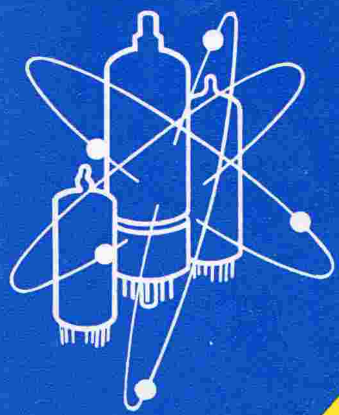

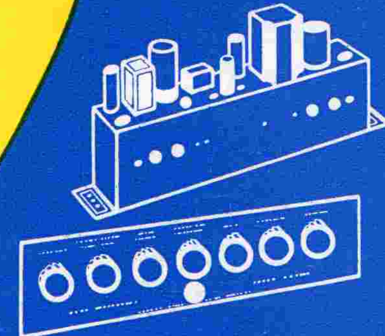

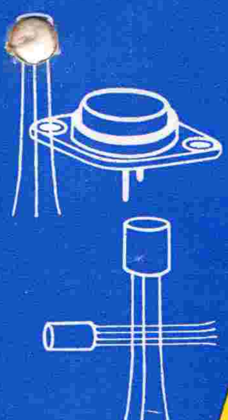

RADIOTRONICS

VOL. 24, No. 2 **FEBRUARY, 1959**

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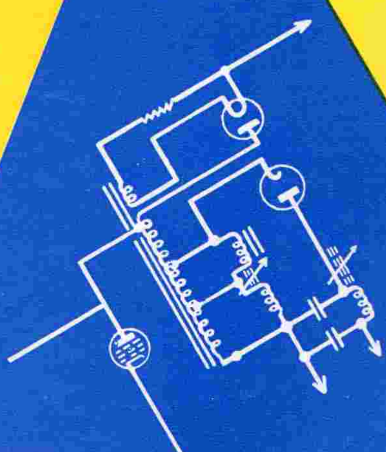
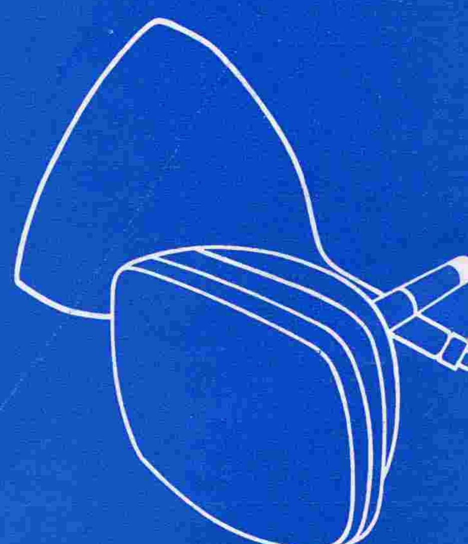
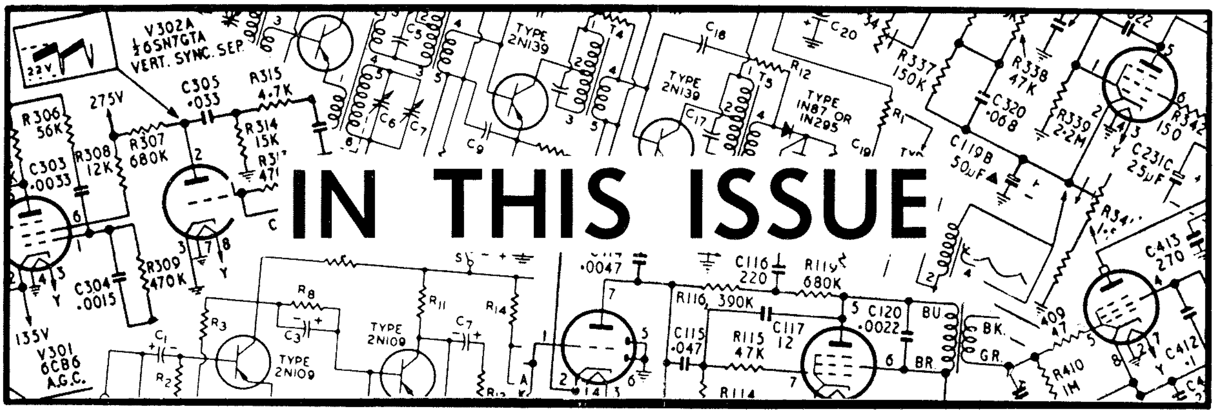




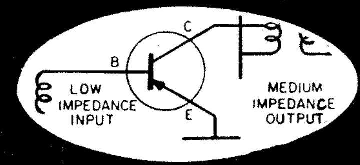


IN THIS ISSUE

By courtesy of RCA we are able to bring you a short course on transistor fundamentals and applications. This course was prepared by the joint efforts of the RCA Victor and Semiconductor Divisions, and is designed to give an engineer or technician with no previous semiconductor experience a quick appreciation of transistors without complex text book operations.

The course will consist of Transistor Fundamentals, in two parts, and Transistor Applications, also in two parts. These sections will be printed in successive issues of Radiotronics. In June we will present a set of review questions on the course, enabling readers to check themselves on the theory which has been presented during the previous four months.

TRANSISTOR FUNDAMENTALS



CHAPTER ONE

INTRODUCTION

The development of many new inventions in the field of electronics is perhaps not startling to us. One new invention after another has led us to believe that this is the normal way of advancement of the electronics industry. We have accepted these inventions and proved to ourselves how they operate by applying our knowledge of basic theory. However, transistors are an entirely new concept and require more than just basic electronics to understand their operation. The invention of the transistor in 1948 was not accepted as just a routine development but an achievement destined to make electronics history and leave a lasting impression on the future development of the electronics industry.

The transistor has many superiorities when compared to the thermionic valve. Transistors are generally housed in tiny cylinders less than an inch long. They weigh just a fraction of an ounce, have no filaments, consume very little power, have long operating lives, are solid in construction, extremely rugged and free from microphonics. In addition, transistors have no warm up period. They can be made impervious to the weather and in special applications can even operate under water. Their associated circuitry is greatly simplified. They have the ability to oscillate or amplify, serve as an electronic switch, mixer and modulator as well as a detector.

Engineers are designing new products to make use of the advantages offered by transistors. Although there are many types of transistors offered by the leaders of the electronic industry, a few of the more popular types are illustrated in Figure 1. It is the intent, first of all, to familiarize the reader with the theory of operation and characteristics of transistors.

FIGURE 1

TRANSISTOR PHYSICS

The study of the transistor can best begin by reviewing the structure of matter. Everything about us is composed of matter. Matter may appear in various states such as liquid or solid. We can best describe matter as that substance of which any physical object is composed.

Take water for example. If we were to repeatedly divide a given quantity of water until we had the smallest amount of water and still not change its **chemical characteristics,** we would have one molecule of water. A **molecule** is, therefore, the smallest amount of a given substance. The single molecule of water can be further divided into **elements** of oxygen and hydrogen. The smallest subdivision of an element is called an **atom**; therefore, the molecule of water can be split into two atoms of hydrogen and one atom of oxygen. In the study of transistors we will be dealing with atoms of germanium, silicon, antimony, arsenic, aluminium and gallium. It will be necessary for us to consider the atomic structure of these atoms.

The Germanium Atom

Germanium is one of the elements most commonly used in the manufacture of transistors. A germanium atom is graphically illustrated in Figure 2 (a). It consists of a **nucleus** in the centre and tightly bound **electrons** surrounding it. Upon closer examination it can be seen that the nucleus is composed of 32 **protons** which constitute the principal part of its mass. These protons exhibit a positive charge of electricity.

The nucleus is surrounded by 32 electrons which rotate in fixed orbits. The four electrons in the outer ring are not as tightly bound to the nucleus as those electrons in the inner rings. The electrons in this outer ring are called **valence electrons.** We are mainly concerned with the valence electrons and therefore, we can simplify the diagram of the germanium atom as shown in Figure 2 (b). Here we show a net charge of (+) four in the nucleus which is the total number of protons in the nucleus, minus the tightly bound electrons.

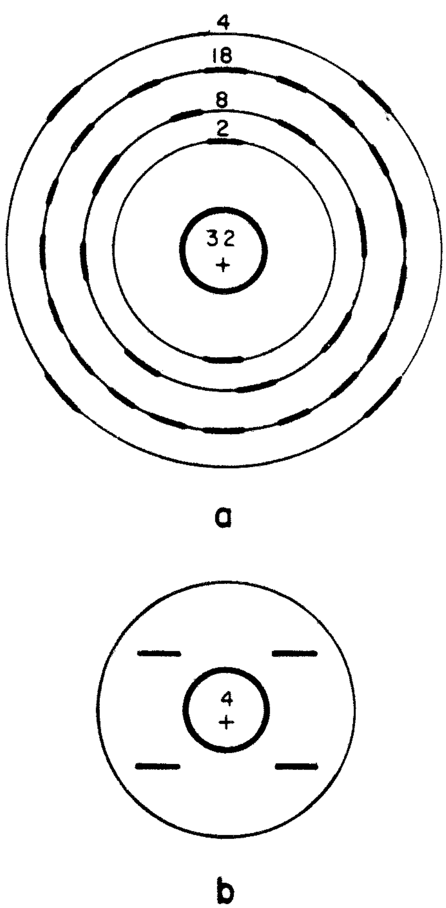


FIGURE 2

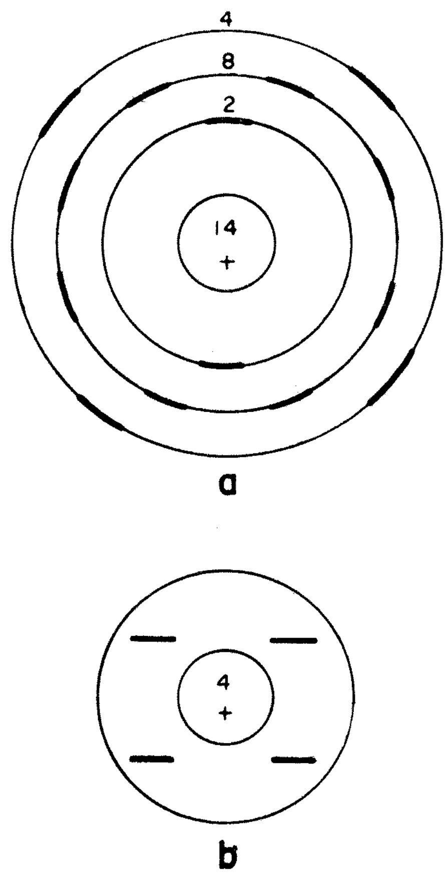


FIGURE 3

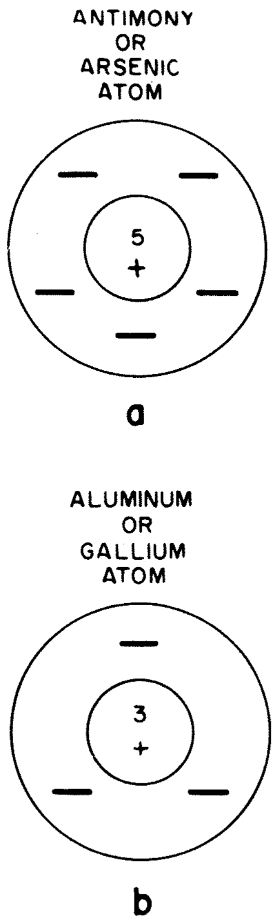


FIGURE 4

The Silicon Atom

Silicon is another element used in the construction of transistors. In Figure 3 (a) a silicon atom is illustrated. There are 14 protons in its nucleus and 10 tightly bound electrons surrounding it. The valence electrons are shown in the outer ring and as in the germanium atom, there are four.

The simplified diagram of a silicon atom is illustrated in Figure 3 (b) showing only the net charge on the core and the valence electrons. You will notice it looks exactly like the germanium atom. In fact, germanium or silicon can be used equally well in the making of transistors.

ATOMS OF SEVERAL SUBSTANCES

We mentioned earlier that antimony and arsenic, in addition to germanium and silicon, can be used in the making of transistors. In Figure 4 (a) are the simplified diagrams of these elements. Note that there are 5 valence electrons for these elements and a net charge of 5 protons. It is important at this time to realise that the number of valence electrons may differ for various elements.

The final two elements with which we shall deal are aluminium and gallium. In Figure 4 (b) we can see that there are 3 valence electrons and a net charge of 3 protons in the nucleus. We shall see shortly how these atoms of various valences are put to use in the making of transistors.

Crystal Structures

Certain substances have the ability to take on a very stable crystalline form. The most popular crystalline substance is the diamond. In this crystalline form valence rings of adjacent atoms interlock with each other. This action of binding the valence rings together is known as the formation of **covalent bonds.** Germanium also has the ability to form covalent bonds. Figure 5 shows the plan by which a pure germanium crystal is formed. Upon examination of the structure you can see that electrons of neighbouring atoms interlock with one another.

Keeping in mind the structure of the atom, specifically the valence electrons, we can say whether a particular element is classified as a conductor or insulator by the degree of difficulty with which the electrons can be dislodged from the outer ring. Those elements in which the electrons cannot be dislodged easily are called **insulators.** Contrary to this, those elements in which the electrons can be dislodged easily are good conductors. An element which falls somewhere between is a **semiconductor.** Semiconductors are the basic materials of which transistors are made.

Semiconductors

Two semiconductors often used for transistors are germanium and silicon. For transistor action, however, it is necessary to control the electrical properties of the semiconductor material. This

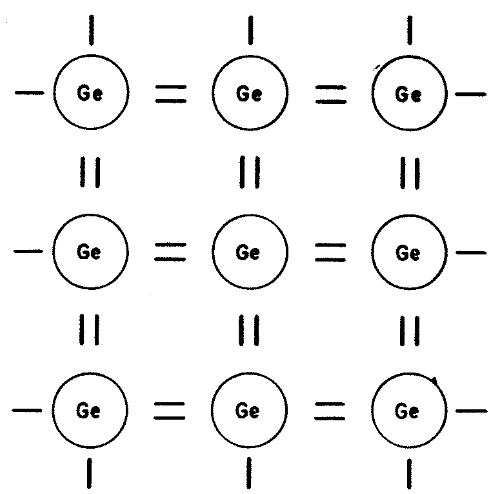


FIGURE 5

control is achieved by the addition of minute quantities of impurities. The impurity can be any of several elements such as antimony, arsenic, aluminium or gallium. The ratio of impurity to germanium need be only 1 part to 10 million. Depending on the type of impurity used, two types of semiconductors will result; namely n-type or p-type.

N-Type Germanium (donors)

Impurities such as arsenic or antimony, having five electrons in their valence ring, may be added to germanium. Four valence electrons of the impurity atoms form covalent bonds with their neighbouring germanium atoms.

The fifth electron is free to drift through the crystal structure. The effect of adding arsenic or antimony to the germanium or silicon crystal is illustrated in Figure 6. Impurities that have a valence of five are called **pentavalent-type** impurities or **donors** because they donate electrons to the semiconductor crystal.

If we were to connect a battery across this type of semiconductor, conduction takes place. The free electron in the semiconductor is attracted by the positive potential and enters the positive terminal of the battery as shown in Figure 7. Simultaneously, an electron leaves the negative terminal of the battery and enters the semiconductor. Thus, a continuous flow of electrons is maintained from the negative to positive terminal as long as the battery potential remains. This type of semiconductor is called n-type.

P-Type Germanium (acceptors)

A second method of modifying a semiconductor is by the addition of aluminium or gallium to germanium. In our discussion of elements we noticed that the aluminium and gallium atoms had a valence of three. Remember that the

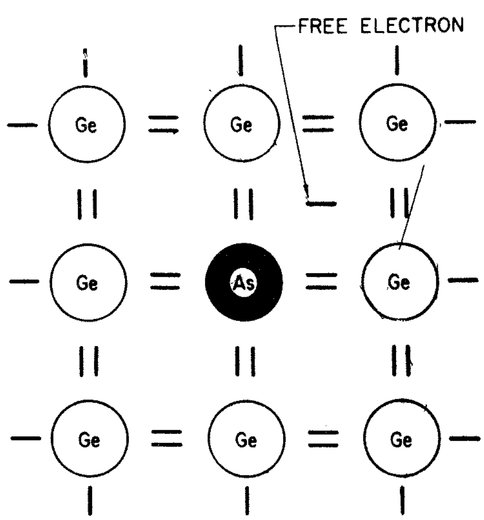


FIGURE 6

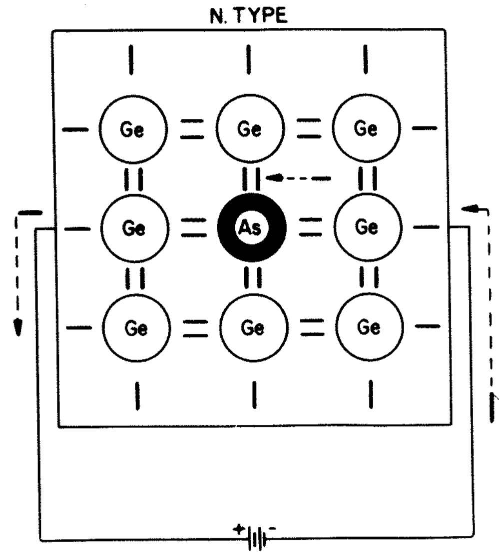


FIGURE 7

aluminium or gallium atom has one less valence atom. Therefore, one covalent bond is incomplete, resulting in a deficiency of an electron or the presence of a "hole". This is illustrated in Figure 8. Impurities that create a hole in germanium or silicon are **trivalent**, meaning a valence of three and are called **acceptors** because they take electrons from the germanium crystal. This type of semiconductor with acceptor impurities is termed p-type germanium.

Let us examine how conduction takes place in a p-type semiconductor. Figure 9 (a) illustrates a piece of p-type semiconductor. The hole is shown near the centre of the semiconductor. In reality it may be located any place in the semiconductor, but for simplicity let us have it exist in the centre. A battery is also shown. The instant the battery is connected, an electron from an adjacent covalent bond moves from its present position and fills the hole. This action is illustrated in Figure 9 (b). The movement of this valence electron creates a vacancy in the covalent bond it just left. Once again an electron from a covalent bond nearer the negative terminal moves out of the bond and fills the hole. This action is illustrated in Figure 9 (c). The hole is now located on the extreme end of the semiconductor. In this position there is room for an electron from the supply (negative terminal) to enter the semiconductor and fill the hole. The instant an electron enters the semiconductor from the battery, an electron from a covalent bond nearest the positive terminal of the battery leaves the semiconductor and enters the positive terminal of the battery. The removal of this electron from a covalent bond results in the formation of a hole. An electron must leave the semiconductor in order to maintain

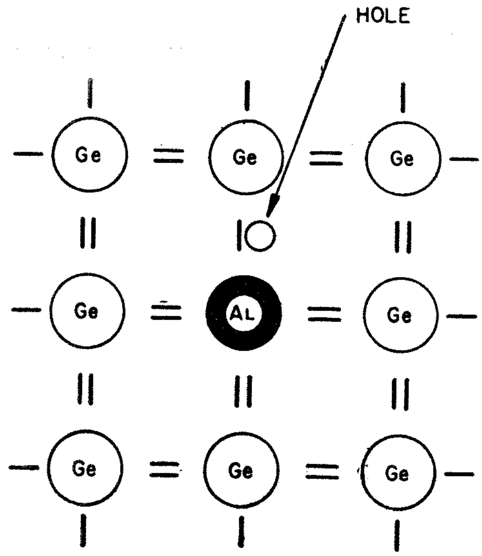


FIGURE 8

the **original characteristic.** That is to have a deficiency of one electron. This action is illustrated in Figure 9 (d). It is possible for conduction to take place within the p-type semiconductor because by the application of an external supply (battery), valence electrons are made to move into the hole made by the preceding movement of the valence electrons from an adjacent covalent bond. This process is in effect as though the hole was moving toward the negative battery potential. Actually, it is the valence electrons that are moving, however, for ease of explanation we will consider hole movement in preference to electron movement in p-type semiconductors.

Now we have two types of semiconductors, the n-type and the p-type. The n-type is formed by a donor when arsenic or antimony joins the crystal structure in which electrons are the principal current carriers. The p-type semiconductor is formed when an acceptor such as aluminium or gallium joins the crystal structure. In this instance holes are the principal current carriers.

Intrinsic Germanium

Absolutely pure germanium or germanium having an equal number of donor and acceptor atoms has an intrinsic characteristic. Conduction in this type of semiconductor can only take place if the covalent bonds are broken down by external energy in the form of heat or light. Very pure germanium exhibits some intrinsic conductivity at normal room temperature.

THE P-N JUNCTION

The electrons or holes in semiconductors of either n or p-type are constantly on the move or drifting about in an irregular manner. This intrinsic activity takes place without the presence of an external potential. As we mentioned in discussing the manufacture of n-type semiconductors, the impurity atom is of the pentavalent type. Keep in mind that the nucleus of the impurity atom is +5 and there are a total of 5 electrons surrounding the impurity atom. This is equal in number to the nucleus and, consequently, the impurity atom exhibits no charge. But this is not always the condition since the excess electron is always on the move.

Now consider the excess electron having moved from its present association with the impurity atom. This time the charge of +5 in the nucleus cannot be equalled by the 4 valence electrons surrounding it. Therefore, the impurity atom takes on a charge of +1. It can be seen then, that as long as the electron is associated with the impurity atom, the atom exhibits no charge and as soon as the electron moves away, the impurity atom takes on a +1 charge.

In the p-type semiconductor there is a similar activity going on. The introduction of impurity atoms of the trivalent type into germanium results in a deficieny of an electron or the formation of a hole. Once again this hole is not fixed in the crystal structure but **effectively** moves about. In considering the trivalent impurity atom, we know it has a charge of +3 in its nucleus. But because of its thieving nature it takes an electron from a neighbouring valence bond to add to its own 3 valence electrons; as a result there is one more electron than necessary to satisfy the +3 charge on the nucleus. The end result is that the impurity atom takes a -1 charge. As long as the hole is

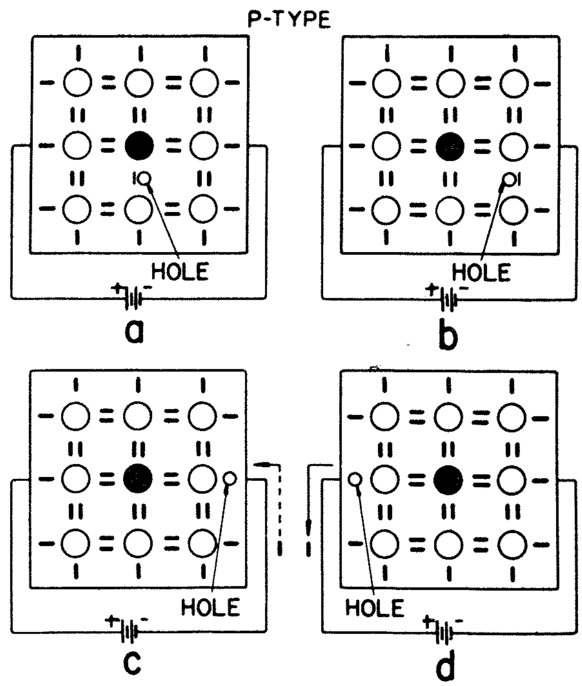


FIGURE 9

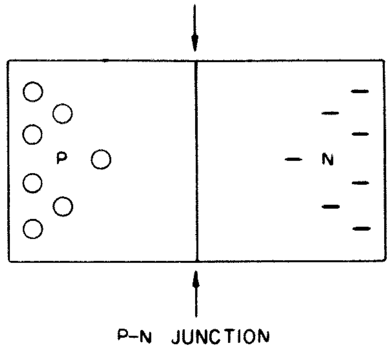


FIGURE 10

associated with the impurity atom, the atom exhibits no charge and as soon as the hole is filled, the impurity atom takes on a -1 charge.

Although this activity is going on within the semiconductor without an applied potential, the total mass of the n or p type semiconductors **do not** exhibit a charge. That is, we cannot measure a plus or minus charge on either type.

Keeping this in mind, let us form a piece of germanium with p-type semiconductor on one end and n-type on the other. This is illustrated in Figure 10 and shows the free holes in the p-region and free electrons in the n-region. The area in the centre is designated as the p-n junction. It might appear at first that some of the free electrons would inadvertently diffuse across the junction, but because of the negative charge exhibited by the fixed impurity atoms in the p-region, they are repelled as illustrated in Figure 11. This is caused by the simple fact that unlike charges attract and like charges repel. The free holes in the p-region remain there for the same reason. That is, the fixed donor atoms in the n-region exhibit a positive charge, thus repelling the holes. The potential which exists at the junction because of the unlike charges on either side is commonly called the **potential gradient** or **potential energy** barrier.

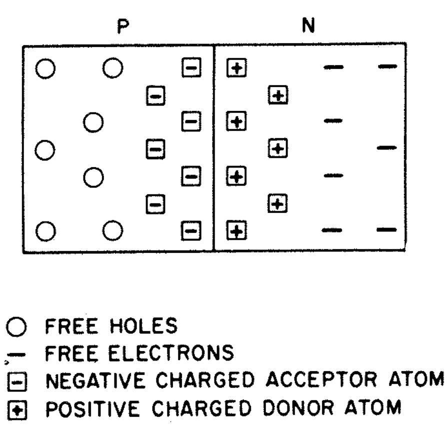


FIGURE 11

Current Flow

Let's connect a battery across a p-n junction as illustrated in Figure 12, and examine the effects. The holes will move to the left toward the negative potential of the battery. Simultaneously, the electrons will move to the right toward the positive terminal of the battery as illustrated in Figure 12. This movement of holes and electrons effectively increases the potential barrier at the junction and there is less chance for electron flow through the p-n junction. We can, therefore, conclude that the resistance to current flow has been increased. The battery connected in this manner is sometimes referred to as **reverse bias.**

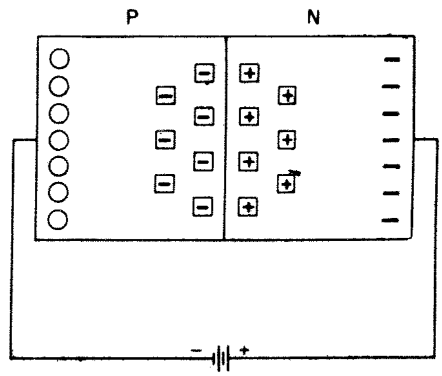


FIGURE 12

Now let us take the same p-n junction and reverse the external battery connections. That is, connect the positive potential to the p-region and the negative potential to the n-region. This is illustrated in Figure 13. This method of connection effectively decreases the potential barrier at the junction and decreases the resistance to current flow.

The electrons present in the n-region move toward the junction due to the negative potential of the battery. Some of the electrons are forced across the junction and enter the p-region where they combine with existing holes. For each combination, a covalent bond in the p-region nearest

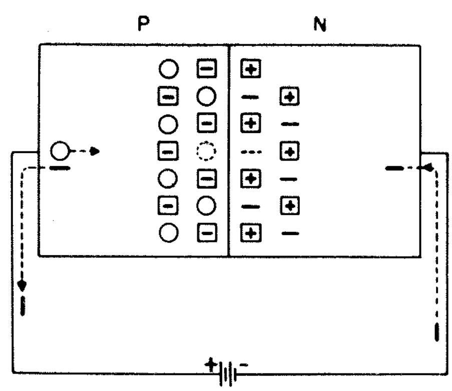


FIGURE 13

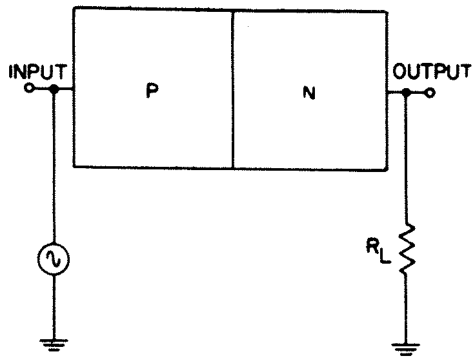


FIGURE 14

the positive terminal of the battery breaks down and the liberated electron enters the positive battery terminal. This action creates a new hole which moves toward the junction. Simultaneously, for each electron that combines with a hole in the p-region, another electron enters the n-region from the negative terminal of the battery and moves toward the junction. The total current flowing through the semiconductor material is composed of electron flow in the n-region and hole flow in the p-region. The battery connected in this manner is sometimes referred to as **forward bias.**

It is obvious now that the junction formed by the n and p type semiconductors is capable of rectification. If an ac signal were applied across the p-n junction, as illustrated in Figure 14, current would flow during the positive half cycle and there would be little or no current flow during the negative half cycle. Therefore, the junction formed by the combination of n and p-type semiconductors is an effective rectifying device and is commonly referred to as a **junction diode.**

(Continued next month)

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"Television Engineering — Principles and Practice", Volume Four, General Circuit Techniques, S. W. Amos and D. C. Birkinshaw, Iliffe and Sons Ltd., London, 8to, 268 pp. + plates.

Most readers will be aware that this volume completes a comprehensive text book on the fundamentals of television theory and practice, forming one of the BBC Engineering Training Manuals published by Iliffe by arrangement with the BBC. The promise of excellence inherent in this fact and in the authors' names is fully realised. The wide variety of subjects dealt with in this volume makes it obvious that it will find a place not only as a text book but as a reference book. The teaching ability of the authors is shown by the choice of material and treatment. Matters already adequately dealt with in the literature of the art have been given a brief but comprehensive coverage, whilst other aspects less well covered have been given an expanded and most welcome treatment. There should be more of this outlook — engineers assailed by masses of literature would welcome it.

"Reflex Klystrons", J. J. Hamilton, Chapman and Hall, London, 8to, 260 pp. + plates.

Even today, the users of reflex klystrons are probably still comparatively small in number, but what Mr. Hamilton may miss in volume he will probably gain in appreciation. To the reviewer, who was first concerned with klystrons in the early 1940's, when they were still wrapped in the secure name of "Sutton" tubes, this volume was not only instructive but interesting. Ample references are appended to each chapter, and the diagrams and illustrations are of high quality. It was a little surprising to find that among discussions of so many makes and types of klystrons, many of them American in origin, there was no mention of the excellent range of reflex klystrons manufactured by the English Electric Valve Company.

"Radiotron High Fidelity", Amalgamated Wireless Valve Co. Pty. Ltd., Qto., 44 pp.

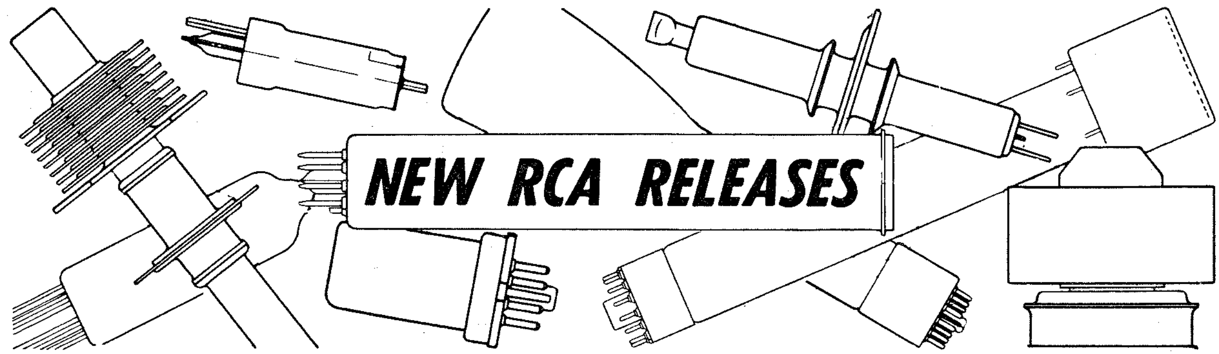
This latest publication is a collection, in handy and convenient form, of seven articles which have recently appeared in "Radiotronics". Five of these articles deal with high fidelity, and form a very sound resume of the principles and practice of Hi-Fi reproduction. The other two articles perform a similar service in respect of tape recorders.

This booklet provides a good introduction to the various techniques and considerations involved, and is likely to be particularly useful to those just starting out or still comparatively new to Hi-Fi. To the more experienced enthusiast the book provides a useful survey of the history and practice of "Hi-Fi".

This book, like all Radiotron publications, adheres to sound lucid explanations of the various matters involved. This makes the text, whilst still of great educational value, easy to read and assimilate.

"AWV Transistors", Amalgamated Wireless Valve Co. Pty. Ltd., Qto., 89 pp.

In this handbook AWV have produced what is probably the most ambitious transistor manual yet attempted in Australia. The impressive technical data section contains full data on 51 types of transistor, amplified and illustrated by copious diagrams, characteristic curves, typical circuits and the like. For everyone interested in transistors today, and who isn't? this manual is a necessity. Of particular interest is an article by two leading AWV engineers on rating and operating considerations, which describes just how transistors should be used.



RADIOTRON 6112

AWV announce the addition of the 6112 high-mu twin triode to its line of receiving - type industrial tubes. This subminiature type, which utilizes flexible leads, is constructed and processed to meet critical military and industrial requirements in communication equipment, where dependable performance under conditions of shock, vibration, high altitude and high temperature are primary design considerations.

The 6112 is intended for use primarily as a low-level audio amplifier valve. In audio service as a resistance-coupled amplifier, this valve is capable of providing high voltage gain.

RADIOTRON 6342-A

A new multiplier phototube 6342-A, which supersedes the 6342, features improved pulse-height resolution, reduced transit-time variation, higher cathode luminous sensitivity, higher current amplification, and low dark current over a wider range of operating voltages. Because of these improvements, the 6342-A gives superior performance in scintillation counters.

Design features of the 6342-A include a semi-transparent photocathode on the curved inner surface of the face end of the bulb, a minimum photocathode diameter of 1.68 inches, a faceplate with a flat external surface to facilitate the mounting of flat phosphor crystals in direct contact with the surface, 10 electrostatically focused multiplying (dynode) stages having stable high-current-carrying capability, and a focusing electrode with external connection.

Like the 6342, the 6342-A has a spectral response covering the range from about 3000 to 6500 angstroms, with maximum response in the blue region at approximately 4400 angstroms. When operated at a supply voltage of 1250 volts, the 6342-A has a median luminous sensitivity of 14 amperes per lumen and a current amplification of 175,000.

RADIOTRON 7199

The Radiotron 7199 is a medium-mu triode — sharp-cutoff pentode for high quality, high fidelity audio applications. In such equipment, the 7199 is useful in tone-control circuits, phase-splitter and high-gain voltage amplifier circuits, and in pre-amplifier circuits if the input signal level is 100 millivolts or more.

RADIOTRON 7262

A new type has been added to our line of vidicons. The Radiotron 7262 is being introduced to meet a call for a vidicon designed for use in transistorized TV cameras — black-and-white or colour. This new type employs a low-power heater which requires only 0.6 watt and has a short overall length of only 5-1/8".

The 7262 can produce pictures of broadcast quality with as little as one footcandle of highlight illumination on its faceplate. Resolution obtainable with the 7262 is about 600 television lines.

A high degree of uniformity of characteristics from tube to tube is realized in the 7262 through utilization of newly developed photoconductor processes. The photoconductive surface has uni-

Continued on page 39.

$$e = E\sin\omega t(1 + m\sin pt)$$
$$= E\sin\omega t + mE\sin\omega t\sin pt$$
$$= E\sin\omega t + (mE/2)\cos(\omega - p)t - (mE/2)\cos(\omega + p)t$$

AMPLITUDE MODULATION TODAY

By Kenneth W. Uhler, S.M.I.R.E.

A Review of Some Modern Amplitude - Modulation Systems

(With acknowledgements to RCA)

Single sideband, synchronous detection, compatible single sideband! These and many other similar phrases appear in many of today's publications. But too often the advantages claimed for one of these systems in the article you are currently reading conflict with the claims made for another system featured in the article you read last week. This seeming confusion leaves the reader with the question: "Which is what?" Hence, this article — intended as a review of the basic systems in the hope that it will lead to a better understanding of the published material.

Before the comparison of amplitude-modulation systems is made, however, some of the terms used in this article should be defined. The symbols are derived from the terms used and refer to frequencies, not magnitudes.

The radio frequency to be modulated is referred to as the carrier and the symbol is f_c. Similarly, this article is concerned with radiotelephony, where the modulating signal is the voice, and the symbol used is f_v.

Amplitude modulation can be defined as the process of varying the amplitude of a carrier at an audio rate. The result is that two new frequencies, $(f_c + f_v)$ and $(f_c - f_v)$, are produced.

For example, if the carrier frequency is 14 Mc, and it is modulated by an audio frequency of 1000 cycles:

14,000,000 (f_c) modulated with 1000 (f_v) will give:

14,001,000 $(f_c + f_v)$ and 14,000,000 (f_c) and 13,999,000 $(f_c - f_v)$.

The sum of the two frequencies $(f_c + f_v)$ is referred to as the upper sideband and the difference between the two frequencies $(f_c - f_v)$ is referred to as the lower sideband.

AM (Both Sidebands and Carrier)

In the example of amplitude modulation given above, the modulated signal consists of three frequencies: the lower sideband $(f_c - f_v)$, the carrier (f_c), and the upper sideband $(f_c + f_v)$. Figure 1 illustrates a frequency versus power curve for AM. The width of the sideband is dependent on the highest audio frequency used to modulate the carrier.

One of the common methods of obtaining amplitude modulation utilizes the fact that a power valve when operated Class C has a generally linear output for wide variations in plate voltage. Modulation is accomplished by inserting the audio signal in series with the plate of the valve.

No practical modulating system is without some non-linearity, and non-linearity, however small, leads to the generation of some unwanted frequencies. Because the plate tank has a relatively low Q when loaded and, therefore, relatively poor selectivity, all the unwanted frequencies generated are not filtered out. When these unwanted signals appear outside of the desired

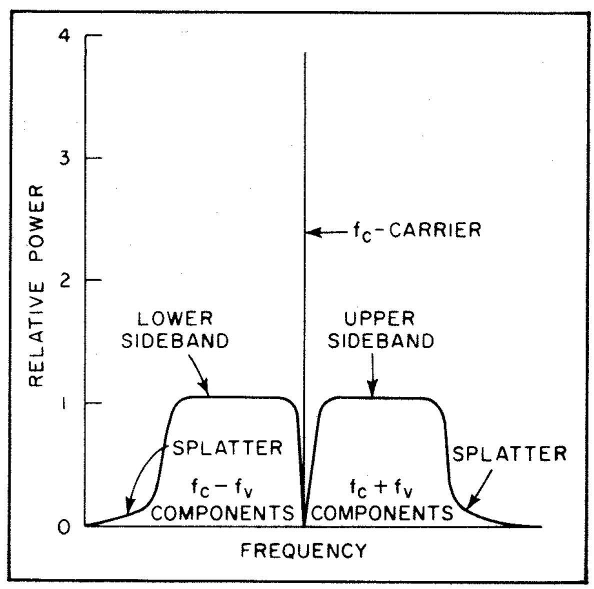


Figure 1: amplitude modulation.

band, they can create very undesirable interference.

The AM system is not complete until we consider how the modulated wave can be translated back into intelligence at the receiver. The process by which the audio is recovered from the radiated wave is known as demodulation or detection. In the process of modulation, the audio frequencies produce sidebands which are centered about the carrier frequency. In demodulation, the carrier frequency is mixed or intermodulated with the sidebands to produce an audio frequency signal. Most receivers employ a local oscillator to heterodyne with the incoming rf and produce an intermediate frequency (if). The fixed-tuned if stages provide easier control of both bandwidth and gain.

One of the most common methods of demodulation utilizes the unidirectional characteristics of a diode which provide the non-linearity needed to intermodulate the carrier with the sidebands. One product of the intermodulation is the audio frequency. The unwanted sideband, carrier, and higher-frequency products are filtered out in simple RC circuits.

The diode demodulator has two distinct disadvantages. First, it has no gain, and the desired signal is usually attenuated 10% to 20% because rf filtering is required. Second, the desired modulation component becomes distorted at low signal levels and high percentages of modulation.

The complete AM system is subject to another commonly experienced phenomenon known as selective fading. Briefly, selective fading is a reduction in signal strength of a part of the band of frequencies transmitted. It can affect the amplitude and/or phase relationship between the carrier and either or both of the sidebands. This distortion in ordinary receivers often results in a significant loss of intelligibility.

The primary advantages of AM systems, as described, lie in their simplicity and low cost. Moreover, many practical techniques have been developed which greatly enhance the usefulness of AM. Improved bandwidth control and oscillator stability, better noise limiting and blanking circuits, and heterodyne detectors are all widely used in new receiver designs. The heterodyne detector, for example, produces much lower-order distortion for small signal inputs than any of the simpler diode circuits, and can handle high percentages of modulation. This detector mixes a local oscillator signal with the radio frequency or intermediate frequency to produce an amplified audio signal.

Speech clipper and modulator design in the transmitter also can be greatly improved, and at only small additional cost and complexity. In comparing "new" systems to "ordinary" AM, one should be careful to determine how much of the advantage offered by the system comes from improvements that could be added to any systems.

DSB (Both Sidebands. No Carrier)

"Double sideband" is also referred to as synchronous AM. The term "synchronous AM" comes from a method used to detect amplitude modulation. Basically, this method uses a heterodyne detector which demodulates directly to audio by mixing the modulated rf with a local oscillator signal. The local oscillator signal must be synchronized (in phase) with the original carrier to prevent unwanted phase distortion.

One such proposed system demodulates in two simultaneous heterodyne detectors. The local oscillator signal fed to one of them is phase shifted 90 degrees, so that the audio-output signal from this detector is zero.

When the local oscillator is phase locked (exactly in phase) to the original carrier frequency, the phase-shifted heterodyne output will remain zero. If the local oscillator is not in exact phase with the original carrier, the shifted detector will have an audio output proportional to the phase difference. This signal is used to provide a correction voltage for an automatic-frequency-control circuit. The frequency of the local oscillator is controlled at the apparent carrier frequency, reducing the effect of any selective fading present.

The principal advantages of this system come from the fact that no carrier is needed and the single receiver oscillator is frequency controlled. Of all the systems, synchronous AM is the least affected by selective fading.

Figure 2, drawn to the same scale as the AM diagram in Figure 1, points out the increased sideband power available for DSB operation without taking into account possible transmitter redesign. Balanced modulation in the transmitter will reduce the carrier level at least 30 db without special circuits of any kind. Balanced modulation is usually accomplished by using a push-pull final, which retains one of the advantages of AM in that it allows plate modulation of the final.

Two distinct advantages are inherent in the double-sideband system: 1) Reduction of the carrier eliminates the most annoying source of a continuous beat-frequency whistle interference produced by a co-channel station which reduces signal intelligibility and produces operator fatigue to a far greater degree than the "monkey chatter" of sideband cross-modulation products. 2) The final power amplifier is generally operated Class C in a balanced circuit so that rf power is produced only when modulation is present.

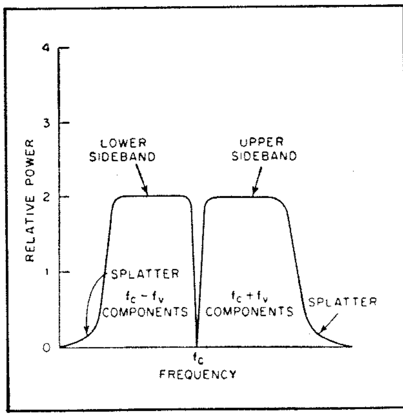


Figure 2: double sideband.

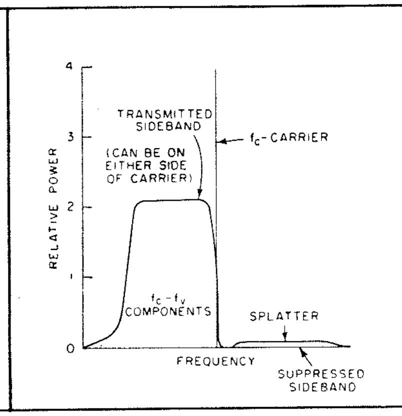


Figure 3: compatible SSB.

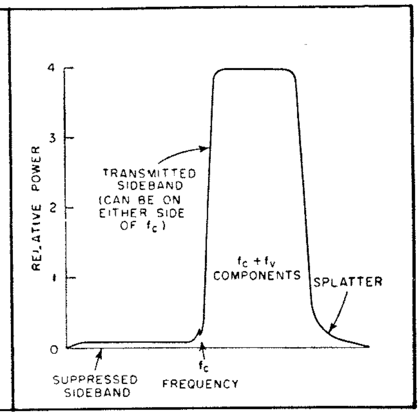


Figure 4: single sideband.

COMPATIBLE SSB (Single Sideband with Carrier)

The compatible single sideband system — currently being used by the "Voice of America" and WMGM — can be received on the present ordinary diode detector receivers. Balanced modulation is used to suppress the carrier, as in synchronous AM. One sideband is then filtered out and a controlled amount of carrier reinserted.

Compatible SSB can be represented as shown in Figure 3. Either sideband can be used. This system is subject to selective fading much in the same manner as conventional amplitude modulation, and is somewhat more susceptible to fading than AM and synchronous AM because the single sideband does not afford the redundancy of the double sideband. The advantages of this system are very important in applications like the "Voice of America" and other ground-to-fixed-station systems because of the following characteristics:

(1) Half the normal AM bandwidth.
(2) Compatible with existing receiving equipment.
(3) Allows increased efficiency in high-power transmitter design.

SSB (Single Sideband. No Carrier)

SSB goes all the way and transmits only one sideband, as shown in Figure 4. The lack of a carrier eliminates the whistle type of co-channel interference.

The bandwidth is the same as the bandwidth of the modulating frequency. The signals handled in the transmitter final are entirely modulation components. RMS power ratings become somewhat meaningless because voice modulation has such a complex waveform. For this reason, SSB finals are usually rated in terms of peak power capability. Balanced modulators are used to reduce the carrier at least 30 db. Phase networks, or filters, can be used to remove the unwanted sideband and further reduce the carrier.

Somewhat more complexity results from the low frequency used. Heterodyne circuits must be used to bring the signal frequency up to the rf region. Non-linear frequency multipliers, such as harmonic generators and doublers, are not suitable because they would produce a high percentage of unwanted signals and distortion. Such circuits would also multiply the voice frequencies. This result would require complex frequency-divider circuits in the receiver.

The driver stages and final amplifier must be linear for the same reason. Efficiency of the final amplifier is considerably higher due to the fact that no carrier power is involved and the final can be designed to handle much greater peak power without exceeding the dissipation ratings. Because the zero signal condition exists until modulation is present, two-way single-channel communications are simplified (simplex operation).

The main disadvantages of the SSB system stem from the fact that demodulation must be accomplished by the addition of a demodulating signal at the receiver (often referred to as reinserting the carrier). Variations in the frequency of this injected signal will cause distortion of the voice frequencies that sound like a variable-speed phonograph. It is my personal opinion — through listening — that although this distortion is objectionable from a theoretical standpoint, it actually results in very little loss in intelligibility over a $\pm$ 150 cycle range. Critical applications are usually governed by a $\pm$ 50 cps maximum. The interference from an adjacent channel results in variable-pitch "monkey chatter" which can be tolerated even at quite high levels.

Selective fading becomes just plain fading in the case of only one sideband. The ability to select sidebands could provide the necessary redundancy to overcome this effect, but it would double the bandwidth.

The disadvantages of SSB are: (1) increased complexity, (2) tight frequency-drift specifications; (3) non-compatibility with existing equipment, and (4) both the transmitter and the receiver have tight linearity requirements. Cost is not always a factor. For equipments designed to produce the same degree of intelligibility between any two points, savings in power supply and valve cost make it entirely possible to build SSB equipment in the same price range as the comparable AM equipment.

The advantages of SSB, other than those associated with the improved circuitry, are: (1) narrow bandwidth and (2) improved co-channel and adjacent channel operation (elimination of carrier whistle). Although these advantages are small in number, they are large in their importance to commercial and military communications.

EDITOR'S NOTE

The following comparison of four types of modulation (including FM, which was not, of course included in the foregoing discussion) presents a clear picture of the relative merits of the modulation methods as far as voice communication is concerned. This data is based on Table 1, "Selection of Modulation for Speech Communication", G. J. Kelley, Electronics Engineering Edition, March 28, 1958, to which acknowledgement is made.

COMPARATIVE TABLE OF MODULATION METHODS

CHARACTERISTIC	AM	DSB ‡	SSB	FM
Compatibility of receiver with other modulation methods. *	Receives modified full-carrier SSB	Receives AM and SSB	Receives AM and SSB	Receives FM only.
Effective range.	Intermediate, determined by noise threshold.	Longer. All rf power is effective intelligence signal with lower noise threshold.	Equal to DSB for same average power.	Shortest. Larger bandwidth increases noise threshold.
Bandwidth	Twice the highest modulating frequency.	Same as AM.	Equal to highest modulating frequency, assuming complete suppression of one sideband.	Twice the highest modulating frequency plus nominal deviation of FM wave.
Signal-to-noise performance ϕ	Poorest. Carrier power does not contribute to output signal. Speech may be processed by pre-emphasis and peak clipping.	All rf power contributes to output signal. Speech processing available as in AM.	Like DSB but audio peak clipping produces higher rf peaks, limiting its effectiveness.	Improvement possible by increasing nominal deviation and pre-emphasis.
Interference rejection	Selective filter rejects discrete interference.	Selective filter rejects interference from either sideband.	As for AM	Rejects interference by capture effect, but capture requires signal stronger than interference.
Distortion, circuit linearity	Intermediate.	Intermediate	Greatest	Least.
Distortion, over-modulation	Peak sharply limited to four times carrier power.	Peak limited by maximum transmitter capability.	As for DSB.	Peak limited by channel bandwidth.

(Table continued on next page)

Multipath distortion	Subject to fading.	Less fading than AM. Relative advantage 3 to 9 db for good to bad conditions.	Like DSB.	Subject to fading.
Stability	Less frequency control and stability required.	Intermediate stability required.	Close frequency control and stability required.	As for AM.
Transmitter power°	Average: carrier power plus average modulating power. Peak: four times carrier power. Circuit efficiency intermediate.	All rf power is in modulated signal. Relative average and peak values depend on modulating waveform. Circuit efficiency high.	As for DSB, but circuit efficiency low.	Constant rf power. Relative proportions of carrier and modulating signal calculated by Bessel-function analysis. High efficiency.
Circuit complexity				
1. Receiver	Least complex	Less complex than SSB.	Most complex.	More complex than AM.
2. Transmitter	More complex than FM	Least complex.	Most complex.	Intermediate.
3. Two-way system §	Least complex	More complex than AM or FM.	As for DSB.	More complex than AM.
4. Components.	Least critical	Less critical than SSB.	Most critical.	More critical than AM.

‡ Double sideband with suppressed carrier is understood in this table.

* Each modulation integrates best with the same type of system

ϕ AM, SSB and DSB give equal performance for equal average sideband powers.

° Typical ranking for total dc power required to produce equivalent intelligence signal output:— 1, DSB; 2, SSB; 3, FM; 4, AM.

§ SSB two-way transceivers can use some circuits for both transmitting and receiving.

NEW SERVICES TO READERS

In the December, 1958 issue of Radiotronics we promised an announcement of two services which we are inaugurating for our readers. These services are described below.

READERS' REPRINT SERVICE

Many articles in Radiotronics have in the past been re-issued in reprint form through advertising and similar outlets. We now plan to offer this service to Radiotronics readers. Articles which we plan to issue as a reprint will in future carry a distinguishing mark. Copies of the article will then be available free and post free to readers requesting them.

READERS' PHOTOSTAT SERVICE

We frequently receive requests for copies of Radiotronics, or articles and circuits therefrom, which are now out of print. Frequently only a circuit is required. Alternatively, where constructional articles are carried, readers may like a copy of the diagrams so that the magazine may be kept clean. In such cases, as a service to readers, we offer full-size photostats at the nominal charge of 2/- per page or part of a page, post free. Requests for this service should specify full details of the material required, and be accompanied by a remittance for the full amount due.

Drift Transistors In Computers

General Description

The "Current Switching Model" is a system of using transistors in computer circuits in which full advantage may be taken of the properties of drift transistors. The system may be qualitatively described as follows:

1. All transistors are operated non-saturated. The minimum collector voltage may be set arbitrarily by the circuit designer.
2. The emitter current of an "ON" transistor is held constant and is essentially independent of any transistor parameters.
3. The system inherently uses no reactive components although these may be added in special cases.
4. Direct coupling is employed and the system may be made to operate with small voltage swings.
5. In general, the system uses a relatively large number of transistors and a relatively small number of diodes.
6. The system is capable of very fast switching speeds.

Detailed Description

The basic circuit for p-n-p transistors is shown in Figure 1. Assume that the base of the transistor T_1 is a slightly positive voltage, +E volts. The potential of both emitters will then be approximately 0 volts because the base of T_2 is at 0 volts. Thus the current will flow into the emitter of T_2 and T_1 will be cut off because its base is positive with respect to its emitter. If we ignore I_{co} and assume that $x = 1$, the collector current of T_1 is zero and the collector current of T_2 is 1. Thus the collector potential of T_1 is -V-RI/2 while collector potential of T_2 is -V+RI/2. We will define this state as the "1" state, i.e. positive input will be defined as binary "1". When the input is negative (or binary "0") the base of T_1 is negative with respect to the base of T_2 and T_1 now conducts the current I. The collector potential of T_1 is now -V+RI/2 and the collector potential of T_2 is -V-RI/2.

It should be noted that V, R, and I may be chosen independently and that the output level swing is symmetrical around -V volts.

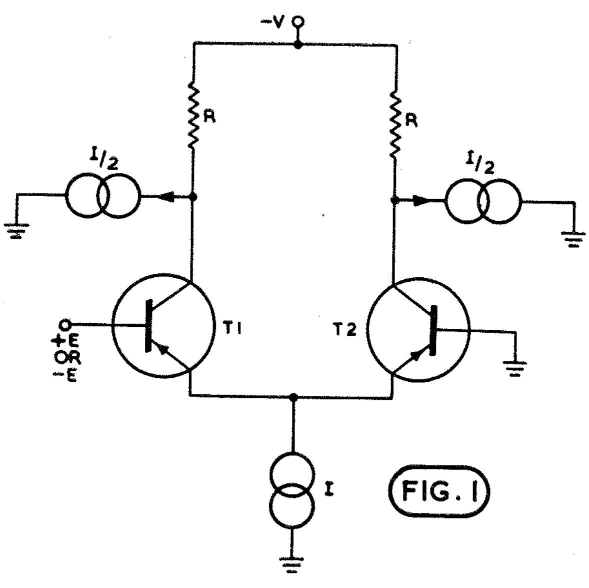


FIG. 1

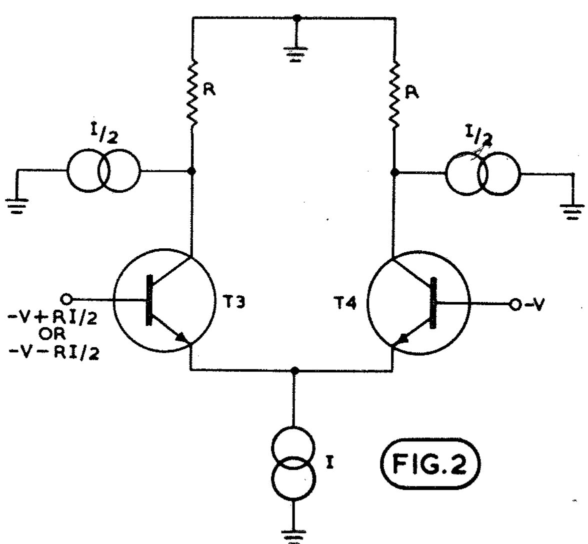


FIG. 2

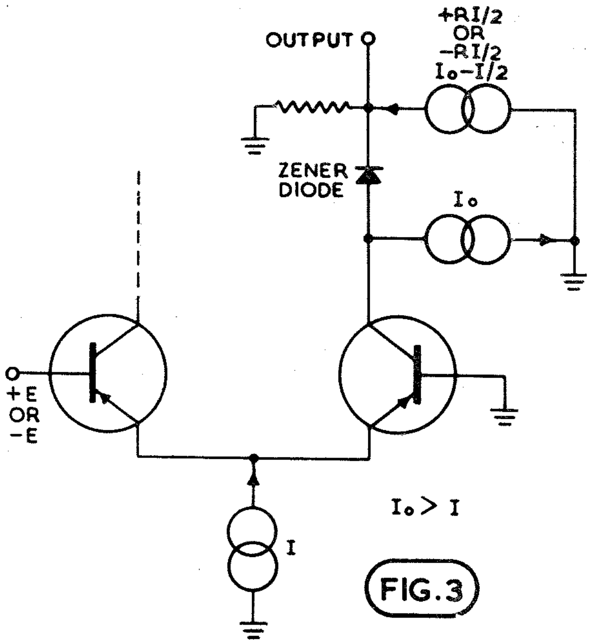


FIG. 3

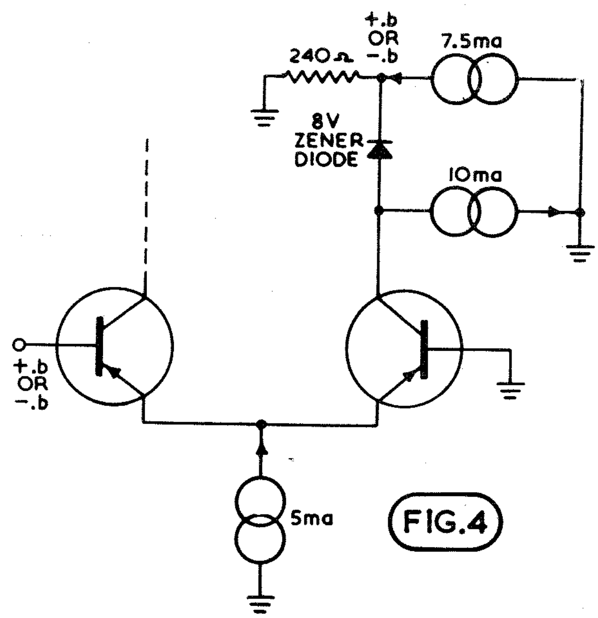


FIG. 4

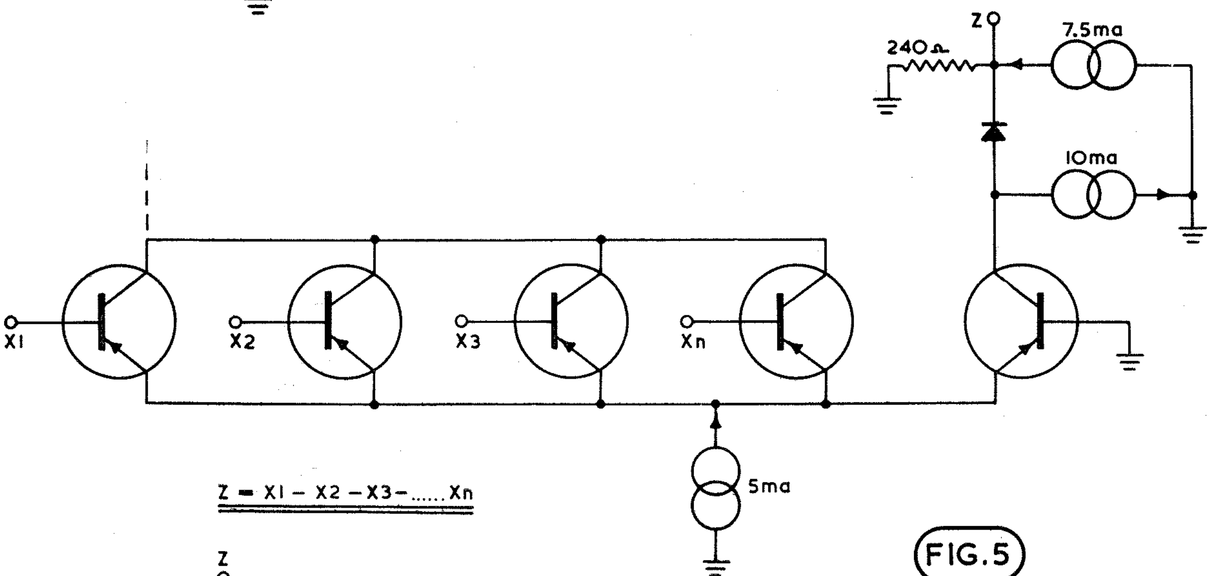
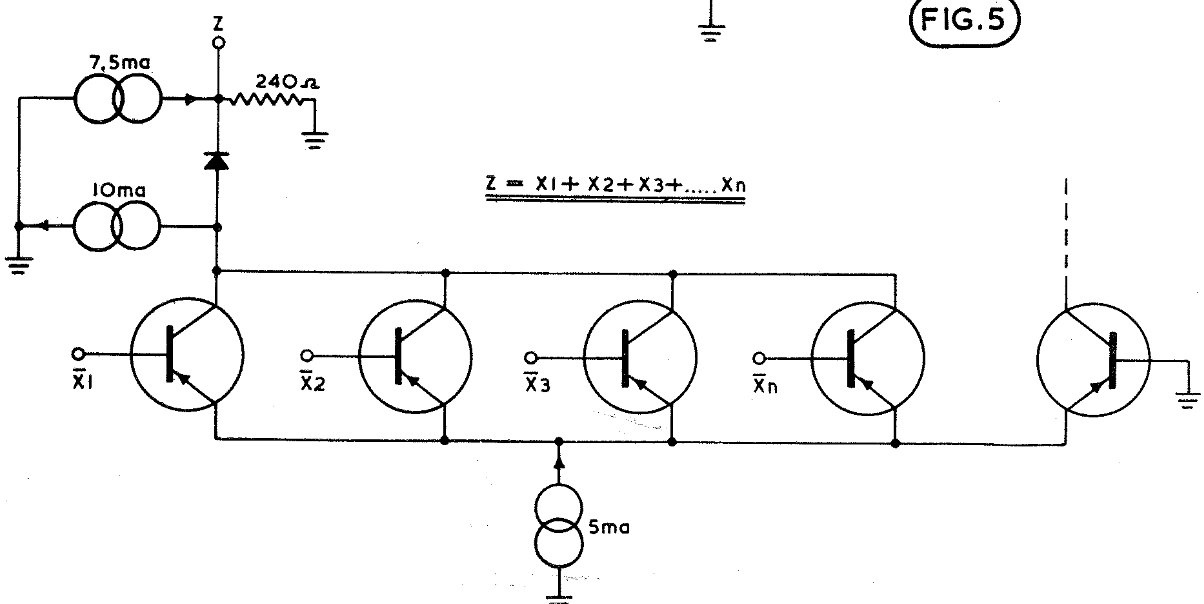


FIG. 5



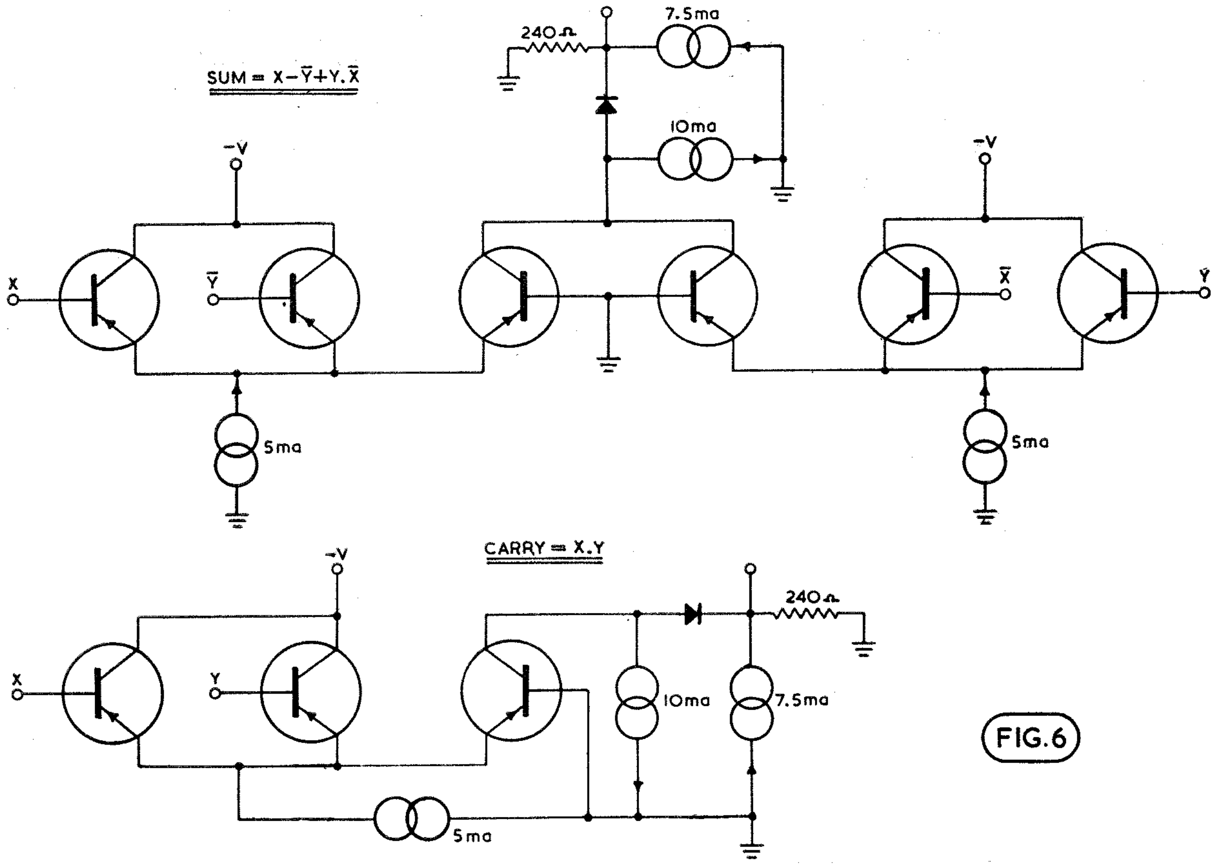


FIG.6

An important consideration in using current switching circuits is the method used to couple the output of one circuit to the inputs of other circuits. Two methods will be discussed; the first requires n-p-n transistors and is illustrated in Figure 2. Note that the base of T_4 is held at constant potential of -V volts.

Thus the symmetrical swing of $\pm RI/2$ volts around -V volts from the collectors of the p-n-p stage is just what is required to drive the n-p-n stage. The output of the n-p-n collectors is also seen to be symmetrical around ground and is therefore suitable to drive a p-n-p stage. The combatibility offered by the use of alternate p-n-p/n-p-n stages is a very important feature of the current switching mode of operation.

Another method which requires only one type of transistor employs a voltage translating device such as a zener diode. Figure 3 shows such a system. If the breakdown voltage of the zener diode is V volts, the operation of this circuit is such that the transistor operates with a collector voltage the same as in Figure 1 but the output is now symmetrical around ground and can thus be applied to the input of another p-n-p stage. A typical circuit is shown in Figure 4.

Logical operations may be performed with the basic circuit by the addition of one or more transistors. Figure 5 shows an n-input AND circuit as well as an n-input OR circuit. In Figure 6 the circuit of a half-adder is shown. The circuits shown in Figure 5 and Figure 6 assume a positive signal is binary "1".

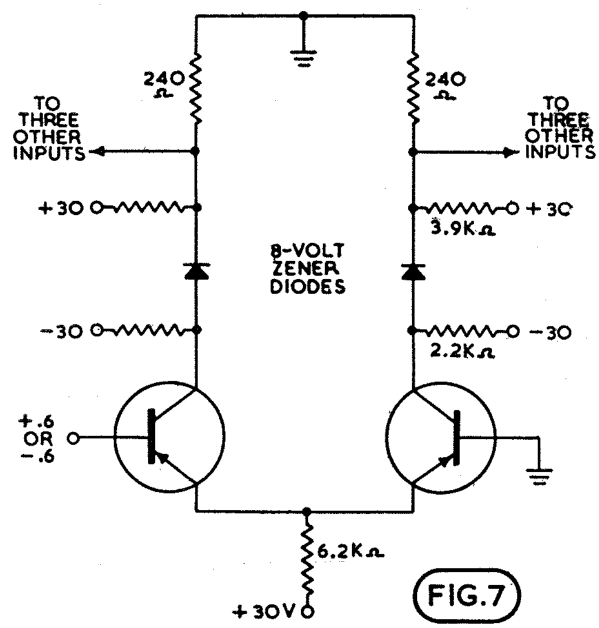


FIG.7

SUPPLY VOLTAGE TOLERANCE ± 10%
ZENER DIODE TOLERANCE ± 25%
RESISTOR TOLERANCE ± 5%

Figure 7 shows a practical circuit in which the current generators have been replaced by resistors and voltage supplies. Typical switching times of this circuit for two conditions of loading are shown in the table below:

Type	**Unloaded**				**Driving 3 other identical stages form each side**			
	TDR	**TR**	**TDF**	**TF**	**TDR**	**TR**	**TDF**	**TF**
2N269	25	75	20	80	30	280	30	300
2N247	25	25	20	30	25	180	20	180
TA-1692	8	15	4	30	8	60	4	60

All times are in millimicroseconds. TDR is the delay time from the leading edge of the input to the 10% point of the output, TR is the rise time, TDF is the delay time from the trailing edge of the input to the 90% point of the output, and TF is the fall time.

The input waveform had rise and fall times of approximately 15musec and the rise time of the scope used to measure the output was 13mμsec. The times shown for the unloaded condition are therefore somewhat pessimistic.

(With acknowledgement to RCA)

EDITOR'S NOTE

The drift transistor type TA-1692 is an RCA experimental type included because of the very short operating times. No commercial availability of this type has been announced.

NEW RCA RELEASES (Continued from page 30)

form thickness, permitting uniform sensitivity and dark current, and hence, high effective sensitivity over the entire scanned area.

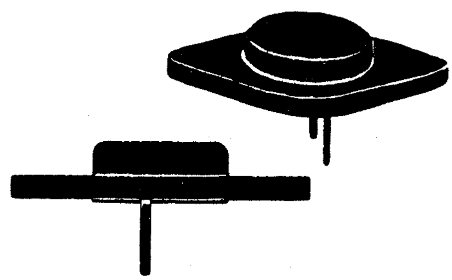
The design of the 7262 utilizes non-magnetic parts in the front end, an optically flat faceplate free from optical distortion, and an envelope without a side tip. Because of these features the 7262 is capable of providing excellent colour translation, colour uniformity, and balance when it is used in three-vidicon colour cameras.

RADIOTRON 7264

The Radiotron 7264 is a new head-on type multiplier phototube intended for use in scintillation counters for the detection and measurement of nuclear radiation, and in applications involving the measurement of low-level light sources. The 7264 has fast response, high current gain, high peak-current capability, extremely small spread in electron-transit time, and a pulse-height resolution of about 8 per cent.

Other design features of the 7264 include a semitransparent photocathode on the inner surface of the spherical faceplate of the tube; a minimum photocathode diameter of 1.68"; 14 electrostatically focused multiplying (dynode) stages; and a focusing electrode with external connection. The spectral response of the 7264 covers the range from about 3000 to 6500 angstroms. Maximum response occurs in the blue region at approximately 4400 angstroms. When operated at a supply voltage of 2000 volts, the 7264 has a median luminous sensitivity of 875 amperes per lumen and a current amplification of 12,500,000.

insulated mounting washers for power transistors



This article describes a method for mounting 2N301 and 2N301-A power transistors which provides electrical insulation of the collector electrode from the chassis without appreciable reduction in heat-transfer efficiency. This method makes use of anodized aluminium insulating washers or thin mica washers having relatively high thermal conductivity between the mounting flange and chassis and, therefore, permits these transistors to be operated at relatively high power dissipations in class B push-pull amplifier service and in applications where the chassis is connected to the positive terminal of the voltage supply.

Transistor Heat-Dissipation Considerations

The 2N301 and 2N301-A are alloy-junction power transistors of the germanium p-n-p type, designed specifically for use in class A or push-pull class B power-amplifier service. As shown in Table 1, the maximum power-dissipation ratings for these transistors vary with the temperature of the mounting flange, which is connected internally to the collector electrode. Because the collector should be maintained at the lowest practicable temperature, it is usually desirable to connect the mounting flange directly to a good "heat sink" (generally the chassis) so that heat generated at the collector junction will flow to the heat sink and be dissipated to the surrounding air.

In some circuits, however, particularly push-pull arrangements and those in which the chassis is connected to the positive terminal of the voltage supply, the collector must be electrically insulated from the chassis. If the maximum power capabilities of the 2N301 and 2N301-A are to be utilized in such circuits, this insulation must be accomplished without appreciable reduction of heat-transfer efficiency. An anodized aluminium or mica washer placed between the mounting flange and the chassis has the necessary heat-transfer efficiency and, at the same time, provides the required electrical insulation. In the case of the aluminium washer, the anodizing process coats the washer with aluminium oxide so that it becomes a good electrical insulator without losing its high thermal conductivity.

Preparation of Anodized Aluminium Washers

A detailed drawing of an aluminium washer suitable for use with the 2N301 and 2N301-A power transistors is given in Fig. 1. This washer, which is 0.125 inch thick, is easy to fabricate and is relatively inexpensive. The two mounting holes and the clearance holes for the emitter and base pins are drilled or punched in the washer, and any burrs are removed. Prior to anodization, the washers are (1) degreased in a solution of Diversey No. 202* (concentration 6 ounces per gallon of water) for 30 seconds at a temperature of 80 degrees centrigrade; (2) rinsed in water; (3) etched in a solution of Diversey Aluminux (concentration 4 to 6 ounces per gallon of water); (4) again rinsed in water; (5) cleaned in a concentrated solution of nitric acid; and (6) given another rinse in water. After this preparation, the aluminium washers are suspended in the electrolyte or anodizing bath, which contains 15 per cent. sulphuric acid by weight, and a current of 0.5 ampere is passed through the plating circuit for 30 minutes. A schematic representation of the anodizing process is given in Fig. 2. The electrolyte is cooled during the process so that its temperature is maintained at 23 degrees centigrade. An aluminium-oxide coating having a thickness of approximately 0.005 inch is developed on the washer. After anodization, the washers are given a final rinse in boiling water containing 2 to 3 drops of acetic acid per litre of water

The ability of the anodized washer to withstand abrasive forces depends primarily on the hardness, as well as the thickness, of the aluminium-oxide coating. In general, an aluminium-oxide coating having a thickness of 0.005 inch or more provides a surface which can withstand the normal abrasive forces encountered in production.

Preparation of Mica Washers

Fig. 3 shows a detail drawing of a mica washer suitable for use with the 2N301 and 2N301-A power transistors. This washer, which is 0.002 inch thick, is also easy to fabricate and is rela-

*Obtainable from Diversey (A'sia.) Pty. Ltd., Lane Cove, N.S.W.

Table I - Maximum Ratings for 2N301 and 2N301-A Power Transistors.

AUDIO-FREQUENCY POWER AMPLIFIER--Class A and Class B

Maximum Ratings, *Absolute Values:*	*2N301*	*2N301-A*	
PEAK COLLECTOR-TO-BASE VOLTAGE	-40 max	-60 max	volts
DC COLLECTOR-TO-BASE VOLTAGE (For inductive load)	-20 max	-30 max	volts
DC EMITTER-TO-BASE VOLTAGE	-12 max	-12 max	volts
PEAK COLLECTOR CURRENT	-3 max	-3 max	amperes
DC COLLECTOR CURRENT	-1.5 max	-1.5 max	ampere
PEAK EMITTER CURRENT	2 max	2 max	amperes
DC EMITTER CURRENT	1.5 max	1.5 max	ampere
TRANSISTOR DISSIPATION:			
For mounting-flange temperatures up to 80°C*	11 max	11 max	watts

* The maximum transistor-dissipation rating is reduced 1.0 watt for each degree centigrade the mounting-flange temperature is increased above 80°C.

tively inexpensive. The two mounting holes and the clearance holes for the emitter and base pins are punched in the washer. The thickness of 0.002 inch represents the minimum mica thickness which can be handled in production and still provide good electrical insulation and high conductivity without excessive flaking or cracking.

Mounting of Transistors and Washer to Chassis

As shown in Fig. 4, the anodized aluminium or mica washer is mounted between the copper flange of the 2N301 or 2N301-A power transistor and the chassis. All burrs should be removed from holes in the chassis to insure that the anodized insulating coating on the aluminium washers will not be destroyed during mounting. It is important that a fibre washer be used between the mounting bolt and the chassis, as shown in Fig. 4, to prevent a short circuit between them. A spring-type lock washer should also be used to compensate for dimensional changes in the fibre washer. Because either an anodized aluminium washer or a mica washer has relatively high thermal conductivity, the total thermal resistance of the collector circuit is not appreciably increased by the addition of the washer. Tables II and III show the effects of the washers on heat dissipation to the chassis and to the air surrounding the transistor. As shown in Table II, the heat transfer to the chassis drops less than 10 per cent. when either type of washer is used. For a constant power dissipation of 7 watts and transistor-case temperature of 55 degrees centigrade, the temperature of the chassis is 51 degrees centigrade

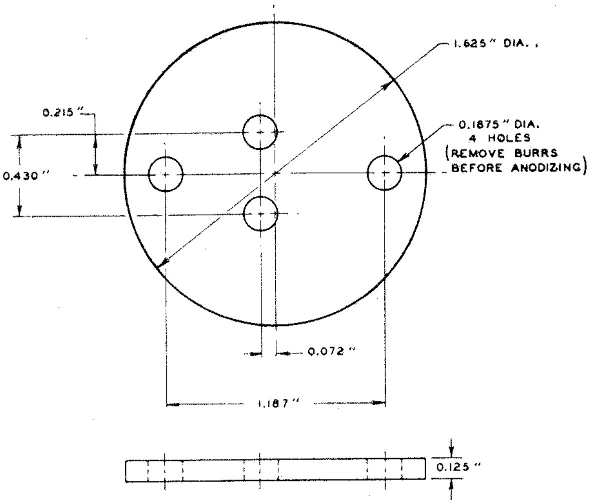


Fig. 1 — Detailed drawing of anodized aluminium washer for use with 2N301 and 2N301-A power transistors.

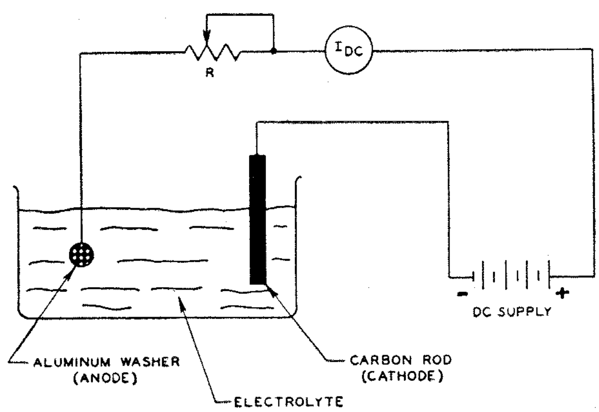


Fig. 2 — Schematic representation of anodizing process.

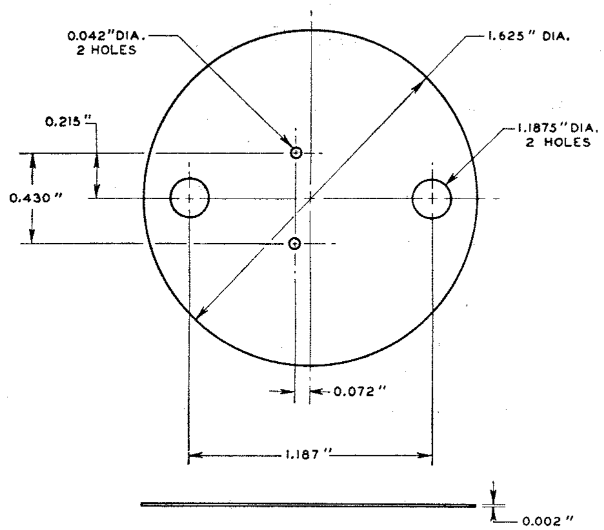


Fig. 3 — Detailed drawing of mica washer for use with 2N301 and 2N301-A power transistors.

when no insulator is used and 46.5 degrees centigrade when the anodized aluminium washer is used. When the 0.002-inch mica washer is used, the chassis temperature is 47 degrees centigrade. Table III shows that the heat transfer to the surrounding air also drops less than 10 per cent. when either the anodized aluminium washer or the mica washer is used. These tables also show changes in thermal resistance of the heat flow paths when the anodized aluminium or mica washer is inserted.

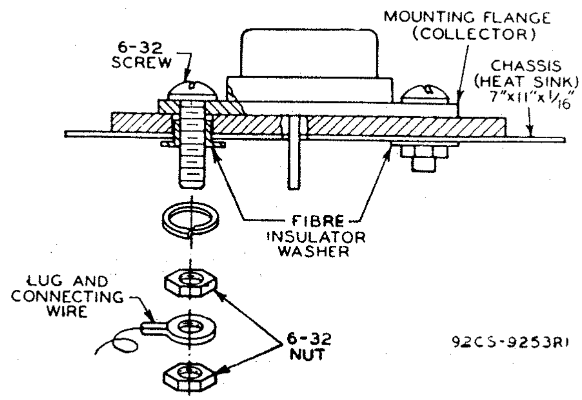


Fig. 4 — Method of mounting anodized aluminium washer or mica washer between power transistor and chassis.

Table II - Effects of Washer on Heat Transfer to Chassis (Power Dissipation = 7 watts)

Temperature of Transistor Case (°C)	Insulator	Temperature of Chassis (°C)	Thermal Resistance of Heat-Flow Path from Case to Chassis (°C/W)	Thermal Resistance of Insulator (°C/W)	Breakdown Voltage of Insulator (Volts)
55	none	51	0.57	-	-
55	anodized aluminum	46.5	1.21	0.64	250
55	mica	47.0	1.150	0.580	>250

Table III - Effects of Washer on Heat Transfer to Surrounding Air (Area of chassis = 77 sq. in.; thickness = 1/16 in.)

Temperature of Transistor Case (°C)	Insulator	Ambient Temperature (°C)	THERMAL RESISTANCE OF HEAT-FLOW PATHS (°C/W)		
			Case to Ambient	Collector to Case	Collector to Ambient
55	none	40°C	2.09	2.5	4.59
55	anodized aluminum	36°C	2.73	2.5	5.23
55	mica	39°C	2.67	2.5	5.17

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