THE TRANSISTOR - SUCCESSOR TO THE VACUUM TUBE?

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ERRATA

Page 5, column 1, paragraph 10 should read:

"The alternating current equivalent circuit of a Transistor (as shown in Fig. 24) for most - - - - - - - - - - - - - -."

Page 5, column 2, paragraph 4 should read:

"The output impedance is equivalent to r_c plus r_b.

This may be from 20,000 ohms to over a megohm. Figure 26 shows typical - -."

Page 5, column 2, paragraph 7 should read:

"- - - - are not permanently damaged by elevated temperature as long as the critical point is not exceeded."

THE TRANSISTOR - SUCCESSOR TO THE VACUUM TUBE ?

We, who work in the communication phase of this industry, when we get to the heart of many of our problems, have the feeling that "There's nothing wrong with electronics that the elimination of a few vacuum tubes would not fix." This is a sordid thought to have concerning the element around which our industry revolves. Yet many of our basic short comings can be traced back to the vacuum tube.

Most serious, a tube has a limited and unpredictable life. A piece of communication equipment is often called on to operate continuously for years. It is desirable that this equipment be completely unattended yet tube failures require constant and costly maintenance.

Next, a tube consumes power inefficiently. No one knows this better than those of you in the television industry. Very large power transformers are required for our television sets, a good share of whose burden is filament power for 15 to 20 tubes in the set.

Mechanically too, tubes are bulky and fragile.

Now, for the first time, we have an alternate device which can be considered a legitimate contender to the throne that has been occupied by the vacuum tube for over 35 years. It can do many of the jobs now done by vacuum tubes and do them more efficiently and more dependably.

This device is called a TRANSISTOR.

In this paper, we are going to attempt to give you answers to the following questions:

1. What is a TRANSISTOR?
2. What can it do for us?
3. Why get all excited about TRANSISTORS at this time?
4. How does the TRANSISTOR work?
5. What are its characteristics?
6. How do we use it in circuits?
7. What new problems does it pose?

1. What is a TRANSISTOR?

Transistor is the name given to a crystal-type amplifying element made of a semi-conductor such as silicon or germanium. At present, a transistor is equivalent to a triode. Its physican embodiment is extremely small, since its ability to amplify does not depend upon its size. Three different types of transistors are shown in Figs. 1, 2 and 3.

It is interesting to note that the name is derived from the fact that it was called a transit resistor by early workers in the field who were really searching for new ways of making non-linear resistors.

The TRANSISTOR is essentially a small piece of one of the semi-conductor materials wherein various portions of it have been constructed to have different conducting properties.

Its ability to amplify depends upon the unusual property of semi-conductors to support two kinds of conduction simultaneously: One, the travel through the material of excess electrons which we know of as negatively charged particles, and Two, the travel through the material of "holes", which are really the lack of electrons and, therefore, constitute an equal positive charge. In a semi-conductor, electrons travel much slower than they do in a conductor and "holes" travel even slower than the electrons.

TRANSISTORS are constructed in two distinctly different types. One type is called the point contact type whose construction is shown in Fig. 4. The other, called the junction type, is shown in Fig. 5. Their construction results in different performance characteristics as will become apparent as this story unfolds.

2. What can the TRANSISTOR do for us?

The TRANSISTOR is extremely important to our industry for two basic reasons:

1. It is a very efficient amplifier.
2. It shows promise of extreme dependability and unbelievable long life.

In most circuits, the transistor will do the same job as a vacuum tube while consuming 1/1000 as much power. Let us look at a radio or television set. In all stages up to the second detector, the signal level is less than a milliwatt and in most of them, less than a microwatt. Yet we burn up on the average of a watt or more filament power and a watt of plate and screen power to obtain the amplification we desire.

Transistors can give us 20 to 50 db of gain, depending upon the type, while consuming less than two milliwatts of power. The junction type TRANSISTORS are about 10 times more efficient than the point contact type for small-signal amplification.

The TRANSISTOR has no filament so there are no problems of filament burn-out. TRANSISTOR life has been predicted in several ways. All of these predictions point toward a figure of 70,000 to 90,000 hours. This is approximately 10 years. Since a TRANSISTOR does not stop suddenly, as there is nothing to burn out, the life figures above have been based on the time at which its gain will drop 3 db. For most applications, this is not necessarily the end of its useful life. The change in α and the output impedance of a sample lot of TRANSISTORS is shown in Fig. 6.

The TRANSISTOR is extremely small and rugged.

Let's look at a tabulation of the properties of both types.

	Point Contact Type	Junction Type	Tubes
Gain	20 - 30 db	30 - 50 db	20 - 50 db
Efficiency (Class A)	30%	45 - 49 %	1 to 25 %
(Class C)	90%	95%	70%
Life	70,000 hrs.	90,000 hrs.	5,000 hrs. ?
Vibration	100 g	100 g	
Shock	20,000 g	20,000 g	
Uniformity	±3 db	±2 db	±3 db
Minimum Powers	1 mw.	1 microwatt	1/10 watt
Temperature	70° C	70° C	500° C
Frequency	30 - 70 mc	3 - 5 mc	60,000 mc
Gain X Bandwidth	1000 mc	120 mc	1000 mc
Noise Figure	45 db	15 db	10 - 30 db
Maximum Power	100 mw	1 watt	1 megawatt

Summarizing - up to 30 mc, transistors can do a better job than tubes within the limits of power and temperature.

Photo Transistors

It is important to mention one other characteristic at this time. The boundary in a junction type transistor is extremely photo sensitive and, therefore, can be made into an attractive photo cell. The first types made were simply diodes as shown in Fig. 7.

One important characteristic of a transistor photocell is its spectral sensitivity which is most strong in the red and infra-red region as shown in Fig. 8.

The second is its efficiency. A PN junction unit (diode) has a sensitivity of 30 ma/lumen, 10 to 15 milliwatts of AC can be obtained from the simple circuit using this type of unit shown in Fig. 9.

An NPN photo transistor can give a light conversion efficiency about 30 times greater than this or about 1 ma/millilumen. The construction of this unit is shown in Fig. 10.

Using the same circuit, about the same output level can be obtained from this unit. Fig. 11 shows a photograph of several photo-transistors compared to a normal pencil.

3. Why get all excited about TRANSISTORS at this time?

1. Production of practical quantities of the point contact units has begun.
2. Large advances in circuit design have been accomplished in the past year.
3. The bringing out of the laboratory of the junction transistor and readying it for production opens even newer field of application.
4. Stability of design has been established.
5. Dependability of units has been assured by uniform production.
6. Designability has been established. Units can now be designed to a certain set of parameters. (Fig. 12)
7. There is a need to alert the industry to the impact of this element so that circuit design work can be done now to take advantage of transistors.
8. Manufacturers believe that most rapid progress can be made under pressure of circuit designers in way of stabilizing types.
9. Already five manufacturers are "in the business." These are Western Electric, General Electric, Raytheon, Sylvania and RCA. Also Motorola has inaugurated a substantial transistor research and circuit application program.

How does a TRANSISTOR work?

We do not have time here to derive the basic physics that defines transistor operation.

However, like many other things in this engineering world, we need not get back to the basic physics in order to provide an explanation of behavior which will be accurate from the point of view of the circuit designer.

The TRANSISTOR lends itself very well to a simplification of this sort.

We can best understand the operation of the transistor, if we first review some of the characteristics of semi-conductors. Certain elements in the fourth column of the Periodic Table exhibit properties where, under certain conditions, they seem like insulators, while under other conditions they seem like conductors. These elements have been called semi-conductors.

In the molecular structure of a material like diamond, shown in Fig. 13, all valence bonds are satisfied and the material behaves like an insulator.

If the crystal is heated, the thermal excitation can cause a valence electron to be knocked out of its usual place, and this electron (negative charge) is free to move about in the crystal. The place from where the electron came is called a "hole" and this area exhibits a local positive charge. Under this condition, the diamond behaves somewhat like a conductor.

Eventually, the electron and the hole may recombine. At all times, however, the entire crystal is electrically neutral.

Certain other elements in the fourth column of the Periodic Table, like silicon and germanium, require less energy to knock electrons out of the valence bond position, in fact at normal temperatures, electrons and holes are being liberated and recombined continuously. These are called intrinsic semi-conductors. Fig. 14 shows diagramatically the structure of intrinsic silicon.

If an electric field is applied to an intrinsic semi-conductor, the electrons move toward the positive terminal and the holes move toward the negative terminal. Holes can be treated exactly like electrons except that their charge is of opposite sign.

It was learned early that the presence of certain impurities in a semi-conductor greatly change its conductivity. The impurities were identified and the two effects catalogued.

If an impurity from the 5th column of the Periodic Table is present, atoms of this impurity replace atoms of the semi-conductor in the crystal structure. Since 5th column elements have 5 valence electrons, the extra electrons are free to migrate throughout the crystal. This is called an N-type (negative) semi-conductor and the impurity atoms are now called donors or donators as illustrated in Fig. 15.

If an impurity from the 3rd column of the Periodic Table is present, the impurity atoms similarly replace atoms of the original material in the crystal. Third column elements have only 3 valence electrons and consequently, one valence bond is left unsatisfied. The "holes" thus formed are also free to move about in the crystal and the material is now called a P-type semi-conductor as illustrated in Fig. 16. These impurity atoms are generally referred to as acceptors.

It is interesting to note that only a few donor or accepter atoms are required to produce substantial changes in the resistivity of a semi-conductor as shown in Fig. 17.

Two other properties of semi-conductors are important:

1. Holes can be introduced into N-type and electrons liberated in P-type semi-conductor by passing current into it.
2. Electrons travel much slower in a semi-conductor than they do in a conductor and holes travel even slower than electrons. These velocities in germanium have been established as,
   Electrons - 3700 cm/sec/volt/cm
   Holes - 1700 cm/sec/volt/cm

Let us examine the operation of a PN junction rectifier as shown in Fig. 17. This may be made up of a single crystal of germanium, for example, where the two parts of it contain different impurities. One part is N-type and the other part is P-type. If a potential is applied to the two ends of this rectifier as shown in Fig. 18, such that the positive terminal is connected to the p material and the negative terminal to the n material, the electrons and holes move toward each other and recombine. The voltage source keeps this going. The apparent resistance is very low and a high current flows.

Next, if we reverse the polarity of the applied potential as shown in Fig. 19, the effect is much different. The holes and electrons are pulled away from each other and the unit tends to become an insulator. Very little current flows. A volt-ampere plot, as shown in Fig. 20, shows this type of junction to be a very good rectifier.

Next let us pass on the junction-type TRANSISTOR, (Fig. 21). Here we have two junctions very close together. This is usually made from a single crystal of the semi-conductor material.

The left-hand junction is biased in its forward direction forming a very low resistance path for the flow of current. To insure an efficient emitter, the n-type material is more strongly n than the p-type is p. An excess of electrons are generated and these travel into the center region.

The right-hand junction is biased in its non-conducting direction. The electric field across this junction makes it attractive for the excess electrons liberated at the emitter junction to continue on across the collector junction to the collector terminal.

Variations in the emitter current will cause variations in the number of free electrons available and will thus cause variations in the collector current. The value α has been established as the transfer current gain of the TRANSISTOR. This may be defined as the change of collector current for a specific change in emitter current at a constant collector potential.

$$\alpha = \left(\frac{\Delta I_c}{\Delta I_E}\right)_{V_c}$$

This quantity, α, is dependent upon the efficiency of the emitter, the transport ratio, and the efficiency of the collector.

$$\alpha = \gamma \times B \times A$$

γ - Emitter Efficiency
B - Transport Ratio
A - Collector Efficiency

If the emitter current were all electrons and none recombined with holes in the center, p-region, and all of them reached the collector, then α could attain a maximum value of unity. In practice, values of .95 to .98 can be achieved.

As mentioned previously, the emitter (or input) junction is a very low impedance, but the collector (or output) junction is a very high impedance. The variation of a current through the high impedance collector circuit by an almost equal current variation in the low impedance emitter circuit constitutes an appreciable power gain. Junction transistors are made with up to 50 db of gain.

Next, let us consider the point-contact type of TRANSISTOR, as shown in Fig. 22. This is basically a block of semi-conductor material, such as germanium or silicon, where two pointed probes are placed very close together on top of the block. This looks, at first glance, like a conventional crystal diode except that it has two probes instead of one.

During manufacture, the contact areas are "formed" by passing current pulses through them. This creates a small area of P-type material directly under the points and the resulting TRANSISTOR is essentially a P-N-P- unit, as shown in Fig. 23.

Operation is similar to that described for the NPN transistor except that all supply potentials are of opposite polarity and the important conduction is principally by holes instead of electrons.

However, because of the geometry of this unit and the relative mobilities of holes and electrons, α values as high as 3 to 4 can be obtained in commercial units.

A TRANSISTOR, therefore, possess two mechanisms whereby we can obtain power gain when used as an amplifier.

One of these is due to the fact that the output impedance is considerably higher than the input impedance.

The other is due to the α gain possible in point-contact types, and the newer hook-collector type of units.

5. What are the characteristics of the TRANSISTOR?

The TRANSISTOR is definitely a three terminal device. Unlike the vacuum tube, we cannot even for equivalent circuits forget that the transfer characteristics are bi-lateral. Changes in output conditions affect the input characteristic as also do changes in input conditions affect the output characteristic.

The TRANSISTOR is definitely the dual of the vacuum tube and the application of the duality principle is very helpful in circuit design. From this point of view, a vacuum tube is really a current amplifier. By varying an extremely small current in its input, we obtain a much larger currect variation in its output circuit. In practice, we pass this output current through a load resistor to use it as a voltage.

The TRANSISTOR is definitely a voltage amplifier. We vary an input voltage and as a result, we get a much larger variation in an output voltage. Too, TRANSISTORS like best to see constant-current power supplies whereas tubes work best with constant supply potentials.

As mentioned previously, the emitter circuit of a TRANSISTOR is a diode biased in its forward or conducting direction. The bias supply for this element must definitely be of a constant current nature to prevent self-destruction.

The alternating current equivalent circuit of a TRANSISTOR for most applications is represented as a three terminal network with two series resistances (r_e and r_c) and one shunt resistor (r_b). These parameters are resistive at normal audio frequencies. The truest representation of the transfer generator would be a current supply, having the value αI_e shunted across r_c. Since it is inconvenient to work with current generators, this may be replaced with an equivalent voltage source in series with r_c having the value $r_m I_e$, as shown in Fig. 25.

The input impedance of a TRANSISTOR is equivalent to the sum of r_e and r_b and has practical values from 200 to 600 ohms.

The output impedance is equivalent to r_e plus r_b. This may be from 20,000 ohms to over a megohm. Figure 20 shows typical parameter values for a point-contact unit (left column) and a junction unit (right column).

Like a vacuum tube, a TRANSISTOR has an upper frequency limit caused by the capacities between the elements. Because of the close spacing, these capacities are somewhat greater than in vacuum tubes. Capacity effect on the emitter is not serious, however, because of its inherently low impedance. The principal frequency limitation in a TRANSISTOR is due to another cause, namely the slow transit speed of the electrons and holes in the semi-conductor material. A plot of α versus frequency is shown in Fig. 27.

These two effects define an upper frequency limit for junction type units at 3 to 5 mc while point-contact units have been used up to 70 mc.

Temperature provides another serious limit to the environment of a TRANSISTOR. High temperature causes a large change in the collector impedance and thereby affects the amplifications as shown in Fig. 28. It is interesting to note that these units are not permanently damaged by elevated temperatures as long as the Curie point is not exceeded.

Much has been said about noise in transistors and this is evidence that research is only begun on the fundamental causes. This noise decreases as frequency increases, as shown on Fig. 29. A point contact type unit shows a noise factor of 40 to 50 db while junction type units have a much better noise figure, 10 to 15 db. This latter value compares favorably with tubes.

The most used characteristic for circuit analysis is the family of collector curves illustrated by Fig. 30. These show the volt-ampere characteristic of the collector at varying emitter currents.

For point contact units, these are in the third quadrant of our usual rectangular coordinate convention. The plot shows good linearity and uniformity. Constant dissipation lines may be added to this plot to aid in evaluating power handling capabilities.

Similar curves for the junction type unit (Fig. 31) show almost an ideal characteristic. These are in the first quadrant, since supply polarities are reversed as compared with the point contact unit.

These curves give the key to the high efficiency possible with TRANSISTORS. Signals may swing almost from ordinate axis to abscissa axis without incurring appreciable distortion.

An enlargement of the lower left hand corner of this polt (Fig. 32) shows that this uniformity is maintained almost to the origin. Thus, when small signals are to be amplified, very low supply power is needed.

6. How do we use the TRANSISTOR in practical circuits?

Like a vacuum tube, the transistor lends itself readily to all types of circuits including amplifiers, oscillators and switching circuits. In many cases, the TRANSISTOR shows improved flexibility since there is no common filament supply to consider. The low input impedance minimizes shielding problems.

The commonly used grounded-base connection is equivalent to a grounded-grid vacuum tube circuit as illustrated in Fig. 33. In this connection, the principal problem is stability. The base resistance is common to both input and output circuits. Since there is no phase reversal in the TRANSISTOR element, this common base resistance constitutes a regenerative feedback path. This is most important in units with an α greater than unity.

The value of r_b has been controlled in units of more recent manufacture to provide an inherent stability when no external resistance is added to the base circuit.

In the grounded base connection, between matched impedances, up to 20-30 db gain per stage is easily achieved. Because the impedance transformation through a transistor is a step up, it is always necessary to use an interstage transformer to realize full gain. (Fig. 34)

At a sacrifice in gain, it is possible to cascade transistor stages directly as shown in Fig. 35. In this sort of an amplifier, 6-8 db gain per stage is possible.

Another popular circuit is the grounded emitter circuit as shown in Fig. 36. This is equivalent to a conventional grounded cathode tube circuit.

Input and output impedances are both of the same order of magnitude, from 2300 to 4000 ohms.

The output impedance of this type of circuit is negative if α is greater than 1 and must be stabilized with external resistance in the collector circuit.

This circuit has a transfer phase shift of 180°. Practical amplifiers can be built with 20-30 db gain per stage. Cascaded stages, shown in Fig. 37, without interstage transformers show an improvement over the grounded-base connection.

The TRANSISTOR may also be used in a grounded collector circuit (Fig. 38). This circuit, which has a high input impedance and a low output impedance, is equivalent to a cathode follower tube amplifier.

Both input and output impedances may be negative in this connection, but the circuit can be stabilized with external resistors. It is interesting to note that this circuit has a phase reversal going through it in one direction while it has no phase shift in going through it in the oppostie direction. It is possible to make an amplifier of this type with 15 db of gain in both directions.

To produce more gain per stage without interstage transformers, combinations of grounded collector and grounded emitter followed by grounded collector may be used as shown in Fig. 39.

For oscillators several circuits have shown good performance. A parallel resonant circuit in the base is a very popular circuit. Coupled series resonant circuits in the emitter and collector leads produces a TE-TC oscillator. (Fig. 40) A few conventional circuits that have been used in practice are shown in Fig. 41, 42 and 43.

Another important application of TRANSISTORS is in switching circuits. In a vacuum tube, we can control the plate impedance from several megohms to a few thousand ohms. A gas tube can provide a switch from several megohms to a few thousand ohms.

The TRANSISTOR, on the other hand can provide a switch which is capable of several megohms in its non-conducting condition to a fraction of an ohm in its conducting condition. This is the most effective electronic switch that we have known to date. It can be made to operate in a fraction of a microsecond and be stable in either the open or closed condition much like a flip-flop circuit. A typical circuit is shown in Fig. 44. It can also be used as a single-tube relaxation oscillator as shown in Fig. 45.

This makes the TRANSISTOR extremely useful in computors, telephone switching circuits and many industrial control operations.

7. What new problems does the TRANSISTOR bring to us?

The TRANSISTOR provides miniaturization of the major element of our electronic circuits. This shifts the impetus for improvement back to the transformer and, more particularly, the condenser manufacturers. Transistor circuits require the use of high capacity, low voltage coupling capacitors which at present are neither small, inexpensive, nor dependable.

The transistor also throws out an interesting challenge to the battery manufacturers to produce a constant current source rather than a constant potential source. At the present time, we are forced to waste 80% of the power used in transistor circuits in the dropping resistors required to provide the constant current supplies from a constant voltage source.

We are limited in amplifier and oscillator circuits at the present time to about 70 mc. This is a problem which is being worked on by all those engaged in transistor research.

The elimination of heat in the equipment employing transistors is a problem which does not have a too attractive solution. Obviously, it is not desirable to locate a TRANSISTOR next to a red-hot 6L6. On the other hand, in an all transistor equipment, the heat dissipated will be extremely small and the use of TRANSISTORS will solve some of the currently existing problems.

8. Summary

In conclusion, it can be said that the TRANSISTOR is an adequate substitute for the vacuum tube with attractive improvements in power required, efficiency and dependability. At the present time, its application is confined to the limits of 70°C, 70 mc and about 70 milliwatts.

A BEADED n-p-n TRANSISTOR

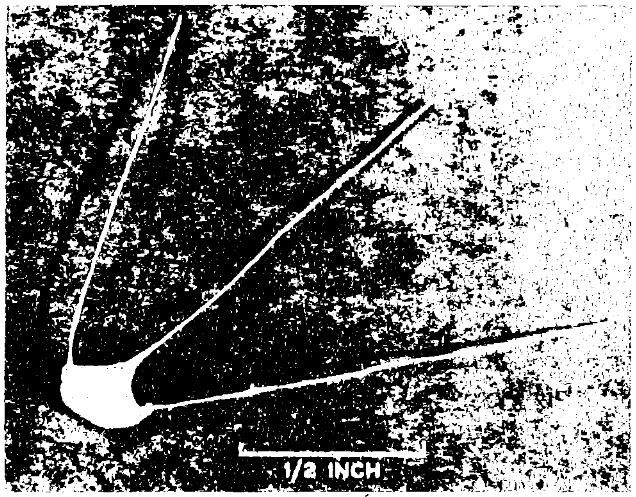


FIGURE 1

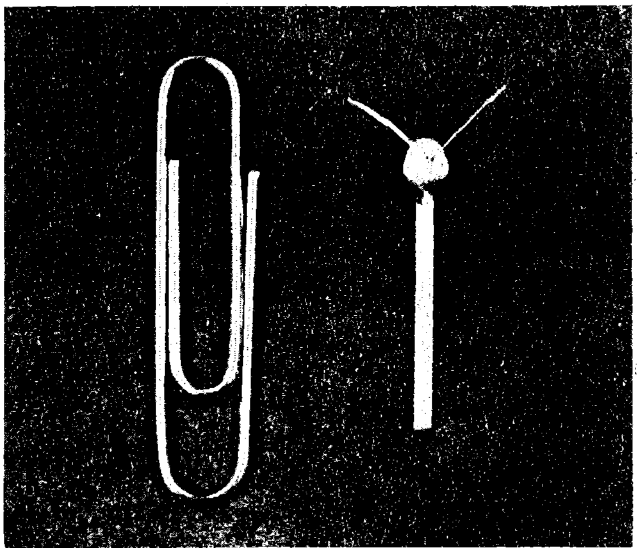


FIGURE 2

SOME POWER TRANSISTORS

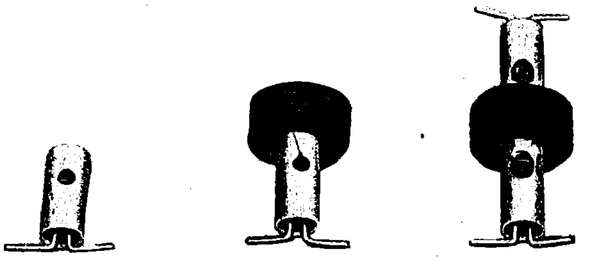


FIGURE 3

TRANSISTOR MECHANISM

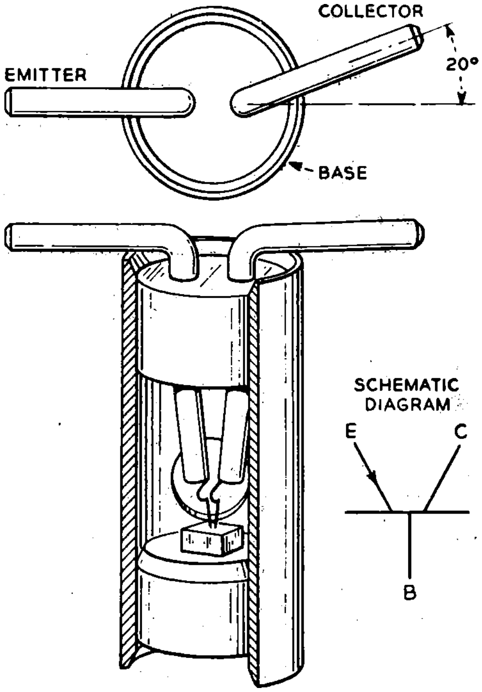


FIGURE 4

THE HEART OF AN n-p-n TRANSISTOR IS A TINY BAR OF GERMANIUM TO WHICH THREE MECHANICALLY STRONG ELECTRICAL CONNECTIONS ARE MADE

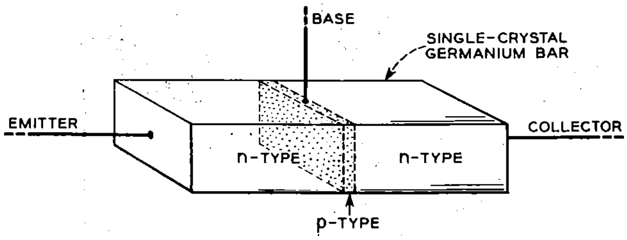


FIGURE 5

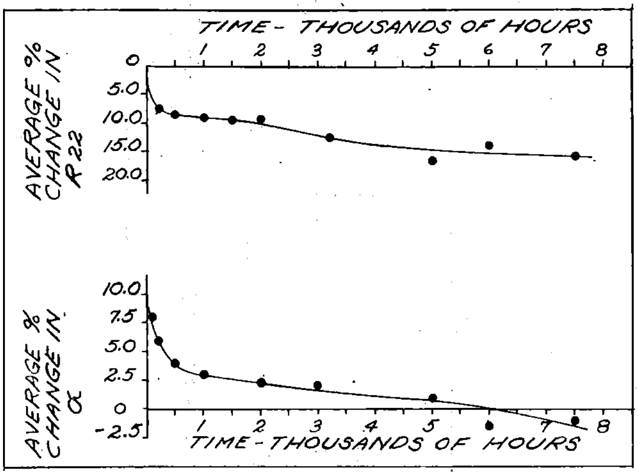


FIGURE 6

LONGITUDINAL SECTION OF PHOTO TRANSISTOR

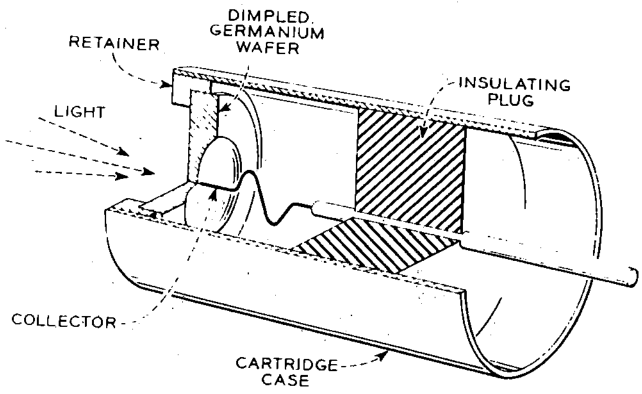


FIGURE 7

SPECTRAL RESPONSE

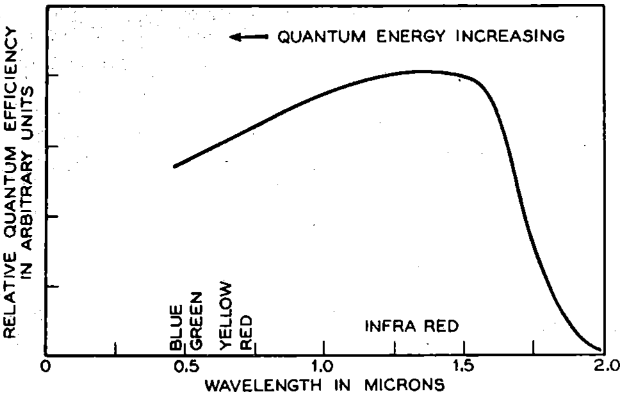


FIGURE 8

TYPICAL CIRCUIT USE

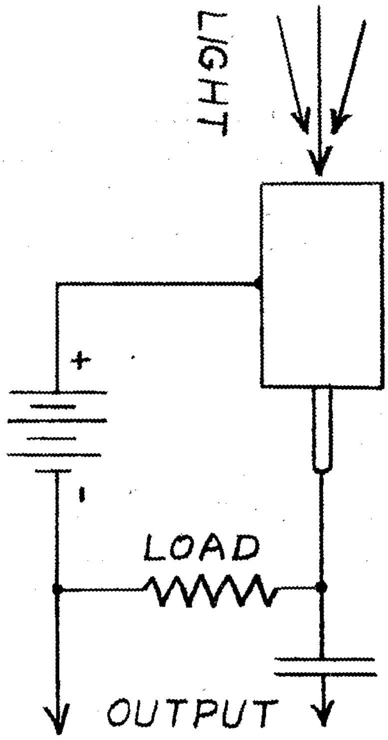


FIGURE 9

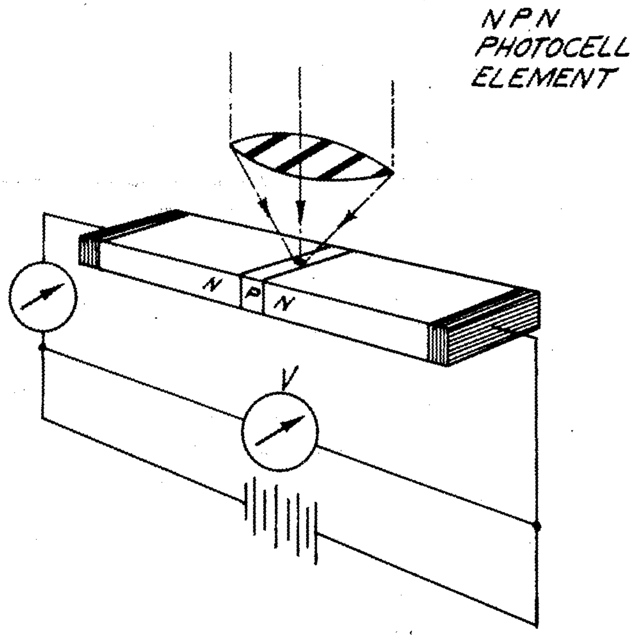


FIGURE 10

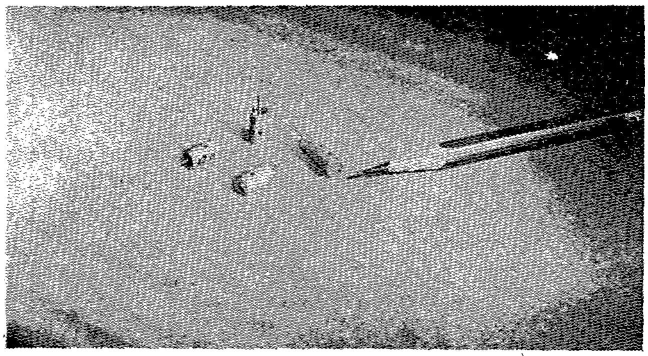


FIGURE 11

REPRODUCIBILITY

α	± 20%
r_c	± 30%
r_e	± 20%
r_b	± 25%
f_c	± 30%
NF	± 3 db
Gain (G.B.)	± 1.5 db

FIGURE 12

DIAMOND STRUCTURE

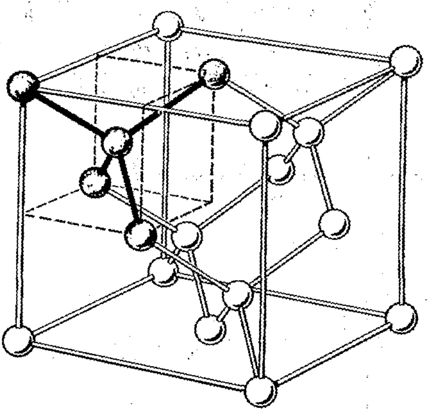


FIGURE 13

INTRINSIC SILICON

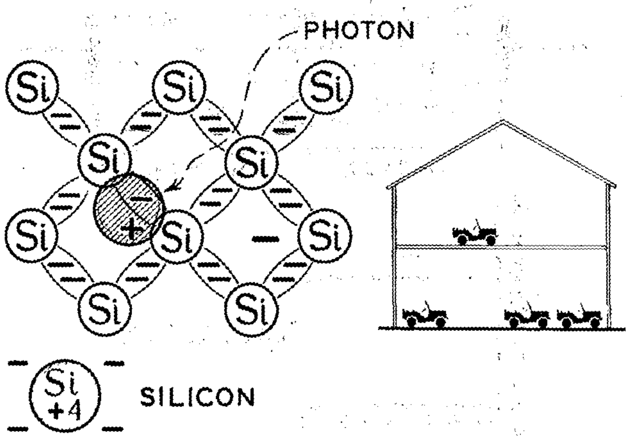


FIGURE 14

N-TYPE SILICON

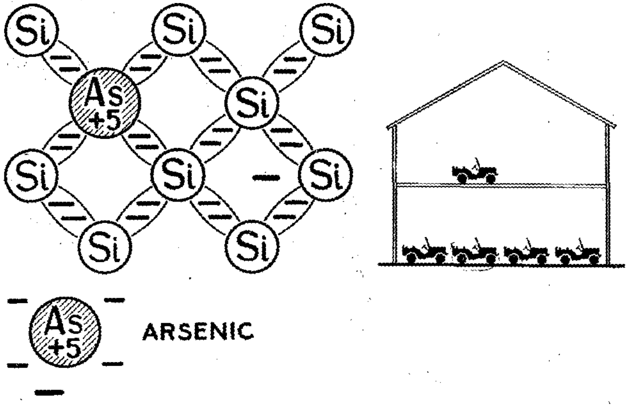


FIGURE 15

P-TYPE SILICON

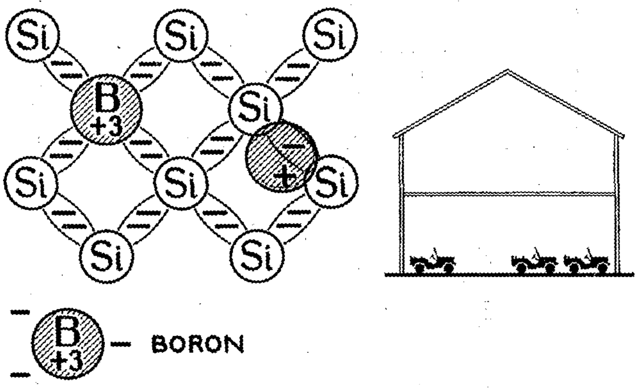


FIGURE 16

p-n JUNCTION WITHOUT APPLIED BIAS

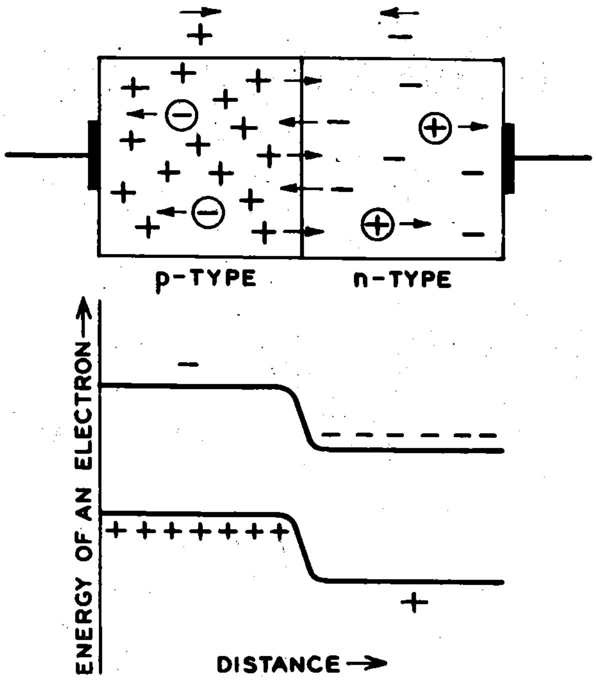


FIGURE 17

p-n JUNCTION WITH BIAS APPLIED IN THE FORWARD DIRECTION

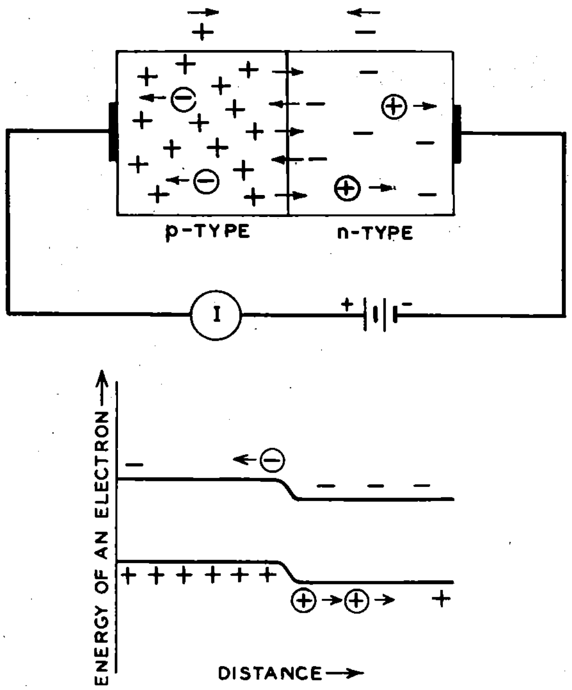


FIGURE 18

p-n JUNCTION WITH BIAS APPLIED IN THE REVERSE DIRECTION

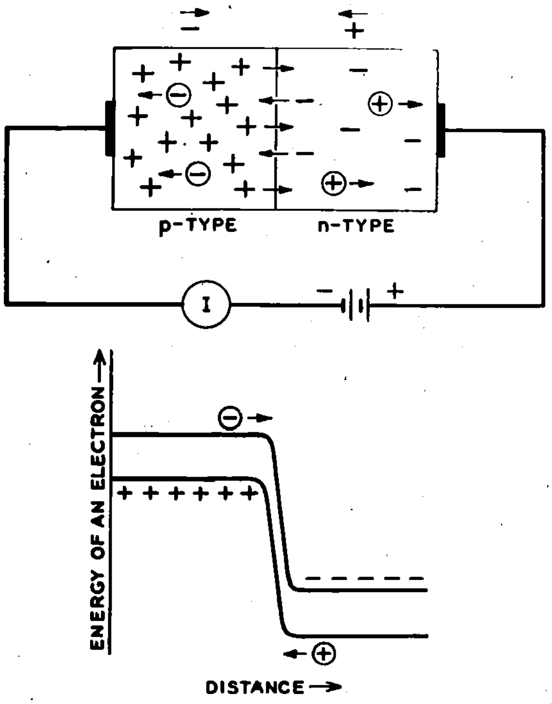


FIGURE 19

RECTIFICATION CURVE OF p-n JUNCTION WITH FORMULA GIVEN

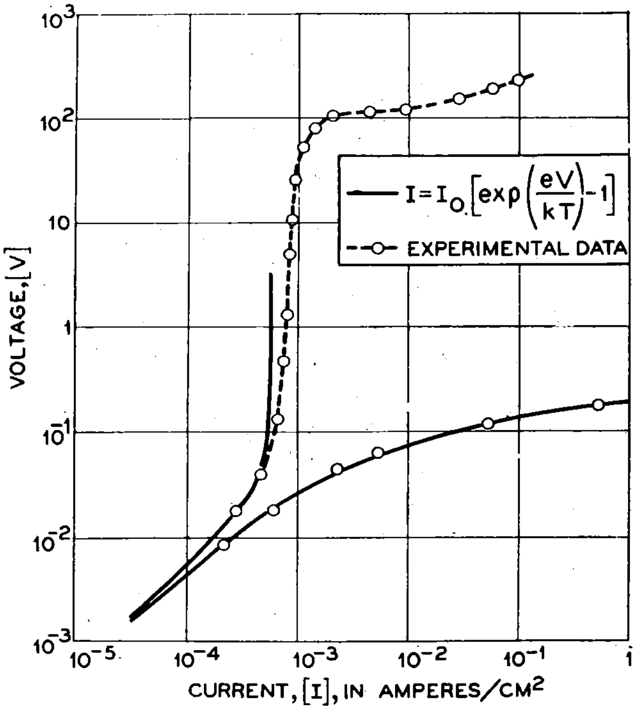


FIGURE 20

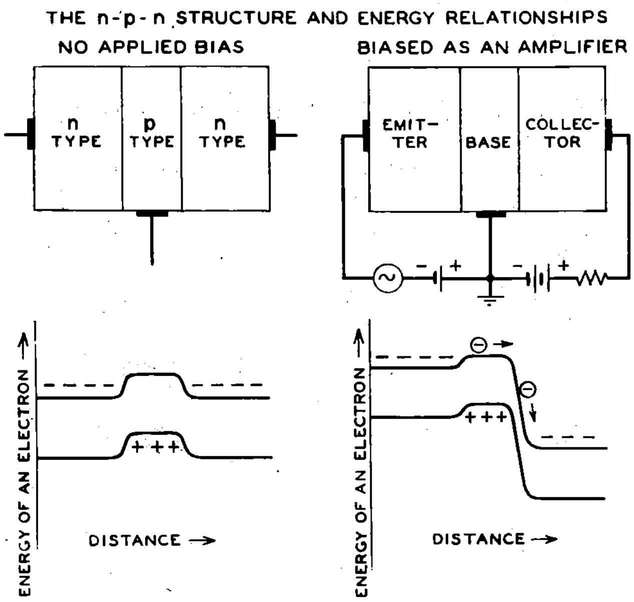


FIGURE 21

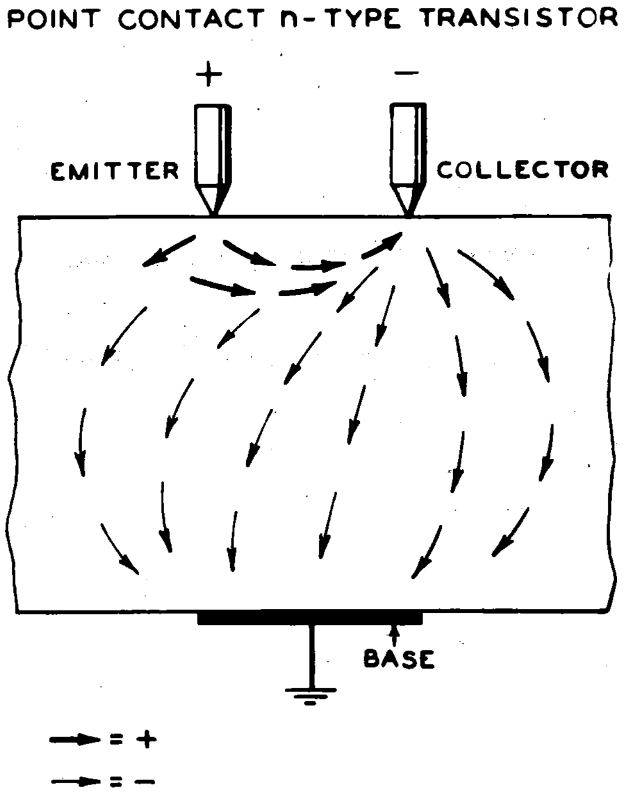


FIGURE 22

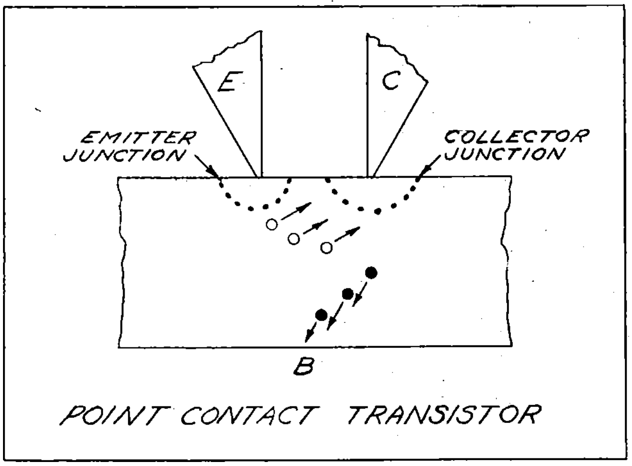


FIGURE 23

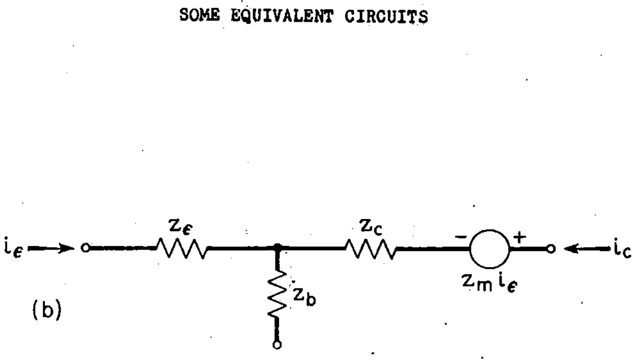


FIGURE 24

THE LOW-FREQUENCY EQUIVALENT CIRCUIT OF A TRANSISTOR

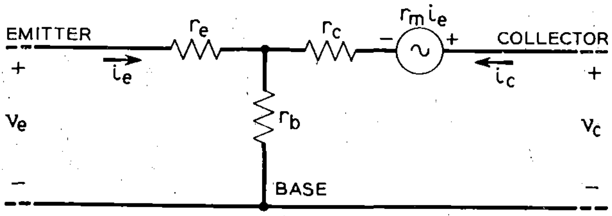


FIGURE 25

TYPICAL TRANSISTOR PARAMETERS

Type	1729	1752
r_e	120	26
r_b	75	240
r_c	15,000	13,000,000
r_m	32,000	13,000,000
α	2.5	0.98

FIGURE 26

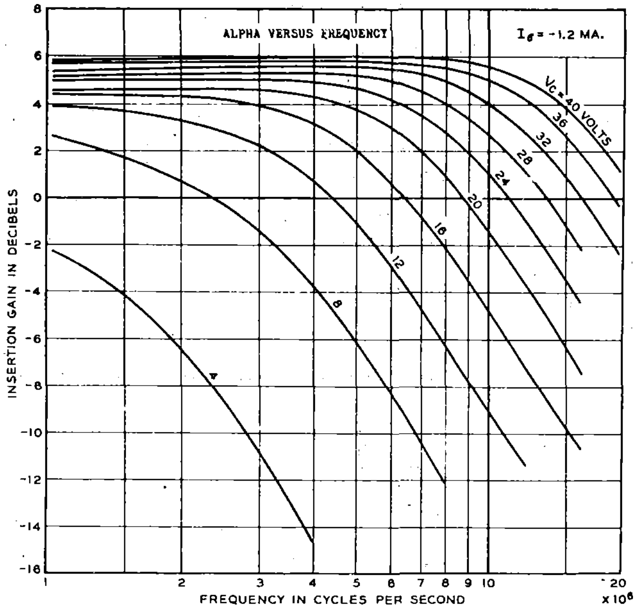


FIGURE 27

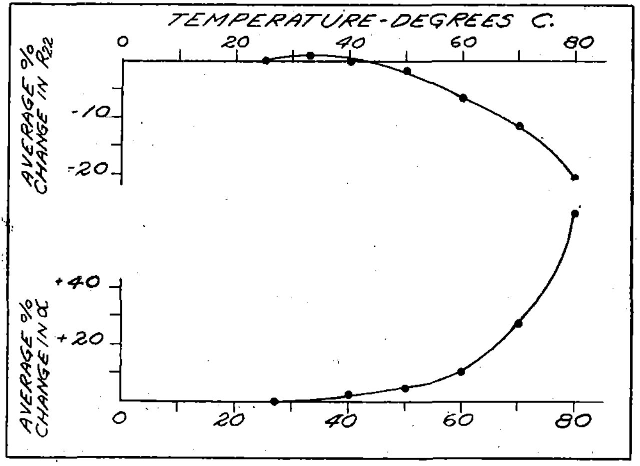


FIGURE 28

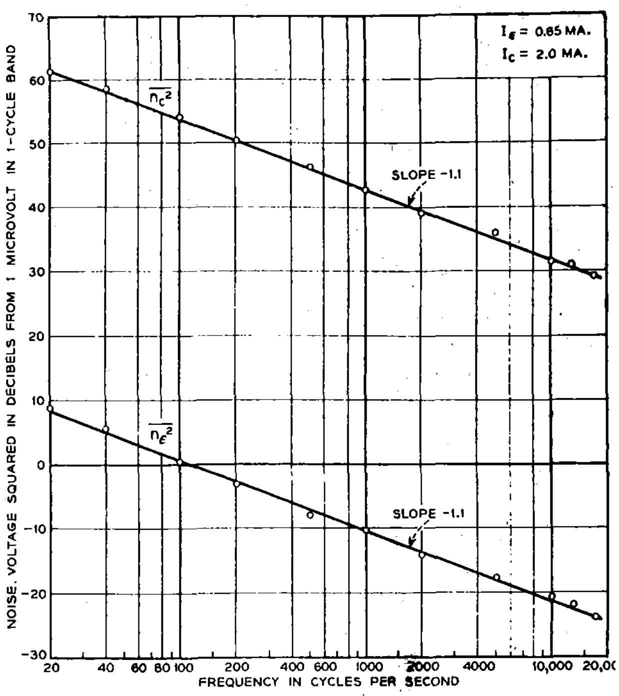

TRANSISTOR NOISE VERSUS FREQUENCY

FIGURE 29

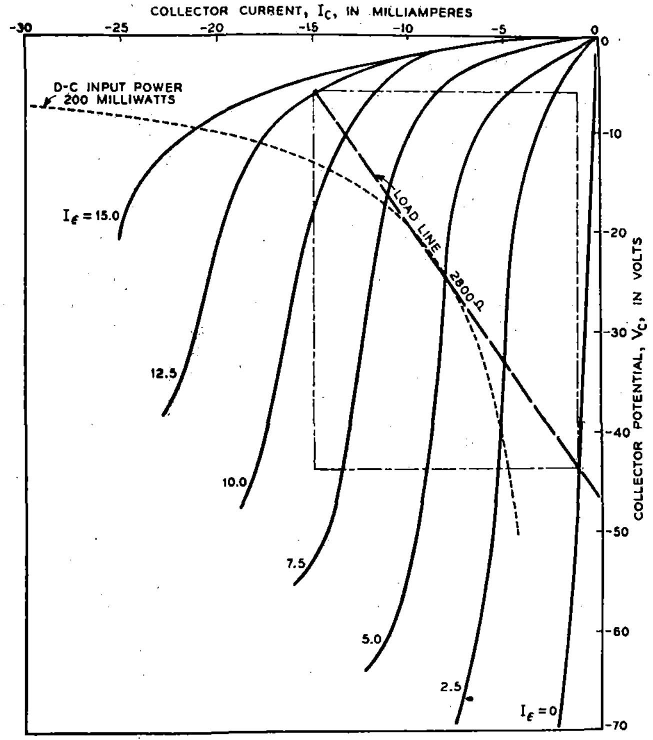

COLLECTOR POWER OUTPUT PLOT

FIGURE 30

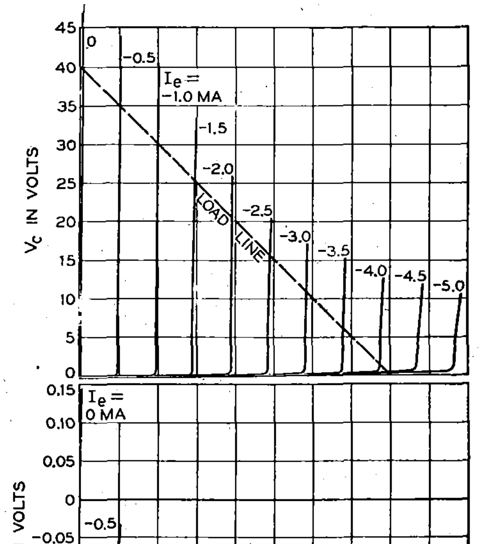

STATIC CHARACTERISTICS OF AN n-p-n TRANSISTOR

FIGURE 31

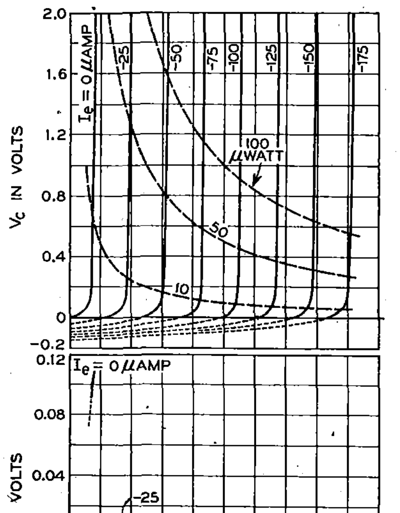

STATIC CHARACTERISTICS SHOWING BEHAVIOR AT VERY LOW APPLIED VOLTAGES AND CURRENTS

FIGURE 32

TRANSISTOR-ELECTRON TUBE ANALOGY

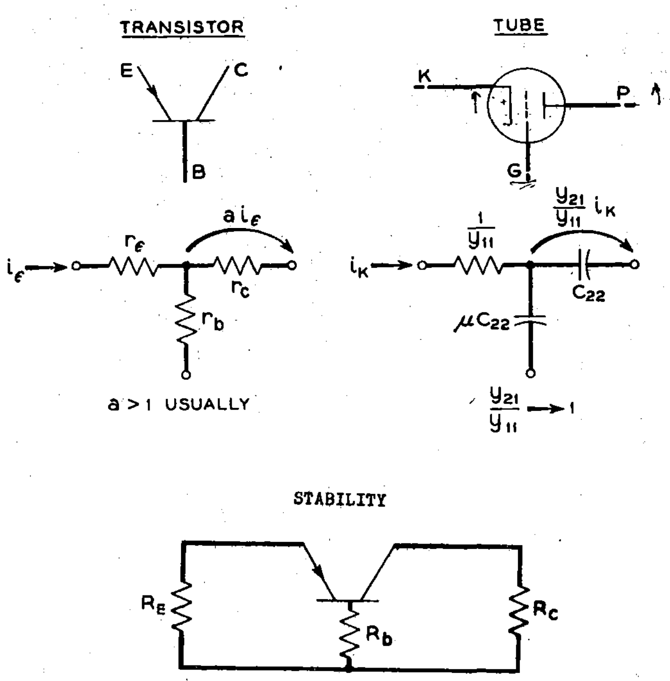


FIGURE 33

GROUNDED BASE CASCADE WITH TRANSFORMERS

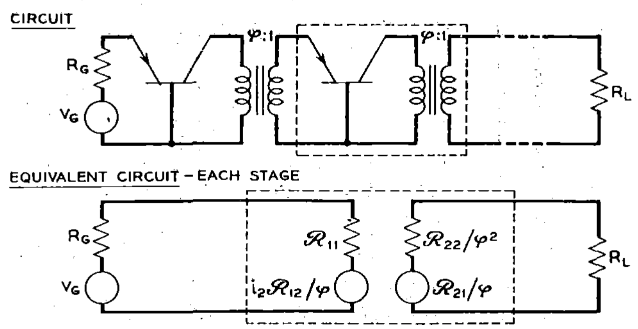


FIGURE 34

GROUNDED BASE CASCADE

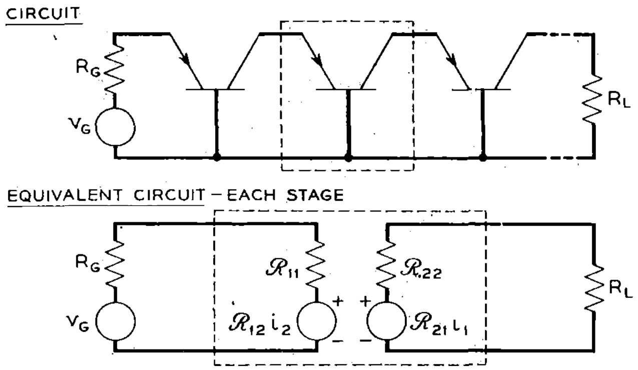


FIGURE 35

GROUNDED EMITTER AMPLIFIER

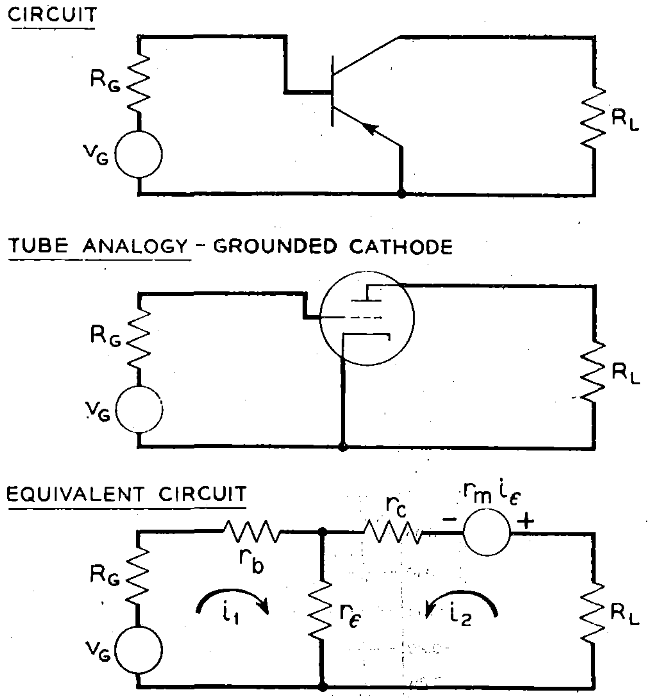


FIGURE 36

GROUNDED EMITTER CASCADE

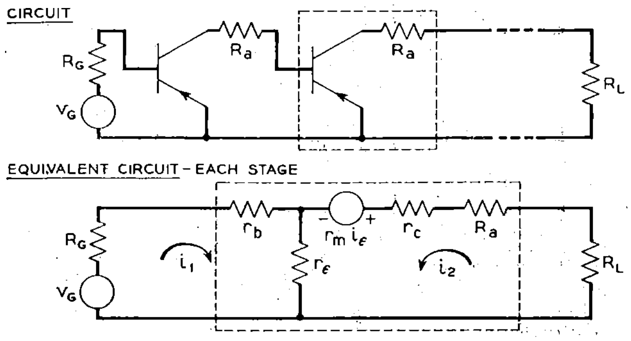


FIGURE 37

GROUNDED COLLECTOR AMPLIFIER

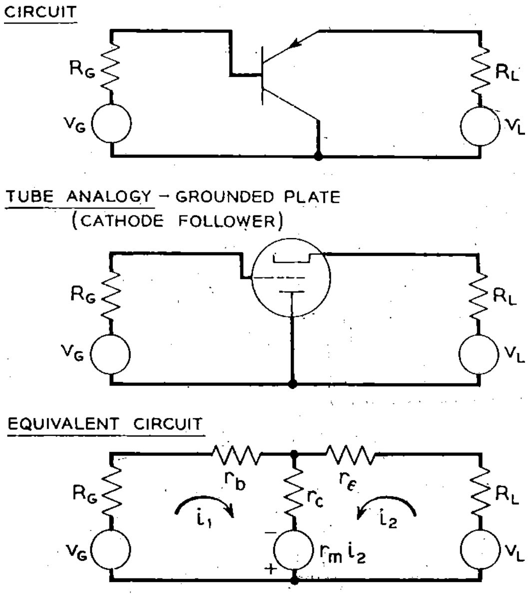
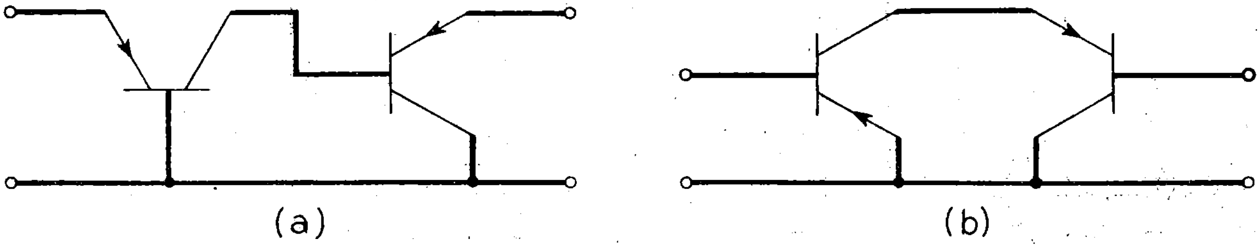


FIGURE 38

NON-ITERATIVE CASCADE AMPLIFIERS


(a)

(b)

FIGURE 39

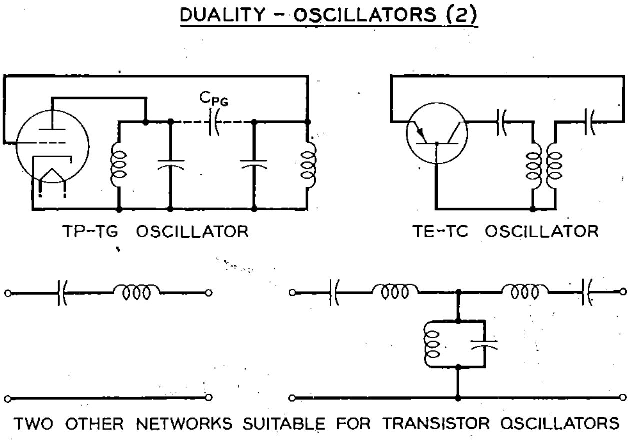


FIGURE 40

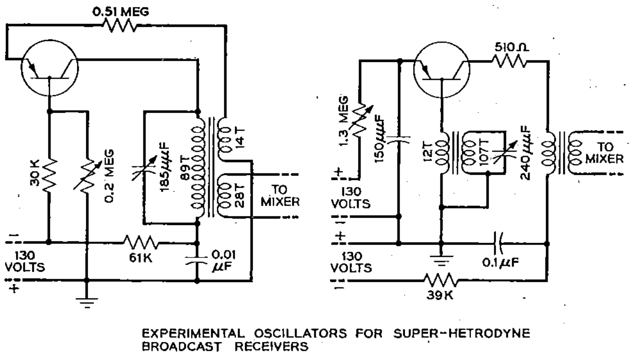
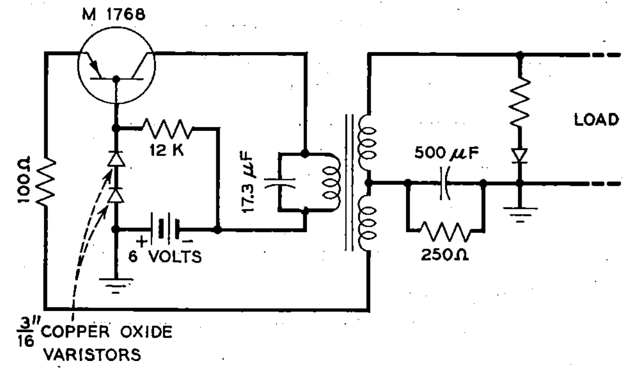
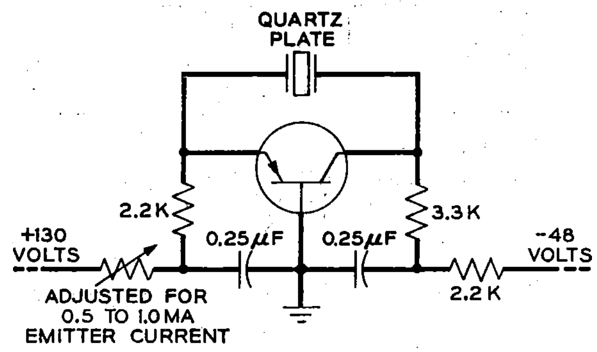


FIGURE 41



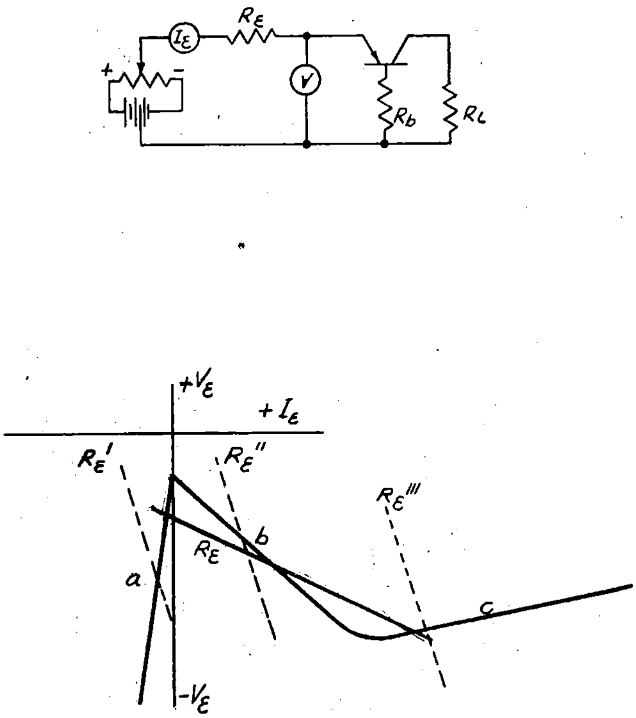
HIGH EFFICIENCY AUDIO OSCILLATOR

FIGURE 42



PIEZO-ELECTRIC CARRIER FREQUENCY OSCILLATOR

FIGURE 43



EMITTER NEGATIVE RESISTANCE CHARACTERISTIC

FIGURE 44

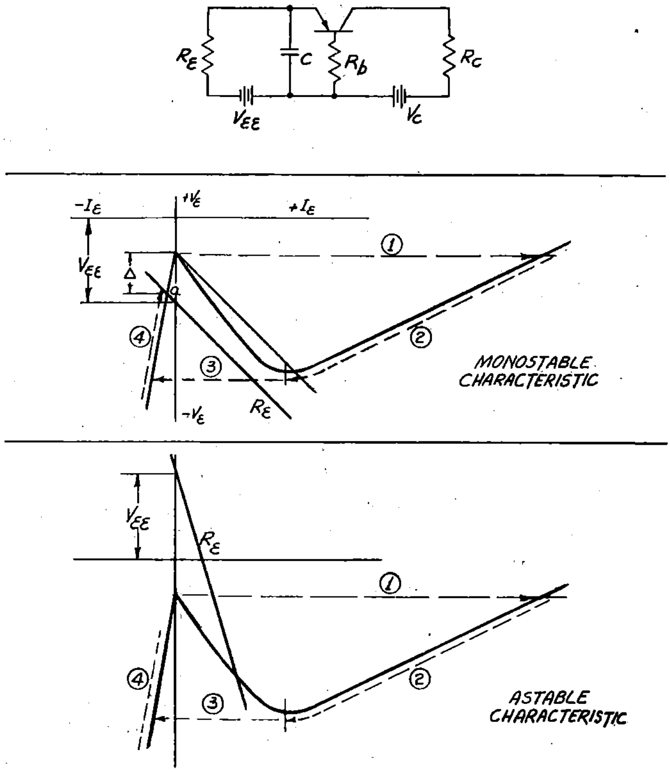


FIGURE 45