing the battery (reverse bias) as explained earlier in section 1.6. During the entire half-cycle the depletion region expands and contracts in proportion to the applied voltage. Thus, during the entire negative half-cycle, the barrier places a very high resistance in the circuit. The voltage appearing across the load, then, is a series of positive half-cycles. These may be used to charge up an electrolytic capacitor to supply nearly pure d.c. to the load.

Figure 1.7-B
THE SYMBOL FOR SEMI-CONDUCTOR DIODE

In the case of a junction rectifier the arrow corresponds to the anode which is of type-P material. The bar is the cathode and is of the N-type. The arrow points INTO the direction of electron flow.

Silicon Power Diodes   The P-N junction makes a very effective rectifier in high voltage and high current supplies, particularly when silicon is used. Silicon is able to perform its duties in the presence of high temperatures and therefore is sometimes preferable to germanium.

Silicon diodes are becoming extremely popular with amateurs and experimenters and have virtually replaced selenium rectifiers in all but the most inexpensive commercial equipment. The reason for their popularity is the depletion region or potential barrier mentioned earlier. It requires some 0.6 volts to cross over the barrier. Once this potential is exceeded, the diode acts as a virtual short circuit.

Examine the power supply shown in figure 1.7-A. Apply 150 volts a.c. and connect a 500 ma. (0.5 ampere) load to the output. As soon as the barrier is overcome (0.6 volts), current surges through the load on the positive half-cycle. At the peak of 150 volts, the load is drawing 500 ma. What about the diode losses which generate heat and limit the operation? Only 0.6 volts is "lost" inside the diode, and at 500 ma. one finds that only 0.3 watts is absorbed (and must be dissipated) by the diode. Actually, this is slightly utopian, for the diode resistance does not drop to zero. Even so, the losses are not likely to exceed one watt, which may easily be dissipated without cooling fins.

The selenium rectifier, on the other hand, has comparatively high losses. This can be proved without an atomic explanation simply by examination. A typical 500 ma. selenium rectifier might be three inches square, one inch thick, and contain five or six plates with selenium oxide spread on the cooling fins. Compare that area to the tiny 0.5 ampere diodes shown in the photographs!

The P-N junction contained in a 0.5 ampere silicon diode might be the size of a pin head. The junction is securely fastened to the metal case (which would fit inside a thimble) to provide all the heat dissipation necessary.
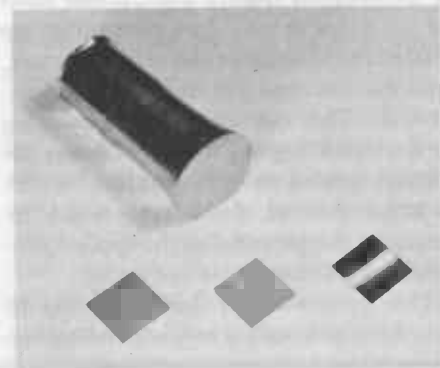
GERMANIUM USED IN THE MANUFACTURE OF TRANSISTORS MUST HAVE NO MORE THAN ONE PART IN TEN BILLION OF IMPURITIES.
The amount of impurity then intentionally added to "dope" the pure germanium in order to form a N or P type is roughly comparable to two people in the population of the United States.   (Courtesy, CBS Electronics)

Figure 1.7-C
ZENER DIODE VOLTAGE/CURRENT CHARACTERISTICS

**Zener
Diodes**

Earlier it was mentioned that excessive reverse voltages could break down the P-N junction. Certain diode types are cultured to exhibit this effect at a very low reverse voltage. When the breakdown voltage is exceeded, the lattice structure collapses and the electrons *avalanche* through the junction. Thus, nearly total recombination occurs.
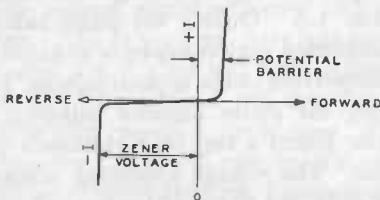
Through careful manufacturing techniques it is possible to provide diodes which break down at discreet voltages, say 3.9, 4.7, 5.6 and so on up to several hundred volts. Such a diode is known as a *zener diode*, or more correctly as an *avalanche diode*. A diode which breaks down at some exact voltage (figure 1.7-C) makes an excellent regulating device.

**Junction
Capacity**

Although not particularly applicable to this discussion, an interesting point is the capacity exhibited by the depletion region. As the reverse bias on the diode junction is increased, the depletion region expands. The action is similar to moving the plates of a capacitor farther apart. This, of course, effectively reduces the junction capacitance which in turn reduces the terminal capacitance of the diode. By the same token, lower reverse voltages narrow the depletion region, thereby decreasing the capacitance. This variable capacitance effect may

THIS TINY VARIABLE CAPACITY DIODE WILL REPLACE THE CAPACITORS SHOWN
These "Varacap" diodes will undoubtedly be widely used in amateur equipment. (Courtesy, Pacific Semiconductors, Inc.)

be used to advantage by applying diodes to adjust the resonant frequency of tuned circuits. Such a device is known as a *variable capacitance diode*.

1.8   Transistor Action

The diode (or P-N junction) provides an excellent foundation of blocks upon which to build a transistor. The simple junction transistor may be thought of as a triple-deck germanium sandwich.

**The
P-N-P
Transistor**

When a block of P-type germanium is sandwiched between two blocks of N-type germanium, two potential barriers develop---one at each junction.

The block diagram of a *P-N-P transistor* is shown in figure 1.8-A. From left to right, the blocks are termed *emitter, base,* and *collector*. The recombined electrons and holes in the depletion regions are not
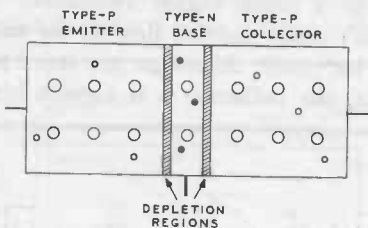
**Figure 1.8-A
P-N-P TRANSISTOR WITHOUT APPLIED POTENTIAL**
The holes and electrons drift aimlessly about.

Figure 1.8-B
FORWARD BIAS

Forward bias of the emitter-base junction allows holes to recombine in the collector, creating a current flow in the reversed-bias base collector junction.

shown due to space limitations. For the purpose of explanation, connect two batteries as shown in figure 1.8-B. Wired in this manner, the P-N junction (emitter to base)is forward biased, and recombination occurs. The holes that would normally speed off to the battery are instead driven through the P-N junction (base to collector), due to the greater attraction of the negative collector for the positively charged holes. If the forward bias battery is reduced to zero, the emitter base barrier increases and reduces the amount of holes reaching the collector. The action is quite similar to that of the grid in a vacuum tube, which controls the electron flow between cathode and plate.

The The action of this transistor is
N-P-N identical with the P-N-P tran-
Transistor sistor except that the blocks contain the opposite type of impurities, and the majority current carriers are electrons rather than holes. Since electron carriers have a negative charge, all the battery polarities in figure 1.8-B must be reversed.

Before proceeding, it might be wise to review two points which are important to the following discussion and which should be kept firmly in mind.

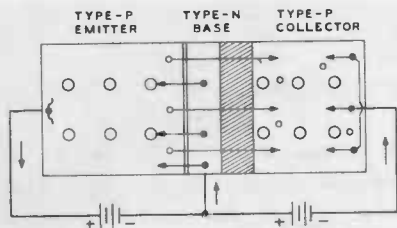1. The emitter base junctions must be *forward biased* in any transistor, or the majority current carriers (holes P-N-P and electrons N-P-N) cannot be propelled to the collector region.

2. In either transistor type, the collector must be *reverse biased* to prevent all the holes (P-N-P) or electrons (N-P-N) from going directly to the collector. If the collector base junction were forward biased, the barrier would be greatly reduced, and the emitter to base junction could not control current flow.

Transistor At this point the reader may
Gain relegate to memory the elusive atoms, electrons, and holes to deal with the more tangible external effects created by the transistor. The illustration, figure 1.8-C, shows a more schematic-like version of figure 1.8-B. As before, the emitter base junction is forward biased and the base collector junction is reverse biased. Recall that a forward biased junction behaves relatively like a medium resistance, since the base emitter circuit allows some electrons (or holes) to exit at the collector connection.

Under the bias conditions just described, an external milliammeter will show that approximately one ma. is flowing in the emitter circuit. Further investigation will show that approximately 95% of this current (0.95 ma) is flowing in the collector circuit. This may be hard for the reader to reconcile since it has been emphasized that the emitter base junction is equivalent to a low resistance, and the base collector junction to a much higher resistance. Why doesn't more current flow in the emitter base junction? Although not stated previously, the collector is at a much higher
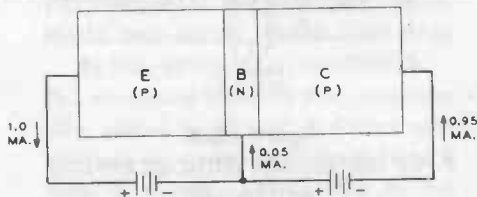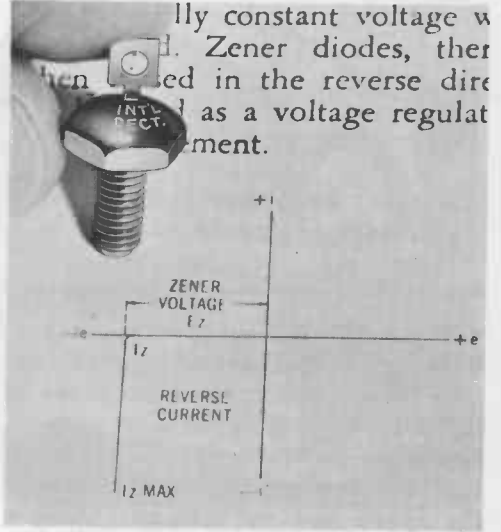

Figure 1.8-C
CURRENT FLOW IN A P-N-P TRANSISTOR

potential than is the base, with respect to the emitter. An inspection of figure 1.8-C will make this fact obvious. It can be seen that the collector-to-emitter voltage source is actually two batteries in series, while there is only one battery between emitter and base. In practice, the emitter base potential may be only 0.2 volts, while 1.5 to 100 or more volts may exist between collector and emitter.

Another consideration is the width of the base region. The base width is quite narrow, and the number of recombinations of electrons from the emitter circuit and holes from the base circuit is very small, with only about 5% of the electrons leaving the emitter. The remaining 95% of the emitter electrons will traverse the emitter collector depletion region and reach the collector. This accounts for the division of current as shown in figure 1.8-C.

Amplification If, in our experimental circuit (figure 1.8-C), the battery started to weaken, the terminal voltage would drop. The current in the emitter base junction might drop from 0.05 ma. to 0.03 ma. We know that this current drop would widen the potential barrier and reduce the amount of electrons (or holes) flowing in the collector circuit. For example, in practice, the collector current might drop from 0.95 ma. to 0.75 ma. Thus, a change of 0.02 ma. in the emitter base junction has caused a 0.2 ma. change in the col-

**Figure 1.8-D
SCHEMATIC REPRESENTATION OF
P-N-P AND N-P-N TRANSISTORS
Note that the direction of the arrows
points INTO the current flow.**

**ZENER DIODES ARE MANUFACTURED
TO "BREAKDOWN" AT DISCREET
VOLTAGE.**
They thereby provide excellent regulating characteristics. Note the "Z" shape of the voltage/current curve.
(Courtesy, International Rectifier Corporation)

lector circuit. Stated another way, the transistor exhibits *current amplification*. Simple mathematics will show that this transistor has a *current gain* of 10. The current gain ratio is termed *beta* (β) and is defined as the *change* in collector current divided by the *change* in base current. The beta of a transistor is always more than one (assuming it is not defective) and may reach one hundred or more.

In the preceding example, when the base current dropped from 0.05 ma. to 0.03 ma., the collector current dropped from 0.95 ma. to 0.75 ma. The emitter current, then, must have dropped from one ma. to 0.78 ma. Even though the margin between collector and emitter current is less, it can never reach unity, or one. This brings us around to the term *alpha* (α) which is expressed as the *change* in collector current divided by the *change* in emitter current. Alpha can never exceed one, and is usually closer to 0.95.

Figure 1.8-E
**A SIMPLE EXPERIMENT DEMONSTRAT-
ING GAIN IN A COMMON-BASE CIR-
CUIT.**

Voltage   To illustrate how voltage ampli-
Gain   fication may be obtained, con-
nect the transistor as shown in
figure 1.8-E.   It is similar to the previous
figure, but the schematic symbol is used.
Resistors have been inserted in series with
the emitter and the collector.   Also, a
source of alternating current is connected
in series with the forward bias battery.
Since the emitter-base junction represents
a low resistance, this series resistor is small
(100 ohms). The collector-to-base junction
appears to be a greater resistance, and there-
fore this resistor is larger (1000). Assume
that additional batteries have been added to
compensate for the resistors, and the cur-
rent flowing in the circuit is the same as
before (0.05 ma. base and 0.95 ma. collector).

The a.c. is at very low voltage, however.
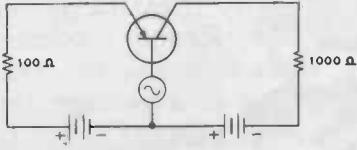The negative peaks aid the forward bias
current causing the transistor to draw more
collector current. Positive peaks oppose the
forward bias, which in turn reduces the
base current. As before, this changing cur-
rent is amplified by the transistor and ap-
pears as a large variation in the collector
circuit.

The transistor has a current gain (β)
of 10.   For every unit of current change in
the base circuit there will be 10 units of
change in the collector circuit. Similarly,
the transistor will exhibit a voltage gain. In
other words, one unit of current through
the base resistor will cause one unit of
voltage drop across it, and 10 units of cur-
rent through the collector resistor will cause
10 units of voltage drop across it.   The
amplified voltage can be used to drive a

following transistor for additional gain.

The transistor emitter, which may be
thought of as emitting the electrons (or
holes), is similar to the vacuum tube cath-
ode.   The base, which acts as the control
center for the electron flow, may be likened
to the tube's grid. The collector, which gath-
ers up the electrons (or holes), acts much
the same as a vacuum tube plate.

The transistor may be compared to the
vacuum tube in yet another way. If the
positive peak of the driving signal is too
great, it opposes the bias current to the
point where the transistor collector current
will be *cut-off*. If the negative peak is high,
it aids the bias in forcing almost all of the
electrons (or holes) into the collector, *pro-
ducing saturation.*

This section has presented some of the
highlights of transistor action. Voltage and
current applification, bias, stabilization, cir-
cuit configurations and impedance match-
ing are much too diverse subjects to include
in this chapter.   These subjects are covered
more fully in Chapter 2.
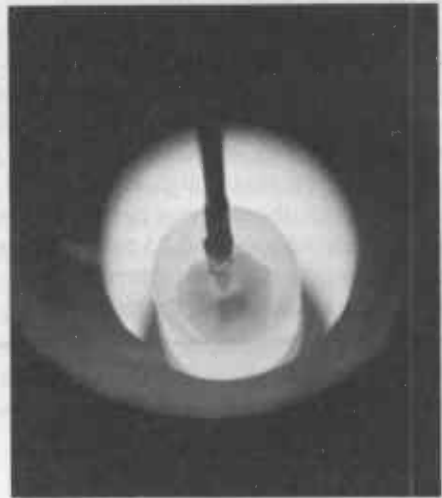
**A CRYSTAL BEING GROWN BY A
HIGH TEMPERATURE - METHOD**
The molten material is cooled as it is
withdrawn from the crucible to form a
germanium crystal ingot. (Courtesy,
CBS Electronics)

1.9 Transistor Construction

The physical construction of transistors is interesting, but knowledge of the subject is not necessary for design of circuits using transistors.

Purification There are so many difficulties and variables connected with manufacturing a transistor that it is difficult to believe that one can be manufactured to sell for less than $1.00. But it is done, and the manufacturer, distributor, and supplier each make a profit!

Take, for example, the purity required. To make a transistor, the impurities should be reduced to one part in 10^{11}, or about one grain of sand in a boxcar load of sugar! This is accomplished by *zone refining* the germanium or silicon. The contaminated material is placed in a carbon boat or supported between carbon holders. Carbon for this purpose is inert, and its impurities do not affect the material being refined.

The boat containing the slender rod of semiconductor material is passed through an induction coil which melts a narrow zone of material. The boat moves slowly through the coil allowing the melted zones to solidify again. The impurities are forced along ahead of the melting area much the same as one might wipe dirt off a mobile whip antenna with a cloth. The end result is a practically pure ingot of germanium or silicon.

**CLAIMED TO BE THE WORLD'S LARG-
EST TRANSISTOR**
This demonstrator dynamically shows the flow of holes and electrons in a junction transistor. (Courtesy, Texas Instruments.)

**Point
Contact
Transistor** The invention that heralded the dawn of the semiconductor era in 1948 was the *point contact* transistor. The *junction transistor* was not invented until late in 1949. Point contact transistors are not now used or manufactured. In fact, they are considered collector's items.

Internally, the point contact transistor looks very much like the 1N21B radar diode, but it has two very closely spaced "catwhiskers", as shown in figure 1.9-A. The contact points rest on a slab of N-type germanium. By itself, this device would not work at all. However, in manufacture, a very short pulse of high current is passed through the contact and the germanium. This is known as *forming* and produces a film a few atoms thick which exhibits the same characteristics as a type-P germanium. Since the contacts are very close together, the emitter base junction is capable of controlling the current flow in the base collector junction.

E   B   C

**Figure 1.9-A
SIMPLIFIED CONSTRUCTION OF A
POINT-CONTACT TRANSISTOR**

	INITIAL CONDITIONS	INTERMEDIATE STAGE	FINISHED STRUCTURE
ALLOY (IMPURITY CONTACT)	DOTS APPLIED	HEAT MELTS DOTS	DOTS RECRYSTALLIZE
DIFFUSION (IMPURITY CONTACT)	GASEOUS DOPING AGENTS APPLIED	DOUBLE DIFFUSION COMPLETED	ETCHING EXPOSES BASE
RATE GROWING (GROWN)	CYCLE JUST COMPLETED	HEAT REMOVAL GIVES RAPID GROWTH	HEAT REAPPLIED TO FORM JUNCTIONS
MELTBACK (GROWN)	DOUBLE DOPED PELLET	HEAT MELTS TIP	TIP FREEZING FORMS JUNCTIONS
GROWN DIFFUSED (GROWN)	MOLTEN METAL DOPED WITH EMITTER AND BASE IMPURITIES	BASE IMPURITY DIFFUSES RAPIDLY INTO COLLECTOR	EMITTER REGION ALONE CONTINUES TO GROW

Figure 1.9-B
ALLOY AND GROWN TRANSISTOR JUNCTIONS

(Courtesy, General Electric Company)

These early point contact transistors have a β as low as 2.5. They have the further disadvantage of being very delicate, since a sharp blow could dislodge the fragile cat-whiskers. As they could not be made in production quantities, they were priced very high.

To its credit, the point contact transistor could operate to approximately 100 Mc. The input impedance was of medium value, while the output impedance was of the order of 20,000 ohms.

Alloy and Grown Transistors   Impurities may be added to the pure germanium or silicon in one of several ways. Some of the methods are shown in figure 1.9-A. The alloy transistor technique was probably a major contribution to the mass production of transistors.

In this operation *dots* of impurities are placed in contact with the pure material and heated. The applied heat melts the dots and the impurities alloy into the base material. When the dots recrystallize, we find the impurities in the formerly pure material.

The impurities may also be added in a gaseous state as in the diffusion method. The impurities are allowed to envelop the pure material. It is then cut up and etched to expose the base region.

Another way to make transistors is to grow them! The pure material is placed in a graphite crucible (also inert) which is inserted in a *crystal-growing furnace*. The material is melted by induction and a *pull rod* with a *seed* on the end is dropped into the molten metal, then withdrawn slowly. The heat may be applied intermittently causing spaced junctions on the single crystal pulled from the molten metal. A more common method is to add impurities to the molten area just below the crystal. With careful timing and temperature changes, it is possible to grow a long series of P-N-P or N-P-N junctions.

Upon completion of the growing cycles, the ingot (containing the junctions) is cut into thin *wafers*. The wafers, in turn, are diced up into tiny blocks and mounted in the transistor case. Leads are connected to the elements, usually by a system of *thermocompression bonding*. Finally the air is removed, an inert gas inserted, and the transistor is sealed.

The completed transistor is then tested and *graded*. The grading process is necessary, since not all transistors from the same batch will test the same. The best units are labeled with a particular $2N$ number, while the remaining transistors are again graded. The transistor *run* is sorted into specification groups, such as the maximum frequency of amplification, and the remaining few are either destroyed or sold as salvage.

The Drift Transistor   The drift transistor, pioneered by Radio Corporation of America, is manufactured in such a manner as to accelerate the electrons on their journey through the junction. This shortens the time it takes for the electrons to traverse the material. This shortened *transit time* increases the high frequency performance much the same as in a vacuum tube.

Surface Barrier Transistor   The *surface barrier transistor* was developed by the Philco Corporation. In this device, two pits are etched into opposite sides of the base material. The spacing between the pit bottoms is only a few tenths of one-thousandth of an inch (a fraction of one mil). Next, the surface of the bottom of the pit is electroplated with emitter and collector material and electrodes are attached. This close spacing between emitter and collector greatly reduces the transit time, which improves the high frequency performance of the unit.

M.A.D.T.   The *micro-alloy diffused transistor*, a product of the Philco Corporation, is similar to the surface barrier transistor. The base width, diffusion layer width, and collector diameter are individually controlled by electrochemical etching. Since these factors are largely responsible for determining the transistor's high frequency properties, precise control results in a device of excellent uniformity. Several current M.A.D.T. type transistors, such as the Philco 2N1745, are very inexpensive, yet have an $f^{max.}$ as high as 1300 Mc.

Mesa   The *mesa transistor* is well suited to high frequency, high power applications. Using photolithograph techniques, gaseous impurities are diffused into the semiconductor wafer to form two P-N junctions. The semiconductor wafer is etched away from the base

NEW METHODS OF GROWING SILICON AND GERMANIUM ACCOUNT FOR MUCH OF THE PROGRESS IN SEMICONDUCTORS
Silicon diodes are the end products of the crystal ingot pictured here. (Courtesy, CBS Electronics)

emitter area, leaving these elements on a plateau or mesa. The mesa transistor exhibits low saturation resistance, high current beta, and, in addition, many useful v.h.f. characteristics. Its high dissipation makes the design of high-power amplifiers quite feasible.

Epitaxial Transistors   The *epitaxial transistor* is a late development in semiconductor technology. The device is similar to the mesa, but the semiconductor layer is formed by an epitaxial (Greek for "settling") process and evaporated on a base substrate. These transistors feature all the favorable characteristics of the mesa, but are somewhat easier to construct. They should play an important part in future high-power communications equipment.

PROCESS DESIGNATION	GEOMETRICAL SHAPE B = BAR D = DOUBLE SIDED WAFER S = SINGLE SIDED WAFER	CROSS-SECTIONAL VIEW SHOWING JUNCTIONS (NOT TO SCALE)
RATE GROWN	B	
MELTBACK	B	
MELTBACK-DIFFUSED	B	
GROWN-DIFFUSED	B	
DOUBLE DOPED	B	
ALLOY	D	
DIFFUSED ALLOY (DRIFT)	D	
ALLOY DIFFUSED	S	
DIFFUSED BASE (MESA)	S	
DIFFUSED EMITTER-BASE (MESA)	S	
SURFACE BARRIER	D	
MICRO ALLOY	D	
MICRO ALLOY DIFFUSED	D	

Figure 1.9-C
CHART SHOWING JUNCTION PRO-
FILES FOR VARIOUS TRANSISTOR
TYPES
(Courtesy, General Electric Company)

Power The construction and manu-
Transistors facturing techniques for *power transistors* are similar to those of alloy transistors. In this device, however, more material is used to increase the power handling ability. In addition, several steps are taken to remove heat from the junctions. Since the power transistor has more mass, its high frequency performance is reduced.

The transistors discussed represent only a few of the popular types. A more complete listing is shown in figure 1.9-C.

In section 1.6, it was mentioned that thermal agitation was responsible for the action of the minority carriers (leakage current). This points up a basic flaw of the transistor. Changing temperature will affect the transistor by influencing both the majority and minority carriers. To illustrate the point, bias a transistor to draw one milliampere in the collector circuit. As a soldering iron or match is brought near the case, the heat causes increased thermal agitation in the unit and the collector current increases beyond one ma. This effect is inherent in transistors and must be compensated for in circuit design. The temperature influence on current is minimized in the better transistors but is always present.

Abnormally high temperatures may make the transistor useless or actually destroy it. Germanium transistors are usually rated to 85°C (185°F.), which is more than adequate for most applications. Military equipment, on the other hand, must have a wide margin of safety. This type of equipment almost always employes silicon transistors which may be used in external temperatures as high as 350°F.

High The *high frequency transistor*
Frequency places special emphasis on
Performance reducing the base width to shorten transit time and to increase the high frequency performance. In addition, the emitter and collector junctions are made as tiny as practicable to minimize junction capacity, which also inhibits the high frequency performance.

These techniques do increase the high frequency operation but have one serious drawback. As the junction size is reduced, so is the heat-dissipating ability. For this reason *most* high frequency transistors have very small dissipation rating. One exception is the mesa transistor.

A power transistor has a relatively large mass and junction area. Although it can be made to dissipate hundreds of watts, the operating frequency is reduced when com-

pared to smaller transistors. Some high-power audio transistors do not exhibit flat response between 20 cycles and 20 kilocycles, and feedback correction in amplifier circuits using these devices must be incorporated.

Noise The early transistors were very noisy. Although this gave transistors a very bad name, modern devices are the equal of tubes insofar as noise generation is concerned. In theory, at least it should be possible to make a transistor which is quieter than a vacuum tube, due to the lower operating temperature of the transistor. Currently, transistors are replacing tube preamplifiers in applications where quality and performance are of paramount importance.

Transistor Life It is impossible to make a flat statement as to the life of a transistor. If it is adequately sealed to prevent external contamination and operated conservatively it might last forever! The fact that it has no filament weighs heavily in its favor.

Transistors are far more rugged than are vacuum tubes. Military transistors have

HIGH POWER AT HIGH FREQUENCIES These transistors have 125 watts dissipation and an alpha cut-off of 50 mc. and are the smallest types in the series. These triple diffused mesa transistors are available up to 1200 watts dissipation. (Courtesy, Pacific Semiconductors, Inc.)

actually been shot from a gun into a telephone book to advertise dramatically how well they are constructed. When the transistors were reconnected into the circuit they worked perfectly!

Audio Amplifiers

Fundamentally, the transistor is a *valve* which controls the flow of electrical charges. We call these charges *current carriers*. As current carriers pass through the transistor they are controlled as easily as the current carriers which pass through an electron tube.

It is sometimes advantageous to compare transistors with vacuum tubes, for in many ways they are similar, but there are major differences to be pointed out as we proceed.

The transistor may be compared with a vacuum tube by considering the actions of the two devices. The emitter, which may be thought of as emitting electrons (or "holes"), is similar to a tube cathode. The base, which influences electron flow, may be likened to the tube grid. The collector, which gathers the current carriers (electrons or holes), acts in a manner similar to the vacuum tube plate.

2.1 Circuit Configurations

We can make further comparisons between the transistor and vacuum tube by examining the circuit configurations. There are several circuit arrangements for introducing a signal into a transitor, and for extracting the amplified signal from the circuit.

Common-Base Amplifiers Many have used the circuit in which a carbon microphone is connected in series with the cathode of a tube amplifier. This is a simple *grounded-grid* audio stage.

In the transistor equivalent, shown in figure 2.1-A, the signal is introduced into the emitter-base circuit, is then amplified by the transistor, and is extracted from the collector-base circuit. Since the base element is common to the input and output, this circuit is termed a common-base configuration. The emitter requires a positive voltage, and the collector requires a negative potential (for a P-N-P transistor), and, in this circuit, two separate batteries are required.
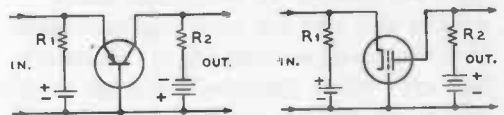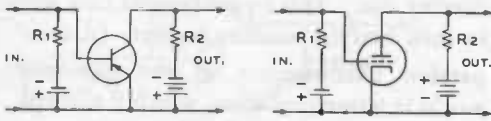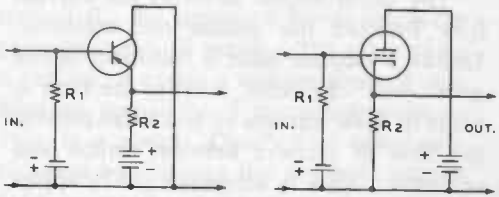

Figure 2.1-A
A COMMON-BASE AMPLIFIER COMPARED TO THE GROUNDED-GRID VACUUM TUBE AMPLIFIER

Figure 2.1-B
A COMMON-EMITTER AMPLIFIER
COMPARED TO A GROUNDED-CATH-
ODE VACUUM TUBE AMPLIFIER

Figure 2.1-C
A COMMON-COLLECTOR AMPLIFIER,
OR EMITTER FOLLOWER, IS SIMILAR
TO THE VACUUM TUBE CATHODE
FOLLOWER

Common-Emitter Amplifiers   This is the most common configuration in transistor (and vacuum tube) equipment and is shown in figure 2.1-B. Not only does it exhibit more power gain than the other circuits, but like the vacuum tube equivalent, it is the only configuration which provides signal *phase* inversion between the input and output circuits.

In this configuration both the base and collector are biased with negative potentials. Since both potentials are negative with respect to the emitter, a single battery may be used. Internally, the base-emitter junction forms a voltage divider in conjunction with R_1, which provides the necessary low value of forward bias voltage.

Common-Collector Amplifier   The *cathode follower* is a circuit which operates with its plate "grounded" for the signal frequency. The transistor equivalent is a common collector stage or *emitter-follower,* and is shown in figure 2.1-C. Contrary to other circuits, a cathode or emitter follower may have *power* gain but has no *voltage* gain.

Symbols   In figure 2.1-D will be found the symbols for P-N-P and N-P-N transistors. Note that in both cases the arrows point in the direction of the *hole* flow, and opposite to the movement of electrons.

2.2   Bias Considerations

A transistor which is designed to have a negative d.c. voltage applied to its collector is a P-N-P type (positive-negative-positive). An N-P-N transistor has a positive potential on the collector (with respect to the emitter).

The circuit of figure 2.2-A is one of the simplest transistor audio amplifiers. Ignoring resistor R_1 for the moment, the signal is applied between the base and emitter of the transistor. This is equivalent to driving the grid and cathode in a vacuum tube circuit. The emitter (cathode) is grounded, and the collector (plate) is connected through the headphones to the *negative* terminal of the battery.
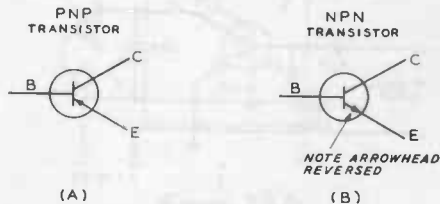
Figure 2.1-D
STANDARDIZED SYMBOLS FOR THE
PNP (a) AND NPN (b) TRANSISTORS

The input signal controls the current flow between the emitter and collector. Unlike a vacuum tube, a transistor *requires current bias.* In other words, the base is made to draw current so that it can control the flow of carriers between emitter and collector. This is accomplished by applying a negative potential to the base until it draws the correct current. This is the purpose of R_1, which is known as the *forward bias resistor,* and its value may be determined by Ohm's Law. The required base current is given in the transistor data and characteristic charts.

If the audio amplifier must handle a large input signal, the transistor is biased near the center of its collector current curve so that the instantaneous collector potential may swing an equal amount in each direction. If the amplifier is biased near the bottom of its curve it will operate class-B.

The circuit of figure 2.2-A is a simple and practical one, and many similar circuits will be found in this and other books. It might be considered as an audio "package" which could be added to crystal sets or transistor regenerative receivers.

2.3   Stabilization

It is an unfortunate characteristic of the transistor that when it is *heated* the collector current *rises.* This larger current flow will in turn heat the junction further. (A comparable phenomenon in the economic world is termed inflation, which if allowed to continue unchecked will cause a structural collapse!) Most of us have, at one time or another, inadvertently made the plate of a tube glow cherry red, yet have seen the tube go on working year after year. One cannot do this with a transistor. Once a transistor is over heated, its characteristics are altered and the unit often is rendered inoperative.

If the radio equipment containing the transistor is heated (in a closed car, for example, that has been standing in the hot sun) the current flow through the transistor may well rise to startling figures. Some means must be adopted to check the current and heat rise. This means, or measure of control, is known as *stabilization.*

D.C. Feedback   The circuit of figure 2.3-A is identical with that shown in figure 2.1-B, except that the earphones have been replaced with a load resistor. When the current through the transistor increases, voltage is dropped across the resistor R_2. If the forward-bias resistor R_1 is connected to the collector as in figure 2.3-B, a measure of stabilization is obtained. As the current through the
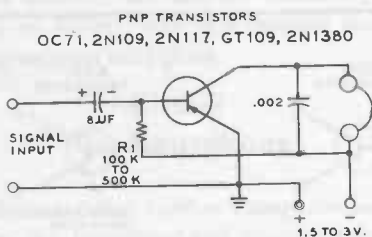

PNP TRANSISTORS
OC71, 2N109, 2N117, GT109, 2N1380

Figure 2.2-A
A SIMPLE TRANSISTOR AMPLIFIER
A simple transistor amplifier showing the easiest method of applying bias.
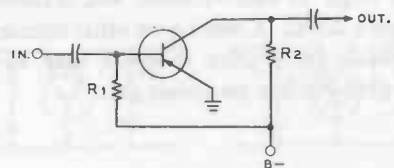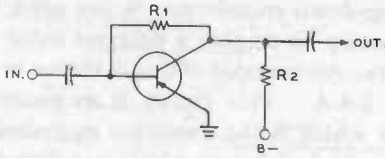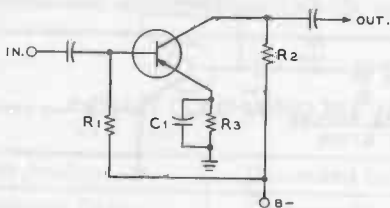
Figure 2.3-A
This circuit is similar to fig. 2.2-A, but uses a collector load resistor. It is susceptible to thermal disturbance.

Figure 2.3-B
Connecting the bias resistor to the collector provides a degree of stabilization.

transistor rises and voltage at the collector decreases, the available base bias is decreased. As a result, the flow of current through the transistor is decreased. This circuit (or variations of it) is used to a considerable extent in small radios and hearing aids where the number of components must be held to a minimum.

Emitter Bias   The circuit of figure 2.3-C is identical with that of figure 2.2-A except that the components C_1 and R_3 have been added. When the collector current rises, an increased voltage drop occurs across R_3. This, in turn, has the effect of lowering the difference in potential between the base and the emitter. In other words, an increase in collector current reduces the bias on the base and "drags" the collector current down again.

Capacitor C_1 is used to bypass the signal around R_3, for without it severe signal degeneration would result. The value of R_3 is chosen to create a voltage drop of one-third to one-sixth of the supply voltage. This is a simple Ohm's Law calculation obtained by dividing the required voltage drop across R_3 by the collector current of the stage concerned.

Bias Voltage Dividers   In figure 2.3-D, another resistor, R_4, has been added to the circuit. A voltage divider is formed by the two resistors, R_1 and R_4, and the junction is connected to the base. Due to improved regulation of the base voltage the bias is unable to change. The system shown in figure 2.3-D will provide superior stabilization. It is the most widely used bias system of all and will be found extensively in this book.

Whether they are audio amplifiers, oscillators, or class C amplifiers, most transistor circuits will have a means of obtaining stabilization and bias as depicted in figure 2.3-D. The larger the value of R_3, and the smaller R_1 and R_4, the better will be the stabilization. A point to remember is that if R_3 is made too large, the voltage between the collector and emitter will become too small. This causes the transistor to *saturate* (as explained later in this chapter) and will create severe signal distortion.

Figure 2.3-C
An emitter resistor also helps stabilize the transistor to temperature variations.
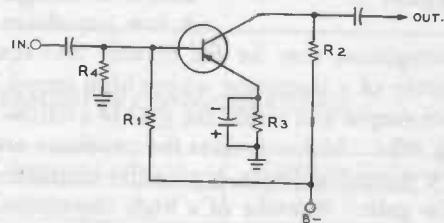
Figure 2.3-D
PREFERRED CIRCUIT FOR BIASING A TRANSISTOR
This circuit is almost immune to temperature effects.

Thermistor   The resistor, R_4, may be a
Stabilization   thermistor. A thermistor
                    is a special resistor whose
resistance decreases when heated. When
used in the circuit of figure 2.3-D (in place
of R_4) it will reduce the base bias when
the temperature increases. Thermistors
are used when very precise stabilization is
required or when transistors are working
very close to the maximum collector dis-
sipation rating.

2.4   Transistor
            Impedances

One of the major differences between
transistors and tubes is that transistors are
current amplifiers and tubes are *voltage* amp-
lifiers. A small increase in *current* in the
base of a transistor will cause a large in-
crease in *current* in the collector circuit. Since
the transistor base draws current, its impe-
dance will be low. This is quite the oppo-
site of a tube.

The transistor may have a high output
impedance. The common emitter circuit
(figure 2.1-B) may have an input imped-
ance of 1,000 ohms and an output imped-
ance of 50,000 ohms. In some instances
the output impedance may be more than a
megohm.

Impedance Matching   The differing im-
In Transistor   pedances may be
Circuits   used to advantage.
                          A low impedance
microphone may be fed directly into the
emitter of a transistor whose high imped-
ance output will match the grid of a follow-
ing tube. Not only does the transistor act
as a matching device, it provides consider-
able gain. The use of a high impedance
crystal microphone creates an immediate
problem because of the low transistor input
impedance. When shunted across the mi-
crophone, the transistor will reduce con-
siderably the output voltage and distort the
frequency response of the microphone. If

a step-down transformer is not used, it is
necessary to employ a different input cir-
cuitry. An example of this is shown in fig-
ure 2.4-A. This circuit is an *emitter fol-
lower* which is the transistor equivalent of
the cathode follower which was discussed
in section 2.1. Like the cathode follower,
it has a high input impedance, approxi-
mately 100,000 ohms in this version. The
shunting effect of the transistor on the mi-
crophone is further reduced by placing a
resistor, R_1, in series with the microphone.
Although some gain is lost, the over-all
result is improved.

Capacitive   To obtain maximum transfer
Coupling   of power from one transistor
                 stage to another, it is neces-
sary to match the output impedance of the
one to the input of the other. This may
readily be done with transformers. Trans-
formers, however, are expensive and usually
occupy considerable space. Often it is ad-
vantageous to use resistance-capacitance
coupling and accept the reduced gain
brought about by the impedance mismatch.

Negative   If feedback is used around an
Feedback   amplifier, the input impedance
               may be raised. A cathode fol-
lower has a high input impedance because
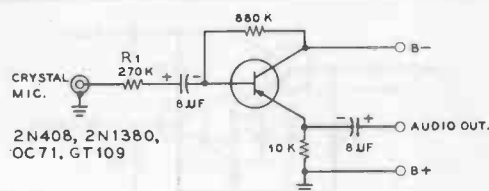of its complete feedback.

Figure 2.4-A
AN EMITTER-FOLLOWER STAGE
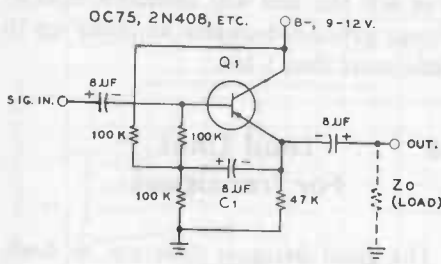Suitable for use with high impedance
microphones.

Figure 2.4-B
An emitter-follower stage with feedback
to further raise the input impedance.

Figure 2.4-B shows the circuit of an amplifier which employs feedback to raise the input impedance. Capacitor C_1 is the feedback component. Without C_1 (and without a load) the input impedance is around 100,000 ohms. With C_1 the impedance is around 500,000 ohms. But, if a 1,000 ohm load is placed across the output terminal of this circuit, the input impedance again drops to 100,000 ohms. Without C_1 it drops to about 51,000 ohms. These figures tell an interesting story. They reveal that the input impedance of a transistor stage is dependent upon the output load. Therefore, the stage following this circuit should also have a high input impedance.

The table of figure 2.4-C shows the various impedances which may be obtained from different circuit configurations. The common-base configuration (which is e-quivalent to grounded-grid) has a low input impedance and a high output impedance. Quite often it is advantageous to follow one configuration with another such as following a common base with a common collector circuit.

2.5 Interpretation Of Transistor Data

In the figures published by transistor manufacturers concerning their products, the following information is usually listed:

(a) Maximum collector voltage.
(b) Maximum collector current.
(c) Maximum collector dissipation.

If the maximum current is multiplied by the maximum voltage, the result will be much greater than the maximum collector dissipation figure. All values given are absolute maximums, and if the maximum voltage is used, the maximum current cannot be used, and vice versa. The figure produced when the operating voltage is multiplied by the current *must not exceed the dissipation figure.*

If there is a transfomer, pair of headphones, coil, choke, or any inductance in the collector circuit, the *peak voltage* present will be twice the battery voltage. As a further caution, it must be realized that the sudden make or break of the circuit may produce voltage "spikes" many times the maximum collector break-down rating. For this reason, never remove or insert a transistor in a circuit when voltage is applied.

Figure 2.4-C
A CHART COMPARING THE VARIOUS TRANSISTOR CONFIGURATIONS

Tube Analogy	Grounded Grid	Common Cathode	Cathode Follower
Transistor Equiv.	Common Base	Common Emitter	Emitter Follower
Current Gain	Approx. Unity	High, 40 to 60	High, 40 to 60
Input Impedance	Low	Medium	High
Output Impedance	High	Medium	Low
Max. Frequency	Higher than Alpha	Lower than Alpha	Varies with Circuitry

**Current
Gain** If the current in the collector circuit rises one milliampere as the base current is made to rise ten microamperes, the transistor has a current gain of 100. This assumes that there is no resistance in the collector circuit.

The symbols for current gain are *alpha* (α) or *beta* (β). Both terms are used, but *alpha* applies to common-base circuitry and will be less than unity. *Beta* applies to common-emitter circuitry, with typical figures being between 20 and 100. In the common-base circuit, a one milliampere rise in emitter current might produce a corresponding rise of 0.98 ma. in the collector. In themselves, these figures appear to give no gain. The impedance of the emitter circuit in which the one milliampere change takes place is very low (possibly 50 ohms). However, the 0.98 milliampere change in the very high impedance output circuit shows that the grounded-base circuit is capable of very high values of current gain.

**Alpha
Cut-off** Alpha cut-off, or f_{ab} as it is written, is the frequency at which the gain of the transistor decreases to 0.707 of the gain at 1,000 cycles. As the term implies, this ratio is measured in the common-base configuration. The transistor will perform beyond its alpha cut-off frequency, but at that frequency, its gain is *falling*. Consequently, from this figure, one is able to ascertain with some assurance whether or not a certain transistor will do a certain job. Suppose one desires to build an r. f. amplifier at a frequency of 4 Mc., with either a 2N331, a 2N1380, or a 2N371. Which would be the best transistor to use? The data on these transistors shows that the 2N331 has an alpha cut-off of 1.6 Mc. The 2N1380 has an alpha cut-off of 2 Mc., and the 2N371 has an alpha cut-off of 30 Mc. Obviously, the 2N371 is the transistor for this application.

If the transistor is operated as a grounded emitter, it is well to choose a device with an alpha cut-off of five times the operating frequency. The 2N139 has an alpha cut-off of 6.8 Mc. and will therefore make an efficient grounded-emitter amplifier up to a little more than 1 Mc.

2.6 Load Lines
For Transistors

The good designer does not sit down with a box of resistors and capacitors before him, trying different values in the transistor amplifier until the speaker gives off the desired sound. Rather, he obtains charts containing characteristic curves, and from these curves he is able to work out the various circuit component values. The designer may do all this without having even seen the components. The *collector voltage-current* curves yield much information to those who take the trouble to read them. Figure 2.6-A shows the circuit of a simple transistor amplifier. Follow the step-by-step process of circuit design, just as a designer might do.

**Dissipation
Intersects** It is wished to operate the amplifier class A and obtain the maximum possible signal output from it. Figure 2.6-B is a plot of the collector current for different collector voltage values at various base currents for a transistor. Assume that the transistor has the following ratings: maximum collector voltage = -12 volts; maximum collector current = -40 ma.; maximum collector dissipation at $25°C$ = 80 mw. (milliwatts).
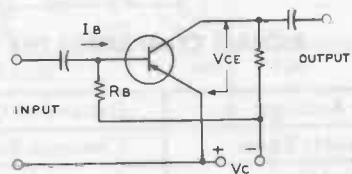

Figure 2.6-A
A TYPICAL TRANSISTOR AMPLIFIER
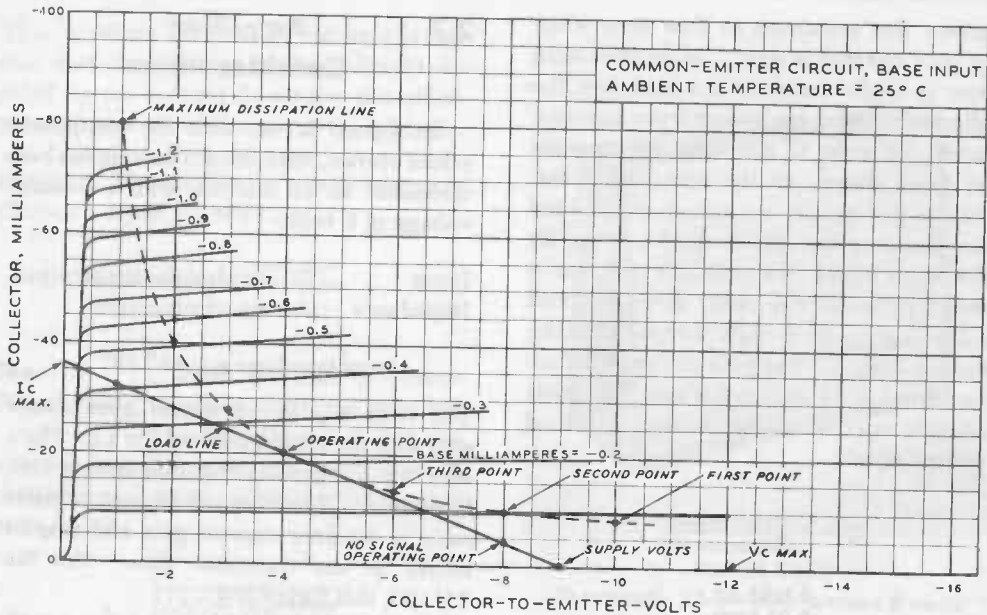The circuit values are determined in
the text.

Figure 2.6-B
BASE CURRENT CURVES FOR A TYPICAL TRANSISTOR
A "family" of base current curves for a typical transistor showing how to determine the operating conditions for the transistor. The component values may also be determined by correctly interpreting this data.

First, draw intersects showing the maximum dissipation of the transistor. Starting at 10 volts, 80 mw. divided by 10 volts = 8 ma. Find and mark the point on the graph where the 10 volts and 8 ma. intersect. This is marked "First point" on graph. Do the same at 8 volts. 80 mw. divided by 8 volts = 10 ma. (Second point) Repeat at 6 ma. and so on along the graph. Connect the points with a dotted line. The area to the left of the dotted line represents all the points which are within the rated transistor dissipation (under the maximum dissipation line).

Next, decide upon a supply voltage. A 9-volt battery is a common size, so in this example assume 9 volts. Mark 9 volts on the base line ("supply volts"). Draw a line from this point toward the vertical current scale so that it *just touches the dotted line.* This

line crosses the collector (Y) axis of the graph at approximately 37.5 ma. Had the line higher than this been taken the transistor would operate in the overload portion of the graph. By *just touching the maximum dissipation line,* it is possible to realize the *maximum output* from the transistor. Had maximum output not been required, the line could have been taken to a lower collector current point. This would have lowered the standing collector current and, of course, limited the collector swing.

Operating Point   Now select the operating point. This should be approximately halfway along the load line. The left-hand limit is set by curvature of the "base milliampere" line at the left hand edge of the graph and the right-hand limit by the I_{co} or collector

current that continues to flow even when the base current is zero. If the operating point is at the center of the load line, the collector voltage can swing from approximately 0.8 volts to 8.5 volts. Four volts has been chosen as the operating point. This is not exactly the center of the load line, but near enough for the purpose. By selecting a figure of 4 volts, the collector to emitter potential may swing down to 1 volt and swing up to 8 volts without running into *non-linearity*. The base current will fluctuate from 0.04 ma. to 0.4 ma. The static collector current will be -20 ma. The load resistor equals:

$$R^l = \frac{\text{Collector voltage}}{\text{Collector current}}$$

$$= \frac{4 \text{ volts}}{0.02 \text{ amps}}$$

$$= 200 \text{ ohms}$$

The base current at the operating point = 0.22 ma. From Ohm's Law, resistor R_b is:

$$R^b = \frac{9 \text{ volts} \quad (\text{supply volts})}{0.22 \text{ ma.}}$$

$$= 41,000 \text{ ohms.}$$

From the graph, one may obtain the current gain for d.c. The base current varies from 0.04 to 0.4 ma., or a total variation of 0.36 ma. The collector current varies from 4 to 32 ma., or a total of 28 ma. The d.c. gain of the transistor is 28 ma. divided by 0.36 ma. or a *Beta* of 78.

Thus, from one graph we have obtained the following: static collector voltage and current, minimum and maximum collector currents and voltages, collector load resistance, forward bias resistance, static base current, minimum and maximum base currents, and the d.c. current gain.

2.7 Amplifier Considerations

In figure 2.7-A, with the component values shown, the collector current has been calculated to be one ma. with a collector voltage of 6 volts.

Input Impedance — To calculate the input impedance use the formula:

$$\text{Input Impedance} = (1 + h^{fe})h^{ib}$$

The term h_{fe} is the *forward current transfer ratio* with the output shorted for a.c. The e after the h_f signifies common emitter configuration. The forward current transfer ratio is the base current gain and may be found in the transistor data. For the 2N190, this figure is 43.

The term h_{ib} is the *input resistance* with output shorted for a.c. The b after h_i indicates common base operation. This figure is also given in the transistor data and is 29 ohms for the transistor in question.

At one ma. of collector current, the input resistance for the circuit shown in figure 2.7-A is 43 x 29 or approximately 1250 ohms.

Output Impedance — The output impedance is given by the formula:
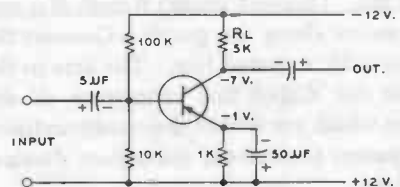
$$R^l = \frac{V^{ce}}{I^c}$$

Figure 2.7-A

A PROPERLY DESIGNED AUDIO AMPLIFIER STAGE

Impedance calculations are discussed in the text.

This is simply Ohm's Law and says in this case that the voltage on the collector divided by the current flowing in the collector will give the resistance of the load, R_1.

Power   The maximum power output is
Output   again Ohm's Law.

$$\text{Power output} = \frac{V^{ce} \times I^c}{2}$$

The   When the load is a trans-
Transformer   former, the turns ratio has
                  to be adjusted to suit the
speaker impedance or the impedance of the following stage. The formula for this ratio (N) is:

$$N = \sqrt{\frac{\text{Output impedance}}{\text{Load impedance}}}$$

Assume the output impedance is 4,000 ohms and the load is 1,000 ohms. The formula becomes:

$$N = \sqrt{\frac{4000}{1000}} = 2$$

Thus a ratio of 2:1, in the step-down direction, is required.

Class B   Unlike a tube, a transistor
Amplifier   cannot be completely cut off.
                  Even when the base current is
zero there will still be a small flow of collector current. This is known as the I_{co}. Class B transistors must be biased a little *above* the cut-off point. This is the no-signal operating point shown on the graph of figure 2.6-B.

Input   The calculation of the input
Impedance   impedance is more difficult
                  now because the base imped-
ance is varying widely with signal. The greater the input signal, the lower will be the base impedance. The impedance of the driver transformer may be made other than

XR-2P Right View

HEATH XR-2P
The Heath XR-2P uses a class B push-pull audio output stage. (Photo by Heath)

optimum in order to give the signal source a higher impedance. This has the effect of reducing the variation in input resistance at low current values, which in turn makes a sizable reduction in distortion.

Transformer   The output impedance for
Output   a push-pull Class B stage
Impedance   is given by the formula:

$$R^l = \frac{2(V^{ce})^2}{P^o}$$

Power   The maximum power output of
Output   a push-pull Class B stage for a
                  given load and supply voltage is:

$$P^o = \frac{2(V^{ce})^2}{R^l}$$

The   mer   The transformer-turns
Transformer   ratio may be calculated
in the same manner as for a class A stage.

Efficiency   The efficiency of the class B
                  stage is *considerably higher* than
for class A configuration. The standing collector current is small, and the peak
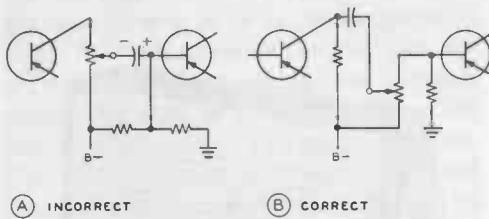
(A) INCORRECT   (B) CORRECT

Figure 2.7-B

AUDIO-AMPLIFIER VOLUME CONTROL CONNECTION

Correct and incorrect methods of connecting the volume control in a transistor audio-amplifier are shown.

collector current is large. As a rule, the class B stage may be designed to deliver power equal to five times the collector dissipation of one transistor. That is, a transistor with a dissipation of 80 mw., when operated in push-pull class B (with another transistor, of course), may deliver 400 mw. of power output.

Class-B operation is preferred for portable receivers so that the standing current drawn from the battery is low.

The Volume Control   The gain control circuit of figure 2.7-B(a) is poorly designed because the current flowing in the control will make it noisy. The circuit of (b) should be used. If the amplifier follows a receiver, the gain control may be the diode detector load.

The Tone Control   Transistor tone controls will differ little from tube designs. A variable resistor in series with a fixed capacitor connected from base to ground of one of the audio stages will give ample treble cut. There are so many systems of bass and treble tone controls it is impossible, in the space available, to cover them. In general, they are identical to those used with tubes. Differences will be brought about due to the lower transis-

tor impedances, and as a consequence capacitors may be larger and resistors smaller.

Inverse Feedback   This technique also follows tube practice. The resistor R_1 in figure 2.7-C feeds back energy from the output stage to the driver stage. Its value in this instance may be about 33K. Inverse feedback is helpful in reducing distortion and in stabilizing the gain of a transistor.

An unbypassed emitter resistor will produce negative feedback. If carried too far, as with tubes, the stage gain will suffer severely.

Saturation   This is more important than might be supposed. The term *saturation* could well explain the reason the amplifier or receiver that was built "didn't work the way the book said it should." In figure 2.7-D, assume that the forward bias resistor R_1 has a resistance of 10,000 ohms. Under these conditions the 2N1380 will draw about 8 ma. when the output transformer has a d.c. resistance of 300 ohms. The potential between the collector and the emitter will be about 1.5 volts. If a pair of earphones whose d.c.
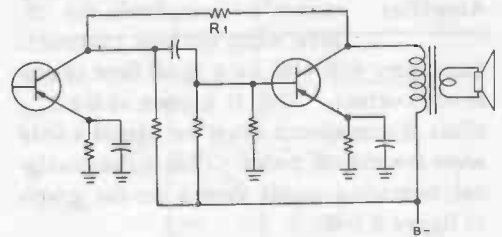

Figure 2.7-C

A SIMPLE METHOD OF APPLYING INVERSE FEEDBACK TO A TWO-STAGE TRANSISTOR AMPLIFIER

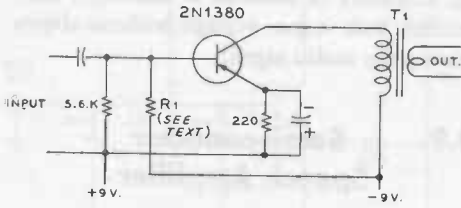This technique increases the frequency response and decreases the distortion.

Figure 2.7-D
An amplifier such as this will saturate
easily if the collector load resistance
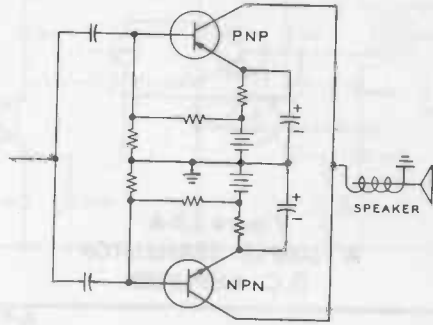varies too far from the nominal value.

Figure 2.7-E
A COMPLEMENTARY AMPLIFIER
The amplifier operates class B, yet re-
quires no input or output transformers.

resistance measures 2,000 ohms is con-
nected in place of the transformer the cur-
rent will drop to 3 ma. and the collector-
emitter potential will drop to 0.1 volts.
The large current flowing through the high
resistance earphones has reduced all the
available collector voltage. The result is
severe distortion and very low output.

If R_1 is increased to 47K, the collector
current will fall and the voltage on the col-
lector will rise, allowing the transistor to
operate normally. The rule to be inferred
from this study is that the d.c. resistance
of the output transformer must be the same
as that specified to obtain the proper
results. Otherwise, the experimenter must
be prepared to change the bias condition
on the transistor. The lower the d.c. re-
sistance of the output transformer, the
greater will be the power output that may
be obtained from the stage.

Complementary   N-P-N and P-N-P tran-
Amplifiers   sistors may both be
                      used in the same am-
plifier stage.   Figure 2.7-E shows how a
push-pull complementary circuit that does
not use an input or output transformer
may be constructed.

Although single-stage amplifiers may
drive a speaker directly, without an output
transformer, the steady d.c. collector cur-
rent displaces the speaker cone from its

normal position and the result is inferior
operation. A *complementary amplifier* config-
uration such as that shown in figure 2.7-E
causes the two collector currents to oppose
each other, and the speaker cone is not dis-
placed. The two transistors must be close-
ly matched in their characteristics.

2.8   Miscellaneous
          Audio Circuits

There are many transistor circuits found
in communications equipment which are
difficult to classify. Some of them are dis-
cussed here.

D.C. Amplifier   A *d.c. amplifier* is exactly
                       what the name implies:
d.c. voltage applied to the input is ampli-
fied and presented in the output circuit.
It may or may not appear in the same
phase.   The a.g.c. circuit of figure 3.7-A
(Chapter 3) is really a d.c. amplifier. The
r.f. is converted to d.c. by the base-emitter
diode, and the d.c. causes the collector volt-
age to vary. The voltage drop across the
resistor at the collector will be consider-
ably greater than the voltage which pro-
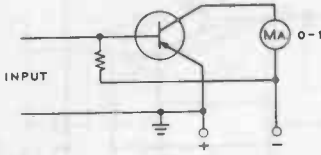duced it. In this case it will be of the op-
posite polarity.

Figure 2.8-A
A SIMPLE TRANSISTOR
D.C. AMPLIFIER

The d.c. amplifier of figure 2.8-A is a current amplifier. A small increase in current at the base (input) of the transistor will cause a large increase in current through the meter. This circuit may be used to increase the sensitivity of a meter.

D.c. amplifiers are considerably more difficult to temperature-stabilize than are a.c. amplifiers. Temperature changes may make necessary frequent adjustments to the zero setting in circuits such as in figure 2.8-A.

S-Meter Amplifier   The circuit of figure 2.8-A is shown as an S-meter amplifier in figure 2.8-B. This amplifier is little affected by temperature changes. The potentiometer R_2 adjusts the meter zero, and R_1 adjusts the sensitivity of the meter. The circuit has been redrawn in B to show its operation. From this, it will be seen that the transistor and its associated components are a bridge circuit, of which TR_1 is a variable arm. Any change of TR_1 causes unbalance of the bridge and a consequent meter reading.

Reflex Circuits   A *reflex stage* is one which amplifies one signal twice, on two separate frequencies. For example, an i.f. amplifier may also be an audio amplifier. After the signal has left the i.f. amplifier, it is detected and then fed back through the same transistor again as an audio voltage. Reflexing can only be done when the two frequencies are sufficiently far apart that no interaction between the two signal components can occur. If an i.f. amplifier is reflexed it cannot be controlled with a.g.c. voltage without depreciating the audio signal.

2.9   Semiconductor Speech Amplifier

High impedance crystal and dynamic microphones are the phone operator's stock-in-trade. But, as pointed out in section 2.4, such microphones are heavily *loaded* due to the low input impedance of a transistor. When the microphone does not "see" the proper load impedance, the low frequencies are severely attenuated. The net effect makes even the most resonant voice sound like a young boy. Even under the best possible conditions, the mismatch will cause a loss of gain.

The solution to this dilemma, also shown in section 2.4, is to connect the input stage in a grounded collector (or emitter-follower) configuration and employ feedback to raise the input impedance.

How It Works   A speech amplifier featuring a high-input impedance is shown in figure 2.9-A. The input transistor, TR_1, is an emitter follower with feedback between emitter and base. The output of this stage drives a common emitter amplifier, TR_2, which has the necessary components for proper temperature stabiliza-
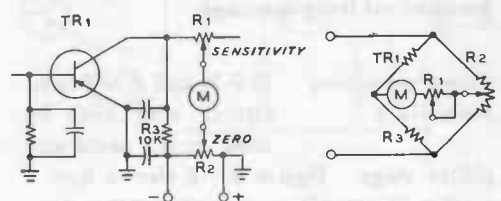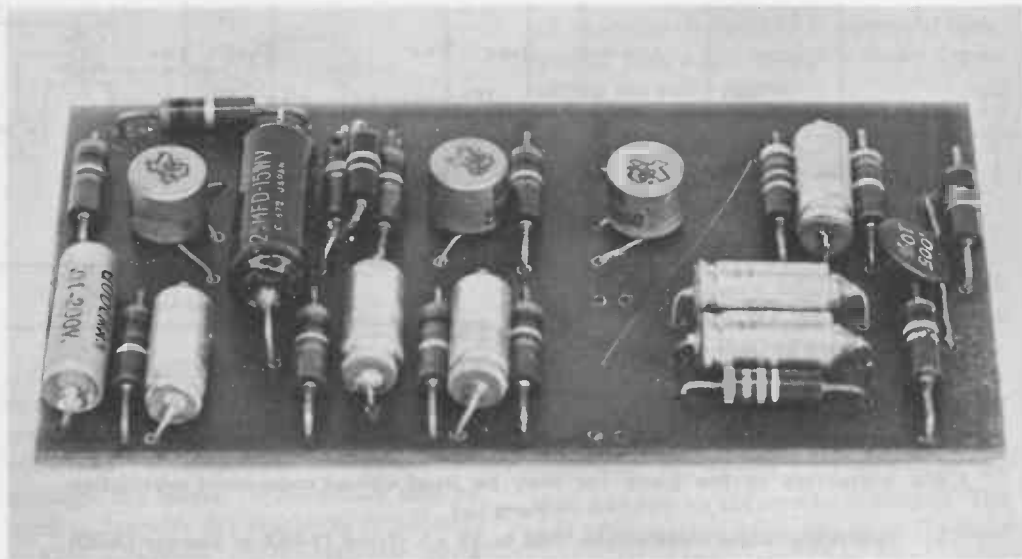

Figure 2.8-B
S-METER AMPLIFIER
A circuit similar to fig. 2.8-A, but modified for use as an S-meter amplifier.

Figure 2.9-A
MICROPHONE PREAMPLIFIER
A properly designed microphone preamplifier which will bring a -54 db micro-
phone up to about one volt. The coupling and bypass components are selected to
amplify only those frequencies in the voice spectrum (300-3,000 cycles). Any of
the transistors in the parts list may be used without component substitution.
Parts List
T_1 - Interstage audio transformer, 10K to 2K c.t. (Triad TY-56X or Stancor TA-35).
TR_1, TR_2, TR_3 - Use either 2N217, 2N406, 2N1380, GT109, or OC71.

tion. This stage, in turn, drives a similar stage, TR_3, with a matching transformer as its collector load. A 10K resistor is connected across the primary of the matching transformer to help provide a constant load for TR_3. This resistor may not be necessary in some audio applications. The output winding will match a transistor push-pull load such as the Mini-amplifier described in section 2.11. This speech amplifier may also be used to drive an audio phase shift network or diode balanced modulator in s.s.b. phasing and filter transmitters.

Audio feedback through the power sup-ply circuit is prevented by decoupling the first and second stages from the output transistor. A 1K resistor and a 25 μfd. capacitor are used for this purpose. Feed-back due to stray fields is minimized by using an R-C filter network in the micro-phone lead.

The amplifier has more than adequate gain for most applications, and it may be necessary to install a volume control. This may be accomplished by substituting a 10K potentiometer for the stabilization resistor

in the base circuit of TR_3. The electrolytic coupling capacior would connect to the arm of the potentiometer. This is shown in figure 2.9-A by dotted lines.

Construction The amplifier can be con-structed on a piece of term-inal strip material. The transistors mount by their leads to the terminals, and the com-ponents are laid across the board, between the terminals. The layout is entirely up to the builder, and is not particularly critical. There is no tendency for the speech ampli-fier to oscillate due to proximity of com-ponents. The builder should be cautioned to use shielded cable for the microphone lead, however. Due to the high input im-pedance, the transistor speech amplifier is just as likely to pick up stray a.c. as is its vacuum tube counterpart! Noise on the supply line should not be a problem due to the large decoupling components (1K and 25 μfd.).

Note that the amplifier is designed with both a common plus and a common minus line. This will allow the builder to use the unit in a mobile installation with either a positive or negative electrical system.

SEMI-CONDUCTOR SPEECH AMPLI-FIER

This transistor speech amplifier has an input impedance of approximately 100K and provides an excellent match to crystal and dynamic high impedance microphones. It occupies a space of only 4" X 2" x 3/8" when mounted on the etched circuit board.

Operation   The best way to test this amplifier is to connect it to a transmitter with known audio characteristics. Connect a 470-ohm resistor across one-half of the secondary of T_1. In parallel with this, connect a 100 to 1 divider (a 100K and 1K resistor will do nicely). Using shielded cable, connect the 1K resistor across the high impedance microphone input on your transmitter. Ground the speech amplifier to the transmitter (either plus or minus line) and connect the microphone you will be using with the unit. Have some reliable person check your audio quality while you adjust resistor R_1 for the most pleasing balance between highs and lows. In most cases you will find that no resistance is necessary, but a minimum of 4.7K should be used to act as an r.f. filter. This is necessary to prevent stray r.f. picked up by the microphone lead from being rectified by TR_1 and producing audio feedback.

When you are satisfied with the frequency response, disconnect the divider which was temporarily placed across the output. Measure the audio voltage across the 470-ohm resistor while speaking into the microphone. You should be able to obtain almost one volt of audio before noticeable distortion takes place. This is more than adequate drive for s.s.b. audio phase-shift networks and is just about ideal for diode balanced modulators which operate with about 6 volts of r.f. signal level.

The noise generated by the input transistor is approximately 30-40 db down from full output. This figure may be improved considerably by substituting an input transistor intended for low-noise audio applications.

2.10   A Deluxe Audio Compressor

An audio compressor, when used ahead of public address amplifiers or commercial and amateur transmitters, will provide a major gain in "talk-power." The average voice level may be held high, but the peaks (which would normally overload an amplifier or transmitter) are compressed to a safe or desirable level. In tube compressors, use is made of the variable-μ characteristic of the control grid to adjust automatically the gain of the amplifier.

Ordinarily, the transistor gain is varied by (a) reducing the emitter current, or (b) by reducing the collector voltage. The two systems are discussed in Chapter 3, under the heading *automatic gain control*. It will be realized that automatic gain control is much the same whether the signal being controlled is audio, r.f., or i.f. energy. Both of these control systems drive the transistor into a non-linear portion of its characteristic curve in an effort to reduce stage gain. This, while perhaps permissible in r.f. applications, is not desirable in audio circuits. Considerable experimental work (both with characteristic curves and compressors) based on the above principles was undertaken, and the conclusions confirmed that distortion of a serious nature did take place.

A New Principal-How It Works   Apart from the two methods mentioned, the gain of a stage may be controlled by shunting its output element with a low-value resistor. A resistor placed across the output transformer primary of a tube receiver will reduce the audio voltage across the transformer to an extent dependent upon the value of the resistor. If the resistor is reduced in value whenever signal in the transformer exceeds a predetermined voltage, the audio (as delivered by the speaker) will never rise above a certain loudness level.
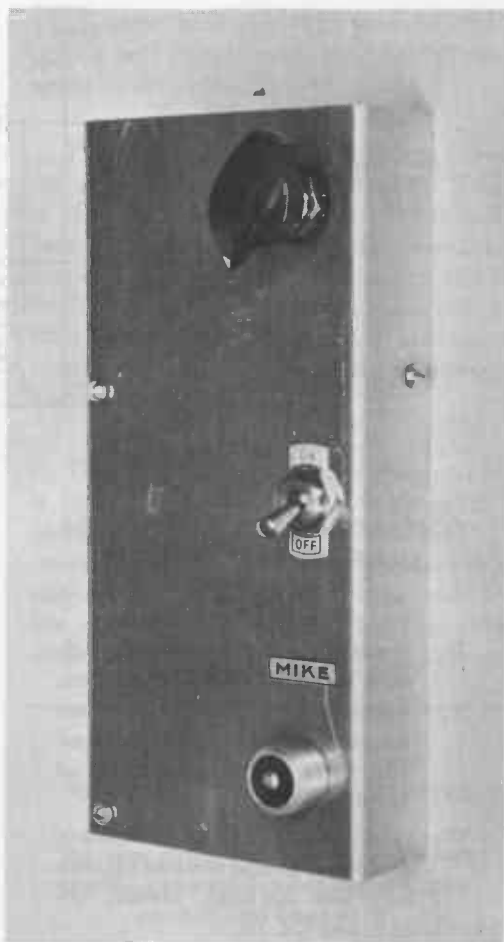
THE COMPRESSOR
The compressor was constructed in a small L-shaped chassis box. The knob is the compression control.

In this case the resistor is a nearly-saturated transistor connected in parallel with the load resistor of an audio amplifier. The control transistor is biased to operate just above the knee in its curve. Signal is extracted from the amplifier, further amplified, converted to negative d.c., and applied to the base of the control transistor. The operating point of the transistor "slides down" the curve, and the internal resistance rapidly falls. As the connection between
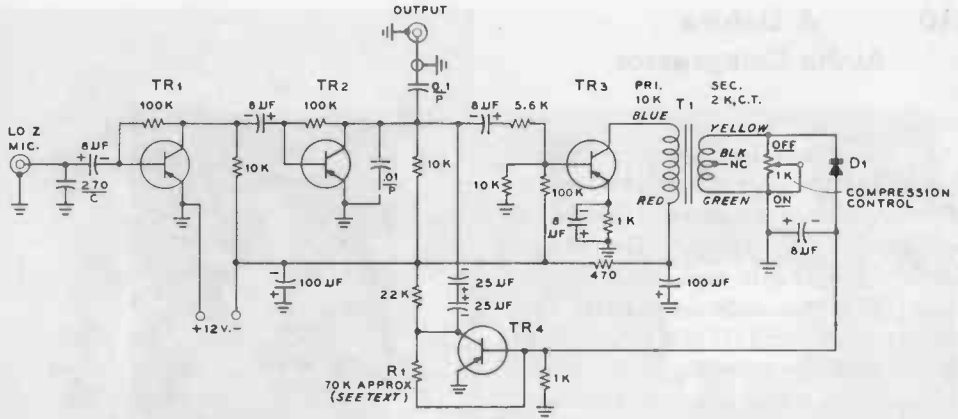
Figure 2.10-A
SCHEMATIC DIAGRAM FOR THE DE-LUX AUDIO COMPRESSOR

Parts List

D_1 - General purpose germanium diode, 1N34A, 1N64G, OA85, etc.

R_1 - Approximately 70K.   See text.

T_1 - Interstage matching transformer, 10K to 2K c.t. (Stancor TA-35 or Triad TY-56X)

$TR_{1,2,3,4}$- General purpose transistors, prototype model worked successfully with 2N1380, 2N408, GT-81R, and OC75.

Note that the two 25 µfd. electrolytics are connected in the manner shown to eliminate polarization, not to increase breakdown voltage.

A single 15 µfd. capacitor cannot be used as a substitute. Ceramic, mica, paper, and electrolytic capacitor notations are given below the values.

the control and the controlled transistor is via a large value capacitor, the a.c. part of the signal is shunted to ground, leaving the d.c. working point of the controlled stage unchanged.   Clipping of the signal cannot occur unless the amplifier is considerably

overdriven.   A large signal at the collector of the controlled stage may conceivably be rectified by the controlling stage. However, with normal operation this undesirable condition does not exist (figure 2.10-A).

Construction   The unit may be constructed in any convenient form. The main point to observe is the matter of shielding, which must be complete. R.f. from the transmitter should not be allowed in the compressor unit.

The resistor R_1 may be left out until the unit is completed.   Transistors considerably different from those suggested may require a different value for this resistor.   A potentiometer could be substituted and then replaced with a resistor of the measured value.

Adjustment   After the wiring has
And Operation   been completed and checked, measure the battery current, which should be between 3 and 4 ma.   Next, turn the compression control off and connect an audio generator to the compressor (you can whistle into the microphone).   Adjust the temporary potentiometer R_1 until the output signal just starts to fall.   This indicates that the bias
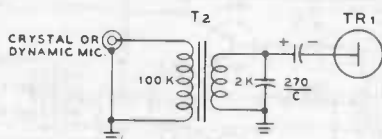
Figure 2.10-B
MATCHING CIRCUITRY FOR HIGH IMPEDANCE MICRO-PHONES
Schematic showing how a transformer may be connected to allow crystal or dynamic microphones to be used. Transformer T_2 may be either a Stancor TA-46 or a Triad TY-50X.

has been adjusted to place the transistor on the knee of its characteristic curve. A further reduction in resistor R_1 will very rapidly reduce the output which indicates that the correct point has been passed. If the resistor is too high in value, and the bias too low, the rapid change in the collector voltage of the control stage will cause a pronounced thump at the beginning of each word and will show on the scope as a "blip" that exceeds the compressed level.

Excessive compression *is to be avoided.* An overcompressed signal will become harsh and unpleasant. Background noise will become excessive, and a voice controlled rig will trigger every time a fly moves a foot on the ceiling!

The transformer T_1, if different from that suggested, may require phasing. That is, the input or the two output leads will have to be connected in the right manner. Incorrect phasing will show spikes at the beginning of each audio cycle and a rough hum in the monitor. The remedy is simple: reverse either the primary or the secondary leads, but not both.

The input impedance to the compressor is low and suitable for a dynamic microphone without a matching transformer. A crystal microphone will require a matching transformer or a matching stage such as the one shown in figure 2.4-B of this chapter.

INSIDE VIEW OF TRANSISTORIZED SPEECH COMPRESSOR
The size of the unit could have been greatly reduced if subminiature components had been used.
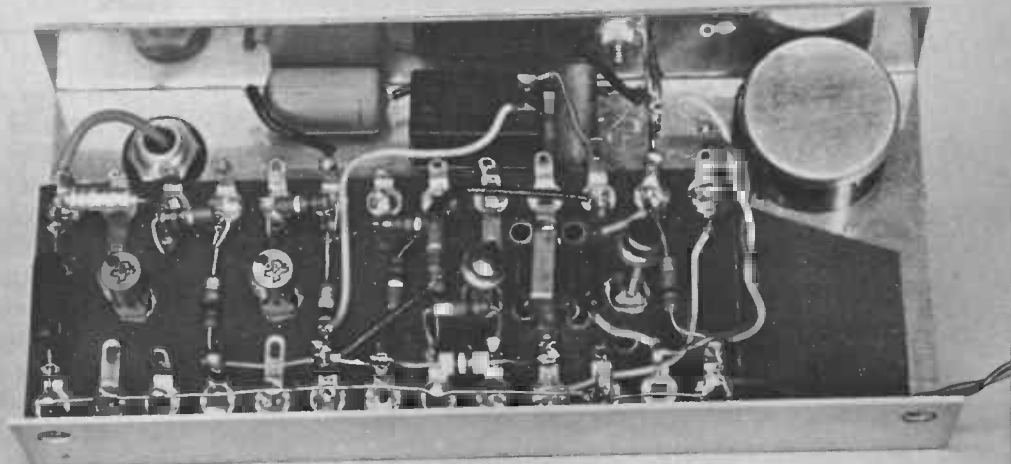
2.11   The Mini-Amplifier-Modulator

The *Mini-amp-modulator* is designed to follow a receiver which in itself has insufficient amplification for comfortable listening. The amplifier may be used in conjunction with many of the receivers described in this book. It is also a permanent part of the communication receiver described here-in. By substituting a suitable transformer, it may be used to modulate a 1/2 to 1-watt walkie-talkie. The *Mini-amplifier* should do much to dispel the incorrect impression gained through listening to too many 2-inch speakers. Transistor quality can be as good as tube quality!

How It Works   Refer to figure 2.11-A. The signal is fed to the bases of the two transistors via the step-down transformer T_1. The input impedance was calculated for transistors with a rather low h_{fe} so that a variety of transistors may be used with only small alterations to the circuit.

The transistors operate in class B and are biased just sufficiently to prevent *crossover distortion* due to curvature of the transistor characteristics. A lower output transformer primary impedance would allow greater output without saturation and distortion, but the transistors might then exceed their ratings. Output is much more than sufficient for the average room.

Negative feedback is applied over the stage via feedback resistor R_2. This resistor may be omitted if desired. The result will be a slight increase in gain and distortion.

Construction   Any practical layout may be followed. Printed circuit boards as used in the prototype make for compactness, yet allow open, easy-to-get-at wiring.
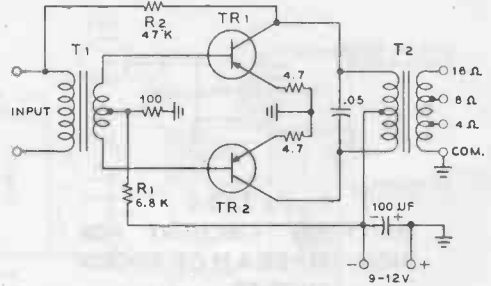
Figure 2.11-A
THE MINI-AMPLIFIER
The Mini-amplifier has a power output of approximately 350 milliwatts, which is more than adequate for amateur radio work. The various taps on T_2 provide correct speaker matching. If the amplifier oscillates when R_2 is connected, connect it to the other collector.

Parts List
T_1 - Interstage transformer, 10K to 2K c.t. (Triad TY-56X, Stancor TA-35, or equiv.).
T_2 - Speaker matching transformer, 500 ohms c.t. to 4, 8, or 16 ohms (Triad TY-45X, Stancor TA-42, or equiv.).
TR_1-TR_2 - 2N1380 (Texas Instruments). Other transistors may be used if R_1 is adjusted for minimum crossover distortion. The 2N109, GT 109, 2N408 and OC72 were all used in the prototype with good results.

Operation   If transistors other than the 2N1380's are used, the resistor R_1 should be adjusted to give an idling collector current of around 3.0 ma. If the idling current is too low, *crossover distortion* will be apparent at low volume levels. If it is too high, battery power will be wasted for no useful purpose.

If the amplifier is operating from a battery to which the other equipment is also connected, "motorboating" or oscillation may take place. This is particularly true if
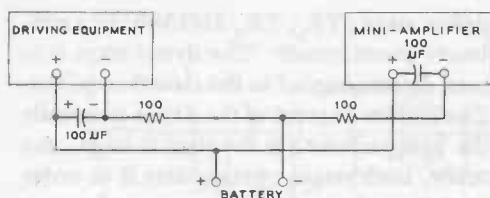
Figure 2.11-B
It may be necessary to add decoupling components as shown when the Mini-amplifier is used with accessory equipment. A 100 µfd. capacitor is already built into the Mini-amplifier.

the battery is partly discharged or if there is resistance in the battery circuit. The class B current of the amplifier may reach very high peaks which can pull down the battery voltage. This, in turn, will reduce the signal. The result is a "phut-phut-phut-phut," not unlike the sound of a motorboat. If there is very little capacity in the circuit the "motorboat" may reach jet speed and give forth the appropriate sound! As the cause is almost always due to coupling through the power supply, adequate decoupling is essential. A 100 µfd. capacitor directly across the battery should be sufficient to prevent the voltage variation. If the motorboating continues, it may be nec-

essary to add decoupling resistors as shown in figure 2.11-B.

Modulator   A small r.f. power amplifier (either tube or transistor) can be modulated by substituting a 500-to-5,000 ohm transformer (such as the the Triad TX-49X or Stancor TA-4) for T_2. It may be necessary to re-adjust the bias divider network for minimum crossover distortion.

2.12   The Mini-Amplifier #2

Many applications call for more gain than provided by the *Mini-Amplifier* alone. When this is the case, a suitable driver stage (figure 2.12-A) may be added. The driver should draw approximately 1 ma. of collector current to match correctly transformer T_1.

Note the polarity of the coupling capacitor C_1. If the input side of this capacitor is connected to the collector of a preceding stage, the capacitor must be reversed. Since the collector will be more negative than the base of TR_1, the negative end of the capacitor must be to the input side.

The motorboating condition described earlier cannot occur in the *Mini-amplifier*

THE MINI-AMPLIFIER
The completed Mini-Amplifier with driver mounted on an etched circuit board
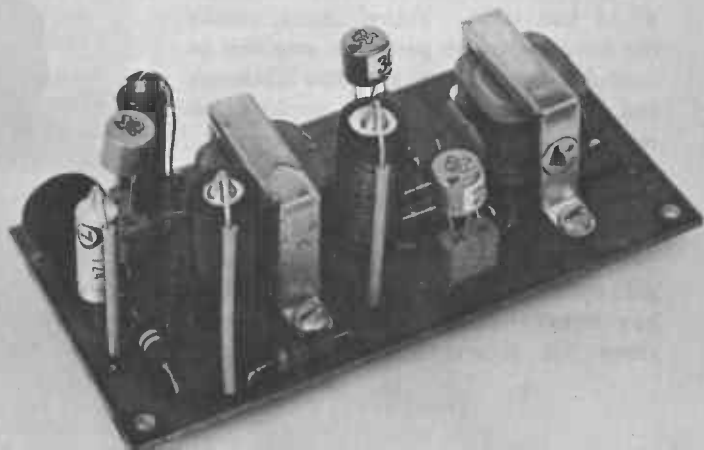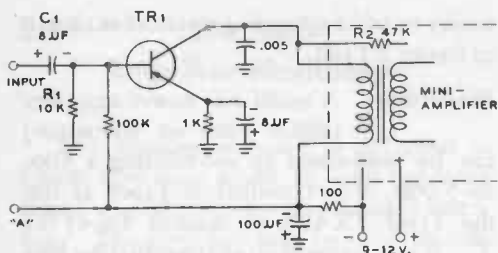
Figure 2.12-A
MINI-AMPLIFIER
Many other transistors may be used
in this circuit without component value
alteration. Resistor R₁ may be adjusted
to give a collector current of approxi-
mately 1 ma. when the transistor char-
acteristics are considerably different
from the types specified.

No. Two due to the added 100 ohm/100
μfd. decoupling network in the supply lead.
If the amplifier is used with accessory radio
equipment (receiver, i.f. strip, etc.), the
B- buss should be connected to the point
marked "A" in figure 2.12-A.

2.13   A 10 Watt
Amplifier/Modulator

Because it uses so few components (and
these are inexpensive), this amplifier should
be very popular for public address or modu-
lator applications. The amplifier has been
designed around the Motorola 2N554, a
$1.35 transistor. Transformers, usually
the most expensive part of an amplifier or
modulator, have been kept to a minimum
and direct coupling has been employed be-
tween the driver and the output stage.

How TR_1 is a conventional common
It Works   emitter amplifier and requires
                      very little mention. If an audio
gain control is required on this stage it may
be wired as shown in figure 2.13-B. Tran-
sistor TR_1 is coupled to the push-pull

driver stage (TR_2, TR_3-2N1380) by a min-
iature transformer. The driver stage is in
turn direct-coupled to the class B amplifier.
The emitter current of the driver is actually
the base current for the class B stage. Ac-
tually, both stages operate class B in order
to deliver the maximum amount of output
power. The driver stage operates very
close to its maximum dissipation rating,
and a heat sink is recommended if the am-
plifier is to be operated in high temperature
environments. The heat sink may consist
of a small piece of copper plate bent around
the transistor case and bolted to the chassis.
The amplifier may be used as a modulator
simply by substitution of the output trans-
former. No component value changes are
required.

Adjustment   Before the amplifier is con-
                        nected to the battery ascer-
tain that the potentiometer P_1 is at *maximum*
resistance. With a tone fed into the input,
and an oscilloscope connected across the
output, adjust P_1 for minimum crossover
distortion   consistent   with   minimum
2N554 collector current. If a scope is not
available, adjust P_1 until the two driver tran-

**TOP VIEW OF AMPLIFIER/MODULA-
TOR**
The remaining transistors are mounted
on terminal strips under the chassis.
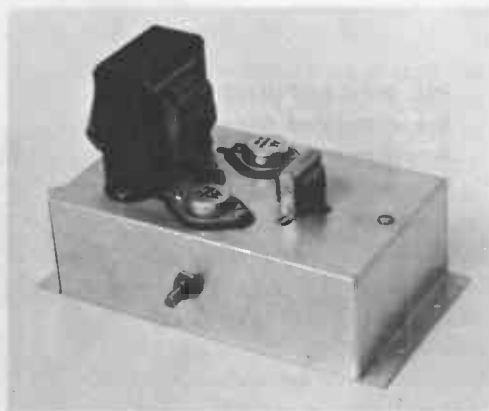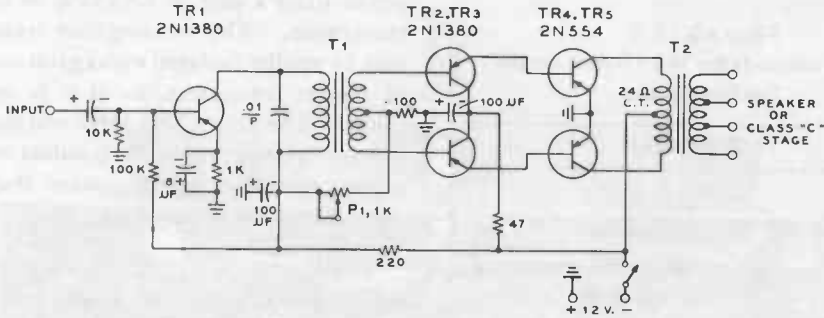
Figure 2.13-A

A 10-WATT EMITTER-FOLLOWER AMPLIFIER AND MODULATOR

Experimenters could use this same circuit as a 40-watt amplifier/modulator by using the 2N554's as emitter followers to drive a pair of 5 ampere transistors. A Triad TY-66A (modulator) or TY-67A (amplifier) transformer would be used, and T_2 would be eliminated.

PARTS LIST

P_1 - 4-watt wire-wound potentiometer.
T_1 - Interstage transformer, 10K to 2K - c.t. (Stancor TA-35 or Triad TY-56X).

T_2 - Collector to speaker, 24 ohms c.t. to 4,8, or 16 ohms (Triad TY-29X). Collector to 20-watt modulated stage, 32 ohms c.t. to 4K, 6K, or 3K (Triad TY-65Z).

A universal push-pull plate to speaker transformer can be reverse-connected as a modulation transformer.

If such a transformer is used, connect the 16 ohm tap to one collector, the 4 ohm tap to B-, and the common lead to the other collector. The secondary will then be twice the original value of impedance.

---

sistors draw 7 ma. of idling current. This should provide a 2N554 idling current of approximately 100-150 ma. The idling current may fluctuate a little, according to temperature, but should not differ greatly from this figure.

Application   A phonograph cartridge fed directly into the input stage will provide plenty of output if it offers a reasonable impedance match to the transistor. A crystal pickup will require matching, which can be provided by an emitter-follower or 100:1 stepdown transformer. A dynamic microphone will drive the amplifier to full output with close talking, and when a matching transformer is used it will provide a reserve of gain.

The input impedance of the amplifier is around 1,000 ohms.

Other Transistors   Other transistors may be used in place of those suggested. However, caution should be used in the selection of substitutes. The two driver transistors must have a dissipation of at least 150 mw. each if they

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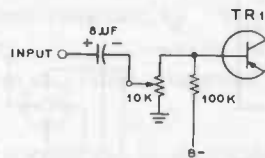
Figure 2.13-B
VOLUME CONTROL CONNECTION
A method of connecting a volume control to the 10-watt amplifier/modulator.

NO SIGNAL
TR_1 . . . . 1.0 ma.
TR_2, TR_3 . . . . 7.0 ma. total
TR_4, TR_5 . . . . 100 - 150 ma total (measured at T_2 c.t.)

SIGNAL
Maximum current
TR_1 . . . . 1.0 ma.
TR_2, TR_3 . . . . 60 ma. total
TR_4, TR_5 . . . . 1 ampere total (measured at T_2 c.t.)

are to drive a pair of 2N554's, or similar transistors. The pre-amplifier transistor may be readily replaced with a great number of similar transistors, for it is in no way critical. The driver 2N1380's and the output 2N554's are particularly suited to each other, and it is recommended that this combination be retained.

For maximum output, the 2N554's (or substitutions) must be matched to each other and to the load. If the output transistors are unbalanced, one will run warm while the other remains relatively cool. The recommended transformers provide the proper impedance match either to a speaker or to a 20-watt class C final r.f. amplifier.

2.14 A Kit 10-Watt Modulator

Figure 2.14-A

THE HEATHKIT PUBLIC ADDRESS AMPLIFIER MODEL AA-80

* *PAIR MATCHED FOR POWER GAIN.*
** *Q3 MUST BE INSULATED FROM SUBCHASSIS.*
1. Q_1, Q_2 = 2N408
2. Q_3, Q_4, Q_5 = CDT1337
3. *ALL VOLTAGES ARE MEASURED IN RESPECT TO THE POSITIVE BUS BAR USING A HEATHKIT MODEL MM-1 VOM.*
4. *R_{17} IS A 2 OHM THERMISTOR USED FOR TEMPERATURE COMPENSATION.*
5. *VOLTAGES SHOWN ARE AVERAGE READINGS OBTAINED USING A 12 V. BATTERY AND WITH NO SIGNAL APPLIED TO THE AMPLIFIER.*
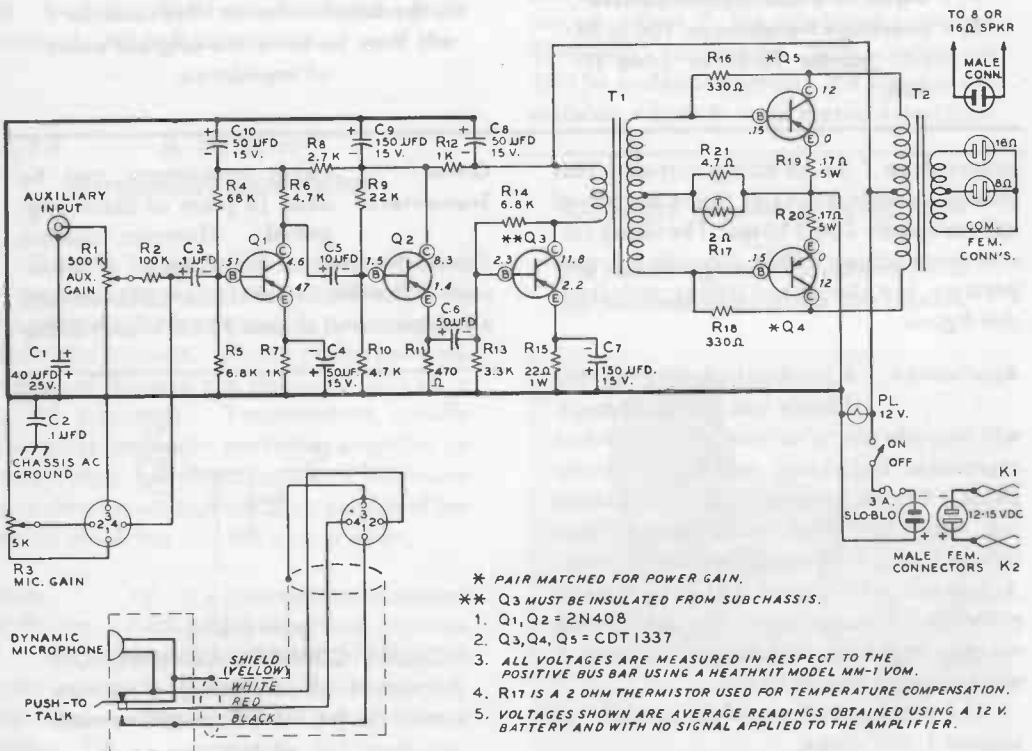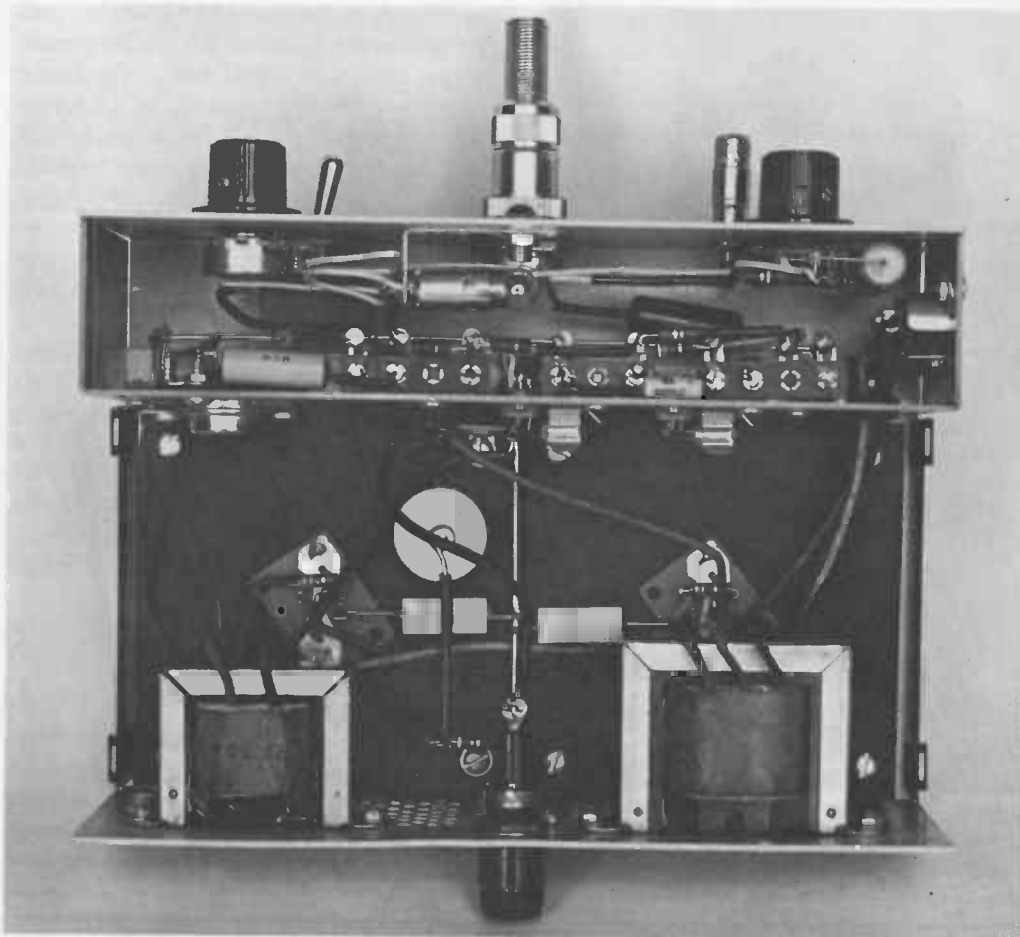
HEATHKIT AA-80 PUBLIC ADDRESS AMPLIFIER
Top view showing the layout of components.

Those who like to integrate commercial kits into their equipment will be interested in the *Heathkit AA-80 10-watt Public Address Amplifier*. It can be used to modulate a 20-watt transistor transmitter with no modifications. In addition, it contains interesting circuits which can be adapted to existing equipment.

The circuit diagram of the AA-80 is shown in figure 2.14-A. No input impedance matching stage is included since this unit is designed for use with a low-impedance dynamic microphone. Impedance matching is required, however, between this stage and the very low base impedance of the driver transistor, Q_3. The driver stage supplies sufficient power to swing the class B output stage into saturation.

The circuit can be duplicated easily by experimenters. Transformer T_1 is similar to the Triad TY-61X, while T_2 is almost identical to the Triad TY-29X. An experimenter's transistor, such as the 2N234A, 2N307, or 2N554, is suitable for Q_3. A matched pair of transistors, rated at 10

FRONT VIEW OF HEATHKIT AA-80 PUBLIC ADDRESS AMPLIFIER

Amplifier can be used as a modulator with no modifications.

watts or more, can be used in place of Q_4 and Q_5.

In transistor-transmitter applications, the 16-ohm connection would drive the final amplifier, while the 8-ohm winding would supply modulation power to the transistor driver stage. This technique is described in more detail in Chapter 5.

2.15   A 5-Watt Class A Amplifier

When battery consumption and output stage efficiency are not considerations, constructors may wish to use a class A amplifier in receivers and modulators. The aver-age collector current of a class A stage is constant. Therefore, audio excursions are less likely to frequency-modulate the local oscillator in a communications receiver.

The circuit shown in figure 2.15-A was not constructed or duplicated, but appeared in the *Philco Application Report #309,* a dependable source of construction information. The input impedance of this amplifier is 100 ohms, and at 5 watts output it has a total distortion of 5.4% (combined 2nd and 3rd harmonic). The 3 db bandwidth is 110 cycles to 14 kc. The 39-ohm resistor across the secondary of the driver transformer is necessary to reduce distortion at high levels of power output. This distortion occurs because the input impe-

dance of the T-1041 output transistor rises sharply when the collector current is reduced to very low levels. The effect causes a peaking of the output waveform on one-half of the audio cycle. At output levels below 4 watts, the effect of this resistor is negligible. The 0.27-ohm resistor in the emitter of the T-1041 output stage is necessary to insure thermal stability of the unit. The prototype of this amplifier employed a U.T.C. type LS-33 five-to-one interstage transformer and a Freed type QGA-37 for the 2:1 output transformer. It would appear that the more common Stancor TA-48 and TA-50 would make excellent substitutes for these transformers. The output transistor, which is not commonly available, can be replaced with a 2N234A (Bendix), 2N301 (RCA), or 2N554 (Motorola).

2.16 Sliding Bias Amplifiers

The 5-watt amplifier just described draws a larger amount of collector current since it is biased for class A operation. This means the transistor must dissipate large amounts of power in the form of heat.
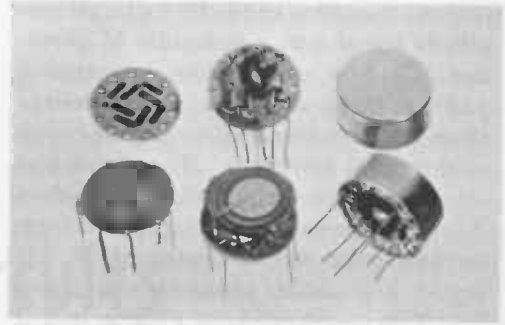
CENTERLAB AUDIO AMPLI-FIER

This Centerlab audio amplifier, which is about the diameter of a dime, contains 4 transistors and associated components. It features 80 db of voltage gain.

A more efficient "pseudo-class A" amplifier is shown in figure 2.16-A. This trick circuit, developed by Phillips of Holland, is called a *sliding-bias amplifier*. Some of the audio output signal is rectified and fed back to the transistor in the form of additional forward bias. Thus, at higher audio levels, the forward bias increases, permit-

Figure 2.15-A
A 5-WATT CLASS A AMPLIFIER

Transformer commercial equivalents are given in the text.
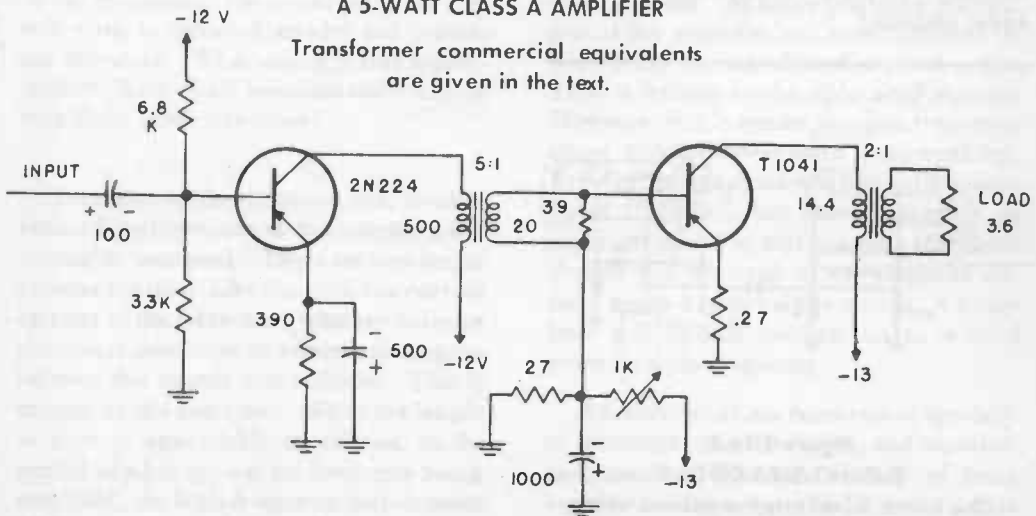
ting the transistor to handle the larger amplitude signal with a minimum of distortion. The bias, and therefore the operating point, slides up and down the characteristic slope of the dynamic curve in proportion to the signal amplitude. The sliding-bias amplifier is much more efficient than class A for it consumes only enough power from the battery for proper operation. In this regard it is similar to the class B amplifier. This circuit produces a higher level of distortion products than the class A or B systems.

In figure 2.16-A the rectified audio voltage adds to the bias. Thus both the bias value and amount of audio must be adjusted for best performance. A 2N301 or any experimenter power transistor can be used in place of the OC-16. Note that the phasing of the output transformer is important for proper operation.

Figure 2.16-B shows an adaptation of the Phillips circuit which is used in the *Autocrat* (New Zealand) car radio. A separate winding is used for the sliding-bias source permitting the speaker to be grounded. Note that the phasing of the bias winding is important. It should be pointed out that the sliding-bias circuit should always be adjusted with the aid of an oscilloscope and audio oscillator.
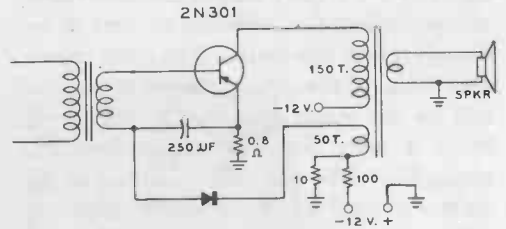
Figure 2.16-B
A SECOND SLIDING BIAS CIRCUIT
Principle is similar to that of Fig. 2.16-A.
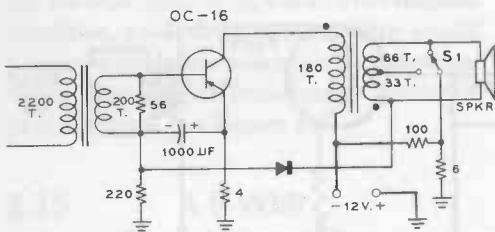
Figure 2.16-A
SLIDING BIAS CIRCUIT
The switch S_1 adjusts the point at which rectification occurs.

RF Circuits

In principle there is very little difference between an audio and an r.f. amplifier. The comments made in Chapter 2 regarding bias, stability and so on, are equally applicable to r.f. circuits.

3.1   Alpha Cutoff

One factor to consider when dealing with r.f. circuits is the *alpha cutoff frequency* of the transistor. No doubt you have seen this term in technical articles and transistor literature. What exactly is this mysterious attribute which separates some transistors from other transistors?

Transistors, like vacuum tubes, exhibit reduced performance as the operating frequency is increased. There are two major reasons for this. Like the tube, the current carriers of the transistor (whether holes or electrons) take time to traverse the region between the emitter and collector. This is known as the *transit time*. When the length of time is appreciable in relation to the period of a full cycle at the frequency being amplified, the high frequency performance of the transistor is impaired.

High frequency performance is also limited by the base-emitter capacitance and the base resistance, R_b, which is in series with the source. These two components form a 'built-in' phase-shift network which cannot be compensated for externally. The effect of the capacitance can be minimized somewhat by reducing the source impedance.

If a transistor is driven with a 1,000 cycle audio signal, the circuit will exhibit a certain amount of gain (expressed in decibels). If the applied frequency is then increased, a decrease in the output voltage will be noted. At some frequency the output of the amplifier will have decreased by 3 db from the signal level at 1,000 cycles. This is known as the *alpha cutoff frequency*. However, this is not an absolute frequency above which the transistor quits working. Transistors will work well beyond the alpha cutoff frequency, but above this point *the output declines*. For this reason a transistor should not be used in r.f. amplifier circuits much beyond alpha cutoff. A transistor will usually oscillate up to 4 or 5 times its alpha frequency.

R.f. transistors are constructed specially to minimize the transit time and junction capacitance. The construction of these various transistor types is discussed under section 1.10.

3.2 Impedance Matching

As stated earlier, r.f. and audio amplifiers are essentially the same. An r.f. amplifier has a tuned circuit in place of the audio transformer. It is necessary to select a transistor whose alpha cutoff will allow efficient amplification at the frequency concerned.

As with the audio amplifiers, an impedance match must be provided to obtain the greatest possible gain. In r.f. circuits, matching also prevents the low impedance of the transistor from loading the tuned circuit, which would cause poor selectivity in addition to reduced gain.

Transformer Coupling Coupling from one transistor to another may readily be accomplished by auto-transformer action. This is shown in Fig. 3.2-A.

The collector of the driver transistor is tapped down the tuned circuit to reduce loading, and the base of the following stage is fed from a link winding. Instead of a link, the base may be tapped on the coil through a suitable coupling capacitor. The advantage of the link is that the bias voltage is fed in at the bottom of the winding, whereas in the tapped coil arrangement the bias components are shunted across part of the tuned circuit. This reduces both gain and selectivity. If a double-tuned trans-

Figure 3.2-B
A capacitive voltage divider will also match collector to base.

former is used, the base may be tapped down on the secondary and the bottom of the secondary returned to the bias circuit.

Common step-down figures range between 25,000 ohms and 5,000 ohms and from 100,000 ohms to 600 ohms. The primary impedance is determined by the output impedance of the collector of the driving transistor. If the preceding stage is an r.f. mixer, its collector current will often be *low*, and the impedance will thus be *high*. It is common to use an i.f. transformer having a primary impedance of 100,000 ohms following a mixer. If the secondary of the transformer feeds the base of a following stage, the impedance will be lower than if the secondary feeds a diode detector. The two quoted figures, 600 and 5,000 ohms are typical for a transistor base and a diode detector, respectively.

Capacitive Coupling The system of obtaining a capacitive step-down impedance ratio is shown in Fig. 3.2-B. This circuit will be recognized as being similar to the *pi coupler* so often used in the output stages of transmitters. If C_2 and C_2 have the same capacitance value, the junction of the two will be equivalent to a coil center tap. As C_2 is made larger and C_1 smaller (to maintain resonance), the junction of the two assumes a lower impedance. If the following stage requires a very low impedance source (such as a grounded-base stage), it may often be more easily obtained from such a capacitive stepdown system. It may be impractical to pro-

Figure 3.2-A
Link coupling provides an interstage impedance match between transistor stages.

vide the very few turns, or part of a turn, which are required in the inductive matching system in Fig. 3.2-A. This may be particularly true at very high frequencies.

Which   The inductive system is gener-
System?   ally used at the lower radio fre-
                   quencies because it is simple and
efficient. At the higher frequencies, especially in switched circuits, the capacitive system wins favor. Both systems are excellent when used in the proper places. They are, in fact, similar. Both accomplish the same job - *impedance transformation.*

Tuned Circuits   In some circuits it will be
Without   noticed that the base of
Step Down   the following stage may
                      be connected to the 'top'
of the previous tuned circuit (Fig. 3.2-C). This may be done where a very low Q circuit exists and selectivity is *not* required. Though it is possible to raise the Q of the circuit by using a very high C to L ratio, it is preferable to either tap the tuned circuit or provide a low impedance winding coupled to the coil.

3.3   Neutralization

The triode tube and the transistor have one thing in common. They each have internal capacitance between the input and the output terminals through which high
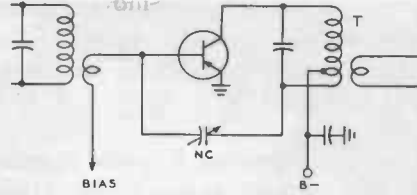
Figure 3.3-A
Many commercial I.F. transformers (T) provide a tap for neutralization voltage.

frequency energy may flow from the output to the input. This *feedback* causes circuit oscillation when it is neither required nor desired.

Early tube experimenters found that oscillation could be prevented by feeding back an out-of-phase component via an external path between the output and input circuit. This technique is called *neutralization.*

Neutralization may be applied to transistors as well as to vacuum tubes. In Fig. 3.3-A transformer T is tapped, and the lower end is connected back to the base through the neutralization capacitor NC. The phase of the fed-back energy will be the opposite of that which has passed through the transistor itself, and neutralization will be accomplished. The neutralization capacitor will be small, for in this case the source feedback voltage is quite
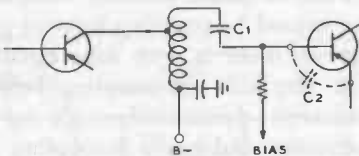
Figure 3.2-C
When the transistor capacitance is high the internal junction capacitance may be used in place of C$_2$.
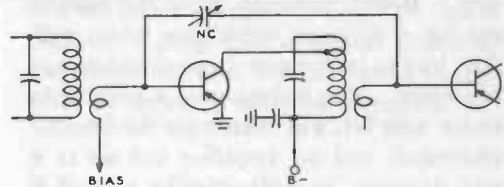
Figure 3.3-B
The neutralization voltage may be taken from the link secondary instead of a primary tap.

high. If, however, the tap is moved down the coil, the capacitor NC will need to be increased in value to obtain the same feedback voltage.

Instead of providing a special primary tap for this purpose, we may utilize the base winding which is a low impedance secondary. NC must then be increased in value accordingly. This circuit is shown in Fig. 3.3-B. To calculate NC you need to know the value of the capacitance between the base and the collector. This value is then multiplied by the turns ratio of the transformer. For example, if the transformer impedance is 25 K to 1 K the ratio will be:

$$R = \sqrt{\frac{25K}{1K}} = 5$$

NC will therefore be five times the base-collector capacity. The base-collector capacity may be found in the transistor data provided by the manufacturer.

Unilateralization The path between the base and the emitter may contain some resistance as well as capacitance. The combination of resistance and capacitance imparts to the feedback energy a phase shift which will not be completely cancelled out by the energy that is deliberately fed back through NC. The incomplete cancellation may not lead to oscillation unless the amplifier has very high gain. It will, however, cause the base to exhibit a different impedance which will then lead to loss of gain through impedance mismatch. The inclusion of a resistor in series with NC will correct for the internal phaseshift, and the amplifier will act as it was designed to act. This is known as *unilateralization*.

Not all transistors require neutralization or unilateralization. Many modern transistors have a very low internal base-collector capacitance and insufficient feedback takes place to cause oscillation. This is
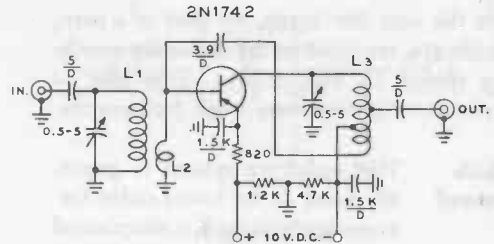
L1 = 3 T. #18 ENAM. CLOSEWOUND ON BRASS SLUG 1/4" COIL FORM.
L2 = 1 T. #18 ENAM. WOUND AT COLD END OF L1.
L3 = 6 T. # 14, 3/8" I.D., 7/8" LONG. –10 V. TAP AT 4 T. FROM
    COLLECTOR END. OUTPUT TAP AT 2.5 T. FROM COLLECTOR END.

Figure 3.3-C
A PRACTICAL EXAMPLE
OF A NEUTRALIZED R.F. AMPLIFIER
This 220 Mc. preselector has a power gain of 14 db and a noise figure of 5.5 db. The nominal bandwidth is 20 Mc. into a 3.5K load.

particularly so at the lower broadcast and intermediate frequencies. Among transistors of this nature are the Philco MADT types, the RCA Drift series, the *mesa* transistor, and many others. However, some circuits using these transistors do call for neutralization or unilateralization. It is best to follow the specifications of the designer.

3.4 RF and IF Amplifier Stability

Because of low transistor impedances there is not as much tendency toward oscillation caused by coupling between components as there is with tube circuitry. But one may still get coupling between the transistor elements through the external circuits. Adequate decoupling and bypassing must be used to keep the circuit stable. Capacitors used to bypass base and collector circuits should be connected back to the emitter as shown in Fig. 3.4-A. These components are designated C_2 and C_3. If returned to ground, the path back to the emitter would be
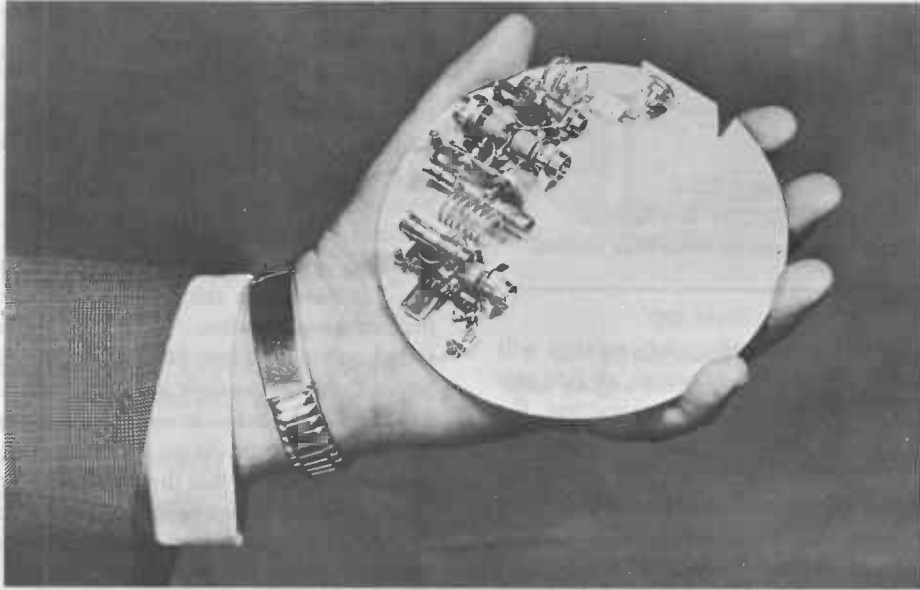
SATELLITE TRANSMITTER
This transmitter uses an overtone oscillator and pushpull amplifier, similar to
the circuits discussed in this chapter. (Photo courtesy of DuKane)

through C_1. Capacitor C_1 will have some reactance and this is often sufficient to convert the amplifier into an excellent oscillator! Similarly, oscillation may take place as a result of the common power supply impedance between stages, and adequate decoupling is necessary to prevent this. These components are C_2 and R_1 in Fig. 3.4-A. With tube circuitry in particular, the value of R_1 is not critical. In trans-

istor circuits, however, R_1 should be chosen with care, for it may well be part of a forward a.g.c. system (as explained later), and its value might be critical.

Decoupling capacitors for transistor circuitry may be large by tube circuitry standards. Typical values may be as high as 1,000 μfd. Usually, the decoupling resistor has a very low resistance value because a few milliamperes through a decoupling resistor that is too large might well drop half the power supply voltage. To obtain sufficiently long time constants with low impedance circuits, the decoupling capacitance by necessity must be increased.
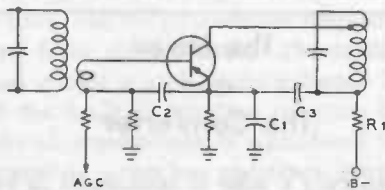
Figure 3.4-A
For best circuit stability,
bypass capacitors should be returned
to the emitter.

3.5   Detection

In Fig. 3.5-A, r.f. is applied to the diode and is rectified. Positive portions of the r.f. wave are able to flow through the diode, but negative portions are rejected.
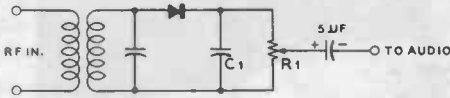
Figure 3.5-A
A SIMPLE DIODE DETECTOR
Commonly used in transistor radios.

The resultant pulsating d.c. voltage will flow through the gain control. R.f. is separated from the audio by capacitor C_1, which stores the d.c. component.

Fig. 3.5-B is a common-emitter transistor detector. Its operation is similar to that of the diode detector. Here the diode is the base-emitter junction, and R_1 is the diode load. Pulsating d.c. current flowing through the junction and through the resistor R_1 causes the current in the collector circuit to vary. The transistor is therefore acting not only as a detector but as an audio amplifier as well. Several receivers using this type of detector are to be found in this handbook.

The Product Detector The product detector (Fig. 3.5-C) is a special form of detector, designed to mix a carrier with the received signal as well as to detect it. The product detector may be regarded as a *mixer*. It is operated on a curved portion of the transistor's dynamic characteristic curve. Mixing between a sig-

nal and the local carrier occurs, and sidebands are created. Assume the b.f.o. is tuned to 455 kc. and a signal at 456 kc. is fed to the base circuit. The two sidebands will be 1 kc. (456 kc. minus 455 kc.) and 911 kc. (455 kc. plus 456 kc.). The capacitor C from the collector circuit to ground bypasses the unwanted image (the 911 kc. component) and the 1 kc. sideband is passed to the audio amplifier for further amplification. The b.f.o. voltage is fed to the product detector via the emitter. Correct product detector action is indicated if the b.f.o. is considerably *detuned* and audio output ceases. If there is audio output it indicates that the detector is either overloaded or is not functioning correctly. If the b.f.o. is turned off, audio output will appear because the transistor biasing condition is upset. The product detector is actually functioning as a common-emitter detector of the kind shown in Fig. 3.5-B.
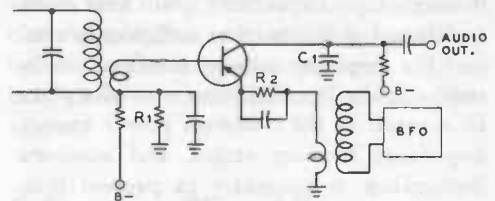
Figure 3.5-C
A TRANSISTOR PRODUCT DETECTOR
The mixing signal is injected into the emitter circuit.

3.6   The Mixer and The Converter

Generally a *mixer* is considered to be a transistor in which two signal components are mixed. For example, these might be a signal from the antenna and the energy from the local oscillator. The resultant, which is either the *sum* or *difference* of the two input

Figure 3.5-B
A TRANSISTOR INFINITE-IMPEDANCE DETECTOR
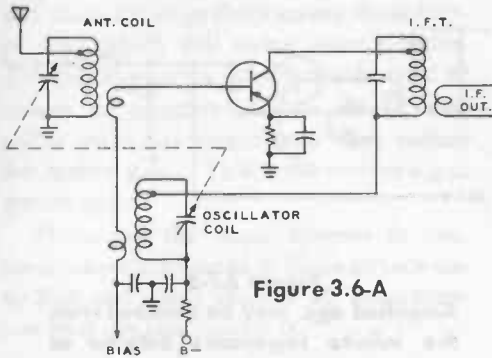
Figure 3.6-A

A TRANSISTOR   CONVERTER.   WITH
BASE INJECTION

frequencies, is recovered from the collector circuit.   The local oscillation usually takes place in another transistor.   A *converter* stage is similar to the above, but the transistor is its own oscillator.   These terms are often confused. A converter is often called a mixer, and vice-versa.   The mixer was explained in the preceeding paragraph on product detectors. The only difference here is that the output frequency is now at the intermediate frequency instead of in the audio range.   The external oscillator may be coupled to the mixer in one of three ways: through the base circuit, through the emitter circuit (Fig. 3.5-C), or through the collector circuit.   All three systems are effective.   The two methods generally used are base injection and emitter injection. The converter is similar to the old *autodyne* circuit in which the triode tube was made to oscillate in the cathode circuit and a signal was injected into the grid.

In Fig. 3.6-A the signal is injected into the base, and the intermediate frequency is taken from the collector.   The oscillator tuned circuit is also in the collector lead, and the feedback winding is in the base. If the i.f. transformer is considered for a moment as a very low resistance, it will be seen that it joins the oscillator coil directly to the collector.   Local oscillators will be discussed later in this chapter.

Fig. 3.6-B show the circuit of a different converter configuration. The oscillator-

tuned circuit is in the emitter circuit, and the feedback winding is connected to the collector.   The very low impedance of the emitter necessitates that it be coupled to the oscillator coil through a link.   In some circuits a tap is made on the oscillator coil. Both systems are used, and the authors are not able to state that one is better than the other.   In general, the adjustment of converters is more critical than that of mixers. Converters are popular in portable radios because of the saving in space and components.   Coupled to large antennas, converters are more likely to generate spurious products called 'birdies', and in areas near strong stations these might be quite troublesome.
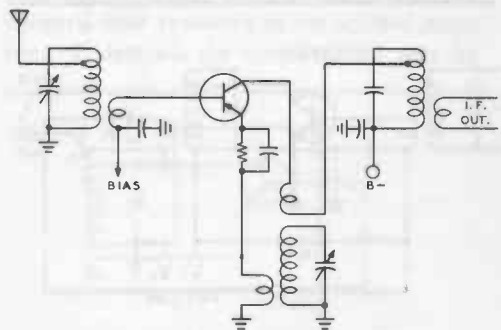
Figure 3.6-B

A TRANSISTOR CONVERTER   WITH
EMITTER INJECTION

3.7 Automatic Gain Control

As discussed in section 3.5, a d.c. voltage is recovered from the incoming signal in the process of detection. The stronger the signal the greater is the voltage across the load resistor. This voltage may be used to automatically control the signal level in the r.f. and i.f. amplifiers. There are two ways whereby the gain of an r.f. or i.f. transistor amplifier may be controlled. Most transistors exhibit maximum gain at an emitter current of about 1 ma. If the emitter current is reduced, the gain will also be reduced.

The simplest way to reduce the emitter current is to reduce the bias. In Fig. 3.7-A, TR$_1$ is biased to have an emitter current of approximately 1 ma. A strong signal is rectified by the diode. A positive d.c. voltage is built up across the audio gain control which, in this instance, is the load resistor. This voltage is fed back to the base of the i.f. amplifier stage or stages, reducing the standing bias and thus the collector current. At the same time, since the bias conditions on the i.f. transistor have been changed, the impedance matching between the i.f. transformer and the transistor has been upset, bringing about a further reduction in gain. This system may be ex-

Figure 3.7-B
Amplified agc. may be obtained from the infinite impedance detector as shown here.

tended further by not only applying it to two i.f. stages, but by putting a resistor in the lead marked 'X' in *only one* of the stages. A circuit may use the voltage drop across this resistor to forward bias a diode which is connected in parallel with one of the tuned circuits. This diode causes a considerable loss in sensitivity, thereby providing additional effective a.g.c. action.

The gain of a transistor may also be controlled by varying its collector voltage. This may be done in two ways. If a resistor is inserted at the point marked 'X' in Fig. 3.7-A and a negative voltage is fed along the a.g.c. line from the diode detector, the transistor will react by drawing heavy collector current which will, in turn, cause a voltage drop across resistor X. The collector is thus deprived of voltage and the gain is reduced. This is known as *forward a.g.c.* The previous method is known as *reverse a.g.c.* The negative bias required for forward a.g.c. is obtained simply by reversing the diode in the detector circuit.

The transistor detector of Fig. 3.5-B may also be used to supply an *amplified* a.g.c. voltage. When a signal is rectified it causes a d.c. voltage to build up across the load resistor R$_1$. (See section 3.5.) This voltage causes an increase in collector current. Before the arrival of a signal the transistor is biased to almost cutoff, and the potential at the collector is about equal to the supply voltage. An increase in collector current

Figure 3.7-A
I.F. STAGE
Controlled by diode detector agc.

will cause a voltage drop across the collect-or load which will swing more positive. This positive-going voltage may be used to reduce the negative bias on the i.f. am-plifier stage, or stages, and thus reduce the system gain.   This is the reverse a.g.c. system again.

These are the main systems in use. Most others are related to those already de-scribed, and a little analysis will soon show just what the relationship is.

3.8   Self-Excited Oscillators

Transitor oscillators are similar to tube oscillators.   The differences are brought about by the differing impedances and ca-pacitances common to transistor circuitry. The capacitances which exist between the transistor elements are *variable* and will be changed by temperature and supply vol-tage. Whereas a one-degree increase in tem-perature is a small increase when compared with the internal heat of a tube, it is a large increase when compared with the internal heat of a transistor.

Oscillators work on one principle and one principle only. A portion of the r.f. output of a transistor is fed back into the input where it is amplified, fed back to the input, amplified, and so on. The process builds up until it is limited by the loss in the circuit.

Proper oscillator design suggests that the tuned circuit be as loosely coupled as possible to the tube or transistor. This is even more important with transistors than with tubes because of the higher input and output capacitance of the transistor. Pru-dent designers introduce as much external capacitance into the tuned circuit as the os-cillator will permit. Assume that the trans-istor has an input capacity of 100 $\mu\mu$fd. and the transistor base is connected to a reson-ant circuit which is tuned with a 100 $\mu\mu$fd. capacitor. Across the coil will be a total of
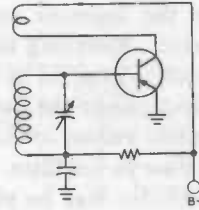
Figure 3.8-A
A tickler coil oscillator
with feedback between collector
and base.

200 $\mu\mu$fd., 50% of which is made up of transistor input capacity. The emitter-base capacitance is subject to variation. If, there-fore, the external capacitance is increased to 1,000 $\mu\mu$fd., the total capacitance will then be 1,100 $\mu\mu$fd., of which less than 10% is made up of the base-emitter capacitance. Obviously, variations in base-emitter capac-itance will now have less effect upon the os-cillator stability. Too much external C will prevent oscillation altogether, however.

The Tickler   This "old-time" circuit will
Coil   be familiar to most readers.
Oscillator   The tube has merely been
                     replaced by a transistor. In
Fig. 3.8-A, r.f. is taken from the collector and fed back to the coil in the base circuit. The vacuum tube's usual grid leak and capacitor should not be used with the tran-sistor. Bias is very easily obtained with the forward bias resistors in the normal man-ner. If desired, the tuned circuit may be
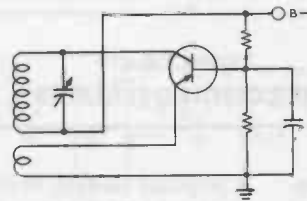
Figure 3.8-B
A tickler coil oscillator
with feedback between emitter
and collector.

connected to the collector and the *tickler* coil to the base. Referring to Fig. 3.8-A, the tuned circuit is damped by the low base impedance, and unless the base is tapped down the coil to reduce loading, the transistor may refuse to oscillate. Alternately, a capacitive divider may be placed across the coil and the junction connected to the base. This was discussed under r.f. amplifiers in section 3.2.

Fig. 3.8-B shows the tuned circuit in the collector lead and the feedback winding connected to the emitter. To further reduce loading, the collector may be tapped down the coil.

The Colpitts Oscillator The similarity between the tube and the transistor *Colpitts* circuits, Fig. 3.8-C, will be apparent at a glance. The base-emitter capacitance is effectively in parallel with C_2. Thus C_2 should be made large to reduce the influence of the transistor capacitance upon the tuned circuit. Capacitor C_1 should also be made large to reduce the effects of the collector capacitance upon the tuned circuit. The collector capacitance changes in value with variations in supply voltage. In general, a high C-low L circuit is required to maintain a stable oscillation frequency.
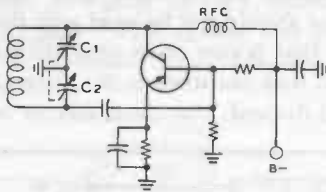
Figure 3.8-C
THE COLPITTS OSCILLATOR

The Clapp Oscillator A popular version of the Colpitts is the Clapp circuit illustrated in Fig. 3.8-D. In this oscillator the parallel tuned circuit is replaced with a series-parallel tuned circuit. The remarks concerning the size of C_1 and
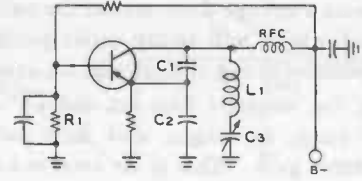
Figure 3.8-D
THE CLAPP OSCILLATOR

C_2 above also apply to the Clapp oscillator. Note that that ground point has been changed in this oscillator. In transistor circuitry there is no good reason why any one point should not be connected to ground. One may even ground the collector if desired. Obviously, the base and emitter lines would not be grounded at the same time! Resistor R_1 in Fig. 3.8-D may be a thermistor if better stability is required. Fluctuating temperatures cause a resistance change in the thermistor which in turn causes a compensating change in base current.

The Hartley Oscillator The Hartley, too, is an old favorite circuit. Little need be said except that the collector and the base, as with the previously discussed oscillators, may be tapped down the coil to obtain better isolation from the tuned circuit. The oscillator may be series or parallel fed.

The Ultra Audion Oscillator In tube circuitry, the Ultra Audion, Fig. 3.8-E, is an oscillator similar to the Colpitts, but no capacitive center tap is made to the tuned circuit. The internal capacitances of the transistor (collector-to-base and base-to-emitter) are the equivalent of C_1 and C_2 of the Colpitts oscillator (Fig. 3.8-C).

Fig. 3.8-F is a form of Ultra Audion oscillator in which the tuned circuit is connected between the collector and the base, which is at the r.f. ground potential. C_1 and C_2 (the latter representing the emitter-to-base junction capacitance) form a capac-
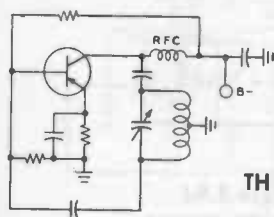
Figure 3.8-E
THE ULTRA-AUDION
OSCILLATOR

itive voltage divider connected across the coil L_1. At the lower frequencies it becomes necessary to place a capacitor in parallel with C_2 to sustain oscillation. In the interests of stability, C_1 and the external capacitor C_2 should have as large a value as possible. This circuit has been extremely useful in grid dip meters.

RC Phaseshift Oscillator   In this oscillator, Fig. 3.8-G, output is taken from the collector, passed through the phase shift network N, and fed back to the base to sustain oscillation. The
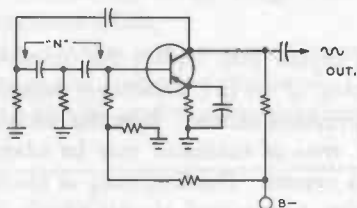
Figure 3.8-G
A PHASE-SHIFT AUDIO
OSCILLATOR

time constant of the network components determines the frequency of oscillation. This oscillator is mainly used at audio frequencies. For proper operation, a high beta transistor should be employed in conjunction with the highest permissible collector supply potential in order to overcome the losses in the phaseshift network.

The Multivibrator   The *multivibrator* (Fig. 3.8-H) is an arrangement of two transistors wherein the output of one transistor is fed to the input of the other. The output of the second transistor
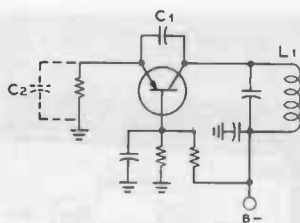
Figure 3.8-F

AN ULTRA-AUDION OSCILLATOR
This oscillator uses the base-emitter capacitance of the transistor to complete the tank circuit.

is then returned back to the input of the first. Once started by inherent circuit imbalance, the multivibrator rapidly builds up into a state of oscillation. Multivibrators may produce a variety of waveforms and are especially useful for generating square and sawtoothed waveforms. The multivibrator finds special application in test equipment, TV transmitters and receivers, and a multitude of calculating machines. A host of configurations have been evolved, each with different or special properties which are far too numerous to describe here. However, multivibrators may be divided into two classes, those which require a triggering pulse and those which do not. The oscillator which requires no pulse to start operation is said to be *free running*. If the oscillator has one transistor which needs to be pulsed into operation, it is said to have one *stable element*. If the oscillator requires that both transistors be pulsed, it
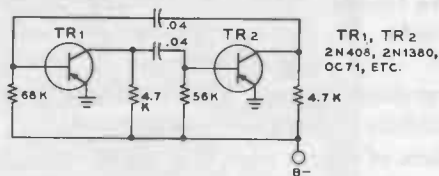
Figure 3.8-H
A SQUARE-WAVE GENERATOR
(MULTIVIBRATOR)

THE KNIGHT
CODE PRACTICE OSCILLATOR
This oscillator is a simple tickler coil
audio oscillator similar to Fig. 3.8-A.
(Photo by Allied Radio)

is said to be *bi-stable*. A trigger pulse fed
to the base of one transistor may cause it
to flip from a saturated condition to a bi-
ased-off condition, where it rests until an-
other pulse flops it back on again. Hence
the term *flip-flop*.

The Tunnel   The tunnel diode operates on
Diode   an entirely different principle
                from either the tube or the
transistor. Briefly, it is a conductor which
exhibits a negative resistance. Unlike a
piece of copper wire, through which a rise
in voltage will cause a corresponding rise
in current, in a tunnel diode a rise in volt-
age will cause the current to decrease. This
is the state (negative resistance) required
to begin and sustain oscillation. The cir-
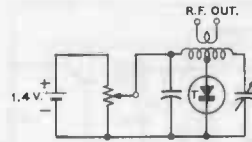
Figure 3.8-I
A TUNNEL DIODE
R.F. OSCILLATOR

cuit of an oscillator using a tunnel diode
is shown in Fig. 3.8-I. It is likely that the
tunnel diode will greatly benefit radio as
we know it. This is particularly true of
the ultra-high frequencies, for the relatively
low noise figure places the tunnel diode
second only to the parametric amplifier in
weak signal response.

3.9   Crystal Controlled Oscillators

A crystal may replace the tuned circuit
in most of the L/C oscillators described in
the previous section. Even the tickler feed-
back type of oscillator may be adapted to
use a crystal. The frequency of oscillation
is now determined almost wholly by the
crystal. Capacitance in the circuit will have
some effect on the frequency of operation
and a capacitor may be provided as a means
of vernier frequency control. Fig. 3.9-A
shows the circuit of the tickler feedback
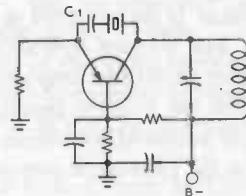
Figure 3.9-D
Another oscillator of the Colpitts
family, with the frequency determining
crystal in series with the feedback path.
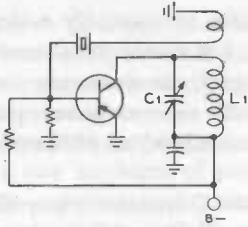
Figure 3.9-A
A TICKLER COIL
CRYSTAL CONTROLLED
OSCILLATOR
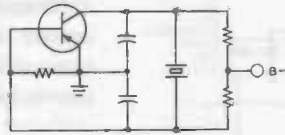
Figure 3.9-B
THE COLPITTS CRYSTAL
OSCILLATOR
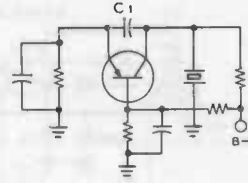
Figure 3.9-C
A MODIFIED COLPITTS
CRYSTAL-CONTROLLED
OSCILLATOR

type of transistor oscillator with the crystal in the feedback path. The frequency of operation is determined by the *series resonant frequency* of the crystal. Better stability will be obtained if the collector is tapped down the coil. L_1 and C_1 are tuned to the same frequency as the crystal.

The oscillator circuit shown in Fig. 3.9-B is a *Colpitts*. The coil has been replaced by the crystal operating in the parallel resonant mode.

Fig. 3.9-C is similar to the Colpitts and is a popular transistor oscillator. Capacitor C_1 may be used to control the feedback.

Another popular oscillator which also belongs to the Colpitts family is that shown in Fig. 3.9-D. The transistor operates in grounded-base configuration. Grounded-

THE HEATH GC-1A
TRANSISTORIZED
COMMUNICATIONS RECEIVER
This receiver uses many of the circuits discussed in this chapter.
(Photo by Heath)
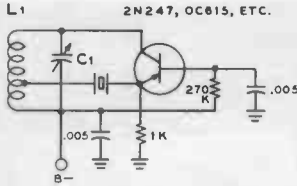
Figure 3.9-E
OVERTONE OSCILLATOR
If the crystal capacitance is properly
neutralized, the circuit may be used
with fifth overtone crystals.

base operation extends the frequencies at
which the transistor will operate and is preferred for the higher frequencies. If C_1 is
too large, the oscillator may *super-regenerate*
or *squegg*. If C_1 is too small, the transistor
will refuse to oscillate. The stability of this
oscillator is excellent when properly adjusted.

Overtone   Fig. 3.9-E shows the circuit of
Oscillator   an overtone oscillator in which
                 the crystal is placed in the feedback path. L_1 and C_1 are tuned to the crystal harmonic frequency.

3.10   Transmitting RF Amplifier

An r.f. amplifier may be operated in
class A, B, C, or any point in-between. The
class of operation is determined entirely by
the bias. Class A amplifiers were discussed in Chapter 2.

Class B   The bias on a class B transistor
Amplifiers   stage is set near the cutoff point.
                 If the stage is handling a signal with a carrier, the maximum ratings of
the stage will be considerably reduced, as
the presence of the carrier will cause a high
static collector current. If the class B amplifier is handling s.s.b., the standing current is low, but the peaks (on voice) might
reach very high figures.

A *linear amplifier* may amplify a single-sideband signal, but due to the absence of
carrier in the signal, the operating conditions will not be the same as those required
for amplitude modulated amplification.

Class C   Class C transistor amplifiers
Amplifiers   are usually modulated in the
                 collector circuit. If an amplifier increases the level of a modulated signal, it is usually not operated class C. It
should be operated class A, B, or at some
point in-between. Class C operation of an
amplifier clips the r.f. waveform, but the
clipped portions are restored by the flywheel action of the tuned circuit. A tuned
circuit, however, *cannot* restore the clipped
portions of a modulated waveform! A class
C amplifier will be rich in harmonics which,
if not prevented from reaching the antenna,
may cause severe television interference.
High power transistor transmitters often
have modulated driver stages, followed by
a collector-modulated class C stage. This
is done to increase r.f. drive and results in
higher modulation percentages.

Class C amplifiers are biased beyond
cutoff. In the amplifier shown in Fig. 3.10-A, the bias is determined by resistors R_1
and R_2. The stage is operated with the
base at ground potential for r.f. This type
of circuit does not require neutralization.
In the past, the unavailability of suitable
r.f. transistors has been a severe check on
the development of high power semiconductor transmitters. However, the state-of-the-art has advanced to the point where r.f.
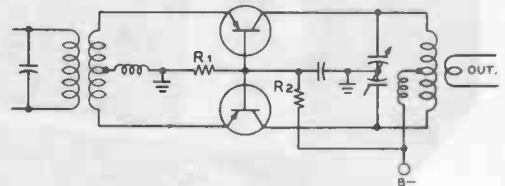
Figure 3.10-A
A PUSH-PULL CLASS C
R.F. AMPLIFIER

transitors of a type known as *triple diffused layer mesa* and *planar style* have collector dissipation figures as high as 125 watts. These transistors are capable of operation to several hundred megacycles. It would seem that a new problem of providing suitable power supplies might now emerge.

Transmitting circuits are described in greater detail in chapter 5.

3.11   Modulating RF Circuits

Modulation may be regarded as a *mixing process,* and any of the usual mixer circuits may be used to modulate an r.f. carrier with an audio signal. However, *plate* or *high level* mixing (or modulation) has found considerable favor in communications applications for a very good reason. R.f. amplifiers may be operated class C and thus are much more efficient.

The process of modulation creates sidebands which are transmitted in addition to the carrier.   The carrier itself does not change in amplitude during the modulation process. The term 'amplitude modulation' is something of a misnomer, for nothing of the sort takes place unless the amplifier is incorrectly operated or overmodulated.

The High Level Modulator   The circuit of Fig. 3.11-A will deliver 12 watts of audio from the modulation transformer T_2.   The secondary of T_2 should match the impedance of the amplifier it modulates. The primary of T_1 should
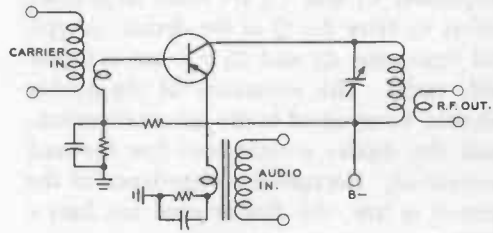
Figure 3.11-B
LOW LEVEL MODULATOR

match the driver.   This is a class B audio amplifier, and its operation has been covered in Chapter 2.

The Low Level Modulator   The low level modulator is little different from a conventional mixer.   The audio circuit replaces the r.f. oscillator. The circuit is shown in Fig. 3.11-B. The modulated stage should be followed by a linear amplifier.

The Diode Balanced Modulator   The diode balanced modulator performs two functions: (a) the r.f. is mixed with the modulation and (b) the carrier is balanced out. In Fig. 3.11-C, both the carrier and the audio are fed into the balancing potentiometer P_1. This control compensates for the unequal characteristics of the two diodes. Because the diodes are low impedance devices, they load the circuit to which they are connected. As a con-
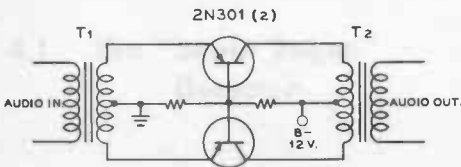
Figure 3.11-A
HIGH LEVEL MODULATOR
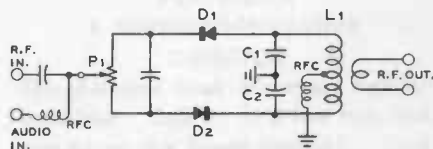
Figure 3.11-C
DIODE BALANCED MODULATOR

sequence, C_1 and C_2 are made large in an effort to raise the Q of the circuit. A typical figure for C_1 and C_2 at 4 mc. is 0.002 *u*fd. each. The resistance of the diodes should be matched in the *forward* direction, and the diodes should have low forward resistance. Because the impedance of the circuit is low, the diodes need not have a high reverse resistance.

The Transistor Balanced Modulator A transistor balanced modulator circuit is shown in Fig. 3.11-D. The action of each transistor is similar to that of a mixer. The two transistors opposing each other balance out the carrier. For better stability, the resistor R_1 should be left unbypassed for audio. The carrier is balanced out by the potentiometer P_1.

The impedance of the tuned circuit is considerably higher than that of Fig. 3.11-C, and the capacitors C_1 and C_2 may have smaller values.
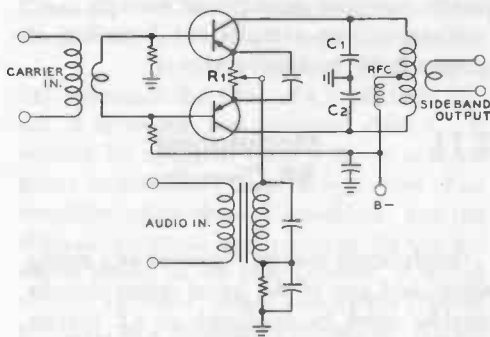
Figure 3.11-D
TRANSISTOR
BALANCED MODULATOR

Receivers

Several of the construction projects which follow are not really of a radio amateur nature. However, the authors feel that the construction of these simple broadcast radios will be good preparation for the more elaborate equipment to follow.

Not only are these circuits quite simple, but the authors have tried to build-in guaranteed performance. The little radios have been duplicated on both sides of the globe, using different components, and they work as advertised.

In getting circuits to work properly, all too often overseas readers are left in doubt regarding the exact description of components. Component descriptions needing clarification are the correct number of turns on coils, turns ratio of transformers, and approximate inductive values. Sufficient information of this type is included here so that reasonable substitutions can be made.

4.1 The "Super Regen" Detector

One of the most popular circuits constructed by amateurs and experimenters alike is the superregenerative detector. With only one transistor it is possible to amplify a radio frequency signal from two or three millionths of a volt up to headphone volume! Truly, the superregenerative detector creates a minor miracle!

One of the first high-frequency transistors available was the *Philco surface barrier* type, and many circuits have been devised to employ this unit. The Philco SB-100, the AO-1, 2N232, 2N346, and the T-1768
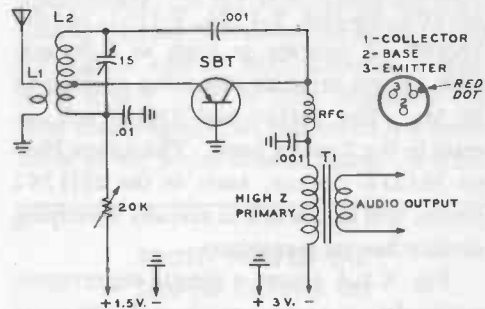
**Figure 4.1-A
A SUPERREGENERATIVE
DETECTOR**

This detector uses a surface barrier transistor. Coil L_1 is a two turn link placed at the lower end of L_2. Coil L_2, for 28 Mc., is 7 turns, #22, 1 inch diameter, 1-1/8 inch long. Transformer T_1 is a 10K to 2K transistor interstage transformer.
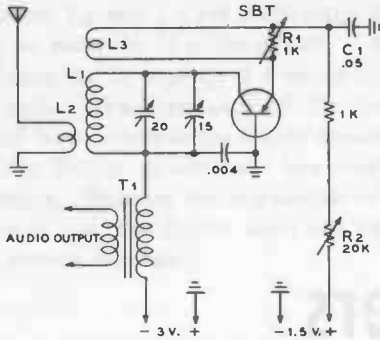
Figure 4.1-B
A SENSITIVE
SUPERREGENERATIVE DETECTOR
For 10 meters, coil L$_1$ is 7 turns, #22,
1 inch diameter, 1-1/8 inch long. Coil
L$_2$, the antenna link, is 2 turns at the
bottom end of L$_1$. Coil L$_3$, the feed-
back winding, is 3 turns at the top end
of coil L$_1$. Transformer T$_1$ can be a
10K to 2K transistor interstage
transformer.

all work on the 27 Mc. Citizens' band and
the 10-meter amateur band. The SB-101,
SB-102, SB-103, T-1324, T-1767, and the
2N588 all operate as high as 6 meters,
with several varieties operating as high as
90 Mc. The 2N500 and 2N588 will op-
erate in the 2-meter band. The newer Phil-
co MADT devices, such as the 2N1742
series, will also work in circuits specifying
surface barrier transistors.

Fig. 4.1-A shows a simple superregen-
erative detector which works well with most
surface barrier transistors. With the values
shown, the receiver will tune both the
Citizens' band and 10 meters. The poten-
tiometer is adjusted for best sensitivity, as
are the antenna coupling coil and the
emitter tap.

A more sensitive circuit is shown in
Fig. 4.1-B. Potentiometer R$_1$ is adjusted
for maximum sensitivity and should be
reset for each station. Potentiometer R$_2$ is

also set for maximum sensitivity. How-
ever, once the best setting has been found,
no further adjustment is required. Capa-
citor C$_1$ controls the quench frequency and
may have values between 0.015 μfd. and
0.1 μfd., depending upon the transistor
used. This circuit has been operated with
a 12-foot antenna and provides excellent
performance, even without an external
ground. Amateur stations on the 10-meter
band were received from distances as great
as 2,000 miles.

Another superregenerative detector is
shown in Fig. 4.1-C. Notice the similarity
to Fig. 3.8-F (the Ultra Audion oscillator).
This circuit differs from the previous super-
regenerative detectors in the method of
antenna coupling. Note that the antenna
is connected to the emitter through a trim-
mer capacitor.

The circuits just described will work on
11, 10, and 6 meters. But what about 2
meters (144 Mc.)? The circuit shown in
Fig. 4.1-D was designed by Philco for use
with their 2N1742 transistor for operation
between 85 and 185 Mc. This includes
the f.m. aircraft, 2-meter, mobile services,
and television bands.

In this circuit the bias control is set
for a collector current of 1.1 ma. Capa-
citor C$_1$ is the tuning control, and capa-
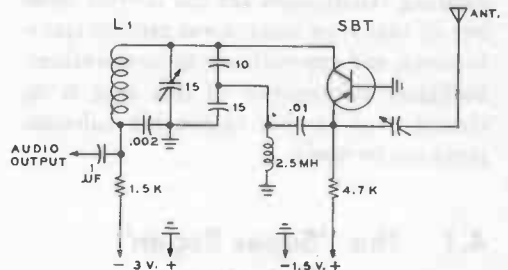
Figure 4.1-C
This circuit will work on the 6-meter
amateur band with the Philco T-1324,
T-1657, and 2N299 surface barrier
transistors. Coil L$_1$ is 5 turns, #16 wire
3/8 inch inside diameter, 1 inch long.
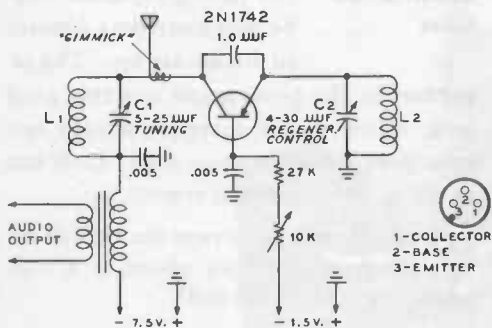
Figure 4.1-D
THE SUPERREGENERATIVE DETECTOR

Shown here is designed for operation on the two-meter band and will work to at least 180 Mc., using the Philco 2N1742 MADT transistor. Coil L_1 is 3 turns, #12 self supported, 1/2 inch inside diameter, and 1 inch long. Coil L_2 consists of 18 turns, #30 space wound on a 3/16 inch form, 1/2 inch long. The "gimmick" is a few turns of wire wound around the collector lead.

citor C_2 is adjusted for maximum sensitivity. Although not specifically stated in the Philco *Application Report #505*, this circuit could be moved up to 220 Mc. for use in tiny hand-held transceivers.

4.2　Simplex Crystal Set

Excluding the headphones, this crystal set uses four inexpensive components: the coil, the tuning capacitor, a germanium diode, and a 0.005 μfd. fixed capacitor. Yet the circuit offers much in the way of knowledge and experience to those new to the fascinating hobby of radio. There is much to be learned from the humble crystal set. The circuit is shown in Fig. 4.2-A.

REAR VIEW OF THE SIMPLEX CRYSTAL SET

How it Works　The antenna couples a multitude of signals to the coil and variable capacitor, which together select the desired station. The chosen signal is then rectified by the diode. This means that the audio component is recovered from the radio wave and passed to the headphones. In the headphones the fluctuating current (the recovered audio) flows through a coil of wire, creating a magnetic field. This in turn vibrates a soft iron diaphragm. The end result is a movement of air which creates sound. It is im-

FRONT VIEW OF THE SIMPLEX CRYSTAL SET

Figure 4.2-A
THE SIMPLEX CRYSTAL SET
Parts List

C_1 - Tuning capacitor, any value between 300 and 385 $\mu\mu$fd.

CR_1 - Any germanium diode, such as 1N34A, 1N48, 1N60, etc.

L_1 - One inch closewound winding of #34 enameled wire on 1-1/4 inch form. Tap 1/4 inch from ground end of coil. (J. W. Miller #2004 or similar loopstick may also be used.)

portant to realize that the flow of current must complete the circuit. It must flow from the tuned circuit (coil and capacitor) through the crystal, through the headphones, and back to the tuned circuit. The direction of flow is governed by the way the crystal is connected. Reversing the crystal will reverse the direction of flow. The sound, however, will be unaffected by the reverse connection. The capacitor across the phones bypasses any r.f. which manages to get past the crystal.

Construction Hints The tuning capacitor may be obtained from a discarded broadcast set. The capacitor in the photograph is a two gang unit, which means there are actually two capacitors on a common shaft. Only one of the capacitor sections is used.

Don't forget to scrape the enamel insulation from the wire whenever a connection is made to the coil!

Experiments to Perform If the antenna is connected near the top of the coil, it will detune the circuit. The stations will cover large portions of the dial, one station often interfering with another. If the antenna is connected near the bottom of the coil, the selectivity of the circuit will be immensely improved but the volume will be less. The tap shown has been adjusted to give a compromise between selectivity and gain.

4.3   Simplex Audio Power Pack

A capacitor, a resistor and an inexpensive transistor are all the components required to add an amplifier (power pack) to the Simplex Crystal Set. The amplifier will provide pleasant listening, and even
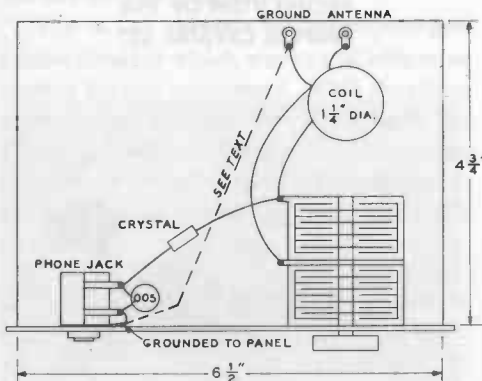
Figure 4.2-B
CHASSIS LAYOUT OF THE SIMPLEX CRYSTAL SET
Note that the phone jack and the tuning capacitor are connected together through the metal panel. If an insulated panel is used, a wire will have to be connected from the phone jack to the ground post as shown (dotted lines).
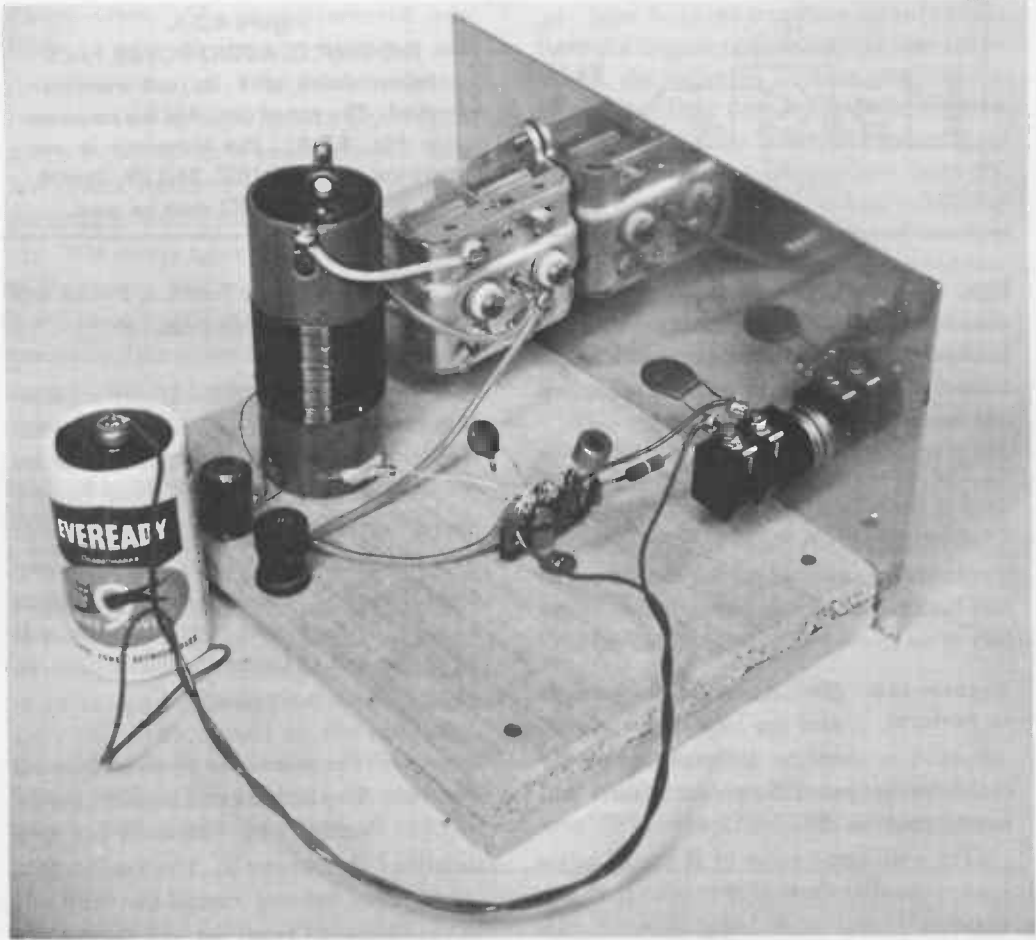
WIRING CONNECTIONS FOR THE SIMPLEX AUDIO POWER PACK

weak stations will be brought up to good headphone strength. The circuit is shown in Fig. 3.4-A.

How It In this receiver the crystal diode
Works is connected to the antenna tap on the coil. If the diode is connected to the top of the coil, the stations will have a very broad tuning range and will interfere with each other to a considerable extent. The other end of the diode is connected to the base of the transistor, which amplifies the signal and passes it on to the headphones. The resistor R_1 places

a small amount of bias on the transistor base. This bias is necessary for correct operation.

Construction The transistor may be sol-
Hints dered directly into the circuit, or as an alternative, it may be plugged into a transistor socket. If the wires are soldered, leave the leads long, but cover them with vinyl tubing to prevent shorts. Be careful not to let the heat from the iron flow up the leads and ruin the transistor. One end of the crystal will be marked with a red, white, or black dot or
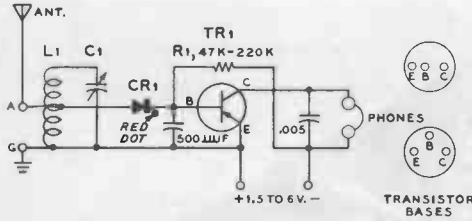
Figure 4.3-A
THE SIMPLEX AUDIO POWER PACK
Adjust value of R_1 to suit transistor used. The tuned circuit is the same as in Fig. 4.2-A. The transistor is not critical and a 2N107, 2N109, 2N408, 2N1380, or 0C72 may be used.

line. This end connects to the base of the transistor. If the panel is made of metal it is important that the headphone jack be insulated from the panel to avoid shorting out the battery.

The transistor will operate from a discarded flashlight cell, but best results will be obtained from a small 6-volt battery.

No switch is used in the amplifier circuit because the current drain from the battery is so small it will last the shelf life.

Experiments   Try connecting the antenna
to Perform   and the base of the transistor to different taps on the coil. Sometimes different transistors will work better on different taps.

Try a different value of R but *do not use* a value smaller than 47,000 ohms. A low value of R will cause heavy collector current which *may* ruin the transistor. Almost any type of PNP audio transistor will work in this ciruit. If you connect a 0-1 ma. meter in series with the battery, resistor R may be adjusted for a current of approximately 0.25 ma.

4.4   The TR One

This receiver uses only one transistor. Yet is is "a receiver with a difference" because it will give good results with only a fraction of a volt of power supply. Even if the battery circuit is opened and one lead held in each hand, allowing the circuit to be completed through the body, the receiver will still give good volume! There is no

point in using more than 1 1/2 volts supply with a receiver of this nature!

Using   The TR ONE will give excellent
A Solar   results when powered with a sin-
Cell   gle solar cell. The results are comparable with those from a battery, even in the shade. The cell used with the prototype receiver was in *International Rectifier Co.* #SA5-M, costing less than $2.00. The receiver works equally well when the cell is under an electric light, so batteries are not necessary.

How it   The transistor operates without
Works   bias and is a common-emitter de-
                tector. Its operation has been described in Chapter 3. The base to emitter junction behaves exactly like the diode in the Simplex Crystal Set, and the remainder of the transistor acts as an amplifier.
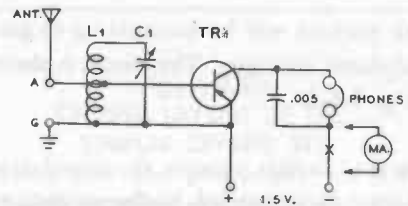
Figure 4.4-A
**SCHEMATIC DIAGRAM
OF THE TR-ONE**
The tuned circuit values are the same as in Fig. 4.2-A. Almost any transistor, except the drift types, may be used (see Fig. 4.3-A).

Construction The same baseboard, pan-
Hints el, tuning capacitor, and
coil used in the previous
receivers may be used again. The transis-
tor is mounted on a small terminal strip.
No special layout is necessary. Complete
the receiver before soldering in the transis-
tor. It is always a good idea to have a meter
in the battery lead so if anything is wrong
it will immediately show on the meter. For
example, if the meter indicates an excessive
current after the battery is connected, some-
thing is amiss. Prompt disconnection of
the battery would likely save the transistor.
With this receiver, as with the last, the
battery current is so low that a switch is
unnecessary.

Experiments As in the case of the previ-
to Perform iously described receivers,
the coil tap may be varied
to advantage. It is also interesting to ob-
serve the effects of heat on the transistor.
Connect a 0 - 1 ma. meter in the minus
battery lead. The current will normally
be very low, possibly between 30 and 150

μa Now hold the transistor allowing heat
from the fingers to flow into the transistor.
Watch the collector current rise rapidly.
Note how little time it takes for the heat
to affect the current flow. This experiment
indicates the reason why, in later receivers,
extra resistors are used in heat stabilizing
networks. Without a means of limiting
the current caused by heat, the transistor
could destroy itself. Imagine how high
the current would rise if the receiver were
left in a closed auto that had been standing
in the hot sun!

The effects of rectification may be ob-
served by tuning in a station with the meter
still connected in the B-lead. A strong sta-
tion will cause the battery current to rise
considerably. A weak station will cause it
to move only a little. In fact, the meter may
be used to measure the relative strength of
the stations received.

4.5   The TR Two

A transistor, two resistors, and a capac-
itor are the only parts required to add an
amplifier to the "TR ONE". Taking advan-

WIRING VIEW OF
THE TR-ONE
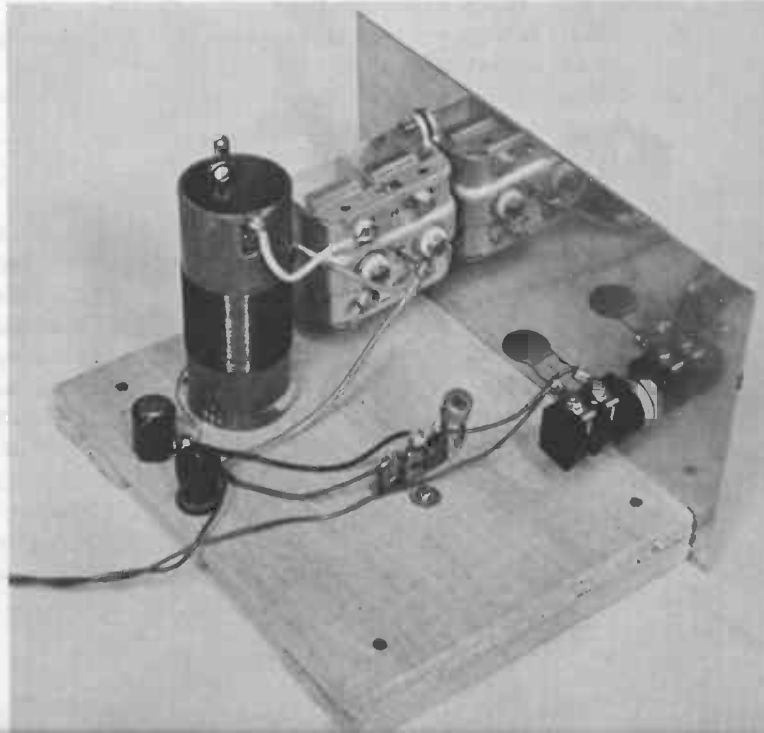
tage of the fact that the "TR ONE" will give excellent results from a very low battery voltage, the detector transistor has been coupled directly to the amplifier as shown in Fig. 4.5-A.

How It   By examining the circuit and **Works**   ignoring the amplifier for a moment, it can be seen that the detector transistor is supplied with collector voltage through resistor R_1. Remember that in previous experiments when a station was tuned in the collector current increased. In this circuit, when the collector current rises it causes a voltage drop across R_1. The changing d.c. voltage is applied to the base of the transistor amplifier. The signal in the headphones is considerably amplified and will even drive a speaker on strong stations. Resistor R_2 is necessary to raise the emitter voltage to nearly the same as the base voltage. The capacitor C_1 is necessary to provide a path to ground for the signal.

Apart from the need to provide another terminal strip on which to mount the few extra components, there is little more to the construction of this receiver.
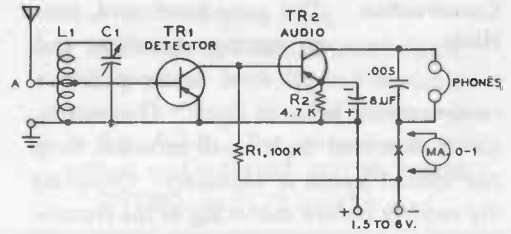
Figure 4.5-A
THE TR-TWO
The tuned circuit is the same as in preceding receivers. The transistors may be 2N139, 2N408, 2N1380, GT-109, or OC72.

Experiments   A 0-1 ma. meter inserted **to Perform**   in the battery lead at "X" will show that heat does not affect the current flow in this circuit. The reason for this is simple. When the applied heat causes a greater flow of current through resistor R_1, the voltage on the detector decreases so that over-all current consumption remains the same. If the amplifier transistor is heated, a larger amount of current will flow through R_2, decreasing the bias between the emitter and the base and thus reducing the collector
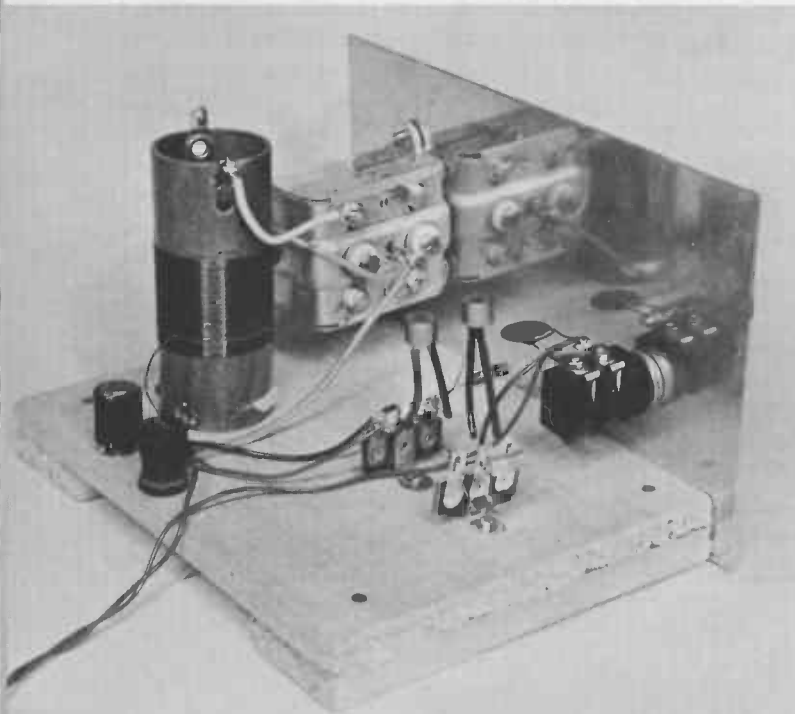
**REAR VIEW OF THE
TR-TWO**

current. This action, known as *temperature stabilization*, is a very important function in transistor circuitry. The total current drawn by the TR TWO is approximately 0.5 ma. at 6 volts.

Amplifier If more output is required, the Mini-Amplifier in Chapter 2 may be added to this circuit with excellent results.

4.6   The Solar Two

The SOLAR TWO is an adaptation of the TR TWO. This little receiver has been designed to operate from one or two *International Rectifier Co. #SA5-M* solar cells. In this circuit the values have been changed to suit the high current, low voltage output of the solar cell. Note that R_1 has been reduced to 10K and that the resistor and capacitor in the emitter lead of TR_2 have been eliminated. The SOLAR TWO must operate with low impedance headphones such as dynamic types. Alternatively, high

Figure 4.6-A
THE SOLAR TWO
The tuned circuit and transistors are the same as in preceding receivers. The solar cell is made by International Rectifier Corporation and is available at most jobbers or mail order supply houses. Transformer T_1 is a 100K high impedance microphone to 1K transistor base transformer, reverse connected. For additional output, two solar cells connected in series could be used.

impedance headphones may be connected through a step-up transformer to obtain optimum performance. When the receiver is operated in bright sunlight or under an electric light its performance is remarkable.

4.7   A Regenerative Receiver

This is a recommended circuit whether the would-be constructor is a young experimenter or an old timer new to transistors. Selectivity is such that two broadcast stations may be copied alongside each other without interference. Although it uses only two transistors, the receiver has an audio output equal to that of many superheterodynes which have more transistors and additional components. The high sensitivity, selectivity, and gain are obtained through the use of regeneration applied to the detector stage and the incorporation of band-pass tuned circuits.

FRONT VIEW OF THE REGENERATIVE RECEIVER
A National dial was used for ease of tuning and a metal panel eliminates hand capacitive effects. The volume control is to the right of the dial, and the regeneration control is below the dial. The phone jack is located to the right of the regeneration control.
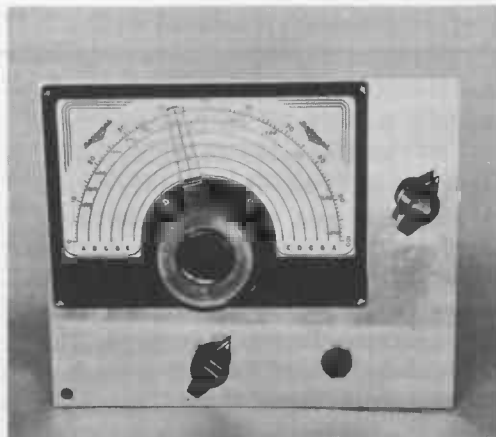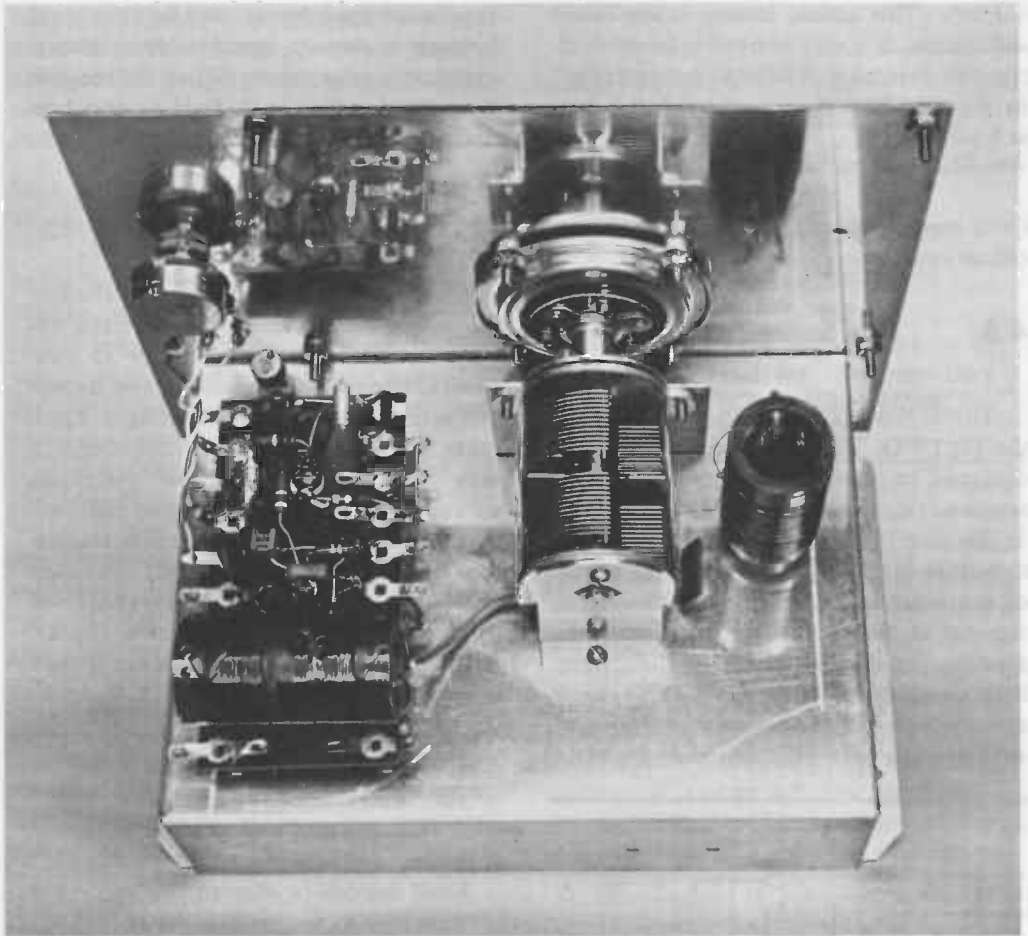
REAR VIEW OF THE REGENERATIVE RECEIVER
Note that the coils are at opposite ends of the chassis to prevent any undesired coupling. The remainder of the components are mounted on the fiber terminal strip.

How It Works A tuned circuit, L_1 and C_1, is top-coupled via capacitor C_3 to another tuned circuit, L_2 and C_2. The value of C_3 has been carefully chosen to give high gain consistent with good selectivity. Transistor TR_1 is a detector similar to that in the TR-ONE receiver. In this case, however, regeneration is added to increase the gain of the stage. This means that a little of the output has been returned to the input of the TR_1 via the tickler winding on L_2, causing the signal to build up to a high value. If the signal is increased too much, the stage oscillates, and the speaker emits sounds akin to a pet shop! The audio stage TR_2 is a conventional amplifier designed to feed into high impedance headphones.

Construction Hints The construction may take almost any form. In the photograph it will be noticed that the authors used a 5" x 7" chassis to support the tuning capacitor and the

strip of phenolic material containing most of the components. A metal panel is an important adjunct to a regenerative receiver to prevent hand capacity effects when the receiver is near oscillation. The coils are wound according to the data given. Note that it is essential that all the coils be wound in the same direction. That is, winding 4-5 on L_2 must be in the same direction as winding 3-1, in order to permit the detector to regenerate. If the windings are in the opposite direction, it will be necessary to reverse wires 4 and 5 to sustain oscillation. Keep the coils away from metal a distance at least equal to their diameter.

Operation Set the trimmer capacitors on C_1 and C_2 to about center and tune a station in with the regeneration control P_1 turned down (arm of potentiometer at the emitter end). Now adjust the trimmers one at a time while rocking the tuning capacitor back and forth. Several maximum settings will be found, but one setting in particular will be louder than the others and this setting is the one which should be chosen. The alignment should be done with the tuning capacitor somewhere near the center of its range.

A drift, MADT, or other type of high frequency transistor, will give superior results at TR_1. Ordinary i.f. amplifier types are not recommended. Almost any general purpose transistor may be used for TR_2.

Figure 4.7-A
SCHEMATIC DIAGRAM OF THE
REGENERATIVE RECEIVER
Parts List

C_1, C_2 - Tuning capacitor, 365 $\mu\mu$fd. per section (Miller #2112).

L_1 - Primary (1 and 2) 40 turns, #32 enamel. (Use this size wire for all windings.) Secondary (3 and 4) 85 turns, leave 1/8" between windings.

L_2 - Tickler (4 and 5) 35 turns. Secondary (1 and 3) 80 turns, tapped at 28 turns from #3 end, spaced 1/4" between windings.

TR_1 - 2N247, 2N274, 2N371, 2N-1745, OC44.

TR_2 - 2N408, 2N1380, GT81R, OC-75.

It will be found that the setting of P_1 which gives maximum output is just below the point at which oscillation commences. This setting is also the point at which greatest selectivity occurs. If the receiver is allowed to oscillate, output will be low and distorted.

4.8   The Super Three

As its name implies, the Super Three is a three-transistor superheterodyne which will drive a speaker on strong stations and will operate from the loopstick antenna .
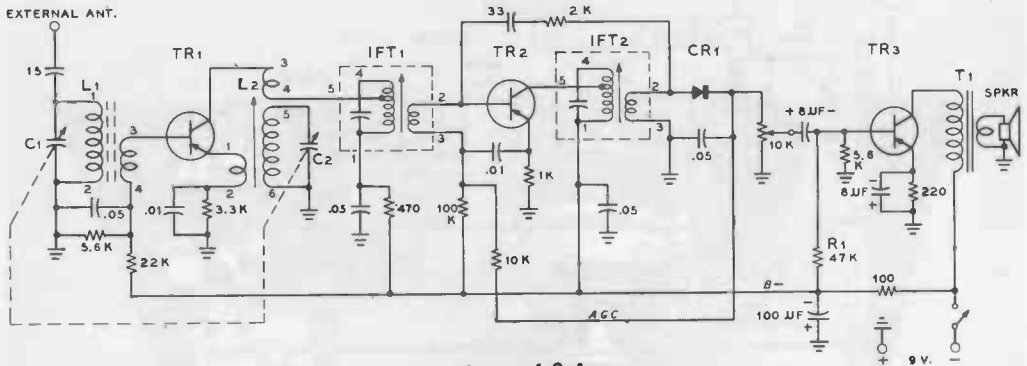
Figure 4.8-A
SCHEMATIC DIAGRAM FOR THE SUPER THREE
Resistor R_1 may be adjusted to suit different transistors in the output stage. Its value will determine the collector current of TR_3, which should provide a collector voltage of approximately 4.5 volts. The total battery current is 6 to 8 ma. If phones are used in place of T_1, resistor R_1 may need adjustment to provide the proper collector voltage.

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alone when the stations are not too far away. With an external antenna, stations more than 500 miles away come through at good headphone strength. The receiver is equipped with an automatic gain control circuit so that stations maintain a fair average loudness.

How It Works The first stage (TR_1 in Fig. 4.8-A) is a converter. It is both mixer and oscillator combined. The oscillator beats against the incoming signal and produces an intermediate frequency.

Transistor TR_2 is an i.f. amplifier of 455 kc. which increases the signal fed to the diode detector (CR_1). Here the signal is rectified and fed back to the i.f. amplifier as a.g.c. voltage. It also is used to drive the audio stage. The i.f. amplifier is neutralized as explained earlier in Chapter 3.

Construction Hints A little more care is necessary in the construction of the Super Three than is necessary with some of the simpler receivers. While layout is not critical, it should follow some sort of order so that the input and output circuits are reason-

Parts List

C_1, C_2 - Two gang tuning capacitors, antenna section 290 $\mu\mu$fd., Oscillator section 130 $\mu\mu$fd. (Miller #2112 with plates removed to track, or Alps #-72)

CR_1 - 1N64, 1N295, OA85, or similar germanium diodes.

IFT_1 - 25K to 600 ohms i.f. transformer (Miller 2041 or similar).

IFT_2 - 25K to 1,000 ohms i.f. transformer (Miller 2042 or similar).

L_1 - Antenna loopstick. For winding data see text. (Miller 2003 with a few turns removed from the primary)

L_2 - Oscillator coil, for winding data see text.

T_1 - Collector to speaker transformer, 500 or 1,000 ohms to 4, 8, 16 ohms (Stancor TA-9 or Triad TY-44X).

TR_1, TR_2 - 2N1380, 2N371, 2N410, GT-139, OC615 or similar.

TR_3 - 2N408, 2N1380, GT109, OC-72 or similar.
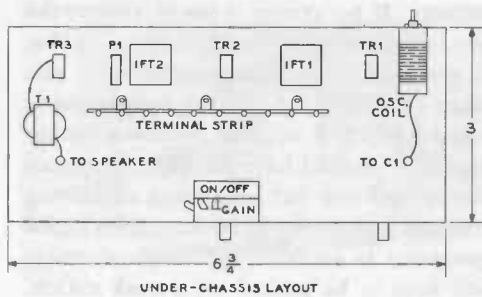
Figure 4.8-B
UNDER CHASSIS LAYOUT OF THE
SUPER 3 RECEIVER
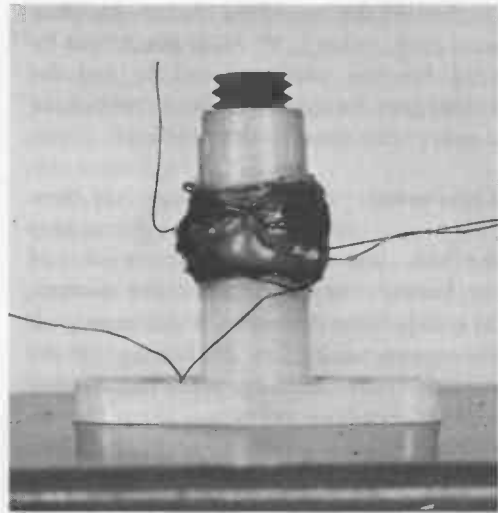
CLOSEUP VIEW OF THE
HOME-MADE I.F. TRANSFORMER
The performance is comparable to the
miniature Miller series, but this ver-
sion requires a shield.

ably well separated. The receiver may
be condensed into a very small package
of about the size of a pack of cigarettes if
the *Miller* subminiature i.f. transformers
are used. The prototype model was delib-
erately spread out so that the construction
could be clearly seen and followed (fig.
4.8-B). It is advised that constructors use
the larger layout unless they have had con-
siderable experience building receivers.

The chassis is bent up from a piece of
#18 gauge aluminum to a length of 6 1/2"
a width of 3", and a depth of 1", but a
commercial 5" x 7" chassis may be sub-
stituted. The panel is made from a scrap of
laminated plastic 31/2" high. A small ply-
wood cabinet, covered with imitation lea-
ther, is used to give the receiver a profession-
al appearance. The gain control was later
changed to a switch-type potentiometer, and
the switch is used to disconnect the battery.

The Coils The coils are wound in the
following manner. On coil
L₂, a 1/2" slug-tuned form, wind 4 turns
of #32 enameled wire. Space the winding
out to occupy about 1/4". This is the
emitter winding marked 1 and 2 on the
schematic. Next, closewind 13 turns over
the previous winding. The ends of this
winding are 3 and 4. On top of this wind
130 turns. The start of this winding is #6
on the schematic. The latter winding is

jumble would to a width of about 1/2".
Melt a little candle wax over the coil to pre-
vent it from coming undone.

The antenna coil L₁ is wound on a loop-
stick which is a long ferrite rod or slab.
Different loopsticks will call for a different
number of turns. As a guide, closewind
28 turns of #32 enameled wire about one
third of the distance from one end. The
ends of this winding are 1 and 2. Wind-
ings 3 and 4 consist of 5 turns of hookup
wire wound alongside the larger winding.
The two windings should both be wound
in the same direction and 2 and 4 should be
adjacent to each other. The loopstick is
connected by 6" leads so that is may be

Figure 4.8-C
Construction details for the home-made
455 kc. transistor i.f. transformers.

attached to the top of the chassis *away from metal work.* The *J. W. Miller #2022* can be used for the oscillator coil L_2 and the #2004 can be used for the loopstick L_1 if you prefer not to make your own.

Adjustment After the wiring has been finished and thoroughly checked, insert a milliameter in one of the battery leads and check the current. If it is greater than 6 to 7 ma. switch off the receiver and check the wiring. If the current reads correctly, place the receiver near a broadcast radio and listen for the carrier from the transistor oscillator as the tuning capacitor in the SUPER THREE is rotated. Place the receiver near the antenna for this. The oscillator beat note should tune 455 kc. higher than the capacitor

setting. If no carrier is heard, reverse the two leads 3 and 4 on coil L_2. An r.f. probe, if available, will determine whether this stage is oscillating. If the heterodyne is heard on 1500 kc., the oscillator tuning capacitor should have the plates approximately half way out, indicating a receiving frequency of about 1050 kc. If no signal generator is available, the i.f. transformers will have to be peaked on a weak station. Once a signal is received, the rest will be easy. All stages should now be aligned with the tuning capacitor set at approximately center position. If the trimmer is fully meshed and cannot peak the signal, the loopstick secondary winding requires more turns. The loopstick may be pre-adjusted to frequency by using it and its associated tuning capacitor as a wavetrap and nulling out a station on the broadcast receiver. For example, if the nulled-out station is on 1200 kc., then the setting of the tuned circuit is also 1200 kc.

**UNDER CHASSIS VIEW OF THE
THREE-TRANSISTOR
BROADCAST RADIO**
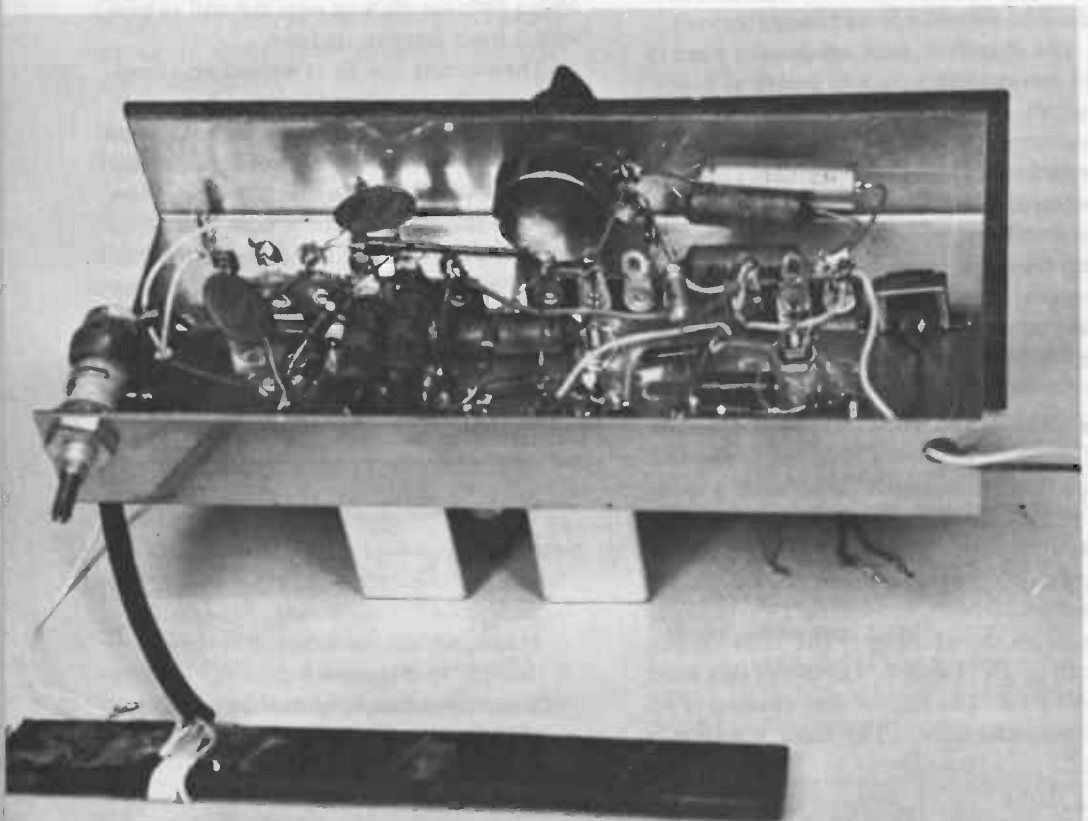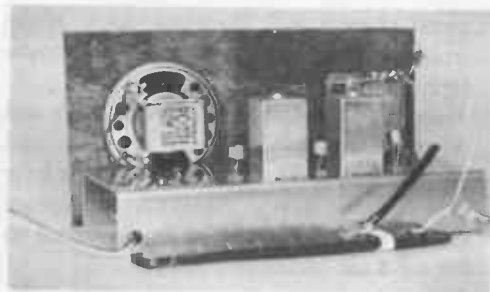
**REAR VIEW OF THE
THREE-TRANSISTOR
BROADCAST RECEIVER**

Constructing IF Transformers

J. W. Miller i.f. transformers have been used in this section of the book because they are inexpensive, compact and readily available. However, overseas readers may have trouble locating these units or any transistor i.f. transformers. When this is the case, home-built transformers can yield the same performance as can commercial units.

Remember that core material and size may change the inductance of the windings considerably. Therefore the data to follow must be considered only a guide. The important parameter of these transformers is the *turns ratio*, and if it is necessary to increase or decrease the number of turns on the primary, the secondary and also the taps should be varied in the same proportions.

The home-built transistor i.f. transformer shown in the schematic (Fig. 4.17-A) and accompanying photograph was wound on a *Neosid* 3/8" form. These forms are generally available throughout the British Empire. Similar forms should function as well.

The Primary   The primary should consist of 180 turns of fine wire, #32 to #38 swg enamelled, jumble wound to a width of approximately 3/8" on a 3/8" form. Subject to the conditions mentioned above, the total primary turns

will be the same in all cases for a frequency of 455 - 465 kc. This winding, in conjunction with the 200 $\mu\mu$fd. resonating capacitor will have an impedance of approximately 90,000 ohms (based on a reasonable working Q).

Drift transistors are designed to work into an impedance of approximately 100K and therefore may be connected across the primary without using a tap. Other junction transistors generally will require an impedance of 10K to 25K for reasonable impedance matching.

Transformer Designed to Match 10,000 ohms   Place a tap on the 180-turn primary at 60 turns up from the battery end of the winding (terminal #1). For a 600-ohm secondary, to match the transistor base, use a 9-turn link of the same wire. For a 2,000 ohm secondary, to feed the diode detectors, wind an 18-turn link over the primary.

Transformer Designed to Match 25,000 ohms   Place a tap on the 180-turn primary at 95 turns up from the battery end of the winding (terminal #1). For a secondary, use the same turns ratio as for the previous transformer.

The secondaries are wound with the same gauge wire as the primaries and are

**FRONT VIEW OF THE SUPER THREE
BROADCAST BAND RECEIVER**
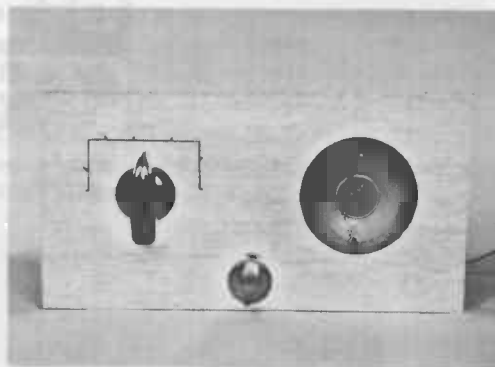
wound directly over the primaries. The end of the primary nearest the core is terminal #4. The end of the primary farthest from the core is terminal #3. If Litz wire is used to wind the primary, the transformer will have a higher Q. The transformer should be shielded by a can with a diameter of at least one inch.

4.9   A Four Transistor Superheterodyne

The four transistor superheterodyne has been designed around the popular midget MILLER coils and i.f. transformers. The cans of these components are about 1/2" square and 3/4" high. With care, it is possible to build a receiver into a very small space indeed. The wristwatch radio of the comic strips is almost a reality! However, the compression of a receiver into a 2" x 4" area calls for a certain amount of experience if unnecessary coupling and consequent undesired oscillation are to be avoided. A larger layout on a

metal chassis will eliminate many of the troubles that otherwise may be encountered (Fig. 4.9-A).

How It Works   The loopstick and oscillator coil output links are in series, and oscillator injection is to the base of transistor TR_1. Feedback takes place via the lead from the collector circuit to the tap 5 on oscillator coil L_2.

The forward bias resistor R_1, on the second i.f. stage, is fed back to the emitter of the first stage. The voltage drop across R_2 supplies the forward bias to TR_3.

When positive a.g.c. voltage is fed to the base of TR_2, the current through TR_2 decreases. The voltage across its emitter swamping resistor R also decreases, and the forward bias to TR_3 decreases. This is a means of offering good a.g.c. action over two stages with a considerable reduction in the number of components in the a.g.c. line.

The neutralizing capacitors, C_2 and C_3, may not be necessary with many transistors, particularly the drift type. However, with other transistors, neutralization may be desirable even though oscillation is not taking place. The presence of feedback through a transistor may modify the input impedance of the stage and reduce the gain. This subject was discussed in section 3.3.

TOP VIEW OF THE FOUR-TRANSISTOR BROADCAST RECEIVER
A piece of insulating board was used for the chassis.
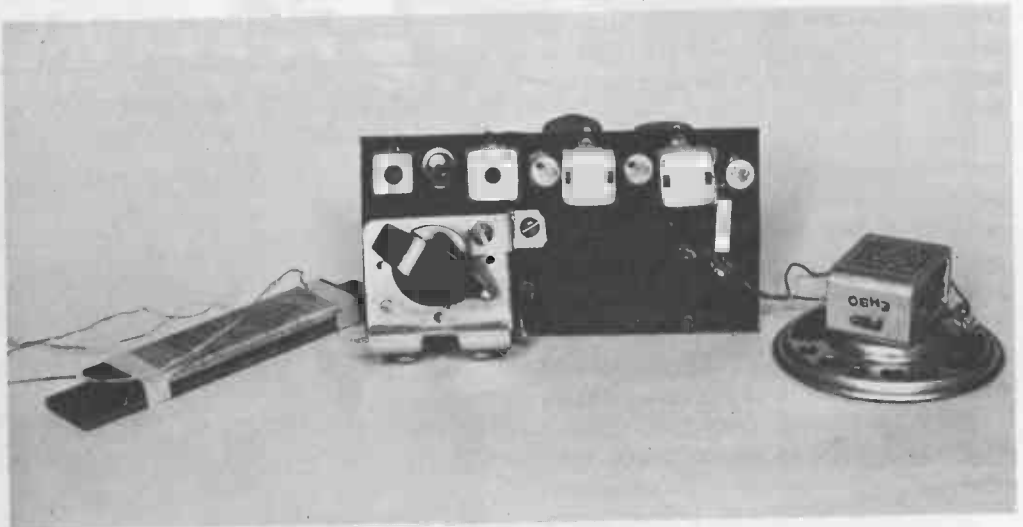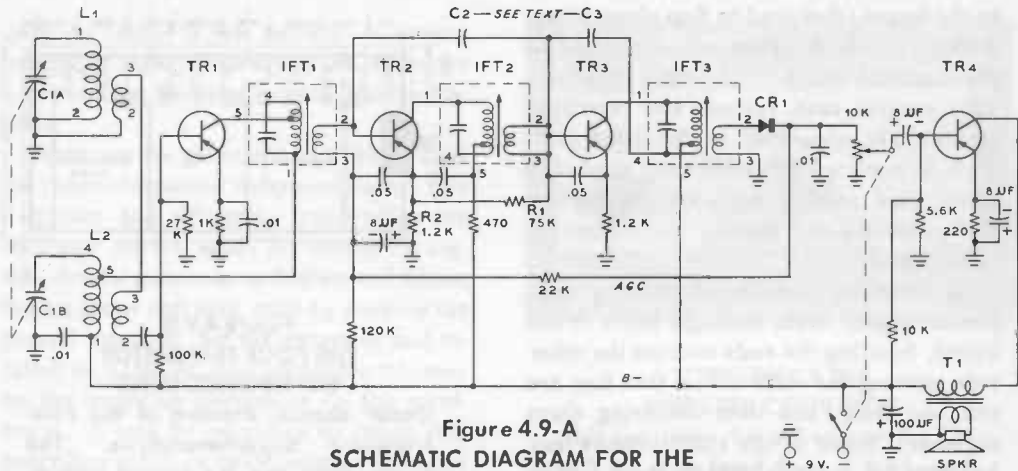
Figure 4.9-A
SCHEMATIC DIAGRAM FOR THE
FOUR TRANSISTOR SUPERHETERODYNE

Parts List

$C_{1a,b}$- Tuning capacitor, antenna sec-
C_2 tion 10-130 $\mu\mu$fd., oscillator sec-
       tion 10-78 $\mu\mu$fd. (Miller #2110
       or similar)

C_3 - Varies with transistor type. For
       2N1380, CK760, 2N139, GT139,
       use 15 $\mu\mu$fd. For 2N136 use 5
       $\mu\mu$fd. For 2N371 no capaci-
       tance is required.

CR_1 - R.f. diode, 1N48, 1N60, 1N64,
       1N295, OA85, or similar types.

IFT_1 - 25K to 600 ohms (Miller #2131
       or similar type).

IFT_2 - 10K to 600 ohms (Miller #2031
       or similar type).

IFT_3 - 25K to 1,000 ohms (Miller #2042
       or similar type).

L_1 - Loopstick antenna (Miller #2005,
       or see Fig. 4.8-A).

L_2 - Oscillator coil (Miller #2021, or
       circuitry of Fig. 4.8-A may be
       substituted for handwound coil).

T_1 - Collector to speaker trans-
       former, 500 or 1,000 ohms to
       4, 8, or 16 ohms (Stancor TA-9
       or Triad TY-44X).

$TR_{1,2}$- 2N136,   2N139,   2N371,
TR_3 - 2N1380,   CK760,   GT139.
TR_4 - 2N107,   2N408,   2N1380,
       GT109, OC70.

The i.f. signal is rectified by CR_1 and fed to TR_4, which, in turn, passes the amplified audio signal via the output transformer to the speaker.

Construction The prototype receiver was
Hints   built on a piece of 1/16"
                  thick phenolic board meas-
ing 2" x 4". The oscillator coil and i.f. transformer are mounted along the rear from left to right. The tuning capacitor is at the left in front of the oscillator coil, and the 2" speaker is at the right. There is just room for the frame of the speaker to project over the i.f. transformers. The midget audio gain control is under the board at the left and does not show in the photograph. The oscillator and i.f. cans are mounted with their lugs fore and aft. The lugs are pushed through small holes in the board and bent over. Two pieces of #22 tinned wire are run along the board in line with the lugs to which they are soldered. A third wire is run along the front of the board. The ends are bent over and pushed through small holes in the board material. A couple of cross members are now added forming a grid, and all the cross-over points are soldered. The purpose of the grid is three fold: (a) it holds all the cans firmly

to the board (they tend to flop about otherwise); (b) all the cans are connected to the common line; (c) the tuning capacitor, gain control case, resistor and capacitor, returns are connected to the wire grid. This is really a busbar hook-up similar to those used in receivers years ago, before the point-to-point wiring technique became popular.

A tie point is made by pushing component pigtail wires through holes in the board, bending the ends over on the other side, cutting the ends off so that they are not too long, and then soldering them together. Some of the solder knobs may be seen on the top side of the board in the space normally occupied by the speaker. The output transformer feet are soldered to two of the ground point knobs on the top of the chassis.

The receiver may be installed in a plastic case. The case must not be metal, as metal will render the loopstick useless. The original case used once housed a woman's necklace. The interior of the receiver (though a thing of beauty to the person who builds it) may not necessarily be considered beautiful by those who know nothing about radio. Consequently, the transparent case was sprayed inside with a paint bomb. Before the painting, a small dial card was glued to the inside, face up. Also, a number of small holes were made in the lid to let the sound come out. The shaft was cut off of the gain control potentiometer. Both ends were tapped, and then the shaft was replaced through a hole in the side of the cabinet. A case a little larger than the prototype would make this step unnecessary.

It is not essential that you use transistor sockets. It is a simple matter to drill three holes underneath the transistor and make tie points as described above. This was done with the output transistor in the prototype model and may be seen in the photograph. Sockets were generally preferred in the prototype because this made
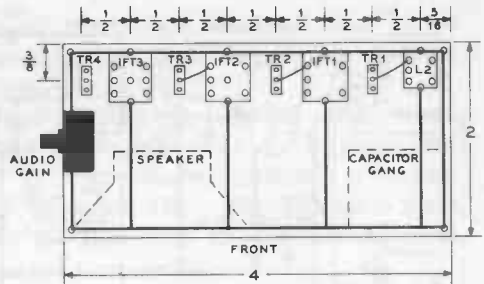
Figure 4.9-B
THE FOUR TRANSISTOR
SUPERHETERODYNE
Under chassis drawing of the Four Transistor Superheterodyne. The heavy lines are the ground busbar.

it easy to try different transistors and compare their performance.

It is strongly recommended that unless you have had considerable experience building compact receivers, you construct the receiver first on a chassis similar to that used to house the *Super Three* previously described. Then, when you feel that you have mastered any problems which may arise, have the feel of the alignment operation, and are confident enough to go further, remove the parts from the chassis and start the condensed model. Draw the layout on a piece of paper the same size as the phenolic board and try various layouts until everything fits in without the receiver taking on the unkempt appearance of a sparrow's nest.

Alignment   A signal generator is invaluable when it comes to the alignment of a superheterodyne. Those who do not possess one may follow the alignment procedure suggested for the *Super Three.*

To proceed with the alignment, couple the generator (tuned to 455 kc.) through a small capacitor of 5 to 20 $\mu\mu$fd. to the stator of C_{1a} . Switch on the generator tone and peak the i.f. transformers for maximum volume. Reduce the generator gain

until the signal is just audible. A strong generator signal will create an excessive a.g.c. voltage which will cause false indications.

Next, set the generator to 1500 kc. Set the receiver capacitor to approximately this frequency and adjust the trimmer on the oscillator section of C_1 for maximum signal. Set the generator at 600 kc. and adjust the oscillator coil slug until C_1 peaks at the correct position. Set the generator and receiver to 1100 kc. and adjust the trimmer on the loopstick portion of C_1 for maximum. It may be necessary to repeat this procedure once or twice because there is a certain amount of interaction between the various adjustments. Finally, with the loopstick in position and the generator output lead held near the loopstick, adjust C_{1a} trimmer and the i.f. transformers again for maximum volume.

In an area far removed from stations, an external antenna may be connected to the fixed plates of C_{1a} through a 5 $\mu\mu$fd. capacitor. Volume should then be sufficient for all normal listening.

4.10   The Mobileer

Many have wished to copy 75 meter stations on the auto radio, or perhaps on the XYL's broadcast band receiver. The wish can be fulfilled for the price of a week's supply of cigarettes and the time you would have spent smoking them.

Here are a few of the MOBILEER's excellent qualities. (1) In a side by side test with a commercial 75 meter communications receiver the MOBILEER held its own. There was no noticeable difference in sensitivity between the two. (2) If the battery voltage is dropped from 12 to 6 volts the crystal oscillator will move only a few cycles. (3) Image and spurious signals are negligible and certainly no more than a tube counterpart. (4) The MOBILEER uses only two transistors, employs a war surplus crystal, and draws 3 ma. from a 12 volt battery.
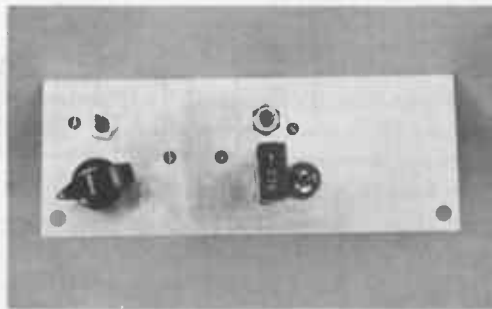
**TOP VIEW OF THE
MOBILEER CONVERTER**
This simple device will convert the 3.5-4.0 Mc. ham band down to the broadcast receiver range. The knob at the left is the antenna trimmer. Above that is the antenna coil slug. The crystal (near the center of the chassis) is between the mixer coil and the oscillator coil.

The selectivity or ability to separate stations is determined by the receiver to which the MOBILEER is connected, and nothing can be done in the converter itself to improve this.

The MOBILEER is designed to operate with 9 to 12 volt batteries, although good performance, with reduced gain, is obtainable from as low as 6 volts.

How It Works   The heart of the MOBILEER is the combined mixer and crystal oscillator. Considerable work went into the design of this important part of the converter. A great number of circuits were tried but all suffered from very bad image and spurious signal breakthrough. So bad in fact were these undesired signals, that the whole idea of a converter using only two transistors was nearly abondoned. Careful thought brought the realization that the spurious signals were due to incorrect operation of the mixer-oscillator stage. The transistor had been operating over the entire part of the dynamic transfer characteristic curve.
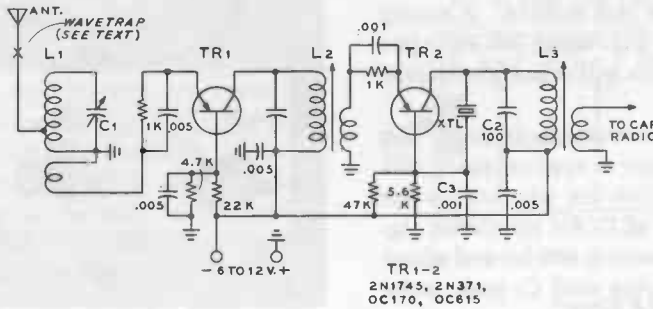
Figure 4.10-A
SCHEMATIC DIAGRAM FOR THE
MOBILEER CONVERTER

This is a 3.5 - 4.0 Mc. converter for car or house radio. The Mobileer uses only two transistors, yet has a performance equal in every respect to its tube counterpart.

Parts List

C_1 - 35 to 50 $\mu\mu$fd. antenna trimmer.

C_2 - 100 $\mu\mu$fd. mica.

C_3 - 0.001 μfd. mica or ceramic.

L_1 - 70 turns, #32 enamel jumble wound on 3/8" form, 3/8" long. Antenna tap 5 turns from bottom, emitter link 2 turns, small hook-up wire over primary. (Miller #4400 or similar slug tuned form)

L_2 - 40 turns #32 enamel, same as L_1. Emitter link 3 turns of hookup wire over primary.

L_3 - 90 turns, #36 s.c. wire, otherwise same as L_1. Link 3 turns hookup wire over primary.

The peaks of the oscillator waveform were being rectified, producing exactly the same effects one gets when a diode is connected in series with the antenna lead in the presence of a strong station (cross modulation). With this realization, the circuit design was modified, the cross modulation stopped, and the MOBILEER took its present form, Fig. 4.10-A.

The oscillator is a Colpitts circuit with the capacitor's C_2 and C_3 forming the ca-

pacitive voltage divider. This is explained in section 3.2. The values of C_2 and C_3 should not be changed. The oscillator operates in the common-emitter configuration. The mixer part of this stage operates common base with the signal injected into the emitter.

The r.f. amplifier also operates common base. This configuration was chosen for simplicity and to prevent the need for neutralization, which might have been necessary if transistors other than those suggested were used. If other transistors are incorporated in the present circuit they should have a high alpha cut-off frequency.

Both stages are fully stabilized to allow safe operation in the high temperatures often encountered in closed automobiles.

The   The crystal for the MOBILEER
Crystal   need cost no more than a dollar.

A vast number of crystals are available on the surplus market for much less than this. Any crystal between 4550 and 5100 kc. will operate in this circuit. If a 4550 kc. crystal is chosen, the broadcast receiver is tuned between 550 and 1050 kc., which represents the frequencies between 4.0 and 3.5 Mc. respectively. A 5.1 Mc. crystal will place 3.5 Mc. at the high end (1600 kc.) of the broadcast band. A crystal frequency between these limits will cause the 75-meter band to cover the middle portion of the receiver dial.

A point to note is that the broadcast receiver tunes backwards. That is, the low frequency end of the 75-meter band will
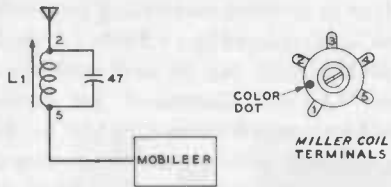
Figure 4.10-B
If strong broadcast stations "break-
through" the converter, a wavetrap
may be inserted in the antenna lead.
The best position for the trap is inside
the Mobileer case close to the antenna
connection. The coil may be any os-
cillator coil, such as the Miller #2022.
Tune the slug until the offending sta-
tion nulls out.

be on the high frequency end of the re-
ceiver dial and vice-versa. However, if
either of the suggested crystal frequencies
are used, the stated calibration marks on

the receiver dial will hold for 75 and 80
meters.

Construction Construction may take any
Hints   desired form. The main
                  points to observe are that
the input and output circuits should not
be placed too close to each other, and com-
plete shielding of the whole unit is requir-
ed, *including* the lead to the broadcast re-
ceiver. Incomplete shielding will allow
broadcast stations to be picked up and to
compete with the 75-meter signals. If the
unit is constructed on a flat plate, as shown
in the photograph, it may be easily dropped
into a small U-shaped chassis and secured
in place.

If desired, a switch may be built into
the unit for bypassing the converter and
allowing normal operation of the receiver,
Fig. 4.10-C. If a switch is used, take care
with the lead dress and shield the wires

UNDERCHASSIS VIEW OF THE MOBILEER
Note that the components are mounted on a length of terminal strip stock. It
should be possible to use the Mobileer on 40 meters by using a 6.0 Mc. crystal
and removing a few turns from the coils.
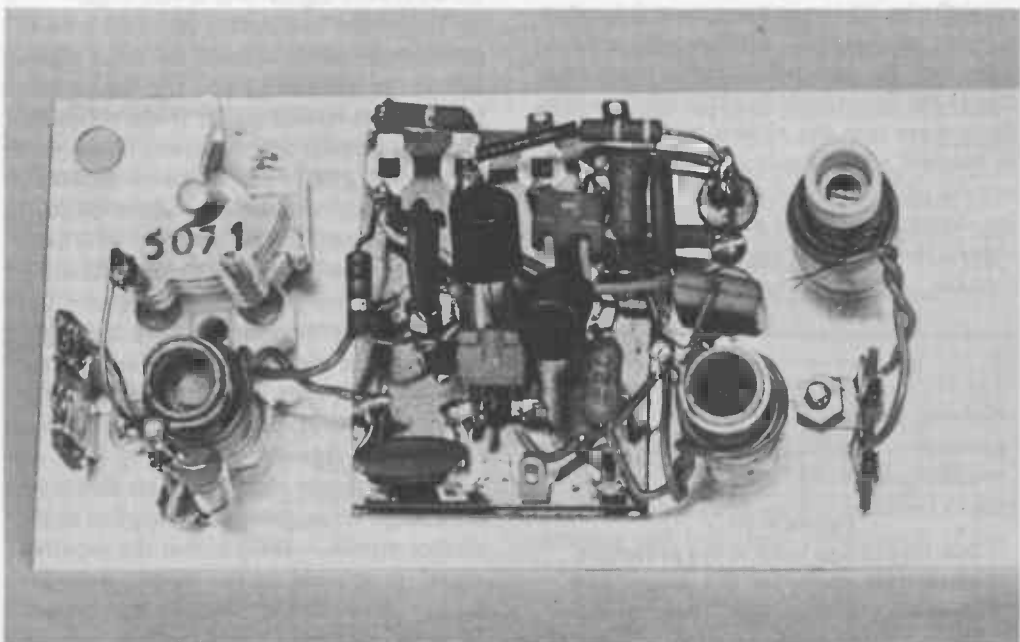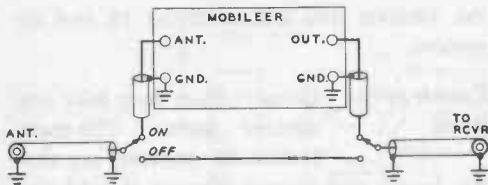
Figure 4.10-C
A double pole, double throw switch
will remove the Mobileer from the
circuit when broadcast reception is
required. A third deck on the switch
may be used to break the battery
voltage.

right up to the switch. Since the input and
output leads of the MOBILEER are brought
to the same switch, this is a likely place for
the transfer of broadcast stations past the
converter.

Home   The MOBILEER may be operated
Station from a large outdoor antenna a-
Use   head of a domestic receiver, but
           it is possible that in areas close to
strong broadcast stations some break-
through may be experienced. If this is the
case, the crystal frequency may be altered
to shift the 80-meter band away from that
portion of the dial. Alternatively, a wave-
trap may be inserted in the antenna lead
close to the converter. Suitable components
for a wave trap are shown in Fig. 4.10-B
A receiver with a built-in antenna should
not be used with the converter, for it will
be almost impossible to prevent broadcast
signals from QRM'ing 75 and 80 meter
signals.
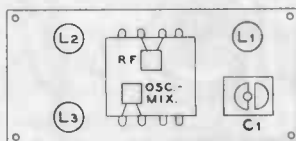
Figure 4.10-D
This layout was used in the prototype,
which left room for the switch and
wave-trap at one end. Any similar
layout may be used.

Here is another interesting possibility.
If coil L_3 is replaced by a 2.5 mh. r.f. choke,
the MOBILEER can be used with the fa-
mous "Q-5'er" Command Set receiver
(BC-453A), which tunes 190-550 kc. Not
only will this make an excellent home sta-
tion for the Novice or General Class Am-
ateur, but it will also provide a stable mo-
bile receiver. The MOBILEER could be
located in the trunk of the car, along with
the transmitter, and only the "Q-5'er"
need be positioned near the driver.

4.11   The Product
Detector

As mentioned elsewhere in the book,
a product detector is a mixer combining
the i.f. signals with the b.f.o. to produce
a separate i.f. in the audio range. Most
mixer circuits may be converted to a prod-
uct detector with little alteration. However,
a mixer is used at the front of the i.f. strip
where the signal level is very low, and a
product detector is used at the rear of the
i.f. where the signal level is very high.

To prevent overload of the detector when
the normal mixer is used, the input signal
has to be attenuated and the consequent
loss in recoverable audio is considerable.
This necessitates additional amplification to
bring the signal to par with a.m. detection.

A slightly different product detector
(though it may appear to differ very little
from the usual) has large signal handling
capabilities and very linear output. The
circuit of this detector is shown in simpli-
fied form in Fig. 4.11-A. The detector
operates with little or no applied collector
voltage and will handle as much as one
volt of input signal at the base.

A large input signal requires that there
be a large b.f.o. component applied to the
emitter circuit. Assume that the required
signal is applied to the emitter from the
b.f.o. Also assume that the bottom end
of R_2 is grounded. Positive half cycles of
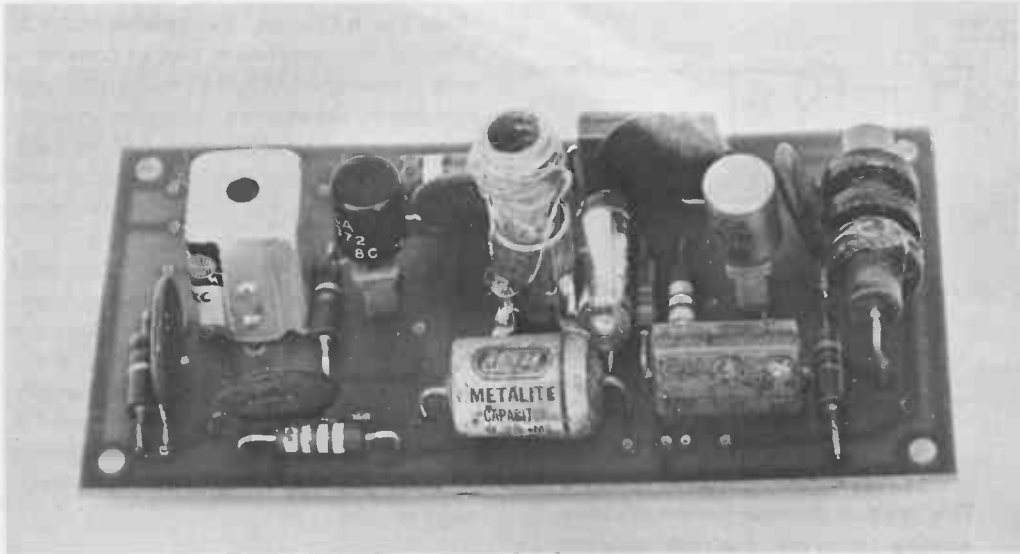
An etched circuit version of the product detector shown in **Fig. 4.11-B.**

b.f.o. voltage will cause the base to be negative with respect to ground, and the base will be forward biased. The base-emitter path will be a very low impedance, and consequently, the base will assume a positive potential with respect to ground. The base-collector path will now be a low impedance, and the collector will also assume a positive value. This will cause the capacitor C_1 to charge and actually maintain a steady voltage. The transistor has developed its own collector voltage. This voltage is a product of the b.f.o. voltage and is negative with respect to the base although positive with respect to ground. Thus, a signal at the base will be superimposed upon the

collector voltage, causing it to vary in amplitude. Negative b.f.o. cycles applied to the emitter will increase the base emitter impedance, and the collector current will cease to flow. However the charge on C_1 will remain.

In practice, when the product detector is built into a receiver, and where the b.f.o. and signal voltages are not excessive, optimum output requires that a small d.c. voltage be applied to the collector. The transistor is thus biased part way up the knee of its characteristic curve. This means that since the transistor is drawing current, the collector-base impedance is low. The output impedance of the product detector is consequently very low.

Adjustment Fig. 4.11-B shows the circuit of a transistorized product detector which may be added to an existing receiver. The input from the receiver should be adjusted so that overload of the detector and frequency modulation of the b.f.o. does not occur.

When the b.f.o. is detuned 10 kc. away from the intermediate frequency, there
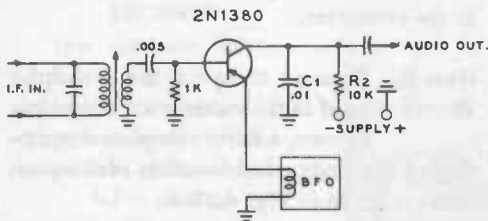
Figure 4.11-A
THE BASIC PRODUCT DETECTOR
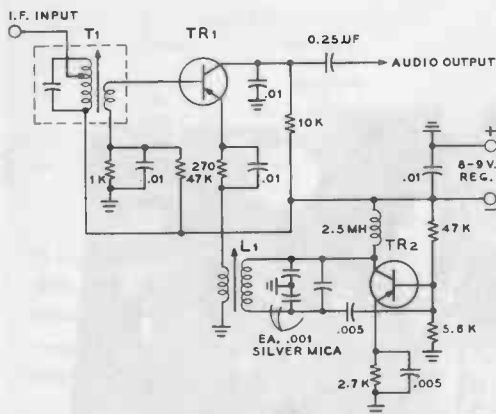
Figure 4.11-B
A SIMPLE PRODUCT DETECTOR
This product detector can be added to existing receivers. For maximum stability, silver mica capacitors are used in the oscillator circuit.

Parts List

L_1 - 90 turns, #34 enamel scramble wound on 3/8" slug tuned form. Link 10 turns of the same wire, wound over primary.

T_1 - 455 kc. transistor i.f. transformer (J. W. Miller #2041).

TR_1, - 2N247, 2N274, 2N371, 2N-
TR_2 1745, OC139.

should be no audio output. Any output under these conditions indicates that the product detector is being overloaded. However, when the b.f.o. is turned off, a.m. detection should normally take place. If the circuit is to be used for a.m. reception, a small amount of bias should be applied to the detector base as in Fig. 4.11-B to prevent distortion at low signal levels. The bias will not affect the product detector action.

The value of the collector load resistance of TR_1 is not critical. However, the operating point may be changed if an incorrect value is used. A potentiometer could be temporarily inserted in the circuit to substitute for the detector load.

With the b.f.o. on, the potentiometer is adjusted for maximum output consistent with linear operation. In many tests carried out by the authors, optimum collector voltage seemed to be around 0.25 volts. The collector current under these conditions will be around 2 ma. with a supply of 12 volts.

If a high audio output level is required from the product detector, it may be necessary to use a b.f.o. amplifier to increase the injection voltage. The signal at the base of TR_1 should never exceed in amplitude the b.f.o. voltage at the emitter. A large signal at the base may frequency modulate the b.f.o. unless an isolating stage is used.

4.12   A Professional Communications Receiver

This receiver has amplified a.g.c., a product detector, and provision for an S meter. The receiver covers the basic frequency range of 3.5 to 4 Mc, and can be used in conjunction with a converter for the other bands. Then the receiver becomes a tunable i.f. and the stability, even on 10 meters, is exactly the same as on 80 meters. To make the project less complicated, the converter was not built into the receiver. However, there is no reason why this cannot be done, and the only precaution to observe is in shielding. This is necessary to prevent receiver oscillator harmonics from mixing with other products and producing a multitude of "birdies" in the converter.

How it   Because many of the principles
Works   used in the receiver are not widely known, a fairly complete description of the design and function of components are given in Fig. 4.12-A.

The r.f. stage transistor TR_1 is operated grounded base. This is the equivalent of grounded grid in tube circuitry.
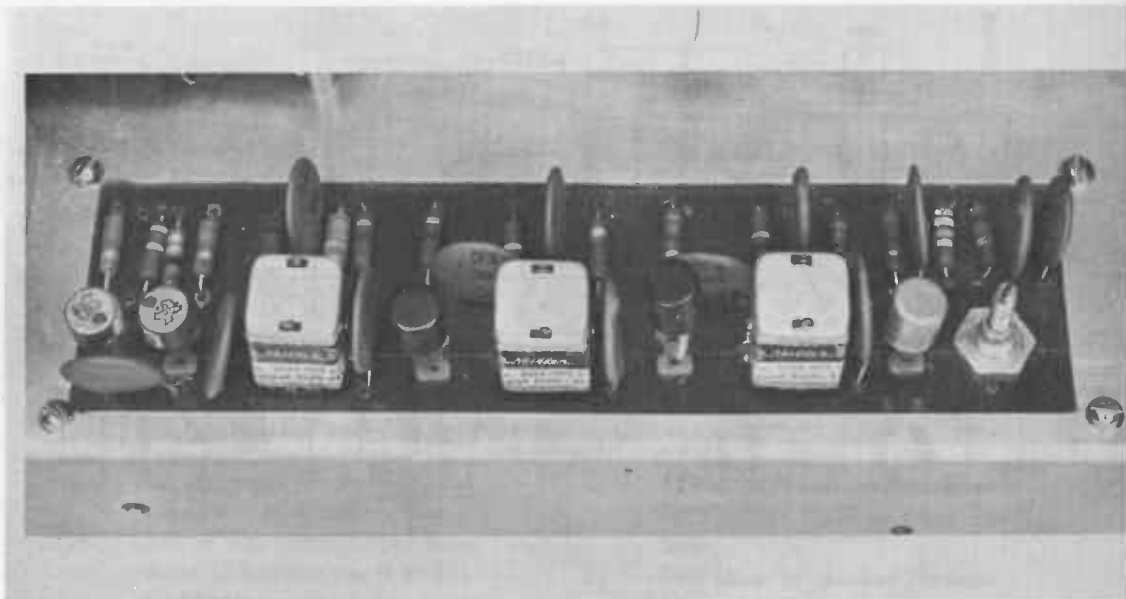
**CLOSEUP VIEW OF THE
COMMUNICATIONS RECEIVER
I.F. AMPLIFIER STRIP**

Originally, the r.f. stage was operated grounded emitter. This was changed when it was observed that the action of the a.g.c. on the r.f. stage was causing detuning of the local oscillator. When the a.g.c. varied, the flow of collector current and the output impedance of the stage also changed and reflected a change in mixer input impedance. The input impedance of this latter stage, as far as the oscillator is concerned, is highly capacitive and is actually a capacitor connected across part of the oscillator coil, L_3. On strong stations the

frequency variations were quite severe. Although unnoticeable on a.m., s.s.b. stations gave a gargling sound. Because the output impedance was very high with grounded-base configuration, an impedance change was but a small percentage of the whole. Thus, the reflected change across the oscillator coil was negligible. Another advantage offered by grounded base is freedom from the need for neutralization.

**FRONT PANEL VIEW
OF THE TRANSISTOR
COMMUNICATIONS
RECEIVER**
The controls, from left to right, are antenna trimmer, r.f. gain, on-off switch, audio gain, and b.f.o. tuning.
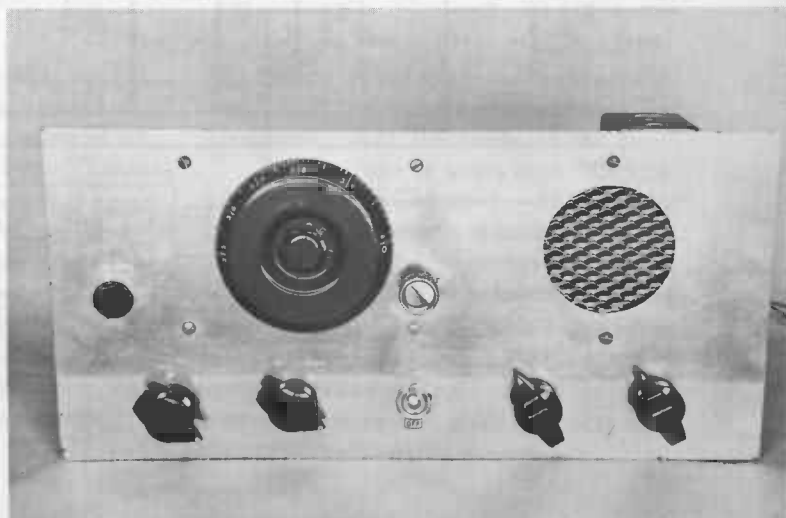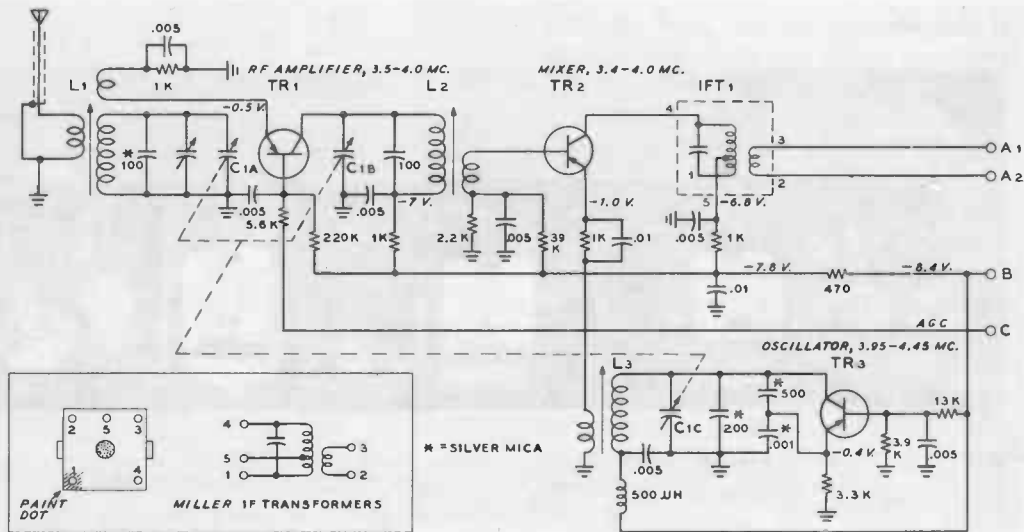
Figure 4.12-A

SCHEMATIC DIAGRAM FOR THE PROFESSIONAL COMMUNICATIONS RECEIVER

Note that voltage data is included, and readings are from the points given to chassis ground.
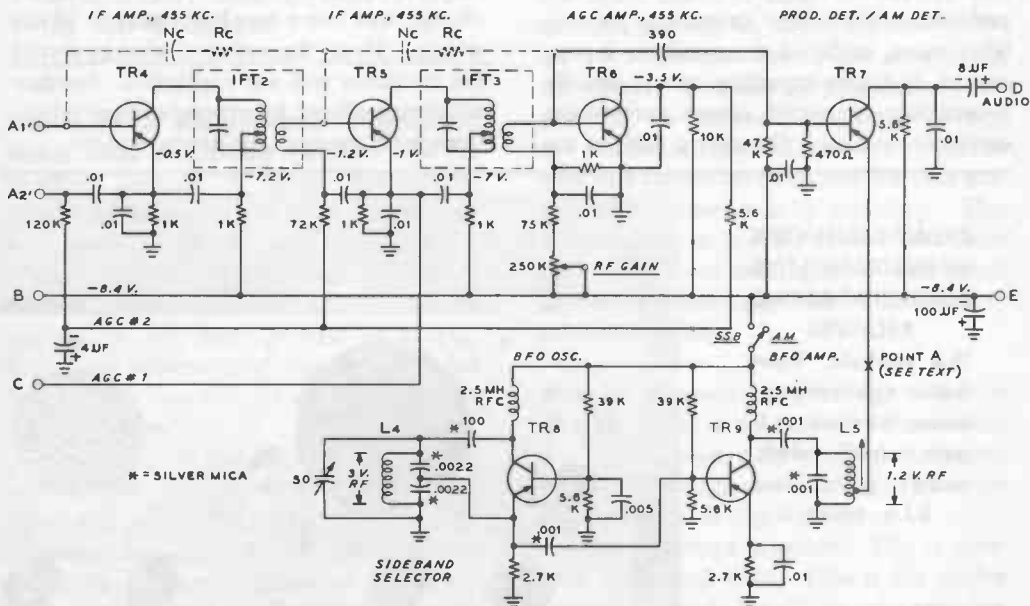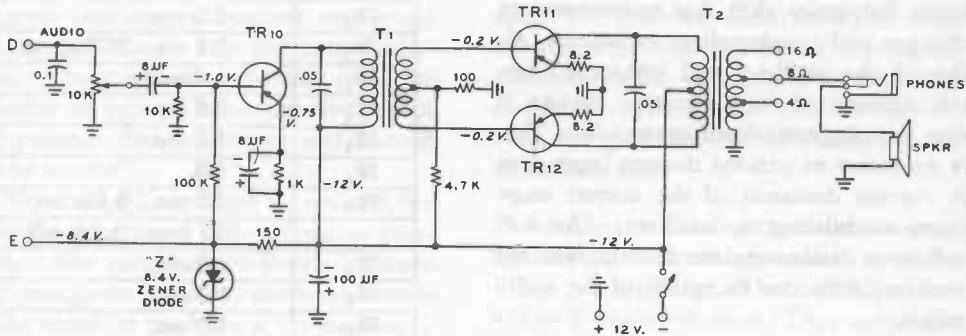
Figure 4.12-A cont.

Parts List

$C_{1a, 1b, 1c}$ - Tuning capacitor from BC-455 receiver. Modified per text.

$IFT_{1, 2, 3}$ - 25K to 600 ohms, 455kc. transistor i.f. transformer (J.W. Miller #2041).

L_1 - 27 turns, #34 enamel, on 3/8" diameter slug tuned form (Miller #4400 or similar), antenna tap at 7 turns, emitter link 2 turns small hookup wire wound beside or over primary.

L_2 - 27 turns, #34, form as above, base link 3 turns as in L_1.

L_3 - 16 turns, #34 enamel, on 3/8" form as in L_1. Link, 1 turn at ground end.

$L_{4,5}$ - 90 turns, #36 silk covered on 3/8" form, tap 30 turns from bottom.

T_1 - 10K to 2K interstage transformer (Stancor TA35 or Triad TY-56X).

T_2 - 500 ohms to speaker (Stancor TA35 or Triad TY-45X).

$TR_{1, 3,8}$ - 2N247, 2N274, 2N371, OC-619.

TR_2 - 2N412, OC45.

$TR_{4,5}$ - 2N247, 2N371, 2N410, GT139, OC44.

TR_6 - 2N1380, 2N408, GT81R, OC72.

$TR_{7,9}$ - 2N412, 2N1380, OC44.

$TR_{10, 11,12}$ - 2N188A, 2N408, 2N1380, OC72 (see Mini-Amp data, Chapter 2).

Z - 8.2 volt zener diode (International Rectifier 1N1511 or similar).

No doubt the observant reader has noticed an unusual connection between the base of the r.f. stage and the emitter of the second i.f. stage in Fig. 4.12-A. This is another way of obtaining amplified a.g.c. voltage. Because of the presence of the i.f. emitter resistor, the emitter of TR_5 is negative with respect to ground. Automatic gain control voltage decreases the i.f. stage emitter current, and the voltage across the resistor also decreases. The stage produces amplified a.g.c. voltage.

The Mixer and Oscillator The mixer is conventional, with the oscillator signal fed into the emitter. The oscillator is a very high "C" Colpitts circuit (see Chapter 3). As this is the heart of the receiver's stability, considerable care went into the design. The result is an oscillator which shifted only 150 cycles in 4 days of continuous operation, with a maximum excursion noted of 400 cycles. The operating point of the oscillator has been very carefully chosen to min-

imize frequency shift due to temperature changes and supply voltage variations. Although the oscillator will withstand a certain amount of supply voltage change, it *must* be voltage stabilized, nevertheless. This is necessary to prevent the very large class B current demands of the output stage from modulating the oscillator. An 8.2-volt zener diode regulates the supply to the receiver, with the exception of the audio stages.

Mechanical considerations will govern the stability of the receiver perhaps more than will electrical. For this reason the excellent variable capacitor from an ARC-5 surplus receiver was chosen to tune the transistor receiver. This capacitor has a built in gear mechanism of unsurpassed quality. Unfortunately, its plates are cut for straight line frequency when straight line capacity would have been better for this circuit. However, by not using the whole range of the capacitor, and by removing many of the moving plates, excellent spread and good tracking were obtained.

The I.F. Amplifiers The i.f. amplifiers are conventional and are built around the compact Miller i.f. transformers. A duplicate i.f. strip was also constructed using home-built transformers, and its performance was also excellent. Data for these homebuilt transformers is supplied at the end of this chapter. The i.f. stages are a.g.c. controlled by reducing the negative base bias and thus the emitter current. The r.f.-i.f. manual gain system controls the same bias line.

The AGC Amplifier The a.g.c. amplifier (TR_6) is in reality a detector with a high value load resistor. It operates near cutoff, and the standing collector voltage is high. Consequently, the a.g.c. line from its collector to the i.f. amplifiers is highly negative. A signal at the base is rectified by the base-emitter portion of the

TR_1	0.6 ma.
TR_2	0.2 ma. (200 μ amp.)
TR_3	1.0 ma.
TR_4	0.8 ma.
TR_5	1.0 ma.
TR_6	Nil.
TR_7	2.0 ma. (b.f.o. on)
	30 amp. (b.f.o. off)
TR_8	2.0 ma.
TR_9	1.0 ma.
TR_{10}	1.0 ma.
$TR_{11,12}$	3.5 ma. (approx.)

Figure 4.12-B
Chart showing current drawn by PROFESSIONAL COMMUNICATIONS RECEIVER transistors. For these measurements, the r.f. gain is maximum and no antenna is connected to the receiver.

transistor, and a voltage drop is developed across the 1K load resistor in the base circuit. This voltage, being negative in value, causes a collector current to flow and a resultant drop in collector voltage. Bias to the i.f. amplifier (and indirectly to the r.f. amplifier) is reduced. Note that the varying collector current may also be used to operate an S meter. This adaptation is described later.

The Product and AM Detector The product detector (TR_7) is a mixer circuit, and its similarity to the mixer stage at the front of this receiver has been described in section 4.11. The base of the detector is fed through the 390 $\mu\mu$fd. capacitor which was chosen to present the correct signal level to the base.

A low collector voltage provides a curve best suited to the purpose. It is significant that when the b.f.o. is detuned, the product detector has no output. The component values are somewhat critical, and it is recommended that the transistor indicated be used. However, information will

be given later so that builders may adjust the components to suit different transistors. The 0.01 μfd. capacitor from the collector to ground is an essential part of the product detector circuit and should not be omitted.

When the b.f.o. voltage is removed, the collector current of TR_7 drops to near-zero. The transistor is forward biased just enough to overcome distortion which is the result of the knee at the bottom of the characteristic curve.

The BFO and Amplifier Except for the difference in frequency, the b.f.o. (TR_8) is the same as the local oscillator described earlier. The large signal at the base of the detector causes a change in impedance which, if no b.f.o. buffer is used, causes a change in the beat frequency. If the input signal is reduced in value, the detector output becomes low, and under certain circumstances transistor hiss level can become a problem. The authors turned to the use of a b.f.o. amplifier and buffer (TR_9) only as a last resort. The effect was remarkable. With the r.f. gain wide open and the a.g.c. pumping violently on the strongest of sideband signals, not a cycle of shift could be detected. Even c.w. gained a musical quality not previously noticed.

The Audio Section Following the detector comes a class A audio amplifier (TR_{10}). This amplifier drives a class B push-pull stage ($TR_{11\text{-}12}$) similar to the MINI-AMP described in Chapter 2. Because of its low idling current and the consequent saving of battery power, class B operation was chosen.

UNDER CHASSIS VIEW OF THE COMMUNICATIONS RECEIVER
Note the construction technique used to fabricate the i.f. amplifier. The beat frequency oscillator is mounted in a can above the chassis, at the lower right corner. Components for the receiver local oscillator are located below the chassis, just to the left of center.
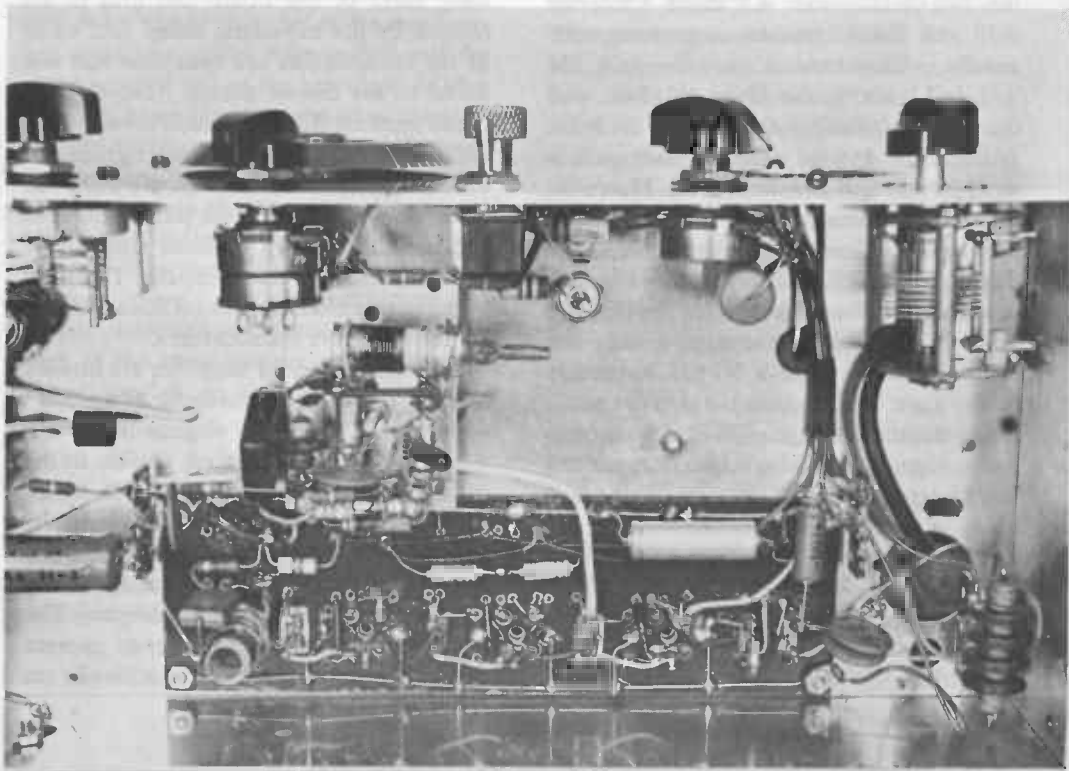
A "gremlin" distorted the signal even in this, the simplest of circuits. This distortion was traced to an above-audibility audio oscillation and was remedied by placing a 0.05 μfd. capacitor across the primary of the output transformer.

The audio output is greater than 250 milliwatts and is of excellent quality when connected to the headphones or to an external speaker. The small inboard speaker will handle only 100 milliwatts and leaves something to be desired in the way of quality.

Techni- The zener diode, like the VR
calities tube in a vacuum tube sideband
receiver, is an absolute *must*. Its value is not particularly critical. Any value around 8 volts is satisfactory.

A great number of different transistors were tried in the various circuits to ascertain that others than those specified could be used without too much circuit alteration. In most cases it is only necessary to plug the substitutes into the sockets. The two important transistors in the receiver are the two oscillators. Of those tried, the drift and MADT transistors gave superior results. Those tested were the *RCA* 2N 371 and 2N274, the *Philco* 2N1745, and the *Amperex (Phillips)* OC139. If the b.f.o. is tuned to 455 kc., the 8th harmonic is at 3640 kc. and can be heard. However, by placing a small trap in the base lead of the product detector, the harmonic is reduced to negligible proportions. The connections for the trap are shown in Fig. 4.12-C. To adjust the trap, tune in the b.f.o. harmonic with a VTVM connected to the a.g.c. line. Adjust the trap for minimum negative voltage. This means minimum signal from the b.f.o. Repeak the last i.f. transformer.

Construction The prototype receiver was
Hints built upon a standard 5" x
11" x 2" aluminum chassis.
A cut-out at the rear houses the i.f. strip which was built upon a 6 1/2" x 2" piece
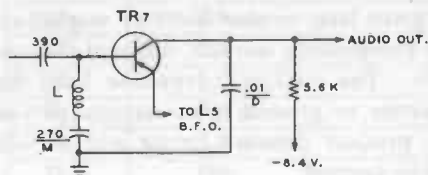
Figure 4.12-C
SCHEMATIC DIAGRAM FOR THE
B.F.O. TRAP USED IN THE
COMMUNICATIONS RECEIVER
Note that the trap must be grounded at the same point as the collector bypass for TR$_7$. Coil L consists of 30 turns, #34 enamel., jumble wound on a 1/4" diameter form.
(J.W. Miller 20A000RB1)

of phenolic sheet for the sake of convenience. Components are mounted on top, and the wires are brought through small holes as in an etched circuit board. In lieu of a ground strip around the edge, a piece of #18 tinned wire was run down the two long sides of the board and held to the chassis by the mounting bolts. End wires of the components are bent over and soldered to the closest points. Coupling between sections does not result as one might expect. The i.f. cans are likewise grounded to the busbars. Note that the *Miller* i.f. transformers shown in the picture have pin connections slightly different from those presently made by that company. The numbered connections shown on the schematic are for the newer transformers.

The b.f.o. and its amplifier are housed in a surplus i.f. can measuring 2" x 1 3/8" wide and 4" high. A slightly larger can would have allowed the r.f. choke, in the collector of the b.f.o. amplifier, to be included. This is desirable where possible. The b.f.o. and amplifier, like the i.f. strip, are built on phenolic board of a size necessary to make a neat fit in the can. The can is lined with thick paper to prevent short circuits, and the ground leads are

taken to a single lead that is insulated from the can. *That lead is brought below the chassis by insulated wire* and soldered to a lug on the chassis alongside the product detector. The 0.01 μfd. disc ceramic, bypassing the product detector collector, also is soldered to this point, along with the ground connection for the b.f.o. trap. If the b.f.o. harmonic is to be reduced to a minimum, these connections must be strictly observed. Similarly, the B- lead entering the can is also bypassed at this point. The b.f.o. tuning capacitor must also be shielded so that no harmonic energy may escape to the front of the receiver.

The Tuning Capacitor   The tuning capacitor is removed from a surplus BC-455-B receiver and is modified in the following manner. Remove all the rotor plates except two from the gang farthest from the worm drive. Begin at the split plate end and work back. Do this by bending each plate back and forth, not by pulling on the plates. The authors well remember the frantic hunt for the small steel balls which shot out of the end bearing when the plates were pulled and the rotor jumped out of the bearings! With a small hacksaw blade cut the strap connecting the moving plates together. Because it is without trimmers, this section of the gang is used in the r.f. stage. Connected across this section is an auxiliary antenna trimmer capacitor which is adjusted from the front panel. The center capacitor section is connected to the mixer and is modified in the same manner. Eight moving plates are left in the oscillator section.

Coils   Constructors may wish to use coil forms differing from those specified. If this is the case, the coils may be grid-dipped to frequency. The present *turns to tap ratios* should be retained. Remember that the oscillator coil tunes 455 kc. higher than the r.f. and mixer stages.

The b.f.o. may be set to frequency by measuring the frequency separation between harmonics which result when the b.f.o. is coupled to a broadcast receiver. The difference between the harmonics is the fundamental frequency of the b.f.o.

The r.f. oscillator section was built onto a small plate and mounted below the chassis because there was insufficient room on the top of the chassis. The empty space at the end of the i.f. strip is reserved for either a mechanical or a crystal filter. The oscillator components *must* be rigidly mounted. Only ceramic materials should be used for the coil form, and the tiepoints must be of good quality wherever they support portions of the tuned circuit.

The r.f. stage is built on a small phenolic strip and mounted below the chassis at one end. The coil (L_1) is mounted on the chassis proper, and the adjustment screw is accessible from the top.

Battery   When the battery is new, the idling current of the entire receiver is around 20 ma. and drops to 17 ma. when the battery is down to 10.5 volts. The average current is around 30 to 50 ma., depending on receiver volume. Peaks may reach as high as 100 ma. If the receiver is used in an automobile and is operating from the car battery, the stability will be excellent, even though the voltage may fluctuate as the generator output varies. When the battery voltage falls below the zener diode control level, frequency shift will appear on c.w. and s.s.b., and distortion will be present on all signals.

Protecting the Front End   If there is danger of r.f. from the transmitter entering the receiver and burning out the r.f. stage transistor, a small diode may be connected directly across the first tuned circuit. Because most diodes (especially the silicon variety) do not conduct until a certain voltage level is reached, rectification will not occur on the signal.

Even better protection is afforded by two diodes connected in parallel but each facing in an opposite direction.

Other Transistors and Neutralization If transistors other than the drift type are used in the i.f. stages, neutralization may be required. The neutralization components are shown dotted in the schematic, but the resistors and capacitors may not be necessary. The subject of neutralization has been covered in Chapter 3. If 2N139's or 2N 410's are used, R_c will be 470 ohms and N_c approximately 100 $\mu\mu$fd. If in doubt, make N_c variable and later replace it with a fixed value. The b.f.o. amplifier may be any of the lower frequency transistors, and the a.g.c. amplifier may be any general purpose audio transistor having low I_{co} and drift.

Alignment The process of alignment is identical to that used with tube receivers. The coil slugs align the low frequency end of the band, and the trimmers are used for alignment at the high end. The i.f. stages are aligned to 455 kc. A v.t.v.m. connected to the a.g.c. line is a very sensitive alignment indicator. To tune to lower sideband, the b.f.o. capacitor is set about 1 kc. lower in frequency than zero beat. Conversely, on upper sideband, the b.f.o. is set about 1 kc. higher.

To adjust the b.f.o. injection voltage, tune in a strong a.m. station until it is zero beat with the b.f.o. Next, detune the b.f.o. coil slug off-frequency until the heterodyne cannot be heard. Output from the receiver should drop considerably. Adjust the amplifier coil slug (L_5) until the station nulls, indicating the correct injection voltage and current. The b.f.o. slug is then returned to the normal position.

Using the Receiver Because the a.g.c. action is exceptional, a strong pumping action will take place on strong c.w. or s.s.b. stations. This is caused by the a.g.c. holding back the receiver gain on strong signals but opening up the receiver sensitivity the moment the transmitter operator pauses for breath. The audio gain should be turned up and the r.f. set so that the a.g.c. just operates on the weakest station. The tuning may be difficult if the r.f. gain is high and every weak signal is brought up to the same level and allowed to compete with the stronger stations.
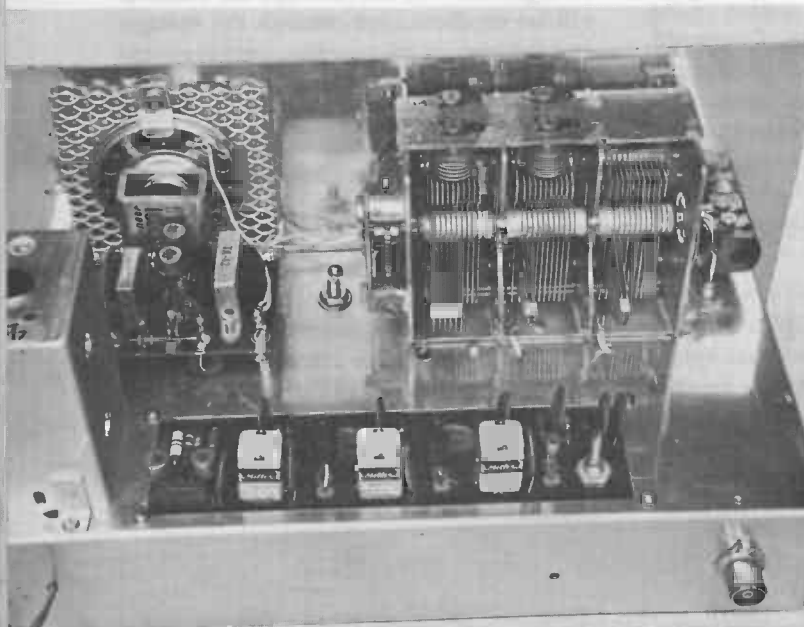
TOP CHASSIS VIEW OF THE COMMUNICATIONS RECEIVER
The Mini-Amplifier (described in Chapter 2) is located at the left, behind the speaker. The space at the right rear corner of the chassis is reserved for the crystal i.f. filter

An I.F.
Filter

Without an i.f. filter, the selectivity of the receiver is poor. Three tuned circuits are insufficient to keep out an intruding neighbor. However, the receiver was designed to be used with a filter, and a suitable circuit is shown in the following section.

4.13   Crystal Filters for a Communications Receiver

Three tuned circuits in the i.f. section of any receiver designed to cover the amateur bands are insufficient. Double tuned circuits will improve the selectivity to a marked extent. However, unless ten to twelve tuned circuits of high Q and correct coupling factor are used, selectivity, by today's standards, will still be poor. Modern receivers, especially those designed for single sideband reception, use crystal, mechanical, or complex tuned filters to obtain a high order of selectivity. Better filters improve passband shape by providing steep skirts and a flat top passband.

The readily available surplus crystals in the i.f. region offer the chance to construct a filter costing no more than a few dollars, yet comparing favorably with filters costing ten to twenty times as much. The crystal filter shown in Fig. 4.13-A uses four 50 cent surplus crystals in a back-to-back half-lattice arrangement. Adjustment is merely a matter of aligning transformers T_1 and T_2 and capacitor C_1 for maximum output midway between the two crystal frequencies. Skirt selectivity is excellent.

Two filters are described in this section. Each is shown connected into the receiver just described. These types of filters may be used with other transistor receivers to obtain additional selectivity.

A *Collins Mechanical Filter* can also be used. The input circuitry is the same as in Fig. 4.13-A except that the primary transducer coil is resonated with a 100-150 $\mu\mu$fd. capacitor. The output transducer is
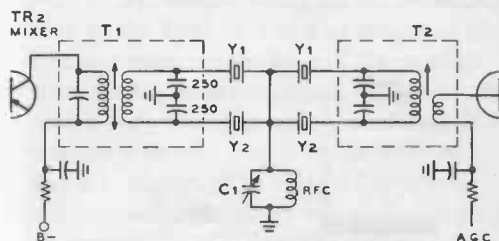
Figure 4.13-A
SCHEMATIC OF THE 3KC. CRYSTAL FILTER FOR THE PROFESSIONAL COMMUNICATIONS RECEIVER
Crystal Y_1 is a surplus channel 327, and Y_2 is channel 329. Capacitor C_1 is a 3-30 $\mu\mu$fd. compression padder, used to tune the 2.5 mh. r.f. choke (this value is critical). See text for transformer and alignment data.

connected to the base of the first i.f. transistor *through* a 100-150 $\mu\mu$fd. capacitor. Both of these resonating capacitors should be adjusted for maximum gain. Use of this filter is described in more detail in section 4.14.

Filter #1

The filter shown in Fig. 4.13-A has a passband of about 3.5 kc. Insertion loss is very small and no extra stages are required to overcome filter loss. The filter may be constructed on the chassis in the extra space at the input end of the i.f. strip, or can be built on a separate plate. This sub-assembly can be surface, sub-chassis, or above-chassis mounted. The i.f. transformers shown in the photograph are not normally available and are, in fact, modified broadcast receiver types. However, *J. W. Miller Co.* should have double-tuned i.f. transformers suitable for this application. Other transformers may be used providing they satisfy one or two conditions. Choose transformers which are fixed-tuned with a 100 to 200 $\mu\mu$fd. capacitor. The capacitor in the secondary winding of T_1 and the capacitor in the primary of T_2 are removed and replaced by two

**THE COMMUNICATIONS RECEIVER
CRYSTAL FILTER FOR
TWO KILOCYCLE BANDWIDTH**

250 $\mu\mu$fd. capacitors series-connected as shown in the schematic. Transformers with different L/C ratios may give considerably different results.

Choosing the Crystals Crystals should be fairly well matched before being used in the filter. Connect one pin of the crystal to a frequency meter or signal generator, and with the r.f. probe of a VTVM on the other pin, tune the oscillator through the crystal frequency. At the series resonant frequency, the meter will show a large peak and a deep null alongside it. Choose two crystals of the same channel numbers with peaks of the same height and similar frequencies. All four crystals should show the same peak amplitude. Crystals are readily available from various sources ready-matched and paired.

Alignment Adjust the frequency meter or signal generator to midway between the two peaks as read on the voltmeter. The generator *must* be midpoint between these two frequencies. Align all transformer slugs for maximum output. Connect a VTVM to the receiver a.g.c. line. Tune the generator across the passband. If there is a large peak at one side of the passband, it indicates that the generator was not set at mid-frequency, or that the crystals were not matched for amplitude (or Q). It is possible to minimize this condition by realigning to the lower frequency side until the two peaks are equal in height.

Next, adjust C_1 for more capacitance, (approximately one-half turn) until the skirts are at their maximum steepness. This point should coincide with a dip approximately 7% of total passband amplitude. If the trimmer is screwed in too far, the dip will become excessive. The selectivity of the filter is such that the carrier of an a.m. station may be dropped right off the passband and the signal actually turned into s.s.b. On a.m., high frequency response will be considerably down. To obtain maximum fidelity, the receiver should be detuned a little to favor one sideband.

Care must be used to prevent signal from leaking around the filter. You have a shielding problem if the signal is still heard when the crystals are removed.

Filter #2 The passband of the filter shown in Fig. 4.13-B is only 2.0 kc. wide. Thus, the recovered audio in the communications receiver will tend toward bass. If the ultimate quality in selectivity is desired, this is the filter to use. However, the high audio frequencies attenuated to this degree may be objectionable.

The alignment procedure is the same as for the filter just described, except that the trimmer C_1 is tuned for maximum output and left at that setting.

Installing the Filter There are several ways of mounting the filter in the receiver. If the receiver is already built, the filter assembly may be placed on end in the space saved near the r.f. end of the i.f. strip. The filter
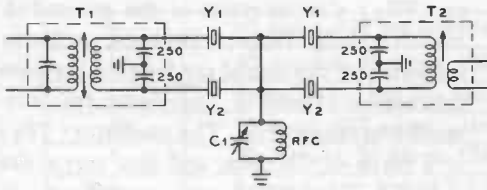
Figure 4.13-B
**WIRING DIAGRAM FOR THE 2KC.
PASSBAND RECEIVER FILTER**
Crystals Y_1 and Y_2 are war surplus
types for channel 327 and 328 re-
spectively. All other component val-
ues are the same as in Fig. 4.13-A.

should be connected to the receiver through
a short length of small coaxial cable.

Transformer T_1 in the receiver should
be disconnected or removed. No other
wiring in the receiver is altered. An altern-
ative position for the filter is on the i.f.
strip itself, with the mixer moved to make
space for it.

Which   Those who have neither used nor
Filter?   constructed filters will no doubt
              be in a quandary as to which filter
to build. Filter #1 is best for those who
prefer a.m., yet it will allow good s.s.b. or
c.w. copy. Filter #2 is essentially for the
c.w. or sideband man, and a.m. may be
copied only on one sideband. Of course,
QRM with the narrower filter is consider-
ably reduced.

4.14 A Mechanical Filter
for the
Communications Receiver

Those fortunate enough to possess a
mechanical filter may wish to install it in
the receiver just described. The method
of connection is applicable to other receiv-
ers such as in Fig. 4.14-A. The second
i.f. transformer is removed and replaced
by the mechanical filter. The primary cir-
cuit is otherwise undisturbed. It is neces-

sary to use series tuning on the secondary
side of the filter in order to obtain an im-
pedance match to the base of the transistor.
Because this means inserting a capacitor in
series with the filter output winding, it is
necessary to add an r.f. choke to complete
the d.c. circuit. The small 22 $\mu\mu$fd. capaci-
tor across the secondary brings the winding
to resonance. It is possible that other tran-
sistors with different input capacities may
require a different value, in which case
the $\mu\mu$fd. capacitor may be replaced with a
3-30 $\mu\mu$fd. trimmer. A number of transis-
tors have been tried with little variation in
gain. No other changes need be made in
the base circuit of the i.f. amplifier.

Note that the filter is installed between
the first and second i.f. amplifiers, not be-
tween the mixer and the first i.f. amplifier
as is customary. It was found that a better
impedance match was possible when the
mechanical filter was driven by an i.f. am-
plifier stage (in preference to the mixer),
and a considerable increase in gain result-
ed. Ground the case and make sure that
no signal is getting around the filter in-
stead of through it.

Both the 3.1 kc. and 2.1 kc. plug-in
type *Collins* Filters gave excellent results in
the Communications Receiver. The 2.1 kc.
(type 455 J 21) is now a permanent part
of the device.
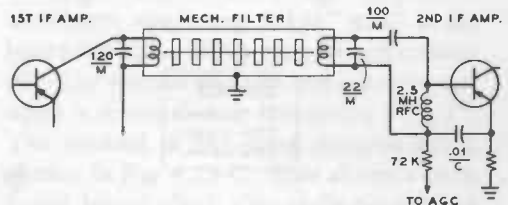
Figure 4.14-A
**SCHEMATIC DIAGRAM FOR COLLINS
MECHANICAL FILTER
I.F. AMPLIFIER MODIFICATION**
(Project 4.12)

There is ample gain in the receiver in spite of the relatively high filter attenuation, and no further amplicication stages are necessary.

The b..fo. capacitor setting is quite critical with this type of filter.

4.15   A Transistor All-Band Converter

The converter described in this section is crystal controlled. This means that the stability on any band is determined only by the receiver to which it is connected. If the receiver is stable on 80 meters, then 10-meter signals will be equally stable. The converter can be used ahead of the receiver described in section 4.12, or with any receiver that covers 3.5 to 4.0 Mc. The circuit is shown in Fig. 4.15-A.

How it Works   The r.f. amplifier (TR₁) is a conventional grounded-emitter stage. A capacitive divider across the tuned circuit establishes a correct impedance match to the transistor. The mixer (TR₂) also operates in the grounded-emitter configuration. Both the oscillator voltage and the signal are fed into the base through a capacitive impedance transformation arrangement. The oscillator (TR₃) is a form of Colpitts, and is a very active circuit. This circuit gave no difficulty in the several converters which were built. However, it is important to watch that the oscillator is actually operating at the frequency of the crystal. Oscillation at other frequencies may take place when the slug coil in the collector circuit is adjusted incorrectly.

The output circuit on 3.5 to 4.0 Mc. is loaded with resistance to reduce the gain of the converter. The gain was originally so high it caused cross modulation in the receiver r.f. stage.

Note that on 80 meters the antenna is connected through coil L to the base of the mixer (TR₂) which, in the absence of an oscillator signal, acts as an r.f. amplifier. There are several advantages in using the 80-meter connection shown in the sche-
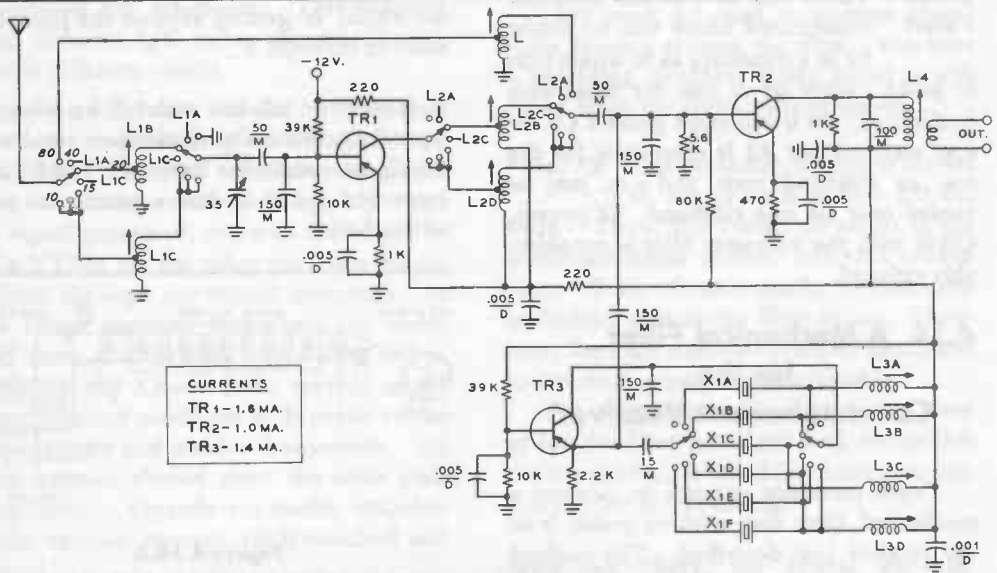
Figure 5.15-A

SCHEMATIC DIAGRAM OF THE ALL-BAND TRANSISTOR CONVERTER

Transistors can be 2N384, OC619, 2N371 or 2N1745. All capacitors marked M should be mica, others may be disc ceramics (d) or similar.

L	65 turns, #36 scc jumblewound on 1/4" form, tap at 10 turns.
L_{1a}	40 meters, 32 turns, #36 scc jumble or pi wound, tap at 5 turns.
L_{2a}	Same as L_{1a} but tap at 8 1/2 turns.
L_{3a}	15 turns, #22 enam., closewound.
L_{1b}	20 meters, 20 turns, #26 enam. closewound, tap at 3 1/2 turns.
L_{2b}	Same as L_{1b}, tap at 7 1/2 turns.
L_{3b}	15 turns, #26 enam. closewound.
L_{1c}	15 meters, 14 turns, #26 enam. closewound, tap at 2 turns.
L_{2c}	Same as L_{1c}, tap at 7 turns.
L_{3c}	8 turns, #26 enam. closewound.
L_{1d}	10 meters, 9 turns, #26 enam. closewound, tap at 1 1/2 turns.
L_{2d}	10 turns, #26 enam. closewound, tap at 4 1/2 turns.
L_{3d}	4 turns, #26 enam. closewound.
L_4	40 turns, #36 scc jumble or pi wound, 1/4" wide, link 8 turns.
Xtals	International Crystals, type FA9.
X_{1a}	40 meters - 11.0 Mc.
X_{1b}	20 meters - 10.5 Mc.
X_{1c}	15 meters - 17.5 Mc.
X_{1d}	10 meters (28.0 to 28.5 Mc.) 24.5 Mc.
X_{1e}	10 meters (28.5 to 29.0 Mc.) 25.0 Mc.
X_{1f}	10 meters (29.0 to 29.5 Mc.) 25.5 Mc.

Figure 4.15-B

**COIL AND CRYSTAL CHART FOR THE CONVERTER
SHOWN IN FIG. 4.15-A**

matic. (1) No extra wafer is required on the bandswitch. (2) The gain on 80 meters is approximately equal to that obtained on other bands. (3) Wiring is extremely simple.

Note that the 10-meter crystals each make use of the same oscillator coil. Also, only one 10-meter coil is used in the r.f. and mixer stages. This system has proven adequate. The extra coils which were originally in the circuit were removed and the switch sections were rewired.

It is emphasized that in numerous tests the transistor converter was as good as several tube counterparts. In addition heater voltage is not required. The only power requirement is a supply of 12 volts at 4 Mc. This may be a simple power supply as shown in Fig. 4.15-D.

Construction Hints The construction shown in the photograph is probably the ultimate in simplicity. At the same time it is effective, small, yet easy to work on. A piece of aluminum measuring 5 1/2" x 5" is the base plate upon which everything is mounted. The various components are mounted upon a terminal strip measuring 5" x 2". The method of mounting components is shown in Fig. 4.15-C. This allows a clean board layout which slips easily beneath the wavechange switch. The ground connections are made by drilling through the lug into the base plate, tapping the hole, and installing a suitable bolt. These bolts serve also to hold the terminal strip in position. If a terminal strip is used with rivets which go through the board, insulating material
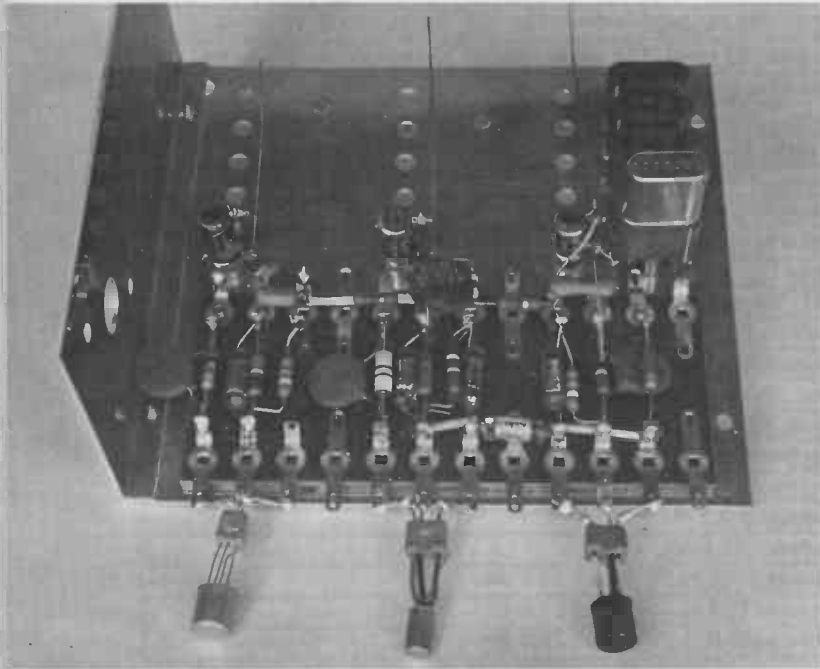
must be placed between the board and the aluminum.

It is suggested that the transistors first be temporarily mounted as shown in the photograph. This leaves the openings between the switch sections clear and allows easy access with a soldering iron. If the coil forms are different from those specified and it becomes necessary to cut and prune to get the coils right, the switch may be left out and the coils temporarily connected in the circuit. They may then be adjusted, sealed, and later connected to the switch. Several converters have been built with the coil data provided. Each functioned without coil pruning of any sort.

Transistor sockets are not necessary and were used in the prototype converter merely to allow experimentation with different types of transistors. If the converter is to be a unit separate from a receiver, it may be encased by a U-shaped cover. The converter shown was built into a receiver. The convenient size allows either under-chassis or above-chassis mounting.

Other   The observant reader will have
Bands   noticed the provision for another
band. There is no reason why coils for the 10 Mc. section of the short-wave bands could not be installed to permit reception of WWV. Even 6 meters may be tuned, although some experimentation may
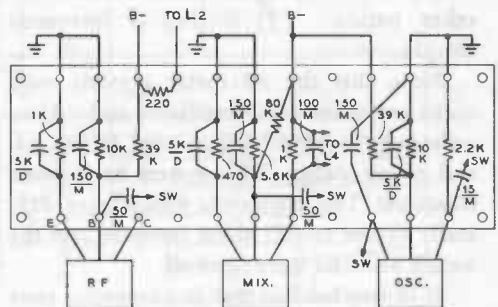
Figure 4.15-C
COMPONENT LAYOUT ON THE
TERMINAL STRIP
The strip stock is similar to J.W. Miller
#460.
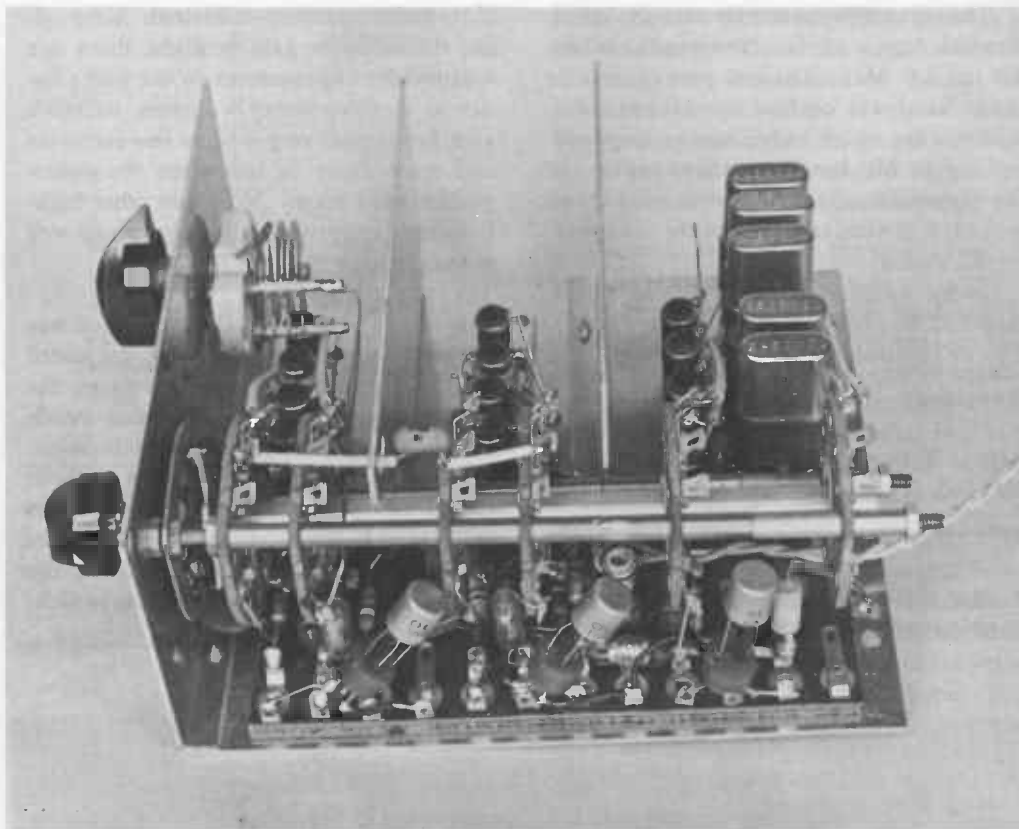
TOP VIEW OF THE COMPLETED CONVERTER

be required with the capacitive matching to achieve a good noise figure.

Adjustment Switch to the higher 10-meter crystal, and adjust the 10-meter coil L_{3d} until stable oscillation is obtained. Signals should be apparent immediately at any setting of the r.f. and mixer coil slugs. The signals should not shift more than a few cycles when the oscillator slug is tuned. If the slug is too far into the coil, spurious oscillation may result. There is no doubt about the correct position once it has been obtained. It should only be necessary to align the r.f. and mixer stage for maximum output on the other 10-meter position. These two stages are best aligned to the center of the band. The r.f. trimmer will take care of any peaking that is necessary at the two ends of the band.

Alignment of the other bands is accomplished by adjusting the respective oscillator coils to obtain oscillation, and then adjusting the r.f. stage and mixer coils for maximum converter output.

The output coil should be adjusted to the center of the band covered by the receiver, with the 1K resistor temporarily disconnected. After the resistor is connected, the tuning is so broad that it is difficult to tell when the coil slug is at the correct setting.

The prototype converter was designed to work into a receiver covering the range 3.5 to 4.0 Mc. The top part of the 10-meter band was omitted in order to make available the spare switch section required for the 10 Mc. band mentioned earlier. If the remainder of the 10-meter band is required, it is necessary to provide one more crystal socket.

If the receiver covers a greater range than 500 kc., some of the 10-meter crystals may be eliminated.

Transistors   RCA 2N371's may be used in the oscillator and mixer stages. However, the RCA 2N384 or Philco 2N1745 is recommended for the r.f. stage

if 10-meter operation is desired. Although the difference in gain is slight, there is a worthwhile improvement in the noise figure at this frequency. Amperex 0C169's also functioned very well in the converter and were those in use when the photographs were taken. No doubt other high-frequency transistors will also perform well in the circuit without alteration.

The Output Coil   Placement of the output coil was a problem. Finally, it was placed under the switch between the mixer and the oscillator switch wafer. This proved to be an ideal location, as it permitted very short leads without cramming.

It is very important that shielded wire be used between the output coil and the receiver. Unshielded wire will cause pick-

SIDE VIEW SHOWING THE RELATION-SHIP OF THE COILS TO THE BANDSWITCH
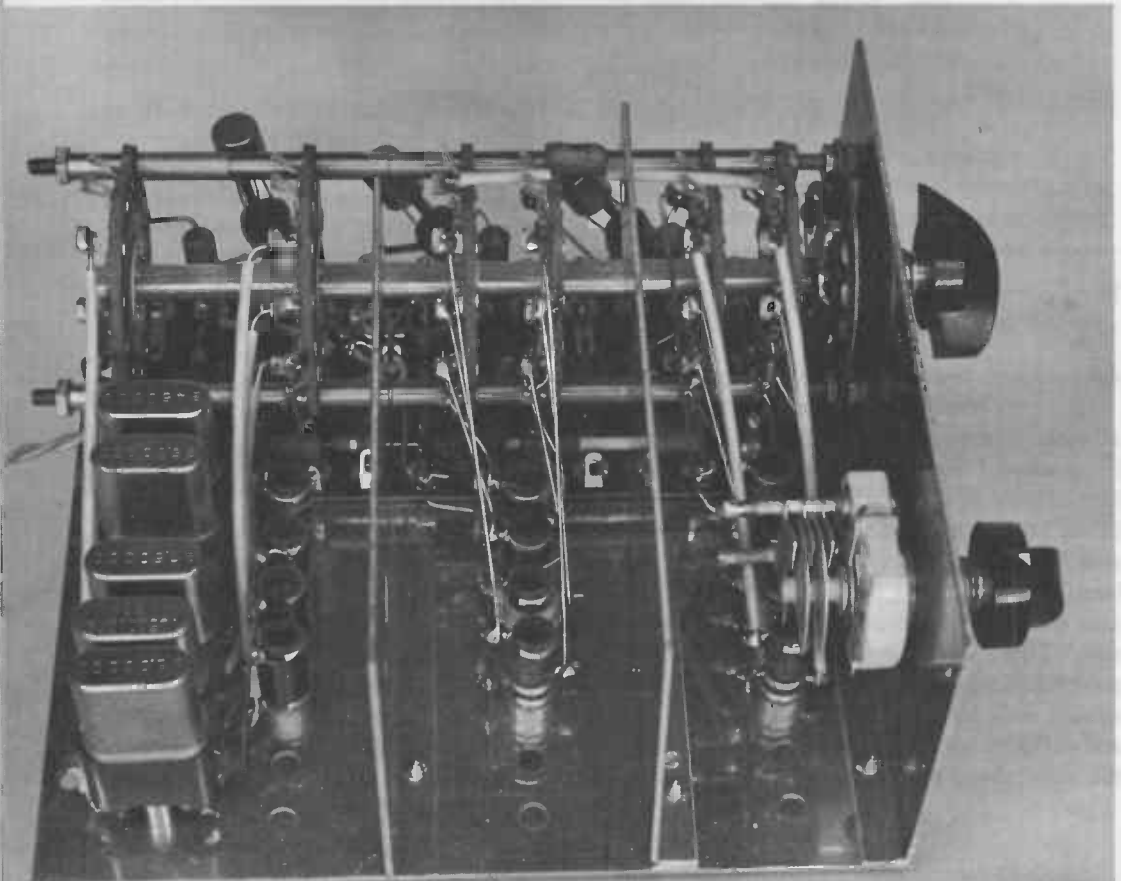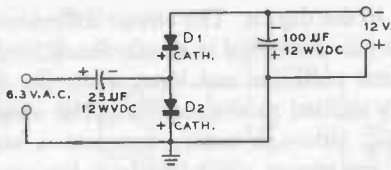
Figure 4.15-D
This circuit will be extremely useful when operating the converter in conjunction with a vacuum tube receiver. The simple voltage doubler supplies 12 volts d.c. by rectifying the 6.3 volt filament potential.

up of numerous 80-meter signals which will ride over those coming through the converter.

4.16   Autodyne Converters

The autodyne converter is a "something-for-nothing" circuit. That is, a single transistor is used for both the mixer and oscillator. This is relatively easy to accomplish in vacuum tube circuitry because the tube exhibits nearly constant gain, and fairly high impedances are involved. However, the transistor has a decreasing gain with frequency. Its terminal impedances vary considerably, and there is much less input-output isolation than the vacuum tube equivalent. Thus, the adjustment of transistor autodyne tends to be critical, and occasionally the device refuses to oscillate for no apparent reason. Even with its faults, it is useful in certain applications and should not be neglected.

One example of a transistor autodyne converter for 27 - 30 Mc. is shown in Fig. 4.16-A. Signals from the antenna appear across L_1 and are coupled to the transistor base. Energy in the collector circuit is coupled to L_2 through the feedback winding. The emitter, which is connected to L_2, reinjects signals into the transistor

where they are again amplified, creating a feedback loop. Thus, the stage oscillates at a frequency determined by L_2 and its associated components. The oscillator energy combines with the incoming signal to produce an intermediate frequency in the manner of all superheterodynes.

The remainder of the circuit is straightforward with the exception of the output transformer T_1. Pin 4 was used rather than the customary pin 5 (the tap) for the collector connection. This permits capacitor C_1 to act as both a bypass for the end of the collector feedback winding and as a tuning capacitor for the primary of T_1. Capacitor C_1 is built into the transformer.

The Autodyne Converter is quite useful in the VHF region where compact, low-cost equipment is often required. Several German portable radios are being marketed in this country and employ novel front ends for the 88 - 108 Mc. f.m. band. Enterprising experimenters could easily adapt these circuits for other VHF applications, even though no coil winding data is available.
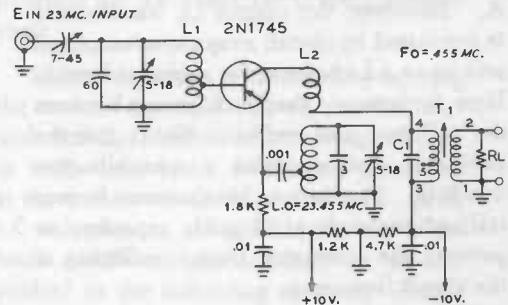
L1 = 12 T. #24 INSULATED, SPACED TO OCCUPY 5/16". TAPPED AT 3 T. LS-6 FORM 1/4" DIA.

L2 = B&W MINIDUCTOR #3004 11 T. FEEDBACK COIL 3T. #24 INSULATED, SPACED DIA. OF WIRE. WOUND OVER TOP END OF #3004. EMITTER TAPPED AT 3/4 TURN FROM COLD END.

T1 = 0.455 MC. MEISSNER #16-9014 OR J.N. MILLER 2041.

RL = 470 Ω

Figure 4.16-A
SCHEMATIC DIAGRAM FOR A
TUNABLE 27-30 Mc.
AUTODYNE CONVERTER
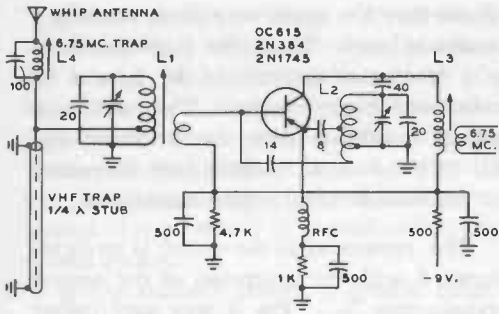
Figure 4.16-B
A ONE-TRANSISTOR
V.H.F. CONVERTER
This converter could be adapted to
either two or six meters. The circuit
is neutralized to prevent self-oscilla-
tion at the signal frequency.

Fig. 4.16-B is the circuit for an extremely
ingenious single transistor converter with
an output i.f. of 6.75 Mc. Signals are fed
into the input tuned circuit through a series
6.75 Mc. i.f. trap and a shunt stub trap
tuned to the image frequency (or interfer-
ing television signals). The autodyne cir-
cuit is very similar to the unit is Fig. 4.16-
A. However, the output i.f. transformer
is resonated by circuit stray capacitance and
acts as an r.f. choke at the signal and oscil-
lator frequency. Feedback occurs between
the collector and emitter. Notice that the
oscillator coil contains a neutralization
winding. The input (base) circuit is neu-
tralized through a 14 $\mu\mu$fd. capacitor to
prevent the converter from oscillating at
the signal frequency.

An autodyne converter and r.f. ampli-
fier are shown in Fig. 4.16-C. Both tran-
sistors operate in a common-base configu-
ration. The autodyne stage does not re-
quire neutralization because L_2 is very
lightly coupled to the emitter.

The autodyne principle can also be ap-
plied to crystal-controlled converters. The
oscillator-mixer shown in Fig. 4.10-A was
developed by ZL1AAX to simplify circuitry
and minimize the number of transistors

used in the device. The circuit differs from
those just discussed in that feedback occurs
between collector and base, while the sig-
nal is applied to the emitter. The output
coil L_3, although tuned, represents a fairly
high impedance at the oscillator frequency
and permits the stage to oscillate at the
crystal frequency.

A third overtone autodyne circuit de-
veloped by W6TNS is shown in Fig. 4.16-
D. The circuit is similar to 4.10-A. How-
ever, a resonant circuit tuned to the third
overtone of the fundamental crystal fre-
quency is inserted in series with the col-
lector signal path. This raises the collector
impedance at the third overtone, permitting
the stage to oscillate at this frequency.

The circuit has one unusual feature
which is the subject of a patent application.
Although not immediately obvious, the os-
cillator coil is in series with the i.f. signal
and the image. If the crystal is on the high
frequency side of the signal, coil L_2 can be
used as an image trap, in addition to its
normal function. It is possible to obtain
an image rejection approaching 40 db. at
30 Mc., even with a 455 kc. i.f. system. In
production equipment, rejection ratios ex-
ceeding 30 db. can easily be obtained.
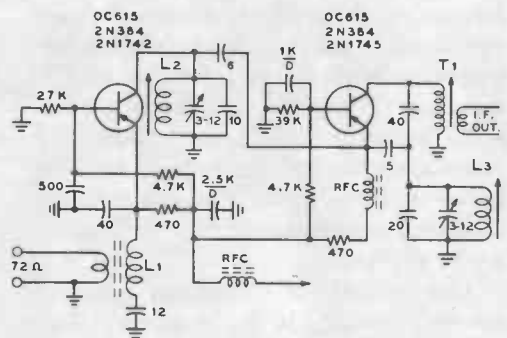
Figure 4.16-C
AUTODYNE F.M. CONVERTER
This converter employs an r.f. ampli-
fier and is designed to operate from
a 6-volt source.
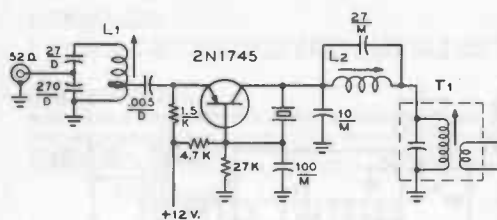
Figure 4.16-D
A THIRD OVERTONE
AUTODYNE CONVERTER
The values shown are correct for the
27-30 megacycle band. Both coils are
13 turns, #26 on a 5/16" form. The
base tap on L_1 is one turn up from
the ground end.

4.17 A Transistorized Six-Meter Converter

This converter employs three Philco
MADT v.h.f. transistors and operates at a
supply voltage of 12 volts. A communi-
cations receiver capable of tuning the 7 to
11 Mc. frequency range can be used as the
i.f. system.

How it   A Philco 2N1742 transistor is
Works   employed in the neutralized r.f.
           amplifier stage (see Fig. 4.17-
A). It operates as a common-emitter stage
with the incoming signal being applied to
the base through the input tuning network
consisting of coil L_1 and shunt capacitor
C_2. It works with either a 50 or 70-ohm
antenna system. The output utilizes a
double tuned circuit made up of coils
tuned to the desired frequency. Neutrali-
zation is provided by capacitors C_7 and C_4.
The tuned circuits are sufficiently broad-
band so that they can be fixed tuned. A
standby/receive switch is inserted in the
emitter lead of the r.f. amplifier.

Manual forward gain control is used to
reduce the gain on strong signals. This
method of r.f. gain control is accomplished
in the following manner. As the collector

current is increased, the voltage between
the collector and emitter drops due to the
series resistors R_4 and R_5. Hence, the
gain of the stage drops. The Micro Alloy
Diffused Transistor is well suited for this
type of gain control and provides much
better overload performance than the con-
ventional reverse gain control method.
R.f. gain control R_2 provides maximum
stage gain when set fully clockwise. By
varying the gain control counterclockwise,
the value of collector current increases,
causing the gain to drop. Emitter resistor
R_4 and the bias dividing resistor network
consisting of R_1, R_2 and R_3, provide the
necessary d.c. stabilization for the r.f. stage.

A 2N1743 is used as a mixer with the
signal being applied to the base through
a tap on the coil L_3. The output trans-
former T_1 tunes to about 8.5 Mc. and
couples the output from the collector to
the output connector. A loading resistor
R_9 is placed across the primary winding
L_4 of transformer T_1 to flatten the i.f. re-
sponse of the output circuit with some
sacrifice of converter gain. Emitter resistor
R_8 and bias dividing resistor R_6 and R_7
provides the d.c. stabilization for the mixer
stage.

Emitter injection is obtained by tapping
the emitter capacitor C_{10} on the oscillator
tank coil L_6. An injection voltage of 0.15
to 0.25 volts r.m.s. should be measured
at the emitter terminals of the mixer. If an
r.f. voltmeter is not available, a test of the
local oscillator injection may be accom-
plished in the following manner. Place a
3 ma. d.c. meter in series with emitter re-
sistor R_8 and positive 12 volts. This is
done by unsoldering the lead from R_8 to
the positive 12 volts, and inserting the
meter between these two points. The pos-
itive side of the meter is attached to the
positive 12-volt point. Now, increase the
loading on the oscillator coil L_6 by moving
the point where C_{10} taps onto the coil to-
wards the collector end and readjust capac-
itor C_{12}. A point will be found where the
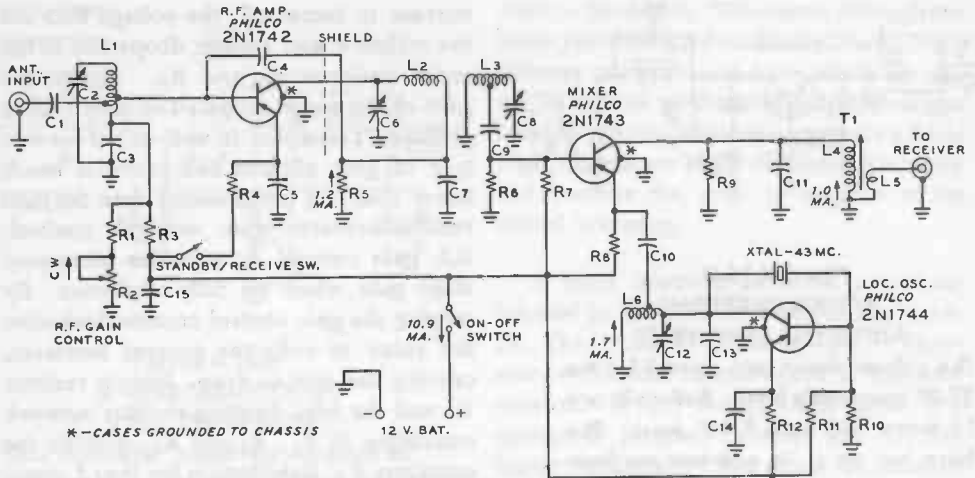
Figure 4.17-A

A TRANSISTORIZED SIX METER CRYSTAL CONTROLLED CONVERTER
The difference between total current and individual transistor current is
drawn by the resistive voltage dividers in each stage.

Parts List

C₁ - 0.005 μfd. 70V disc ceramic
C₂ - 1-18 μμfd. piston capacitor VC-4G JFD
C₃ - 0.0015 μfd. stand off ceramic capacitor, Sprague 508C
C₄ - 1.2 μμfd axial ceramic
C₅ - 0.005 μfd stand off ceramic capacitor, Sprague 508C
C₆ - 1-18 μμfd. piston capacitor VC-4G JFD
C₇ - 40 μμfd. ± 5%
C₈ - 1-18 μμfd. piston capacitor, VC-4G JFD
C₉ - 0.005 μfd. 70V disc ceramic
C₁₀ - 0.005 μfd. 70V disc ceramic
C₁₁ - 3 μμfd. ± 5% silver mica

C₁₂ - 1-18 μμfd. piston capacitor, VC-4G JFD
C₁₃ - 5.0 μμfd. ± 10% silver mica
C₁₄ - 470 μμfd. disc ceramic
C₁₅ - 0.005 μfd. 70V disc ceramic
R₁ - 1200 ohm carbon 1/2 W
R₂ - 10K ohm potentiometer
R₃ - 2700 ohm carbon 1/2 W
R₄ - 1000 ohm carbon 1/2 W
R₅ - 1000 ohm carbon 1/2 W
R₆ - 12K ohm carbon ± 5% 1/2 W
R₇ - 2700 ohm carbon ± 5% 1/2 W
R₈ - 1200 ohm carbon ± 5% 1/2 W
R₉ - 3900 ohm carbon 1/2 W
R₁₀ - 10K ohm carbon ± 5% 1/2 W
R₁₁ - 3300 ohm carbon ± 5% 1/2 W
R₁₂ - 1500 ohm carbon ± 5% 1/2 W

emitter current begins to rise due to the increase in the injection voltage. Any further increase will cause the emitter current to rise higher. A tap point to use on L₆ is the one just below the point that causes the emitter current to rise rapidly. Emitter resistor R₁₀ and bias dividing resistors R₁₁ and R₁₂ provide d.c. stabilization in the local oscillator stage. A 43 Mc. overtone crystal is used to control the frequency of the local oscillator. A *Philco* 2N1744 is used for the local oscillator.

Performance With the gain control set for maximum, an overall power gain of 46.0 db was obtained at 51.5 Mc. The gain drops off to about 43 db at 50 and 53 Mc. The noise figure of the converter is about 4.0 db with a 0.4

ANTENNA COIL

L1 = 8 TURNS OF *B&W MINIDUCTOR #3003*. BASE TAP 3 TURNS FROM COLD END. ANTENNA TAP 2 TURNS FROM COLD END.

INTERSTAGE COIL

MADE FROM A SINGLE SECTION OF *B&W MINIDUCTOR # 3003*. THE COIL IS BROKEN AT 8 1/2 TURNS. THE LEADS ARE THEN UNWOUND A HALF TURN IN BOTH DIRECTIONS AND ARE USED TO CONNECT THE COLD ENDS OF L2 AND L3 TO THE PROPER POINTS.
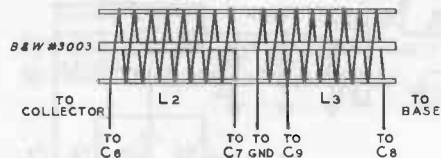
L2 = 8 TURNS OF *B&W MINIDUCTOR # 3003*.

L3 = 8 TURNS OF *B&W MINIDUCTOR #3003*. MIXER BASE TAP AT 2 TURNS FROM GROUND.

OUTPUT TRANSFORMER T1

L4 = CLOSEWOUND #30 *NYCLAD* COPPER WIRE ON A 1/2" DIAM. FORM TO OCCUPY A WINDING LENGTH OF 15/16".

L5 = 15 TURNS OF #28 *NYCLAD* COPPER WIRE CLOSEWOUND OVER COLD END OF L4.
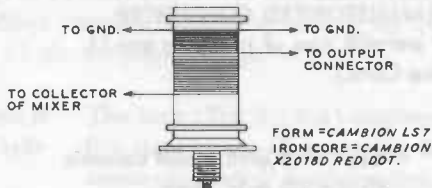
OSCILLATOR COIL

L6 = 9 TURNS *B&W MINIDUCTOR #3003*. MIXER EMITTER CAPACITOR TAP 1/3 TURN FROM GROUND END.

Figure 4.17-B
SIX METER CONVERTER COIL DATA

μv. sensitivity for 10 db signal to noise ratio.

This converter was designed by J. Specialny, Jr. and described in *Philco Application Lab Report #667*.

4.18 A Transistorized Two-Meter Converter

This 144 to 7 Mc. converter provides excellent results in the 2-meter band. Transistors are used throughout, and the only supply voltage necessary is a 12-volt battery.

How It Works The circuit (Fig. 4.18-A) is conventional and no difficulty should be experienced in duplicating it. A Philco 2N1742 is employed in the r.f. amplifier stage which is fixed neutralized

by capacitor C_5. Capacitance dividers C_1 and C_2 provide a 50-ohm match to the input circuit. Coil L_1 and capacitor C_3 form the input tuning. The base of the amplifier is tapped on L_1 to match 75 ohms. Coil L_2 and capacitors C_7 and C_8 tune the output of the amplifier. A portion of L_2 together with neutralizing capacitor C_5 form the neutralizing network. The base of the Philco 2N1743 mixer is tapped down on L_2. The output of the mixer is coupled from the collector by capacitor C_{10} and output coil L_3 at 7 Mc. Winding L_4 provides an output at 50 ohms to permit coupling to the input of a communications receiver.

A Philco 2N1744 is employed as a local oscillator and operates 7 Mc. higher than the signal frequency. Coil L_5 and capacitors C_{12} and C_{13} form the tank circuit.

The local oscillator signal is injected into the mixer emitter through capacitor C_{11} by tapping the oscillator coil L_5.

Operation The r.f. bandpass is about 4 Mc. at the 3 db point. A communications receiver capable of tuning the 7 Mc. band should be used as the i.f.

L1 = 4 TURNS #18 BARE COPPER WIRE 1/4" I.D., WINDING LENGTH 1/4". BASE TAP 1 TURN FROM GROUND END OF L1.

L2 = 8 TURNS #18 BARE COPPER WIRE 1/4" I.D., WINDING LENGTH 4/10".
GROUND TAP 4 TURNS FROM COLLECTOR END.
OUTPUT TAP 3/4 TURN FROM GROUND TAP.

L3 = #30 *NYCLAD* CLOSEWOUND TO OCCUPY 1/2" OF WINDING SPACE ON A 3/8" COIL FORM (*CAMBION LS-5*). SEE BELOW FOR CONSTRUCTION DETAILS. (*RED DOT CORE*)
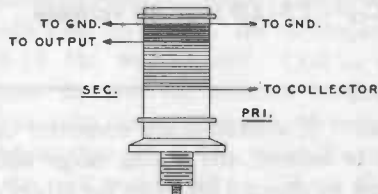
L4 = 5 TURNS #30 *NYCLAD* OVER COLD END OF L3.

L5 = 4 1/2 TURNS #18 BARE COPPER WIRE 1/4" I.D., SPACED TO OCCUPY 5/8".
EMITTER TAP 1/8 TO 1/4 TURN FROM GROUND END.

NOTE: *IN TUNING THE 7 MC. OUTPUT COIL, THE POWDERED IRON IS VARIED SO THAT IT MESHES ONLY THE COLLECTOR END OF L3.*

Figure 4.18-B
TWO METER CONVERTER COIL DATA
(Courtesy of Philco Corp.)

Figure 4.18-A

SCHEMATIC FOR THE TWO METER TRANSISTORIZED CONVERTER
The variable frequency local oscillator permits use of virtually any i.f.
(Courtesy of Philco Corp.)

Parts List

C_1 - 6.8 $\mu\mu$fd. mica ± 5%	C_{14} - 1.2 $\mu\mu$fd. axiial ceramic
C_2 - 22 $\mu\mu$fd disc ceramic	C_{17} - 1.0 $\mu\mu$fd. mica
$C_{3,8}$ - 1.0 - 8.0 $\mu\mu$fd. Tublar trimmer	R_2 - 3.9K 1/2 watt carbon
Erie #532-B	R_1 - 6.8K 1/2 watt carbon
$C_{4, 6, 9, 11, 15, 16}$	R_3 - 1.5K 1/2 watt carbon
- .005 μfd. disc ceramic 70V	R_4 - 15K 1/2 watt carbon
C_5 - 5.0 $\mu\mu$fd mica ± 5%	R_5 - 4.7K 1/2 watt carbon
C_7 - 5.0 $\mu\mu$fd. mica ± 5%	$R_{6,9}$ - 1.8K 1/2 watt carbon
C_{10} - 30 $\mu\mu$fd. mica ± 5% for 7 mc. i.f.	R_7 - 18K 1/2 watt carbon
output	R_8 - 4.7K 1/2 watt carbon
C_{12} - 6.0 $\mu\mu$fd. silver mica ± 5%	TR_1 - 2N1742
C_{13} - 1.5 - 3.0 $\mu\mu$fd. air variable	TR_2 - 2N1743
	TR_3 - 2N1744

system. If a fixed-tuned converter operation is desired, the tuning range will be limited to about 2 Mc. with the mixer output coil used. The frequency range of 144 to 146 Mc. can be tuned without touching the converter once the local oscillator frequency has been set. The i.f. system then tunes from 6 through 8 Mc.

If continuous tuning of the converter is desired, a vernier dial and a panel can be added to the converter. The communi-cations receiver in this case is a fixed tuned i.f. system operating at 7 Mc.

A standby/receive switch should be located in the positive leg of the 12-volt supply. The coaxial antenna switching relay should be located as near as practical to the input terminals of the converter.

Performance The power gain at 146 Mc. is about 30 db and falls off to 27 db at 144 and 148 Mc. The noise figure of the particular 2N1742 used was

5.0 db at 200 Mc. and the overall noise figure of the converter should be no greater than 5.0 db at 144 Mc. It is believed that the newer *Philco* MADT type T2028 r.f. amplifier will provide a noise figure substantially below 4.5 db at this frequency.

This converter was designed by J. Specialny, Jr. and was originally described in *Philco Application Lab Report #651*.

4.19   A 220 Mc. Transistorized Converter

This converter operates at a supply voltage of 12 volts and works into a communications receiver capable of tuning the 10 to 15 Mc. frequency range.

How it The unit (Fig. 4.19-A) employs
Works five transistors, all operating in common emitter configuration. Transistor TR_1, operating as a neutralized r.f. amplifier, is coupled to the mixer through a double-tuned circuit. This method of interstage coupling is preferred because of its ability to reject signals outside the r.f. bandpass and to minimize feedthrough at the i.f. frequency. The antenna is coupled to the amplifier through a tap on the input coil L_1. Shunt capacitor C_1 tunes the input circuit to the proper frequency. A series matching capacitor C_2 applies the incoming signal to the low impedance base which typically is about 60 ohms. Neutralization is provided for by a capacitor network consisting of C_3 and C_6. Neutralization provides an increase in r.f. power gain of approximately 3 db as well as good circuit stability, although the amplifier would be stable if neutralization were not used.

The r.f. amplifier output circuit is tuned by inductor L_2 and capacitors C_4 and C_5. Manual r.f. gain control is incorporated to reduce the gain on strong signals. The method used here, forward gain control, is used because of its excellent overload characteristics. The term forward comes from the fact that the collector current is increased to reduce the stage gain, rather than decreasing the collector current as is done in the reverse method. A resistor R_5 is inserted in series with the output circuit and the negative terminal of the power supply. As the current increases by adjustment of the gain control potentiometer R_3, the voltage available between the collector and emitter of the r.f. stage decreases. This causes the gain to drop. This drop in power gain is nearly linear, as the collector-to-emitter voltage is varied from 8 volts to 0.5 volts. Resistor R_4 provides emitter stabilization and resistors R_1, R_2 and R_3 determine the biasing level. The value of collector current varies from 2.5 to 6 ma. depending on the setting of R_3. The normal operating value is 2.5 ma. for maximum gain. A standby/receive switch is incorporated in the emitter lead.

The output of the r.f. amplifier is coupled to the mixer transistor TR_2 by loosely coupling mixer coil L_3 to amplifier coil L_2 (see coil data, Fig. 4.19-B). Capacitor C_7 tunes coil L_3 and the value of capacitor C_8 is selected to match the input resistance of the mixer. The local oscillator power is injected into the emitter terminal by returning bypass capacitor C_{13} to ground through a tap on coil L_8. An i.f. frequency of 10-15 Mc. was selected. Coil L_4 and capacitor C_9 tune the collector output to this frequency range. The output is coupled to the load through coil L_5, which is wound over the cold end of coil L_3. The 3 db i.f. response of the converter is about 3 Mc. Since most of the activity is centered around 221 Mc., the i.f. response was peaked to 11 Mc. The r.f. response at the mixer base is quite flat from 219.5 to 225.5 Mc.

Emitter resistor R_8 provides d.c. stabilization and resistors R_6 and R_7 determine the operating point.
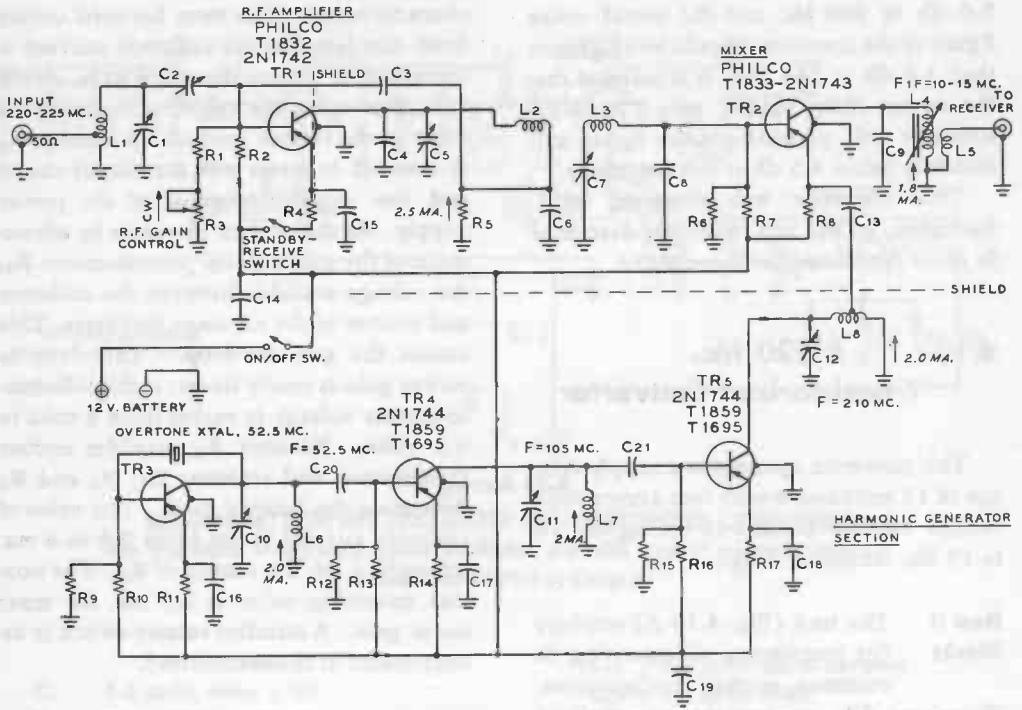
Figure 4.19-A

A TRANSISTORIZED CONVERTER FOR 220 Mc.

The local oscillator energy is furnished by a three-transistor harmonic generator.

The harmonic generator section provides at least 180 millivolts r.m.s. of injection voltage to the emitter terminal of the mixer TR_2. The local oscillator frequency is on the low side and the output frequency is 210 Mc. This high frequency output is obtained through the use of two stages of frequency doubling and a single stage overtone oscillator operating on a frequency of 52.5 Mc.

Transistor TR_3 is used in the crystal controlled oscillator circuit. Coil L_6 and capacitor C_{10} are tuned to 52.5 Mc., the overtone frequency of the crystal. The oscillator output drives TR_4 through coupling capacitor C_{20}. The output is tuned to a frequency of 105 Mc. by coil L_7 and

capacitor C_{11}. The 105 Mc. output from frequency doubler TR_4 is used to drive another frequency doubler TR_5 through coupling capacitor C_{21}. The output frequency of TR_5 is tuned to 210 Mc. by coil L_8 and capacitor C_{12}.

Emitter resistors R_{11}, R_{14} and R_{17} provide the necessary d.c. stabilization and biasing resistors R_9, R_{10}, R_{12}, R_{15} and R_{16} determine the biasing current of their respective stages.

The actual collector current flowing in transistors TR_4 and TR_5 is influenced to some extent by the level of r.f. excitation from the oscillator TR_3, since a combination of fixed and self biasing is employed in these stages.
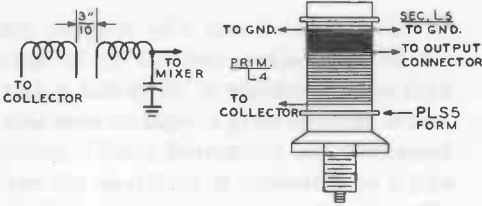
L1 = 6 TURNS #20 TINNED COPPER WIRE 3/16" I.D., 1/2" WINDING LENGTH. ANTENNA TAP 1 TURN FROM GROUND END.

L2 = 3 1/2 TURNS # 26 TINNED COPPER 5/32" I.D., 1/4" W.L.

L3 = 4 1/2 TURNS #24 TINNED COPPER 5/32" I.D., 1/4" W.L.

L2 AND L3 FORM A DOUBLE TUNED CIRCUIT. AIR WOUND IN THE SAME DIRECTION. SPACING BETWEEN COILS AS NOTED ABOVE.

L4 = 72 TURNS #34 *NYCLAD* COPPER WIRE CLOSEWOUND. W.L. ABOUT 5/8" ON 3/8" CERAMIC FORM (*CAMBION TYPE PLS-5 2C4L*) POWDERED IRON SLUG.

L5 = 15 TURNS #34 *NYCLAD* COPPER WIRE CLOSEWOUND OVER GROUND OF L4 (*SEE SKETCH ABOVE*)

L6 = 9 TURNS #3003 MINIDUCTOR (B&W) OR *AIR DUX #416T.*

L7 = 3 TURNS OF #3003 MINIDUCTOR (B&W) OR *AIR DUX #416T.*

L8 = 5 TURNS #18 TINNED COPPER WIRE 1/4" I.D., 1/2" W.L. TAPPED ABOUT 1/4 TURN FROM GROUND.

Figure 4.19-B
220 Mc. CONVERTER COIL DATA

Alignment   The sweep generator method of alignment is suggested in tuning up the converter. However, the unit can be tuned up fairly well by peaking it up on a carrier from the transmitter or from an r.f. signal generator.

If a variable capacitor is used for C_2, alternately adjusting C_1 and C_2 for maximum output should peak the input properly. The point-of-best-noise figure should coincide very nearly to the point of maximum power gain. The noise figure should be in the vicinity of 5.5 to 6.5 db.

Performance   The overall power gain is about 22.0 db. An additional 1.5 to 2.0 db can be realized by inserting a series-tuned 11-12 Mc. trap between the mixer base and ground because the input circuit does not completely short the 12 Mc. input admittance of the mixer. The additional tuning procedure involved did not warrant the addition of the trap.

This converter was designed by J. Specialny, Jr. and was originally described in *Philco Application Lab Report #679.*

Transmitters

When this book was started, high power r.f. transistors were still laboratory curiosities. Shortly thereafter companies such as Pacific Semiconductors, Texas Instruments, Fairchild, RCA, and many others had developed devices capable of generating many watts of r.f. at very high frequencies. The work of these companies has opened the way for developing new designs which will not only render obsolete present tube equipment, but will provide considerable savings in bulk, weight, power consumption, and, in many cases, cost.

To properly utilize the r.f. power transistor, it is necessary to readjust one's thinking to new concepts in transistor theory. It is the purpose of this chapter to introduce these new concepts.
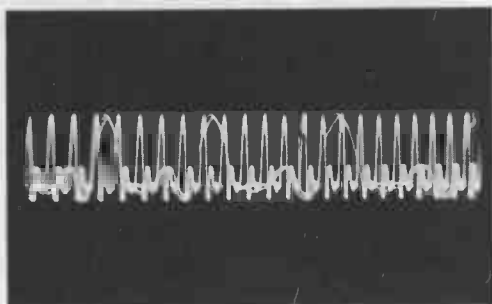
This photograph shows the waveform at the collector of a class B r.f. amplifier.

5.1   R.F. Power Amplifiers

An r.f. power transistor, whether oscillator or amplifier, is rarely matched to the load. The load value is a function of the desired power output and is found from the formula:

$$R_L = \frac{0.5 \ V_{ce}^2}{P_o}$$

where:

R_L = the load resistance

V_{ce} = d.c. collector voltage

P_o = required power output

The transistor may be considered a switch which turns the d.c. on and off at an r.f. rate. Assume that 5 watts is required from an amplifier and that the power supply is 12 volts. From the above formula,

$$R_L = \frac{0.5 \times 12^2}{5} = 14.4 \text{ ohms}$$

In order to develop the 5 watts of power, the transistor must "look into" a load of 14.4 ohms. If, however, the load has an impedance of other than 14.4 ohms, an impedance transformation must be made using transformers, pi networks, or other matching devices.

The output from a single transistor operated in Class B or Class C will be a series of half-waves, as illustrated in figure 5.1-A.

One purpose of a tuned circuit is to, by virtue of its flywheel action, restore the missing half-cycle. A waveform other than a sine wave contains a great number of harmonics. These harmonics are eliminated when the waveform is converted to a sine wave by means of resonant circuits. To restore the waveform to a sine wave efficiently, the output circuit must have a reasonable Q. From the formula:

$$Q = \frac{R_L}{X_c}$$

it will be seen that to maintain Q at a given figure, a reduction in R_L necessitates a decrease in X_c. The term X_c, in this instance, represents the reactance of either the coil or the capacitor. When the load resistance is very low, "C" becomes very high and is often impractical in value. Representative Q figures range from 3 to 15.

By transposing the formula for Q, we find that:

$$X_c = \frac{R_L}{Q}$$

Assuming a Q of 5 and a load resistance of 14.4 ohms, X_c will have a value of 2.8 ohms. At a frequency of 5 Mc. this would be represented by a tuning capacitor of approximately 0.01 μfd. This is impractical and would result in a coil so small that it would be made up almost entirely of the capacitor lead inductance.

A low value of load resistance may be effectively transformed to a higher value by tapping the collector down the coil. If the collector is tapped midway down a coil, the 14.4 ohm load resistance will be transformed to 57.4 ohms (turns ratio^2). Any value of load resistance may be transformed to almost any higher value, and the L/C ratio of the tuned circuit may be chosen accordingly.

The preceding discussion has conveniently ignored the unloaded Q of tuned circuit components. A complete explanation of unloaded and loaded Q is beyond the scope of this book. However, in most practical cases, if the unloaded Q of the components is at least 10 times the loaded Q, the preceding formulas may be considered sufficiently accurate. It is a simple matter to obtain unloaded Q's of 60 or more. Coils should be large and airwound or, as an alternative, wound on some of the newer very high Q ferrite toroids.

Bias Considerations   The primary difference between the various classes of transistor operation is that of bias. A Class B amplifier is operated at the bottom of its V_{be}-I_c curve. Because the transistor is not conducting during one half of the input cycle, heating is reduced and efficiency, compared with Class A, is increased. Efficiency may be further increased by biasing the transistor even beyond the cutoff point so that conduction takes place only for a portion of one-half cycle.

Bias may be supplied from a fixed source or be self-developed. The circuit shown in figure 5.1-B obtains its bias from self-rectification in which a voltage is developed across the 100-ohm resistor in the base circuit.
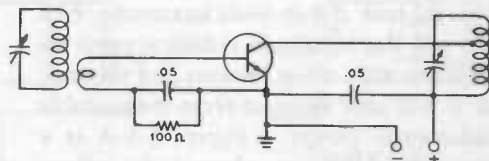
Figure 5.1-B
Large signal NPN r.f. amplifier with collector impedance matching to the tank coil.
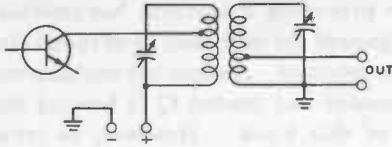
Figure 5.1-C
A bandpass coupler will greatly
attenuate harmonics with little or no
insertion loss.

The Input   The input impedance of an
Circuit   r.f. power transistor is usu-
                  ally quite low, and suitable
impedance matching must be employed for
maximum power transfer from the driver.
Matching may be accomplished by any one
of the usual methods, as discussed in Chap-
ter Three. Some germanium r.f. power
transistors have a fairly low base-to-emitter
breakdown voltage. In this case, care must
be exercised to avoid high values of resis-
tance in the base circuit, across which ex-
cessive self-bias may be developed. This is
quite important. Several transistor break-
downs in some of the authors' experi-
mental breadboard units occurred before
this fact was realized.

The Output   As mentioned earlier, the
Circuit   output of the Class B and
                 C transistor stage is not a
sine wave and the output circuit should be
of high Q to prevent the transfer of har-
monics. This is particularly important
when the tank circuit feeds an antenna. Not
only will the harmonic radiation cause in-
terferance with other stations and services,
but it will also subtract from the available
fundamental power. Figure 5.1-A is a
photograph of the waveform at the collect-
or of a 10-watt r.f. power amplifier. A watt-
meter connected to the output of this trans-
mitter would give an entirely false reading.
The harmonic output would be very high.
In addition, where the power is read by
measuring the r.f. voltage across a known
value of resistance, the actual voltage read-

ing could be greatly in error. This is be-
cause the half-wave type of VTVM measures
only one half of the waveform. Readings
would differ according to whether the pos-
itive or the negative half were being read.

To convert the pulse-type waveform of
figure 5.1-A to a sinewave, it is often nec-
essary to incorporate an additional tuned
circuit between the transistor and the an-
tenna in the form of a band-pass coupler
as shown in figure 5.1-C. As an alterna-
tive, the pi coupler may be used to remove
the harmonics. However, when the im-
pedance of the load is similar to that re-
quired by the transistor, it may be impos-
sible to construct a single pi network of
sufficient Q. In this case a double pi, in
which the input impedance is stepped up
to a higher value (about $10 \times R_L$) and then
down to the antenna impedance, may be
used. The waveform at the antenna may be
viewed conveniently on an oscilloscope for
distortion, a direct indication of harmonic
content. Preferably the oscilloscope should
have provision for direct connection to the
deflection plates unless it is capable of am-
plification of frequencies at least six times
the amplifier output frequency.

Neutral-   The subject of neutralization
ization   and unilateralization was dis-
and   cussed in Chapter Three. Im-
Unilateral-   proper neutralization of an
ization   r.f. power amplifier may cause
                 a severe loss of transistor
gain. At radio frequencies, feedback may
be degenerative and yet become regenerative
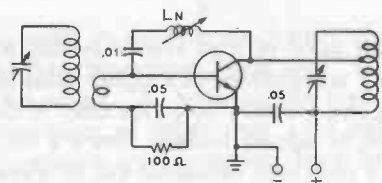
Figure 5.1-D
A neutralized version of the
r.f. amplifier shown in Fig. 5.1-B.

when the output circuit is tuned. In addition to the neutralization methods discussed in Chapter Three, neutralization may be accomplished as shown in figure 5.1-D. In this instance, a tuned circuit consisting of the inductance L and the base-collector capacitance is resonated at the operating frequency. At resonance, $X_c = X_L$. It will be seen that the internal capacitance of the transistor (between base and collector) is effectively cancelled. The arrangement is similar to that employed with tube cascode amplifiers.

5.2   R.F. Oscillators

Almost all the preceding remarks concerning amplifiers apply to the oscillator. This is true whether the latter is crystal-controlled or self-excited. An oscillator may be considered as an amplifier, in which energy is extracted from the output and returned to the input. The fact that the input is supplied from the output circuit is of little consequence to the transistor. The input of the transistor should be matched to the driver. The driver here is the output circuit and, accordingly, an attempt should be made to effect a match between the base and the output circuit. In figure 5.2-A, this is accomplished by adjusting the ratio of the feedback winding turns to that of the collector winding. In the Hartley circuit of figure 5.2-B, the impedance is adjusted by varying the B+ feed-point. This point, as far as r.f. is concerned, is connected to the emitter via the bypass capacitor and the common ground. Thus, the coil is divided each side of the emitter. The impedance of the winding feeding the base will be reduced as the tap is moved toward the bottom of the coil. The Colpitts circuit is matched in a similar manner by selecting the ratio of the two capacitors across the tuned circuit. This is shown in Fig. 5.2-C.

Crystal Control   To convert a self-excited oscillator to crystal control, it is necessary to insert the crystal in series with the feedback path. The crystal, to all frequencies except that at which it is series resonant, will represent a high impedance. Oscillation at these frequencies normally will not be possible. At resonance, the impedance of the crystal may be in the range of 50 to 2,000 ohms. In the three preceding oscillator circuits, the crystal would be operating in the series resonant mode. To use the crystal in the parallel mode, it would be connected in place of the inductance in Fig. 5.2-C. In this case, feedback would still be controlled by the ratio of C_1 to C_2.

In these circuits, crystals can also be operated on overtones, or odd multiples of the fundamental frequency. For ex-
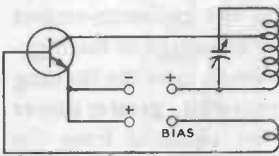
Figure 5.2-A
A tickler coil provides feedback in this oscillator circuit.
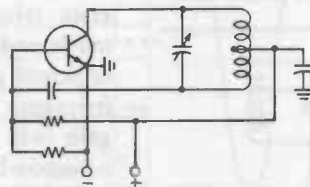
Figure 5.2-B
The Hartley oscillator employs a tapped coil.
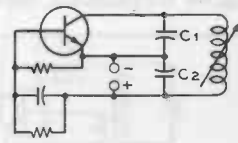
Figure 5.2-C
The Colpitts circuit uses a capacitive voltage divider to establish the level of feedback.
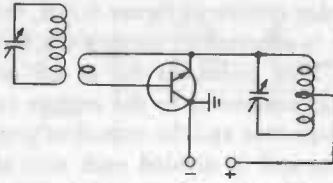
Figure 5.2-D
A grounded-collector r.f. amplifier which is often confused with the common-collector configuration.

ample, a 9 Mc. crystal can be made to oscillate at 27 Mc. by resonating the tuned circuit at approximately the third harmonic of the crystal frequency. Crystals which have a fundamental frequency above 25 Mc. are extremely difficult to make, for they become quite fragile. At frequencies above 15 Mc., overtone operation is desirable, because it avoids the use of expensive crystals and eliminates the components of a frequency multiplying stage. Since unwanted frequencies can feedback through the holder capacitance, crystals used in overtone service may require neutralization. The effect can be eliminated by placing an inductance across the crystal and resonating the holder capacitance slightly above the overtone frequency.

If the feedback voltage is not exactly in phase with the input, it will be necessary to increase the amplitude of the feedback in order to maintain oscillation. At the higher frequencies, undesirable phase shift
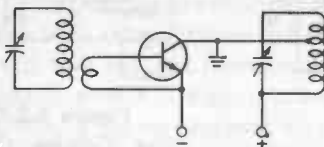
Figure 5.2-E
The grounded collector r.f. amplifier is redrawn here to show the actual circuit more clearly.

may take place in the transistor, necessitating increased feedback. A point is reached, however, where all the available output energy is being fed back to the input, leaving little power to be delivered to the load. In circumstances such as these, it is usual to correct the phase of the feedback with an L/C or other network so that the feedback arrives in phase with the signal.

Circuit Configuration When analyzing crystal oscillator circuit diagrams, it is helpful to break the oscillator down into its basic type. Generally, it may be stated that all the well-known oscillator configurations, such as Colpitts, Hartley, or Ultra Audion, may be found in transistor circuitry. However, it should be remembered that the transistor circuits may not, at first evaluation, appear to be any known configuration. This is brought about by the fact that the capacitance which exists between the elements of the transistor may eliminate the need for an external capacitor. In the circuit of Fig. 5.2-C, for example, C_2 may be made up entirely of base-emitter junction capacitance. When changing a transistor for another type in an existing circuit, it is well to remember this point. The replacement transistor may have considerably different internal capacitances, and may result in improper operation. This is true in any r.f. circuit which employs transistors. In higher power r.f. oscillator and amplifier circuits, there is a notable tendency to operate transistors in the common-emitter mode and thus take advantage of the higher power gain. However, near the limiting frequency of the transistor, greater power gain will usually be obtained from the common-base connection.

The common-collector connection should not be confused with the grounded-collector common-emitter stage. This is shown in Fig. 5.2-D. The circuit is redrawn in Fig. 5.2-E, and inspection will show that the circuits are identical and are of the same configuration as in 5.1-B. The

fact that the collector is grounded does not affect the transistor configuration. Often it is convenient to connect the collector of the transistor directly to the chassis in order to obtain better heat dissipation.

5.3   Linear Amplifiers

Transistor linear power amplifiers pose problems not always encountered with other stages. As the name implies, the stage must amplify the signal presented to the input of the transistor in a linear manner. Linear amplifiers may be operated Class A or B but never Class C. The single-ended Class B stage may be confusing to those used to audio circuitry. In this case the missing half cycle is replaced by the tuned circuit. It is essential, therefore, that the tank circuit of a Class B linear amplifier have a high Q.

Low level Class A stages are readily designed to amplify a signal in a linear manner. An example is the i.f. stage in a transistor receiver wherein the transistor is operated well within its capabilites and at currents very close to 1 ma.

When the transistor operating level is increased, non-linearity of transistor characteristics becomes a problem. Fig. 5.3-A shows a curve for collector current plotted against collector voltage. The base current is the running parameter on which a load line has been drawn. The subject was discussed in Chapter Two. The base current must swing from 0 to 10 ma. to obtain the greatest output. Note the shape of the output waveform over this range of base current. The effect is due to the crowding of the base lines as the base current increases. It is pointed out that this is an exaggerated case but none-the-less valuable as a lesson. The set of characteristic curves, in this case, belongs to a silicon transistor but is plotted at low voltage levels. For comparison, the high voltage characteristics are shown in Fig. 5.3-B using the same transistor. Note the evenly spaced base lines and linear output. In selecting a transistor for use in high-power linear amplifier service, one must make a close study of the transistor's characteristic curves.

The linearity of the amplifier may be considerably improved by applying negative
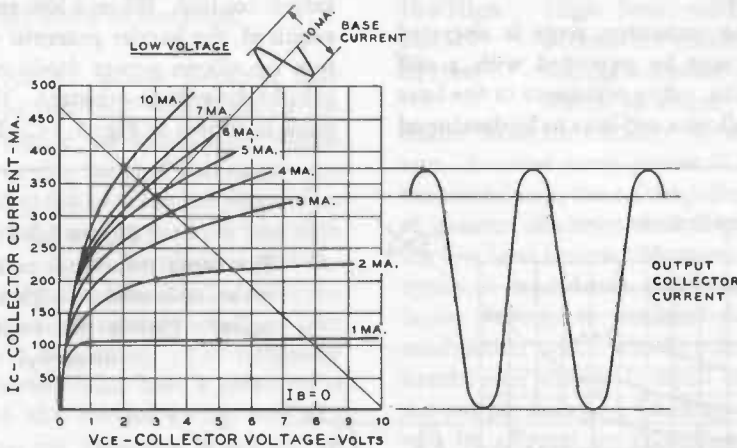
Figure 5.3-A
**BASE CURRENT CURVES FOR
LOW COLLECTOR VOLTAGES**
Note the severe non-linearity.

feedback around the stage. Negative feed-back has the effect of spacing the base lines evenly. However, in some amplifiers, un-wanted phaseshifts in associated compon-ents may make the application of negative feedback difficult, especially at the higher frequencies.

The Emitter Follower Considerable output may be obtained from a transistor connected as an emitter fol-lower if due attention is paid to correct im-pedance matching. The one-hundred per-cent inherent feedback makes it necessary to apply considerably more drive to the stage than is required in the common-emit-ter connection.

Bias Consider-ations If the linear amplifier is op-erated Class A, the stage must be biased so that the collector current will swing equally in each direction. This corresponds to the 15 ma. base current in Fig. 5.3-B. Class B operation demands that the stage be biased close to cutoff. As in class B audio stages, a small fixed bias should be applied to the transistor to lift the operating point above the curved portion of the transistor characteristics.

When the transistor stage is operated class B, it *must* be provided with a stiff source of bias. Any resistance in the base circuit will allow a self-bias to be developed
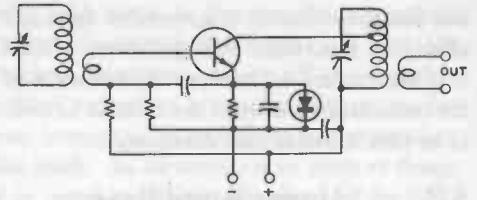
Figure 5.3-C
In linear amplifier service, a stable bias point can be obtained by employ-ing a zener or silicon diode, as shown here.

in addition to the fixed bias. On large sig-nals, the self-bias may cause the stage to enter the class C region, thus creating se-vere distortion of the waveform.

In the interests of temperature stabil-ization, an emitter resistor is mandatory. Unfortunately, an emitter resistor will cause a bias which is subject to variation with changing signal levels. This may be over-come by shunting a zener diode across the resistor so that the bias level is held con-stant.

However, a zener diode connected at this point will subtract from the usefulness of the resistor as a temperature stabili-zation control. When a low emitter bias is required, the barrier potential of a german-ium or silicon power diode may be used to hold the voltage constant. This arrange-ment is shown in Fig. 5.3-C. The potential
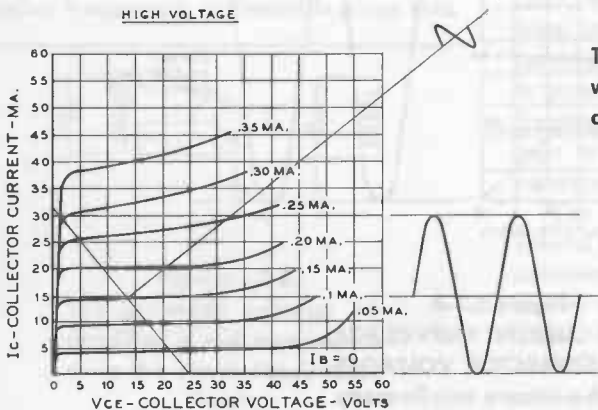
Figure 5.3-B
The same transistor, as in Fig. 5.3-A, when operated at high collector volt-ages. Notice the improvement in linearity.

drop across the diode will be approxi-
mately 0.6 volts for silicon. Two or more
diodes may be connected in series. When
difficulty is experienced in finding a ger-
manium diode capable of carrying the cur-
rent, the base-emitter or base-collector junc-
tion of a germanium power transistor may
be utilized.

The transistor linear amplifier should
be driven from a higher impedance source
so that base-emitter impedance variation is
but a small percentage of the total imped-
ance in the circuit. This will prevent dis-
tortion of the signal due to the nonlinearity
of the base-emitter junction.

5.4   Modulation

Transistor r.f. power amplifiers may be
either high or low level (or efficiency) mod-
ulated. The low level system, though in-
efficient, requires only a small modulating
power. High level modulation is effieient
and generally is more easily put into op-
eration. However, modulator power out-
put requirements are high. More than
50% of the r.f. power amplifier d.c. input
is required for 100% modulation.

The Low   An r.f. power amplifier may
Level   be low-level modulated by ap-
System   plying the modulating signal
              to the base of the stage. An
audio signal at the base has the effect of in-
creasing and decreasing the base bias with
audio signal. It will be obvious that the
collector current must be able to follow the
base excursions if modulation is to take
place without distortion. The transistor
collector current must have a mean value
about which the current swing may take
place. Thus, the transistor is not able to
operate at maximum level and its efficiency
is low.

If the current gain of the transistor is
not constant over the entire range of col-
lector current, the r.f. envelope will not be
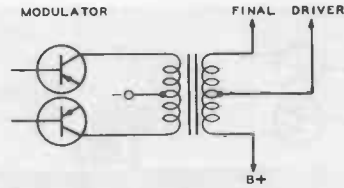
Figure 5.4-A
When high-level modulat-
ing transistor transmitters,
it is usually necessary to
also modulate the driver
and even the oscillator.

an exact replica of the modulating wave
form, and distortion will occur. In Fig.
5.3-A it was shown that decreased spacing
between the base lines, especially at the
higher current levels, created harmonic dis-
tortion. A low level modulated stage, dur-
ing the higher peaks of modulation, will
also have a non-linear output. Accordingly,
the stage should be operated within the
limits of the transistor. The transistor
characteristics illustrated in Fig. 5.3-B show
excellent linearity over a wide range of col-
lector currents.

The High   High level modulation is a
Level   process in which an external
System   voltage supplied by the mod-
              ulator is added to and sub-
tracted from the r.f. amplifier collector volt-
age. Because extra power is supplied by
the modulator, the r.f. amplifier is operated
at greater efficiency than is possible with
the low level system. However, on positive
cycles of modulation (NPN case), the col-
lector voltage is doubled during 100%
modulation peaks, and the collector-to-base
breakdown voltage is equal to four times
the supply voltage. Linearity of the stage
will be affected by crowding of the base
lines on the I_c / V_{ce} characteristic curves.
Positive modulation peaks should not be
allowed to run the transistor into the non-
linear area. Similarly, on negative peaks of
modulation, the transistor should not be
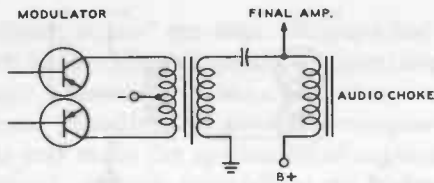
Figure 5.4-B
An audio choke will improve quality
by preventing saturation of the
modulation transformer core.

allowed to saturate, for distortion will occur. The transistor contains some resistance between the emitter and the collector, and therefore the collector voltage cannot be reduced to zero. The above requirements make it difficult, if not impossible, to obtain 100% modulation when the transistor is operated at or near maximum dissipation. In practical cases, 70%-85% modulation is normal.

Modulation percentage may be increased by simultaneously applying power from the modulator to a driver stage. See Fig. 5.4-A. This is accomplished by providing either a tapped or a separate secondary winding on the modulation transformer.

No hard and fast rule can be stated about the division of modulator power between the final and the driver. This is dependent upon a number of factors. It is better to apply as much modulation as possible to the final. This is because modulation applied to the driver causes the final to be partly efficiency-modulated. The limit is set by the factors outlined above.

The Modulator The modulator transistors must be capable of supplying an output power of at least 50% of the r.f. power amplifier d.c. input. In practice, due to transformer losses, considerably more power than this is usually required for 100% modulation. The modulation transformer must be capable of supplying the power to the transmitter without core saturation. Transistor r.f. amplifiers

draw heavy currents, and the transformer core size must be adequate for this. This is an important but often overlooked point.

To prevent saturation of the core, caused by the flow of d.c. current through the transformer, the secondary may be isolated from the supply as shown in Fig. 5.4-B. The choke must offer a high impedance to the audio frequencies.

5.5 A Transistor Phasing Exciter

This exciter has a performance equal in every respect to its tube counterpart. The output is sufficient to drive a pair of 6BQ5's to 10 watts on either 80 meters or 20 meters. The exciter has no tuning controls and has only one switch to change when going from one band to the other. The entire exciter, including batteries, measures only 12" long, 2 3/4" high, and 5" deep. The total weight is less than 4 1/2 lbs. The unit uses only ten low-cost transistors and draws only 12 ma. at 12 volts. Standard components were used throughout, and no attempt was made at super miniaturization. "Barefoot," the rig has worked several countries on 20 meters with a cubicle quad thirty-five feet high. Admittedly, the conditions were excellent and free from QRM
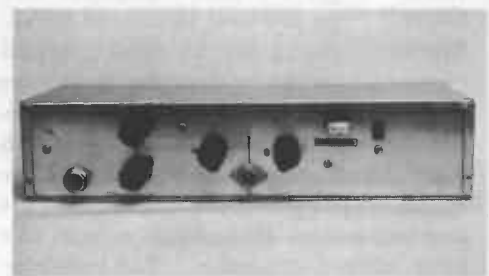
Measuring only 12" long, 2 3/4" high and 5" deep, this little s.s.b. exciter has worked several countries running "barefoot". Controls are, from left to right, 2 carrier balance potentiometers, sideband selector, band change and on/off switch.
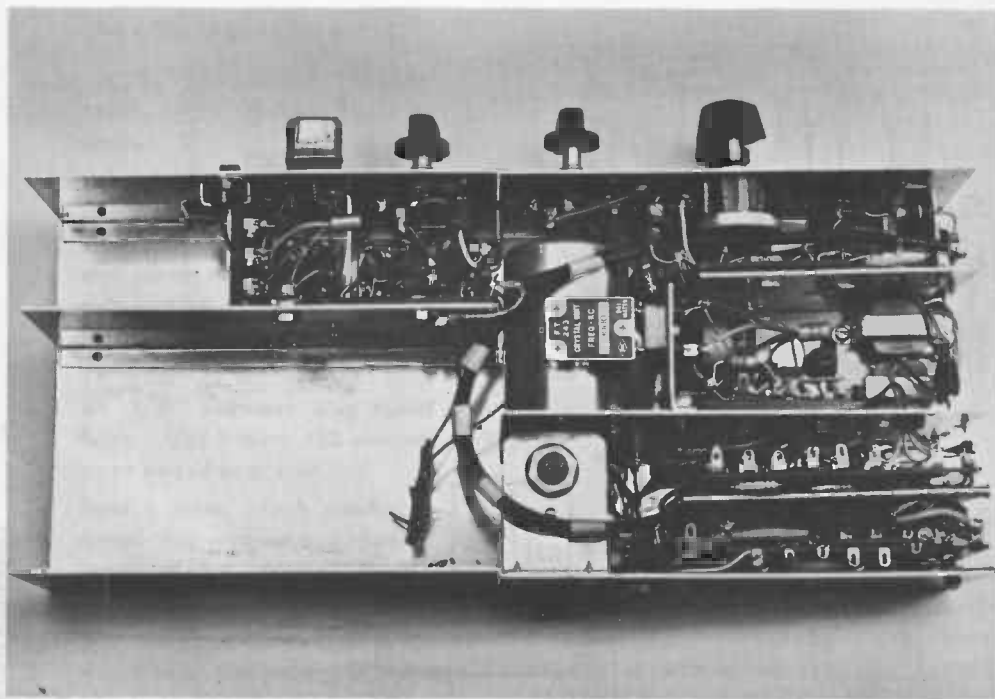
TRANSISTOR PHASING EXCITER

Liberal use of tag boards has allowed a compact construction. Large space at the
left is the 12-volt battery compartment. The small space is for the v.f.o.

at the time, but it does indicate that the exciter has creditable performance.

How It Works   Apart from the first stage, the audio amplifier preceding the audio phaseshift network is conventional transistor circuitry and was described in Chapter Two. The first stage was designed to be driven by a crystal microphone, and it was necessary to raise the amplifier input impedance. This was done by applying feedback via C_1 to the base of a common collector stage. The 100K resistor in series with the microphone also increases the input impedance. In addition, it acts as an r.f. filter in conjunction with the 5K bypass capacitor. The capacitor also restricts the high frequency response. This is necessary to meet present day bandwidth requirements.

The audio phaseshift network was constructed with 1% high stability resistors and 2% silver mica capacitors. The components were taped together and placed in an aluminum can which may be seen beneath the 9 Mc. crystal in the center of the photograph. The values shown in Fig. 5.5-A are also used in the Central Electronics PSN, which can be substituted for the homemade network. Other networks have the wrong impedance for use in conjunction with transistors.

The 0.01 μfd. capacitor across the primary of transformer T_1 is necessary to further limit the high frequency response. This value was found to be most effective with the particular transformers and microphones used. It is possible that a different microphone or other makes of transformers may require a slight change if identical

Figure 5.5-A

This two band phasing type s.s.b. exciter will drive two EL 84/6BQ5 tubes to 10 watts input using only 10 low-cost transistors.

Parts List - Figure 5.5-A

D_1, D_2, D_3, D_4 - Germanium diodes, 1N34, 1N35, 1N198, OA85 or similar.

L_1 - 0.8 microhenry. 9 turns #18 enamel wound on the threaded end of a 1/4" bolt. Remove bolt and screw in a powdered iron coil slug which has an external thread.

L_2 - 15 turns #22 enamel 3/4" long on 1/2" diameter slug tuned form. Link 5 turns #22 enamel close wound over cold end.

L_3 - Total 6 turns. Each winding 3 turns. #22 enamel to a winding length of 3/4" on a 1/2" slug tuned form.

L_4 - 3/4" length of #30 on 3/8" form, slug tuned. Secondary, 7 turns #30, close wound, cold end.

L_5 - Pi or jumble wound coil #26 nylon covered wire. 1/4" wide winding in the center of a 3/8" slug tuned form. (Wire length 6') Link 8 turns of the same wire as close as possible to primary.

L_6 - 16 turns #22 enamel wire spaced to occupy 3/4" on 3/8" slug tuned form. Link 4 turns over cold end.

P_1, P_2, P_3, P_4 - Carbon or wirewound.

$Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, Q_7$ - May be replaced with 2N1274, 2N408 or similar.

T_1, T_2, T_3 - 10,000 ohm primary. 6/1 turns ratio.

R_1 - 100 ohms, 1 watt, carbon. Select value on ohmmeter as close to this as possible.

C_2 - Made up of 150 $\mu\mu$fd. and 25 $\mu\mu$fd. capacitors in parallel. Endeavor to match these components within 5%.

Figure 5.5-B
The audio preamplifier components are mounted on the terminal board as shown. The strip following the PSN is constructed in a similar manner.

results are to be obtained. A tone fed into the microphone jack should produce approximately 1.5 volts of audio at the secondary of T_1 well before distortion occurs. The total d.c. current drain of this section is 2.7 ma. at 12 volts. Production spread in the transistors and components may modify these figures somewhat, but large differences in the readings would indicate something wrong. Potentiometer P_1 is the ratio control, pertinent to most phasing rigs whether they are tube or transistor types. The control may be either carbon or wirewound. Its purpose is to divide the audio into two sections of unequal amplitude. This allows the audio phaseshift network, which has more attenuation in one leg than the other, to deliver two outputs of equal amplitude.

Following the PSN are two emitter followers, Q_4 and Q_5. Emitter followers were used here because of their high input impedance. They are followed by Q_6 and Q_7, which are amplifiers operating with a high negative feedback. This has the dual purpose of stabilizing the transistor gains and raising the input impedance. If the input impedance of Q_6 and Q_7 is raised, this naturally increases the value of the load impedance on Q_4 and Q_5. The input impedance of Q_4 and Q_5 is beta times the load

impedance. Thus, the impedance change is reflected through to the audio PSN. It is necessary to avoid shunting the PSN with a load, for this will depreciate the sideband suppression considerably.

The potentiometer P_2 corresponds to the audio balance control in a tube counterpart and insures that the outputs from the two channels are equal. The output of T_2 and T_3 is more than ample to drive the diode-balanced modulators.

Transistor Q_8 is a 9 Mc. crystal oscillator. The associated components have been very carefully adjusted to provide optimum output. This oscillator feeds the r.f. phaseshift network, which is made up of C_2, L_1, and R_1. When a capacitor and resistor in series are shunted across a source of r.f., a $90°$ phaseshift occurs only if the circuit is unloaded. When the circuit is loaded (in this case by balanced modulators), it is necessary to insert reactance of the opposite sine in the network to correct the phaseshift and maintain equal amplitudes. The slug in L_1 is a vernier and its adjustment is not critical.

Select the diodes by measuring their forward resistance on an ohmmeter. The resistances should be within 10%. The combining coil in the output is bifilar wound, and the two capacitors across it should be matched on a bridge. If the bridge is not available, the capacitors may

Figure 5.5-C
THE BIFILAR-WOUND
BALANCED MODULATOR COIL
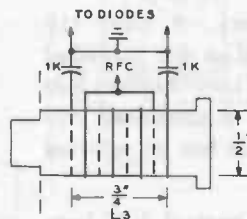
Note how the start of one winding is connected to the finish of the other. The link is wound over the center.

be selected by placing them across an oscillator and noting the frequency shift that occurs.

The link winding from the balanced modulators provides a good impedance match to the base of the 2N371 mixer. The 2N274 5 Mc. crystal oscillator has been designed to provide optimum mixer injection. The r.f. signal at the collector of the mixer should be approximately 4 volts with full carrier insertion. This is more than sufficient to drive the tube amplifier shown in Fig. 5.5-E. In the initial stages of developement, a 2N371 r.f. amplifier was added to the mixer. This proved not only unnecessary but undesirable. It complicated the switching and made swamping of the mixer output necessary to prevent flat topping. The increase in output was small.
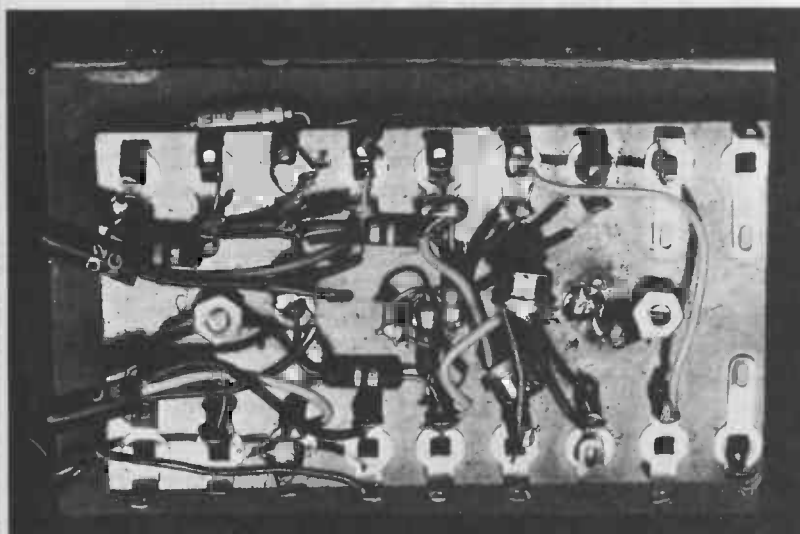
The second audio board. This board follows the audio phaseshift network. The input is at the right.

Construction The mechanical construction of the exciter is unorthodox but has many advantages over normal construction. With this system, miniaturization is accomplished without creating a "rat's nest", and sections are accessible for testing or alteration. If a larger physical size can be tolerated, there is no reason why conventional construction cannot be employed.

Where possible, sections are built upon terminal strips which are in turn bolted to aluminum shield partitions 2 1/2" high. The terminal strips are held away from the metal by small spacers slipped over the bolts. This leaves sufficient space to clear the components, which are mounted on both sides. A layer of thick paper is glued to the partitions wherever there is a possibility of shorts occuring. The shield partitions are held to the base plates by two self-tapping screws. A section may be removed easily by undoing these two screws and then lifting up the strip and aluminum. Whenever practical, the wires are connected at one end of the board and are long enough to allow the sections to hinge.

Audio Amplifiers The audio amplifier, comprising Q_1, Q_2, and Q_3 is on a strip at the left rear of the chassis. The layout is shown in Fig. 5.5-B. Small diameter coaxial cable connects the crystal microphone jack (left front panel) to the base of Q_1 through the 8 μfd. capacitor and the 100K resistor, which are mounted on the terminal strip. The coaxial cable may be seen forming a half circle near the 9 Mc. crystal. The cable enters the audio section at the right hand end. Transistor Q_1 is at the left hand end of the strip. The strip material on which the components are mounted measures 2" wide, with lugs along the two edges spaced 3/8" apart. Grounded terminals are connected to the mounting bolts.

The potentiometer at the end of the strip and close to the battery compartment is the audio balance control, P_2. The ratio control, P_1, and the transformer, T_1, are beneath P_2. The audio phaseshift network is in the aluminum can beneath the crystal. The wires are of sufficient length so that when the strips are removed the wires may be left connected and the circuit operated in this manner.

Transistors Q_4, Q_5, Q_6, and Q_7 are on the 3 1/2" long strip second from the rear. The wires connecting T_2 and T_3 may be seen passing through the rubber grommet at the left hand end of the partition. It is necessary to undo these three wires when removing the strip. The wires at the right hand end are of sufficient length to allow the strip to hinge upwards. T_2 and T_3 are mounted on a small bracket attached to the shield partition, allowing them to be removed as a unit.

The small terminal strip at the right of T_2 and T_3 contains the r.f. phaseshift network and the 9 Mc. crystal oscillator components. The coil is mounted in the compartment beneath the 2N274 transistor and is attached to the bracket which holds the crystal. The bracket is fixed to the shield partition. This whole unit may be lifted out by removing the two self-tapping screws at the bottom.

The bifilar-wound balanced modulator output coil L_3 (immediately behind the microphone socket) is in the front compartment along with the germanium diode-balanced modulators. These diodes are on the terminal strip behind the carrier balanced modulators. These diodes are on the terminal strip behind the carrier balance potentiometers. The control near the center is the sideband selector switch.

Figure 5.5-D
THE OSCILLATOR COIL, L_2
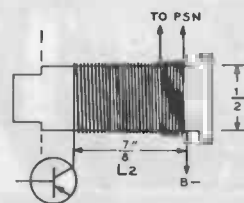
The link is wound over the cold end. Note that the hot end is closest to the chassis.

A coaxial cable is connected from L_3 to the mixer Q_9 and is taped to the microphone cable. Transistor Q_9 may be seen behind the band switch, which is the knob to the left of the crystal socket. Transistor Q_{10}, the 5 Mc. crystal oscillator, is behind the crystal socket. The slide switch next to the crystal removes the B minus from the unit.

The mixer and 5 Mc. oscillator compartment were the most difficult to assemble. Eventually, a new split front panel was made. Now, by undoing two self-tapping screws and removing the nuts and bolts holding the controls to the panel, it can be removed and the compartment completely exposed.

The space at the right front of the chassis was left for the v.f.o. Initially, each portion of the rig was breadboarded while the "bugs" were ironed out. This practice was used with the v.f.o. also. However, the lack of a suitable dial and capacitor gearing mechanism that would fit the space available has made the v.f.o. a project for the future. The space available is 2 1/2" long, 2 1/2" high, and 2" deep. Experiments were conducted with variable capacitance diodes in order to use a potentiometer as the tuning component. The problem is a mechanical one and not electrical, for an excellent v.f.o. was built separately and is described in section 5.7.

Coils   It is recommended that coils L_1, L_2, and L_3 conform with the supplied data. A small shield, not visible in the photograph, was placed between the 20-meter coil L_6 and the 5 Mc. coil L_4, midway between the 5 Mc. crystal socket and the wavechange switch.

Balanced Modulators   The particular diodes used were of English manufacture. Other diodes may be substituted without circuit alteration. The two disc ceramics are mounted on the terminal strip containing the diodes and are connected across the carrier balance potentiometers.

Adjustments   Adjust P_2 to the center of its range. Use an r.f. probe or a receiver and adjust L_2 for oscillation. Turning the carrier balance potentiometers should not stop the oscillator, although a *slight* change in frequency when the potentiometers are at an extreme is permissible. If the frequency change is too great or the oscillator stops altogether, the link is too large or the coupling too tight. No trouble was experienced in three duplications of this portion of the circuit. With the carrier inserted, resonate L_3. Next, adjust the slug in L_4 until the crystal oscillates. There should be 0.25 to 0.5 volts of r.f. applied to the emitter of Q_9. Resonate the 20 and 80-meter coils for maximum output. The
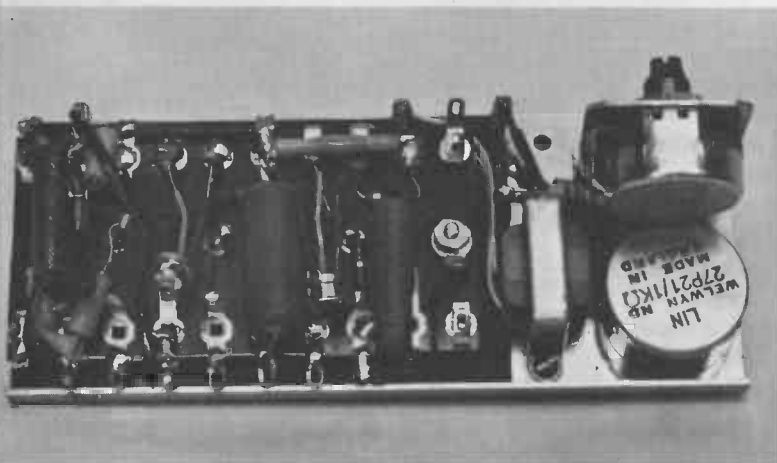
The microphone preamplifier audio board is fitted to a small aluminum partition. The input is at the left. Also shown are the ratio and audio balance potentiometers.

6BQ5/EL84
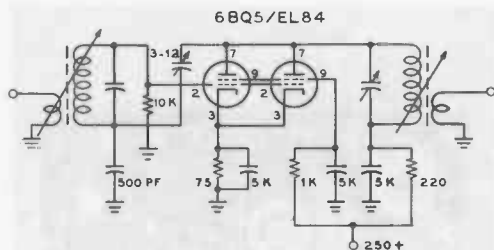
Figure 5.5-E
This amplifier, if used after the exciter, will deliver a large signal to the load. Coils may be bandswitched or plugged in as desired. Make certain that the input and output circuits are well shielded from each other.

tuning of these stages is fairly broad due to the loading of the transistor. Nothing is accomplished by tapping the collector down the coil, for it then becomes necessary to load the coils with resistance to broadband the tuned circuit. There should be no difficulty in obtaining 4 volts of r.f. at the grid of a tube amplifier if a step-up matching device, such as a link coupling, is used.

Balance out the carrier using first one control and then the other, returning again to the first, and so on. The carrier should balance out completely, and there should be a negligible 5 Mc. component in the output. No trouble with self-oscillation of any stage was experienced, and it is logical to suppose that with such low impedance circuits, none should occur.

Next, short out the microphone input socket and feed a tone through *a large coupling capacitor* to the collector of Q_3. If the tone output is very low it may be fed into an earlier stage. It is of the utmost importance that no overloading occurs. Overloading creates a distortion which, when viewed on the scope, is indistinguishable from that due to poor sideband suppression. Adjust the tone gain so that approximately 2 volts of r.f. is developed at the collector of the mixer.

Adjust the slug of L_1 to half way in the coil. Adjust P_1 for minimum ripple on the scope. Switch sidebands and readjust P_1. If a different setting is obtained, set it half way between. Go through the same procedure with P_2. Repeat the adjustments with P_1. When no further improvement can be obtained, adjust L_1 and switch sidebands as before. Repeat P_1 and P_2 adjustments if necessary. There should be no noticeable ripple on a two inch pattern, and 40 db of suppression is readily obtainable. It is important, when making these adjustments, that no sideband is favored.

Do not be concerned if P_2 is not in the center. This might be caused by a difference in the gain of the transistors. However, too much unbalance is undesirable, and an attempt should be made to match the transistors more closely.

Batteries The battery consists of eight flashlight cells connected together and then suitably insulated from the metal compartment. This compartment is located at the right rear corner of the cabinet. The space around the batteries is filled with corrugated cardboard to prevent them from moving about.

Amplifier An amplifier has been built in breadboard fashion. It performs very well and develops more than 10 watts input with a B supply of only 250 volts. Thought has been given to building the amplifier into the battery compartment along with a transistor power supply. This would be ideal for mobile work where an external battery is already available. It does present some difficulties concerning controls on the front panel. No doubt each constructor will have his own ideas on this.

Gain Control In order to keep the number of controls to a minimum, no gain control was incorporated. This has disadvantages, and a miniature potentiometer could be built in. The 10K resistor

in the collector of Q_2 may be a potentiometer, with the moving arm connected to the base of Q_3 through the 8 μfd. capacitor. In lieu of this, gain can be adjusted by detuning the grid circuit of the amplifier.

5.6 A Transistor Filter Exciter

The exciter shown in Fig. 5.6-A is presented for those who prefer the filter system of s.s.b. generation. Many of the comments made on the phasing rig just described also apply to this unit. The exciter develops approximately the same power as the phasing rig and can be used to drive the 6BQ5 final shown in Fig. 5.5-E.

How It Works   The modulation section is similar to the phasing exciter but uses only two transistors. The audio amplifier consists of a common collector stage with additional feedback to raise the input impedance to a high figure. The stage is designed to be driven by a crystal or ceramic microphone. The second stage is a conventional common-emitter amplifier feeding a step-down transformer.

Transistor TR_1 is a conventional crystal-controlled oscillator which supplies the carrier. The r.f. voltage across the secondary winding of T_1 should be at least one volt. Different transistors or matching transformers may require readjustment of the value of capacitance connected between the base of TR_1 and ground.

The balanced modulator circuit is a conventional half-lattice. As in the phasing circuit, the diodes should be matched for forward resistance. The 1 K potentiometer balances out the carrier by electrically balancing the bridge. In actuality only a resistive balance is obtained, and some carrier will remain unless an attempt is also made to obtain a capacitive balance. This is the purpose of the capacitor connected between
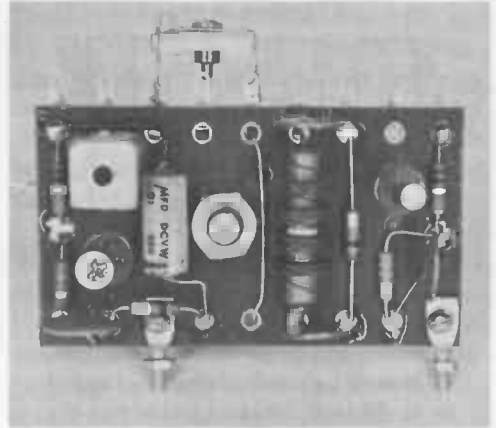
The carrier oscillator, balanced modulator and grounded-base amplifier board (left to right). The potentiometer is the carrier balance control. The trimmer capacitor at the top of the board also aids in balancing out the carrier.

one side of the balanced modulator circuit and ground. With other transformers the value may have to be changed or even connected to the other side of the bridge.

The amplifier following the balanced modulator is connected as a common-base stage in order to raise the output impedance. A high output impedance is required to prevent severe loading of the i.f. transformer, which would result in a poorly loaded Q. The filter circuit has been described in Chapter Four in conjunction with the transistor communications receiver. It should be pointed out that as the surplus crystals have aged, many of them have changed frequency over the years. It may be necessary to select carrier crystals to match the filter. Carrier crystals should be chosen to operate about 20 db down the filter slope.

The output of the filter feeds an ordinary i.f. amplifier which, in turn, drives a mixer stage. Note that the mixer, without v.f.o. injection, has no bias. Bias is obtained by rectification of the v.f.o. signal. Correct

Figure 5.6-A

SCHEMATIC DIAGRAM FOR THE FILTER EXCITER

The v.f.o. is shown in section 5.8.

Parts list - Figure 5.6-A

D₁, D₂ - 1N34, OA85 or similar.

L₁ - 30 turns #30 enamel on 1/4" form. Link 4 turns hook up wire. Miller 20A000RB1.

T₁, T₂ - Miller 2041 455 kc. i.f. transformer. 10,000 ohms to 600 ohms.

TR₁ = .6 MA.
TR₂ = .8 MA.
TR₃ = 1 MA.
TR₄ = 1.7 MA.

VOLTAGES ARE UNDER FULL CARRIER CONDITIONS.

collector current, as shown in the chart, indicates proper v.f.o. drive.

The output of the mixer also contains the v.f.o. signal, and the tuned circuits following this stage should be of high Q.

Construction Hints   The construction technique is similar to that used in the Phasing Exciter. This subject has been covered in the preceding section. The accompanying photographs show the layout of the terminal boards. The photograph of the completed exciter was not satisfactory for reproduction. Unfortunately, this was not discovered until after the unit had been dismantled. In constructing the exciter, none of the circuits were found to be critical. The layout, using the terminal strip technique, can be fabricated to suit the builder.

Alignment   Connect a VTVM to one side of the carrier balance potentiometer and adjust T_1 for an indication of r.f. output. The slug in T_1 should be set so that the drive is approximately the same for both crystals. The oscillator should start immediately upon the application of power. If the activity of the crystals is dissimilar, it may not be possible to obtain equal drive. Next, balance out the carrier by alternately adjusting the 1K potentiometer and associated 3-30 $\mu\mu$fd. capacitor.

**THE I.F. AMPLIFIER
AND MIXER BOARD**

A complete carrier null should be obtained. Unbalance the carrier slightly and adjust the filter circuit as described in section 4.13, using the carrier rather than a received signal as the signal generator. Peak the secondary of transformer T_2 and the output coil L_1 to the center of the operating frequencies.

The circuitry of the v.f.o. is not shown but is described in section 5.8. The v.f.o. can be mounted on the same chassis as the exciter or fed to the exciter through a link as shown.

To test the exciter, connect a microphone to the input or apply a suitable audio tone.

If the diodes are not properly balanced, the carrier may be reinserted with changes in audio or drive levels. Imbalance is caused by the differing currents flowing through the diodes with changes in operating conditions. Since the unequal diode resistance causes a different voltage drop across each, it unbalances the bridge.

5.7   40 Meter SSB Transceiver

The authors are indebted to Mr. Jo Emmet Jennings, W6EI, for the design and construction information presented below.

The audio board takes up very little
room under the chassis.
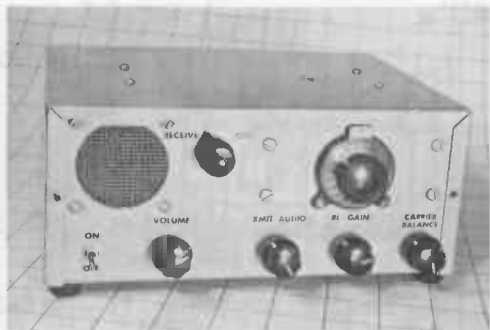
This neat little 40-meter transceiver package was designed and built by Jo Emmet Jennings, W6EI.

The transistorized transceiver is basically made from components which are readily available from the International Crystal Company. Some modifications are necessary, and these are covered in the following paragraphs and photographs.

The Audio The microphone pre-amplifier contains an emitter follower driving a common-emitter stage. The emitter follower is necessary to create a high input impedance, thus allowing the use of a ceramic microphone. A variety of transistors, other than those shown, will perform well in this circuit.

On TRANSMIT, the output of the microphone pre-amplifier is connected to the input of an unmodified International TRA-2 sub-assembly. This assembly acts as a modulator in the TRANSMIT condition and as an amplifier to the speaker in the RECEIVE condition. Audio is more than ample to drive the balanced modulators. The balanced modulators are conventional and differ little from those used with tube circuitry. Output from the balanced modulator combining coil is fed to the input of a modified TRB-1 board.
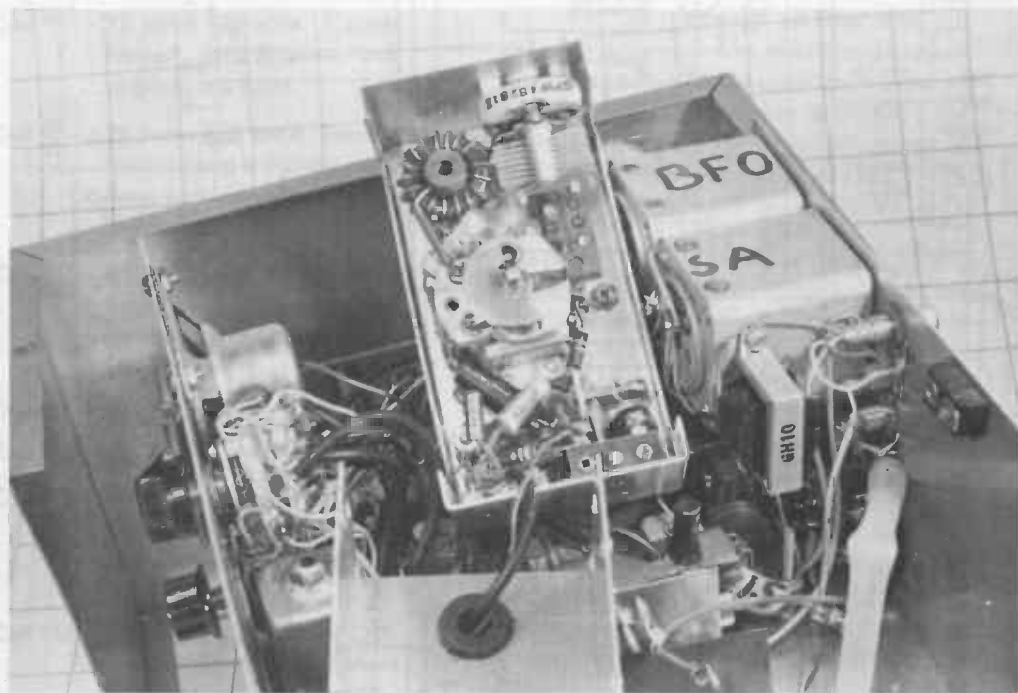
VIEW OF THE V.F.O.

Note how the components are made firm by keeping the wires short and making use of tie points.
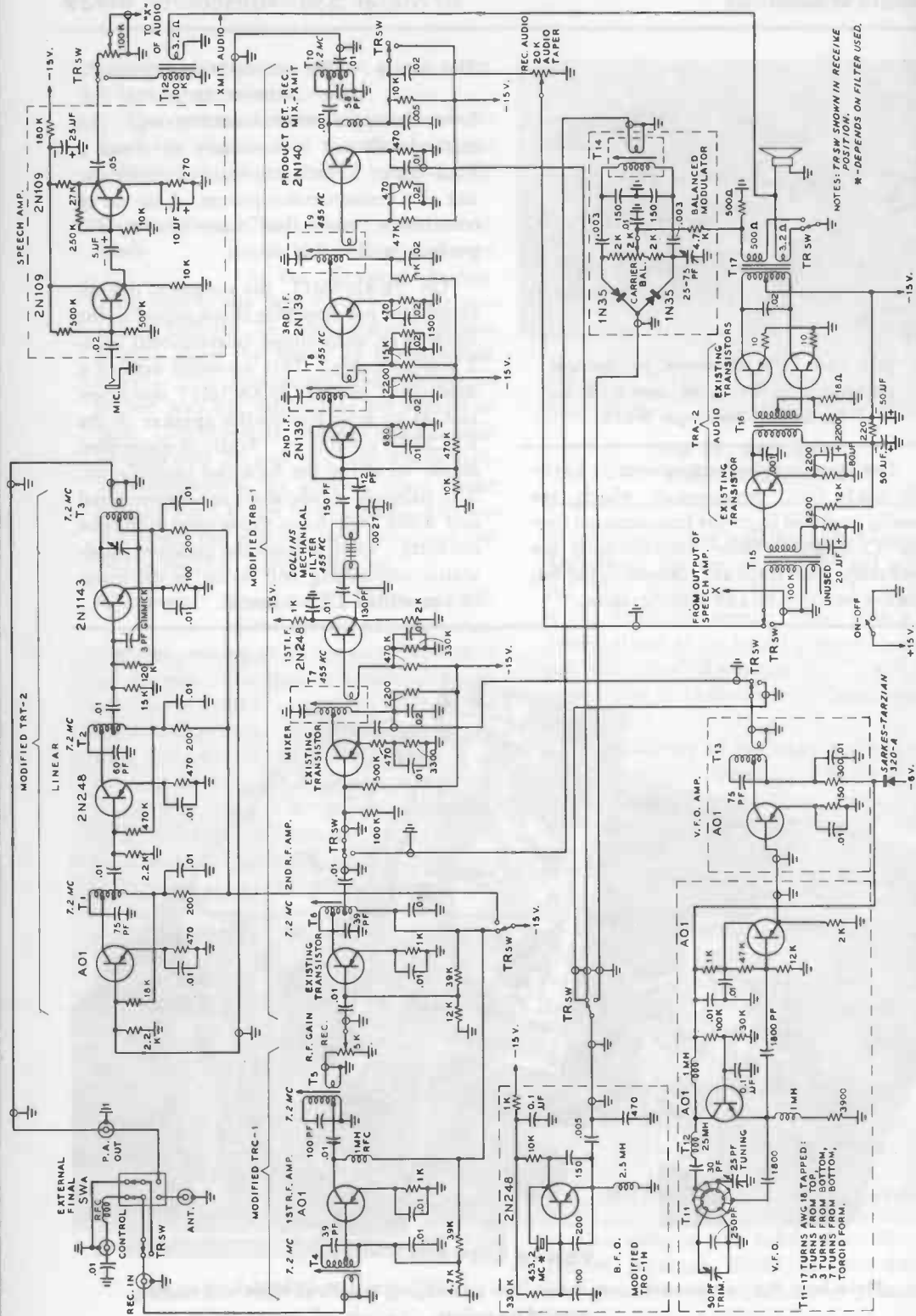
Figure 5.7-A

SCHEMATIC DIAGRAM FOR THE COMPLETE 40 METER S.S.B. TRANSCEIVER

Parts List - Figure 5.7-A

Coil #1 - 30 turns #26 wire. Tap 5 turns from bottom. Coil is wound on original form which is taken from the International unit.

Coil #2 - 29 turns #26. Tap 4 turns from bottom.

Coil #3 - 29 turns #20. Center tapped. Wound on original coil form. The capacitor used to tune the antenna on the International board is now used to tune this coil. As seen, there is a two turn link.

Coil #4 - 35 turns #30 wire. Tap 5 turns from bottom. Link 3 turns. Use original coil form.

Coil #5 - 22 turns #28 wire. Center tapped. Link 4 turns. Use original coil form.

Coil #6 - 25 turns #28 wire. Tapped 6 turns from top and 4 turns from bottom. Use original coil form.

Coil #10 - 25 turns #28 wire. Tap 4 turns from bottom. Center tapped. Use original oscillator coil form.

Coil #11 - See schematic.

Coil #12 - 25 microhenry r.f. choke.

Coil #13 - 25 turns #28 wire. Center tapped. Link 4 turns. 3/8" slug tuned form mounted in i.f. can.

Coil #14 - Miniature transistor i.f. transformer. 15,000 ohms to 600 ohms. The capacitor inside the can is removed.

TRANSMIT/RECEIVE switch - Miniature ceramic wafer. DP8T.

The TRB-1 Modifications to the board are as follows. Remove the squelch amplifier from the board. In its place build the product detector. On TRANSMIT, the product detector functions as a mixer to 40 meters. Next, remove the first and last i.f. transistors and replace them with those indicated on the schematic. The original transistors have the base internally connected to the transistor case, which, in the higher gain unit, is undesirable. The second r.f. collector coil is now rewound to resonate at 40 meters, and the second i.f. transistor is removed. The transistor socket is used to connect the leads of a small sub-assembly containing the transistors and the Collins Mechanical Filter into the circuit. The oscillator portion of the board is now removed, and the unused section of the board cut off.

The TRC-1 This board is modified by removing all but one r.f. stage. If desired, a new board may be built containing just the one amplifier shown on the schematic. The latter is perhaps the better course, because the modifications to the TRC-1 are somewhat drastic. The TRC-1 board is used on RECEIVE only.

The TRO-1H, BFO The b.f.o. board is not altered electrically except for the addition of some decoupling components and a change of value of the output capacitor. The additions and changes are clearly shown on the schematic. The exact frequency of the cyrstal will be dependent upon the type of mechanical filter used. Note that in the TRANSMIT condition, the b.f.o. is the carrier generator. Its output is connected to the diode balanced modulator. In the RECEIVE condition, the output of the b.f.o. is connected to the emitter of the product detector.

The V.F.O. The v.f.o. is the familiar Colpitts oscillator followed by an isolation stage and an amplifier. The oscillator tank coil is wound on a toroid

The TRA-2 board is shown at the left. The other boards may be seen at the left of the chassis.
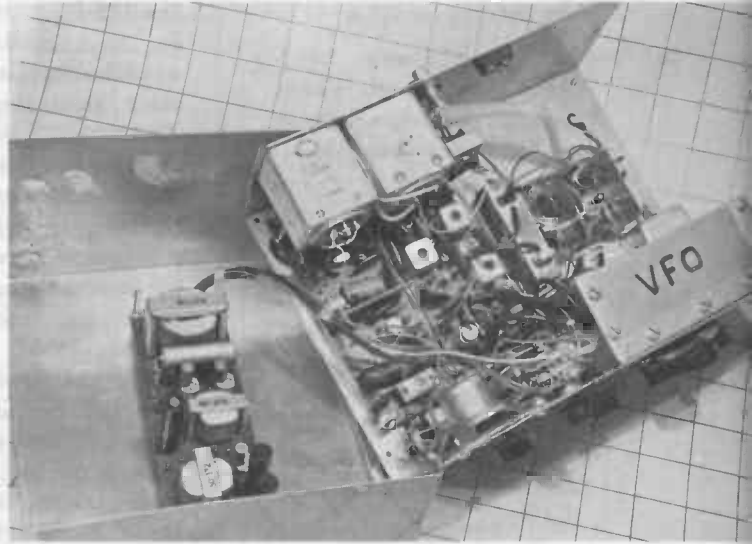
form. This results in a reduced physical size and a smaller electric field, allowing the v.f.o. unit to be housed in a small container. The v.f.o. is operated from a 6-volt tap on the battery. A silicon diode is inserted in the battery lead to prevent the flow of current when the transceiver is turned off. A separate switch, ganged to the main on/off switch, may replace the diode.

V.f.o. construction is clearly shown in the photograph. Other layouts and containers may be used if due regard is paid to stability requirements. Mount all components firmly by short stiff wires. However, be careful to avoid stress on the component parts due to over-tight wires.

During the TRANSMIT condition, the output from the v.f.o. amplifier is connected to the emitter of the product detector which now functions as a mixer. Output from the mixer is connected to the input of a modified TRT-2 board.

The TRT-2 Linear Amplifier Board   Several modifications are required on this board. The modifications may be made in the following order:

a) Remove the crystal socket and cut off that end of the board.
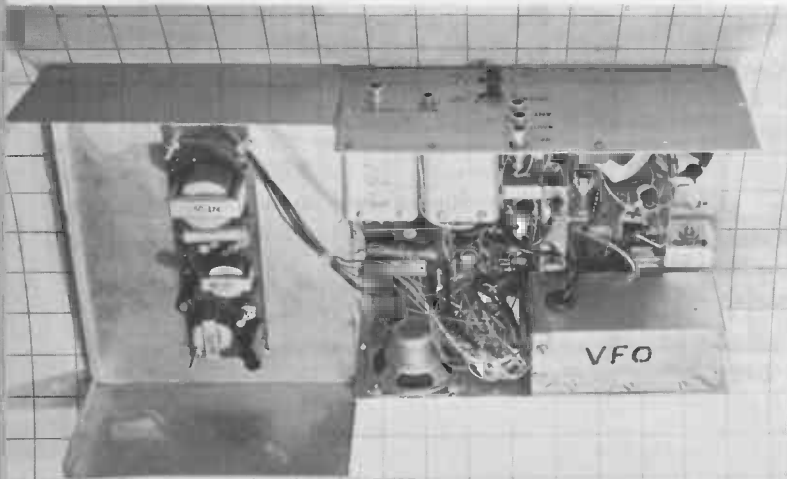
Another view showing the placement of the various boards.

b) Change the first transistor to an AO1 (Philco) and the second to a 2N248.

c) Remove the coils and replace with 40 meter coils wound according to the data provided.

d) Add forward bias resistors to the three stages to operate the transistors class A. The resistor values are shown on the schematic.

Note that the last stage is neutralized to prevent oscillation. The output coil should be wound exactly as specified so that neutralization is accomplished without the need for coil or component alteration.

Alignment   Alignment is most readily accomplished if a signal generator is available. In lieu of this, the v.f.o. and b.f.o. may be set on frequency by listening to their respective outputs in a receiver tuned to the required frequencies. In any case, a receiver should be available and tuned to the output of the transceiver. Coils, i.f.'s, etc., may then be peaked for maximum S meter reading. The length of the antenna on the external receiver should be adjusted to prevent overloading and false meter readings.

Output from the transceiver, when the stages are aligned for maximum signal, is approximately 1/2 watt - sufficient to drive a 6BQ5 or similar tube linear.

5.8 A VFO for AM, CW, or SSB

The v.f.o. to be described was engineered to have better than average stability and linear dial reading. As it so happens, the requirement for a linear reading dial is that there be very high fixed C in the oscillator tuned circuit, preferably as much as 4 times fixed to variable. This is also a condition of high electrical stability in a v.f.o. High C circuits are necessary to swamp out variations of capacitance in the transistor itself.
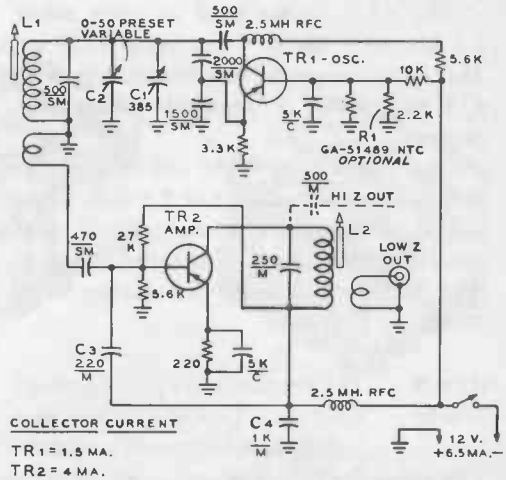
Figure 5.8-A
DIAGRAM OF THE V.F.O.
Note that several volts of r.f. can be obtained by using the high impedance output.

Parts List - Figure 5.8

C_1 - 385 $\mu\mu$fd. variable. Semi-circular plates and ceramic insulation. End plates should be slotted for alignment adjustments. Broadcast type capacitor.

C_2 - National APC-50.

L_1 - 9 turns #22 enamel on 3/8" diameter ceramic form. Miller, catalog #4400. Wind link of 1 turn of hook up wire over cold end of L_1.

L_2 - 28 turns #30 enamel on 1/4" form. Miller 20 A000RB1 or similar. Link 4 turns hook up wire over cold end.

TR_1 - 2N384, 2N371, OC169, 2N1745

TR_2 - 2N371. Other transistors may be used if the neutralizing capacitor C_3 is suitably adjusted.

R_1 - Negative temperature Resistor. Approximately 4,000 ohms. (Thermistor) GA-51489 or similar.

Resistors marked 1 watt may be carbon or wire wound.

The v.f.o. is designed to cover either 3.5 Mc. to 4 Mc. or 3950 kc. to 4450 kc. The latter range is suitable for use with 455 kc. crystal or mechanical filter SSB exciters.

The r.f. voltage at the collector of the output stage is in excess of 2.5 volts when loaded, which is sufficient to drive most small pentode tubes. The output is more than sufficient to drive the average s.s.b. exciter.

How It Works The oscillator is a parallel-tuned Colpitts. This is followed by a lightly coupled tuned amplifier. The amplifier is neutralized to prevent variations in output loading from being reflected back to the oscillator. The values of C_3 and C_4 should not be changed from those shown on the schematic diagram.

The Capacitors The tuning capacitor *must* be of the straight line capacitance variety (semicircular plates) if a linear dial reading is to be obtained. The capacitor may be a standard broadcast unit and should have ceramic insulation, if possible, and slotted end plates. In the prototype model, a two gang capacitor was used only because it happened to be in the junk box. One section was left unconnect-

ed. Remove any mica trimmers which are part of the capacitor.

All fixed capacitors in the tuned circuit *must* be silver mica. The trimmer capacitor C_2 is a ceramic unit such as the National APC-50.

Construction Hints The construction of the v.f.o. *must* be mechanically sound. The best electrically designed v.f.o. in the world is only as good as the mechanical construction which goes into it. Avoid stresses and strains on components, particularly the coil, the variable capacitors, and the dial mechanism. If the dial mechanism does not line up with the capacitor shaft, it will be necessary to keep one hand on the tuning knob at all times in order to stay on frequency. Construction may take almost any form as long as it is sturdy. If the v.f.o. can be dropped from a height of three inches without the frequency of oscillation moving more than a few cycles, the v.f.o. is mechanically stable. Naturally, the unit is mounted in its cabinet for this test. Tie points, when they support components "hot" to r.f., should be of ceramic or similar material.

At first, no attempt was made to stabilize the oscillator against thermal variations, but it was found that the frequency shift was considerable when a change in room tem-
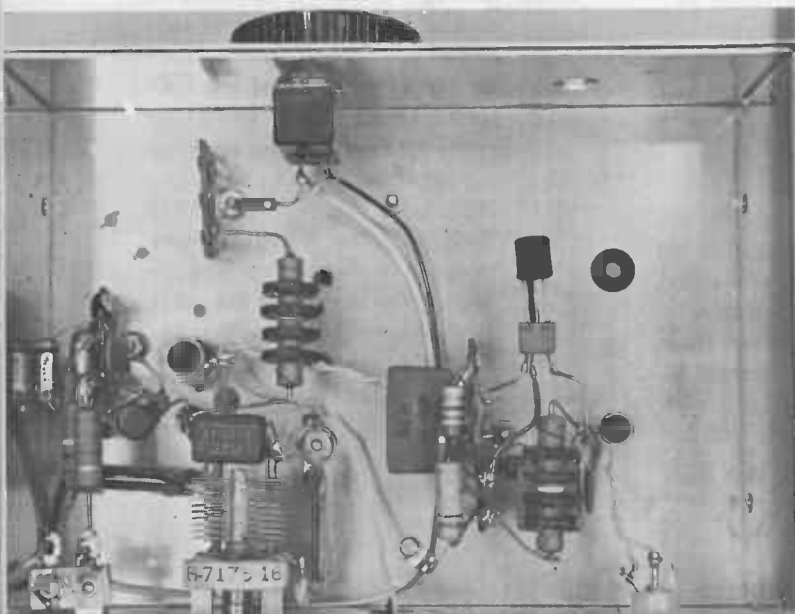
UNDERSIDE VIEW OF THE V.F.O. The oscillator is at the left and the amplifier at the right.
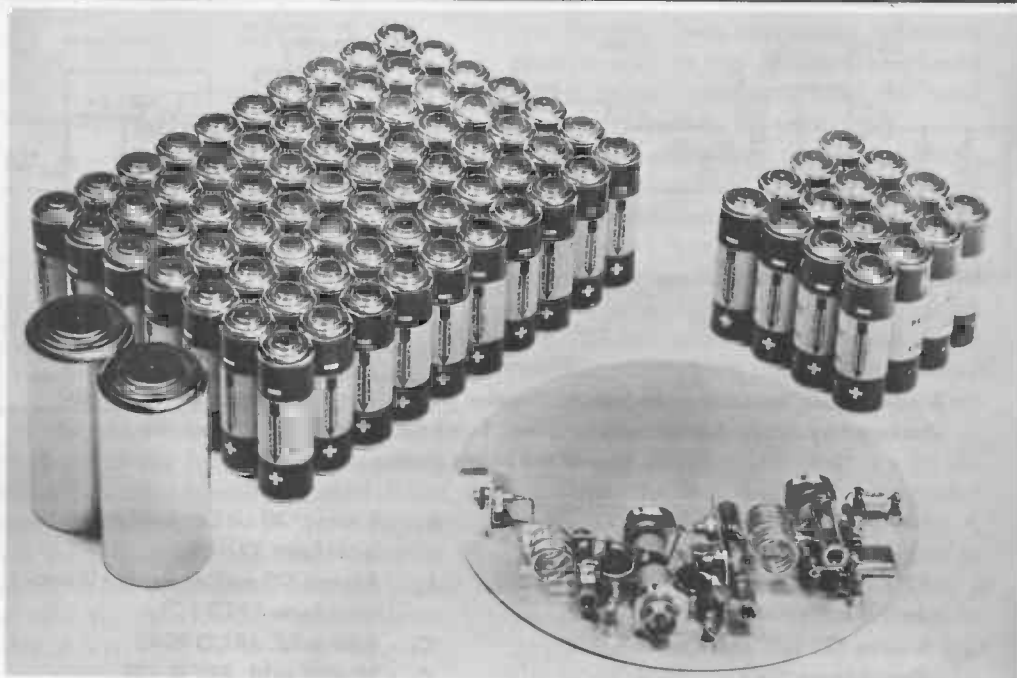
The tiny transmitter in the foreground is intended for satellite service and uses the mercury batteries shown at the right. An equivalent tube transmitter would use the batteries at the left. (Courtesy of DuKane)

perature took place. Most of the movement was traced to the coil. Frequency movement due to the transistor itself was very small. After a little experimentation, a negative temperature co-efficient resistor (thermistor) was added to the base circuit of TR_1. This component reduces the frequency movement to negligible proportions for all but excessive variations. It is recommended that the oscillator be totally enclosed so that the temperature changes take some time to soak through to the components. In this circuit, the NTC resistor actually overcorrects the transistor, and by doing so takes into account the movement of the coil and other components.

Voltage Stabilization A reduction in supply voltage from 12 to 8 volts moves the frequency of the oscillator by 800 cycles. If the v.f.o. is to be used in mobile work the supply should be stabilized with a zener diode. The stabilized supply should be fed to the oscillator *and* the amplifier. For normal fixed station work, no stabilization is necessary.

Alignment To obtain a linear dial reading, the slug of L_1 should be adjusted for the low end of the band and the preset trimmer set for the high end. One adjustment will affect the other, and the builder must work back and forth between the two. If a 100 kc. crystal calibrator is available, align the low end to the 3.6 Mc. check point and the high end to the 3.9 Mc. check point. If there are variations at the intermediate check points, these may be corrected by bending the slotted vanes of C_1. On the prototype model seen in the photograph, v.f.o. dial readings are accurate to within 1 kc. except at the very high end of the range, where the minimum capacitance of the capacitor is too high. Only the last 30 kc. are affected in this manner. All other readings, right down to 3.5 Mc., are exact.
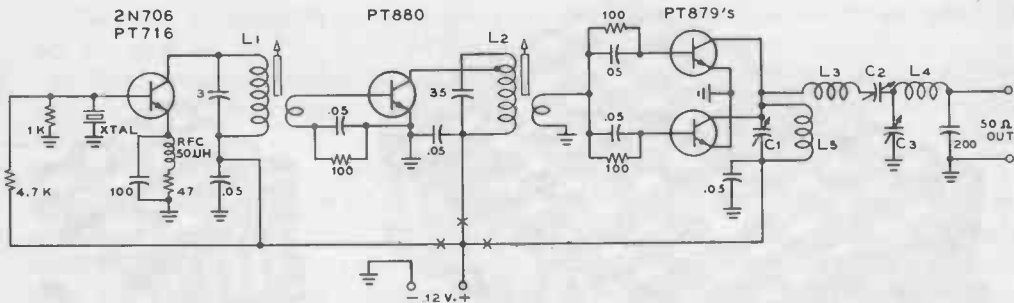
Figure 5.9-A

A completely transistorized 6-watt 10-meter transmitter uses silicon devices manufactured by Pacific Semiconductors, Inc. To modulate the circuit, break the 12-volt line at the points shown.

Parts List - Figure 5.9-A

L_1 - 12 turns #22 1/4" form. Secondary 4 turns #26.

L_2 - 9 turns #22 1/4" form. Secondary 3 turns #26.

L_3 - 7 turns #20 on Cambridge Thermionic form 227-14.

L_4 - 5 turns #20 on Cambridge Thermionic form 227-14.

L_5 - 4 turns #20 on Cambridge Thermionic form SPC2-J-2L.

C_1 - 8-60 $\mu\mu$fd. ARCO 404.

C_2 - 90-400 $\mu\mu$fd. ARCO 429.

C_3 - 90-400 $\mu\mu$fd. ARCO 429.

Xtal - 3rd overtone.

5.9 A 3-Watt C.B. or 10-Meter Transmitter

For some time, Pacific Semiconductors, Inc. have had available a line of silicon transistors which have made possible an inexpensive transmitter capable of delivering 3 watts of r.f. to the antenna. With the values shown in the schematic of Fig. 5.9A, the transmitter is capable of operating over both the Citizen and the 10-meter ham bands.

The Circuit   The oscillator is a PT716 operating as a Colpitts. The overtone crystal is in the feedback path. Following the oscillator is a PT880 buffer amplifier. The stage is not provided with fixed bias but depends instead upon rectification of the signal to develop a self bias. Operation is in the region between class B and class C and is a function of drive.

Similarly, the two paralleled PT879's depend upon the developed bias to establish the operating point. The use of separate bias resistors tends to compensate for unequal transistor gains and prevents either one of the transistors from doing most of the work.

The Output Network   The output circuit consists of a tuned r.f. choke (low Q resonant circuit), followed by a double L network. The network has been designed to present a specific load to the transistors and at the same time prevent harmonics from reaching the antenna. Due to the low impedances involved, this portion of the circuit is perhaps more complex than would be required of tube transmitters. However, the circuits tune broadly and merely need peaking for maximum output.

Input to the final is approximately 6 watts and efficiency is about 50%.
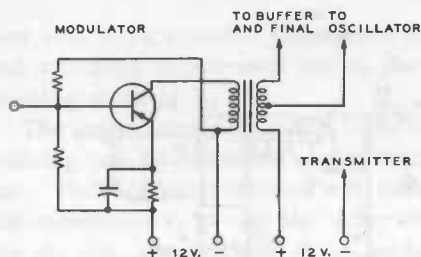
Figure 5.9-B
All three stages must be modulated to reach the 100% level, as shown here.

If the transmitter is to be modulated, The modulation transformer secondary should be center tapped and modulation applied simultaneously to the oscillator from the tapped winding. Both the buffer and the final are modulated from the top of the winding. The connections are shown in Fig. 5.9-B.

5.10 A Two Meter Transmitter

It is hard to believe that low cost receiving type transistors can develop sufficient power on two meters to light a pilot lamp, but this is exactly the case with the circuit shown in Fig. 5.10-A. This can only be accomplished by careful construction. Thought must be given to layout and

lead lengths.   Each component and circuit must operate at top efficiency to prevent circuit losses from destroying the small power generated by the transistors.

Selecting transistors of low cost with a high alpha cutoff and low collector capacitance also proved to be a problem. The RCA 2N384 type transistor proved to be an excellent oscillator and multiplier, but did not provide sufficient power output as a 144 Mc. amplifier. The final amplifier transistor which provided the greatest power output in this application was selected from the available types.

Three transistors are used in a 72 Mc. oscillator, doubler, and power amplifier configuration as shown in Fig. 5.10-A. The oscillator, a 2N384, is connected in the common-base circuit and employs a 5th overtone crystal, which oscillates on 72.02 Mc. Feedback for the emitter circuit is taken from a low impedance tap on the coil in series with the crystal. A neutralizing coil L_1 insures oscillation at the crystal fifth overtone. The oscillator output coil L_2 feeds 72 Mc. energy to the doubler through a modified pi-network.

The highest doubler power output is obtained when the stage is operated between class B and C. The 2N384 doubler stage operates without bias, and positive-going r.f. cycles initiate conduction.

UNDERSIDE   VIEW OF THE TWO METER TRANSMITTER
Note the spacing and coupling of coil L_4. The adjustment is rather critical.
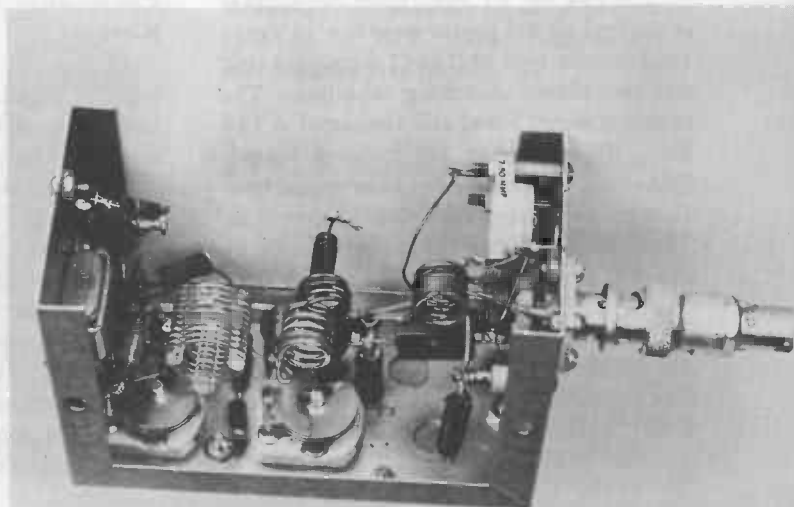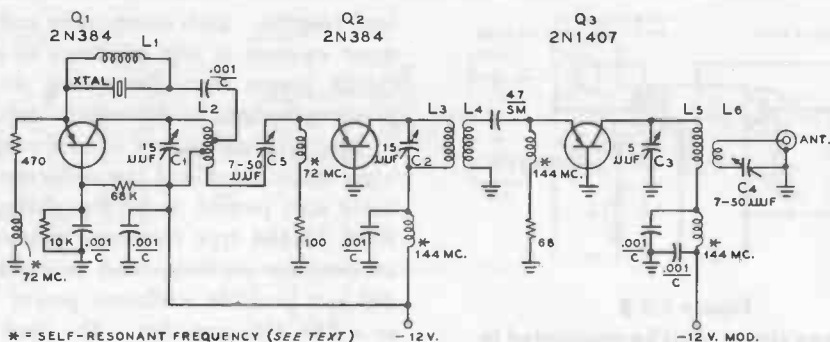
Figure 5.10-A

SCHEMATIC FOR THE TWO METER TRANSMITTER

Note that only the final stage is modulated. Some improvement may be obtained by also modulating the doubler.

Parts List

C_1, C_2 - 15 $\mu\mu$fd. variable (Hammarlund MAPC 15)

C_3 - 5 $\mu\mu$fd. variable (E.F. Johnson 5M11)

C_4, C_5 - 7-50 $\mu\mu$fd. rotary ceramic (Centralab)

L_1 - 21 turns, #28 enamel, closewound on 3/16" form (1 meg., 1 watt resistor)

L_2 - 10 turns, #22, 5/8" diameter, 8 turns per inch, xtal tap 7 turns from bottom, B- tap 5 turns from bottom (AirDux #508)

L_3 - 5 turns, #14, 3/8" diameter

L_4 - 4 turns, #16, 3/8" diameter. Adjust coupling and spacing for max. drive.

L_5 - 5 turns, #14, 3/8" diameter

L_6 - 4 turns #24 enamel, interwound in L_5. Cement to L_5 when correct coupling is obtained.

Q_1, Q_2 - 2N384 (RCA)

Q_3 - 2N1407 (Texas Instruments)

Xtal- 72.02 Mc., 5th overtone (International Crystal Mfg. Company)

The 144 Mc. r.f. drive from the doubler is applied to the power amplifier (a Texas Instruments type 2N1407) through a link and impedance matching capacitor. The circuit is series tuned and resonated at 144 Mc. This stage is not forward biased. Therefore, positive r.f. cycles cause conduction, producing near class C operation. The output of this stage appears across L_5 which is also resonated at 144 Mc. A resonated link coil L_6 couples r.f. energy to the antenna. The series capacitor tunes out the reactance of the link and serves as a loading control. R.f. chokes, self resonant at the operating frequency, are used for isolation in all circuits.

Construction Hints There are no particular problems in constructing the two meter transmitter, but the buider is cautioned to keep all leads extremely short. The photographs show one of several layouts used by the authors. Although not especially attractive the component crowding permits short lead lengths. The 2N384 transistors were mounted in clips drilled from an old fuse holder. The crystal, oscillator transistor, and bias components are mounted on the rear apron. The 15 $\mu\mu$fd. tuning capacitors, the doubler transistor, and coils are mounted on the top of the chassis box. The power amplifier transistor (mounted in a

heat sink clip), capacitor C_3, antenna jack, and matching components are on the remaining apron of the box.

The only critical component is the neutralizing coil L_1 connected across the crystal. This coil must resonate with the crystal capacitance at 78 - 80 Mc. After winding the coil, clip the leads short, solder it across the crystal pins and check the resonant frequency. Add or subtract turns as required to tune 78 - 80 Mc.

The r.f. chokes are made by winding 20-30 turns of very fine wire on a one megohm, one watt carbon resistor. Check and adjust the resonant frequency to either 72 or 144 Mc. by adding or subtracting turns. The exact frequency is not critical.

Testing　A grid dip meter is mandatory when working with high frequency circuits. First, apply 12 volts to the oscillator only, and check for operation with the dipper switched to the absorption wavemeter mode. Check the second harmonic on a receiver to insure that the signal is crystal controlled. Next, connect a milliameter in series with the doubler supply lead and peak the oscillator capacitor C_1 for maximum collector current. Connect the supply lead for Q_2 directly to the 12 volt line, and connect the milliameter in
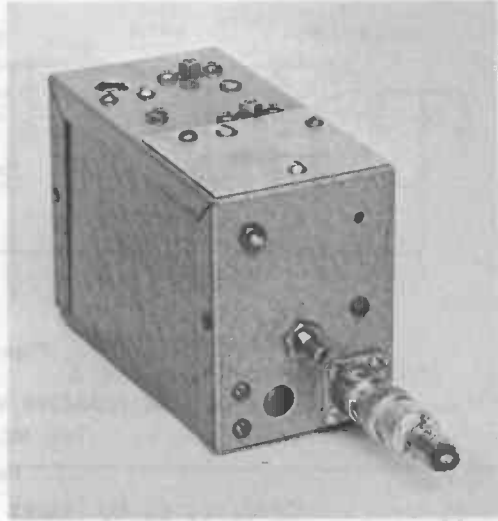
A COMPLETELY TRANSISTORIZED TWO-METER TRANSMITTER
This transmitter will supply sufficient power to illuminate the #49 pilot lamp.

series with the final supply lead. Peak the doubler tuning for maximum final current.

Finally, observe the output with a grid dip meter, field strength meter or receiver S meter. Repeak all adjustments for maximum r.f. output. The circuit values have been selected so that excessive dissipation in any stage cannot occur. The final stage will draw about 10 ma. when fully loaded. It should be possible to see a noticeable glow in the #49 pilot lamp used as a dummy load (see photo).

5.11 A Potpourri of Circuits

Although the authors feel that amateurs should know how to design their own circuits, this is not always feasible. Engineers working in plants manufacturing transistor equipment are no different from amateurs. Everyone borrows circuits for projects when it will save time and get the job done.

This section presents a group of interesting and useful circuits which have been
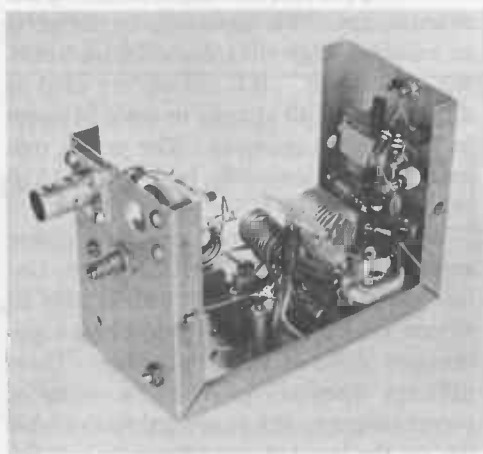
VIEW SHOWING THE OSCILLATOR COIL L_2
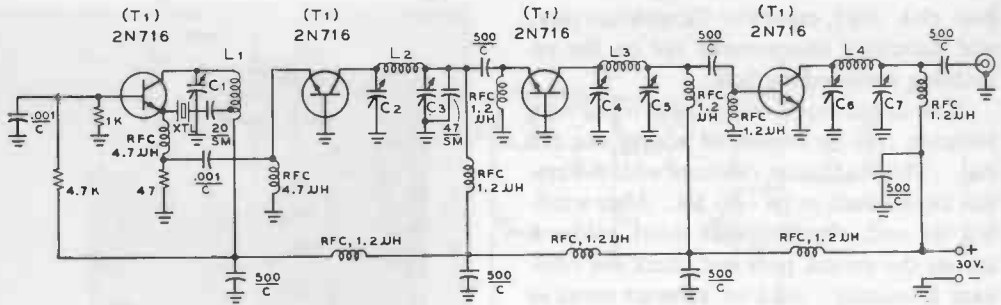
Figure 5.11-A

CIRCUIT FOR THE QUARTER WATT TRANSMITTER DESIGNED FOR 140 Mc. OPERATION

Parts List

C_1, C_2, C_3, C_4, C_6 - 1.8-13 $\mu\mu$fd. trimmer

C_5 - 7-45 rotary ceramic trimmer

C_7 - 3.2-50 $\mu\mu$fd. tuning capacitor

L_1 - 8 turns of #408 AirDux, tapped 2 turns from ground end.

L_2 - 4 turns of #12 enamel, 1/2" diameter, 3/4" long.

L_3 - 3 turns of #12 enamel, 1/2" diameter, 7/16" long.

L_4 - 4 turns of #12 enamel, 1/2" diameter, 3/8" long.

Xtal - 72 Mc., 5th overtone type (International Crystals Mfg. Co.)

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extracted from company application notes and instruction books. With minor adaptations (in some cases) they are all useful in amateur applications. Although the circuits have not been tried by the authors, they do not appear to present any construction or alignment problems.

VHF Circuits   Fig. 5.11-A shows the circuit for a 140 Mc. transmitter which can be returned to 144 Mc. with no coil or tuning capacitor modifications. The circuit was designed by Texas Instruments.

The oscillator, a T_1 type 2N716, is a 5th overtone circuit on 70 Mc. In-phase feedback occurs between a tap on the output coil and the emitter through the crystal. It is interesting to note that 70 Mc. drive for the doubler is taken from the low impedance emitter in the oscillator circuit. The doubler, another T_1 2N716, operates in the grounded-base configuration, and its output network consists of a pi section feeding a 2N716 common-base amplifier. The final stage, a 2N716 common-emitter power amplifier, drives the antenna through a pi network. Note the liberal use of r.f. chokes to prevent unwanted coupling between stages. This appears to be the secret in building high efficiency v.h.f. transmitting equipment. R.f. chokes are used as d.c. returns in all circuits to avoid EI losses in decoupling resistors. The power output of this transmitter is 1/4 watt (250 milliwatts) at 140 Mc.

Fig. 5.11-B is a common-base power amplifier for the 100 - 200 Mc. range. Unlike the preceding circuit whiich uses all silicon devices, this circuit employs a germanium diffused v.h.f. transistor. Three different types are given for a variety of power outputs. R.f. is applied to a suitable tap on the input circuit (depending on the drive impedance) and is coupled to Q_1 through a capacitive voltage divider. This
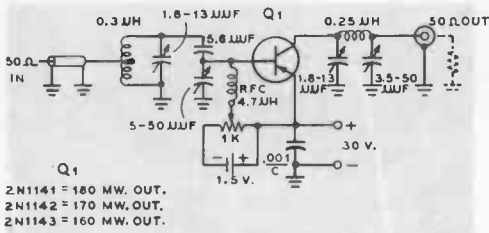
Figure 5.11-B
POWER AMPLIFIER
This power amplifier uses low cost germanium transistors.

CRYSTAL OVERTONE OSCILLATOR CIRCUIT
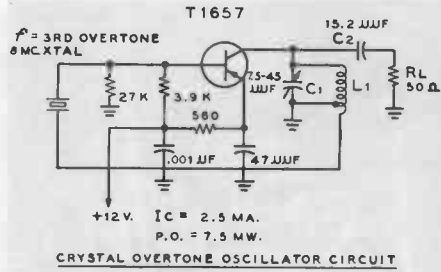
Figure 5.11-D
A THIRD OVERTONE OSCILLATOR
Can be used in conjunction with war surplus 8 Mc. crystals.

serves to impedance match the base of the transistor to the tuned circuit. The operating point of the transistor can be adjusted with the 1 K potentiometer, which varies the base bias. The output circuit, which matches the collector to the antenna, is a pi network. It is particularly important to note that the d.c. return for the amplifier is through the load. The circuit should not be operated without the load connected, as excessive base bias, due to self rectification, may develop.

The new Motorola epitaxial mesa family, types 2N1141 through 1143 and 2N1195, make excellent power amplifiers in the two meter band. The circuit shown in Fig. 5.11-C will deliver 1/4 watt to a load at 160 Mc. and should develop slightly more at 144 Mc. At this level, the power input is 560 milliwatts (14 volts at 40 ma.) for an

180 MC. POWER AMPLIFIER

Figure 5.11-C

QUARTER WATT OUTPUT
POWER AMPLIFIER
Amplifier uses new epitaxial mesa device.

overall efficiency of 45%. The power gain is 10 db at 160 Mc., indicating that a drive level of 25 milliwatts would be required, neglecting circuit losses. The input circuit consists of a capacitive divider similar to Fig. 5.11-B. However, base bias is provided by self rectification of the r.f. current flowing through R_b. The trimmer capacitor in the emitter circuit series resonates the emitter inductance, providing a true ground. The r.f. choke simply provides a d.c. return. The output circuit is the familiar pi network to match a variety of antenna impedances. The collector is shunt fed for d.c. through an r.f. choke.

Amateurs who prefer not to use 72 Mc. fifth overtone crystals will be interested in a circuit described in *Philco Application Lab Report 646*. This report describes a circuit for operating 8 Mc. crystals on their third overtone. The circuit (Fig. 5.11-D) employs a Philco type T1657 transistor, which is believed to have been replaced by the JEDEC type 2N1866. The output tank, consisting of L_1 and C_1, is tuned to the third overtone of the crystal, or approximately 24 Mc. One and one-half turns of coil L_1 provides a degree of regenerative feedback for the crystal, since it is not cut for overtone operation. Capacitor C_2 matches the transistor collector to the load impedance. Coil L_1 consists of 12 turns of #3003 B & W "Miniductor" tapped at

SILICON   GALLIUM ARSENIDE

Figure 5.11-E

Tunnel diode characteristic curves for silicon and gallium arsenide. (Courtesy of
General Electric)

1 1/2 turns for feedback. Since the value
specified for C_2 is not readily available, a
3-30 trimmer could be used. Capacitors
C_1 and C_2 would be adjusted alternately
for maximum power output, which is given
as 7.5 milliwatts. The overall efficiency of
the oscillator is approximately 28%. The
drive from this circuit could be applied to
a suitable tripler-doubler circuit for output
on 144 Mc.

The   When a semiconductor diode is
Tunnel   forward biased, it does not be-
Diode   have in the same manner as a
               good conductor (such as a piece
of copper wire). In a wire, one electron
will "bump" the next one, which in turn
"bumps" the next, and so on. This move-
ment is conducted down the wire even
though the individual electrons may have
moved only a short distance. In a semi-
conductor, current flow takes place due to
an exchange of electrons from one orbit to
another, which slows down the action ap-
preciably.

The tunnel diode exploits the first meth-
od of conduction. The electrons move so
fast that they seem to actually "tunnel"

TUNNEL DIODES
These tunnel diodes are currently
available to experimenters. The Gen-
eral Electric 1N2939 (front) and the
RCA TD100 (rear) are compared to a
common straight pin to illustrate their
compact size.
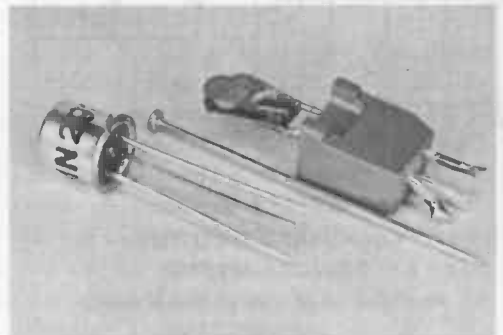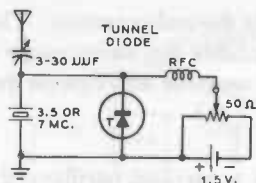
Figure 5.11-F
TUNNEL DIODE TRANSMITTER
This transmitter can be used on 80
and 40 meters.

through the potential barrier of the diode.
See Chapter One. The effect is conduction
similar to that which takes place in a wire.
The quantum mechanical tunneling was
first discovered by a Japanese scientist
named L. Esaki . The tunnel diode is often
referred to as the Esaki diode.

The important feature of the tunnel diode
is its negative resistance quality. Unlike a
pure resistance, current in the tunnel diode
can decrease with increasing applied vol-
tages. Characteristic curves of voltage ver-
sus current for two different types of diodes
are shown in Fig. 5.11-E. The breakup of
the negative resistance slope is probably
caused by parasitic oscillation in the test
jig. This is one of the tunnel diode's
characteristics and it is difficult to prevent
them from oscillating!

A simple tunnel diode transmitter for
the 80 or 40 meter bands is shown in
Fig. 5.11-F and the accompanying photo-
graphs. The only parts required are the
tunnel diode, a crystal for either band, an
r.f. choke (2.5 mh.), and a potentiometer.

A solar operated 80 meter c.w. trans-
mitter. The solar cell, in the fore-
ground, is an International Rectifier
SD-1020-A.

The transmitter can be powered by either
a 1.5-volt penlite cell or a single solar cell
as shown in the accompanying photograph.

The tunnel diode requires less than one-
half volt and draws less than 5 ma. of cur-
rent. Obviously, it is not capable of gener-
ating much power, at least in its present
form. However, Lester A. Earnshaw, when
operating from ZL1AAX in Warkworth,
New Zealand, was able to contact Jack King
ZL1AOF, in Whakatane, N.Z., a distance
of 160 miles. His RST 339 signals were
later confirmed with a QSL and tape re-
cording.

TUNNEL DIODE
TRANSMITTER
This transmitter was
used by ZL1AAX to
contact stations 160
miles distant.

GW-30 (right view)

THE HEATH GW-30

May be easily converted to 10-meter operation by replacing the crystal and retuning the receiver and transmitter coils. (Courtesy of Heath)

A Ten Meter Phone Transmitter   The current crop of Citizen's Band equipment has resulted in numerous walkie-talkie and handie-talkie devices. These units may be easily converted to 10 meters by replacing the transmitter crystal with a third overtone type for the desired operating frequency. If the receiver is crystal controlled, this crystal should be replaced with a third overtone type which is displaced from the operating frequency by the i.f. value. The r.f. tuned circuits will have to be repeaked for best performance.

A 30 milliwatt 10-meter phone transmitter, which uses inexpensive transistors, was described in *Philco Lab Report #610*. The circuit is given in Fig. 5.11-G. Philco MADT (Micro Alloy Diffused) transistors are used in the r.f. section and alloy junc-

tion types in the audio section. The transmitter is suitable for short range civilian defense and amateur activities on the 10-meter band.

A crystal controlled oscillator drives an unneutralized r.f. amplifier, which delivers power to the 50-ohm load. Transistor TR_3 provides a high impedance input for a crystal microphone, while TR_4 serves as an audio driver for the modulator transistor TR_5. The modulator is a series type which does not use a matching transformer.

The transmitter should be tuned for c.w. conditions. Point A of the emitter resistor in the final amplifier is first connected to the battery. Adjust C_1 in the oscillator for maximum drive to the final, using the current meter as an indicator. Next, tune C_2 for minimum final collector current, while adjusting C_3 for desired loading. The collector current should be 5.5 to 6.0 ma. This tuning procedure does not necessarily deliver the maximum output to the load but has been found to be satisfactory. A better method would be to use a sensitive field strength meter located near the antenna. The power input for c.w. is approximately 72 milliwatts, and the measured power output is 52 milliwatts.

For phone operation, point A of the final is tied to A , the collector of the modulator. Bias resistor R is adjusted to a value which causes the collector current to drop to one-half the c.w. value at about 3 ma. This results in about 32 milliwatts input to the final r.f. stage. The modulation envelope appears clean at full modulation (about 85%), and on-the-air reports indicate a good quality phone signal. Care must be exercised not to remove the antenna from the final with the transmitter on!

Although the transistor specified is an early type, the T1657, it is believed that the JEDEC type 2N1866 makes an excellent replacement and may provide even more power output.
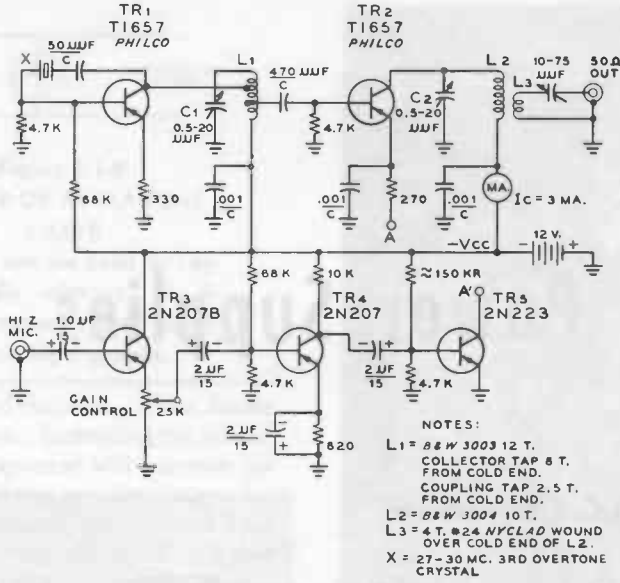
Figure 5.11-G

THIRTY MILLIWATT 10-METER PHONE TRANSMITTER

The transmitter uses low cost germanium transistors.

Power Supplies

6.1 A.C. to D.C. Conversion

If transistorized equipment is used in a location where alternating current is available, there is no advantage in using batteries when an inexpensive power supply may be easily constructed.

A simple transistor power supply is shown in fig. 6.1-A and is suitable for experimenter applications. The regulation of the supply is ample for most needs and only high power audio amplifiers and modulators will require a larger power supply. When connected to the transistor communications receiver described in Chapter 4, the output voltage does not change more than 0.4 volts, even when the receiver is operated at maximum audio output.

A SIMPLE POWER SUPPLY FOR TRANSISTOR EXPERIMENTS

Even without regulation the stability of the output voltage is excellent.
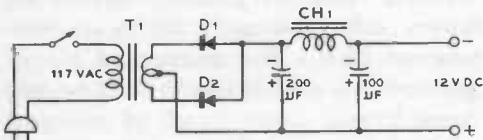
Figure 6.1-A
A SIMPLE POWER SUPPLY FOR TRANSISTOR WORK

The transformer and choke are described in the text. The diodes may be RCA 1N1764 or any similar 500 ma. units.

The transformer, T_1, used in the supply is a discarded 12-volt vibrator transformer. However, a commercial unit such as the Triad F-92A which is capable of supplying approximately 16 volts at more than 500 ma. will be suitable.

How It Works The circuit is a full-wave bridge rectifier which utilized both halves of the a.c. cycle. The rectified d.c., which is pulsating at 120 cycles per second, requires filtering to provide pure d.c. The filter, which consists of the input and out-
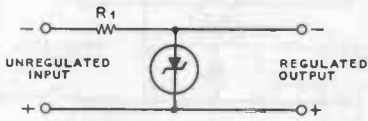
Figure 6.1-B
**THE ZENER OR AVALANCHE
DIODE**
This diode can be used to regulate specific voltages. The diodes are manufactured in different voltage groups.

put capacitors and the filter choke, forms a single pi-network. Increasing the size of the input filter capacitor will increase the output voltage and improve regulation. Increasing the capacitance of the output filter capacitor will decrease the ripple and also improve the regulation.

Construction Any form of construction and layout is practical and no special precautions need be observed. The choke may be constructed by winding a small 3-watt audio-output transformer core full of #24 enamel wire. The wire may be layer or jumble wound on a home-made bobbin. Once the core is stripped it should take only 10 minutes or so to wind the wire and re-insert the core.

BURGESS BATTERIES
The battery is still a convenient power supply for transistor experimenters. These Burgess units are sealed rechargeable nickel cadmium type
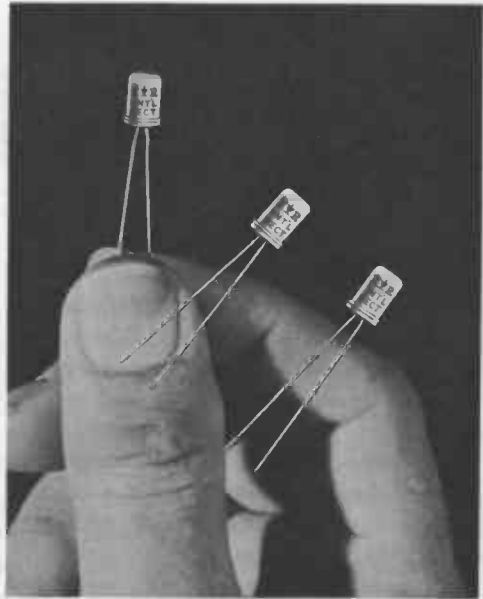
**MINIATURE SILICON
ZENER VOLTAGE
REFERENCE ELEMENTS**
(Courtesy of International Rectifier
Corporation)

When wiring the supply, do not connect either the positive or negative lead to the chassis. The two circuits should be independent of the chassis, as shown in fig. 6.1-A. This prevents transformer leakage from damaging transistor equipment. In addition, a short from the power supply chassis to the equipment being tested could damage the supply if this precaution is not observed. It is advisable to insert a 1/2 ampere fuse in series with the secondary winding to protect the power supply in the event of an external short circuit.

Voltage One of the simplest devices
Regulation for regulating a varying source of d.c. is the zener diode. A property of the zener diode is that when the voltage across its terminals exceeds a certain level, the zener diode conducts. The result is a regulated output voltage much the same as that accomplished

with a gaseous voltage regulator tube, although the mechanism for accomplishing regulation is quite different. Note that the diode is connected in the reverse direction (Fig. 6.1-B). At the breakdown potential (analagous to ionization in the voltage regulator tube) the current carriers avalanche and the diode assumes a relatively low resistance.

The circuit for a simple zener diode regulator is shown in fig. 6.1-B. The resistor, R_1, prevents excessive current flow through the diode when the load is removed.

A transistor can also be used to regulate a power supply as shown in fig. 6.1-C. As the output voltage is decreased with increasing loads, the transistor bias increases. This causes the collector-emitter resistance to decrease. More voltage is then permitted to develop across the load. Thus the output voltage will be regulated at approximately the battery potential.

A heavy duty supply using a small battery for stabilization is shown in fig. 6.1-D. This circuit, described in a *Motorola* application bulletin, uses inexpensive *Motorola* 2N554 transistors. The supply delivers continuously variable voltage at currents up to 4 ameres. As in fig. 6.1-C, the output voltage is determined by the stabiliza-
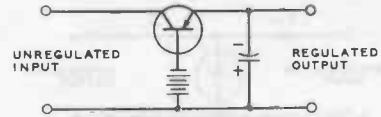
Figure 6.1-C
A battery can also be used to establish a specific bias voltage for a transistor regulator.

tion battery voltage, which acts as a reference for the transistor regulators. The a.c. ripple on the output d.c. will vary between 4 and 28 millivolts as a function of load voltage and current.

This type of regulator is commonly referred to as an emitter-follower wherein Q_3 and Q_4 serve as variable resistances in series with the load. The terminal impedance of the regulator is less than one ohm. A regulation curve for the supply is also shown in Fig. 6.1-D.

The series-regulator transistors should be mounted on a large aluminum heat sink as they dissipate up to 60 watts with the control set for low voltages. The control transistors, Q_1 and Q_2, may also require heat sinking as they each dissipate approximately 1 watt.

Note that when regulation is employed less elaborate filtering circuits are required. A simple explanation is that the ripple ap-
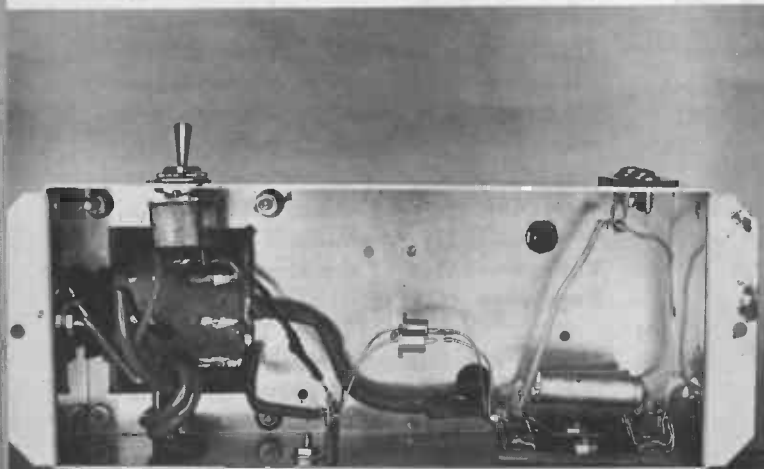
**UNDERSIDE VIEW
OF THE
POWER SUPPLY**
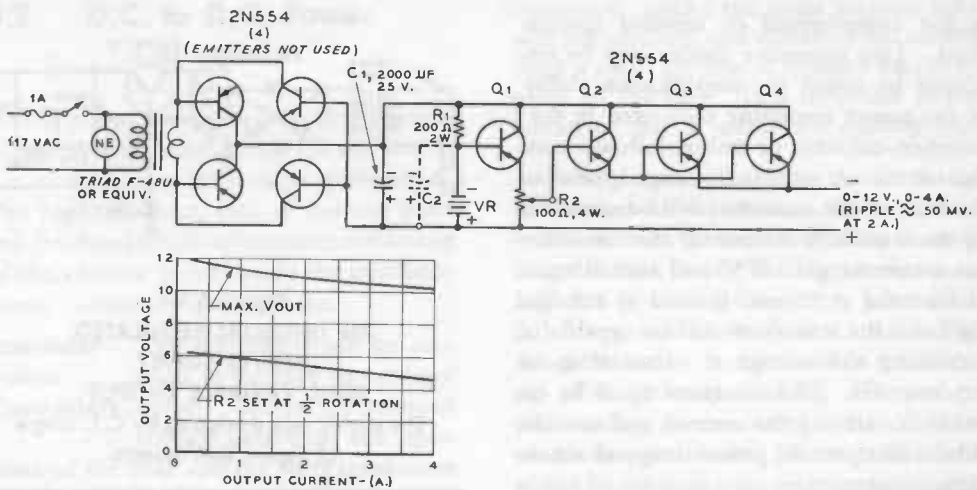
Figure 6.1-D
A HEAVY DUTY POWER SUPPLY
A heavy duty power supply using a battery stabilized emitter follower which
drives two parallel connected series control transistors.

pears as a varying load voltage which is counteracted to a large extent by the regulator.

A zener diode may replace the battery in the circuits described above. The action of the zener diode is the same as in the simple regulator in Fig. 6.1-B. That is, it establishes a fixed potential across its terminals. Thus, it functions as a battery, but does not require periodic replacement.

A Regulated When the load on a recti-
Power fier-type 12-volt supply is
Supply varied, a change in the out-
put voltage is to be expected.
If the load variation is sever, as when a class-B amplifier is connected to the supply, the voltage may fall as much as 50%.

The schematic of fig. 6.1-E shows an inexpensive regulated supply which will provide excellent regulation over a wide range of currents to 1 amp. Even greater currents may be supplied by cascading regulator stages, as outlined later.

The transformer furnishes approximately 24 volts to the rectifier. The rectifier must be capable of carrying the peak load

current, and its peak inverse voltage should be at least 75 volts. Due to the capacitive load, the voltage is higher than that normally encountered in this type of circuit.

Resistor R_1 is used to limit the peak currents to a safe figure. When the supply is first switched on the sudden surge of current into the 2,000 μfd. capacitor may reach many amperes without R_1. The current is limited by the resistance in the circuit, which is composed of the d.c. resistance of the transformer and the resistor R_1. Without knowing all the circuit component values it is difficult to state a definite value for R_1. However, the specified value of 1/2 ohm will give adequate protection for most applications. Resistor R_1 will also provide protection against accidental short circuits at the output of the supply.

A regulated output is available at point A in fig. 6.1-E. In a great number of applications the current available at this point may be sufficient. This is especially true if the zener diode D_1 is capable of passing large currents. However, large zener diodes are somewhat expensive, particular-

ly for experimental or amateur applications. Less expensive diodes may be employed by using the amplification ability of the power transistor connected in the common-collector or emitter-follower configuration. A regulated voltage applied to the base of the transistor will be amplified by the transistor action. If the transistor has a current gain of 50 and a small zener diode rated at 50 ma. is used to stabilize the base, the transistor will be capable of stabilizing the voltage at currents up to 2.5 amperes. The transistor must be capable of carrying the current and must be able to dissipate the power dropped across the transistor.

A 1,000 ohm load resistor is used to maintain a small but constant load at the output terminals.

If further control is required the output of the transistor may be connected to the base of a second emitter follower. The control will then be amplified by the cur-
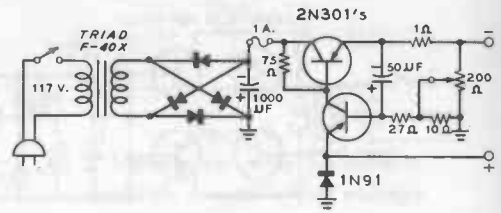
Figure 6.1-F
AN UNUSUAL REGULATED
POWER SUPPLY
WITH VARIABLE OUTPUT
The circuit was designed by C.T. Gage
of Sigma Instruments.

rent gain of the second transistor. Also shown in fig. 6.1-E is a two-stage regulator made by adding a 2N1381 transistor to the circuit. This simple modification results in a constant output voltage from no load to a full load of 2 amperes.

An unusual circuit for an adjustable regulated supply is illustrated in fig. 6.1-F. It may be constructed by using two inexpensive RCA 2N301 power transistors and a 1N91 diode in addition to the semiconductor rectifiers. The supply features 0-25 volts output at up to 500 ma. The output impedance varies between 0.5 and -2 ohms as a function of output voltage and load. The output ripple is less than 100 millivolts peak-to-peak over the entire voltage and current range.

The circuit is conventional except for the use of negative current feedback in the positive lead. The output current passes through the 1N91 regulator. Thus, increasing load currents lowers the bias of Q_2 due to increased voltage drop across the diode. This action increases the forward bias applied to Q_1, lowering its resistance and maintaining the load voltage constant. The regulation linearity is a function of diode characteristics and a number of units must be tried to obtain best regulation.

(AMPLIFIED REGULATOR MODIFICATION)
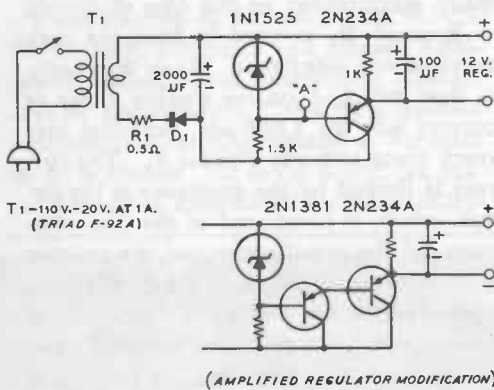
Figure 6.1-E
A SIMPLE REGULATED
POWER SUPPLY
The series current-passing transistor is stabilized by a zener diode. The diode is made by International Rectifier Corp. The transistor is a Bendix 2N-234A. Also shown is a simple modification to increase regulation with high current loads.

6.2 D.C. to D.C. Power Conversion

The power transistor is finding increased use as a replacement for the vibrator in d.c. to d.c. power conversion applications. The high efficiency, lack of moving parts and freedom from interference due to arcing of the vibrator points make the transistor power converter a useful device.

Transistor Power Converters The discussion will be confined to the PNP power transistor. Except for reversed voltage polarities, the operation of the PNP and the NPN transistors are identical.

In power-converter service operation the transistor is nothing more than an electronic switch. The collector-to-emitter resistance is controlled by the influence of the base. When the collector is negative with respect to the emitter, and the base is zero or positive, the junction resistance will be high. The collector-emitter junction will remain a high resistance until the base is made more negative than the emitter. With sufficient negative bias applied to the base, the collector-emitter junction will saturate and exhibit a very low resistance. It should be stressed that a PNP transistor, unlike the usual vacuum tube, will not conduct, and therefore not amplify until a small amount of negative bias is applied to the base. In a transistor power converter this is called the starting bias.

It can be seen that if two transistors are substituted for the vibrator, the only problem is to turn them on and off by controlling the base bias. The circuit shown in Fig. 6.2-B accomplishes this job and is called a power multivibrator. As in Fig. 6.2-A the battery is connected to the center-tap of the primary winding. The ends of this winding are connected to the collectors of the two transistors. The circuit is completed by returning the emitters to the positive battery lead. A few turns are added to the transformer to provide a source of feedback voltage to sustain oscillation. In addition, a voltage divider consisting of two resistors is connected across the battery. This provides the starting bias so that the transistors will conduct initially. These resistors play an important part in the operation of the supply and are explained in detail under the heading, "How to Set the Starting Bias".

When the battery is connected to the circuit the transistor with the lower junction resistance will conduct first. For the

A MINIATURE TRANSISTOR POWER CONVERTER This converter is suitable for receivers and QRP transmitter applications. (Courtesy of Mini-Verters, Los Altos, Calif.)
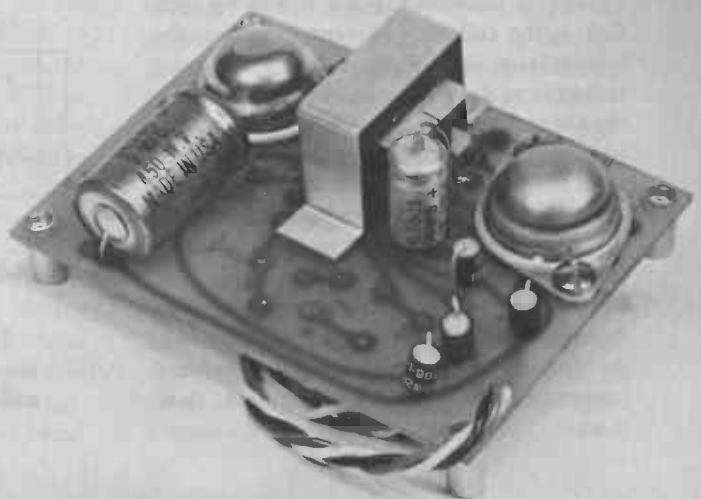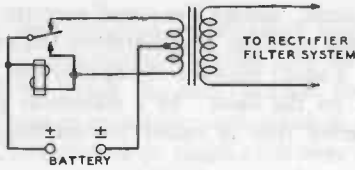
Figure 6.2-A
TYPICAL VIBRATOR
ALTERNATOR CIRCUIT
Note that electromagnetic action switches the contact back and forth connecting the ends of the primary alternately to the battery.

purpose of explanation, assume that the upper transistor, Q_1, is the first to conduct. Current flows from the negative battery terminal through the upper half of the

winding, then through the transistor collector-emitter winding and back to the positive battery terminal. The lines of force emanating from this half of the primary induce a voltage in all the other windings, including the other half of the primary. The base impedance of the transistor is much lower than the collector impedance. Thus, the base winding requires fewer turns than the collector winding to provide the necessary step-down ratio. The base winding leads must be connected so that the polarity of the voltage to the base of Q_1 will be negative-going when the collector voltage is positive-going. It will be seen that as the collector current increases, the base voltage also increases. This forces the collector to draw even more current. When the current reaches a predetermined amplitude the transformer core will begin to saturate. This means the core will not magnetize further and the current fed back to the base from the winding will begin to fall. Thus the condition is reversed; the base voltage will decrease and as a consequence the collector current will decrease. At this point Q_1 is no longer in a heavy current condition and Q_2 begins to conduct.

Notice that during most of the heavy collector current condition of Q_1, the transistor was saturated and that over the same period Q_2 was cut off.

The cycle that has just been described will continue to repeat until the power source is turned off. Although many steps are involved, the whole process happens very quickly. The entire cycle usually takes place in about 1/400th to 1/2000th of a second.

In addition to inducing a voltage in the base winding, the lines of force generated by the collector current induce a voltage in the secondary that is a function of the primary-to-secondary turns ratio. It should be pointed out that when one transistor is conducting and the other is cut off the collector current of the conducting transistor will induce an equal voltage in the other half of the primary. Thus, the end-to-end voltage across the primary will be two times the supply voltage. This explains the term 2E=(E = supply voltage) that is found in transformer formulas. For example, if a supply is operating from 12 volts, and 144 volts are desired from the secondary, it is necessary to have six (not twelve) times the number of primary turns on the secondary.

The number of secondary turns may be adjusted to give the desired output voltage from the rectifier-filter system. The waveform applied to the rectifiers will be a near-
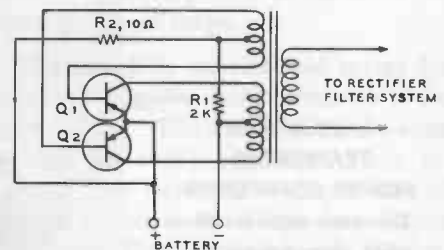
Figure 6.2-B
Transistor power converter
equivalent of the vibrator circuit. The transistors replace the moving contact.
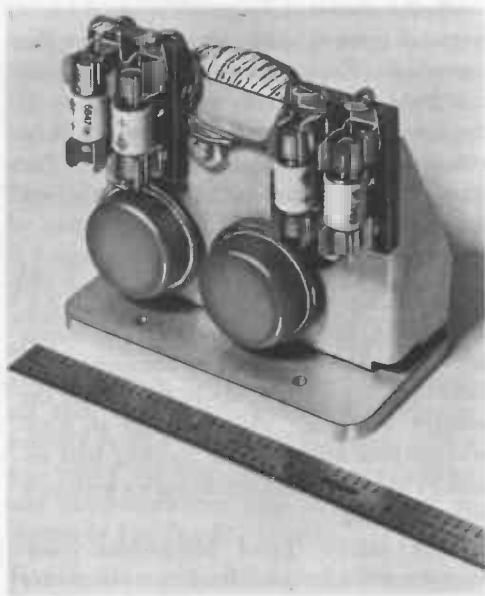
**A TYPICAL MOBILE
POWER CONVERTER
Made by Universal Transistor Products
Corp.**

ly perfect square wave because of the rapid switching action of the transistors. A simple full-wave or bridge rectifier will convert this signal to almost pure d.c. and very small filter capacitors may be used to remove the remaining "spikes".

Efficiency   The efficiency of a transistor power converter may be expressed as the ratio of power output to power input. Thus, for a given input, the higher the power output the more efficient the power supply. The losses always show up in the form of heat, and are referred to as IR losses.

When one of the switch transistors is cut off, it will have only a small IR loss because the junction resistance is so high that only a small current can flow. By the same token, when the transistor is saturated there will be little IR loss because there is only the small resistance of the junction. Thus the only time major IR losses occur

is when the transistor is switching from the on state to the off state, or vice versa. It should be obvious that the faster the switching action occurs, the more efficient is the supply. Since the efficiency figure is directly related to transistor heat, it can be assumed that the faster the switching time, the greater the power which can be handled by a given pair of transistors.

It can be shown that toroid tape wound cores using *Deltamax* or similar alloys produce the fastest switching times, and are used in the most efficient supplies. Certain powdered iron cores are only slightly less efficient than the tape wound style, but are far less expensive. Keep in mind that poor efficiency always means heating (usually in the transistors) which necessitates a reduction in the maximum power handling capabilities. The transistors always produce heat, and it is the junction temperature that determines the power handling ability of the transistors.

In effect, the transistor only works during the instant of switching and rests between these periods. It would be correct to assume that the transistor will handle more power than it would under conditions of continuous operation such as class A. In actual practice, it has been found that any transistor can safely switch from five to eight times its class A power rating. If the system for transferring heat is very efficient, this rule-of-thumb may be increased to ten times the class A power rating. Thus, a transistor that is rated at five watts may switch as much as 50 watts. Naturally, two transistors would be required for the power converter and they would be able to handle 100 watts of primary power.

Rectifiers   Vacuum tube rectifiers are very inefficient devices and are very rarely used in transistor power converters. Silicon rectifiers, by virtue of the fact that they have a fixed 0.6 volt internal drop and no filament are ideal for this application. Silicon rectifiers may be connected in series

SWITCHING   RECTIFIED   FILTERED

Ⓐ TYPICAL A.C. POWER
   SUPPLY WAVE FORMS

Ⓑ TYPICAL VIBRATOR
   WAVE FORMS

Ⓒ TYPICAL POWER CON-
   VERTER WAVE FORMS
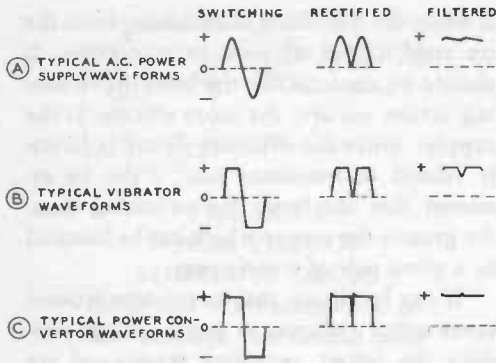
Figure 6.2-C
TYPICAL WAVEFORMS
Typical waveforms encountered in various power supplies.

to obtain a higher breakdown voltage, and balancing resistors are not needed. This application is explained more fully in the section devoted to rectifiers and filter systems.

Circuit   The circuit shown in Fig.
Variations   6.2-B is called a common-
                     emitter configuration. A variation of this circuit is the common-collector shown in Fig. 6.2-D. In this circuit the primary is connected between the emitters, and the collectors are connected together. For PNP transistors the common-collector connection must be returned to the negative battery lead.

The theory of operation is the same as the common-emitter circuit discussed earlier. However, this circuit has the advantage that the transistor case (which is the collector) may be bolted directly to the grounded chassis when the supply is used with a negative-ground automobile ignition system. This eliminates the need for insulation of the collectors, as in Fig. 6.2-B, and allows the most effieient transfer of heat to take place. In this configuration, the emitter impedance is lower than the base impedance, and the transformer must provide a step-up of approximately 1:1.25.

If the automobile power source has a negative ground, by all means use the common-collector configuration and bolt the transistors directly to the chassis. If the automobile has a positive ground, then either configuration may be used. The transistors will have to be insulated from the chassis in either case.

A typical circuit for the popular Triad toroid transformers is shown in Fig. 6.2-E. Note that the emitter-to-base impedance step-up is accomplished by connecting the individual base windings in series with the emitter winding. This provides an auto-transformer action. The starting bias resistors must be installed in series with each base winding.

The earlier Triad ferrite-core transformers were designed for common-emitter applications exclusively. However, these transformers, except the TY-69S, may be modified for use in common-collector circuits. Notice that the base winding consists of enameled leads with two paralleled

MINIATURE SILICON RECTIFIERS
These miniature silicon rectifiers are rated at 400 volts, 500 ma. and are ideal for power converter applications.
(Courtesy of International Rectifier Corporation)
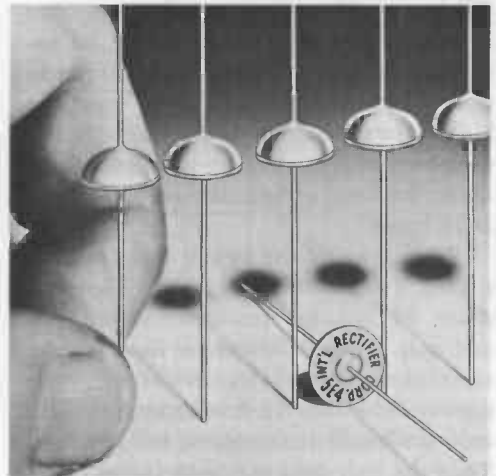
conductors. Although not shown on schematics, the base winding is actually connected as shown in Fig. 6.2-F. Separate the two outside leads (B_1 and B_2). With an ohmmeter establish the two windings and determine which one is center-tapped. Tape up the center tap as this lead will not be used. Connect an a.c. source (between 6.3 and 30 volts) to one half of the secondary, and experimentally connect the three windings as shown in Fig. 6.2-E. Connect an a.c. voltmeter across the full primary and alternately reverse the two base leads on each base winding until a maximum reading is obtained on the voltmeter. This procedure will phase correctly all windings and the transformer may be connected as shown in Fig. 6.2-E.

How to Set the Starting Bias Recall that the transistors will not conduct initially unless a small amount of forward bias is applied to the bases. In the common-emitter circuit the bias is connected to the center tap of the base or feedback winding. The voltage is obtained from a resistor voltage divider connected across the battery. These resistors are shown as R_1 and R_2 in Fig. 6.2-D.

If the transistors do not have enough bias, the supply will not start when connected to a heavy load. If too much bias
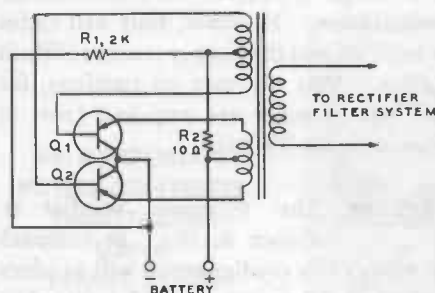
Figure 6.2-D
COMMON-COLLECTOR CONFIGURATION
Common-collector configuration for grounded negative automotive ignition systems.

is applied, the efficiency will be reduced. Excessive bias can also damage the transistors due to additional heat. More important, with excessive bias, the supply may not be self-protecting. When the supply is operating properly, a short or overload in the output circuit will absorb the feedback voltage and the supply will stop oscillating. The battery current will drop to a low value, thereby protecting the transistors from burn out. The bias should be set so that none of the transistor ratings can be exceeded.

You may want to substitute transistors or optimize designs. The bias may be set in this manner. First, short the output so that the supply will not oscillate. Then insert typical values, such as 2,000 ohms and 20 ohms, in the R_1 and R_2 positions. To a great extent, the larger resistor controls the static current (current drawn when the supply is not oscillating). The smaller of the two resistors controls the base current when the supply is oscillating. As a rough rule-of-thumb, the resistors should be selected so that the transistors draw their normal class A current when the supply is not oscillating. To show a typical example, consider the *Sylvania* 2N307. It is rated at two watts and a pair will handle four watts. To comply with our rule, the bias resistors must be set so that the transistors consume four watts of d.c. from the power source. Thus, for a 12-volt system, the transistors should draw approximately 333 ma. static current. Typical values for the two resistors, with these Sylvania transistors, might be 820 ohms and 10 ohms.

The next step in setting the bias is to remove the short and replace it with a resistor that represents the normal full load. Upon applying power, the converter should oscillate instantly and produce full power in the load. If it does not, try reducing the value of both resistors by half. Keep the value of these two resistors as high as possible, consistent with the conditions outlined earlier. If the larger value
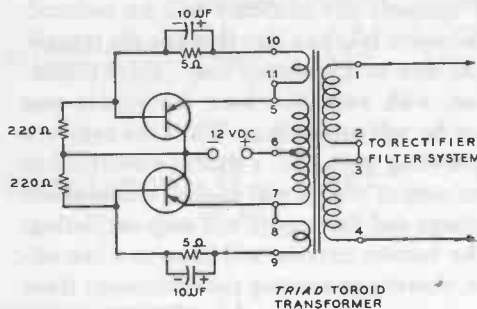
Figure 6.2-E
COMMON-COLLECTOR CIRCUIT
Common-collector circuit with auto-
transformer stepup.

resistor is reduced too far, excessive static
current will flow. If the lower half of the
divider is too small it is unable to limit
base current during signal peaks. Either
excess can damage the transistors.

If it is still not possible to obtain full
power, or easy starting, this indicates that
the transistors have very low Betas when
saturated. If this is the case, it will be nec-
essary to parallel additional transistors.

If the supply does not start easily, but
can be started by removing the smaller re-
sistor, a silicon power diode may be sub-
stituted for the smaller resistor. The cath-
ode of the diode will connect to the tap on
the base winding. In the common-collec-
tor circuit, the diode can be added in series
with, or in place of, the lower value base
resistor. See R_2 in Fig. 6.2-D. In oper-
ation, the diode will not conduct until the
supply has started. The forward resistance
should be about the same as the resistor it
replaced. If R_2 is normally many times the
forward resistance of the diode, it should
be connected in series with the diode.

There is another trick that can be used
to improve starting under load. If the sup-
ply refuses to start until the larger resistor
is reduced in value, try this remedy. Cal-
culate the value of the large resistor needed
to start the supply (even though it may
draw excessive static current). Then locate

a pilot lamp, or series of lamps, that meas-
ure about the same resistance. Substitute
the lamp, or series of lamps, for the large
value resistor as shown in Fig. 6.2-G. The
idea behind this scheme is that the cold re-
sistance of the bulb(s) will be low enough
to start the supply. But when it starts, the
current through the bulb(s) will increase
the filament resistance, thereby decreasing
the base current.

Rectifier Although most transformers
and are designed to work into a
Filter bridge rectifier system, you need
Systems not confine yourself to this cir-
cuit. Most power-converter
transformers will work equally well with
half-wave, full-wave, or voltage doubler
rectifiers.

As a practical example, let us assume
that you have purchased a *Triad* TY-79
transformer. In a bridge rectifier config-
uration, this transformer will develop 300
volts at 200 ma. Following are some of
the things that can be done with this trans-
former and a discussion of the advantages
and disadvantages of the various rectifier
systems shown in Fig. 6.2-H.

Half Wave With a half-wave rectifier sys-
tem (a), you will obtain the
same voltage and current as with the bridge
configuration. However, only half cycles
are rectified and the output is more difficult
to filter. You will save on rectifiers, for
only half as many are required (two in
series, with the Ty-79).

Full Wave The full-wave rectifier is
shown in (b). In compari-
son to (a) this configuration will produce
one-half the d.c. output (150 volts), but
twice as much current (400 ma.). The
amount of filtering required is the same as
for the bridge circuit. Only two rectifiers
are required, one in each leg. Small
amounts of negative bias (10 to 20 volts)
can be obtained by connecting a resistor in

series with the grounded secondary center-tap connection. This resistor must be by-passed with an electrolytic capacitor, 50 μfd., 50 w.v.d.c., positive end grounded.

Voltage Doubler   The voltage doubler circuit (c) is very popular as it reduces the total number of rectifiers needed for a given output voltage. If you use the voltage doubler with the TY-79, it will be possible to obtain twice the voltage (600 v.) at one-half the current (100 ma.). The filtering will not be as good as the bridge system, and it will be necessary to use capacitors that are four times as large as in the bridge and full-wave circuits. For short duty cycle applications, such as power for a s.s.b. or a gated final amplifier, you can use very large filter capacitors (80 μfd.) and obtain peak currents equal to the bridge system (200 ma.). A power converter suitable for use with a s.s.b. linear amplifier is shown later in the chapter.

The voltage doubler may also be put to good use when 12-volt power converter transformers are operated from a 6-volt power source. Approximately 90% of the normal out-put voltage will be obtained because the transistor losses will be higher when used on 6 volts.

Filter Systems   Normally only a minimum of filtering is required when compared with 60-cycle systems (10 μfd., or so) because of the high operating frequency and fast switching time of the transistor power converters. If high peak currents are drawn from the supply, it is advisable to install a large capacitor (80 μfd.) across the output as an energy storage device.

As a safety factor, the voltage rating of the filter capacitors should be at least 25% higher than the no-load output voltage. Higher-than-normal battery voltage could damage a capacitor with a marginal voltage rating. For output voltages in excess of 400 volts (no-load), two 450-volt electrolytic capacitors should be connected in series. The voltage across these capacitors can be equalized by shunting them with 100K ohm, 2-watt resistors. When using the bridge configuration, another method of equalization is to connect the secondary center-tap to the junction of the two filter capacitors. One-half voltage exists at this point and it will automatically equalize the capacitors.

In some applications it may be necessary to include r.f. chokes and disc ceramic capacitors in the B+ circuit. Harmonics, contained in the square wave, can reach the

AN INEXPENSIVE POWER CONVERTER TRANSFORMER USING FERRITE CORES
(Courtesy of Triad Transformer Corp.)
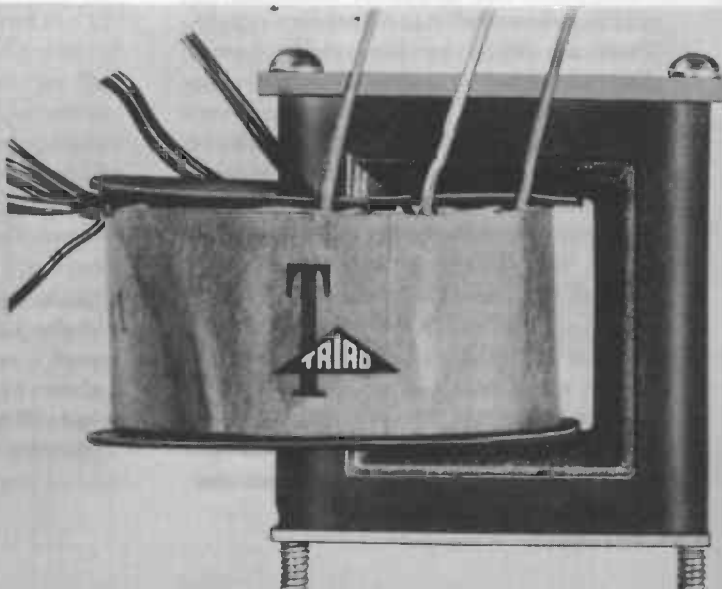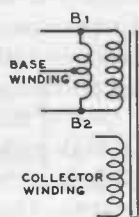
Figure 6.2-F
ACTUAL CONNECTIONS FOR EARLY TRIAD TRANSFORMERS
The modifications for common-collector autotransformer connection are described in the text.

r.f. circuits and cause beat notes or "birdies" on received stations. A 2.5 mh. choke in series with the B+ lead and bypassed to ground at each end with 0.001 μfd. disc ceramic capacitors will eliminate this possible source of trouble.

Selecting Components There are many combinations of components that may be used in conjunction with commercial power-converter transformers. The transistors and rectifiers used in this chapter are not necessarily recommended. They only demonstrate that these, or similar parts, may be used. You may want to use your favorite type of transistor, or those in your parts stock. Here are some of the things you should know when substituting transistors or rectifiers.

Transistors There are three important things to consider when selecting the switch transistors for a supply. These are power handling ability, breakdown voltage (V_{ce}), and saturation resistance.

The primary power flows through the transistor junction and it must be capable of handling the current and dissipating the heat generated in the process. As explained earlier, transistors can be used that were originally intended for class A or class B audio applications. The transistors usually have the ability to switch eight times their class A audio rating, or four times the dissipation rating.

You must consider the breakdown rating as well. When one transistor con-

ducts and the other is cut off, a voltage equal to the supply will be induced in the non-conducting half of the transformer primary winding. The conducting transistor is a virtual short. Therefore, two times the supply voltage will appear across the cut-off transistor and the full primary. The collector-emitter breakdown rating (V_{ce}) must be high enough to withstand this peak potential. Occasionally the breakdown rating listed in the transistor literature is only an average. As a safety factor, it is an excellent idea to allow a larger margin. For example, assume a 12-volt mobile supply is to be constructed. As just explained, a minimum potential of 24 volts will develop across the transistors. Considering that the battery terminal potential might reach 14 volts, a transistor with a 30 volt collector-emitter rating would be marginal. It is interesting to note that you can rectify the full primary voltage to make a 6-to-12, or 12-to-24 volt converter. In such a unit the secondary would be unused.

In an improperly designed supply, it is possible to have "spikes" or switching transients on the leading edge of the square wave. These transients can create peak potentials that are well in excess of twice the supply voltage. If in doubt, when checking a new supply, operate it at reduced input voltage and observe the transistor wave-
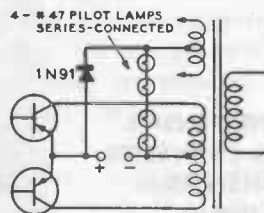
Figure 6.2-G
Two tricks to provide for easier starting under heavy load. Four pilot lamps and a rectifier replace the resistors shown in Fig. 6.2-D as explained in the text. These components would be satisfactory for a high power supply using Delco 2N278's.
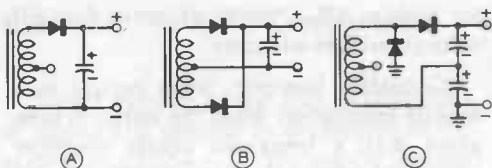
Figure 6.2-H
Typical rectifier systems used with transistor power converters.

form with an oscilloscope. Small "knobs" at the beginning of the square wave flattop may be seen, but they should be less than 2.5% of the total amplitude. However, spikes must be eliminated. A 1600-volt buffer capacitor across the secondary will remove the transients, but will reduce the switching time.

The saturation voltage mentioned earlier may be somewhat confusing. If a transistor were a perfect switch it would have zero ohms resistance when conducting. Unfortunately, this is not the case. Even when saturated, the junction will always have a small resistance. The larger the resistance, the greater the voltage developed across the junction. Since the junction is in series with the primary, the voltage dropped across the junction cannot appear across the primary and must be considered lost. For example, assume that a transistor has 0.1 ohm saturation resistance and the 12-volt converter in which it is used draws 10 amperes. Thus, by Ohm's Law, we find that one volt will be lost across the transistor. Only 11 volts will appear across the primary, and the secondary voltage will be low. If a commercial power-converter transformer is used and the supply has low output voltage, this is probably the reason. Low output can be minimized by selecting transistors that have a low saturation resistance or by paralleling transistors. A good transistor will have a saturation resistance less than 0.1 ohms. Some manufacturers rate the saturated junction by resistance, while others list the voltage drop at a stand-

ard current of one ampere. In either case, the lower the figure the better the transistor.

When paralleling transistors, the emitters and the collectors may be connected together. However, the base of each transistor should have a small (4.7 ohm) series resistor to equalize the feedback voltage.

Rectifiers   Like the transistor, the silicon rectifiers has certain specific ratings such as breakdown voltage and current handling ability which must be considered when constructing a power supply. Most silicon rectifiers will handle 500 ma. with ease, and this rating usually is not of importance in amateur equipment. Rectifiers which handle less current may be purchased at a slightly lower cost. However, be certain that they are adequate for the job. Whenever there are two separate current paths, such as the full-wave and bridge circuits, the rectifier system will be able to handle twice the current rating of one rectifier.

The peak inverse voltage rating must be closely followed, for the rectifier can easily be ruined by exceeding this voltage. A common value rectifier with a PIV of 400 volts can withstand between 150 and 200 volts of square-wave energy. For example, in a 300v., 200 ma. transformer, end-to-end secondary voltage is 300 volts, peak-to-peak. If this transformer were used in the half-wave circuit, it would be necessary to connect two rectifiers in series. In a full wave circuit it would be necessary to use a rectifier on each side of the center-tap. In the bridge configuration, the diodes are connected across the secondary and two rectifiers must be connected in series. Since two current paths exist, it is necessary to use a total of four rectifiers. The same conditions are present in the voltage-doubler circuit, and a total of four rectifiers are required.

The rectifier junctions are self-equalizing and any number of silicon rectifiers may be connected in series without external

equalization. The current rating remains the same no matter how many rectifiers are connected in series. The PIV rating will increase with each rectifier that is added.

Transient Protection Transient protection is one other power converter consideration which should be discussed. An improperly designed power converter can provide satisfactory operation for a long period of time and then suddenly, for no apparent reason, blow a transistor. Examination will show there is no front-to-back ratio between the collector and emitter. This indicates the junction has punched through or broken down.

What causes this to happen? As explained earlier, the autotransformer action results in a collector-to-emitter potential of approximately two times the supply. In 12-volt mobile applications this amounts to approximately 24 volts. Even with the slight overshoot normally encountered in switching, the peak-collector voltage usually will not exceed 30 volts. Thus, a transis-

tor with a BV_{co} rating of more than 30 volts should be adequate.

Consider, however, what occurs in a mobile installation when the starter is energized with a transistor power converter connected across the battery. The starter winding represents a large inductive load and the back e.m.f. can generate transients across the battery. Any induction load on the supply can be a source of transients. Although the average energy contained in the transient may be low, the peak voltage can reach many times the supply voltage. The transient, if allowed to reach the transistors, can add to the 2E collector potential and destroy the transistor. Even when high-voltage transistors (BV_{co} of 60 volts or more) are used, external transients which occur during the switching period can add to the leading edge overshoot and break down the junction.

In the circuit of Fig. 6.2-I, note that two double-anode breakdown diodes are connected between the collector and emitter of each transistor. The diodes are designed to conduct whenever the diode terminal potential exceeds 60 volts. As can be seen in Fig. 6.2-I, any transient which could destroy the transistor is effectively clipped by the diode. Transient suppressors should be used in any high reliability power converter application to minimize the possibility of destruction due to transients. The units are made by General Electric under the trade name *Thyrector* and by International Rectifier Corporation as *Klip-Sels*, and are available with a clipping level as low as 25 volts. As a minimum precaution, any power converter should have a large electrolytic across the supply terminals to absorb as much transient energy as possible.

Figure 6.2-I
Transients in power converters can be destructive. A double anode clipper, such as the International Rectifier "Klip-Sel" will short circuit transients before they reach destructive potentials.

A capacitor connected across the secondary will absorb transient energy, particularly that produced by transformer leakage reactance, but it also reduces the switching speed. Generally it is best to avoid this transient suppression technique, since the slower switching time increases transistor dissipation.

6.3　D.C. to A.C. Conversion

Direct current power may be converted to alternating current by the technique described in section 6.2. The system is similar to the transistor power converter. However, no rectifier-filter system is employed and, of course, the frequency is reduced to 60 cycles. In military aircraft installations the operation frequency is 400 cycles. In either case the conversion device is usually referred to as an inverter.

The circuit for a 120-watt inverter is shown in Fig. 6.3-A. It operates from a source of 12 volts d.c. and delivers 115 volts and 60 cycles at 1 ampere maximum. Note that the common-collector configuration is used to eliminate the need for insulating the collectors from the chassis. This is compatible with modern automobiles which use negative ground, 12-volt ignition systems.

Resistor R_1 applies starting bias to the switching transistors, while R_2 completes the divider network. Capacitor C_1, across R_2, minimizes attenuation of the base drive signal. A 14 ampere fuse protects the primary circuit.
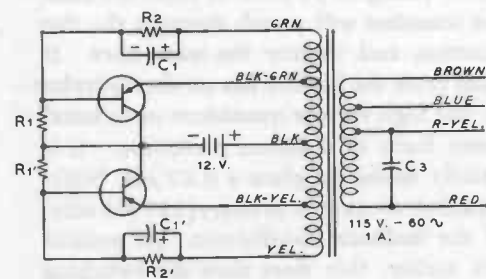
Figure 6.3-A

A power inverter which develops 117 volts a.c., 60 cycles from a 12 volt d.c. supply. Caution must be exercised not to exceed a one-ampere load current. For additional protection, connect a 14-ampere fuse in the supply line.

TRANSISTOR	$R_1 = R_1'$	$R_2 = R_2'$	$C_1 = C_1'$	C_3
DELCO 2N278 DS506	200 Ω 10 W.	2 Ω 5 W	2 UF 50 W.V.	1 UF 200 W.V.
BENDIX 2N678	200 Ω 10 W.	5 Ω 2 W.	2 UF 50 W.V.	1 UF
CLEVITE 2N1146	100 Ω 20 W.	2 Ω 5 W.	2 UF 50 W.V.	1 UF
DELCO 2N173	200 Ω 20 W.	5 Ω 5 W.	1 UF 50 W.V.	1 UF

Figure 6.3-B

A buffer capacitor is connected across a portion of the secondary to absorb transients generated during the switching cycle. This capacitor is mandatory when using the Triad TY-75-A transformer. The secondary also includes two additional output connections to compensate for low battery voltage, etc.

The transistors should be mounted on heat sinks with a minimum surface area of at least 50 sq. in. Caution must be exercised to prevent exceeding the 1 ampere maximum secondary current rating. Further, the transistor heat sinks must be ventilated during prolonged operation.

A chart of the recommended transistor types and the associated component values, is shown in the chart, Fig. 6.3-B.

6.4　A Low Cost Power Converter

This popular power converter was originally developed by John Specialny of Philco Corporation (Application Report #317). It uses no special switching or step-up transformers. Rather, two 6.3 volt center-tapped filament transformers are used, one for voltage step-up and the other for impedance matching of the base drive signal. This technique is particularly useful in power converters delivering 10 to 40 watts output.

Transformer T_1, in conjunction with R_1 and R_2, provides the feedback current necessary to sustain oscillation. The feed-
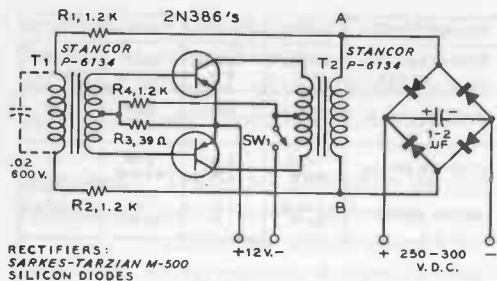
Figure 6.4-A

A low power converter for receiver or QRP transmitter applications. The output ratings are nearly ideal for powering the Command Set receiver series.

back polarity, from points A and B, must be correct or the supply will neither start nor operate properly. As shown, the power supply oscillates at approximately 200 c.p.s. Resistors R_3 and R_4 provide starting bias for the transistors. Transformer T_2 steps up the primary voltage, which is essentially a square wave, by an amount determined by the turns ratio. A simple bridge rectifier system provides nearly pure d.c.

The required load current will determine how much feedback voltage is required. The feedback can be increased by reducing the size of R_1 and R_2 while keeping both values equal.

As shown, the supply has the following characteristics. At 60 ma. the output voltage will be 310 volts (18.6 watts), while the primary current will be 2.5 amperes for an efficiency figure of 60%. At 110 ma., the output voltage will be 265 volts (29.2 watts), and the supply will consume 4 amperes for an overall efficiency of 67%.

The output transformer will run warm due to IR losses. The transistors run relatively cool indicating an ability to switch greater current levels.

The transistors should be mounted on heat sinks with a minimum surface area of 5 sq. in. Since the transistors are connected in the common-emitter configuration, mica or anodized aluminum washers should be used to insulate the transistors from the heat exchanges.

If desired, the power converter can be used at lower input voltages. The output voltage and available power will be almost proportional to the supply voltage.

The circuit is not at all critical with regard to the transistor type used. Any power transistor with two or more watts dissipation could switch the 4 amperes when the supply is operated at full load current.

There are a few precautions which should be observed when working with power converters of this type. The leakage reactance of the transformers introduces severe spikes on the leading edge of the switching waveform. These transients have been measured with a variety of transformers and found to be almost exactly four times the supply potential, peak-to-peak. Unless transistors with a peak collector rating of 50 volts or more are used, the transient will punch through the thin junction and destroy the transistors. In such cases the builder has no alternative but to use high voltage transistors or to install some form of transient protection. It is usually easiest to place a 0.02 μfd. buffer capacitor across the primary (117 volt side) of the feedback transformer. As pointed out earlier, this does slow the switching time and increase transistor heating. However, at the 30 to 40 watt level more than adequate dissipation is available with the transistors listed. As a further precaution, the value of R_1 and R_2 should not be reduced without checking the base current. Reducing the resistor value increases the base drive and excessive current can damage the transistors.

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