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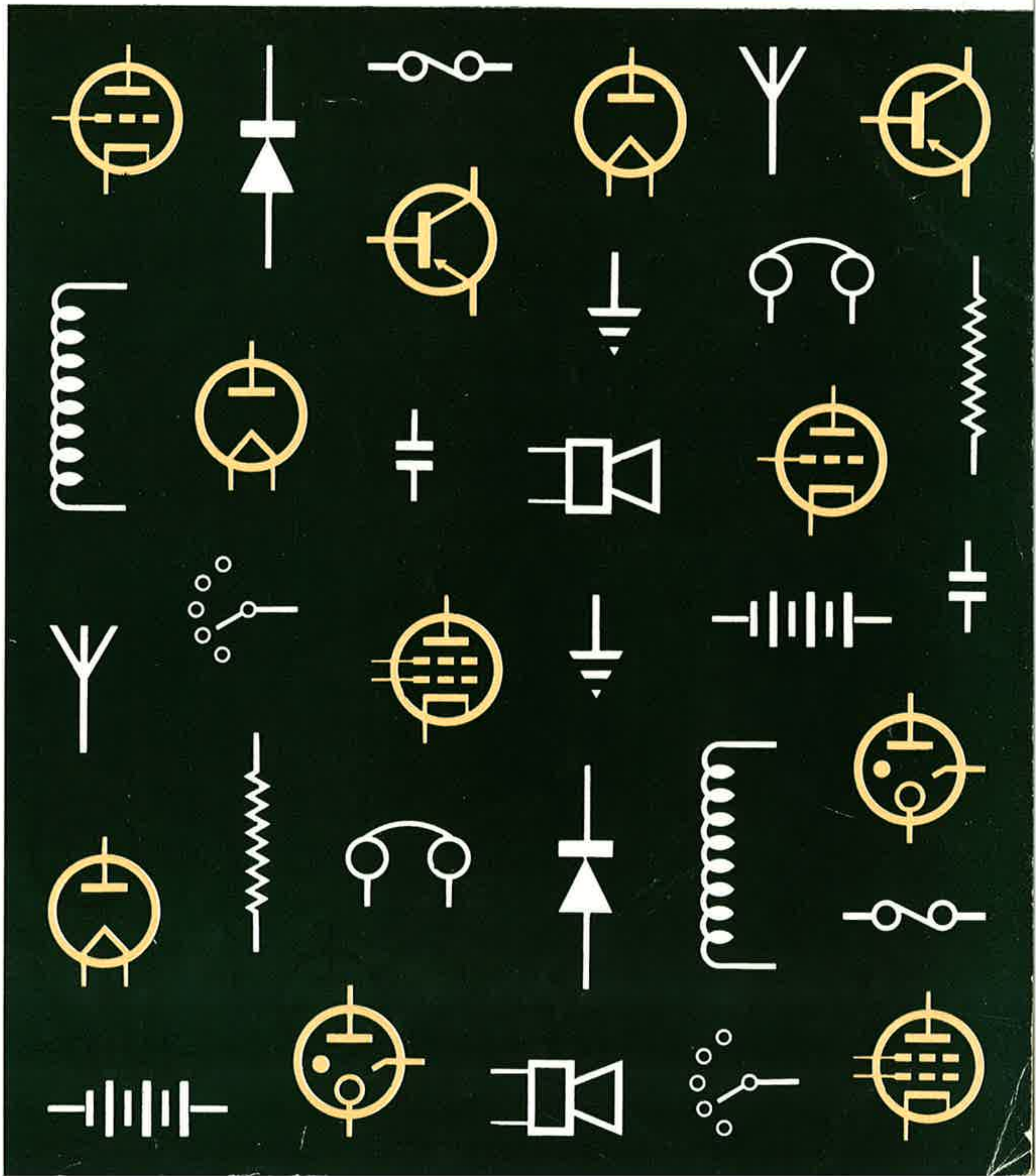

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IN THIS ISSUE

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THE JUNCTION TRANSISTOR

by R. W. Hurst

Part 1 — Basic Transistor Action, and the Common-Base Amplifier

This article, which will be published in three parts, is abstracted from a group of transistor lectures given jointly by the author and Mr. A. C. Luther. The author wishes to acknowledge the fact that many of Mr. Luther's valuable contributions to the lectures have been retained in these articles.

As transistorized equipment comes into use, the engineer will find that a new dimension must be added to his field of knowledge. Transistors — described in simple terms as crystal valves — will put new demands on the skill and ability of the men who install, maintain, and repair electronic equipment. To help engineers acquire this new skill, we present here an explanation of the fundamental behaviour of junction transistors in familiar terms. In these articles, the physicists' point of view of a transistor is intentionally avoided in order to permit the reader to approach this new subject through the concepts of well-known electronic circuits.

The year 1959 marked the tenth anniversary of the invention of the transistor, which during this time has developed from an unpredictable device with sharply limited applications to a stable and reproducible element, which can be employed in a wide variety of circuits. During these years of development, engineers have kept a watchful eye on this promising device. Circuits using transistors were regularly evaluated, and those meeting required standards of quality were incorporated into products. Until recently, however, these products were limited to audio devices because no commercially available transistors were capable of acceptable high-frequency operation. Recently, there has been an accelerated development of new devices and techniques which promise to put the transistor into all types of equipment. Even as this is written, the forerunners of many kinds of equipment using transistors are taking shape.

Hence it is important for the engineer to know something of the characteristics of transistors; how they operate; what their limitations are; what their advantages are; and, ultimately, to

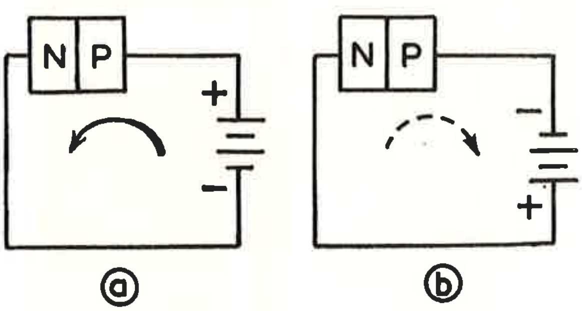


Fig. 1

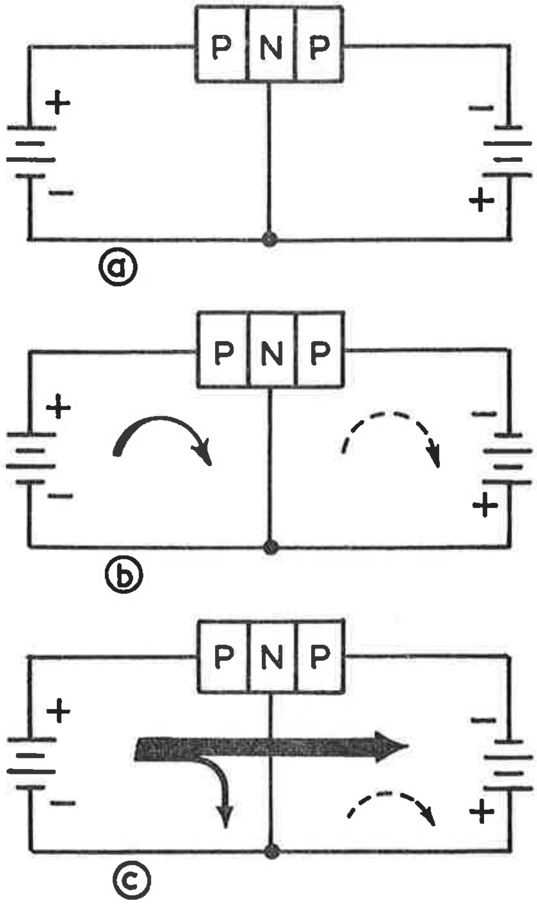


Fig. 2

become as familiar with transistor circuitry as he is with valve circuitry.

Basic Transistor Action

A transistor may be considered as an extension of an ordinary junction diode, which consists of two pieces of semiconductor material of slightly different composition, joined together with wire leads provided for connection to each piece. Although the difference in the chemical compositions of the two pieces is slight, the difference in their electrical characteristics is very great. To identify these different materials, one is called p-type material, and the other, n-type material. The physics of these differences is not discussed here, it is sufficient to say that a junction will conduct heavily if a voltage is placed across it with the p-type material positive and the n-type negative, as shown in Fig. 1a, but will conduct only slightly if the polarity is reversed as shown in Fig. lb. When the diode is conducting heavily, it is said to be FORWARD biased; when it is conducting only slightly it is REVERSE biased.

If this diode structure is extended to include another junction, leaving the original junction reverse-biased as above, and providing a forward bias for the new junction diode which was formed by adding the left-most p-region, the circuit will appear as shown in Fig. 2a.

One might expect (wrongly) that a heavy current would flow in the forward-biased diode, a small current would flow in the reverse-biased diode, and there would be no interaction between the two diodes. That is, one might expect to see the situation shown in Fig. 2b.

This is not the case however. For the circuit shown, the forward-bias current of the left-hand diode would flow completely through both junctions, except for a small current which would flow out of the n-region in the centre of the configuration. The true situation therefore is shown in Fig. 2c. This unexpected behaviour, which is observed only if the centre region is thin, is the basis for transistor action.

Since the left-hand p-region emits current into the transistor, it is called the emitter. The middle region (the n-region here) through which the

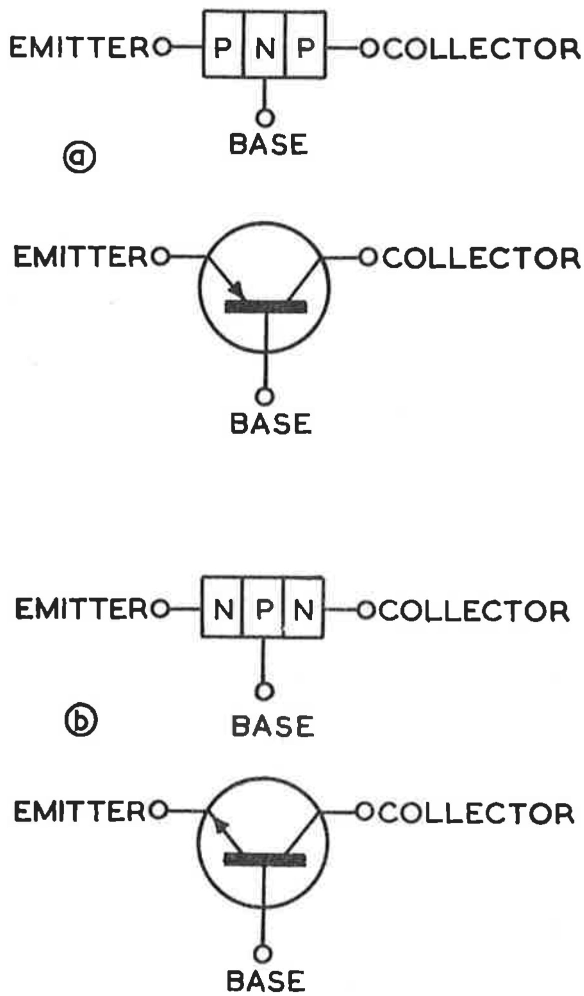


Fig. 3

emitter current passes is called the base. The right-hand p-region, which collects the current emitted by the emitter, is called the collector.

A transistor constructed in this manner is called a p-n-p transistor. By reversing the order of arrangement of the sections of p-type and n-type material, a different type of transistor is formed, known as an n-p-n type. Type p-n-p and n-p-n transistors are shown respectively in Figs. 3a and 3b, together with the graphical symbol used to denote them in schematic diagrams.

It will be noticed that both n-p-n and p-n-p transistors exhibit left-to-right symmetry; that is, the emitter and collector of a given transistor are both made of the same material, and apparently connected to the base in the same way. It is reasonable to ask whether it makes any difference which of the outer regions is the emitter and which the collector. In some transistors, called symmetrical transistors, it makes no difference.

In most transistors however, the emitter and collector regions are manufactured differently. It is this difference which determines the proper naming of these regions. Regardless of this difference, a typical small transistor may usually be made to operate in a very limited manner with emitter and collector leads interchanged. This is not recommended however, and is of purely academic interest.

The transistor, being an amplifying device, is comparable with an electron valve in that the three "elements" of a transistor correspond (approximately) to the three elements of a triode. The emitter, base and collector of a transistor may be compared with the cathode, grid and anode of a triode valve.

One should not infer, however, that these equivalences are anything but approximate. For example, consider the difference between a grid and a base. A grid, in normal negative-biased operation, draws no current. The total cathode current flows in the plate circuit of a valve.

It was stated above, however, that the emitter current in a transistor divides between the collector and the base, so that the base has an appreciable current owing in it. A comparison between the electron valve and the transistor in this regard is shown in Figs. 4a and 4b respectively.

Since the current that flows (for a given voltage) is an indication of the impedance of a circuit, the fact that the base draws current while a grid does not leads to the conclusion that the impedance seen looking into a base would be very much smaller than the impedance seen looking into a grid. The conclusion is correct; a typical valve, it is well known, has a grid impedance of several megohms, while a typical transistor may have a base impedance less than 2,000 ohms.

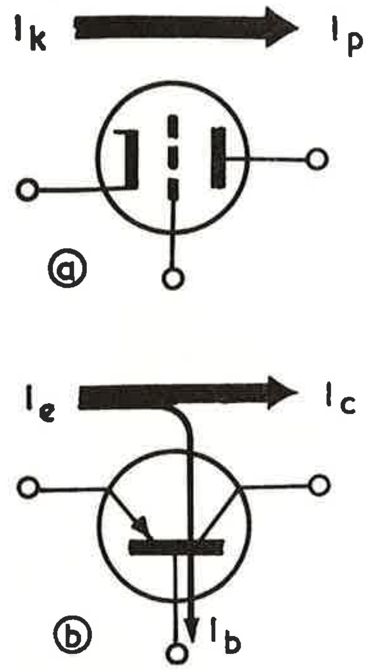


Fig. 4

Definition of Alpha and Beta

Although sufficient current flows in the base circuit to make the base appear as a low impedance, this base current represents only a small portion of the emitter current — approximately two per cent in a typical transistor. The remaining 98 per cent appears in the collector circuit. This current division used to define an important transistor parameter called alpha. If 98 per cent of the emitter current of a certain transistor flows in its collector, the transistor has an alpha of 0.98. Mathematically, it is stated:

$$\alpha_{DC} = \frac{I_c}{I_e}$$

Since I_c (dc collector current) and I_e (dc emitter current) are bias currents, their ratio is called dc alpha, hence the dc subscript. The more frequent use of the word alpha refers to a ratio of signal currents (where i_c and i_e are signal currents in the collector and emitter, respectively):

$$\alpha_{AC} = \frac{i_c}{i_e}$$

The word alpha as used herein always refers to the ratio of signal currents, unless there is a statement to the contrary. It is interesting to note, in passing, that both definitions give almost the same value for alpha.

Since the collector current is always a little less than the emitter current, alpha will always be a little less than one. Therefore, a transistor will offer loss instead of gain for a current signal impressed on the emitter and observed at the collector. Nonetheless, useful arrangements can be made using this circuit, even though it does not give a current gain. Some of the ways of using this configuration, which is called the grounded-base configuration, are discussed later in this article.

How, then, is current gain obtained? It is obtained by controlling the base current (two percent in the foregoing example) by applying a signal to the base. The base current, when controlled by a small fluctuating (signal) current, causes a corresponding fluctuation in the much larger emitter current, thereby causing the same fluctuation in the collector current. Fig. 5 shows how the signal current controls the collector current.

Since the small signal-current introduced in the base circuit causes a larger signal-current to appear in the collector circuit, we say that a current gain has taken place.

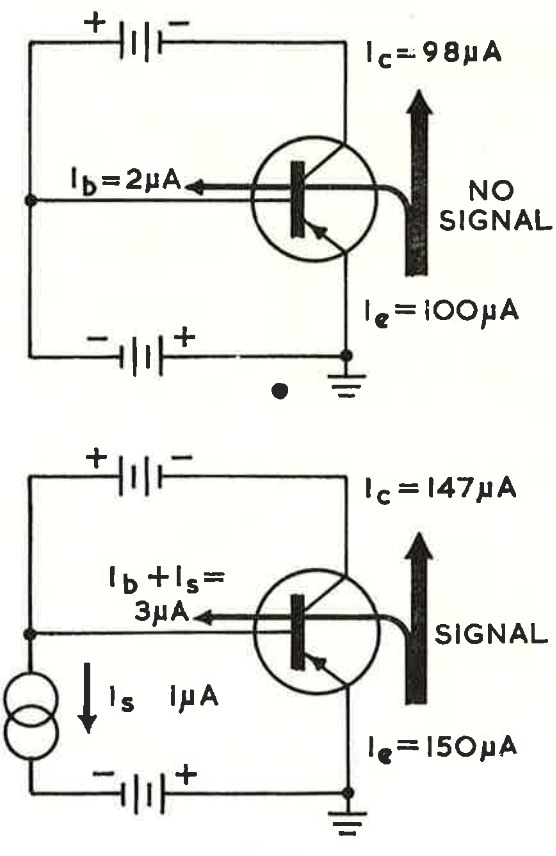


Fig. 5

The current gain obtained here is clearly the ratio between the collector current and the base current. This current ratio is another important transistor parameter, and is called beta. Mathematically, it is stated:

$$\beta_{DC} = \frac{I_c}{I_B}$$

This ratio is called dc beta, for reasons similar to those given for dc alpha. More frequently, the word beta refers to a ratio of signal currents:

$$\beta_{AC} = \frac{i_c}{i_B}$$

This definition of beta is the one which is used in this article unless there is a statement to the contrary.

In Fig. 5, a signal current of 1 μa in the base caused a change of 49 μa (147 μa — 98 μa) in the collector current. The beta of this transistor would be —

$$\beta = \frac{49}{1} = 49,$$

which is a fairly typical value.

Note that in the configuration employed to give current gain, the ground point was moved from the base to the emitter. This circuit is therefore called the grounded-emitter configuration, or common-emitter* configuration. It is roughly equivalent to the grounded-cathode configuration of a valve, but the analogy should be employed with caution. For example, it has already been pointed out that the impedance, looking into the base, is typically 2000 ohms, instead of the high impedance usual for a valve grid.

Note also that signals and biases in transistors are described as currents, not as voltages, as is common in valve. The gain (beta) which roughly corresponds to mu in a valve, is a current ratio, whereas mu is a voltage ratio. It is usually much more convenient, for transistor work, to describe the circuits in terms of currents, rather than in terms of voltages.

Characteristic Curves of Transistors

In the introduction to this subject, the transistor was presented as an extension of an ordinary junction diode. This same approach can be used to derive the characteristic curves of a typical

* In these articles, the prefix "common-" will be used in preference to "grounded-," since it is more general. For example, it is not unusual to have a common-emitter amplifier in which the emitter is not connected to ground.

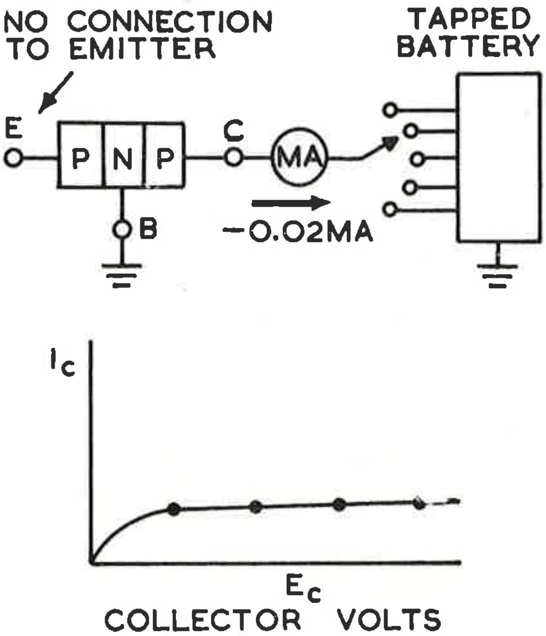


Fig. 6

transistor, which show very clearly the behaviour that can be expected.

If we set up a laboratory experiment in which we apply several different reverse-biasing voltages to a junction diode, and measure the resulting currents, as shown in Fig. 6, we can plot from the resulting data a curve showing the reverse-bias characteristic of a junction diode.

The fact that the junction diode is in fact part of a transistor will not change the curve when there is no connection to the second "diode", in this case the emitter. The battery current is marked negative because it flows out of the transistor.

Conventional network theory states, arbitrarily, that current flowing into a network is positive; current flowing out, negative. This convention is followed in these articles. It is also used in transistor data sheets.

The case must now be considered where forward bias is applied to the second "diode" of Fig. 6, i.e., the emitter. This after all is the way we establish transistor action. A forward bias applied in this way will cause a definite change in the curve, since the forward-bias current will flow through both junctions and appear in the circuit containing the milliammeter.

Fig. 7 shows the additional current flow, which will displace the entire I_c/E_c curve upwards as shown. If we choose a different value of emitter current — say 3.0 ma instead of 2.0 ma — the curve will be displaced upward even further. By selecting several different values of emitter current and showing a curve for each value, a complete family of curves can be built up. The family of curves shown in Fig. 8 is typical of those found in transistor data sheets.

It will be noted that these curves are drawn for a transistor operating with grounded base. Therefore, these curves are called common-base curves, and an amplifier built using a transistor connected in this manner is called a common-base amplifier. These curves can be used to show the behaviour of a common-base amplifier.

Transistor Amplifier

Let us suppose that a piece of equipment contains the common-base transistor amplifier, using a p-n-p transistor, shown in Fig. 9. We wish to know how this amplifier is operating — what the bias is, how much collector current flows, how much power is dissipated in the collector, and how much gain it will offer. All these facts may be ascertained by a simple construction on the common-base characteristics.

Start by drawing a load line on the characteristics. This construction is exactly the same as the corresponding construction on valve characteristics. You will remember that a typical pentode in a circuit with a B + voltage of 200 volts and a plate load resistor of 5,000 ohms will have a load

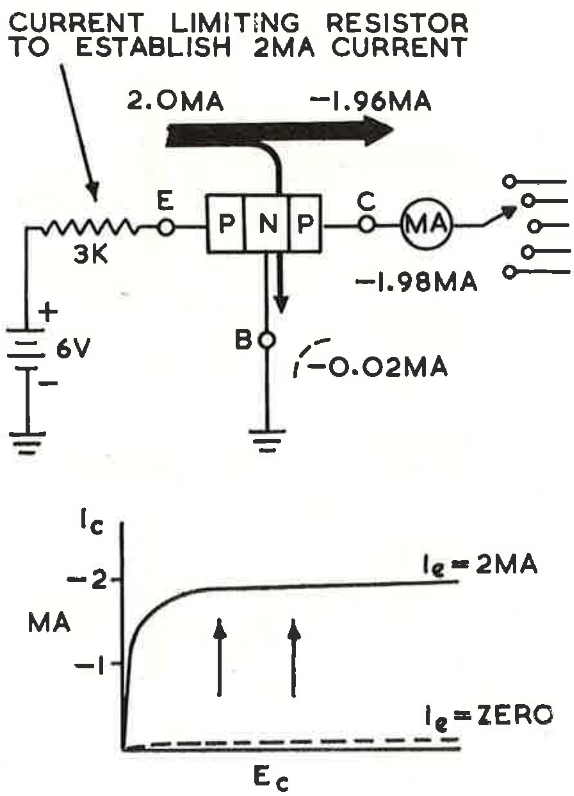


Fig. 7

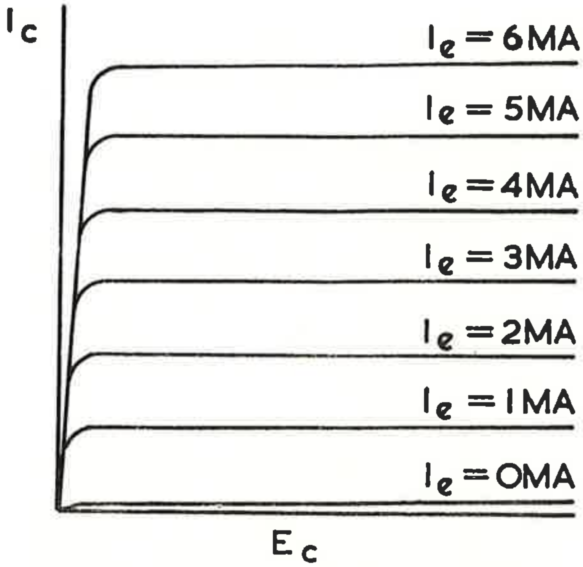


Fig. 8

line drawn on its characteristic curves joining the 200-volt point and the 40-ma point. (The 40-ma point is obtained by dividing 200 volts by 5,000 ohms.)

In an exactly similar manner, the load line for the common-base amplifier will be a straight line connecting the -20-volt point and the -4-ma point, as shown in Fig. 10. Just as for valves, the operating point of the transistor amplifier must lie somewhere on its load line. For the pentode, the operating point lies at the intersection of the load line and the curve representing the particular bias chosen by the design engineer.

The bias for this transistor amplifier, however, is a current, not a voltage. The bias current is that current which the 6-volt supply can cause to flow in the series combination of the 3,000-ohms resistor and the forward-biased emitter junction.

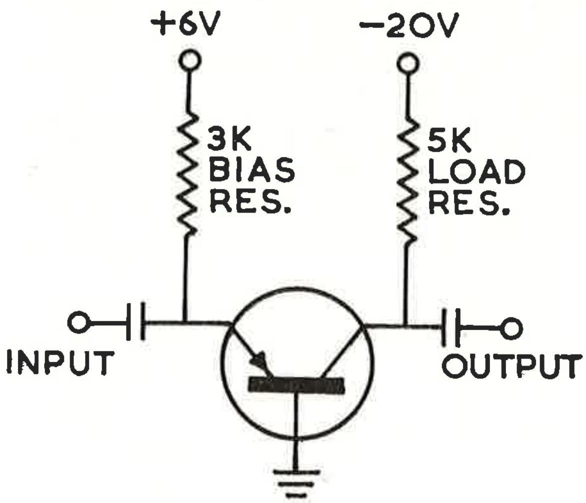


Fig. 9

The comparison of grid bias and emitter bias could confuse the reader into thinking the grid and emitter are equivalent. They are not; the comparison is used merely because the graphical constructions are similar. The grid corresponds to the base.

Since the emitter resistance is usually very small (less than 50 ohms), its resistance may be neglected in computing the bias current. The current is therefore:

$$I_e = \frac{6 \text{ volts}}{3{,}000 \text{ ohms}} = 2 \text{ ma}$$

which will put the operating point at the intersection of the load line and the 2-ma curve, as shown in Fig. 10. This transistor amplifier therefore operates with a bias current of 2 ma, a collector current of -1.96 ma, and a voltage at the collector of -10.2 volts.

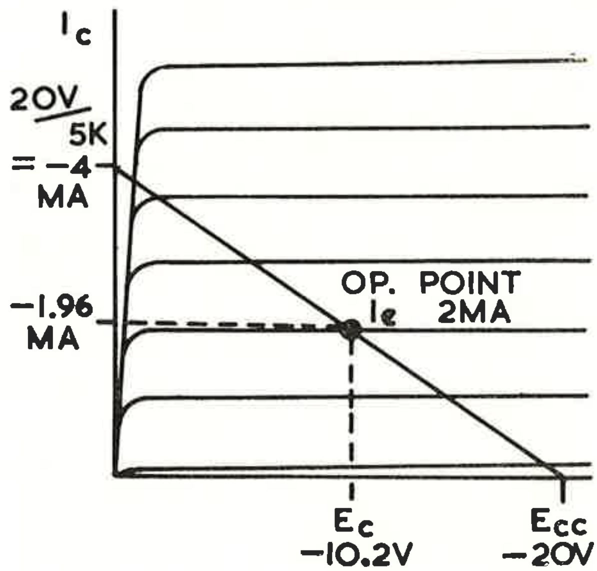


Fig. 10

The power dissipated at the collector is given by the formula: P=IE=(-1.96 ma)(-10.2 volts) = 19.9 milliwatts. The gain of this amplifier depends upon whether it is being used to obtain voltage gain or current gain. Its voltage gain can be large; its current gain is always less than unity; that is, this amplifier produces current loss instead of gain. Its actual current gain is equal to alpha, about 0.98 for a typical transistor.

The voltage gain (the ratio of output to input voltages) can be calculated from the output and input impedances. The output impedance, in this case, is known to be a 5000-ohm resistor, but the input impedance was stated vaguely to be "less than 50 ohms." Fortunately, there is a simple way to calculate the input impedance (emitter resistance). It is given by the formula:

$$R_e = \frac{25.6}{I_e}$$

This expression is derived from basic semiconductor physics. It can be shown that $R_e = (kT/e)/I_e$, where k is Boltzman's constant, T is the absolute temperature, and e is the charge on an electron. Inserting proper values gives a value of 25.6 for kT/e, at 25 degrees Centigrade. This is a theoretical value subject to appreciable variation in practical transistors.

In this formula R_e is the emitter resistance in ohms, and I_e is the emitter current in milliamperes. For the transistor amplifier in this example, the emitter is biased with 2 ma, so the emitter resistance is:

$$R_e = \frac{25.6}{2\text{ ma}} = 12.8\text{ ohms}$$

Now, knowing both input and output impedances, we can calculate the voltage gains. If a 1-ma signal flows into this amplifier, it will produce a 12.8 millivolt swing across the 12.8-ohm emitter resistance.

Almost all of the 1-ma signal current (98 per cent of it) flows in the 5000-ohm load resistor, producing a 5-volt drop across it. The voltage gain in this case is:

$$G_v = \frac{5\text{v}}{12.8\text{ mv}} = \frac{5}{0.0128} = 391$$

The same answer can be obtained by taking the ratio of the output and input resistances:

$$G_v = \frac{5{,}000\text{ ohms}}{12.8\text{ ohms}} = 391$$

The same common-base amplifier, then, can provide a voltage gain of 391, but give a current gain of less than 1. It is clearly to our advantage to use this type of amplifier as a voltage-gain device. But what makes the difference between a voltage amplifier and a current amplifier?

Voltage Versus Current Amplifier

The distinction between a voltage amplifier and a current amplifier is mainly one of convenience. A voltage amplifier is one whose input signal comes from a constant-voltage source (note, this term is defined below). When an amplifier is driven from a constant-voltage source, its input voltage is known or easily determined. If the output voltage is also known or easily determined (as it usually is), it is easy to take the output-to-input ratio, which gives the voltage gain. Under these circumstances, it is convenient to consider the amplifier as a voltage amplifier.

Similarly, if an amplifier's signal source is a constant-current source it is convenient to consider it as a current amplifier, for the ratio of input-to-output currents may be easily determined. This ratio gives its current gain.

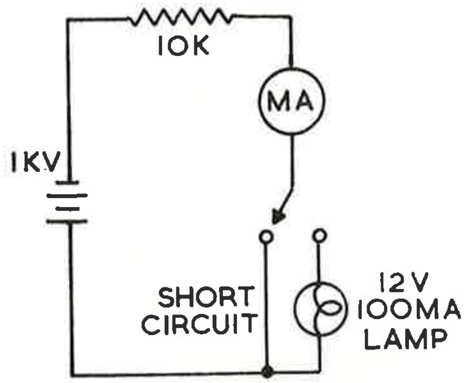


Fig. 11

Constant-Voltage Versus Constant-Current Sources

Practical approximations to constant-voltage sources are familiar to almost everyone. A battery is a good example of a dc constant-voltage source. Note that a 12-volt storage battery lights a lamp when the switch is thrown. When the switch is open, the voltmeter reads 12 volts. When switch is closed and the lamp is connected, the voltmeter shows no perceptible change in voltage. Therefore, the storage battery is a constant-voltage source, for its output voltage does not change when the load is connected.

Constant-current sources are less common, but one can be synthesized for the purpose of explanation. This is done in Fig. 11, in which a 1000-volt battery supplies current to a lamp or to a short-circuit, depending on the position of the switch.

When the switch is in the short-circuit position, the milliammeter indicates that 100 ma flows in the circuit. When the lamp is lit, the milliameter shows no perceptible change in the 100-ma current. We therefore say that the battery-plus-resistor combination is a constant-current source, for its output current does not change when the short circuit is replaced by the load.

One can easily see that these "constant" sources are only approximately constant. How nearly constant they remain depends upon the relationship between their internal impedances and their respective load impedances. In practical cases, a source is called a constant-voltage source when its internal impedance is much less than the impedance of the load it feeds. Likewise a constant-current source is a source whose internal impedance is much greater than the impedance of the load it feeds. Inspect the two dc examples above, to verify these statements. (The 12-volt lamp has an impedance of 120 ohms.)

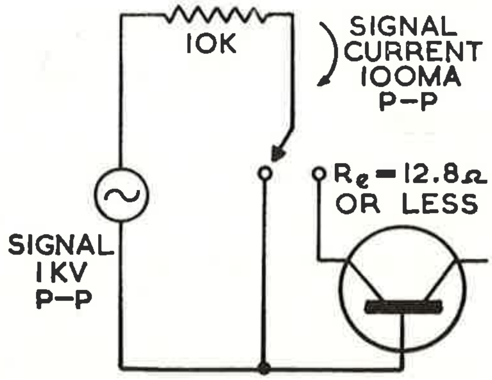


Fig. 12

Voltage Versus Current Amplifiers

Through valve experience, it has become the custom to think of all amplifiers as voltage amplifiers, since the grid of a valve makes almost any source look like a low-impedance (constant-voltage) source, by comparison.

With transistors it is not always thus. If a common-base amplifier has an input impedance of 12.8 ohms, it must be fed from a source of even lower impedance in order to be conveniently classed as a voltage amplifier.

This is not always practical. Transformers may be used to obtain such low impedances in narrow-band or tuned amplifiers, but wide-band amplifiers usually cannot make practical use of such an arrangement.

On the other hand, transistors are particularly well-suited for operation as current amplifiers. A transistor — especially in the common-base configuration — has such a low-impedance input that many sources are higher-impedance in comparison, and therefore are treated as current sources. Consider, as an example, the dc current source used as an example above, but with an ac signal in place of the battery; see Fig. 12.

The impedance of the source, 10,000 ohms, is certainly much greater than the impedance of the emitter. The emitter resistance of 12.8 ohms was calculated for a bias current of 2 ma. To operate linearly with a signal swing of 100 ma, bias current would have to be at least 50 ma, which would give an emitter resistance R_e of 0.51 ohms. A constant signal current of 100 ma, peak-to-peak, will flow, without regard for the position of the switch. Driven thus from a constant-current source, the transistor may most easily be regarded as a current amplifier.

Unfortunately, this particular configuration does not give a useful current gain. With a 100-ma signal flowing into the emitter, only a 98-ma signal will flow from the collector (if alpha = 0.98). The common-base amplifier actually gives a current loss instead of a current gain.

The behaviour of a common-base amplifier may be summarized thus: If a very low-impedance source is available, it will operate as a voltage amplifier, giving large voltage gains. Such sources are rather uncommon, however, particularly for wide-band amplifiers. If a moderately-high-impedance source is available, it will operate as a current amplifier, but will give a current gain of less than one, and hence is not useful.

In spite of such stringent restrictions, the common-base configuration is frequently used in a large variety of circuits. It will be seen acting as an impedance transformer, as a capacity isolator, or as a means of obtaining non-inverted gain from a valve. Examples of these three applications are given below.

Transistor Application as Impedance Transformer

The common-base configuration can be put to practical use in improving the gain obtainable from a delay-line driver. This application is an example of its use as an impedance transforming device.

Consider the circuit of Fig. 13a, in which a pentode drives an 8-ma peak-to-peak signal into a delay line which must be terminated in its characteristic impedance of 200 ohms. The 8 ma will divide equally between the input termination and the output termination.

The 4 ma that flows at the output will result in an output signal of:

$$e_o = iR = (4 \text{ ma})\ (200 \text{ ohms}) = 0.8 \text{ volts}$$

A considerable improvement in the output level can be made by inserting a transistor in the manner shown in Fig. 13b. (Means of biasing are ignored to keep the picture uncluttered). In this case, the 4-ma signal flows through the transistor and appears (except for the two per cent lost in the base, which we ignore here) in the collector

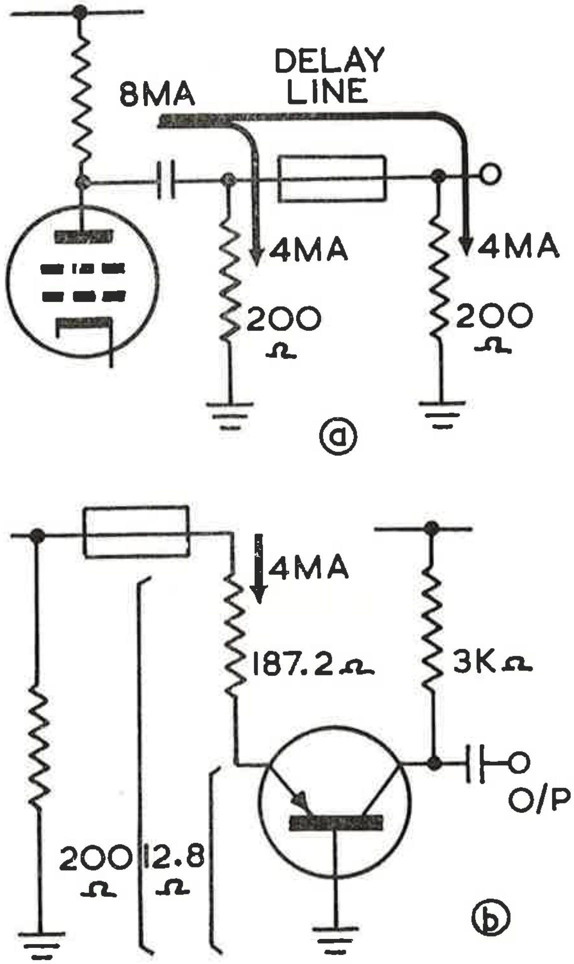


Fig. 13

circuit. The voltage output from this circuit is:

$$e_o = iR = (4\text{ ma})\ (3{,}000\text{ ohms}) = 12\text{ volts}$$

This is an effective gain of 15 over the first circuit.

Capacity Isolator

A common-base amplifier used as a capacity isolator can also give an effective gain. Consider the circuit of Fig. 14a. In this circuit a total of 60$\mu\mu$f of stray capacity shunts R_L, the 20,000-ohm load resistor. If the stray capacitance were less, a larger load resistor could be used. The signal voltage available at the grid of the valve would then be greater, in direct proportion to the size of the load resistor. As the circuit now stands, however, 20,000 ohms is about the largest practical value of load resistor. Now let the circuit be modified as shown in Fig. 14b. Note that only $15 + 5 = 20$ $\mu\mu$f appears across the load resistor. Since this is only 1/3 of the 60 $\mu\mu$f of the first circuit, R_L can be 3 times as big, or 60,000 ohms. The result is an effective gain of three.

Preserving Signal Polarity

A common-base amplifier can also be used to preserve the polarity of a signal, whenever necessary. If a valve giving a gain of ten is required to amplify a pulse, the circuit shown in Fig. 15a might be employed if an output signal of inverted polarity could be used.

However, if a noninverted pulse is required, the above circuit cannot be used. (A noninverted pulse can be obtained at the cathode, but not at the required level.) To obtain a non-inverted pulse of the required amplitude, a common-base transistor amplifier could be added as shown in Fig. 15b.

This circuit gives almost the same gain as the first circuit, and does not invert the signal.

Power Gain

A common-base transistor resembles a transformer in its ability to give voltage gain, but with an important difference.

The difference lies in the transistor's ability to give a power gain as well. For example, consider a 10-to-1 step-up transformer in which the primary signal voltage and signal current are 0.2 volt and 10 ma, respectively. The secondary vol-

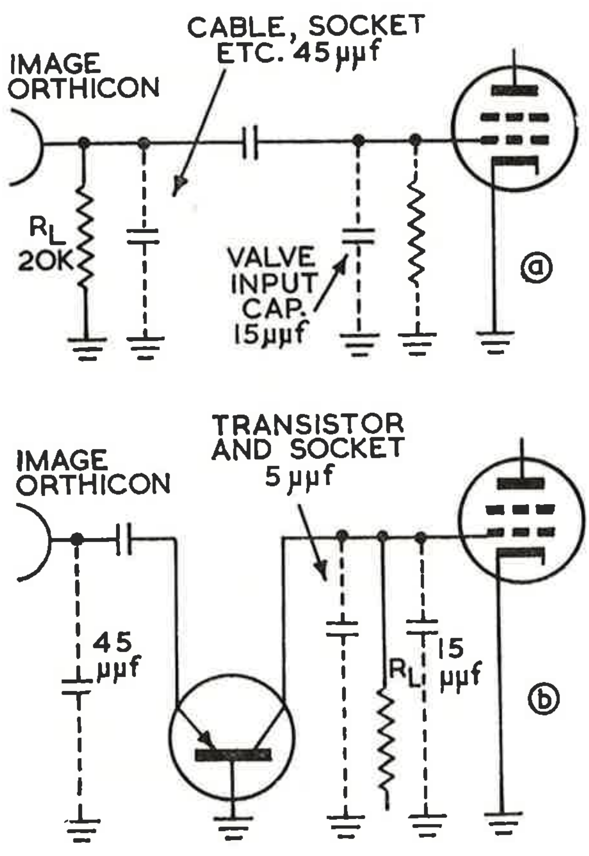


Fig. 14

tage will then be 10 times as great (2 volts) and the secondary current 1/10th as great (1 ma).

The power at the output, (neglecting losses) is the same as the power at the input:

$P_{in} = E_{in} . I_{in} =$ (0.2 volts) (10 ma) $=$ 2 milliwatts.

$P_{out} = E_{out} . I_{out} =$ (2 volts) (1 ma) $=$ 2 milliwatts.

Now, compare a transistor with input similar to the 10-to-1 step-up transformer; see Fig. 16a. The transistor can be given a collector load which will give the same signal voltage gain as the 10-to-1 step-up transformer. The signal current, however, at the output is not reduced proportionally, but instead is virtually the same as the input current; see Fig. 16b.

Therefore, the signal power at the output is ten times greater than at the input:

$P_{in} = e_{in} . i_{in} =$ (0.2 volts) (10 ma) $=$ 2 milliwatts.

$P_{out} = e_{out} . i_{out} =$ (2 volts) (10 ma) $=$ 20 milliwatts.

This power gain is a better indication of a transistor's gain capabilities than is voltage gain

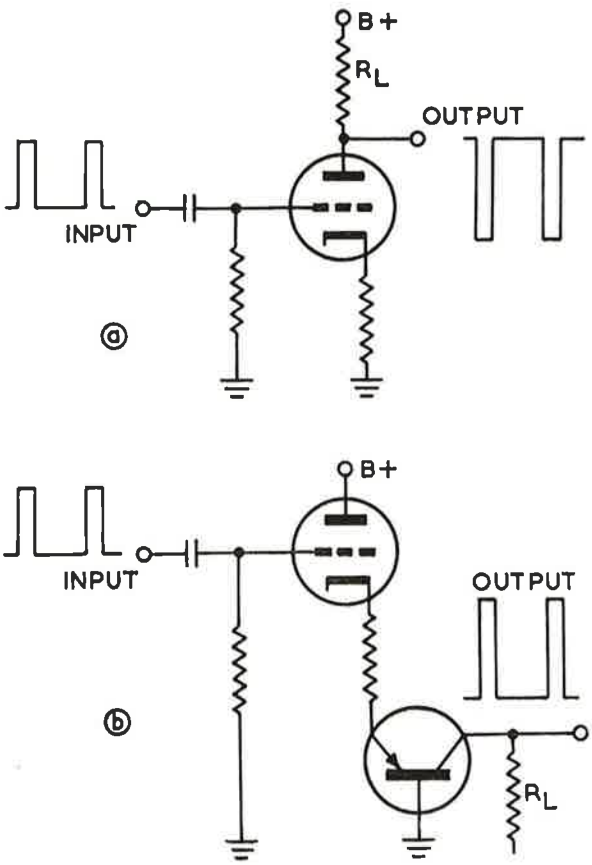


Fig. 15

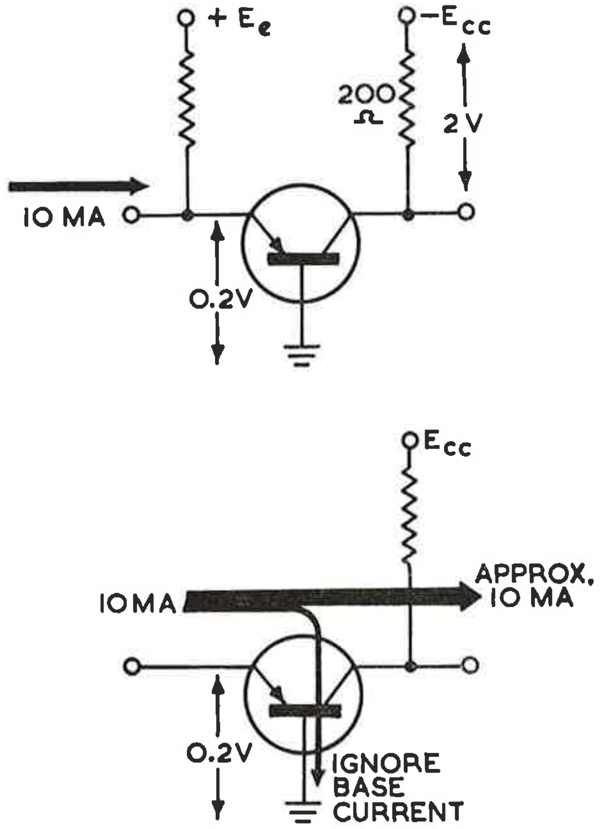


Fig. 16

or current gain. Voltage or current gain can be obtained from an ordinary transformer; power gain cannot.

Maximum Voltages and Currents

The maximum collector voltage that can be applied to a transistor is limited by a phenomenon called breakdown. If the collector voltage is increased beyond a certain limit, the collector junction will begin to pass an abnormally-large current. The voltage at which the collector current increases is called the breakdown voltage. In this region, a transistor does not behave normally. To insure proper transistor action, the operating point must be well removed from the breakdown region.

A transistor will not necessarily be destroyed by breakdown. If a transistor rated at 200 milliwatts breaks down from over-voltage and, while in the breakdown region, dissipates 500 milliwatts, it will very likely be destroyed or at least damaged. On the other hand, a transistor, may go into breakdown without being damaged at all if the circuit includes a series resistance to limit the maximum power to a safe value.

Breakdown defines the maximum allowable voltage. However, the maximum current, which bears no relation to the breakdown voltage, is not so well defined. At higher and higher currents, progressively smaller portions of the emitter current appear in the collector, with the result that alpha, which is around 0.98 at small currents, may become 0.6 or 0.5 or even less. The practical limit on high currents is reached when alpha falls below some arbitrary limit, set by the designer to fit the particular requirements of the circuit at hand.

Thus far the transistor has been introduced and its characteristics and uses as a common-base amplifier have been described. It has been pointed out that there are many restrictions on the common-base configuration which limits its usefulness. The next part in this series will describe a configuration which is not so limited — the common-emitter configuration. It will be shown how a common-emitter can provide both voltage gain and current gain, simultaneously, but at the expense of an inherently narrower bandwidth.

(With acknowledgements to RCA)

DC VOLTAGE MEASUREMENTS

There are many factors that must be kept in mind when taking voltage measurements. Factors such as meter accuracy, production tolerances, line voltage variations, control setting considerations, and signal conditions must be taken into account: they all have a definite effect on the voltage measurements taken.

If a technician is to successfully analyze television circuitry by taking voltage readings and comparing them with normal operating values furnished in prepared service information, he must be aware of the various conditions that can affect his measurements. Voltage readings may not always seem to agree with data provided in servicing publications and a technician should know why.

Meter Accuracy

Various meters can provide different readings even though they are used to measure the same voltage in the same circuit, because meters vary in sensitivity. For instance, a 20,000 ohm-per-volt meter can provide for reasonable accuracy across low-impedance circuits, but this type of meter will tend to read low when measuring voltages across high-impedance circuits. A vacuum tube type voltmeter is preferred by many technicians since it provides for accurate voltage readings in any circuitry.

To insure reliable voltage readings it is advisable periodically to check the accuracy of a meter against a known source or compare its readings with other reliable instruments.

Production Tolerances

Production tolerances should also be kept in mind when evaluating voltage measurements. The tolerance of most component values allows a variation of ± 10% and sometimes as much as ± 20% in the voltage readings. For this reason even two receivers of the same design may not have exactly the same voltage distribution. In most cases variations of this order will not noticeably affect the operation of the receiver. Closely related to voltage variation considerations is the fact that voltage indications provided in service data publications are normally measured at a standard 240-volt line voltage. If this line voltage is not the same when measurements are taken proportional changes in voltage readings should be expected.

Control Settings

The setting of controls also affects voltages in some areas of the receiver circuitry. Most service data state the position in which controls were placed when voltage measurements were recorded. In most instances these controls should be set in their normal positions. If the control settings are not taken into consideration, voltage readings will not compare with information provided in the service data.

Signal Conditions

Voltages given on the schematic diagrams of service data are usually no signal voltages (meaning no signal input to receiver). If the references to these voltages are made while a signal is being fed into the receiver, the voltages may be misleading. The no-signal voltage measurements are used because this condition can be duplicated by the technician regardless of the signal conditions with which he has to work.

Voltage measurements are a factor of considerable importance to the technician in analyzing the operating condition of a television receiver. Voltage measurements can be awfully misleading, if they are misinterpreted. A technician must be able to interpret his voltage analysis intelligently by keeping in mind the various factors that can affect the accuracy of the measurements taken. Don't be led astray, remember these factors when you are making voltage measurements.

Off The Beaten Track

A SERIES DESCRIBING SOME OF THE MORE UNCOMMON VALVES AND VALVE DESIGNS

No. 6 — THE RADECHON

The last article in this series dealt with display storage tubes of the direct view type, suitable for the display and storage of half-tone displays as well as line work and data. This month's article deals with a different type of storage tube, intended for use in information-processing systems. This tube essentially stores charges; information in digital or analogue form is introduced to the active elements of the tube, stored, and then extracted at a rate which may be either the same as the "writing" rate, or at a different rate. The storage time may be varied between microseconds and several minutes, as required.

Typical of this type of tube is the 6499. The 6499 may be operated so that (1) the output signal is linearly related in amplitude to the input signal, or (2) the output signal is proportional to the duration of an input-signal pulse or to several input-signal pulses occurring within a given time interval, or (3) the output signal is proportional to the difference between two successive input signals.

Design features of the 6499 include an electron gun capable of providing an electron beam having high current density and relatively small cross-sectional area at the focal plane, and a storage surface having uniform secondary emission to provide a uniform output signal. Electrostatic deflection of the beam is utilized to permit the design of deflection circuitry having relatively low power consumption and providing high speed of response.

Principles of Operation

The 6499 contains an electron gun of the electrostatic-focus and electrostatic-deflection type, a barrier grid (grid No. 5), a dielectric layer, a backing-electrode, and a collector, as shown in Fig. 2. The barrier grid consists of a fine mesh screen very closely spaced to or in contact with the gun side of the dielectric layer. On the opposite side of the layer and in contact with it is placed the backing-electrode, which consists of a metal disc. The dielectric layer has high insulating qualities and a maximum

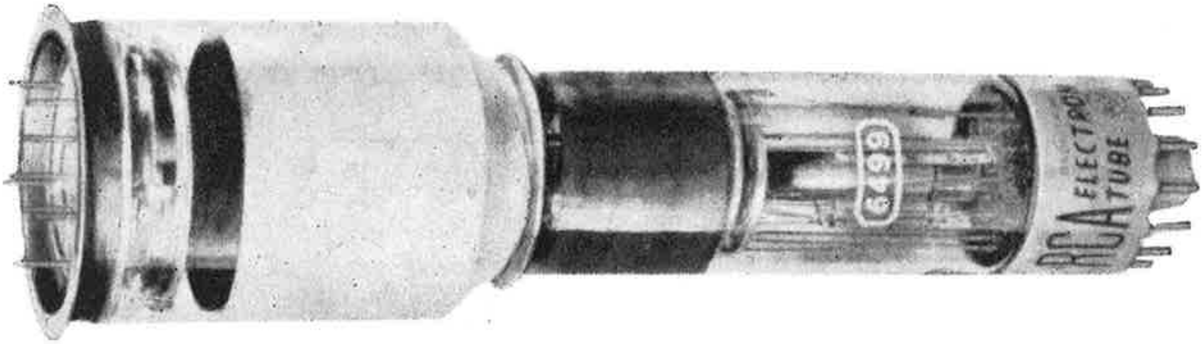


Fig. 1 — A Typical Charge Storage Tube, the Type 6499 Radechon.

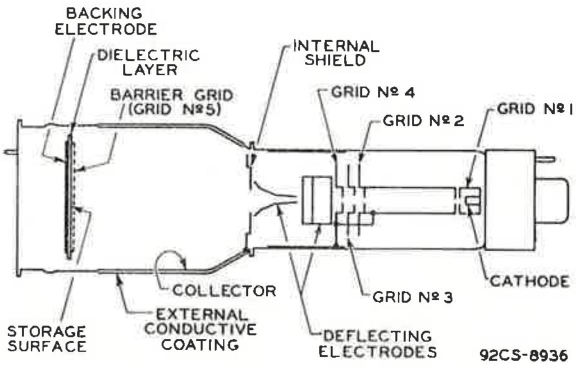


Fig. 2 — Schematic Arrangement of the Type 6499 Radechon.

secondary-emission ratio greater than unity. The barrier grid, the dielectric layer, and the backing-electrode are collectively referred to as the "target" for convenience in explaining the operating principles of the 6499. The collector is a conductive coating on the inside wall of the large part of the tube. This part of the tube also has an external conductive coating which is connected at the seal flange to the collector and internal shield.

By adjustment of the voltage applied to the focusing electrode (grid No. 3), the electron beam may be focused in the plane coinciding with the exposed surface of the dielectric layer. This surface, on which charge storage occurs, is known as the storage surface. Adjustment of the control-grid (grid-No. 1) voltage controls the intensity of the beam current impinging on the storage surface. The control grid may be modulated in accord with system requirements. The area of the storage surface bombarded by the electron beam is determined for any specific application by the magnitude of the voltages applied to the deflecting electrodes.

The effect of storage-surface potential in determining the action of the target is illustrated in Figs. 3, 4 and 5. In Fig. 3 the storage surface is instantaneously some tens of volts positive with respect to the barrier grid. When the primary-beam electrons, produced by the electron gun, go through the barrier grid and impinge on the storage surface, they release secondary electrons from the storage surface. The number released depends on the energy of the impinging electrons. The energy of the secondary electrons is not sufficient to overcome the negative gradient existing between the barrier-grid plane and the storage surface. Consequently, after a transit time of a small fraction of a microsecond, the secondary electrons return to the vicinity from which they were released. Under these conditions, a net electron current flows into the target from the beam. This current has a value equal to that of the beam current multiplied by the effective transmission of the barrier grid. Because the barrier grid is treated so that it has a secondary-emission ratio of very nearly unity, it contributes nothing to the net electron current flowing into the target.

In Fig. 4, the storage surface is instantaneously some tens of volts negative with respect to the barrier grid. When the primary-beam electrons go through the barrier grid and impinge on the

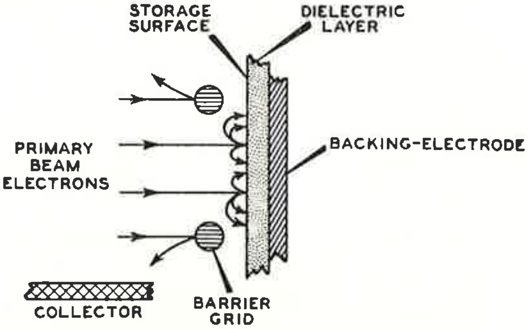


Fig. 3 — Storage Surface Instantaneously Positive with Respect to Barrier Grid.

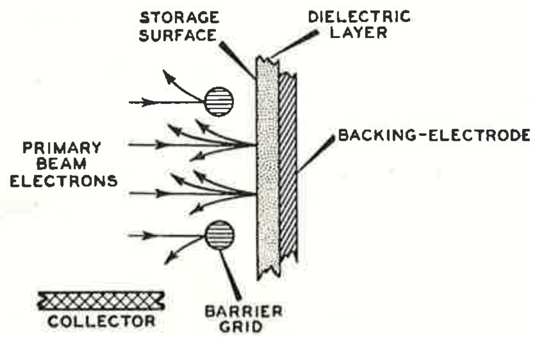


Fig. 4 — Storage Surface Instantaneously Negative with Respect to Barrier Grid.

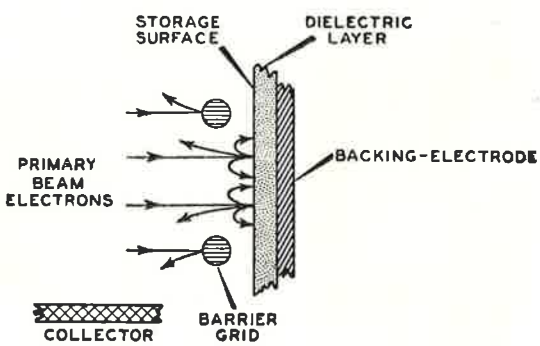


Fig. 5 — Storage Surface at Equilibrium Potential.

storage surface, they release secondary electrons from the storage surface, as in the case of Fig. 3. However, unlike the case of Fig. 3, the secondary electrons are accelerated from the storage surface, pass through the plane of the barrier grid, and go into the space beyond it. These secondaries together with those released from the barrier grid are then accelerated to the collector which is operated at a positive dc potential. Actually, the barrier grid collects some of the secondaries from the storage surface but these may be neglected in considering first-order effects without introducing appreciable inaccuracy. Under the conditions shown in Fig. 4, the net electron current flows away from the target. This current has a value equal to that of the beam current multiplied by the effective transmission ratio of the barrier grid and by the difference between the secondary-emission ratio of the storage surface and unity.

Because the secondary electrons which are liberated from the storage surface have initial energies in the range from 0 to more than 10 electron volts, the transition between the case of Fig. 3 and that of Fig. 4 is gradual. The exact percentage of the secondaries which escape from the target depends on the magnitude of the potential gradient between the storage surface and the barrier grid.

In Fig. 5, the storage surface is several volts positive with respect to the barrier grid. In this case, the escaping secondaries exactly balance those primary-beam electrons arriving at the storage surface. Under these conditions, the net target current is zero, and the potential of the storage surface is known as the equilibrium potential.

The condition shown in Fig. 3 is unstable because charge neutrality can not be maintained within the dielectric layer. In order that charge neutrality be maintained within the dielectric as the beam deposits electrons on the storage surface, it is necessary that a displacement current flow in the storage-surface backing-electrode. As a result of this flow, a voltage gradient is built up across the dielectric. The potential of the storage surface on which the electrons (negative charges) land, becomes more and more negative, assuming that the bombardment is not affected by modulation or deflection of the beam, until the condition shown in Fig. 5 is attained.

Similarly, the condition in Fig. 4 is unstable. However, in this case, the process of charging to the equilibrium potential is in a positive direction.

It is this process of charging, called writing, by means of which the storage of information is effected. A term indicative of the speed of writing is known as discharge factor. It may be defined as the ratio of the shift in potential with respect to the equilibrium potential of a given element of the storage surface during a single exposure to the beam, to the potential of the storage surface with respect to equilibrium potential at the beginning of exposure. The concept of discharge factor is usually applied to cases where the storage surface is scanned by the beam. A single exposure is usually interpreted as meaning a single scan of an element of the storage surface.

An example of a simple writing sequence is as follows: Assume that the storage surface is at equilibrium potential, and that zero potential exists between the backing-electrode and the barrier grid (grid No. 5). A step-function voltage of, say, + 50 volts with respect to grid No. 5 is applied to the backing-electrode. Because of the relatively high capacitance between the backing electrode and the barrier grid, practically all of the step-function voltage appears between the storage surface and the barrier grid. The undeflected beam is now turned on and that part of the storage surface bombarded by it commences to charge negatively towards equilibrium. Assume that bombardment continues until the storage-surface potential, in relation to equilibrium potential, has changed from the + 50 volts to + 40 volts, whereupon the beam is turned off. A charge sufficient to develop a gradient of 10 volts has now been stored in the dielectric layer. For these conditions, the discharge factor is (50-40)/50 = 0.2. If the step-function voltage is now removed, the storage surface becomes 10 volts more negative than the equilibrium value.

This stored information may now be extracted by a discharging process known as reading. During reading, the backing-electrode is held at the same potential as the barrier grid. When the beam is turned on, the resulting target-current flow is that for the storage surface at -10 volts with respect to the equilibrium potential, and may be determined by reference to a target characteristic curve for the appropriate operating conditions.

Since reading is accomplished by the removal of electrons from the storage surface and its consequent discharge toward equilibrium potential, reading is likewise an erasing process. If the discharge factor during reading is sufficiently high, further erasing is unnecessary. However, in critical applications, a second or possibly more subsequent reading processes at high discharge factor may be necessary to restore the storage surface to equilibrium potential prior to the next writing process. A discharge factor of 1.0 represents complete erasure.

Precautions are necessary in the use and handling of the Radechon similar to those necessary with other storage tubes and TV camera tubes. The tube must be transported in such a way that there is no possibility of particles settling on the storage surface. The susceptibility of this type of tube to stray magnetic fields makes it necessary to employ magnetic shielding by means of a screen of mumetal or other high-permeability material.

The resolution of the 6499 is dependent on the beam current value and the beam accelerating voltage in use. These factors will depend in turn on the application of the tube. Resolution figures between 100 and 350 TV lines will be obtained under various operating conditions.

SOME EXAMPLES OF RADECHON APPLICATIONS

INPUT OUTPUT

In Digital Data Storage Systems.

The Radechon Acts as a high-speed, random-access high-capacity memory element.

In Time-Base Conversion Applications.

The Radechon releases a stored signal at a rate different from the input rate, as may be required in systems for the transmission of Video Signals over telephone lines, or in certain systems involving audio-signal multiplexing.

In Signal Delay Applications.

The Radechon stores a signal burst — then releases it after delay periods from microseconds to minutes.

In Radar Systems.

The Radechon offers better radar signal "detectability" — through charge integration in the storage element.

In Fixed-Signal Cancellation Applications.

The Radechon compares successive signals. Originally designed for "line-by-line" moving-target indicators, the Radechon also can be used in "area" MTI systems.

VERSATILE MODULATOR

By PETER KOUSTAS W2SGR

The modulator described in this article can furnish any audio power between 25 and 100 watts and, therefore, can modulate 100% any rf input power up to 200 watts. Maximum power output is determined primarily by the plate voltage applied to the modulator valves. No circuit changes are necessary when the power output level is changed other than in the connections to the proper taps on the modulation transformer.

The input circuit, which will accommodate any type of microphone, utilizes a transistor because of its low power consumption. The stability and low noise factor of the 2N104 made it a logical choice for this application, although the 2N217 is an acceptable substitute.

Circuit Description

A schematic diagram of the modulator is shown in Figure 1. The transistor circuit given here is straightforward and not at all critical. The 2N104 is a germanium alloy-junction transistor of the p-n-p type intended especially for small-signal audio applications. It is shown connected here in a common-emitter, base-input circuit. This method of transistor operation is analagous to common-cathode operation of a triode — with the base, emitter, and collector of the transistor corresponding to the grid, cathode, and plate, respectively, of the valve.

However, unlike the valve, which has a high input impedance at audio frequencies, the input impedance of the 2N104 in the circuit shown is approximately 1,000 ohms. Thus, low-impedance microphones (e.g.: carbon or dynamic types) may be used in this circuit without matching transformers. Crystal microphones, and other high-impedance types, do require a matching transformer in this circuit and one has been provided (T1).

The 12AT7 is a twin triode with two identical sections, each having a μ of 60. One section is used to provide a second stage of voltage gain; the other serves as the driver stage for the modulator valves. In order to take advantage of the full gain afforded by the transistor, an impedance-matching, 3-to-1 step-up transformer is used between it and the input to the second stage. Modulation level is controlled by a 250,000-ohm potentiometer in the grid circuit of the first section of the 12AT7. Resistance coupling is used between the second and third stages of the modulator. Decoupling between stages is provided by R16 and C9. Driver requirements are very modest, since no power is required to drive the modulator to full output. The second section of the 12AT7 develops adequate drive with no difficulty.

The outstanding features which make the 6146 such a proven performer in rf service are the very reasons this versatile valve was chosen for the output stage of this modulator: high perveance and high power sensitivity. The high perveance of the 6146 allows this modulator to operate efficiently at low power levels with relatively low plate voltage. The high power sensitivity of the 6146 enables this modulator to deliver full power output with negligible power required from the driver stage.

The 6146's are operated class AB1 for all power levels up to a maximum of 100 watts. A driver transformer (T4) which has a tapped primary is used to provide push-pull signal voltage for the output valves. If sufficient gain is not available for a particular microphone when using the 1.5-to-1 tap, an additional tap on the primary can provide a primary-to-½ secondary ratio of one-to-one. Two 1,000-ohm resistors in series with the grid leads of the 6146's are used for the suppression of parasitic oscillations. The 47-ohm resistors in each plate lead serve the same purpose. Al-

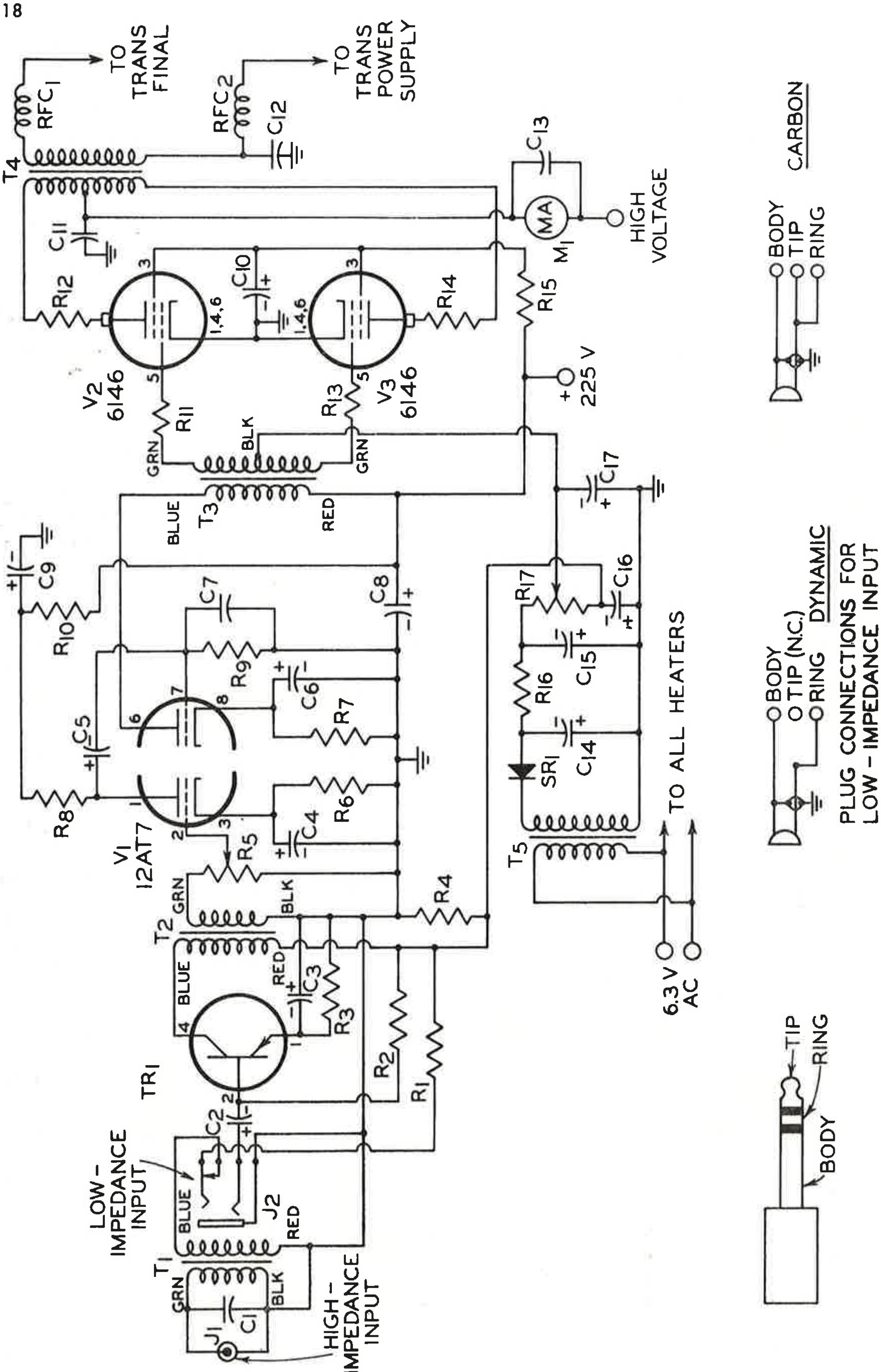


Fig. 1 — Schematic Diagram of the Modulator.

though these resistors are seldom necessary in audio equipment, it is always good practice to include them as a precautionary measure.

The modulation transformer selected must handle the maximum power output of the modulator. To determine the correct secondary impedance it is only necessary to divide the input voltage to the transmitter final by the normal operating current. The correct primary impedance will range from 2,500 to 7,500 ohms, depending upon operating voltage. Figure 2(b) is a plot of the minimum primary impedance required to prevent valve damage, versus operating plate voltage.

Figure 2(a) is a plot of output power versus plate voltage applied to the 6146's. To determine the required modulator plate voltage for a particular transmitter, divide the input power to the final stage of the transmitter by two, to get the audio power required for 100% modulation. Now find the minimum plate voltage required from Figure 2(a).

Higher plate voltages than those found from the above procedure may be used, and the modulation adjusted to the correct level by potentiometer R5. In any event, R5 should be used for fine adjustment of modulation level.

A few words of caution should be injected at this point. Never operate any modulator without having a load connected to the output. The high impedance of an unloaded transformer secondary reflected into the primary will cause abnormally high signal voltages to be generated and will almost always cause the insulation of the transformer to be punctured. Also, to prevent damage to the 6146's, never operate this modulator with the primary impedance of the output transformer below the value given in Figure 2(b) for the plate voltage being used.

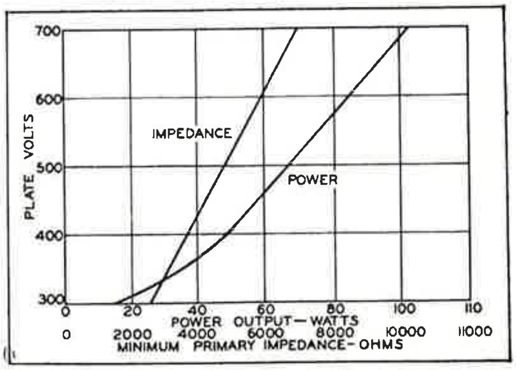


Fig. 2 — (a) Power Output vs Plate Voltage.
(b) Minimum Primary Impedance vs Plate Voltage.

Construction

Construction of the modulator is not difficult and requires only normal care in wiring. It is built on a standard aluminium chassis 5 x 13 x 3 inches deep and mounted on a rack panel 5¼ x 19 inches. This method of construction has two distinct advantages: a) a minimum of panel space is required; b) more complete shielding is obtained by utilizing the panel as the bottom cover of the chassis.

It is necessary to scrape the paint off the panel where the chassis comes in contact with it in order to insure a good rf bond between them.

The leads to the input jacks and gain control must be about five inches long, in order to allow assembly of the panel to the chassis after it is wired It is therefore necessary to shield these leads to minimize any tendency towards stray hum and feed-back pickup. For maximum effectiveness, all parasitic-suppressing resistors must be mounted right at the valve socket, and directly on the plate cap.

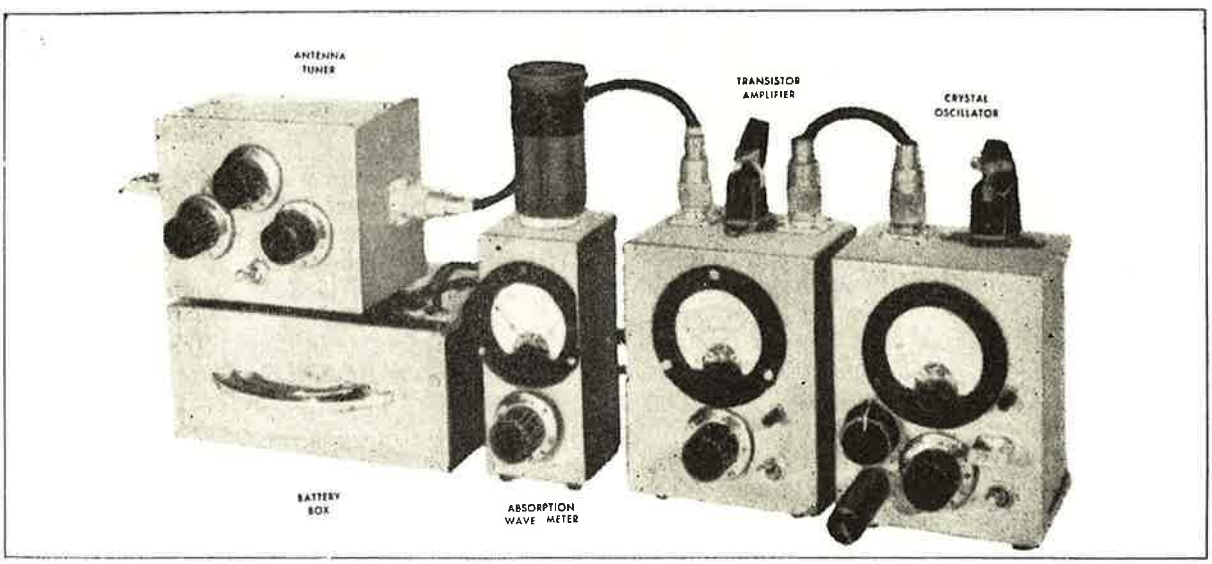


Fig. 3 — Rear View of the Modulator.

Power Supplies

Two external voltage supplies are required by the modulator. The first supply is for the plates of the 6146's. The voltage rating of this supply will depend on the modulation power output desired, as determined from Figure 2(a). Zero-signal drain on this supply will be between 50 and 60 ma. At 750 volts, maximum-signal drain will be approximately 230 ma. The power supply should be capable of supplying maximum-signal current with good regulation.

The second external power supply must deliver approximately 50 ma at 225 volts. This supply powers the 12AT7 and the screen grids of the 6146's. It should never be turned on until after the plate supply has been turned on. Preferably, the supplies should be so wired that the plate supply must be on before the low-voltage supply can be energized.

Operating voltage for the transistor and bias for the modulator valves are supplied by an internal supply. This supply should be turned on before either of the above supplies. Again, sequential switching to ensure the proper order of energizing the supplies is to be preferred. Transformer T5 provides 115 volts from the 6.3-volt heater supply. Alternatively, a 240-volt primary transformer could be used, but this would mean bringing a mains supply into the modulator. A silicon rectifier and RC filter (R16, C14, and C15), provide a negative voltage supply of —100 volts. Resistors R1 and R2 form a voltage divider between ground and the junction of R17 and R4, which provides the 5 volts required to operate the transistor. Bias for the 6146's is adjusted by moving the tap of R17 to the appropriate point.

Operation

Other than usual precautions, there is no special procedure required to place the modulator in operation. The wiring should be thoroughly checked before any power is applied. With the valves but not the transistor inserted, apply 6.3 volts to the heater-voltage input terminals. The bias voltage at the grids of the 6146's should be set initially at maximum and then adjusted when all other voltages in the modulator are applied so that the zero-signal plate current as read on the meter is approximately 55 ma. Before insertion of the transistor, the voltage between ground and the junction of R17 and R4 should be measured. If it is between 4.5 and 6 volts, plug in the transistor. If the voltage at this point exceeds 6 volts, a wiring mistake or a wrong value for R4 may be the cause.

The modulator may be tested separately by using a resistor of the correct value as a load. The resistor used should have the same resistance as the impedance of the secondary taps to which it is connected and should be of sufficient power rating to withstand the output of the modulator. Power output may be measured by applying an input signal and measuring the signal output voltage across the resistor. The output power will be

$$\frac{(Erms)^2}{R}.$$

Again, a warning: in no case should the modulator be run without having a load connected to the secondary of the modulation transformer.

PARTS LIST

C1—500 $\mu\mu$f, mica.
C2—16 μf, 12 vw, electrolytic.
C3—25 μf, 12 vw, electrolytic.
C4, C6—25 μf, 25 vw, electrolytic.
C5—0.01 μf, 400 vw.
C7—0.002 μf, 400 vw.
C8, C9, C10—8 μf, 450 vw, electrolytic.
C11—0.5 μf, 750 vw.
C12—0.005 μf, 1500 vw, mica.
C13—0.1 μf, 600 vw.
C14, C15, C16—20 μf, 150 vw, electrolytic.
C17—8 μf, 150 vw, electrolytic.

J1—Microphone jack, 3-point.
J2—Microphone jack, 3-point.

M1—Meter, 0-100 ma.

R1—3,300 ohms, ½ watt.
R2—220K ohms, ½ watt.
R3, R11, R13—1,000 ohms, ½ watt.
R4—470 ohms, ½ watt.
R5—250K ohms, pot.
R6—2,200 ohms, ½ watt.
R7—390 ohms, 1 watt.
R8, R9—270K ohms, ½ watt.
R10—22K ohms, 1 watt.
R12, R14—47 ohms, 1 watt.
R15—1,000 ohms, 1 watt.
R16—2,200 ohms, 2 watts.
R17—10,000 ohms, 25 watts, adjustable.

RFC1, RFC2—2.5 mh, 125 ma.
SR1—Rectifier, silicon, 1N1763.

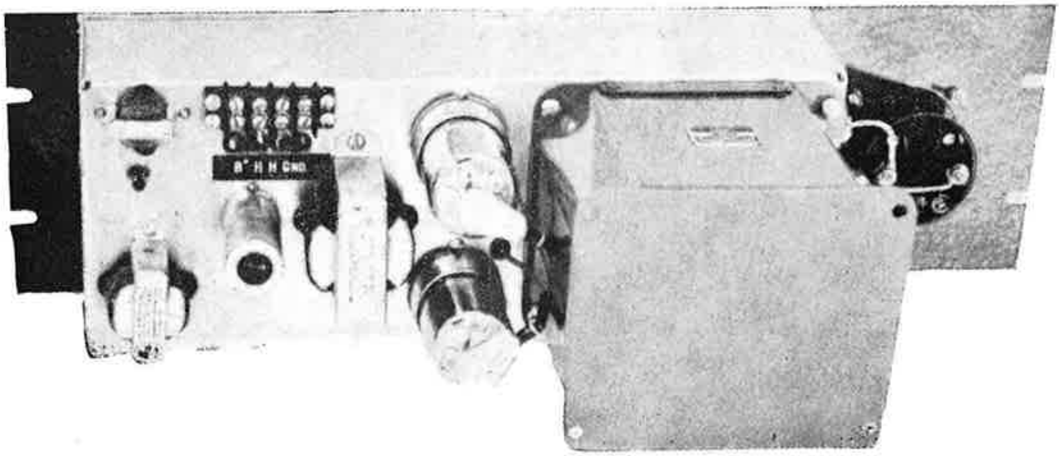
T1—Transistor input transformer, primary 200K ohms, secondary 1,000 ohms.
T2—Interstage transformer, 1:3 turns ratio.
T3—Interstage transformer, 10K ohms primary impedance, 1.5/1:1 primary to half-secondary ratio.
T4—Modulation transformer, 100-120 watts.
T5—Bias transformer, primary 6.3 volts, secondary 115 volts, 60 ma.

TR1—2N104 or 2N217 Transistor.
V1—12AT7.
V2, V3—6146.

(With acknowledgements to RCA)

VERSATILE MODULATOR

(January, 1960, p. 19)



Several readers have drawn our attention to the fact that the wrong illustration was used for Fig. 3 of this article. The correct illustration is shown here.

AWV