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PRACTICAL TRANSISTORS & transistor circuits

by
J. S. KENDALL
Assoc., Brit., I.R.E.

- * How to make your own transistors.
- * Testing & Forming home-made transistors.
- * Practical circuits using transistors.

BERNARDS RADIO MANUALS

The Book of the TRANSISTOR

by

J. S. Kendall

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CONTENTS

Preface	5
Chapter 1. Home construction	7
Chapter 2. Testing transistors	14
Chapter 3. Transistors and their peculiarities	19
Chapter 4. Power supplies for transistors	25
Chapter 5. The transistor as an oscillator	28
Chapter 7. Unusual transistor circuits	37

Brief details of commercially made transistors

Point Contact Types	40
P-N-P Junction Transistors	41
Table of American Transistors	42

TABLE OF ILLUSTRATIONS

1.	The required materials	6
2.	Details of Perspex support	8
3.	Method of assembly	9
4.	Adjusting a Point Contact transistor	10
5.	Details of the Razor Blade transistor	11
6.	Enclosed model of Razor Blade transistor	12
7.	Testing for transistor action	13
8.	Method of "forming a transistor"	13
9.	Circuit for measuring mutual conductance	15
10.	Graph showing transistor performance	16
11.	Audio distortion test using an Oscilloscope	17
12.	R.F. " " " " " "	17
13.	Measuring the voltage gain of a transistor	18
14.	The Earthed Base circuit	19
15.	The Earthed Emitter circuit	20
16.	The Earthed Collector circuit	20
17.	Graph of Earthed Collector performance	21
18.	Direct coupled P.N.P.—N.P.N. combination	22
19.	Push-Pull circuit using P.N.P.—N.P.N. transistors	23
20.	"Bridge" type output circuit	24
21.	Transistor supply obtained from an associated valve circuit	25
22.	" " " " " " " "	25
23.	A thermal shunt made from a crocodile clip	26
24.	Circuit showing a transistor oscillator	29
25.	" " " " " "	29
26a.	Circuit of a simple transistor receiver. Fig. 26b. Details of coil	30
27.	A circuit which uses two transistors	30
28a. 28b.	A transistor used as an R.F. amplifier	32
29.	A transistor Pre-Amplifier	33
30.	The circuit of an audio amplifier	33
31.	Correct and incorrect methods of connecting a volume control	34
32.	A super-regenerative receiver	36
33.	Sensitive relay using a transistor	39
34.	Circuit of a Morse Code oscillator	39
35.	Crystal control applied to a transistor oscillator	39
36.	A transistor power by light	39

Preface

Due to their very nature, the development work on transistors has been restricted to a few elaborately equipped laboratories, and the findings of these establishments have been published in highly technical terms, which are, to a large extent incomprehensible to the radio enthusiast.

The Publishers have much pleasure in presenting for the first time in Great Britain, detailed step-by-step instructions for the construction, forming, and testing, of home made transistors.

Explanations are supplied for all the basic transistor circuits, in an easy to follow manner. The reader is then shown how to put these basic circuits to practical use. Two or more basic circuits are then combined to form more advanced designs, and with an eye on the future, details have been given of circuits incorporating commercially made transistors.

The author (J. Kendall), whose inimitable style will by now be familiar to many of our readers, has once again satisfied a much felt need for information of a practical nature.

JOHN K. MURRAY.

Assistant Technical Editor.

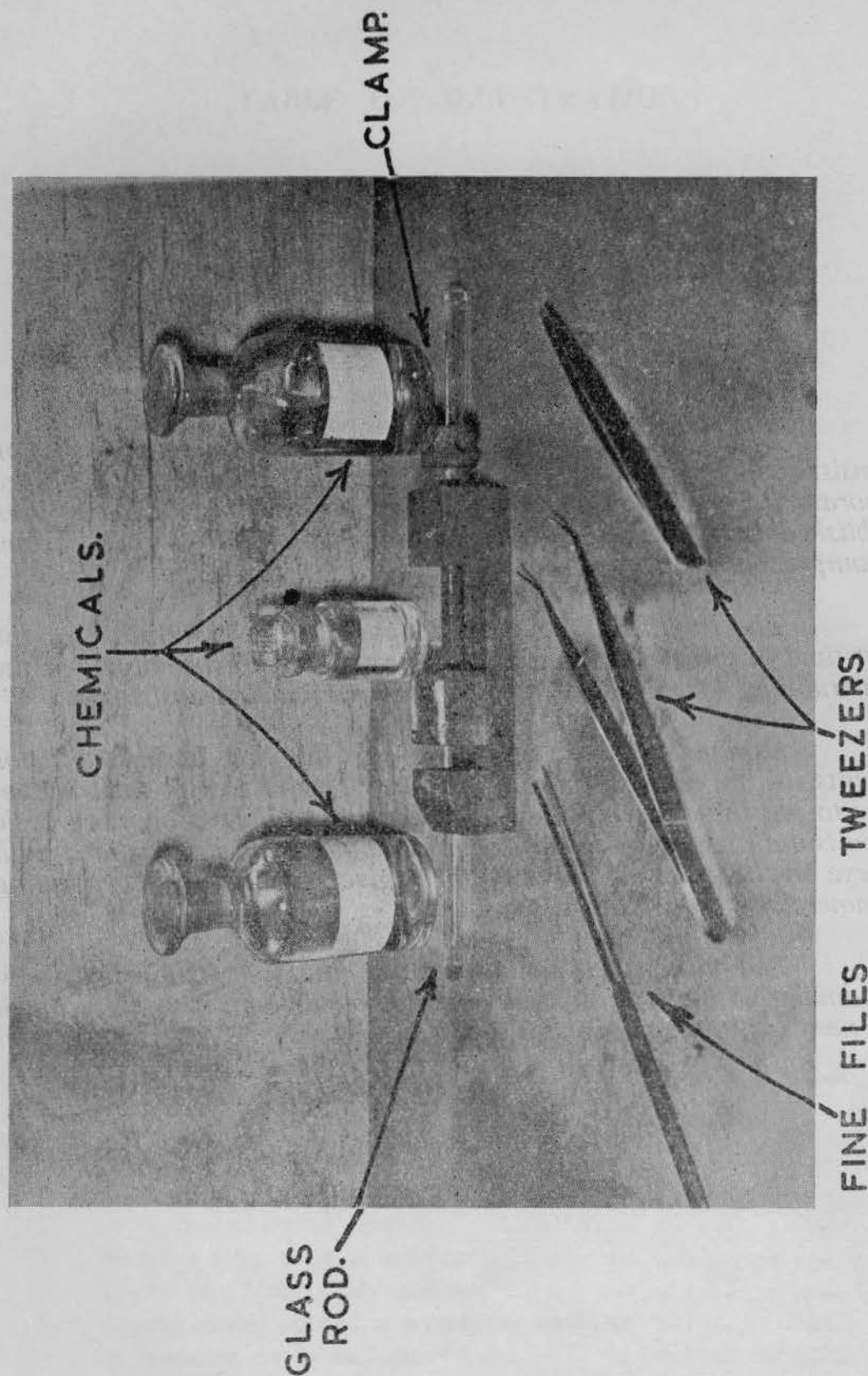


Fig. 1. The required materials

CHAPTER 1

HOME CONSTRUCTION

The transistor is by no means new, but it is only of late that it has become news. It is a fascinating device that can be made by the average amateur constructor. It takes trouble, time, and patience, but on the other hand the commercial versions are extremely expensive and in short supply. The writer has made a number of point contact transistors, one type using "Cats Whiskers" from germanium diodes to form the contacts, and another pieces of razor blade soldered on wires. These latter did not give the service of the whisker contact models.

Perhaps a little on the history of Germanium will not be out of place.

It can be obtained from various sources—from soot, or zinc ore, in fact it has been used for filling teeth in dentistry. During the late war, minerals were required to make diodes for detection in Radar equipment, germanium reacted favourably on test, and consequently quite an amount of research was carried out on this material. Its characteristics as a diode are well known. What is not generally realised is that 100% pure germanium is useless for radio work; impurities, even though in minute quantity, are essential to make it suitable for radio application. These impurities are such a variable factor that at the moment, it is not possible to manufacture a number of transistors and predict the characteristics before they are made. At least one firm makes transistors using a certain grade of a germanium under closely guarded conditions, but they still have to be graded on completion.

There have been articles published on the construction of the transistor from time to time, the author has made them, and experienced no great difficulty in producing working specimens. Materials required are shown in Fig. 1. They consist of fine files, a glass rod, a clamp, a few pairs of tweezers, chemicals, some sheet Perspex, and a quantity of germanium diodes.

The chemicals required are, trichlorethylene for use as a solvent for certain plastics, carbon tetrachloride and a solution of Perspex in chloroform. This solution is produced by placing a few shavings of sheet Perspex in a wide-necked bottle and covering them with chloroform. This will, provided that the stopper is replaced, dissolve the Perspex into a jelly which can be thinned down to a consistency comparable with gum arabic. It is easier to thin the solution than it is to thicken it. Trichlorethylene can be used as a base for thinning, but it is not as good as chloroform. A solution of Perspex in trichlorethylene tends to be more crystalline on solidifying, than is the case when chloroform is used as the solvent. The latter is therefore stronger. The glass rod is to spread the Perspex solution.

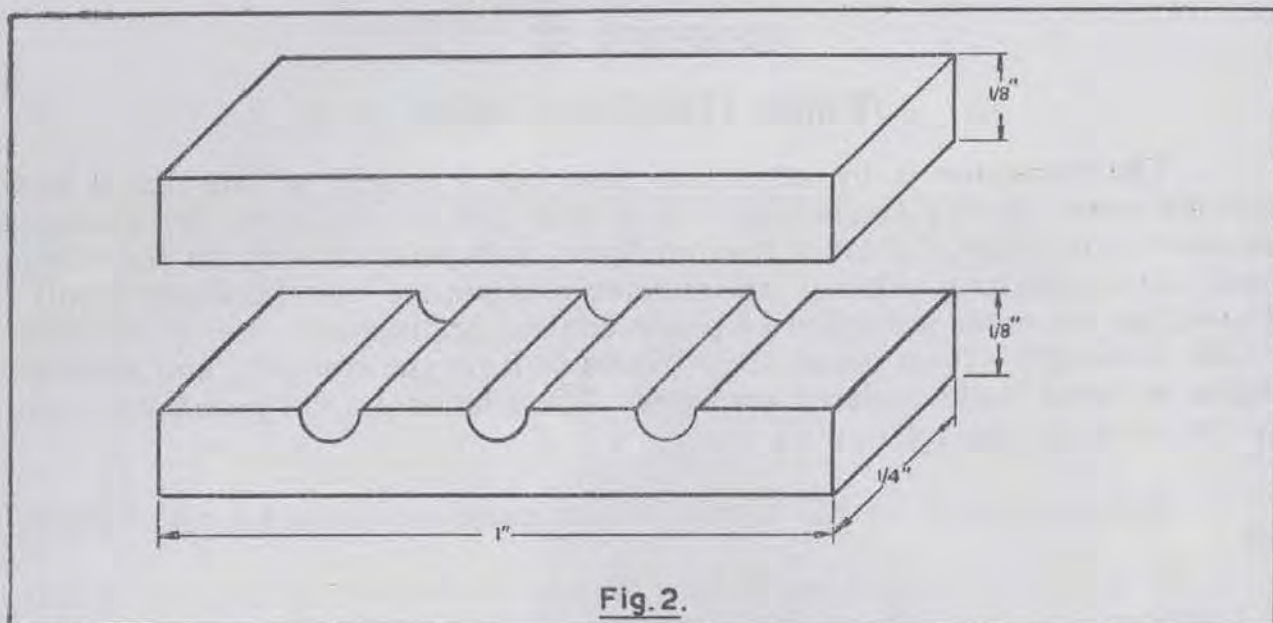


Fig. 2.

The clamp is used for breaking the glass container of the germanium diodes. Fine files, both round and triangular are required for cutting grooves etc. in the Perspex mountings.

A piece of Perspex of $\frac{1}{8}$ " thickness should be cut into small bars 1" in length and $\frac{1}{4}$ " wide. Since these pieces will be used in pairs an even number will be required. Each pair will consist of one plain and one grooved bar as shown in Fig. 2.

The next item is the "breaking" of the germanium diodes—the author has used quite a number of surplus types and found that those with the glass envelopes are the easiest to handle. Place the diode in the clamp and then tighten slowly until the glass is broken—this method saves damaging the "cats whisker" and the germanium. Use of a hammer is not advised; it will result in damage to one or both diode components. Two "whiskers" and one piece of germanium should be mounted on the grooved piece of Perspex already prepared. Bending the support wires of the component parts and the use of a piece of Sellotape as shown, will keep them steady whilst the solution of Perspex is spread with the aid of the glass rod. Fig. 3.

A plain piece of Perspex should be placed over the wires while the cement is still wet. The assembly should be set aside in a warm place to allow the cement to harden. Great care should be exercised owing to the anaesthetic properties of the chloroform vapour, and this operation should only be carried out in a well ventilated room. The constructor may not be aware of the danger until he is almost on the point of collapse. **WORK CLOSE TO AN OPEN WINDOW, AND TRY NOT TO INHALE THE VAPOURS.** If these precautions are observed, no danger will be incurred. The drying of the cement should be thorough, or there will be a tendency for the two Perspex plates to part.

Apply Perspex cement followed by a plain bar.

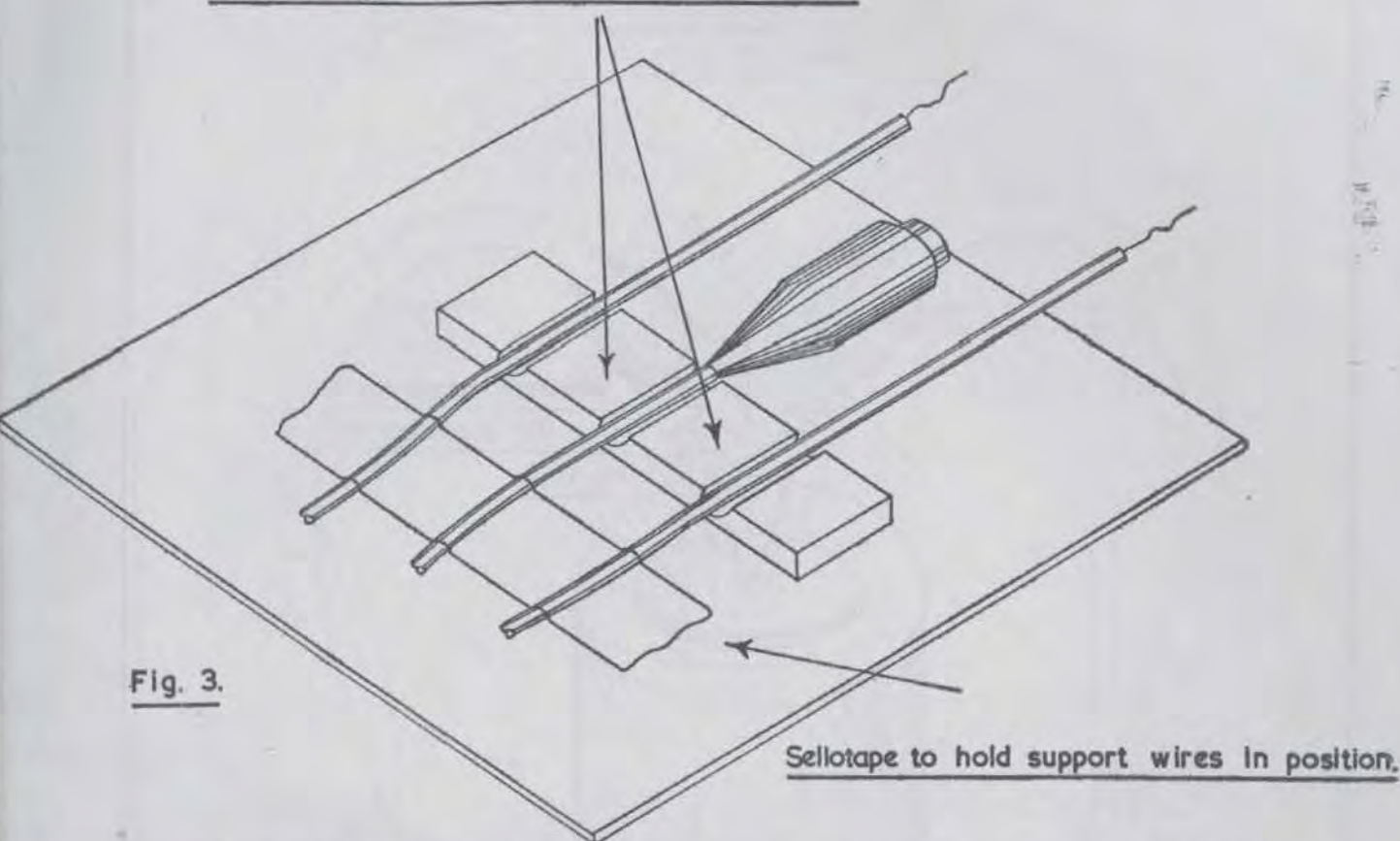


Fig. 3.

Sellotape to hold support wires in position.

The whiskers should be adjusted by bending the support wires, so that they are both making contact with the surface of the germanium. The whiskers should then be further adjusted with the aid of a pair of fine tweezers so that they touch. In the finished transistor the two whiskers are not in actual metallic contact with each other, in fact they should be separated by a very minute amount. This delicate adjustment can be obtained with the aid of a human hair, which should be passed between the two whiskers to separate them by one (literal) "hair's breadth." Fig. 4. Other materials can be used for the spacing, for example certain types of cigarette paper are sufficiently thin, being only .001" in thickness. Mica or metal foil can be used for separating the whiskers, but these materials have the disadvantage that the friction of a flat surface drags the whiskers away from the germanium when the spacer is removed, with the result that they spring together again. If an insulating material is used it can be left in position but in some cases this may cause the transistor to be microphonic. This latter complaint, as well as a considerable amount of noise can result, if the whiskers are not exerting sufficient pressure on the germanium.

If the germanium or the whiskers are touched with the hands during the construction, a small amount of grease will inevitably be deposited which will impair the action. To remove any traces of grease, the assembly should be immersed in a jar of CLEAN carbon tetrachloride, taking care not to immerse the Perspex strips since they may tend to dissolve. It is important to use clean carbon tetrachloride, since any impurities will be left behind when the liquid evaporates. After immersion, any excess droplets should be removed by the careful application of blotting paper, and the assembly should then be left to dry by evaporation.

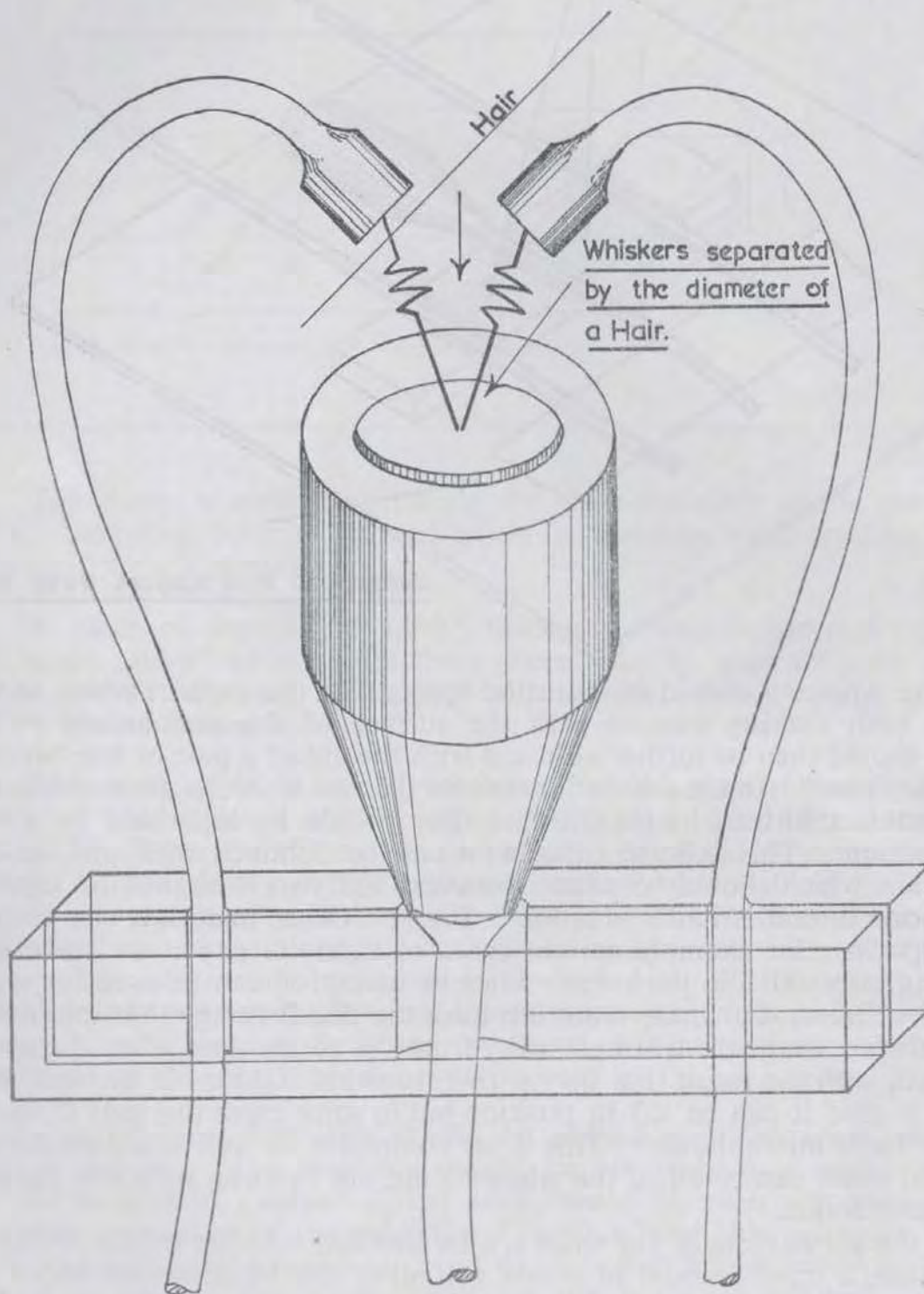


Fig. 4.

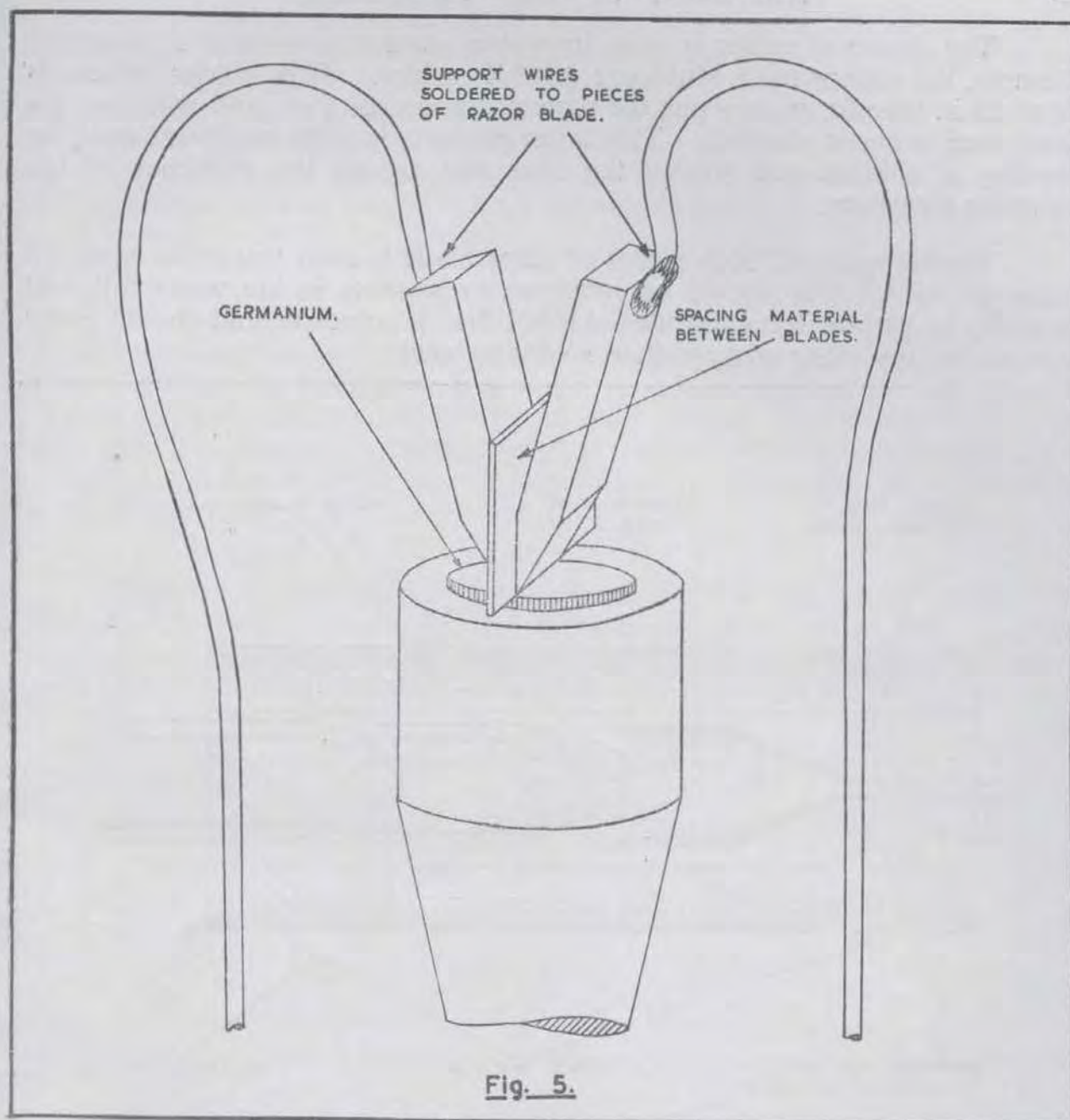


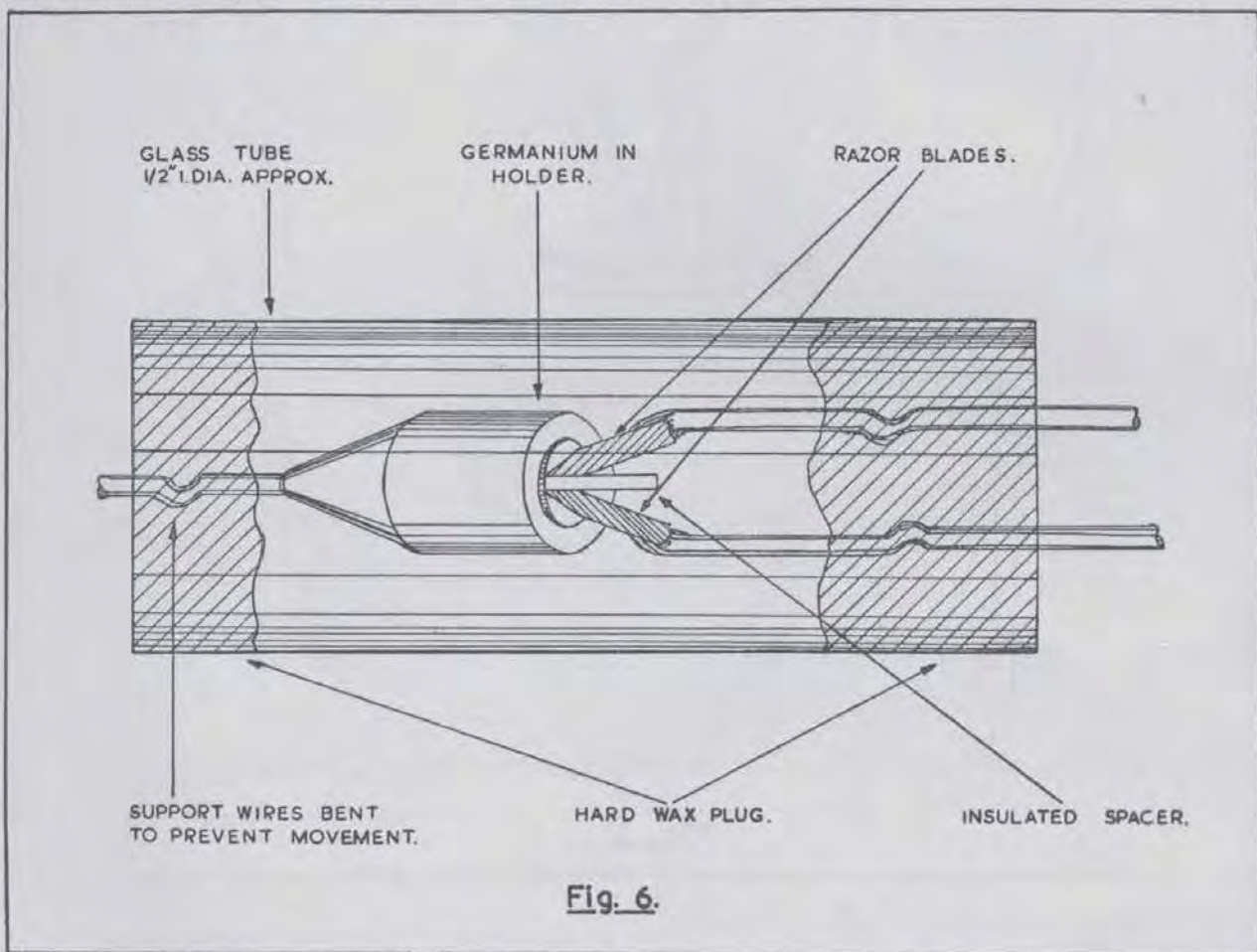
Fig. 5.

It cannot be over-emphasized that the adjustment of the whiskers on the diode is a very delicate job, and that it needs a very steady hand and a keen eye. Good lighting is essential and the operation is best performed over a piece of matt white paper. The choice of tweezers is very important which should be of the surgical type with a good grip. The dental type with the curved ends are well suited to the job, since they enable one to adjust the second whisker without disturbing the one which has previously been positioned.

The author has made a second type of transistor using pieces of razor blade soldered to the ends of stiff pieces of wire. No. 18 s.w.g. was chosen, but there is no reason why a lighter gauge should not be used, providing that it is sufficiently stiff.

The choice of solder is quite important, and after several unsuccessful attempts, the author tried Multicore ARAX solder. This solder which is obtained in wire form, contains the correct amount of flux, and will even tin blued steel without cleaning. This latter property is quite important since the cleaning of a blade can remove the edge and reduce the efficiency of the complete transistor.

Having soldered both pieces of razor blade to their respective wires, all traces of ARAX flux should be removed by washing in hot water followed by a dip in carbon tetrachloride—ARAX flux is corrosive and should never be used for any other purpose than soldering steel.

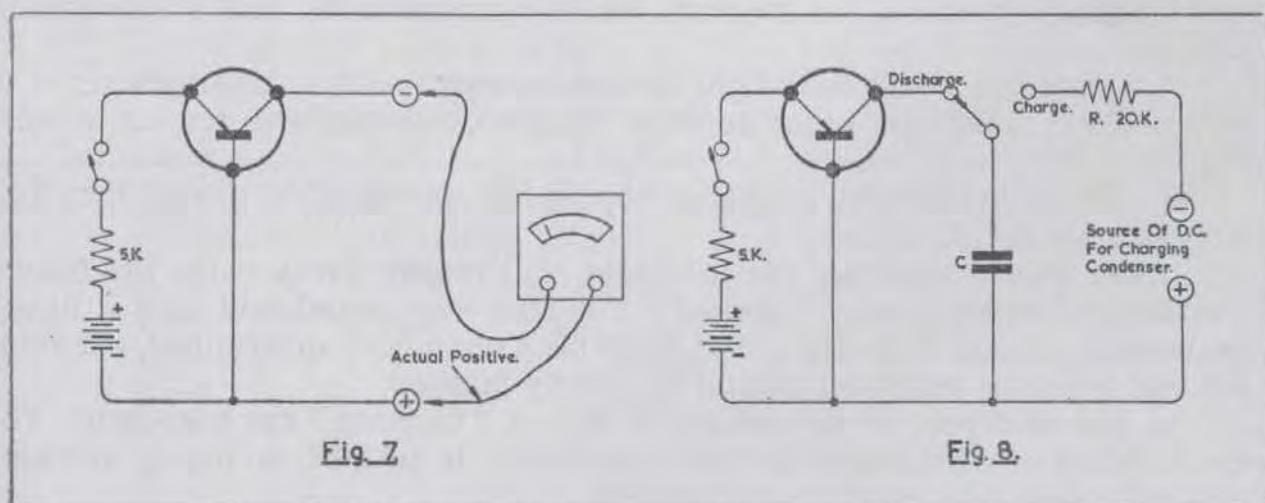


The support wires should be mounted in such a way that the soldered connections are on the outside when they have been bent into their final position. Fig. 5. The angle of the two pieces of blade should be adjusted so that the cutting edges are parallel to each other, and also so that the ground surfaces of the blade are evenly together; if this is done a spacing material can be used, and as stated previously a piece of cigarette paper or mica is ideal. The method of rough setting of the "Razor" type of transistor is much the same as the point contact type. Alternatively the two pieces of blade can be adjusted first, and the germanium moved into position afterwards; both methods having been tried by the author.

This type has been found to be less sensitive and less noisy, but more robust than the point contact variety. There seems to be no reason why the assembly could not be modified for mounting in a glass tube as shown in Fig. 6. Here it is suggested that the two mounted blades should be first set in a suitable insulating material—a hard wax is suggested. The germanium should be mounted in the other end of the tube, and positioned so that it presses against the two blades. Care should be exercised to avoid altering the relative positions of the two blades.

The constructor must bear in mind that the adjustment of the point contact transistor is an extremely delicate task and requires much patience. After a number of unsuccessful attempts, the constructor will probably evolve his own method. The author has found that placing his elbows on a table gives sufficient support. Alternatively the free ends of the support wires could be held in a clamp or small vice, thus enabling the constructor to use one hand to steady the other.

The cost of construction is comparatively low when compared with commercially made transistors, and germanium diodes are readily available. On the other hand, transistors are at present limited to research and development laboratories and are only released in very restricted quantities.



CHAPTER 2

TESTING TRANSISTORS

Having completed the transistor, the constructor who is of an enquiring mind will want to know how to assess its performance.

A few preliminary checks are in order, and the following procedure is recommended.

(1) Using an ohmmeter, check the resistance between the two points. The germanium or "base" should be left floating during this test.

A short circuit indicates that the contacts require readjusting, and a satisfactory figure should be in the region of 1 megohm.

(2) To check the fact that both contacts are on a sensitive portion of the germanium it is necessary to find out whether diode action is present.

First it will be necessary to find out the polarity of the ohmmeter:— A number of multi-range instruments are so arranged that the normal positive connection (Red lead), carries a negative potential when the instrument is switched to read resistance. Having ascertained which is the negative terminal, connect it to the germanium (base), and measure the resistance to each contact.

The reading should be approx. 500Ω and should not exceed 1000Ω .

Reverse the meter connections so that the actual positive lead is connected to the base. Readings between the base and each contact should be between 0.25 to 1 megohm.

If the meter readings fluctuate badly, it will be necessary to increase the contact pressure.

(3) Leaving the actual positive lead connected to the base, connect the negative lead to one of the contacts, which is going to be tried in the role of collector.

Using a 4.5 volt flash-light battery in series with a limiting resistor of about $5k\Omega$, make the other contact (emitter), positive with respect to base. Fig. 7.

The collector/base resistance should fall considerably, though the effect may be only slight.

(4) Interchange the two contacts, and repeat test 3, using the former "collector" in the role of "emitter." One way round will give a bigger percentage change than the other, and this having been determined, the emitter and collector terminals should be clearly marked.

The next part of the process is that of "forming" the transistor. The exact theory of what happens when a transistor is formed is highly complex and even now only partially understood.

Sufficient it is to say that a properly formed transistor will have a power gain of 15 times that of an unformed one.

There have been several methods suggested for carrying out the process and the one set out below has been well tried

Connect the transistor as shown in Fig. 8. A source of D.C. will be required, which is variable from -100 volts to about -250 volts in 25 volt steps.

The condenser C should be quite small at the start, but it has to be increased in value during the process.

Start by using a 500pF. capacitor which should be charged to approx. -100 volts via resistor R. Throw the switch to the discharge position and then measure the collector/base resistance as before (Fig. 7), both with and without emitter bias applied. The charging voltage should be increased in 25 volt steps, until -250 volts has been reached. In between each discharge, the collector/base resistance should be measured. (The ohmmeter should of course be disconnected before discharging the condenser!).

The process should be repeated using a larger capacitor after each voltage maximum, until the collector resistance has fallen to about $1.2\text{k}\Omega$ with bias, or to below $12\text{k}\Omega$ without bias.

The mutual conductance of the finished transistor can be measured by the following method. Connect as shown in Fig. 9, and proceed as follows.

- (1) Close S_1 and measure the collector current I_1 on meter M_1 .
- (2) Leaving S_1 closed, complete the emitter circuit by closing S_2 .

The new collector current I_2 should be noted.

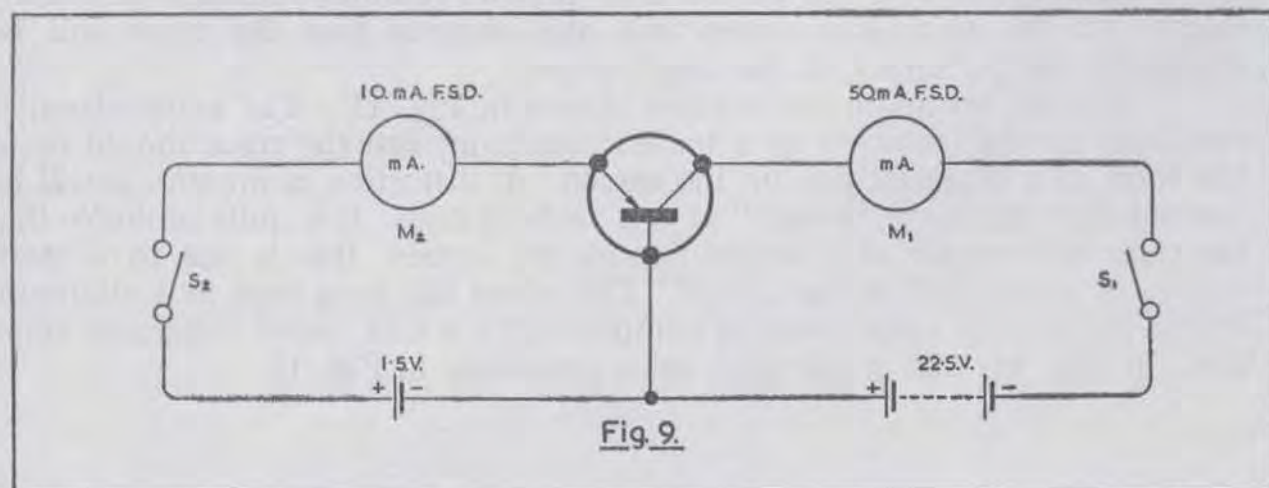
The mutual conductance is given by:—

$$\frac{I_2 - I_1}{1.5} \quad \text{mA/V.}$$

The second meter M_2 is not essential to the test, but in a healthy transistor an emitter current ranging from a few micro-amperes up to about 3 mA. can be expected.

The characteristics of home made transistors are bound to vary within very wide limits, and the following figures are only intended to act as a very rough guide.

Applied collector volts max.	...	...	-40 volts.
Peak collector volts	...	...	-75 volts.
Collector current max.	...	...	25 mA.
Max. collector dissipation	...	...	50 mW.
Max. emitter current	...	...	5 mA.



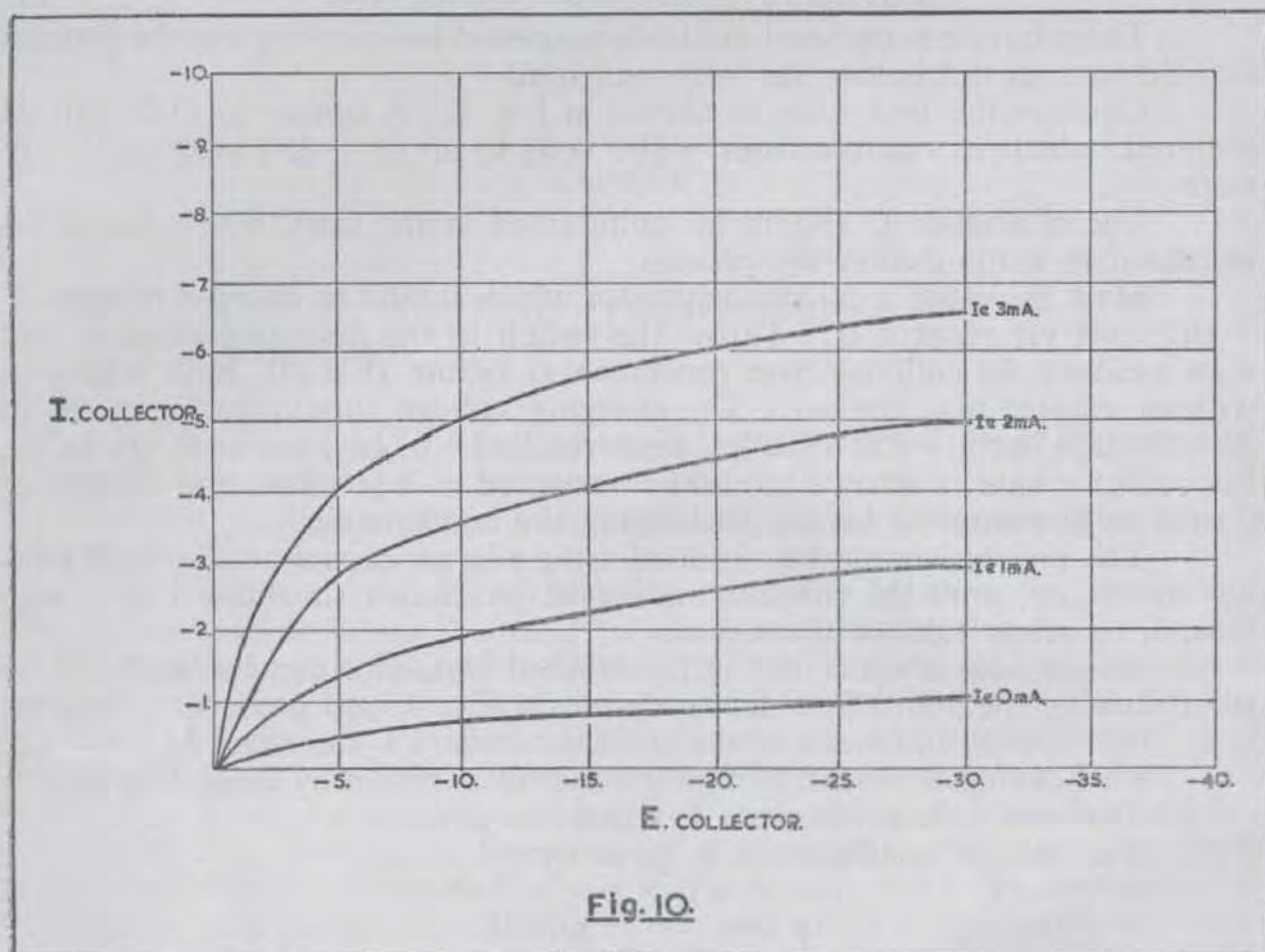


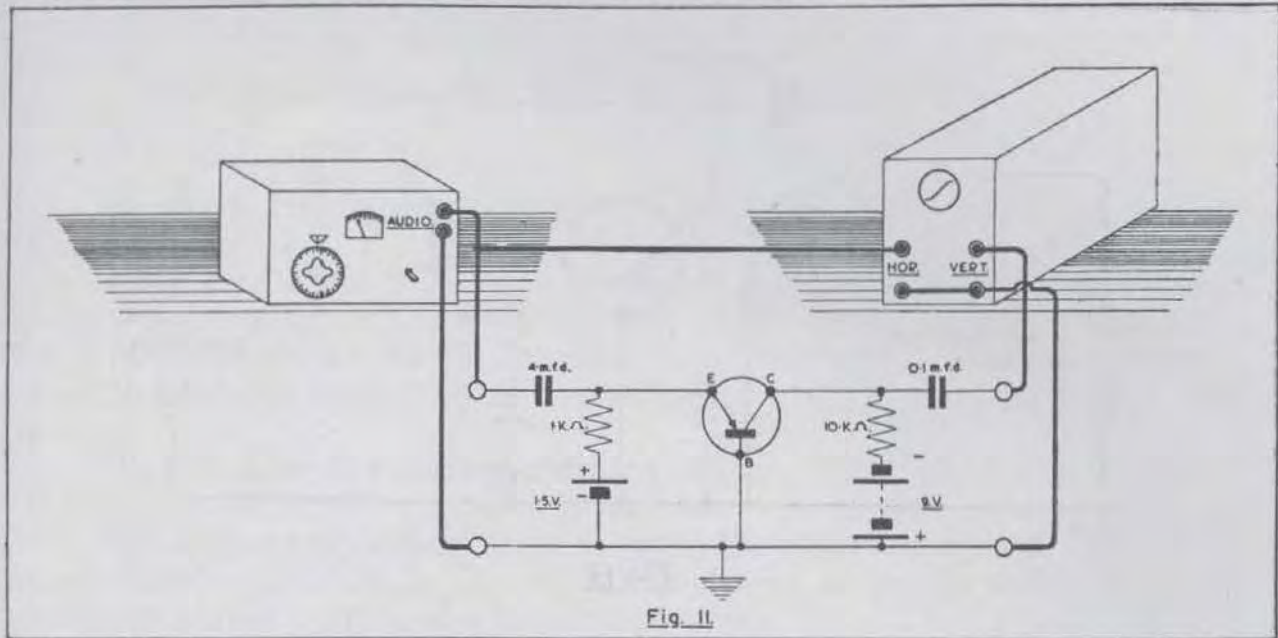
Fig. 10.

Fig. 10 gives an idea of the curves which should be obtainable from a transistor which is functioning satisfactorily.

So far only the static characteristics and behaviour of the transistor have been considered. The next test, for which a signal source and an oscilloscope are necessary, concerns its dynamic behaviour; this enables the constructor to find out in a practical manner what is the best value of emitter bias to apply.

There are two tests that are of importance, the first being for distortion when used as an audio amplifier, and the other for checking detection distortion. The best method is to connect an audio frequency generator to the horizontal amplifier of an oscilloscope, and to apply the same frequency supply to the transistor under test, this ensures that the trace will be stationary on the screen of the oscilloscope.

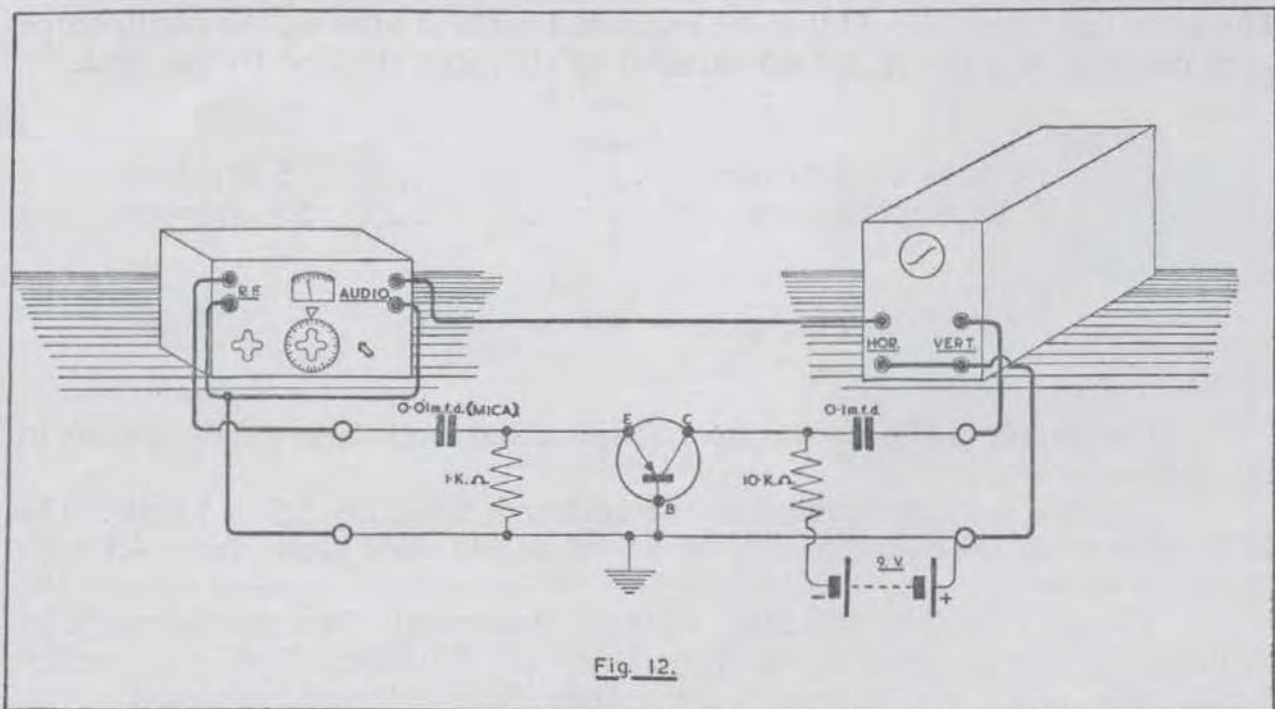
The test for audio distortion is shown in Fig. 11. The audio signal is amplified by the transistor in a biased condition, and the trace should be in the form of a diagonal line on the screen. If distortion is present, it will be noticed that the trace "bends" at one or both ends. It is quite probable that the trace will appear as a double line on the screen, this is due to a small degree of phase shift in the circuit. This effect has been kept to a minimum by the use of large value coupling components; a 4 mfd. paper condenser being used in Fig. 11, and a .01 mfd. mica condenser in Fig. 12.

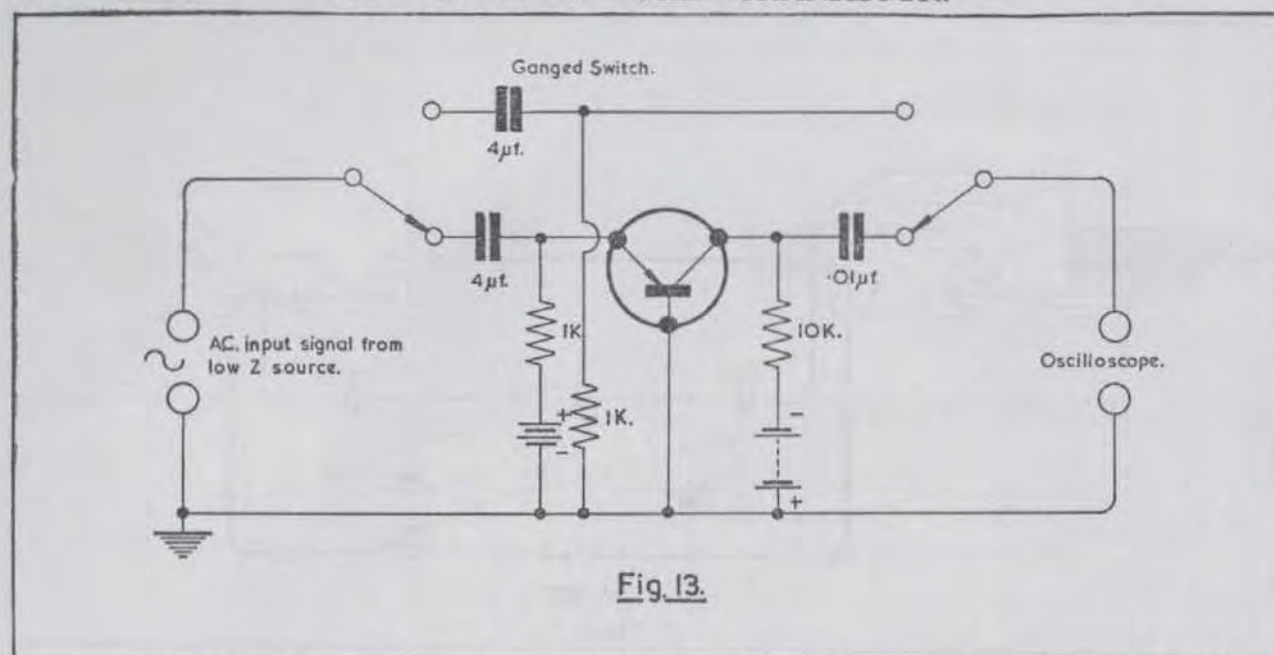


Variation of the bias voltage applied between the emitter and base, will reduce the distortion. A compromise value should be found which gives low distortion consistent with a reasonably low current.

Checking for detector distortion is very similar, and is shown in Fig. 12. In this case the transistor is operating in an unbiased condition.

At very low signal levels, distortion will be present, but as the signal is increased the distortion should diminish.





A simple method of measuring the voltage gain of the transistor is shown in Fig. 13. It can be seen that the method is by comparison of the input signal, with and without amplification.

A squared scale or graticule will be required for the oscilloscope, and the procedure is to note how many divisions the un-amplified signal occupies. The amplified signal should then be examined without altering the oscilloscope gain control, and the increased number of divisions divided by the first.

Example:—

Without amplification	...	...	...	5 divisions.
With amplification	...	...	...	50 divisions.

$$\text{Voltage gain} = \frac{50}{5} = 10$$

The circuit in Fig. 10 has no voltages given, and these values are left to the experimenter.

The bias voltage applied to the emitter is normally 1.5 to 3 volts. The H.T. voltage on the collector may be varied within wide limits, from 4.5 volts up to 30 volts.

Above a certain collector voltage, noise will become increasingly evident. This will show as an irregularity or "fuzziness" on the oscilloscope trace, which will be present even when the input is disconnected.

CHAPTER 3

TRANSISTORS & THEIR PECULIARITIES

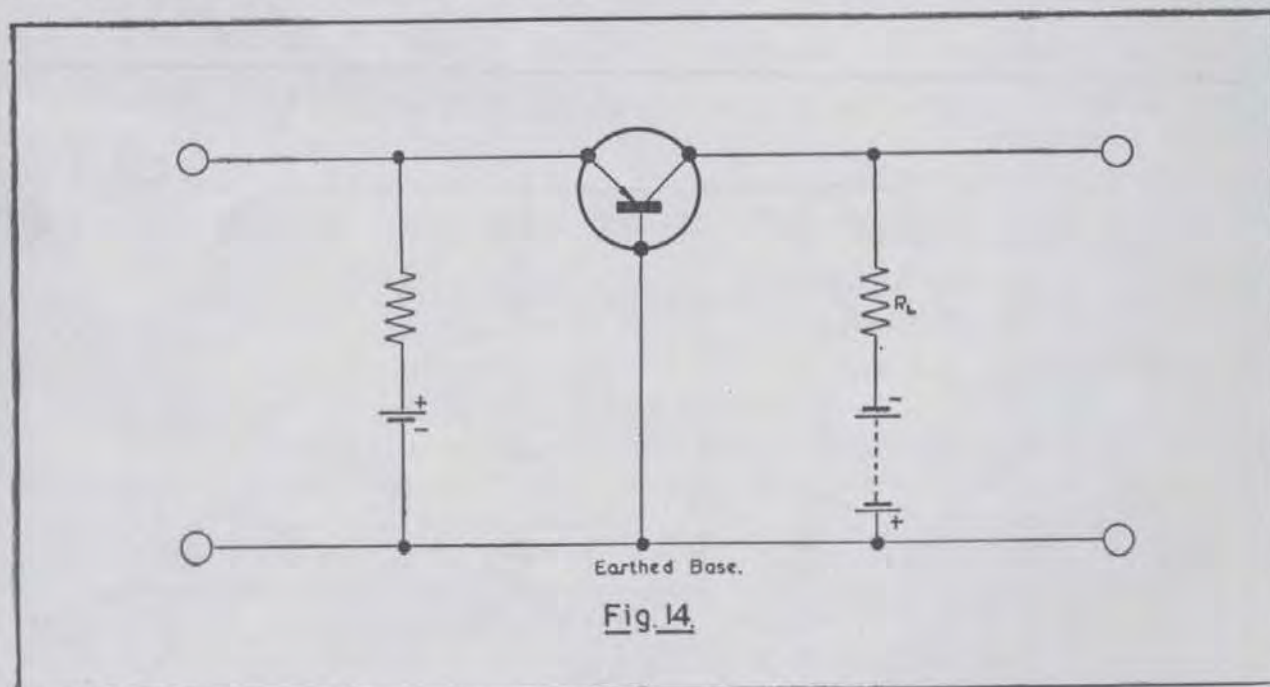
Transistor circuit technique is very different to its valve counterpart for several reasons.

In the case of a triode valve, the input impedance approaches infinity, and the output impedance is relatively low. The triode valve is therefore a voltage operated device which consumes very little energy in its grid circuit, and which produces large changes in anode current for a given change in grid potential.

The transistor is a current operated device. When the signal is applied to the emitter, the input impedance is very low and ranges between 50Ω to $1K\Omega$. The output impedance depends upon the germanium used, but will be between $50K\Omega$ and $250K\Omega$. Thus a small change in input current produces a change in output current at a higher impedance.

This state of affairs prevents the use of resistance capacity coupling between stages, and step down transformer coupling is normally employed. A transistor can be coupled satisfactorily to a thermionic valve by resistance-capacity methods.

For those who intend to develop their own circuitry, the following comparisons may prove helpful.

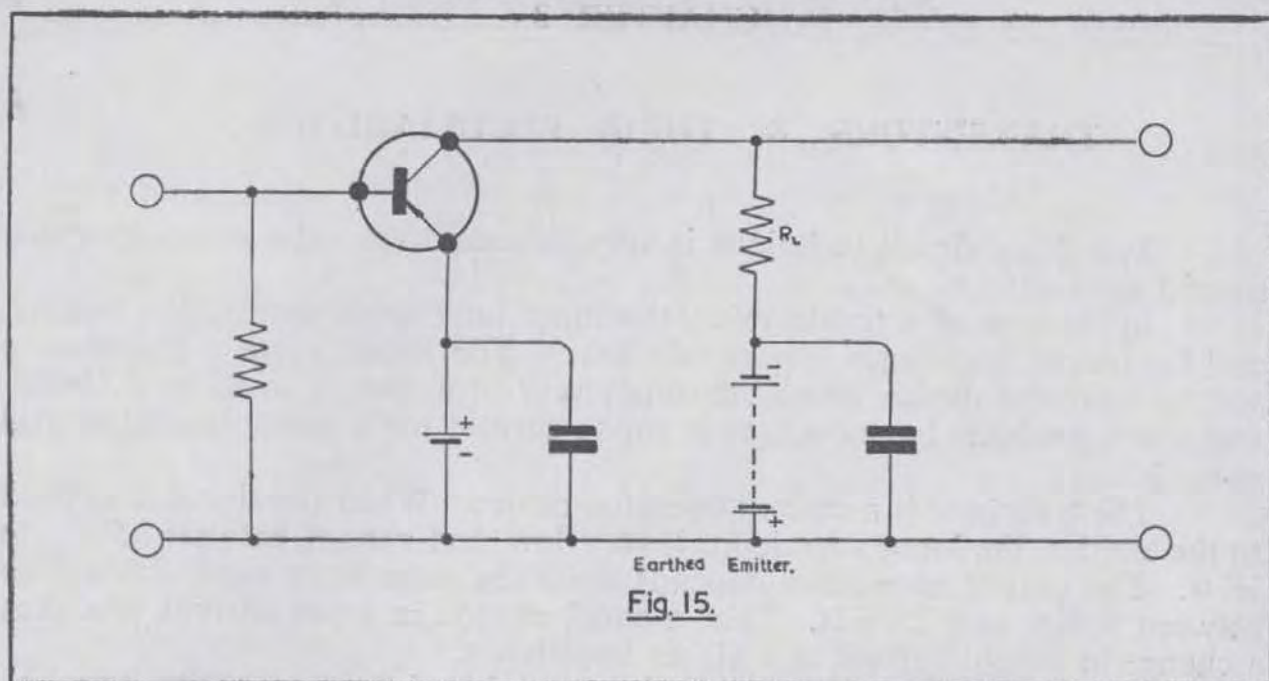


Input impedance approx. 50Ω .

Output impedance approx. $200k\Omega$.

Power gain of approximately 20db. depending on the value of R_L which should be varied between $1k\Omega$ and $15k\Omega$.

Similar to a GROUNDED GRID TRIODE.

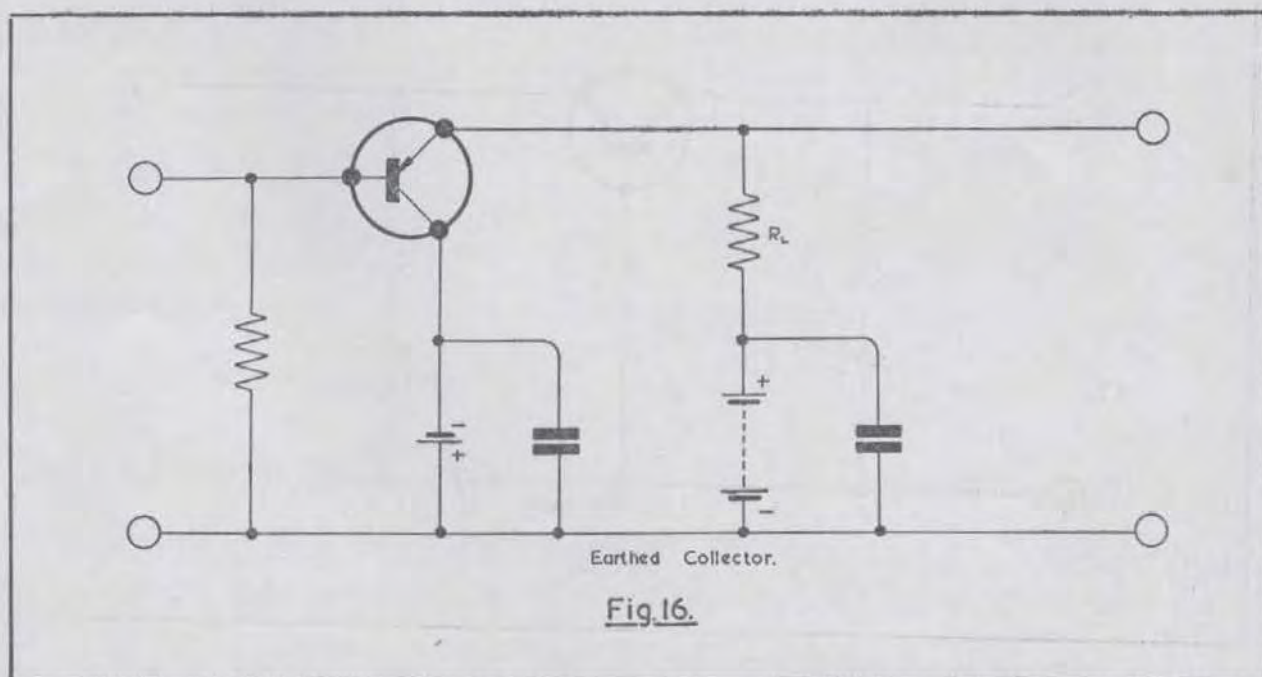


Input impedance approx. $1k\Omega$.

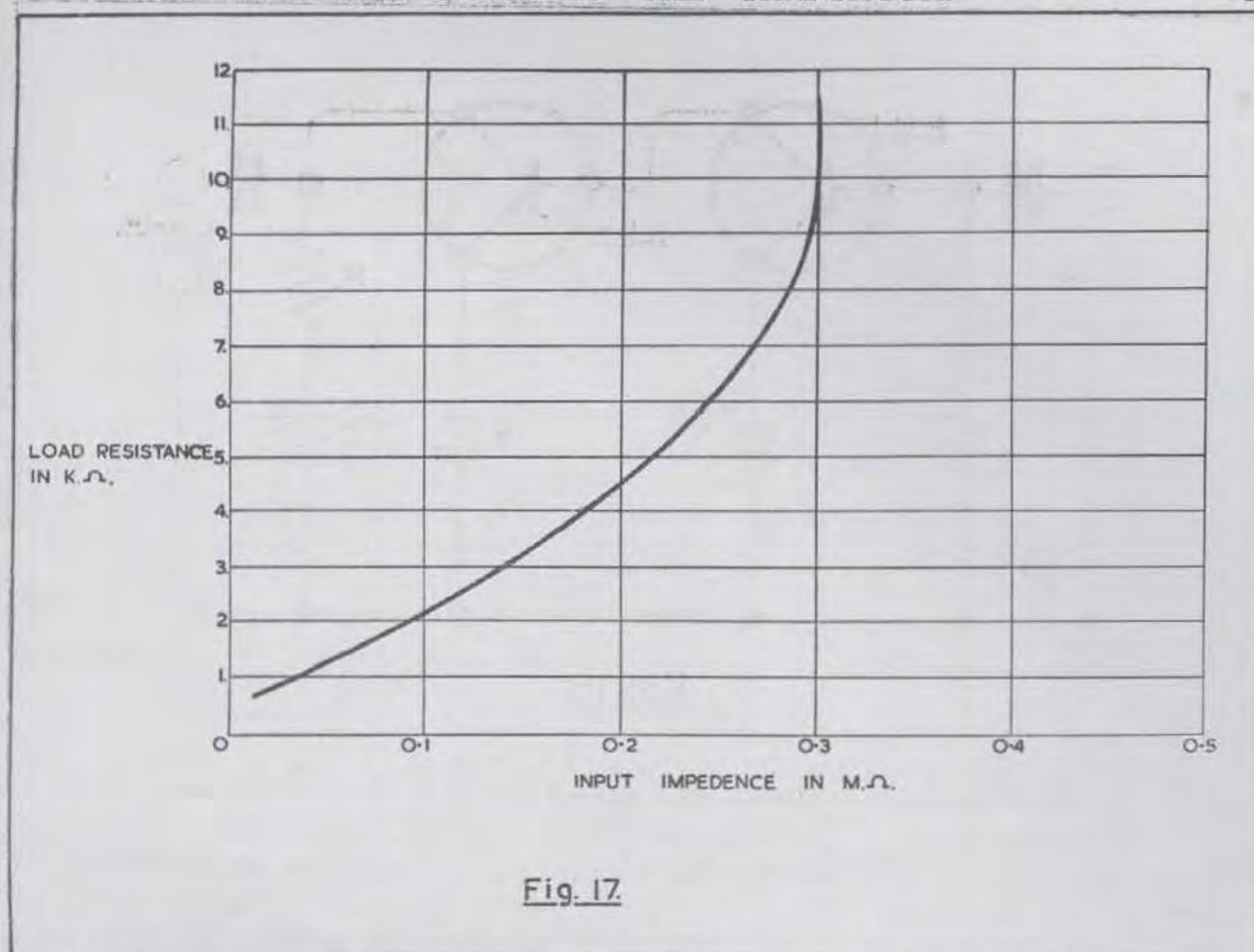
Output impedance approx. $50k\Omega$.

Power gains of up to 30db. depending on the value of R_L which should be in the region of $20k\Omega$.

Similar to a triode with an EARTHED CATHODE.



Input impedance approx. $200k\Omega$ but varies greatly according to the value of R_L . R_L can be anywhere in the range of 400Ω to $10k\Omega$. Power gain is approx. 10db., and remains reasonably constant despite variations of R_L . This circuit behaves much the same as a normal CATHODE FOLLOWER.

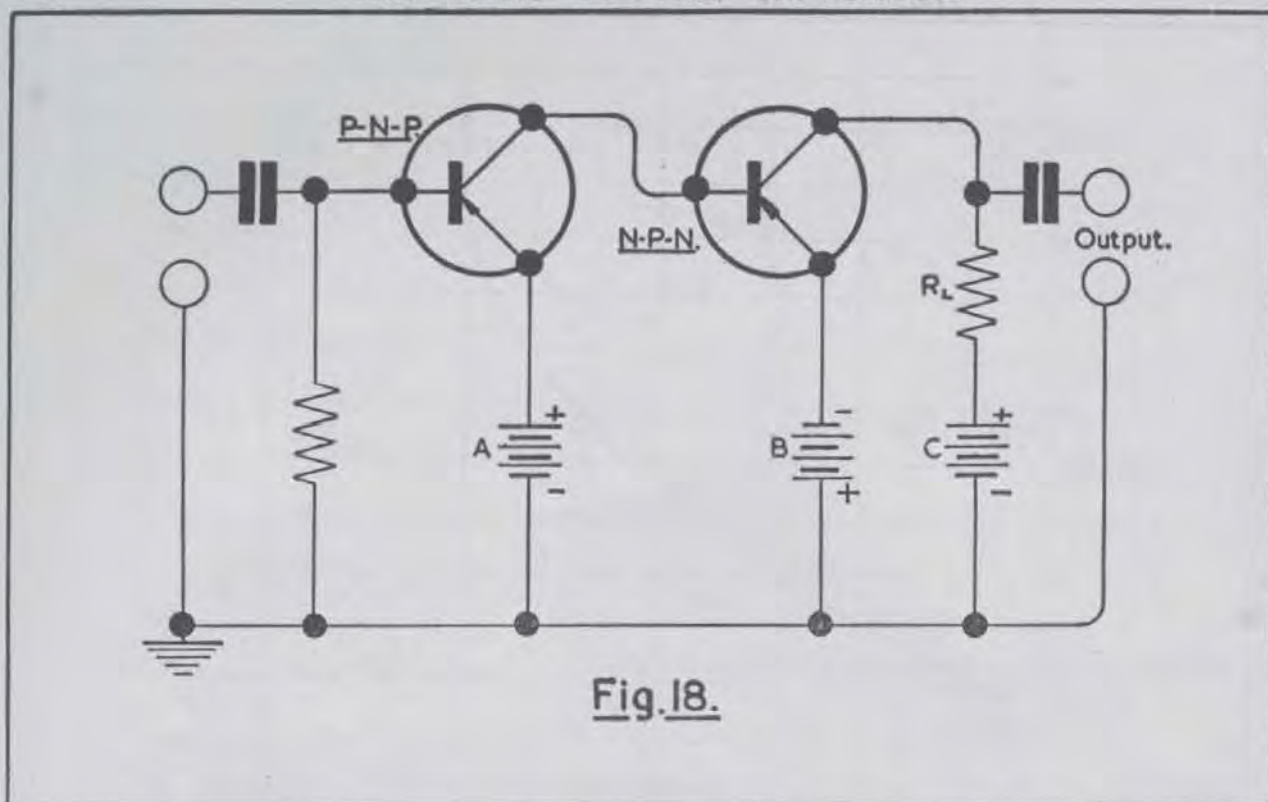


It must be stressed that the values and comparisons given are in no way accurate, and depend entirely upon the transistor used. Another difference between the triode and the transistor, lies in the considerable interaction which exists between the transistor electrodes; an effect which is negligible in the triode valve.

The earthed collector circuit is perhaps the most difficult to understand. The interaction between the value of output load resistor, and the input impedance is very pronounced, and Fig. 17 will give the experimenter some idea of the way a circuit of this nature behaves.

The commercial transistor is very easily damaged by overload, and the home-made variety is no exception. Home-made transistors have the advantage that they can in many cases be re-set. It is recommended that new whiskers should be used, but the old ones can be salvaged providing they are cleaned very carefully before re-assembly. The re-set transistor will require forming in the same manner as a new one.

The point contact transistor was the first type to be developed, but recently the Bell Telephone Co. started manufacturing the co-axial transistor. The base of a co-axial transistor is a thin plate of germanium 0.02" thick, in the faces of which two indentations are ground, and the two contact points are applied co-axially, one in each hollow. These transistors are very small in physical size being only 1/8" in diameter.



A development of the co-axial transistor; the Surface-Barrier Transistor has been announced recently in which the indentations are made by an electro-etching process.

Very fine streams of an electrolyte are directed at the two faces of a thin plate of germanium, and a small current passed through the jets, thus etching away the surface. When the germanium has reached the required degree of thinness, the current is reversed, and microscopic electrodes are deposited in the hollows by an electro-plating process. A salt of Indium is used as the electrolyte, so that the hollows become Indium plated. Wires are connected to the Indium electrodes, and each unit is then sealed.

It is claimed that no forming process is necessary with this type of transistor and that its performance far exceeds other types in R.F. applications.

The early types of transistor lead to the development of the "Junction" transistor, which is used where greater powers need to be handled.

Before the Junction Transistor can be explained, it will be necessary to explain that there are two types of germanium, N type, and P type.

N type germanium is the only kind used for the manufacture of germanium diodes in this country, although P type diodes are used for certain special applications in the U.S.A.

N type germanium can be regarded as being negative with respect to the P type.

In the very unlikely event of the constructor utilizing a P type germanium diode for the home-made transistor, it would be found that the polarities of both supplies would have to be reversed, i.e. The emitter would have to be biased negative and the collector positive. The chances of P type germanium being encountered in a diode are so remote in this country, that the constructor need have no cause for concern.

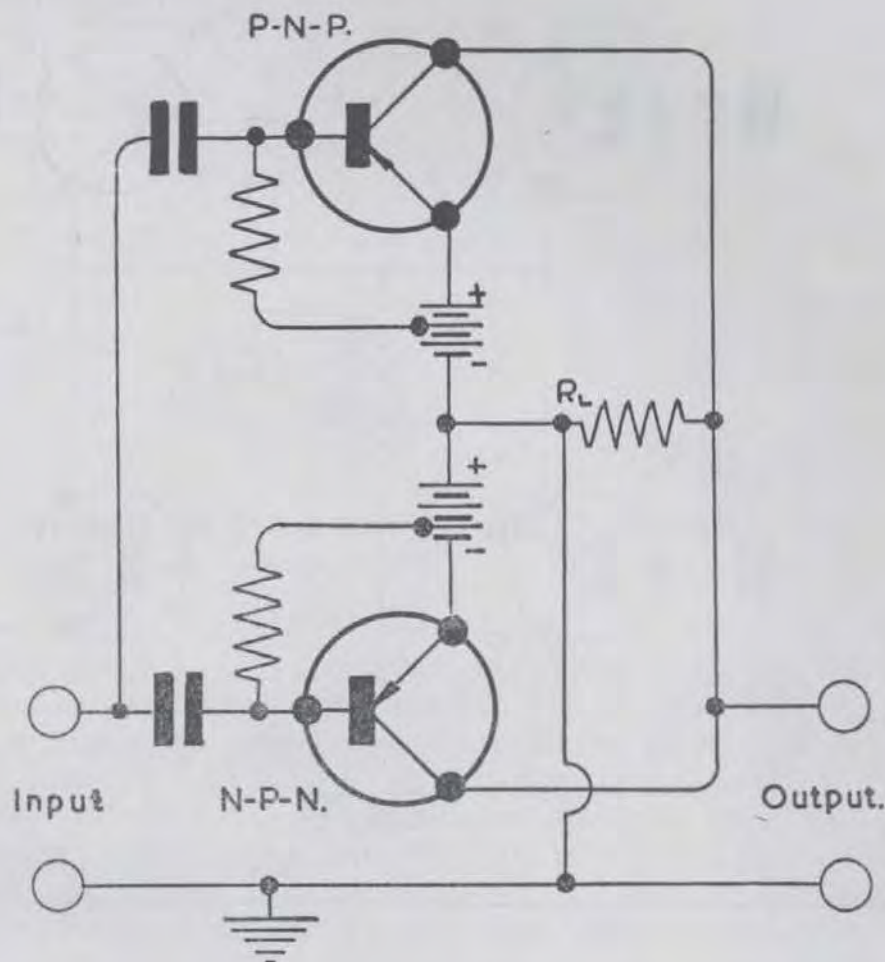


Fig.19.

Certain Junction, or power type transistors can handle up to 0.5 watts. Three pieces of germanium go into its construction, two are identical and the third of the opposite polarity. Thus if two pieces are of P type germanium, the third piece has to be of the N variety. The germanium elements have to be very thin, and the contact faces are made to fit together very accurately in order to present the largest contact area possible.

Junction transistors can be assembled in two ways, either with two P plates, or a pair of N plates. This gives rise to the designation of the types, as P-N-P and N-P-N.

A positive potential is applied to the emitter with the P-N-P type, and a negative potential with the N-P-N type. This means that Junction types can be used in push-pull circuits, and also in direct coupled amplifiers. These employ the absolute minimum of components and enable very compact apparatus to be created. An inherent disadvantage of the junction transistor lies in its large self capacity, which restricts its application to audio circuits only.

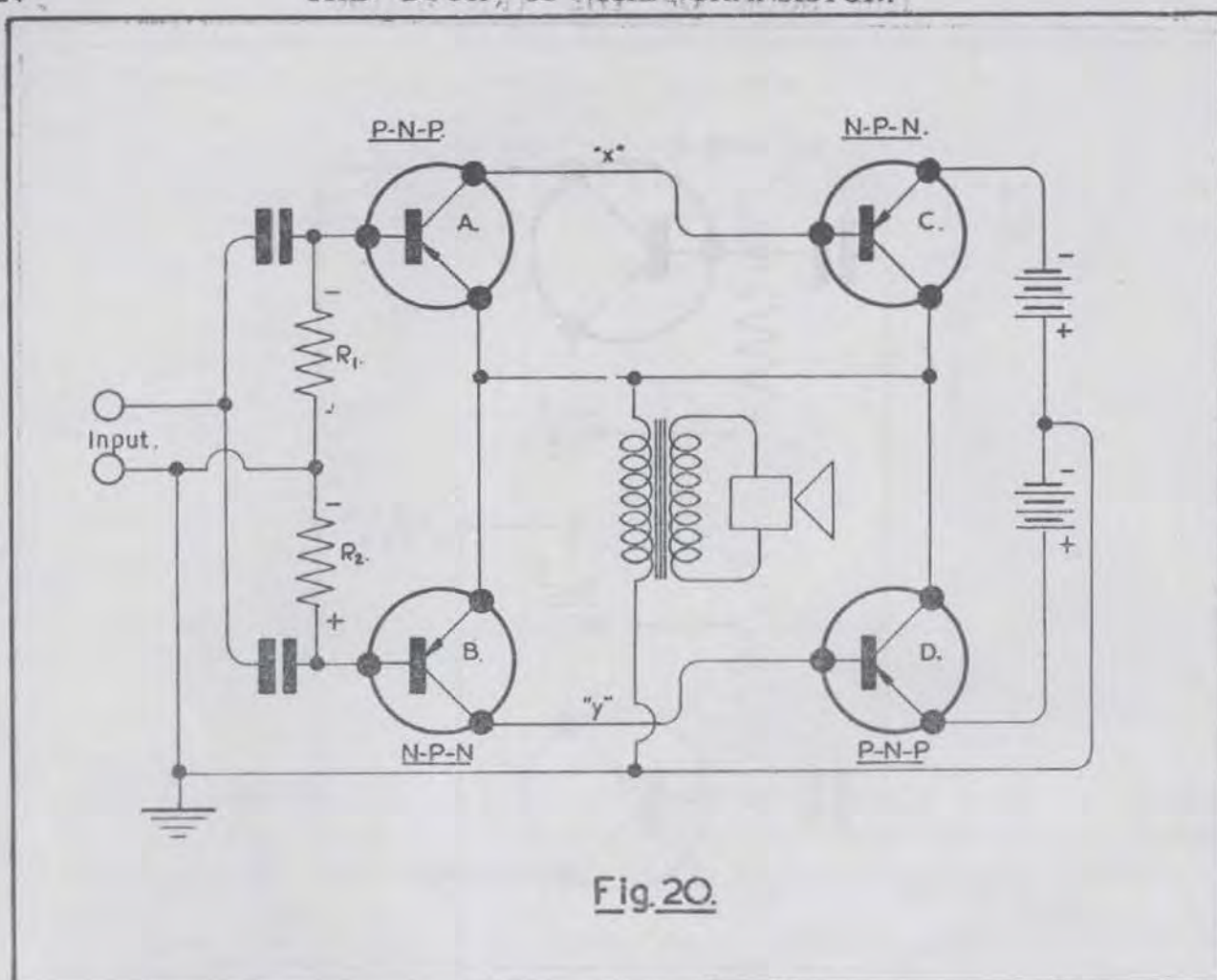


Fig. 20.

It should be pointed out that the manufacture of junction transistors is highly complex, and too difficult for even the most ingenious of home constructors. Nevertheless, they certainly seem to be the amplifier of the future. Fig. 18 shows how junction transistors can be direct coupled by using alternate P-N-P and N-P-N combinations. The first transistor has a small bias potential applied by battery A, so that it is operating on the linear portion of its curve. Battery B supplies bias to the second stage, and at the same time provides collector voltage to the first transistor. The author has not had the opportunity of handling any junction transistors, but understands that in push-pull circuits distortion is almost absent, and also that with a push-pull "bridge" type of output stage, it is possible to get an output approaching two watts.

It is also possible to use these junction type transistors to give a complementary output; Fig. 19 shows such a circuit, in which two transistors are used, one a P-N-P and the other an N-P-N type. Both the input and output are single ended, but the amplifier has all the advantages of a push-pull circuit.

Fig. 20 shows a rather complex circuit which is a combination of the two previous ones. The input transistors A & B serve two purposes, not only are they direct coupled drivers for C & D, but they also provide output via their emitters in the manner of a cathode follower circuit.

The voltage drop across R_1 provides the emitter potential for transistor A, and resistor R_2 functions in a similar manner for transistor B.

The circuit can be readily understood if it is remembered that a P-N-P junction requires a positive emitter, and a negative collector, and that these potentials are reversed for an N-P-N junction. The collectors of C & D are "earthy" and the method of obtaining collector bias is evident when it is remembered that x is negative with respect to earth, and y is positive. The output from the emitters of A & B, combine with the output from the collectors of C & D, delivering a power in the region of two watts to the loudspeaker.

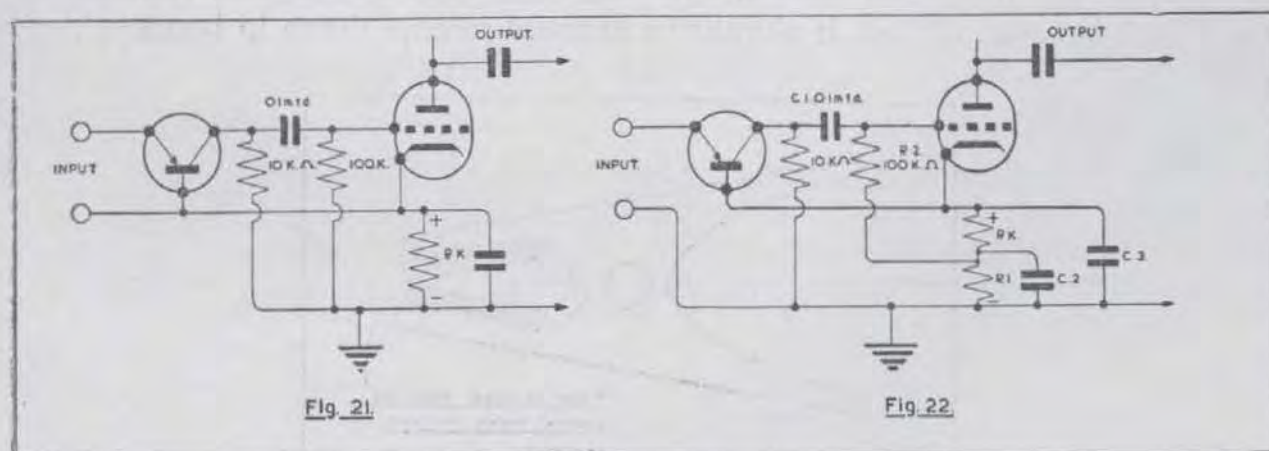
CHAPTER 4

POWER SUPPLIES FOR TRANSISTORS

The transistor can be fed with power in several ways, and batteries are probably the simplest for initial experiments. The current drain is very low and the life should be good. Flash-light batteries are quite suitable, and have greater capacity than the "Grid Bias" type; although "Grid Bias" batteries have an advantage, in that voltage changes can be more easily effected.

The voltages required by a transistor, are governed by the grade of the germanium used, and it is advisable to keep the voltages as low as possible. Use of a high potential on the collector not only creates noise, but increases the chance of damage due to excessive current.

Bias may be obtained by utilizing the voltage drop across the cathode resistor of an associated valve circuit. This method is shown in Fig. 21.



If the valve is one that requires a low bias voltage, it may prove insufficient for the requirements of the transistor. In this case a circuit such as Fig. 22 is suggested, in which a resistor R_1 has been placed in series with R_k . The total voltage drop is used to supply the transistor, and the valve grid return is tapped off the junction of R_1 & R_k . The bias applied to the valve is thus the voltage drop across R_k only. It is important that the two resistors should be decoupled by the use of suitable condensers, C_2 & C_3 . Figs. 21 & 22 show the transistor operating with an unbiased emitter, as would be the case with a transistor detector.

If emitter bias is provided, both circuits would be suitable for audio applications. C_2 & C_3 should be increased in value to become 50 mfd. electrolytic condensers in this case.

Before proceeding further, perhaps a few words of warning would not be out of place.

The experimenter, who has lavished considerable care on the construction of a transistor, will naturally want to take all due precautions to prevent premature failure.

The three main causes of failure can be listed as follows:—

- (1) Mechanical shock, dirt, and humidity.
- (2) Heat, due to soldering iron when wiring into a circuit.
- (3) Overload.

The solution to the first item needs little comment. Transistors should be handled very carefully and kept away from damp locations unless they are of the sealed variety.

Damage can be caused if the support wires become hot when the transistor is wired into circuit. Not only can the heat actually damage the germanium, but the perspex supports are liable to soften.

It is advisable to leave the support wires long, and to make the soldered joint as quickly as possible. If the layout dictates the use of short leads, a "thermal shunt" should be constructed out of an old "crocodile clip" in the manner shown by Fig. 23. The "thermal shunt" should be clipped onto the support wire between the transistor, and the joint which is going to be made. Soldering should occupy the shortest possible time, so that the "shunt" can absorb all the heat without damage being caused to the transistor. It should be pointed out that once the "shunt" becomes hot it ceases to function as such, and because of this, it should be allowed to cool down in between each joint.

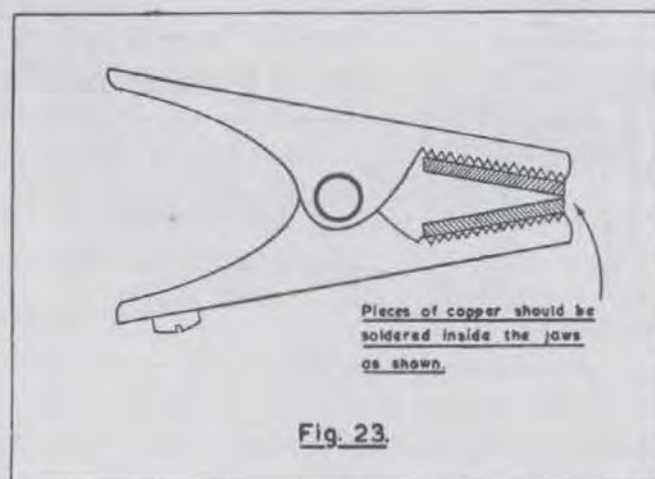


Fig. 23.

Overload is the greatest enemy of the transistor, and for this reason the constructor should ALWAYS check the circuit wiring before connecting the power supply. Reversed polarity can easily ruin a transistor, even if applied only momentarily. Limiting resistors are advised wherever practicable; there is nothing more annoying than to see the "cat's whiskers" melt! The author had this happen when a resistor was accidentally short circuited, and the full battery voltage appeared across the "whiskers." The battery in use was only $4\frac{1}{2}$ volts, but nevertheless quite sufficient to do the damage.

It may be noticed that the behaviour of a transistor is affected by the amount of light falling upon it. This photo-electric effect may be quite marked under the right conditions, and was first put to a practical use by the Bell Telephone Laboratories in March, 1950.

To clear up any misconception which may exist concerning inter-stage coupling transformers, it should be remembered that a transistor has to be fed with current rather than voltage.

Coupling transformers are therefore of the "step down" type. This does not mean that there is an undue loss of power between stages, and the constructor should consider the problem as follows:—

The first transistor gives a certain power (P) watts. The power is in the form of a small current at a fairly high voltage.

$$P \text{ Watts} = \text{Volts (High)} \times \text{Amps (Low)}.$$

The transformer steps down the voltage, and neglecting transformer efficiency THE POWER REMAINS THE SAME.

The secondary of the transformer delivers a lower voltage at higher current.

$$P \text{ Watts} = \text{Volts (Low)} \times \text{Amps (High)}.$$

A 5 : 1 step-down transformer can therefore produce a 5 : 1 current increase between stages. The author offers no excuse for devoting so much space to so simple a matter. It is surprising the number of people who have difficulty in understanding why a step-down transformer should be used.

CHAPTER 5

THE TRANSISTOR AS AN OSCILLATOR

A transistor oscillator differs from a valve oscillator for two reasons:—

(1) Unlike the valve, where the grid and anode circuits are 180° out of phase with each other, the emitter and collector currents are **IN PHASE**.

(2) The zero bias condition with a transistor is similar to a valve which is biased to the "anode bend" portion of its curve. Unlike a valve oscillator which will function with no grid bias, the emitter of a transistor oscillator **MUST HAVE BIAS**.

Fig. 24 shows the circuit of a simple oscillator, in which the emitter bias is developed between Base and Earth. The majority of the voltage drop is developed across R_2 , but if the resistance of the inductance L is sufficiently high, it might be possible to dispense with R_2 entirely. This method of obtaining bias is exactly similar to a normal cathode bias system.

This circuit will oscillate at audio frequencies if an iron cored inductance and large capacitor are employed for the tuned circuit. Alternatively one side of an I.F. transformer could be used to produce a fixed frequency of 465 Kc/s. The output will be a pure sine-wave, but the power very small—depending largely upon the "Q" of the tuned circuit. The highest frequency attainable is governed by many factors, but with a good point-contact transistor 2 Mc/s can be reached.

Fig. 25 shows an alternative method, in which a series resonant circuit is employed. A transistor oscillator relies upon the effect known as "negative resistance," the explanation being as follows:—

In a conventional resistor, the voltage drop is directly proportioned to the current, as shown by the familiar Ohms Law formula $E=I \times R$. Positive resistance absorbs power from a tuned circuit and damps oscillations, and if it were not for this effect, an L-C circuit would oscillate indefinitely after being excited.

In a negative resistance, the voltage drop decreases as the energy increases; it thus contributes energy to the oscillation by causing an increased current to flow through the tuned circuit as the voltage decays. Such circuits will sustain oscillations only so long as the value of negative resistance is greater than the positive resistance, and for this reason it is necessary to use high-Q tuned circuits. In Fig. 25, for instance, it might be found that the positive resistance of R_1 caused too great a "damping" effect for the circuit to oscillate. R_1 , being the only DC path for the emitter supply, cannot be dispensed with, so a higher value could be substituted. This in turn, would reduce the emitter current, and a different collector voltage would have to be tried.

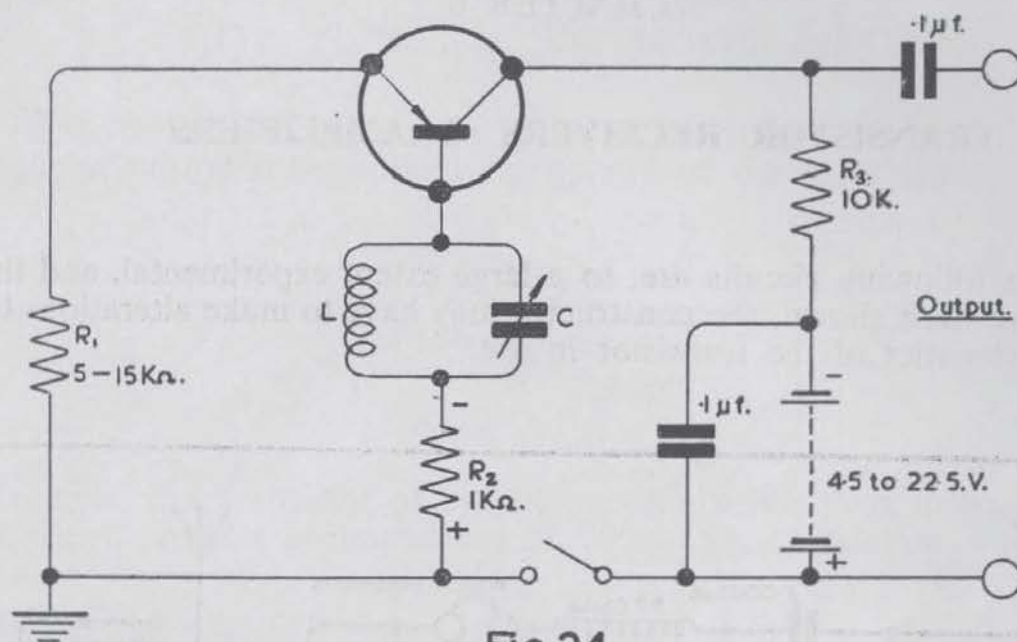


Fig. 24.

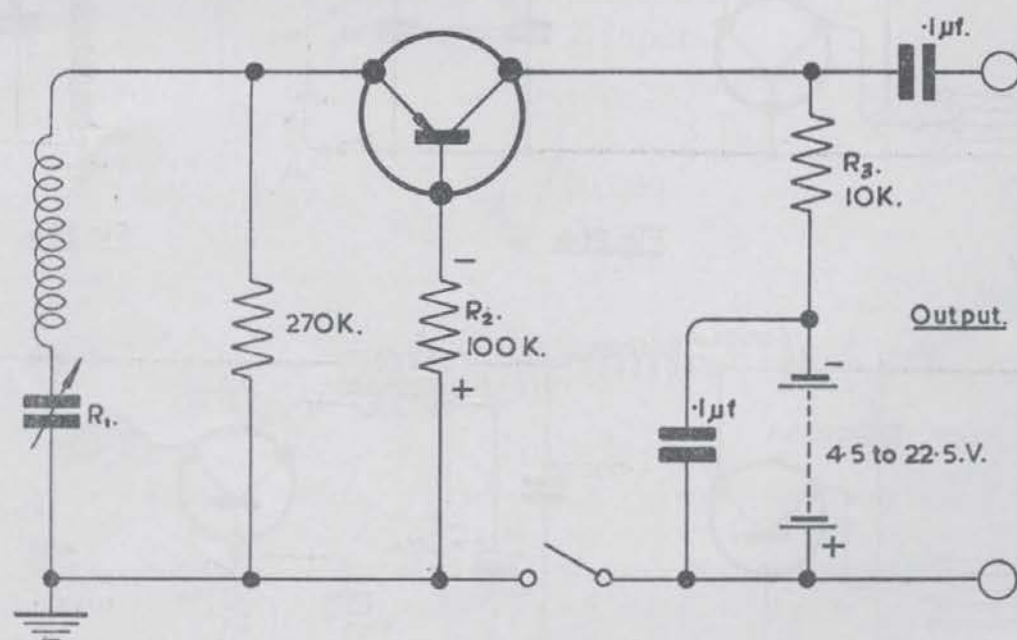


Fig. 25.

CHAPTER 6

TRANSISTOR RECEIVERS & AMPLIFIERS

The following circuits are, to a large extent experimental, and though values have been shown, the constructor may have to make alterations to suit the characteristics of the transistor in use.

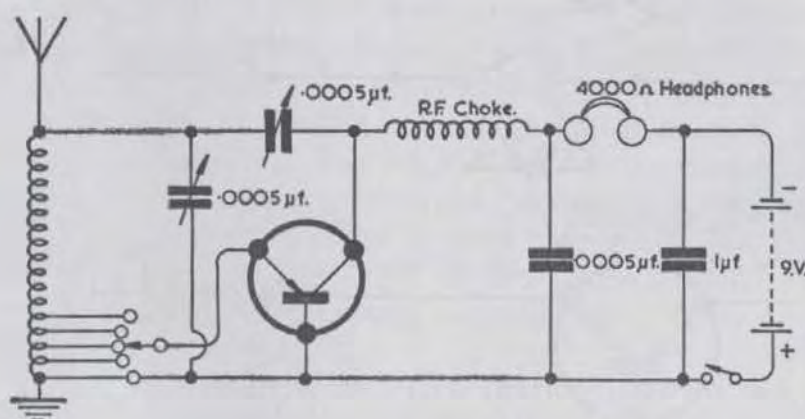


Fig. 26a.

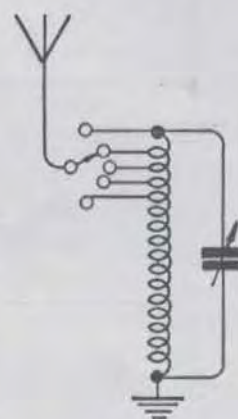


Fig. 26b.

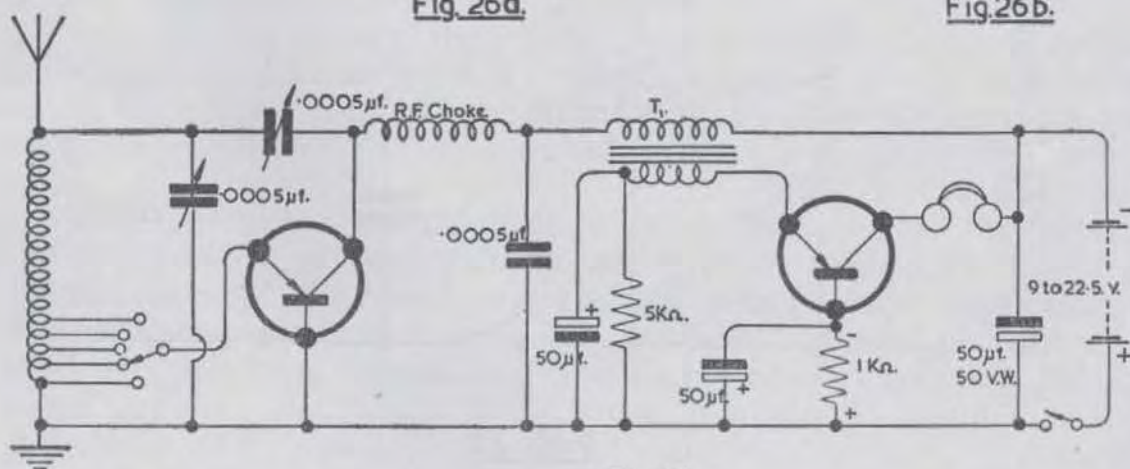


Fig. 27.

Fig. 26a shows the circuit of a simple receiver employing reaction. The coil should be of the type sold for crystal set construction, and if possible of the tapped variety which employs a switch for finding the best aerial connection. In this case, the coil should be connected "upside down," and the tapping used to select the best matching for the low impedance input to the transistor, Fig. 26b shows this type of coil connected in the conventional fashion. This circuit can be used by itself, to operate a pair of High-Z headphones, or if desired, transformer coupled (T_1) to a second transistor, as shown in Fig. 27. The normal ratio of T_1 is 5:1 but this is not always exactly correct.

If the input and output impedances of the transistors are known, then the required ratio can be worked out by use of the formula:—

$$\text{Ratio} = \sqrt{\frac{Z \text{ Output.}}{Z \text{ Input}}}$$

For example, if a transistor of output impedance $20k \Omega$ is to be fed into a circuit which presents an impedance of 200Ω the calculation would be as follows:—

$$\text{Ratio} = \sqrt{\frac{Z \text{ Output}}{Z \text{ Input}}}$$

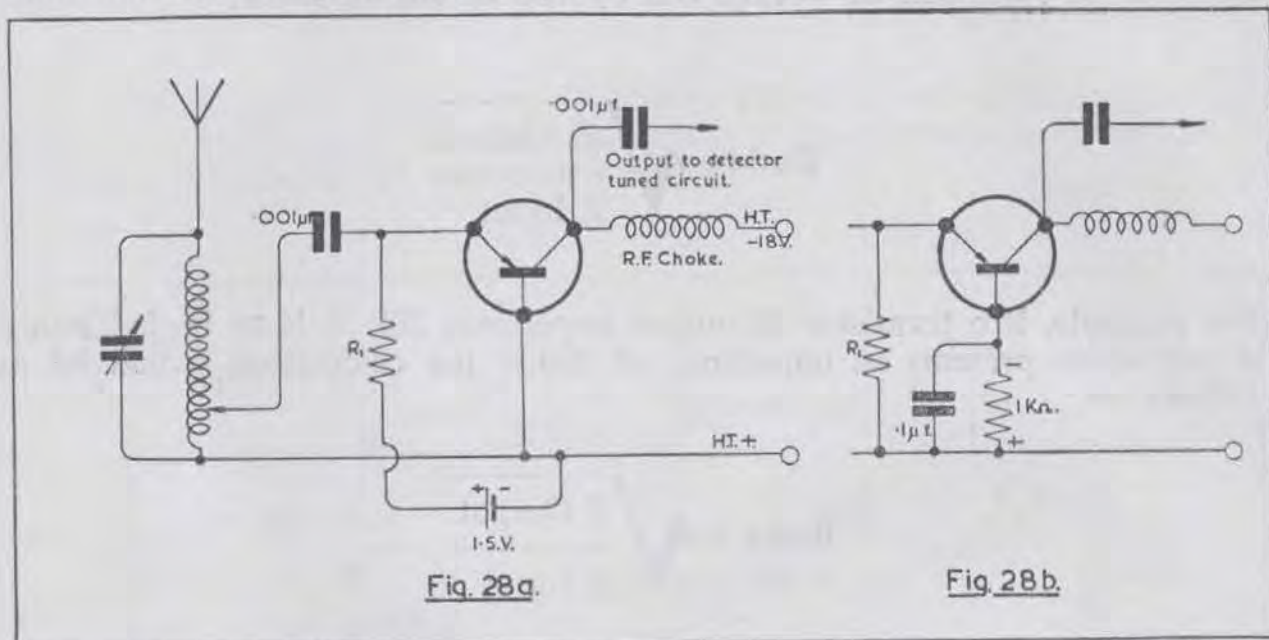
$$= \sqrt{\frac{20,000}{200}}$$

$$= \sqrt{100}$$

$$= 10:1$$

It should be pointed out that the figures used for this example were chosen for convenience, and are not likely to be the figures encountered in practice.

If only one transistor has been constructed, Fig. 26a could be used in conjunction with a valve amplifier, in the manner shown by Fig. 22. In the same way that two or more transistors can be coupled to form an audio amplifier; an R.F. stage could be constructed as shown in Fig. 28a. In this figure, the emitter is shown biased from a separate battery, but there is no reason why a resistor should not be connected in the base circuit as shown in Fig. 28b. The value of the emitter resistance R_1 is best found by a little experimentation and is between 1 & 10k Ω . A point to remember—**ALWAYS DISCONNECT THE COLLECTOR SUPPLY BEFORE BREAKING THE EMITTER CIRCUIT.** If this point is not observed, the transistor can easily be ruined by excessive collector current.



The next circuit which is shown in Fig. 29, is that of a Pre-Amplifier, which should give a voltage gain of nearly 50. Since there is no phase reversal between input and output of the earthed-base connection, the base resistance acts as a regenerative feed-back path. The fitting of a bypass capacitor C across the base resistor provided no detectable advantage in actual practice, but if the circuit proves unstable it will be necessary to connect one as shown dotted on the diagram. This circuit could be used as a moving coil microphone pre-amplifier, by substituting a suitable matching transformer instead of the R-C input as shown.

For those who are lucky enough to be able to obtain them, Mullard are producing P-N-P junction transistors for experimental purposes. The author is not amongst the lucky few, but when he succeeds in obtaining them, he anticipates building a circuit such as shown in Fig. 30. This audio-amplifier should prove suitable for low-output pick-up heads in the "High-Fidelity" class, most of which require an amplifier input sensitivity of 0.01 volts.

It is intended that Mullard Types OC70 & OC71 should be used, but the values shown are purely tentative, and will have to be adjusted when the transistors become available. For the same reason, the exact ratios for transformers T_1 and T_2 cannot yet be calculated.

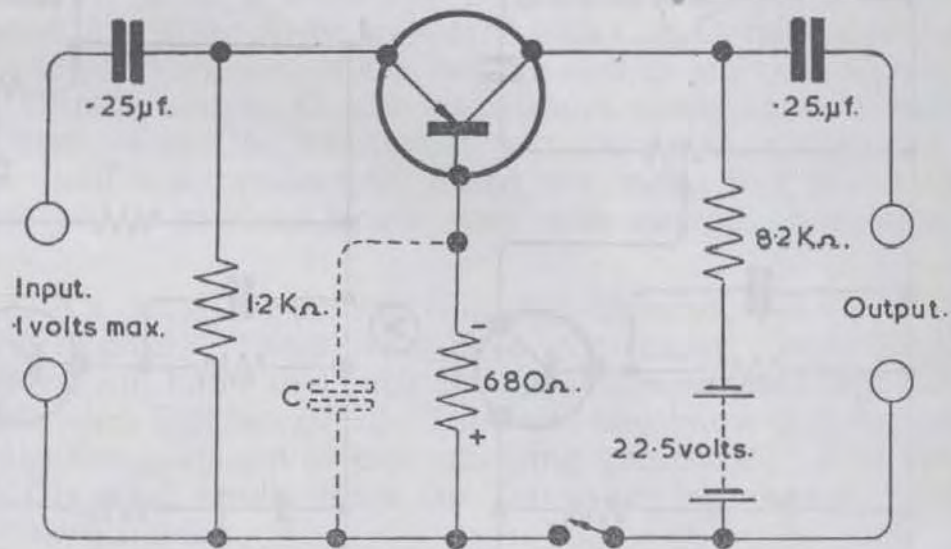
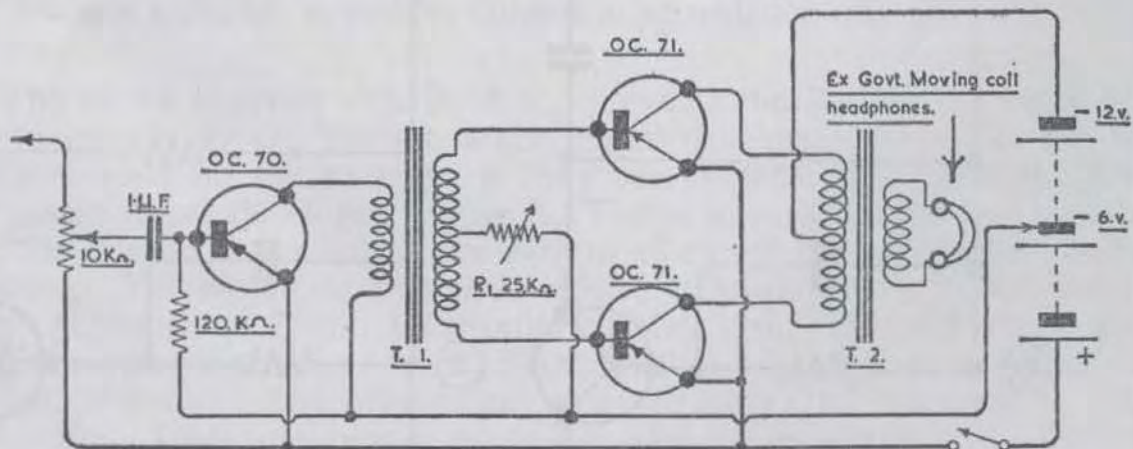


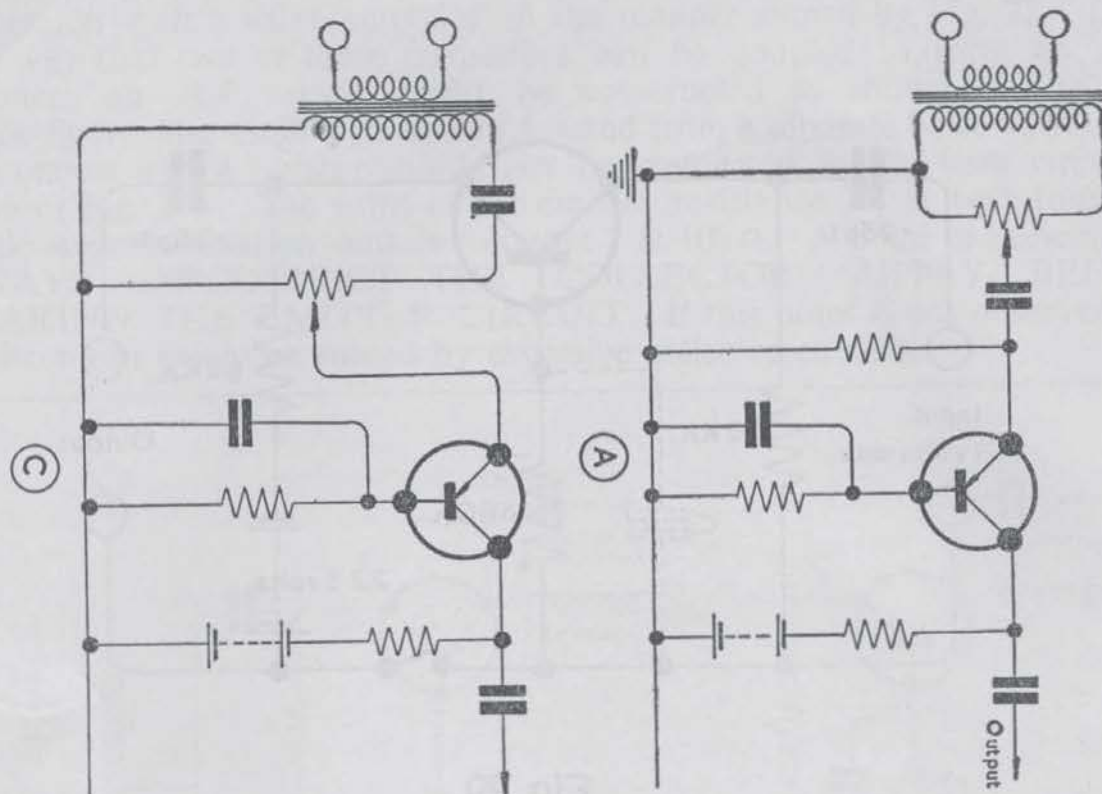
Fig. 29



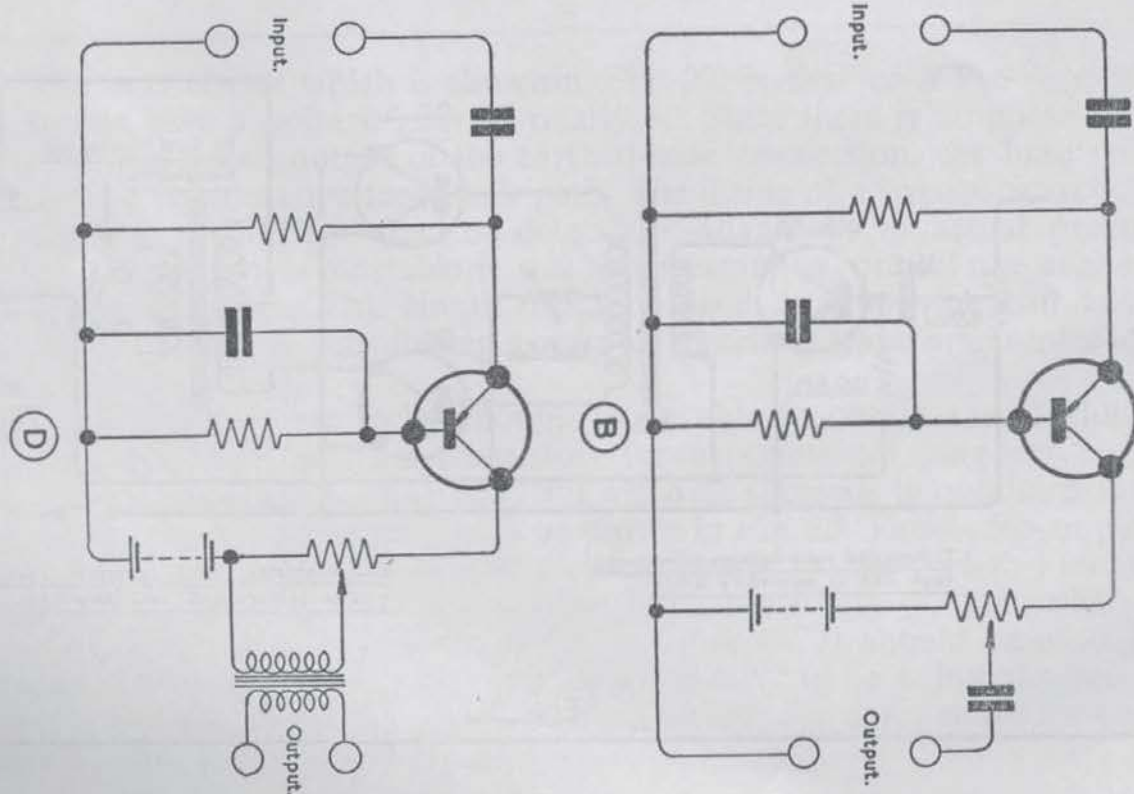
T. 1. Suggested ratio between primary and each half of secondary. 8:16:1.

T. 2. Suggested ratio between each half of primary and secondary. 4:5:1.

Fig. 30



Correct.

Incorrect.
Fig. 31.

The fitting of a volume control to a transistor amplifier is not quite so simple as with the valve counterpart, since it must not affect the current flowing to any of the electrodes.

In Fig. 31, A & B show two satisfactory methods of connecting a volume control which should be compared with C & D, both of which would be unsatisfactory. Variation of the volume control in Fig. 31C, would alter the emitter current; and in D, the transformer would cause a variation of collector current. Even the insertion of a condenser in between the volume control slider and the transformer, would not make this circuit desirable, because the load impedance would vary with changes in volume control setting.

Fig. 32 is a circuit for the experimentally minded, and shows a Super-Regenerative receiver. Those who have constructed Super-Regenerative receivers before, will know that such circuits are sometimes difficult to put into operation when first assembled. They will also know that the results are well worth the small amount of experimenting necessary. This circuit can give remarkably good results when the transistor is operating under the correct conditions.

The tuned circuit is in the collector lead, and feedback is supplied to the emitter via a low impedance coupling coil. The main difficulty with the transistor lies in the fact that it will not function as an oscillator and as a detector, under the same bias conditions.

This difficulty has been overcome in a very neat manner, as follows:—The transistor is biased so that it will oscillate, and a diode is connected in its emitter circuit. This diode rectifies a small portion of the R.F. signal and a voltage is built up across resistor R_1 which is proportional to the amplitude. R_1 being common to the emitter supply, the amplitude modulated signals produce a change in emitter current in accordance with the modulation frequency.

The choke in series with R_1 & C_1 , prevents the R.F. signal being bypassed to chassis by C_1 ; but the audio signal developed across R_1 has no difficulty in reaching the emitter. It may be suggested that C_1 is shunting all the audio signal developed across R_1 . This is actually not the case because the emitter offers a lower impedance path to all except the very highest audio frequencies. The circuit of this little receiver (Developed by Edwin Bohr), was first published in Radio Electronics on May 19th, 1954, and is representative of the many ingenious transistor circuits which have been produced in the U.S.A. recently. The original circuit called for a CK722 transistor, with a IN34 diode. The experimenter, no doubt using his own transistor, will find that a Mullard OA50 is very satisfactory if the IN34 proves unobtainable. The coil used in the original was an adaptation of a rather special dust-cored assembly known as a "Ferri-Loopstick," which is probably unobtainable in this country. Bearing in mind the fact that the "Q" has to be as high as possible, the actual design has to be left to the experimenter. It should definitely be of a dust core construction, L_2 being about 7 turns of 22 s.w.g. wire for a Medium Wave coil. The exact gauge of wire is not critical, and the final choice will be governed by the size of L_2 .

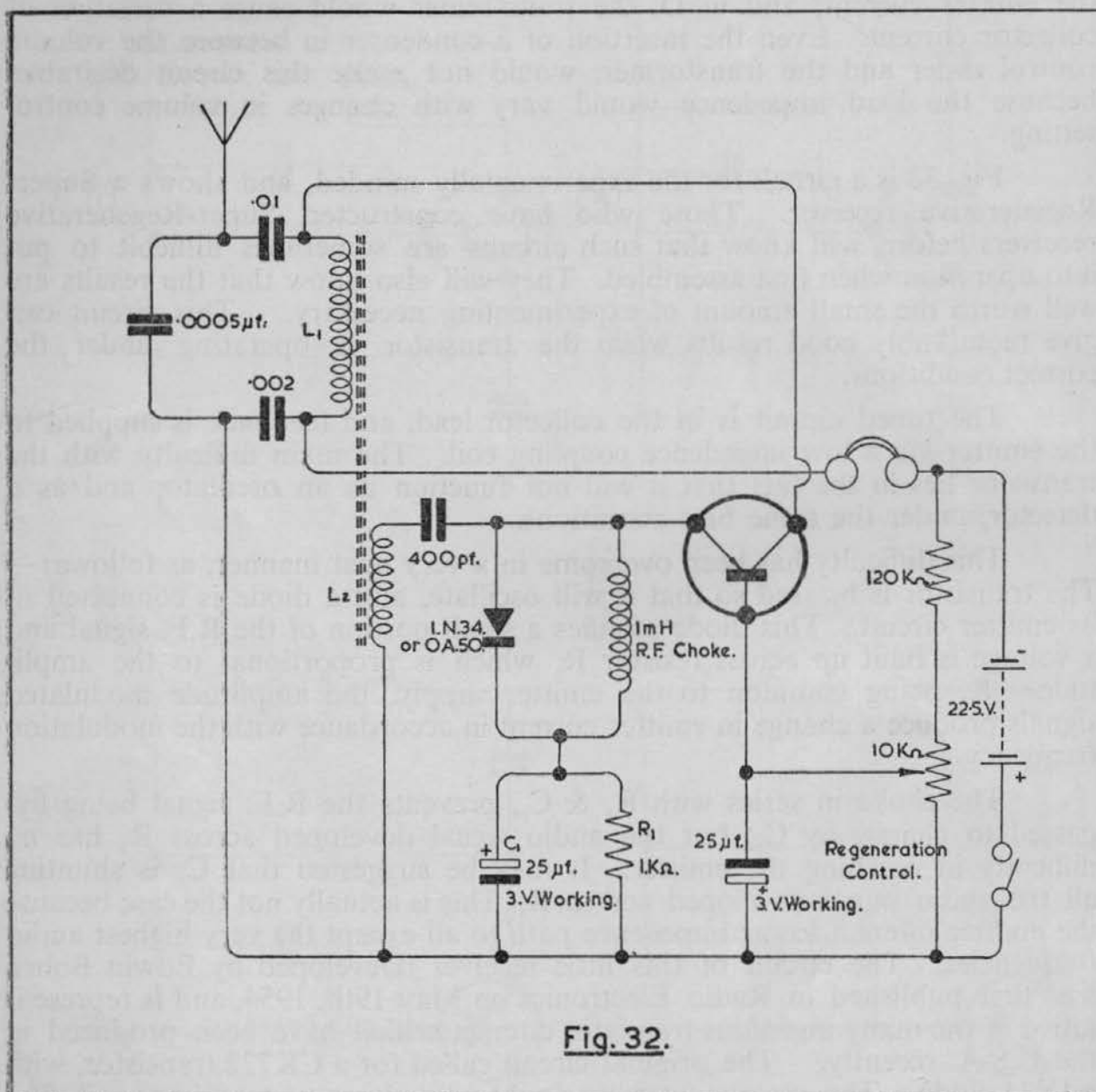


Fig. 32.

CHAPTER 7

UNUSUAL TRANSISTOR CIRCUITS.

In this final chapter, it is intended to show the constructor a few of the many novel uses to which transistors can be put, followed by a short list of commercially made transistors.

Fig. 33 shows a device using a P-N-P junction transistor such as an OC71, with which a sensitive relay can be operated. The transistor is connected so that zero bias is applied to the emitter, under which condition the collector current is only a few micro-amperes. The application of an infinitesimally small signal (in the neighbourhood of .0001 watts), will be sufficient to operate the relay due to the sudden increase in emitter current. The input is only sensitive to a positive pulse of D.C., but the detector action of an unbiassed transistor renders it quite sensitive to an A.C. signal. The peak collector voltage of an OC71 is 10 volts and since the full battery voltage appears across the transistor in the "rest" position (the collector current being negligible), the battery has been limited to 9 volts. For maximum sensitivity, the relay has to be of very high resistance, but if this is so, the voltage drop across it becomes appreciable, thus "starving" the collector of volts and limiting the current output from the transistor.

A relay must be selected which has a resistance value best suited to the transistor and available voltage. This value is of necessity a compromise, and it will be found that a coil resistance of $4k\Omega$ proves satisfactory. The relay should be of the type which closes with a 1 mA current, and such an item should be available from one of the many "Government Surplus" dealers.

A miniature morse-code oscillator can be very easily constructed from a point-contact transistor using the circuit shown in Fig. 34.

The output transformer forms a common coupling impedance which feeds part of the output back into the input, in the correct phase for oscillation. Bias for the emitter is obtained due to the voltage drop across T_1 primary, for which reason the D.C. resistance should be reasonably high. An output transformer having a primary impedance of 8 to $10k\Omega$ should prove suitable.

The resistances in the emitter circuit affect not only the frequency of oscillation, but also the emitter current, and for this reason R_1 should not be made lower than the value shown. The layout can be made very compact using a miniature loudspeaker, and since the key is fitted in the battery lead no ON-OFF switch is required. Instant "warm up" is of course a feature of all battery-operated transistor circuits.

The crystal oscillator shown in Fig. 35 employs a point-contact transistor in an earthed-base circuit. In this case the feedback path is provided by a 7 Mc/s crystal between collector and emitter, instead of a common base impedance. In the interests of simplicity and economy of space, a carbon microphone is used to modulate the collector supply. The inductance L should be wound on $\frac{3}{8}$ " diameter former, using about 16 turns of No. 25 s.w.g. enamelled wire. The aerial coil should be wound on the same former, using No. 22 s.w.g., about 4 turns being sufficient.

If it is desired to use a commercially made transistor, the Mullard Type OC51 could be tried, and although 7 Mc/s is in excess of the manufacturers upper frequency limit, it should be possible to get the circuit to oscillate satisfactorily.

The range of this little transmitter will be limited to very short distances, but a practical use might be found in such instances as "ground to roof" communication, when adjusting the position of a television aerial for maximum signal strength.

The final circuit requires no battery at all. Fig. 36. Power for this audio oscillator is obtained from a Photo-Voltaic cell such as can be found in a photo-electric Exposure Meter. The circuit needs little comment apart from the unusual power source, which should be obtainable at most of the leading photographic dealers. Emitter bias is developed across the $4.7k\Omega$ base resistor which is of sufficiently high value not to shunt the incoming emitter signal.

Output can be taken in two ways; either using a pair of $4k\Omega$ headphones as shown at P_1 , or by using a hearing-aid crystal earpiece as shown by P_2 and C_2 .

The reader will have noticed many "DON'TS" in this small book. These have not been inserted just to make life difficult; but rather to ensure that the maximum amount of pleasure is derived from making, and handling, these fascinating newcomers to the science of radio.

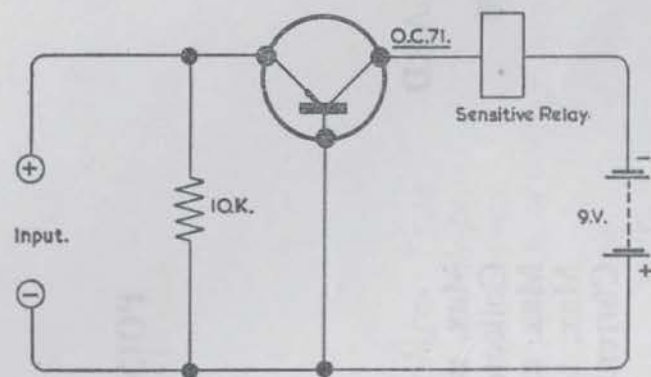


Fig. 33.

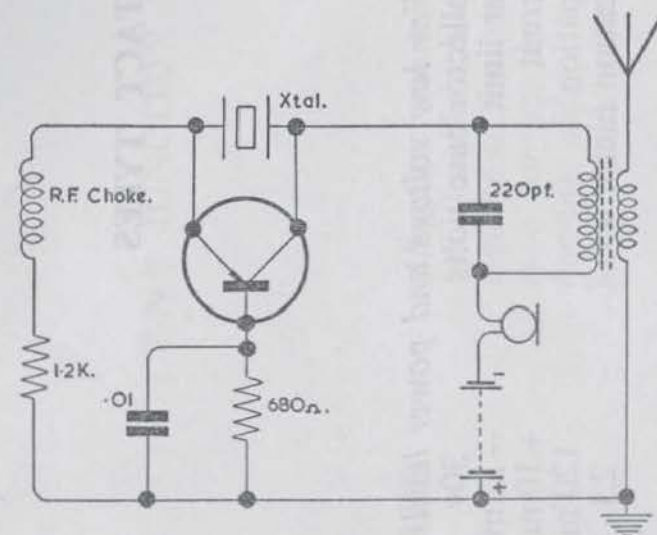


Fig. 35.

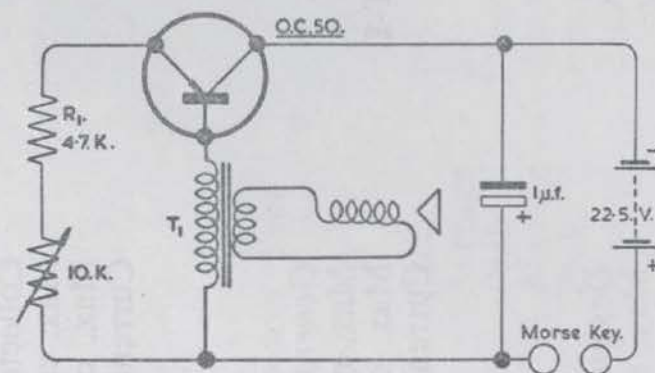


Fig. 34.

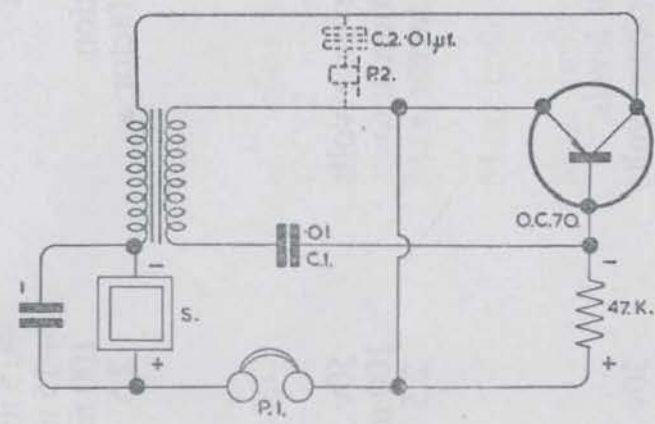


Fig. 36.

BRIEF DETAILS OF COMMERCIALY MADE TRANSISTORS

POINT CONTACT TYPES

MULLARD

For low voltage and power levels.

OC50

Max. negative collector/base volts	30v
Collector current limit	-12 mA
Max. emitter current	+10 mA
Max. total dissipation	120 mW
Current amplification factor α	2.1

MULLARD

OC51

Designed for use in switching circuits where large signal parameters are of primary interest.

Max. negative collector/base volts	50v
Collector current limit	-15 mA
Max. emitter current	+15 mA
Max. collector dissipation	100 mW
Current amplification factor α	2.5

G.E.C.

GET-1

General purposes.

Max. negative collector/base volts	50v
Max. collector dissipation	100 mW
Current amplification factor α	2.5

G.E.C.

GET-2

Designed for low signal levels.

Max. negative collector/base volts	30v
Max. collector dissipation	50 mW
Current amplification factor α	3.9

P-N-P JUNCTION TRANSISTORS

MULLARD

OC70

All glass construction, replaces Type OC10 which had a plastic envelope. Low noise, low voltage audio frequency type for use in amplifying stages of hearing aids.

Max. collector/emitter volts	Peak	— 10v
	Average	— 5v
Max. collector current	Peak	— 10 mA
	Average	— 5 mA
Max. emitter current	Peak	10 mA
	Average	5 mA
Max. collector dissipation		6 mW
Earthed emitter, base input α		30
Earthed base, emitter input α		0.968

MULLARD

OC71

All glass construction, replaces Type OC12 which had a plastic envelope. P-N-P type for use in amplifying or output stages.

Max. collector/emitter volts	Peak	— 10v
	Average	— 5v
Max. collector current	Peak	— 10 mA
	Average	— 5 mA
Max. emitter current	Peak	10 mA
	Average	5 mA
Max. collector dissipation		6 mW
Earthed emitter base input α		50
Earthed base, emitter input α		0.98

No.	TYPE	PURPOSE	TYPICAL OPERATION									LIMITING VALUES				CHARACTERISTICS			
			C volts	C mA	E mA	B mA	R input Ω	R load Ω	db noise	Power gain db	mW power out	C volts	C mA	mW diss.	E mA	C $K\Omega$	E Ω	B Ω	α
2A	P. CONT.	General	-10		1.0		800	15k		20		50	8	120				2	
2B	P. CONT.	General	-10		1.0		800	15k				50	8	120				2	
2C	P. CONT.	Switching	0/-2	4.0	3.0							50	8	100				2	
2D	P. CONT.	General	-15	1.0	0							50	8	100				2	
2E	P. CONT.	General	-15	1.0	0		500	10k		20		50	8	100				2	
2F	P. CONT.	Switching	0/-1.2	5.0	3.0							100	8	120				2	
2G	P. CONT.	Switching	0/-1.2	5.0	3.0							100	8	120				2	
2N30	P. CONT.	Amp. Oscillator					475		57	17						20	200	2.2	
2N31	P. CONT.	Amp. Oscillator					800									20	400	2.2	
2N32	P. CONT.	Pulse or Switching	-25		0.5		400	31k		21		40	8	50	3			2.2	
2N33	P. CONT.	Oscillator 50Mc/s	-8	3.3	0.3						1.0	8.5	7	30	0.8				
2N34	P-N-P	General	-6	10	1.0	0.25				40		25	8	50	8.0			.98	
2N35	N-P-N	General	+6	10	1.0	0.25				40		25	8	50	8.0			.98	
2N36	P-N-P	General	-6		1.0	0.01	1000	30k		40		20	8	50				45	
2N37	P-N-P	General	-6		1.0	0.02	1000	30k		36		20	8	50				30	
2N38	P-N-P	General	-6		1.0	0.05	1000	30k		32		20	8	50				15	
2N41	P-N-P	Audio Amplifier										25	15	50	15				
2N43	P-N-P	Audio Amplifier	-5		1.0				22	40		45	10	150	10				
2N44	P-N-P	Audio Amplifier	-5		1.0				22	39		45	10	150	10				
2N45	P-N-P	Audio Amplifier	-5		1.0				22	38		45	10	150	10				
2N57	P-N-P	Audio Amplifier	-28		40			7k		14									
3N31	P. CONT.	Switching	-25		0.5		500	25k				60		100				2.5	
A1698	P. CONT.	Switching										100	15	120	15		200		
CK716	P. CONT.	General	-10	1.5	0.5		250	15k	45	18	3.0	40	4	100	10			2.5	
CK721	P-N-P	General	-3	2.0		0.3		1250	22	38	2.8	20	5	30	5.0			40	

No	TYPE	PURPOSE	TYPICAL OPERATION									LIMITING VALUES				CHARACTERISTICS				
			C volts	C mA	E mA	B mA	R input Ω	R load Ω	dh noise	Power gain db	mW power out	C volts	C mA	mW diss.	E mA	C $K\Omega$	E Ω	B Ω	α	
CK72z	P-N-P	General	-1.5	0.5		0.2			22	30		20	5	30	5.0				12	
G-11	P. CONT.	Amp. Oscillator					475	20k	57	17		30	7	100	3.0		200		2.2	
G-11A	P. CONT.	Switching	-15		1.0		800	20k				30	7	100	3.0		500		2.2	
M1689	P. CONT.	Switching					800	10k				50	40	80	40.0					
M1725	P. CONT.	Audio and Carrier	-5	4.0	1.5		195	8k	48	18	4.5	50	20	200	15.0		115		2.1	
M1729	P. CONT.	Audio and Carrier	-30	5/7	1/2		190	15k	54	20/18	50	50	20	200	15.0		75		2.5	
M1752	P-N-P	General					25	13k				50	5	50	5.0		240		0.98	
OC50	P. CONT.	Amp. Oscillator	-5		1.5		155	6800	43			30	25	120						
OC51	P. CONT.	Switching	-40	1.6	0		350	26k				100	15	120	15				2.5	
PT-2A	P. CONT.	Audio Amplifier	-30		1.0		300	20k	57	19		40	10	100	5	10	300	500	1.5	
PT-2S	P. CONT.	Switching	-30		1.0							40	10	100	5			500	2.0	
R1734	P. CONT.	Switching												120						
RD2517	N-P-N	Audio and R.F.	4.5		1.0			4500	22	32	1.9	30	5	50		100	35	500	0.93	
RD2520	N-P-N	Audio and R.F.	4.5		1.0			4500	22	34	2.0	40	5	50		500	35	100	0.95	
RD2521	N-P-N	Amp. Oscillator	4.5		1.0				22	37		40	10	50	10.0	300	30	100	0.975	
RD2525	N-P-N	Amp. Oscillator	4.5					4500	22	42	1.9	25	5	25		200	35	500	125	
RR-14	P-N-P	Audio Amplifier	-1.5	0.5					22	36		25	5	50		700	30	270	25	
RR-20	P-N-P	Audio Amplifier	-1.5	0.5					22	40		25	5	50		700	30	270	40	
RR-21	P-N-P	Audio Amplifier	-15.0	3.0				5000			20	25	5	50					25	
RR-34	P-N-P	Audio Amplifier	-1.5	0.5	1.0			30k		30		20	5	30		500	30	270	10	
T-21A	P. CONT.	General	-4.5	1.0	1.0		500	30k	25	38		30	5	50	5	500	50	500	0.95	
TA-161B	P. CONT.	General	-20	3.0	1.5		300	15k	55	22	50			140			120		2	
TP-01	P. CONT.	General	-22.5		0.3/0.8		400	10k		18		35		100					2	
X22	N-P-N	Audio Switching	4.5		1.0		35					40	5	50					0.90	
X23	N-P-N	Audio Switching	4.5		1.0		35					40	5	50					0.95	

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