TANDY

Boys and Beginners Book of Practical Radio and Electronics

by B. B. Babani

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BOYS AND BEGINNERS BOOK OF PRACTICAL RADIO AND ELECTRONICS

BY

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BRITISH OR U.S.A. TYPE	TANDY - ARCHER TYPE
BC108	RS276-2009
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BC158	RS276-2021
AC127	RS276-2001
FuL914	RS276-015
OA91	RS276-1136
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SIMPLE TRANSISTOR AMPLIFIER CIRCUITS

In this chapter for our younger readers, we present a series of amplifier circuits and answer some of the questions which arise out of the design of such circuits.

Many readers have written to us over the past years asking for simple transistor amplifier circuits, preferably using particular transistors that they had in their possession. These requests have generally been hard to fulfil as the transistor types mentioned have often differed from those in our simple amplifier designs. As much as we would like to assist, we are not in the position to design circuits for individual readers.

Recently, however, we reviewed the situation and decided that one way in which we could help would be to present a chapter showing readers how to construct simple amplifiers using general-purpose transistors. The chapter could at the same time show readers the basic principles to be followed in order to achieve the best performance from typical oddment transistors. This is, in fact, that chapter.

Possibly, the first point to be considered when visualising a versatile amplifier circuit is the DC supply voltage. This must be selected so that the various voltage, current and wattage ratings of all components will not be exceeded under any conditions of operation. Other factors to be considered at the same time are the value of the external load on the output transistor (loudspeaker or phones, etc) and the required power output.

We decided upon 6 volts as the most useful "all purpose" supply voltage for the following reasons:-

Firstly, it is low enough so that all transistors likely to be used will be operating within their voltage ratings.

Secondly, it provides a reasonable voltage swing across the load (reasonable power output) without an excessive IR drop (wattage) across the semiconductors; if we had decided upon 3 volts, for example, the usual 1 volt "saturation" voltage (minimum voltage drop) across most silicon transistors would leave only 2 volts peak-to-peak as the maximum obtainable signal across the load, resulting in very limited power output.

Thirdly, and perhaps most importantly from the schoolboy experimenter's view, 6 volts can be obtained readily from two 3-volt cycle batteries, and these can be relied upon to last quite a long time.

In the case of the first four circuits to be discussed the output load is intended to be headphones, of either the 2,000 ohm magnetic variety of the high impedance crystal types. We decided upon this because many of the requests for simple circuits have mentioned that headphones were to be used. Methods of connecting low impedance (typically 8-ohm) earphones will be discussed later in this chapter.

Having decided upon the supply voltage and external load for an amplifier stage, the next consideration is the zero signal current; this is dependent on the collector resistor, in the case of the circuits discussed here, and on the biasing. Having selected a given value of collector load resistor, the bias must be set so as to obtain the maximum output voltage "swing" before clipping the signal waveform. Engineers like to call this composite voltage-current-bias setting the "DC working point".

Referring now to figure 1, let us consider one method of setting the

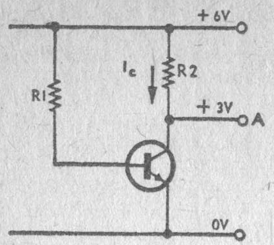


Figure 1

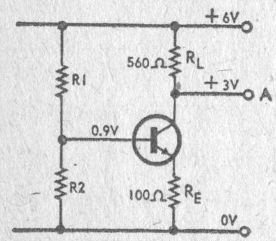


Figure 2

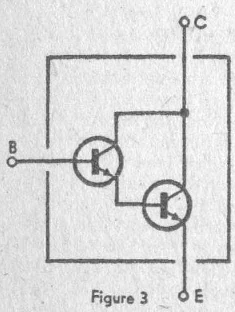


Figure 3

2xOC74,2N647,AC107 etc

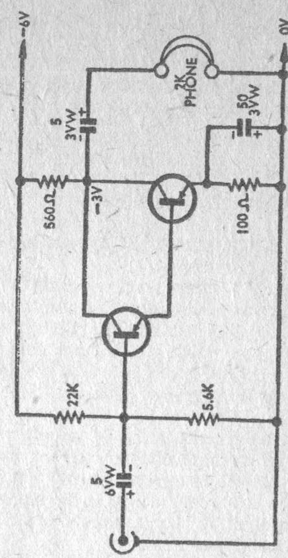


Figure 4

2xBC108,2N3565,etc

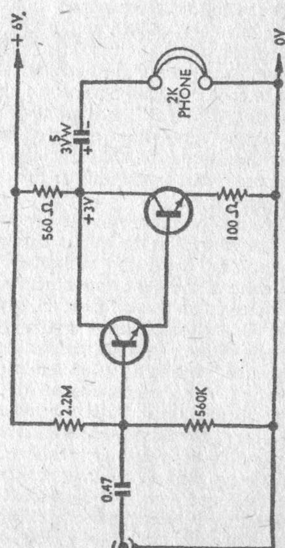


Figure 5

bias and consequently the zero signal current, which is commonly encountered in beginners' circuits. In this case, the bias must be set so that the voltage at point A is equal to half the supply voltage, this condition giving the maximum output voltage excursion, or "swing". Plainly enough the voltage at point A will be dependent on the collector current flowing through the load resistor R2. In turn, the collector current will be equal to the product of the base current (flowing through R1) and the current gain, or Beta, of the transistor. Beta is approximately equal to the ratio of collector current to base current. By varying R1 and thus the base current, the DC voltage at point A can be set. The transistor is then said to be "current biased".

While superficially a simple system, current biasing has certain serious disadvantages. The first is that no two transistors will have exactly the same Beta and so the DC working point has to be set up for each individual transistor. A second disadvantage is that the Beta of many transistors tends to vary with temperature. This means that a DC working point set on a cold day (by current biasing) would be off the mark on a hot day or after the transistor had generated its own internal heat.

The third and most serious disadvantage of all is that with this biasing system transistors will amplify their own collector-base leakage current and this (leakage) is very dependent on temperature. Some improvement in the stability of the DC working point can be obtained by using an emitter resistor but, in general, methods other than current biasing are to be preferred.

The most common method of biasing an amplifier stage is shown in figure 2. The two major features of the circuit are that there is a voltage divider which holds the base to a fixed voltage (instead of letting it "float" as in figure 1) and an emitter resistor, incorporated to improve temperature stability. This emitter resistor ideally should be as high in value as possible to obtain the best stability, but in practice it should not be made so high that there is excessive voltage drop - and consequent power loss - across it. Generally, 0.5 volt is a suitable figure across the emitter resistor.

Now, for transistors which have a reasonably high Beta for all temperatures likely to be experienced, the collector current may be considered to be equal to the emitter current. Since we have selected 560 ohms as a suitable value of collector resistor and the desired voltage at point A is 3 volts, the collector current will be approximately 5 milliamps, therefore, the emitter resistor can appropriately be 100 ohms. In fact, the desired collector current is obtained by setting the DC voltage drop across the emitter resistor and this is done, in turn, by setting the base voltage.

For collector current to flow the transistor must be forward biased. In general, a forward-biased semi-conductor junction has a voltage drop across it which is fairly constant for current variations of two or three to one. For silicon transistors this voltage will be approximately 0.6V and for germanium types it will be approximately 0.25V. An average figure applicable to all transistors is 0.4V. Thus, to bias the transistor correctly, we would arrange for the base voltage to be 0.4V above the emitter voltage. Hence, the voltage divider consisting of R1 and R2 is selected to give a base voltage of 0.9V.

The values of the voltage divider resistors are selected so that variations in the base current of the transistor will have little effect on the base voltage. Note that the effects of leakage current also have to be taken into account. In this respect germanium transistors are worse, as they have much higher leakage currents than silicon devices. In taking these facts into account, it is customary to arrange that the voltage divider resistors pass a current roughly 10 times that of the base bias current, in the case of germanium transistors. Somewhat lower current values can be used in conjunction with silicon transistors.

Thus, in figure 2, if the transistor had a Beta of 40 and the collector current was 5 milliamps, the base bias current would be 125 microamps. Thus, 1 milliamp would be a suitable current for the voltage divider resistors. Using Ohm's Law, R2 would equal 1K and R1 would equal 5.6K to give a base voltage of 0.9V and a current slightly less than 1 milliamp through the resistors. Note that any error occurring due to our assumption of 0.4V as being the forward voltage drop for a semiconductor junction will generally be "swamped" by the error in selection of resistors from the 10 per cent preferred value range.

One can check the accuracy of the resistor selection by measuring the voltage at point A. If necessary, it can be adjusted by varying one or other of the resistors in the voltage divider.

We have seen that the method of biasing shown in figure 2 provides a DC working point which is relatively free from the effects of temperature and which does not have to be varied to suit individual transistors. Thus, we have a circuit with predictable characteristics, but one which has the disadvantages of slightly higher current drain (through the voltage divider resistors) and lower input impedance than the circuit shown in figure 1 which is current biased.

Note that, in the case of girue 2 we have shown an NPN transistor. All the above calculations can be applied to circuits using PNP transistors, but the polarities of all voltages in the circuits must be reversed.

Figure 3 illustrates a more complex configuration known as a Darlington pair configuration, in which two transistors (both either PNP or NPN) are interconnected as shown. They operate effectively as one composite transistor with aBeta equal to the product of the Betas of the two individual transistors. It is important to grasp this concept of the two transistors acting as one with a very high Beta.

An advantage of the Darlington pair configuration is that it offers, in a simple circuit, higher gain than could be obtained from two separate, capacitively coupled transistor stages of the type shown in figure 2. Another advantage is that it enables a higher input impedance to be obtained, especially when the output load is placed in the emitter circuit.

Figure 4 shows a practical amplifier using a Darlington pair configuration. Any general-purpose germanium PNP transistors, excepting high power types, can be pressed into service. Note that the Darlington pair is biased in the way shown in figure 2 (voltage divider) except that the voltage drop from the base to the emitter of the composite transistor is 0.8 volts instead of 0.4 volts since it has two forward biased base-emitter junctions. Note that we have been deliberately conservative in specifying relatively low values for the voltage divider resistors, in spite of the fact that the bias current will be very small. This is to allow for the effects of high leakage current in possibly old, oddment ger-

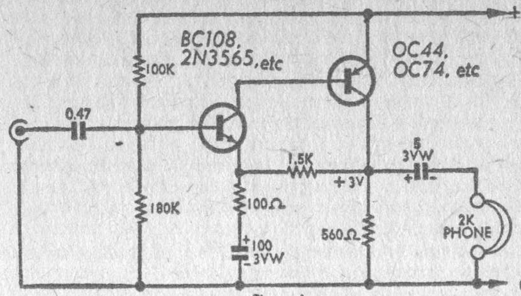


Figure 6

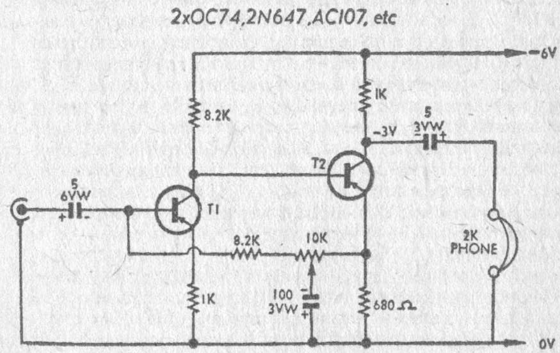


Figure 7

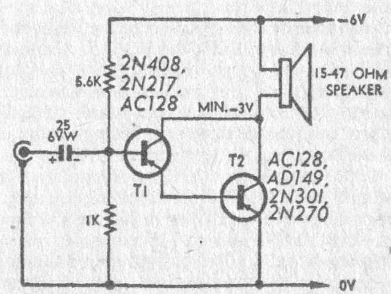


Figure 8

manium transistors. Much higher values could be specified if low leakage silicon transistors were to be used.
The 100-ohm emitter resistor is "by passed" with a 50uF electrolytic capacitor to eliminate gain reduction due to emitter degeneration. If the emitter resistor is not shunted with a capacitor, the output signal voltage due to fluctuating collector current appearing at the collector of the Darlington pair, will appear with reduced amplitude across the emitter resistor. This, in turn, will counteract the signal input voltage appearing between base and emitter and thus cause a reduction in voltage gain. By connecting a capacitor across the resistor, as shown, the signal voltage appearing across the resistor is minimised and gain reduction avoided.
The value of the bypass capacitor selected must be such that its impedance is low for the lowest signal frequency to be handled.
The circuit in figure 4 has an input impedance of something less than 5K. Current drain is 5mA and the typical voltage gain to be expected is at least 40 with general purpose germanium transistors. The gain can be reduced to a value of approximately 5 by omitting the bypass capacitor.
The circuit in figure 5 is basically similar to figure 4, except that we have specified silicon transistors, which, as we have already mentioned, can be expected to have a much lower leakage than germanium types. PNP transistors may be used merely by reversing the polarity of the supply voltage and the electrolytic output coupling capacitor. Note that we have not bypassed the emitter resistor. This is to make use of emitter degeneration to provide a high input impedance. Input impedance is approximately 500K and the typical voltage gain will be 5 times, regardless of the Betas of the particular transistors used. The emitter resistor may be bypassed to obtain a substantial increase in voltage gain but this will reduce the input impedance to approximately 50K.
Figure 6 is a direct-coupled "complementary" configuration using a PNP and an NPN transistor; the latter can be either germanium or silicon. Note that the biasing arrangement is essentially an extension of the method shown in figure 2. The voltage divider at the input determines the current flow through the first transistor and thus the voltage at its collector. This collector voltage then determines the current flow through the second transistor and hence the voltage at its collector.
The voltage gain can be varied by the negative feedback which is controlled by the size of the 100-ohm resistor. With the 100 ohm resistor in circuit the gain will be approximately 16 times. Reducing the resistor to zero will eliminate the negative feedback and maximum gain will result. This will typically be 125 times for the transistors we have specified. By manipulating negative feedback one can thus design for a desired order of gain.
Figure 7 is another direct coupled configuration. Here, the circuit uses DC feedback to the base of T1 to establish the DC working point. In this case, the gain can be varied by the setting of the potentiometer, which isolates the 100uF capacitor to a greater or lesser extent from the 680 ohm emitter resistor. An equivalent effect can be obtained by replacing the potentiometer with fixed resistors which add up to 10K but provide a suitable fixed tapping point.
All the above circuits are suitable for use with 2000 ohm dynamic headphones or the high impedance crystal type. Low impedance types, such as the 8-ohm variety supplied with transistor radios cannot be used directly, because the output impedance of the amplifier stages we have described is too high.

The circuits can be used with low impedance phones if a suitable step-down transformer is coupled to the output, via the 5uF electrolytic capacitor. The transformer could be almost any type - a 6.3V heater transformer would be almost ideal. The 240V winding would be connected to the output of the amplifier while the phones are connected across the low voltage winding.
None of the amplifiers so far discussed has sufficient power output for use with loudspeakers. The circuit in figure 8 represents a novel and economical way of obtaining sound from a loudspeaker. It has one major draw back - DC flows through the loudspeaker voice coil. Normally, loudspeakers should not have DC flowing through them, as the current causes a fixed deflection in one direction and thus restricts the cone excursion in one direction more than the other, this could result in distortion on loud signals. If one is prepared to risk some deterioration in quality, the arrangement is a handy one to keep in mind.
The circuit is again a Darlington pair configuration. T2 should be a power transistor. The current flowing through the loudspeaker should be kept to a minimum consistent with power output, otherwise the cone excursion will be excessive and the power dissipation in the voice coil may cause an undesirable temperature rise. For these reasons and considering the battery drain, the impedance of the loudspeaker should not be less than 15 ohms and the drop across the loudspeaker should not be more than 3 volts. If higher impedance types are on hand they may be used provided the DC working point is adjusted to 3 volts, as shown, to ensure adequate signal excursion. The voltage at the collector can be adjusted upwards by decreasing the 1K resistor and vice versa.
Note that the power transistor does not need to be mounted on a heatsink as, at most, it will only be required to dissipate 600 milliwatts of power. Note also that the available power output with this amplifier is strictly limited because of the limitation on current flowing through the loudspeaker, and the current which can reasonably be drawn from dry cells.
Finally, in figure 9, we have shown an economical, complementary-sysmmetry amplifier with an output power of 300 milliwatts into an 8 ohm speaker. It represents the most economical method of providing this order of power, both in terms of component cost and battery consumption. Particular transistors have been specified and it is not intended as a circuit in which oddment transistors can be substituted.
Note that loudspeakers with an impedance higher than 8 ohms may be used with a consequent reduction in power output and current drain. Current drain with an 8 ohm loudspeaker is 100mA at full power and a mere 1mA at no signal.
The operation of the amplifier is as follows: The input transistor is a high gain silicon NPN type functioning as a common-emitter amplifier stage. Following the input transistor is a silicon PNP transistor which performs further voltage amplification and also acts as the driver for the two output transistors. The output transistors are a complementary germanium pair, AC127/AC128.
Complementary-symmetry operation has the advantage of achieving the phase-splitting which is necessary for class-B operation push-pull operation in the output pair itself. Class-B operation implies that the output transistors are biased so that they draw very little current under quiescent consitions, the current rising with signal level. For those not familiar with phase-splitting in complementary-symmetry amplifiers the principle is as follows:-

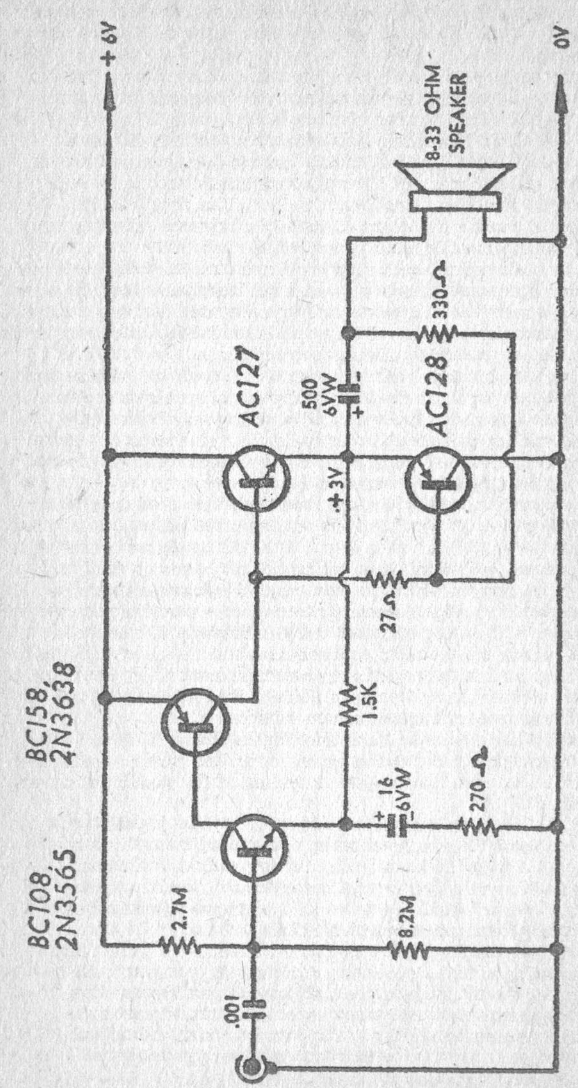


Figure 9

Suppose initially, that the signal from the collector of the driver transistor is positive-going, so that both output transistor bases are driven positive. This will cause the upper (NPN) transistor to conduct and "charge up" the output coupling capacitor via the loudspeaker load, the lower (PNP) transistor meanwhile is turned off. During the following half-cycle, as the signal becomes negative with respect to the junction of the two emitters, the upper transistor turns off while the lower one conducts and discharges the output coupling capacitor through the loudspeaker load.

Class-B operation is thus achieved, with postive-going half-cycle being supplied to the loudspeaker from the positive supply rail and the negative-going half-cycle being supplied by the subsequent discharge of the output coupling capacitor.

Negative AC and negative DC feedback is applied from the junction of the output transistor emitters to the emitter of the input transistor. The degree of feedback is determined by the value of the 270-ohm resistor. Decreasing the resistor increases the gain and vice versa.

The low frequency response of the amplifier is determined mainly by the value of the 16uF capacitor in series with the 270-ohm resistor and also by the size of the output coupling capacitor.

Because all stages in the amplifier are direct coupled, the voltage at the junction of the output transistor emitters is determined by the ratio of the voltage divider resistor at the input. Normally, there should be no need to adjust this voltage, unless the supply voltage is changed.

The last feature of note in this amplifier is the low value of quiescent current necessary to reduce "crossover" distortion to acceptable limits. Cross-over distortion is visually apparent on an oscilloscope as a "nick" in the waveform that occurs when one transistor in the output stage turns off and the other begins conducting. This distortion is very irritating to the ear but can be reduced to negligible proportions by allowing a small current to flow at all times through the output pair; this is the "quiescent" or "no-signal" current referred to earlier. A suitable choice of quiescent current ensures a small overlap and a smooth transition between each transistor.

In this case, both output transistors are slightly forward biased by the voltage divider formed by the 330-ohm and 27-ohm resistors to give a quiescent current of approximately 1mA. This low current means that the usual temperature stabilisation components such as emitter resistors and thermistors can be omitted.

LET'S TALK ABOUT AMPLIFIERS

Many of our readers, particularly the older ones, may be already familar with valve amplifying configurations but are confused when confronted with the transistor equivalents, either on paper or as hardware. One of the best ways to break this barrier is to first study the basic principles of the circuitry, then grab a soldering iron and the necessary bits and pieces and get to grips with it at a practical level. Make up the simple circuit we will describe and learn how it works.

In valve technology there are three basic amplifier configurations : the common cathode; the common plate, more usually called the cathode follower; and the common grid, more usually called the grounded grid.

The solid state equivalents are; the common emitter; the common collector, more usually called the emitter follower; and the common bases. (Fig. 1). Their names come from the fact that each type has one element (collector, base or emitter) common to both input and output. This is an easy way to remember each type. We also used the term "emitter follower". This is

the more common name for the common collector type, chosen because the output signal at the emitter follows very closely the signal applied to the base - both in phase and amplitude.
From now on we will use the term "emitter follower", as this is the one you will invariably meet in practice.
The common emitter amplifier is probably the most widely used of all amplifiers. Its main feature is a high order of gain - typical circuits may give voltage gains of 40 - 180 times, which compares very favourably with thermionic circuits. Similar current gain figures are obtainable. The power gain being the product of voltage and current gains, is high - of the order of 10,000 or more.
The input impedance of a common emitter amplifier is naturally low to medium. However, by choice of components in the bias network, this impedance can be varied. Depending on the bias and the device itself, common emitter input impedance may be anywhere from a few ohms to a few hundred kilohms. In audio circuits, the input impedance will generally be at least a few thousand ohms -probably more. Specialised ciruuits, such as RF, have lower impedances.
The output impedance is approximately equal to the collector load resistor, which is usually fairly low - say 50 kilohms or so. This too is variable. Actually, the impedance is equal to this resistor in parallel with the device output impedance but, because the device impedance is usually very much higher it can be disregarded.
The signal at the collector is 180 degrees out of phase with the signal at the base. This means that if a sine wave were applied to the base, it would appear inverted at the collector. This is not particularly important at this stage - but we mention it as a similarity between this and the common cathode type.
The emitter follower configuration is another very common circuit. It has wide uses, ranging from power amplifier stages to simple buffers and impedance "transformers".
The voltage gain of the emitter follower is always less than unity. For very high gain transistors it may approach unit, but can never equal or exceed it.
The current gain of the emitter follower is high - often 100 or more.
The power gain will be slightly less than the current gain.
The natural input impedance is very high but it can be tailored to suit the circuit. It is mainly dependent on the bias network resistance which can be arranged to have high (w - 3 megohms or more) resistance for silicon devices or lower (few hundred kilohms) in the case of germanium types.
The output impedance is low, making the configuration ideal for output stages which can work directly into low impedance speaker voice coils without the need for a speaker transformer. It is also useful where any high impedance has to be matched to a low impedance and is often used in lieu of a transformer.
The output impedance is determined by the output resistance of the device itself in parallel with the emitter resistor. The device output resistance is generally much lower than the emitter resistor.
The emitter follower does not invert the signal; rather, the emitter follows the input. It is also capable of handling large input signals without overloading.
The common base configuration is not used widely in audio circuits, except where a very low input impedance is required. Its other use is confined mainly to VHF applications (for reasons which are a little involved to go into here) and as part of transistor - transistor - logic (TTL) integrated circuits.

The common base can be arranged to give high voltage gains, but the current gain is less than unity (the exact opposite to the emitter follower). Therefore, power gains are not high - generally somewhere between that of the emitter follower and the common emitter configurations.
The input resistance is very low, being equal to the emitter resistor in parallel with the B-E junction resistance. This makes it suitable for an audio preamplifier; operating from a low impedance signal source; such as a speaker used as a microphone.
The output impedance is roughly equal to the collector resistor. Like the emitter follower, the common base configuration does not alter the signal phase between input and output. We plan to look more closely at the common emitter amplifier.
The common base amplifier applications are rather more limited, so we will leave this one for the present.
Coming to the practical side, how does one go about building even a simple amplifier? More particularly, how does one select a suitable circuit?
There are several possible approaches. One can simply take a published circuit, copy it parrot fashion, and hope that it works when it is switched on. At the other extreme, one can collect all the available data and texts on the subject and attempt to design a circuit from scratch.
Neither is a good approach for the beginner. The first is too easy and teaches little or nothing about how the thing works. The second will almost certainly prove too hard, with consequent discouragement. The best idea seems to be to work from a published design, but one which explains at least the general factors which govern the selection of component values.
Armed with this information the reader can (1) make an intelligent approach to the problem in the event that the project does not operate correctly when first switched on and (2) experiment intelligently in the event that the chosen circuit is not exactly suited to the applications in mind.
This is the aim of this chapter. We are going to describe how to build a simple amplifier and tell you something about how it works and why the various component values are as they are.
One of the first things any experimenter should do is arm himself with as many transistor data sheets or books as he can find. These are normally made available by the manufacturers, sometimes as simple sheets, issued gratis, and sometimes as quite comprehensive books costings a few shillings. Money spent on these will be a sound investment.
These data sheets supply such information as the type of transistor (Germanium or silicon), its general application (amplifier, power output, etc) its polarity (NPN or PNP), together with its ratings such as maximum voltage, maximum current, maximum dissipation, its gain (Beta or hFE).
They will also provide the lead connections. This is important because there is much variation from the nominal "standards", making the identification of some transistor connections difficult. Fortunately, most transistors do follow a standard, but there are some traps for young players.
Take for example, a recently introduced transistor in a T092 silicone package. Two manufacturers (Fairchild and Philips) have near identical transistors in this dpackage - identical electrically as well as physically. However, in one package the leads are oriented one way - E, B, C, - while in the other package, looking at the pins the same way, the

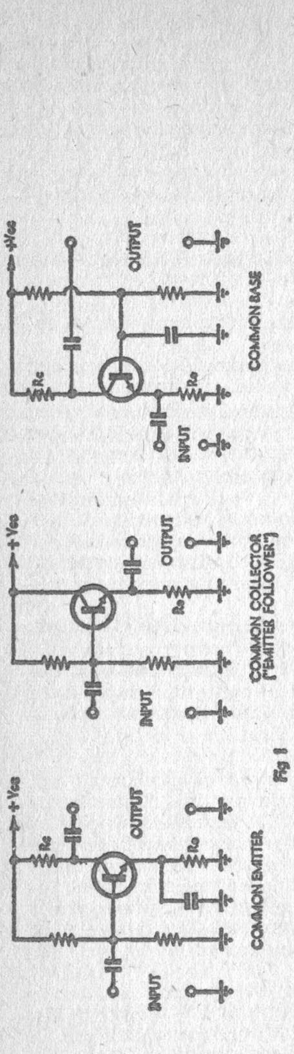


Fig 1

The three basic transistor amplifier configurations; common emitter, common collector (more usually known as the emitter follower), and common base. The first two are particularly important in audio circuits, as discussed in the text.

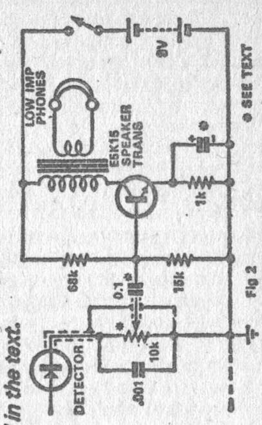
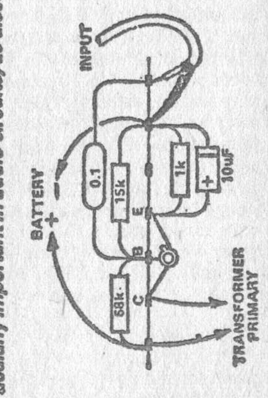


Fig 2

Complete circuit of a simple amplifier to suit the crystal sets described last month. Its design is discussed in the text.



Wiring diagram showing how the amplifier in Fig. 2 may be wired on a tag strip.

configuration is C, B, E. Frustrating, isn't it?
Therefore, if possible, find a reference to the connections. You may have noticed we publish transistor connections along with our circuit diagrams for each project. These will assist in finding the connections for most of the common types.
We have also shown a diagram with most of the common transistor connections. Where doubt may exist types are given.
Now let us consider a practical amplifier (Fig. 2). While we could make an involved type, with high performance, we decided a better place to start would be a simple single stage amplifier, capable of amplifying say the signals obtained from crystal sets.
The first question in designing this (or any) amplifier must be, "Where do we start?"
The place we started was the load - a 5000 ohm speaker transformer. However, there were a few other items to be decided on before we could proceed any further. One was the supply voltage.
For convenience (and economy) we nominated a 9 volt supply - small 9 volt batteries are relatively cheap. The transistor was an NPN, silicon, general purpose type, with a reasonably high beta. Providing any transistors you have on hand meet these general specifications, they could be used.
The transistors are not power types, though they are being used in a "power output" role. Power types as a rule have low current gains(beta); usually less than 200. The types we are using have betas of at least 200 - some go as high as 900. While we have used an NPN type, this does not preclude the use of a PNP - if you have a high gain silicon PNP (such as a 2N3638A) by all means use it, but do not forget to reverse the battery and polarised capacitors.
The potentiometer is optional, being required only in strong signal locations. It can be replaced by a 10k resistor, shunted by the .001uf capacitor, with the output taken directly from the diode.
The input capacitor is shown as 0.1uF which is about the smallest which can be used in a simple application of this kind. Larger values can be used and will give some improvement in low frequency response.
In designing the amplifier, we assume the transistor will "swing" over the range between cut-off and saturation. It will not swing this far in practice - distortion would occur if it did - but it makes the job easier if we make certain assumptions.
Because our load impedance is 5000 ohms, and the supply is 9 volts, the most current which can flow through the load is 1.8mA, occurring when the transistor is saturated. The least current would be zero, when the transistor is cut off.
To obtain the maximum "swing" in the load, the current should ideally vary up and down from the midpoint between 1.8mA and 0mA - or 0.9mA. By providing this value of "quiescent" current, any AC input to the base circuit will make the transistor conduct slightly more or slightly less - resulting in collector current varying in unison.
This current must flow through the primary of the transformer - and whenever there is a change in current, the secondary winding will receive this by transformer action. This operates the headphones. Note that the quiescent current will not produce secondary output. It is only when a change occurs that this can happen.
To make the job easier, we can assume the maximum saturation current to be 2mA (instead of 1.8mA) and the half-current (quiescent) 1mA - a much easier figure to work with.
Now, we can consider the base circuit. Logically, the transistor needs

to be biased on if it is to work. This bias must set the collector current at the chosen figure of 1mA.
There are two main methods of biasing. The first is called current biasing - see Fig. 3. A single resistor, Rb, is used to bias the transistor from the supply line. The value of this resistor is determined by two formulas - one being Ohm's Law, and the other probably the most-used formula in solid state design. It says that base current will be equal to the collector current divided by the current gain (beta) of the transistor.

Expressed as a formula :

$$Ic = B \times Ib$$

where Ic is collector current, B is beta and Ib is base current. Learn this formula - it will come in very handy.
This formula plus Ohm's Law, gives us the value of the resistor. The collector current, which we talked about earlier, has been decided as 1mA. The beta of the transistor may be from 200 to 800 for a BC109 (which we used) but the minimum figure is always taken, so we used the figure of 200. It is safe enough to assume this beta for most of the common "audio" general purpose transistors.
Therefore, base current will be equal to 5uA. From Ohm's Law, the resistor value will be equal to the voltage across it (8.4V - supply voltage less the drop across the B-E junction), divided by the current through it. Therefore, this resistor should be 1.7M. Simple, isn't it?
Yes, too simple. This type of biasing, while used in some applications, has a number of serious disadvantages. The worst is that it is very dependent on the beta of the individual transistor (no two transistors will have the same beta - even of the same type number) and it has no inherent protection against changes in temperature.
There is another biasing system which, for practical purposes, overcomes these problems. This is "voltage divider" biasing, illustrated in Fig. 4. The bias network consists of three resistors; Rd1, Rd2 and Re. As before, these resistor values can be calculated using Ohm's Law and the current gain formula.
We have already established that we require a quiescent current of 1mA. Resistor Re is calculated from this figure on the basis that it is required to develop a small voltage across it which, within certain limits, can be selected arbitarily. The main requirement is that this voltage be small relative to the supply voltage. In a case like this a convenient value would be 1V but, whatever value we select, it will be taken into consideration in the next step.
This is to calculate the voltage divider resistor values, Rd1 and Rd2. Because the current which can be taken from a voltage divider is limited (too much loads the divider and upsets calculations) we have to ensure that current through the divider is many times the base current. A good rule of thumb is to make the divider current at least ten times the base current - but for high gain transistors (say 200 or more) this can be increased.
We elected to make it 20 times. Since we have already worked out our base current as 5uA, this makes our divider current 100uA. Thus, we calculate a resistor which will pass 100uA at 9V; which works out at 90K. We now have to break this into two resistor values to provide the correct voltage at the base of the transistor.
We have already established that there will be 1V at the emitter and, as it requires at least 0.6V to turn on a (silicon) transistor, the base must be elevated to at least 1.6V above the negative supply line. At 100uA this

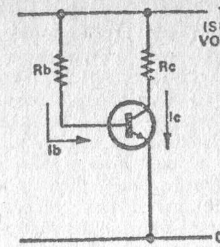


Fig 3

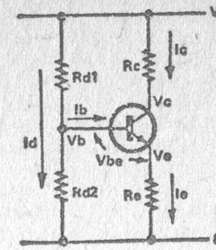
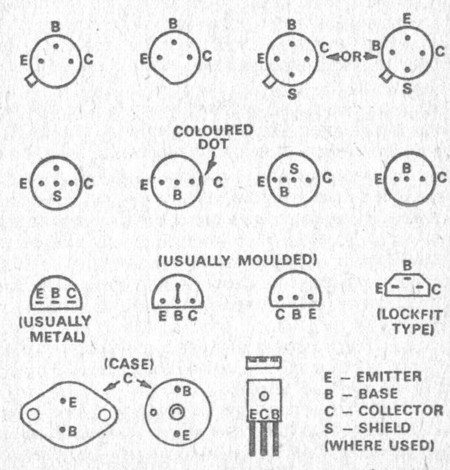


Fig 4

Fig. 3. The simplest form of bias, called current biasing. While simple, it has several serious limitations. Fig. 4 illustrates voltage divider biasing which is a much more practical approach.



The most popular transistor connections are shown here but these should be backed up by manufacturers' data sheets.

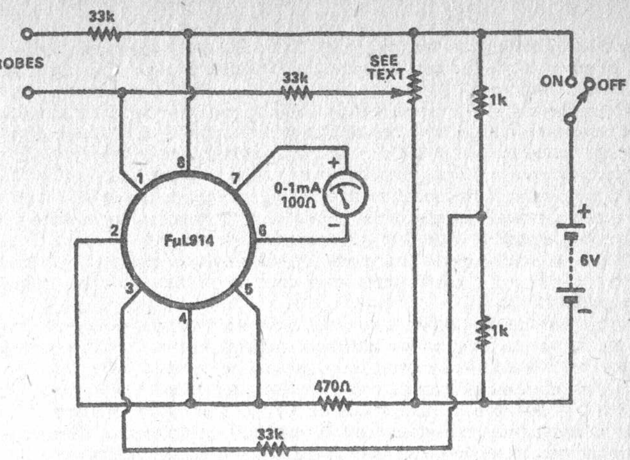
sets Rd2 at a calculated 16k, or the closest preferred value, 15k. Resistor Rd1 will be 90K (Total resistance) less 15k, or 74k. We used the nearest preferred value, 68k.
Operation of this network is largely self balancing. The voltage across Re is, in effect, a "bucking" voltage which opposes the voltage generated by Rd1 and Rd2. Thus, with 1V across Re and 1.6V across Rd2, the 1V of Re is subtracted from the 1.6V of Rd1 to produce a value of 0.6V between the base and the emitter. Thus, if the voltage across Re increases the base emitter voltage, or forward bias, will decrease.
The only way in which the voltage across Re can increase is by an increase in collector current. But should this happen (or tend to happen) the immediate result will be a reduction in forward bias, which will reduce the collector current, thus tending to re-balance the system. Similarly, the reverse applies for any tendency to reduced collector current.
While voltage divider biasing has a number of advantages over current biasing, it has one disadvantage. The introduction of a resistor into the emitter circuit has an unfortunate side effect - that of reducing gain quite considerably.
Because the signal across the emitter resistor is proportional to the collector current (that is, proportional to the voltage across the collector load) and the input signal voltage is applied between the base and the negative supply, any signal voltage appearing across the emitter resistor will be subtracted from the input signal voltage, thus reducing gain.
However, just as easily as we lost the gain, we can get it back. All we need do is make the emitter resistor "blind" to the AC signal, while maintaining the DC bias voltage. To do this, we bypass the emitter resistor with a capacitor. This capacitor must have a low impedance at audio frequencies so at least a few microfarads is required. We used a 10uF, 6VW - but this component, of all in the amplifier, is probably the least critical. Probably anything from, say, 1uF to 50uF or more would be quite satisfactory.
Earlier, we hinted at the need for protection against temperature changes. This is important because an unprotected transistor can go into a condition called "thermal runaway" and bias itself into saturation. At the least this will seriously upset the operating conditions and, in extreme cases (but unlikely in this circuit) can destroy itself.
Increase in temperature can increase the collector current, the beta, and the leakage, and reduce the base-emitter junction voltage. In a simple circuit like Fig. 3, an increase in temperature would increase the collector current, which would increase the power dissipated by the transistor, which would increase the temperature ...... which is where we came in.
In some amplifiers, "thermistors" are used to counteract heat rises. In other amplifiers, devices with opposite temperature-characteristics are used to balance each other.
The biasing system of Fig. 4 provides an adequate order of protection for simple circuits of this kind. As we have already explained, any tendency for the collector current to increase - in this case due to temperature rise - will produce a decrease in forward bias to counter this tendency. Thus, the voltage divider biasing system not only accommodates the quite wide spread of characteristics from one transistor to another, but also provides the necessary temperature compensations.

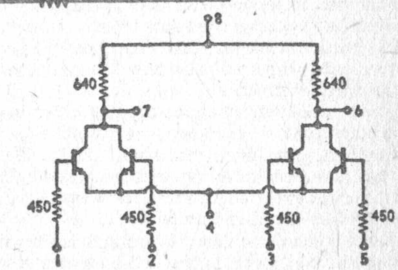
A LIE DETECTOR FOR YOUR NEXT PARTY

HERE'S SOMETHING FOR ALL. A SIMPLE LIE DETECTOR WHICH YOU CAN USE TO TRAP CRIMINALS INTO CONFESSIONS.

Seriously, while the project is, after a fashion, capable of detecting lies under certain conditions, we are not suggesting anyone use it for that purpose other than at an entertainment level. Rather, it is an amusing novelty - but one which would be a great party-starter.
Lie detectors, or polygraphs, as they are officially known, were very popular some years ago with law enforcement bodies, particularly in the United States. More recently their use has diminished, as the results achieved have been largely discredited.
Our simple lie detector bears only a slight resemblance to a proper polygraph. While our detector is capable of measuring only one parameter of the human body - galvanic skin resistance - a polygraph may measure heartbeat, respiration, brain waves (literally), and a number of other conscious and subconscious functions of the body, as well as skin resistance. It requires a highly skilled operator to deduce, from all these readings, whether a person (probably) is or is not telling the truth. Even then they are not infallible!
It was possible for a person to fool the machine - by consciously increasing his respiration and heartbeat, or causing some other reading to be misleading and so throw the whole system out.
Skin resistance is proportional to the amount of sweat glands, which, in turn, are activated by processes within the body. In times of emotional stress, pain, or danger, the glands release a large amount of sweat - and the skin resistance drops.
This release is surprisingly rapid. It happens even while you are thinking about the situation - even before you have had time to react in a positive manner. This you can prove later.
The reason a lie detector works (or is supposed to) is that, when a question is asked of a person, he reacts in one of two ways. He tells the truth and he remains calm. Or he may tell a lie - in which case, his body reacts. Have you ever noticed how you feel uncomfortable when you have told a lie?
When a lie is told, the body does a number of things. The reasons for this are not clear, but it may have something to do with a psychological fear of being found out. In any case, the skin resistance drops - and if the "liar" is connected to a lie detector, this can be measured.
While all this is fine in theory, it doesn't work so well in practice. For example, a question may be asked which produces a positive reading even before an answer is given. There are two possible explanations for this, one is that the subject realises that a truthful answer will be embarrassing or incriminating and will therefore be tempted to lie. Either way he will suffer enough emotional stress to produce a reading.
Such a situation might fairly be regarded as genuine lie detection or, at the very least, a means of allowing the questioner to arrive at the truth, which amounts to much the same thing. The second explanation is quite different.
The question - or a suggestion implied by it - may embarrass, annoy, disgust or even horrify the subject and thereby produce a reading by reason of these emotions. In this case the question itself, for reasons quite removed from the truth or falsity of any answer, has created the emotional disturbance. Hence the reading itself can be false.
We would probably have been closer to the truth if we had called the device

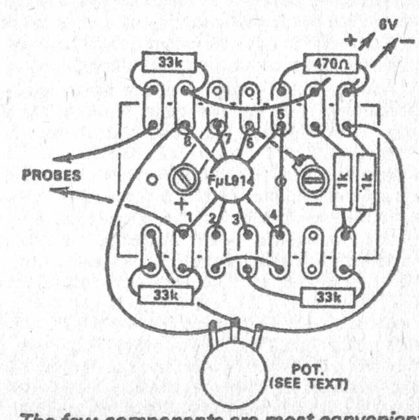
an emotion detector, rather than a lie detector. It picks up any change in the emotional state of a person - but this may not imply a lie or anything as drastic.
The heart of the detector is a wheatstone bridge, in which the skin resistance becomes the "unknown" resistance. The bridge actually measures the skin resistance - and if the meter were calibrated, this could be read off in ohms.
However, for our purposes, all we need is a change of the pointer - there is no way of calibrating the meter for "lie". The pointer movement itself is this indication, as the skin resistance drops.
As shown in the diagram, it consists of four resistors : Ra, Rb, Rc and Rd. In bridge terminology, Ra and Rb form one "arm" of the bridge. Rc and Rd form a second "arm".
If a voltage is applied between points X and Y current will flow through two paths; through Ra and Rb, and through Rc and Rd. The amount of current flowing in each arm will depend on the values of the resistors.
Let us take an example :
Suppose that Ra is 20 ohms, Rb is 100 ohms, Rc is 100 ohms and Rd is 20 ohms. Note that the ration between Ra and Rb is the same as the ration between Rd and Rc. While ever these ratios are equal the bridge is said to be balanced. The two arms need not have the same values of resistance, provided the ratios are equal. For example, Ra and Rb could be 2 ohms and 10 ohms; or 40 ohms and 200 ohms, just so long as the ratio (five to one in this case) is the same.
If we assume a specific value of voltage applied between points X and Y we can work out the current in each arm, using Ohm's law. Suppose we connect a 12V battery between X and Y.
The total resistance of the right arm (Ra, Rb) is 120 ohms. Ohm's law says that the current flowing through a resistor is equal to the voltage applied to the resistor, divided by its resistance (I=E/R). From this we find that 0.1A flows through this arm. Since the other arm has the same resistor values, it will also have a current of 0.1A flowing through it.
Having found these current values we can now work out the voltage across each resistor, again using Ohm's law. Transposing the formula we get E= I X R. From this we find that if 0.1A is flowing through a 20 ohm resistor, there must be 2V applied to the resistor. Similarly, 0.1A through a 100 ohm resistor means that 10V is applied to the resistor. (Note that these total 12V, the voltage applied.)
Now we come to the crux of our discussion. With reference to point X, point O is 2V positive. Also, since the other arm (Ra, Rb) has the same ratio, point P will also be 2V positive with respect to point X.
Since the indicating meter is connected between points O and P, and these two points are at the same potential, there will be no reaction by the meter. In this condition the bridge is said to be balanced. The important characteristic of this set-up, as far as we are concerned at the moment, is that, even though current flows in each arm of the bridge, none of it is registered by the meter while ever the bridge is balanced. However, if anything should happen to cause the value of any one of the four resistors to change its value, the voltages at points O and P will no longer be identical and the meter will read. Thus, while the meter will not respond to a normal standing current, it will immediately respond to any change of resistance which alters the current.
It is this ability to balance out the standing current which allows the bridge to be made quite sensitive. Once the standing current - which





FµL914 CIRCUITRY

Based on a popular IC, the circuit is very simple. The circuit of the IC is shown at the right. Compare it with the bridge circuit substituting Rd and Ra for the two transistors.



The few components are most conveniently assembled on a short length of terminal board and mounted on the meter terminals.

might be quite high - is balanced out the most sensitive meter available may be used, since it is required to respond only to the changes in the balanced situation.
The bridge circuit in the lie detector is slightly different from the explanatory circuit. In fact, our bridge is closer to a solid state equivalent of a vacuum tube voltmeter (VTM) than to a standard bridge circuit.
This is because we have replaced two of the resistors in the bridge with transistors; or to be more precise, an IC (integrated circuit). The IC is a low cost digital type, an FuL914. While it is not intended for use in the role we have given it, its performance is quite satisfactory.
We can already hear the question; why use only two transistors from a four transistor IC, particularly when only one of these two is actively employed?
The reason is simple. While we could use a single transistor, and replace the inactive one with a resistor, the temperature characteristics of the transistor and resistor would not match, making it impossible to maintain a balanced condition with changes in ambient temperature.
Using two discrete transistors would better, since they would have simlar temperature characteristics. Using two transistors on the same IC chip is even better because they are thermally bonded and must both change temperature at the same rate.
The fact that this IC is relatively cheap also influenced our thinking. And it gives us a chance to show how ICs are put to work - and not always in the manner intended!
As can be seen from the circuit, the meter is connected between the transistor collectors - and therefore measures a difference in potential between them. Because a very small change in base current is enough to change the collector voltage quite markedly, the potential between the collectors is great enough to allow a common 1mA meter to be used, yet provide very high sensitivity.
No protection across the meter itself is shown or needed, the circuit is self protecting. Because the collector resistors are 640 ohms, and the resistor between the emitters and negative rail is 470 ohms, the maximum current which can flow through the meter is 6mA. A current of this magnitude is only likely to occur when one transistor is cut off and the other is saturated. Most meters can withstand a ten times overload without undue worry, so the maximum current is well within this.
A really severe overload (such as supply voltage being applied directly between the inputs and emitters) might damage the IC but would not worry the meter. If the wiring diagram is followed exactly even this possibility should not eventuate.
During our initial experiments, we used a standard bridge circuit (without amplifier), using three resistors and a 0.5mA meter. We found that the sensitivity was quite reasonable, but there was a quite unpleasant side effect. The probes we used were two pieces of curved tinplate, held on the inner fore arm by two rubber bands. This appears to be a good compromise location, providing good conductivity with minimum inconvenience.
Even though the current involved was very low, small burn marks appeared on my arms as a result of localised heating. This we put down to insufficient contact between the tinplate and the arm proper - only the points were making contact and thus carrying all the current. Clearly, some sort of conductive paste or liquid was needed to improve conductivity.
We tried a number of ideas, including water, paste, and salt solutions,

with varying degrees of success. We then thought of a different type of substance - one specifically made for improving conductivity between the body and a metal probe. This is ECG paste, which is used by hospitals on patients having electrocardiograms. This paste is available in small tubes from firms supplying analytical chemicals.
Our later experiments with the "amplified bridge" indicated that the con deuctive agent did not seem to be necessary. The higher sensitivity appears to overcome any serious losses while the much lower current (less than 2mA) avoids any problems of localised heating.
The lie detector circuitry is, with the exception of the potentiometer, mounted on a seven lug section of resistor tagboard screwed to the back of the meter.
Fit the resistors and links first. When mounting the 1K voltage divider resistors, make sure you have enough clearance to allow the meter terminal screw to fit.
Like all semiconductors, the IC should not be subjected to too much heat. A good hot iron, well tinned, should be applied for a brief time to each lead.
The spacing of the meter terminal screws is exactly five holes apart on the tagboard. The holes have to be enlarged to take the screws. When mounting the lugs, take care that they do not short to any other wiring.
If there is any danger the exposed wiring should be covered with a short piece of spaghetti insulation.
As mentioned earlier, the probes are small curved metal plates, cut from tinplate designed to fit the curve of the inner fore arm near the wrist. The general shape is shown in Fig 4.
Rubber bands are used to hold these in place firmly on the wrist. This appears to be as good a location as any - the release of sweat on the wrists is quite reasonable for our purposes.
A simpler arrangement would be to use short lengths of metal tubing held in the hands. The objection to this is that the overall resistance will vary quite markedly with the strength of the subjects grip. This introduces a variable factor which is quite unacceptable.
Even with the probes shorted together, not enough current flows to damage the meter. Normally, the probes are not shorted, but have at least a few thousand ohms resistance between them. The skin resistance varies over a very wide range from person to person and day to day. On a hot, humid day, one would naturally expect to find that lowest skin resistance. The body cannot get rid of sweat released (since the air is already laden with moisture) and the skin is saturated.
Conversely, on a cold winter day the body releases little sweat; the skin resistance, therefore, is quite high - it can be as high as 50K ohms or more.
The bridge circuit will cope with these two extremes. In fact, the pot varies the postion of the pointer over a very wide range - from hard FSD to hard against the bottom stop. As we have mentioned, this is extremely unlikely to damage any meter - so it is nothing to worry about.
While we have specified a 1M linear taper pot, this is not critical. Values from 470K to 2M could be used without upsetting the operation too much.
A log pot may be used in place of the linear type if you are prepared to put up with some difficulty in setting the meter at one end. Because of the log taper, at one end of the travel a very small rotation of the shaft gives quite a large variation in resistance. If the zero point happens to occur around this area of rotation, the setting is made harder.

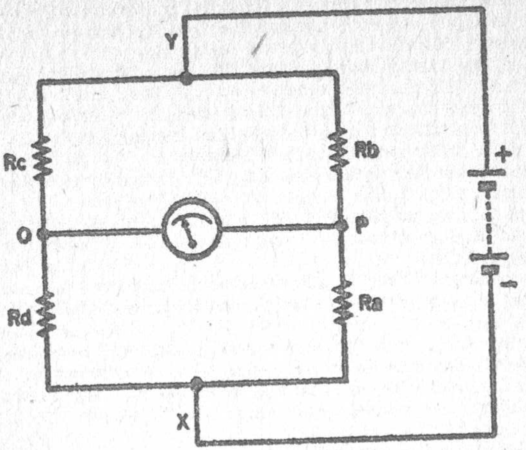
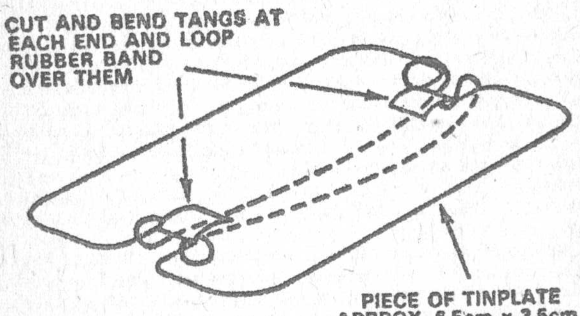


Fig 1. basic bridge circuit. Heavy current may flow in both arms without deflecting the meter, if the bridge is balanced.



The wrist contacts, or "probes," can be cut from a scrap of tinplate to the shape shown, then curved slightly to fit the wrist.

Use of the detector is quite simple - as long as you have made no wiring mistakes just connect power and go!

In no circumstances should you use a mains operated power supply with this project. A six volt battery should be the only power source. If anything goes wrong inside the power supply .... The probes are in the worst possible position, because a circuit exists directly across the heart.

When connected to a battery supply, the lie detector is less dangerous than simply touching the contacts on a six volt battery, as there is a high resistance in series with the battery.

A simple first experiment is to merely hold the probes in the hand, adjust the meter for zero, and then vary the pressure exerted on the probes. Even with moderate pressure it should be possible to produce quite large deflections.

There are a number of ways of cheating against the lie detector; a fact which has contributed to their loss of popularity. One of these is to induce pain, and "professional" subjects have been know to dig sharp fingernails into the palms of their hands, or burn themselves with a cigarette, in order to produce readings at a time when there should not be any, thus making all subsequent readings suspect.

As a matter of fact, in some cases it is not even necessary to feel the pain - just the fear of impeding pain can cause a reaction. These facts can be used to good advantage as a means of testing our own simple device.

With the probes worn in the normal position (on the inside forearm) and the pot set to place the pointer down at the bottom of the scale, induce pain (try biting your fingernail!) You should get a quick reaction on the meter. In fact, it may even react before the pain is actually inflicted - the anticipation may be enough.

Having satisfied yourself that the device does work, you can now try it out on your first subject - or should we say victim!

Operators of polygraph machines usually begin with a series of quite innocuous questions: Where were you born? Did you like school? Did you like the place you lived in? What was your favourite hobby? How old were you when you stopped believing in Santa Claus? Where did you hide the loot from the bank hold-up?

The subject would have been just as surprised as you with that last question. However, it achieves its purpose: to throw him off guard. The operator can now begin to fire more questions - some of which may seem harmless enough, but all serve their purpose. Some bring about a marked reaction while others help give the subject a false sense of security. Other questions would again throw him off guard.

By piecing all the information together, a pattern begins to emerge - and the operator may use this pattern to his advantage, by pretending he knows more about this aspect of his questioning than he really does.

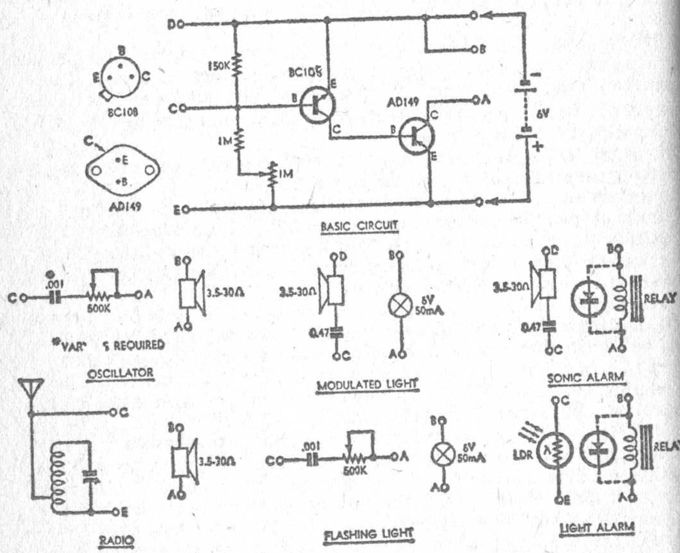
With our simple lie detector, the results you achieve may not be as clear-cut as those obtained on a proper machine - but then again, we doubt whether many readers will have a bank robber to try it out on! But the mode of operation is still the same.

There is not much more we can say about the operation of the device - it is really up to you. Good luck!

(By the way, if any reader does manager to catch a bank robber, don't forget to let us know!)

VERSATILE EDUCATIONAL PROJECT

Recently, there has been an interest in educational projects. We submit the following circuit.
It is simple - five basic components and breadboard construction. It is modern - solid-state components in a direct coupled configuration.
It is versatile - I have suggested six ways in which it may be employed but these are just a few of the possibilities. Others are : water alarm, temperature alarm, using either audio or visual alert.
In use, the appropriate sub-circuits are connected as indicated (A to A, B to B etc.) and the 1M pot in the biasing circuit adjusted for bes operation.
The original design used a 6V battery, but should work on 3 to 9V.
Alternative transistors are : for the BC108; BC109, BC107, or similar high gain NPN silicon types. For the AD149: OC26 or similar power transistor.
When used with a speaker load, the bias pot should be adjusted until half the supply voltage is developed across the load. A modest heatsink should be provided for the AD149 etc, when used with supply voltages higher than six and low load impedances, i.e. four ohms. About six square inches of 16 gauge aluminium - $2\frac{1}{2}$" x $2\frac{1}{2}$" - should be adequate.



LET'S TALK ABOUT CRYSTAL SETS

The crystal set was the first radio used by the public for broadcast reception. Its inherent simplicity was its main advantage, since it suffered from limited sensitivity, selectivity and signal output. When better sets became readily available it was soon discarded. Yet enthusiasts continually revive it from time to time, and marvel that such a simple device works as well as it does.

Rather ironically, the crystal set built as a novelty today is likely to perform a whole lot better than the serious version of 1923. Technological advances aimed at more elaborate circuits can also help the crystal set. Today we can produce more efficient coils, we have more efficient detectors, and more efficient headphones. On top of that, broadcast stations use many times the power they did in the old days. It all adds up to a quite surprising order of performance for the "simplest radio set".

When I build my first crystal set nearly fifteen years ago, one thing really puzzled me. That was the name "crystal set". Nowhere had I seen a "crystal set" containing a "crystal".

I knew what a crystal was–it was a device used as a frequency standard. But there certainly wasn't one of those in my set.

I wondered whether I had left something out, but no–I hadn't. Besides which, the darn thing worked!

The trouble was, I was born about fifty years too late. Had I made my crystal set early this century–or even later–I would have used what was then one of the first types of detectors–a crystal.

The crystal detector of fifty years ago bears absolutely no resemblance to the frequency standard crystal we know today. Whereas the latter is a crystal of quartz, very accurately cut and mounted, the crystal detector resembled, to some extent, a small lump of shiny coke.

This material was actually galena, or lead sulphide. It was not just one crystal, but a crystalline structure. To make contact with the crystal, a fine wire was used to press against the surface. This could be moved around the surface of the crystal to find the best position. The wire assembly was known as a "cat's whisker"

Even though the cat's whisker and crystal were not forgotten, the invention of the thermionic valve led to their eventual demise. From the late 1920's radio receivers began to move away from the novelty stage, and crystal sets were left to the experimenters.

The invention of the germanium diode was the last straw as far as the crystal and cat's whisker were concerned but, rather strangely, created a mild revival for the "crystal set" itself. In one small package came all the features of the crystal detector, but with improved sensitivity and none of the disadvantages. Perhaps some readers remember how the fiddling cat's whisker would move at the slightest heavy footstep–just as England won the test match!

So it was that germanium diodes became the "crystal" in a crystal set. And they are used in sets other than crystal sets. Many transistor radios use diode detection in exactly the same way as in the crystal sets to be described.

A crystal set is interesting because it performs, at an elementary level, all the functions needed to receive a radio signal, and most of those performed by larger sets. Granted, it does not do all of them particularly well, but an understanding of what it does and where it fails provides excellent grounding for understanding more elaborate circuits.

It is not difficult to understand how a radio receiver processes a transmitted signal, at least at an elementary level. A first requirement is to understand the nature of the signal. This consists of a radio frequency "carrier" which is "modulated" by the speech or music we wish to transmit. The modulation is achieved by varying the amplitude of the carrier at the frequency of the signal. (Hence, amplitude modulation). Thus, if we wish to transmit a 1000Hz note we cause the carrier amplitude to vary 1000 times a second.

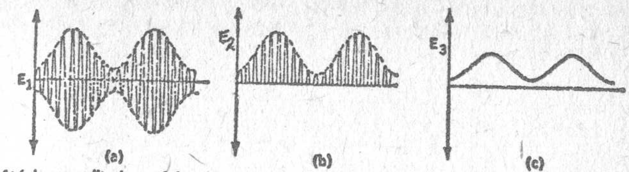
Reception of such a radio signal requires that we provide four basic facilities: (1) means to intercept a portion of the radiated signal, (2) a means to separate the wanted signals from unwanted ones, (3) a means to extract the audible ("audio") information from the radio frequency carrier, and (4) a means to convert the audio signals into sound.

For (1) we use an aerial or antenna system. Considered at its most basic this is simply two plates of a capacitor. Traditionally, one plate is the aerial wire and the other plate can take a number of forms. It may be a second aerial wire underneath the first (a counterpoise), the metal frame of a vehicle (car or aircraft) or the metal body of a ship and the surrounding water. Generally, the larger the plates and the greater the distance between them, the more signal will be intercepted.

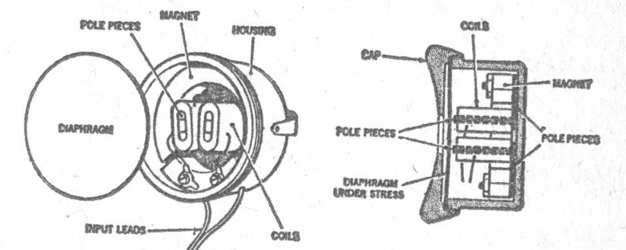
For (2) we use a tuned circuit or, in more elaborate sets, a number of tuned circuits. A tuned circuit consists of two components: a capacitor and an inductor. The exact manner in which is works is quite complex, and somewhat beyond the scope of this article. Suffice it to say that any given combination of inductance and capacitance will resonate at a particular frequency. We make it resonate at the frequency of the station we wish to receive.

In our crystal set the tuned circuit is coupled to the two sides of the aerial system. At resonance, it allows the maximum signal voltage to be developed across it. Signals at any other frequency will develop a lesser voltage. By varying the inductance, or capacitance, or both, we can adjust the resonant frequency and select the signal we want.

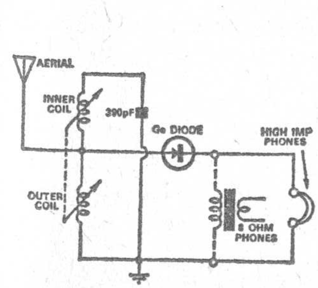
For (3) we use our much discussed "crystal" or the diode which has replaced it. It can be considered simply as a half wave rectifier. The diode clips off one half of the cycle, leaving either a positive or negative going waveform.



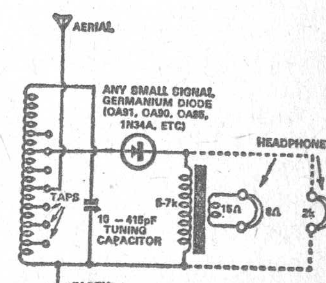
At (a) an amplitude modulated RF carrier, the dotted line representing the audio modulation. At (b) one half of the carrier has been removed by the diode and at (c) the audio signal derived from the outline of the RF carrier.



Construction of typical magnetic headphones. The permanent magnet provides an initial mechanical bias for the diaphragm, which then moves in or out according to the polarity of each half wave of AC (audio) signal applied to the coils.



The circuit of the Matchbox Crystal Set. Tuning is achieved by varying the coupling between the two coils.



Circuit of our crystal set. The main point with this version is the use of a speaker transformer with low impedance earphones.

Remember how we described an amplitude modulated signal? How the carrier strength (amplitude) varies up and down at the frequency of the modulating signal? Well, it is these variations in strength we wish to recover.

Since the carrier frequency is much too high for us to hear, neither can we hear any changes in its strength. As far as the ear is concerned each half cycle of the carrier occurs so rapidly after the previous one that it might just as well have occurred at the same time. As a result the two halves effectively cancel one another.

But if we remove one set of half cycles (with a rectifier) the remaining ones will all be effective in the one direction. While we still cannot hear the carrier frequency, we can create a new signal which is an exact copy of the changes in the carrier amplitude. This is our audio signal.

This brings us to requirement (4): a means to convert the audio signal into sound. For this we use a pair of earphones. In their most common form these are magnetic devices; a coil of fine wire on a magnetised pole piece is mounted close to a thin metal diaphragm. When a varying current flows through the coil it causes the diaphragm to vibrate in sympathy with it. This vibration we hear as sound. This is necessarily a much simplified explanation of the earphone; also other types operate on quite different principles.

But it is not hard to see how a series of RF pulses, all operating in the same direction, will behave when applied to such a device. Each pulse will try to move the diaphragm, and will succeed to some extent. Each following pulse will have the same effect and, because they occur so rapidly one after the other, each will reinforce the previous one. The inertia of the diaphragm is too great to allow it to respond to the gaps between pulses but not so great that it cannot respond to the relatively slow variations in the strength of succeeding pulses.

As already explained, tuning the set involves adjusting the resonant frequency of the tuned circuit. There are three ways of doing this–adjusting the capacitor and leaving the inductor fixed, adjusting the inductor and leaving the capacitor fixed, or, in some cases, adjusting both the inductor and capacitor.

Most readers will be familiar with tuning capacitors – a device with two sets of plates, which can be adjusted so that the area they have in common changes. When the plates are fully closed ("in mesh") they provide the maximum capacitance obtainable (usually about 400 picofarads). Conversely, when they are wide open they are at minimum capacitance (usually about 10 picofarads).

Instead of varying the capacitance we can vary the inductance, and there are a number of ways of doing this, which we will discuss in greater detail later.

But now, let us look at our most popular crystal set. This one has become our "standard" model, because it is about the simplest and easiest to make. The parts involved are readily obtainable from either

the junk box or your normal parts supplier. You should be able to "scrounge" some of the parts, at least.

For example, you should find a tuning capacitor in almost any discarded receiver–do not worry if it has more than one section–it is still quite useable, as we will explain.

The only item you may have trouble procuring is the headphones. The circuit calls for 2000 ohm (or higher) types, but there are not many of these around these days. Many readers may not be willing to pay at lot for a set of headphones which, we agree, have strictly limited value. Also, (as many of our older readers will remember) high impedance headphones were never particularly reliable.

Our solution is to use a set of low impedance (hi-fi type) headphones. The cheapest of these are about the same price as the high impedance types, but have much more use. They are not likely to be stored away as soon as the project is finished.

The trick is to use a speaker transformer between the crystal set and the headphones. We used a 5000 to 15 ohm type.

Again most valve amplifiers and radios will have a speaker transformer, and the primary impedance will seldom be less than 5000 ohms. It is best to use a type which has a secondary impedance close to that of your headphones, but do not worry too much about this.

The first headphones we tried were an expensive pair. The individual phones were connected in series to give the best load impedance, but this does not matter all that much. (Normally, each 8 ohm phone is driven from a separate stereo channel.)

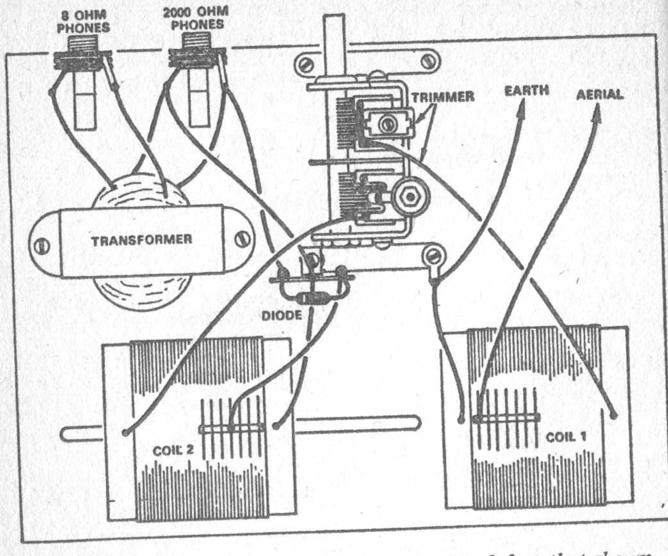
We also tried a pair of cheap stereo headphones–the cheapest we could find. While no one would pretent that these sound anything like as good as a pair costing ten times as much, in terms of sensitivity and for the very simple role we used them for they compared quite favourably. (They still sound a lot better than most of the old fashioned 2000 ohm types.)

The headphones are easily arranged with the voice coils in series. Take note of the headphone plug (usually a 6.5mm jack plug). You should see three distinct sections–the tip, then a ring of insulation, another band of metal, another ring of insulation, and finally the main metal body of the plug. Disregard the main metal body, and make the receiver connections to the tip and first band. It is easier to do this using a suitable socket. These connect to the "hot" side of both voice coils, effectively connecting them in series.

With a good aerial, this set will give quite reasonable volume in the headphones. With an exceptionally good aerial, results are outstanding.

Our aerial is exceptionally good! On top of the building, 16 floors up, there is a tall radio mast to provide communication with our many cars. From the top of this mast we have an aerial which runs right down to our 12th floor laboratory.

With this aerial, the volume obtainable from the crystal set is positively deafening using either the eight or 2000 ohm phones. Because it was so loud, we tried connecting a speaker to the transformer. It was loud enough to hear clearly across the laboratory!



The layout of the Deluxe Crystal Set is not critical, but that shown here is a logical one. The coil on the left is the movable one, sliding in the slot shown. Refer to the front panel on the previous page for terminal and jack positions.

We do not expect readers to be able to duplicate our aerial system, but with a good aerial close to the transmitters, some readers may obtain enough power to drive a speaker. If you want to try this, keep the following points in mind:

Use the largest speaker you can find. Contrary to popular belief, a large speaker is not harder to drive than a small one. Rather the larger one will normally be many times more efficient.

Now that we have explained how it works, we can get down to building the actual device. The best place to start is the coil.

You will need approximately 15–20 metres of 22 or 24 SWG enamelled copper wire and a stiff cardboard mailing tube, approximately 5.5cm diameter. If thin wall cardboard tube has to be used, it would be wise to give it one or two coats of clear enamel to stiffen it.

The tube should be long enough to allow easy working–say 15cm or so. It can be trimmed after the coil is completed. Incidentally other non-metallic materials can be used for the former, such as a plastic bottle.

Start by drilling two 1/16 holes, close together, near one end of the tube. Pass about 15cm of wire through one hole then the other, several times, to provide a secure anchorage. Then wind on five turns (either direction, it doesn't matter) and make a tap. This is to be repeated every five turns.

The easiest way to do this is to wind the tap turn over a match. The match can be pushed up the coil as the turns progress. While we used ten taps on the prototype, we recommend seven. We found that only seven of the taps are useful–and it is easier to wind without taps.

After the seventh tap (35 turns) wind on another 35 turns, making seventy in all. This number will be adequate for coil formers close to or the same as ours, but may have to be changed slightly for readers who (a) use different size formers or (b) have a station close to either end of the band.

If the coil cannot pick up stations at the high frequency end of the band, take a few turns off. If it cannot pick up stations at the low end, add a few turns.

As can be seen the start, taps and finish are all in one straight line. To finish the coil, drill another pair of 1/16in holes, and pass at least 15cm of wire through them, as before. This wire goes vertically through the coil centre, and emerges through another hole near the bottom. This makes a neat coil and keeps the windings tight.

We used a small tagstrip to mount the diode and provide tags for the headphones connection. A flying lead makes connection from the detector to the tap required. The same system is used for the aerial connection.

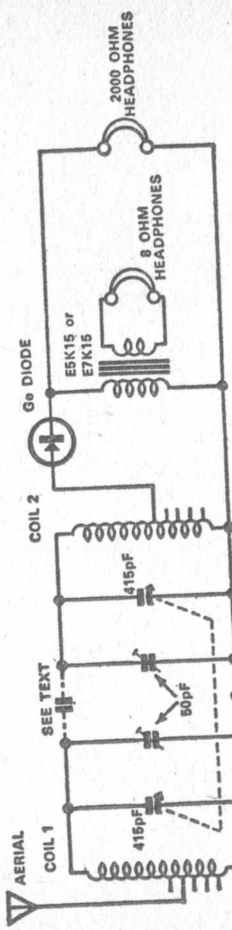
One the same tagstrip, connections to the impedance transformer are made. Separate tags are used for low impedance and high impedance headphones.

There are a number of ways of fastening the coil to the baseboard, but avoid using metallic parts. Metal near the coil may not only change its inductance, but could effect what is called the "Q". The Q is a measure of the quality of the coil–and it should be as high as possible for optimum results.

We glued our coil former directly onto the baseboard. Aquahere or a similar wood glue does the job nicely. The aerial and earth terminals are screwed directly into the baseboard, with a solder lug under each. A single length of stiff tinner copper wire runs from each terminal to its respective connection.

The tuning capacitor and impedance transformer, can be mounted so that they share a common mounting hole–a convenient arrangement, as we will explain. All parts are screwed into the baseboard using number 4 self-tapping screws.

Because the capacitor and transformer are connected, the connections from the earth terminal need be connected only to the transformer case, simplifying connection. The components on the tagboard are connected by a short length of wire to the capacitor frame.



Circuit of the Deluxe Crystal Set, showing the two tuned circuits. The capacitor (dotted) between them may be needed only in some circumstances. The trimmer capacitors are used to "line up" the two circuits at the high frequency end of the band.

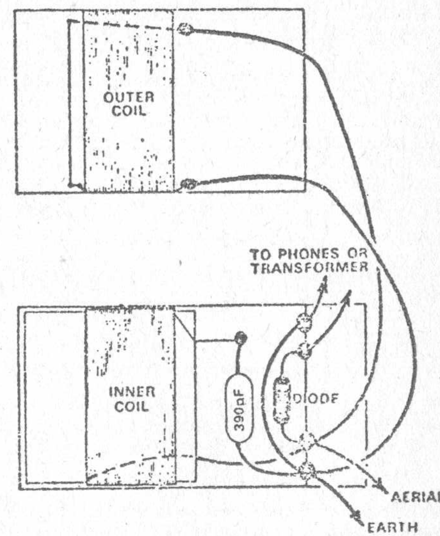
We fitted an extra three lug tagstrip on the baseboard. One lug connects to the aerial terminal, and another to a tap on the coil. This was for an experiment which we will discuss later. For the present, the two lugs are simply joined together.

Use of the crystal set is simple. It does, however, depend on a good aerial and an equally good earth. Remember that there are no power connections, so the set is not earthed through the power cord. You must provide an external earth, preferably a water pipe or a metal stake driven well into moist ground.

Connect the aerial and earth to the terminals, the aerial terminal to a tap about midway up the coil, and the diode to the one below—towards the earthy end. Connect your headphones, and you should hear signals when you tune the capacitor. If not, try changing the taps.

The best aerial and detector taps will be found by experiment. The higher taps will give the loudest signal, but poor selectivity, and vice versa. A compromise is necessary depending on your location, size of aerial, etc. Use the highest taps which will allow you to separate the stations.

This, then, is our basic crystal set. Next we will describe a number of variations on the crystal set theme; each one designed to exploit one or other of the novel characteristics of the "simplest radio set"



Layout of the Matchbox Crystal Set. Aerial, earth and phone connections are mounted on the end of the matchbox tray.

First, let us briefly recap on what we said previously: A basic radio receiver consists of an aerial (and earth) to receive the signals; a tuned circuit to separate the wanted signals from all the other signals in the radio spectrum; a detector to extract the audible signal from the radio signal, and an earphone—to convert the audio signal into sound.

The aerial, detector and earpiece were discussed in the first part of this article. There is not much (at least in this type of receiver) which one can do to improve them. However, the tuned circuit can take a variety of forms–and it is this with which we are now concerned.

The basic crystal set was tuned by varying the capacitance. Our first set now uses the same method, but the other uses variable inductance. We will explain more about this later.

Our first set is similar in some respects to the first design, but has one vital difference: instead of a single tuned circuit we now have two: two coils and two tuning capacitors.

Why two tuned circuits? A serious limitation with any crystal set is its poor selectivity. The reason is simple; a single tuned circuit just cannot provide sufficient discrimination between the wanted and unwanted signals. This is aggravated by the fact that the single tuned circuit will be loaded by both the aerial and detector circuits connected to it. (More about "loading" in a moment.)

It is for this reason that larger sets use several tuned circuits (plus other tricks) in order to achieve adequate selectivity. If the output of one tuned circuit can be fed into a second one, resonating at the same frequency, the rejection will be greatly improved.

It is a similar process to purifying a liquid. The first process gets rid of most of the impurities, but some are able to sneak through. The second process is able to get rid of most of those missed by the first, but there will still be some which manage to find their way through. This process could go on and on, but there are limitations. At each purifying (as at each tuned circuit) some of the wanted material is lost. Therefore, there is a limit to the number of stages one can have.

Unfortunately, feeding the output of one tuned circuit directly into a second one is the least desirable procedure. If these two circuits are too intimately coupled they cease to function as separate circuits, and behave more like a single circuit. On the other hand, if they are not adequately coupled, there will be a serious loss of signal.

This problem is overcome in larger sets by interposing amplifying stages between the tuned circuits, which also effectively isolate them. Since we have no such stages, we must select a compromise order of coupling.

When a tuned circuit is at resonance, the wanted frequency builds up voltage and current to a maximum, while the signals of other stations are largely rejected. Because the voltage and current are changing, a changing electro-magnetic field is set up around the coil.

If a conductor is placed in a magnetic field, a current is set up in the conductor. If we place another coil so that it is in the magnetic field, it will have a current set up in it. This is a transformer action)it is the same effect which allows a transformer to step voltage or current up or down from another voltage or current.

Maximum transfer from one coil to the other occurs when the coils are oriented in the same direction (either end to end or alongside one another) and are close together. But, as we have seen, it is not always desirable to have maximum coupling between the coils.

For this reason we have made the coupling variable, by arranging one coil so that it can slide along a slot cut in the baseboard. This is quite a simple method of altering coupling.

The situation may arise that, no matter how close the coils are placed, there is still not enough coupling for reasonable listening. In this case, a small amount of capacitive coupling may be added by connecting a 4.7pF capacitor between the tuned circuits. (See circuit.) Note that 4.7pF will be about the maximum value–it will probably not require this much.

The coupling is not the only item which needs adjustment. Note the trimmers on top of the tuning capacitor. These are used to adjust the individual tuned circuits so that they both resonate at the same frequency for a given dial setting. Adjustment should be made at the high frequency end of the band.

We used two different types of trimmer, mainly to show what to look for on discarded sets. The first is a compression type, adjusted with a screwdriver, while the other is a concentric type, screwed in by hand. Any other type may be used. Simply solder them between the fixed plates of the capacitor and the frame.

As in the first part of this article, a high impedance to low impedance speaker transformer is included. Most old valve radios will have a speaker transformer with an impedance of 5000 ohms or more–these are quite suitable.

Earlier in this discussion we used the term "loading" in regard to the tuned circuits. The selectivity of a tuned circuit is effected quite markedly by the external circuits we connect to it; such as the detector and earphones, and the aerial. The more intimately these are coupled to the tuned circuits the more they load it, and the worse the selectivity.

This is the reason for the taps on the coil; they allow us to select the best order of coupling. The tap giving the smallest number of turns produces the lightest loading and the best selectivity, but gives the weakest signal. Then conversely, the tap with the largest number of turns gives the strongest signal, but the worst selectivity.

In any given situation the best tap will depend on such factors as the size of the aerial, strength of the signals, number of stations available, etc. Thus the user has to make his own selection, possibly even changing them to receive different stations.

Construction of the set is not too involved – anyone with basic woodworking tools could manage it. In fact, some may like to treat our construction as a starting point, and enclose the crystal set in a wooden case.

We used a plywood base board, measuring 200 x 140mm, with a Masonite front panel measuring 200 x 120mm. The front panel is glued and nailed to the baseboard. Placement of components is not critical, as long as you place both coils in a straight line. The slot for the moving coil is 115mm long, and starts 10mm from the side of the baseboard, 30mm from the back.

Lightly centre punch marks along the slot line every 5mm, and drill them with a 1/8in drill. Then elongate each hole so that it meets its neighbour. Finish the slot with a rat tail file.

Both the moving and stationary coil are secured with 1/8in Whit screws and nuts. (The amount of metal is too small to have any serious adverse effect.)

When mounting the moving coil leave enough wire to allow it to travel the full length of the slot. Similarly for the lead from the taps.

Longer nuts and screws are needed for the moving coil, as this has two nuts on each screw. Watch that the shaft of the tuning the heads from coming through the slot, washers must be placed on each screw before insertion. We used washers between the nuts and cardboard former, to prevent undue stress on the cardboard.

Because the screwheads protrude below the bottom of the baseboard, rubber feet are screwed to the four corners to provide clearance.

Other components (gang, transformer) are mounted with no. 4 or 6 self-tapping screws. Watch that the shaft of the tuning capacitor emerges in the middle of the front panel–it would be wise to make the first. The transformer mounts between the moving coil and the headphone sockets.

A 3-lug tagstrip (1-E-1) is mounted underneath the right hand side screw holding the gang. On this is mounted the detector diode.

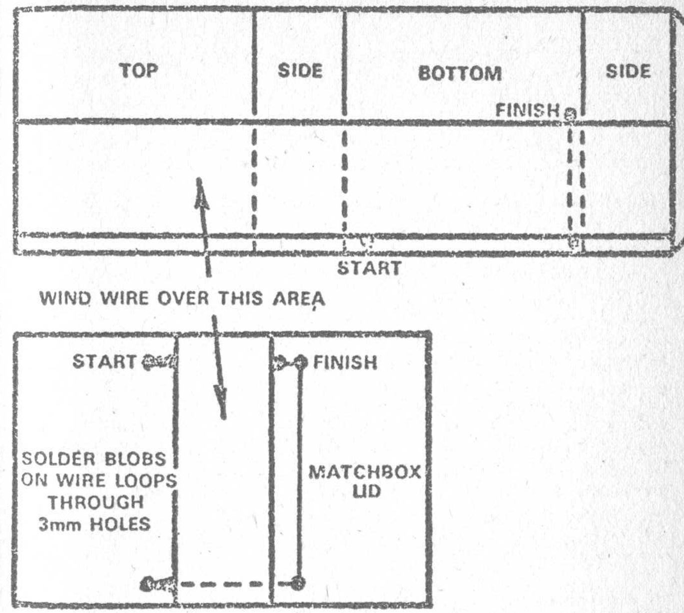
On the front panel, two terminals (red and black) provide aerial and earth connections, with two sockets (one stereo, one mono) for high and low impedance phones. The dial is a push on "handspan" dial suitable for ¼in shafts. As many older tuning capacitors have 3/8in shafts, an adaptor may be necessary. These should be available from your supplier, along with the handspan dial.

The high impedance socket is optional. Its place may be taken by a tagstrip, if you are sure you will not be using high impedance phones. The impedance transformer connects between the high impedance socket or tag (primary winding–red and blue) and the low impedance socket (secondary winding–green and black).

The front panel is made from a piece of thin cardboard, lettered with "Letraset". The cardboard was stuck to the Masonite with wood glue.

Lettering of the stations is best left until the set is complete. When the wiring is completed, check for errors. If you are sure there are none, connect the aerial and detector leads into the highest tap on the coil. This should ensure that at least something will be able to brute-force its way through.

If stations are well separated, leave the taps where they are. But we imagine there will be little or no difficulty on this high tap. Even moving the coils wide apart may not help much. Move the aerial and detector taps to about half way down, and check. Keep moving down until you are able to separate each station well. Then tune to a high frequency station and adjust both trimmers for maximum volume. Once the trimmers are peaked, try moving the coil back and forth.



The upper drawing is an exact size template for the coil former to mount in the tray. Lower drawing shows lid holes and winding.

Incidentally, the only way to make sure alignment is correct at the low frequency end is to ensure that the coils are identical. It is difficult to provide adjustment on either coil to correct this. So take care when winding the coils.

As you learn to use the crystal set, you should find the right combination of taps and coupling give optimum results from all your favourite stations.

The next set is quite novel–believe it or not, it is build in a matchbox!

It contains just two commercial components–a diode and a small fixed capacitor. The other two major components are a pair of home-made coils. One coils is mounted inside the matchbox tray and the other is wound over the outer portion of the box. To tune it, all you do is try to get a match out of the box–in other words, move the tray. This tunes in the stations!

Why build a crystal set in a matchbox? Well, why not? Apart from its novelty and simplicity, this little crystal set is capable of a good performance. Connected to a good aerial and earth, it will perform just as well as the "straight" crystal set described first, and nearly as good as the deluxe model just described.

The operation of this set is based on the fact that the inductance of one coil can be changed by another coil in close proximity. Because the coils are simply connected in series, it might appear that the resonant frequency of the tuned circuit would be governed only by the capacitance across the coils.

This is only part of the story. Because the coils can be moved relative to one another, we have a situation where the inductance of one coil can "buck" or oppose the inductance of the other coil. By the same token, the opposite is true. By physically turning one coil through 180 degrees, the inductances can be made to assist, or add to one another. In practice, more range is obtained by opposition than addition.

By planning the size of the coils, and the amount of fixed capacitance across them, we can make them ocver the broadcast band. The natural resonant frequency of the inside coil will be around 750Hz. By placing the outer coil on one way, down to 530KHz is covered. Turning this coil around will cover the other end of the band–up to 1600kHz.

As with all other crystal sets described, this may be operated with 2000 ohm phones, or 8 ohm phones through a speaker transformer.

Construction of the matchbox crystal set could hardly be simpler. No woodwork, very little soldering and few components. You will need an ordinary matchbox (try to get one as new and strong as possible), some thin cardboard, some good paper or cardboard glue, a germanium diode, a 390pf polyester, mica or ceramic capacitor and around ten metres of 30 SWG insulated copper wire.

The first step is to construct the cardboard former for the inner coil. Using the pattern given as a template, cut a thin cardboard piece the same size, and bend where shown. Glue this and leave to set. While it is setting, you can wind the outer coil on the matchbox cover.

Where shown, drill two holes 3mm apart. Scrape the enamel off 50mm of wire and pass the end of this wire through the hole closest to the centre of the box. Pass it back out the other hold, and continue to loop it in this fashion four or five times. This will securely anchor the wire. Cut off any excess wire.

Now wind on the turns. These should be as tight and neat as possible. They should not be able to move when the job is completed. Wind

on 39 turns and, when these are completed, drill another two holes similar to the first pair, as close to the last turn as possible.

With a hot, clean iron, place a blob of solder over each of the loops. You will use these as anchorage points later.

Before glueing the former into the tray, you must perform minor surgery. If you look closely at a matchbox tray, you will see the end is made by folding the two sideflaps in and the bottom up and over these sideflaps. The bottom flat must be unfolded–this is used to pull the tray in and out–while the side flaps must remain in position as the anchorage points for all connecting leads.

Because unfolding the bottom flap reduces the strength, it is a good idea to give all flaps a liberal coating of glue before going any further. At the same time, another piece of cardboard, the same size as the extended flap, can be glued over this to give added strength.

Now the former can be glued in place. The former is glued as close as possible to the end of the tray opposite to the end we have been working on. When the glue is dry, you can prepare the components for soldering.

We have evolved a rather novel way to make connections and hold the components in place. In the end of the tray, we made four small holes. As you can see from the drawing, these are for the aerial, earth, and earphone connections. Through the "earth" hole, we passed one end of the capacitor lead, bent it 90 degrees vertically, then bent it again 180 degrees over the top of the tray and back down the inside. This was then squeezed hard with a pair of pliers to hold it in place.

The other three terminals were treated similarly. Where possible, component pigtails were used as the bend-over terminals. For the "earthy" phone terminal, a piece of tinned copper wire was bent over the flap, then along the bottom of the box to the earth terminal.

Connections to the terminals were made by drilling four holes through the tray underneath the wire terminals. Thin leads pass up through these holes and solder onto the wires. The advantage of the crimped wire terminal may now be seen. If we relied on solder connections alone inside the matchbox, when we soldered the wires to the terminals, the solder inside might come unstuck. By mechanically holding the components in place, soldering can be carried on without this risk.

The outer coil is connected by means of flying leads to the aerial and earth terminals. These flying leads are cut from thin hookup wire (we used 5/0076), and soldered to the "solder blobs" on the matchbox lid.

You may note that after we soldered the leads to the outer coil, we wrapped a piece of insulation tape around the box. This is to prevent undue stress on the solder joints.

Using this set is child's play–simply move the inner tray in relation to the outer cover, and you should find stations coming and going! As with the other sets, 2000 ohm phones may be used directly, or 8 ohm phones through a suitable transformer.

6 EXPERIMENTAL CIRCUITS

Those experimenters who feel that the advent of the mass produced printed wiring board has robbed the home builder of his individuality, will welcome the latest innovation in this field. Called Veroboard, it is a pre-punched, pre-etched board with a uniform hole and wiring pattern easily adaptable to almost any circuit configuration. In this chapter, we show how it can be used in a number of interesting beginner projects.

The physical form of electronic devices has undergone quite a revolution in the past ten years or so. Not so long ago the popular and almost only concept of radio and TV sets, amplifiers, and industrial electronic gear, was a metal chassis on which were directly mounted the major components; power transformer, tuning capacitor, valve sockets, etc. Minor components were supported either between the major ones or on terminal lugs mounted on insultated strips. Additional interconnection was by individual lengths of insulated hookup wire.
The first hint of a change came with the development of the printed wiring board; a sheet of copper clad insulating material on which was etched, by a photo-litho process, a complete wiring pattern in the copper film. The new concept offered many advantages; low cost for large quantities, uniform quality free from wiring errors and, where other components permitted, compact construction.
This last possibility did not make much impact initially, except in special applications, for we were still in the days of the valve and the valve exclusively. Nevertheless, components specially designed for printed wiring began to appear, including valve sockets for soldering directly into the boards, and "single ended" minor components with both pigtails at one end to facilitate the new form of mounting.
Then, with the introduction of the transistor, and the rapid development of miniature components to go with it, the revolution was almost complete. For miniature equipment at least, the chassis virtually ceased to be, being replaced by what really amounted to a glorified terminal strip, albeit a highly specialised one.
Which was fine for the manufacturer, but rather left the design engineer experimenter, home constructor, or anyone else who wanted to make "one off", out in the cold. Printed wiring was ideally suited to mass production, once the design had been finalised, but offered no equivalent in a hand made form, such as had been possible with the old style construction.
Anyone who wanted "one off", therefore, had either to revert to the older form of construction, with all its disadvantages, or make what use he could of such printed wiring patterns as were already in existance. The latter was useful where only the value or type of component was to be changed within the same circuit configuration, but obviously was of little use beyond this.
There have been several approaches to this problem. One was to simplify the printed board process to the point where it became practical to make "one off", usually by hand painting the pattern on the copper with a suitable resistant paint, then etching in a simple bath. While useful up to a point, it is better suited to second stage working, such as copying a pattern already worked out, but for which no commercial board is available. It also suffers the disadvantage that, without some means of image reduction, it is difficult to prepare a complex pattern directly on the copper.

A better approach is the sytem using insulating board similar to that used for printed wiring, carrying no copper pattern, but pre-punched with rows of holes, rather like the arrangement used in a Meccano set. Any hole may be made in to a terminal point by simply inserting an eyelet and crimping it in place, these points then being joined by short lengths of tinned copper wire.
In practice, the idea works very well and, by deliberately arranging the wiring so that no leads cross, the first step is taken toward a layout suitable for a conventional printed board, should this be the ultimate aim. In any case, it puts the individual worker on very nearly equal terms with mass production techniques.
More recently, another system has appeared on the market, and this too appears to offer the individual a convenient means of "one off" production. Like the previous system it uses a sheet of insulating material carrying a pattern of holes - there are several different hole centre dimensions available - but goes one step further in that it is already equipped with a copper pattern on one side, consisting of parallel strips running along the adjacent rows of holes.
Thus, all the holes in each row represent a common circuit, running, if necessary, the full length of the board. However, it is quite a simple matter to break the copper strip at as many points as may be desired, making it into a number of short runs, each connecting together as many holes as required. A special tool is available for cutting the copper strip, but a 1/8" drill makes a very good substitute for the home constructor.
A variety of other accessories are available, including terminal pins, edge connectors, Varicon contacts, etc., and these would particularly interest the advanced worker. Initially, however, the home constructor will find that he can tackle a wide range of construction projects with nothing more than a piece of board and the ordinary workshop tools.

1 - SINGLE STAGE AMPLIFIER FOR CRYSTAL SETS

This one stage audio amplifier should be of particular interest to those who have a simple crystal set and wish to hear either local or distant stations with increased volumes in their headphones.
Firstly, let us consider the advantage of a crystal set followed by an audio stage. The first, and most obvious, is the amplification of signals to a more comfortable listening level. The second, although not so obvious is the improvement in selectivity which may be obtained by reducing the aerial coupling which is achieved by tapping the aerial further toward the earthy end of the coil.
This reduces the load on the tuning coil, thus enabling it to achieve a higher "Q", the major factor governing selectivity. Since the headphones also load the coil, a further improvement should result by reason of the higher input impedance of the amplifier, compared with most headphones, particularly the low impedance types. If the gain allows tapping further down the coil, we will be that much better off again.
At this point it may be useful to define what is meant by high and low impedance headphones. Those referred to as "high impedance" types have a DC resistance of about 2,000 to 4,000 ohms, and an impedance of about 7,000 to 20,000 ohms, depending on construction. The so-called "low impedance" headphones are the most common types available from disposal dealers having a DC resistance of a little more than

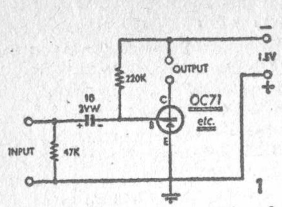
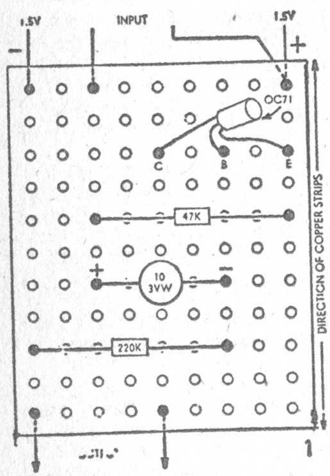
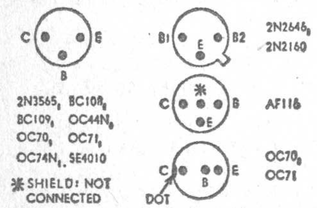


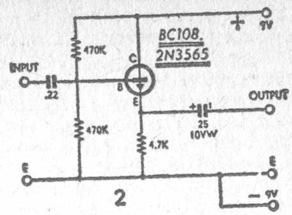
Fig.1

1 OC41 transistor.
1 47K ½ watt resistor.
1 220K ½ watt resistor.
1 10uF 3 volts working electrolytic capacitor.
1 Piece sample Veroboard 1¾in x 1⅝ in, 1 1.5V battery, signal and battery wires, sleeving.





This diagram illustrates the collector, base and emitter connections for the transistors used in these projects.



1 BC108 transistor.
2 470K ½ watt resistors.
1 4.7K ½ watt resistor.
1 .22uF capacitor.
1 25uF 10 volts working electrolytic capacitor.
1 piece sample Veroboard 1¾in x 1-3/8 in, 1 9V battery, signal and battery wire, sleeving.

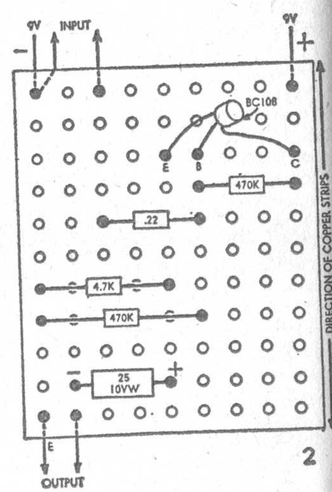


Fig.2

100 ohms and an impedance of several hundred ohms.
This circuit is about the simplest amplifier possible, in which the transistor has a grounded emitter and the collector voltage is supplied from a single pencil torch cell of 1.5V. Bias current is provided by the 220K ohm forward bias resistor and the signal is fed to the base via a 10uF low voltage type electrolytic capacitor. The headphones are connected in series with the transistor collector and negative 1.5V.
A marked improvement in level may be obtained by reducing the 220K resistor to about 68K when using low impedance headphones.
The transistor used is an OC71 although it is likely that other suitable types may be on hand. A few typical types are as follows: OC70, 2N406.
Construction of this amplifier on a sample piece of Veroboard is very simple and straightforward, the photograph and drawings providing all the information required regarding component location and solder points.

2 - AN IMPEDANCE-MATCHING STAGE

Our next project is a one transistor impedance matching device which has a number of useful applications in audio circuitry.
The matching of high impedance sources to the input of valve circuits is reasonably easy to achieve by design, and in fact, input impedance up to the order of 10M are possible as long as the valve operating conditions are carefully watched. In the case of transistors, however, it is not so easy, and high input impedances are not a natural characteristic. Therefore, it is not so easy to match high input impedance sources to transistorised circuits as it is to valve circuits.
To overcome this problem an impedance matching device is required. This is where our little unit finds its use, for it is capable of matching a high source impedance to a low input impedance. This does not imply that it can only be used for matching into transistorised circuits, because not all valve circuits have high input impedances, and it can be used equally well for matching into low impedance input valve circuits.
The circuit, using a BC108, or 2N3565, NPN transistor, is connected as a common collector, emitter follower, and operates from a 9V supply. The voltage gain of this device is less than unity, and therefore, does not amplify. For this reason, there must be a sufficiently high level of signal available from the source being matched to ignore the lack of gain of the circuit. The signal is applied to the base via a .22uF capacitor, and the output extracted across the 4.7K emitter resistor via a 25uF capacitor.
The input impedance of this circuit is about 220K. Frequency response is better than plus or minus 2dB between 20cps and 20KC. With a 10K load in the output, a signal input level of 1.5V can be handled without the circuit clipping, this effect actually occurring at approximately 1.7V. With the output load reduced to 1K, clipping occurs at an input level of 350mV.
This project is not at all difficult to build, and, as with all the others in this series, should prove interesting to both beginners and experienced constructors alike. The photograph gives a general idea of the layout, whilst the drawings give precise details of both the component layout and underside copper strip soldering points. One check that the circuit is functioning correctly is to measure the total battery drain, which should be approximately 0.9mA.

3 - TWO-STAGE AMPLIFIER WITH RF PROBE

This project, a two stage audio amplifier with volume control and supply switch, is a "big brother" to the one stage audio amplifier for crystal sets described elsewhere in this series. It is suitable for a wider range of applications, as we shall see.

One use for this amplifier is that of tracing signals in audio circuits, the input of the amplifier being connected across signal points in the circuit being examined. This enables the user to determine the presence, or otherwise, of signals at any given point.

For example let us assume that it is desired to locate a fault in an audio amplifier. The input of the test audio amplifier can be connected to the input of the first stage of the equipment being tested, where a signal should be heard if all is in order. This being so, the signal tracer can then be connected to the input of the second stage, and so on towards the loudspeaker until the signal cannot be heard. When this has been determined we know that the fault lies between that point and the last testing place where the signal was heard. A thorough examination of the circuit between these two points should reveal the faulty component.

It is also possible to trace distortion in audio equipment using this approach, the signal tracer indicating at which point in the circuit the distortion is occurring.

When the amplifier is to be used in this application an isolating capacitor of about 1uF, 400V, should be connected in series with the active input terminal (top of the 10K pot.). Additional isolation can be provided by adding a resistor in series with capacitor, say 10K or as much higher as can be tolerated without serious loss of gain.

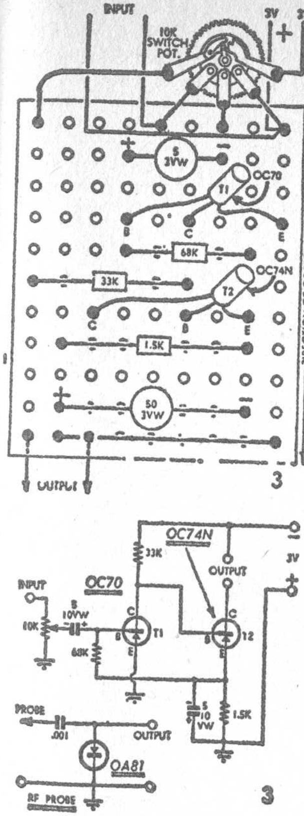
The sensitivity of this amplifier is such that it may be connected directly to tape heads, microphones and pickups to check their outputs. However, there are no equalisation circuits in this amplifier and, where equalisation is necessary due to the recording characteristics of either tape or disc or where mismatch between pickup or microphone and the amplifier input suppresses the bass response, the overall balance may sound "thin" or "tinny".

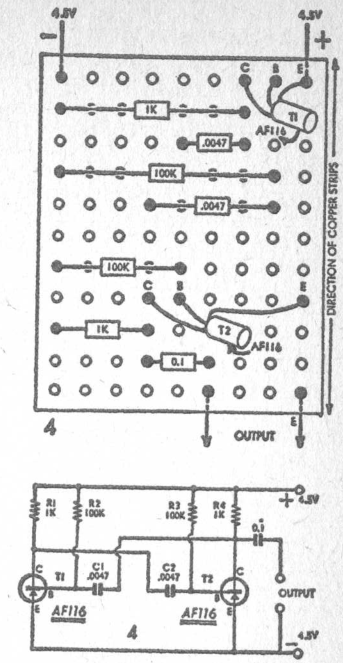
Most magnetic headphones can be used with this unit, including both low and high impedance types, although the low impedance types would be nearer a correct match for the output stage. Crystal earpieces are not suitable and should not be tried.

This circuit has been fully proven in earlier projects and uses an OC70 and OC74 combination of transistors. The input signal is developed across the 10K potentiometer which serves as an input level or volume control. It is then applied to the base of T1 via a 5uF capacitor, amplified, and then directly coupled to the base of T2. The further amplified signal is then used to drive a pair of headphones.

One of the problems of simple circuits of this kind is thermal stability. Transistors are noted for their sensitivity to changes in ambient temperature and their tendency to "thermal runaway". To compensate for this, most transistor stages involve resistor and/or thermistor networks so arranged that an increase in collector current is offset by an automatic decrease in the forward bias.

Our circuit uses direct coupling between the two stages, the first operating as a low level amplifier and the second as a power amplifier. By reason of the direct coupling the temperature co-efficient of each transistor is made dependent on the other.





2 AF116 transistors.
2 1K ½ watt resistors.
2 100K ½ watt resistors.
1 0.1uF capacitor.
2 .0047uF capacitors.
1 piece sample Veroboard 1¼in x 1-3/8 in, 3, 1.5V pencil light batteries, signal and battery wires, sleeving.

Fig.3

1 OC70 transistor.
1 OC74N transistor.
1 Miniature 10K switch potentiometer.
1 1.5K ½ watt resistor.
1 33K ½ watt resistor.
1 68K ½ watt resistor.
1 5uF 3 volts working electrolytic capacitor.
1 50uf 3 volts working electrolytic capacitor.
1 piece sample Veroboard 1¼in x 1-3/8 in, 2 1.5V pencil light batteries, signal and battery wires, sleeving.

RF PROBE

1 OA81 rectifier.
1 .001uF 350 volts working capacitor.
1 pen light torch or ball-point pen (see text), screened wire, earth lead wire and crocodile clip.

Fig.4

The forward bias on the base of T1 comes from the emitter of T2. Transistor T1 draws collector current through its 33K load and the same potential which exists at the collector is applied to the base of T2. The effective forward bias on T2 is the difference between this potential and the potential developed across its own 1.5K emitter resistor.
In this circuit, any increase in the average collector current of T2, due to temperature rise, will produce a corresponding increase in potential across the 1.5K emitter resistor. This will increase the negative bias at the base of T1 producing an increase in the collector current. And T2 base voltage shift towards, tending to offset the original. This decreases the voltage between T1 collector and chassis and, by reason of the direct coupling, also between T2 base and chassis. Thus the bias on T2 is reduced and the collector current reduced. However, it would require a much higher ambient temperature than normal before the power output was reduced by a significant amount.
The temperature rise in T1 is not so important, since it is an amplifier rather than a power output stage, and operates under much less critical conditions.
As it stands, this circuit can only be used for tracing audio signals. In order to trace modulated RF signals it is necessary to preceed the amplifier with a detector or demodulator. Such a device is simplicity itself, and consists of only two components, as shown in the circuit diagram. The RF signal is applied across the OA81 diode via a 1,000pF capacitor, and, with the circuit connected to the amplifier, the 10K input potentiometer acts as the diode load. Such a piece of equipment is called an RF probe.
As our circuit contains only two components, it is possible to construct it in a number of ways as a small and handy item. Probably the most convenient method is to house the capacitor and diode in a hollow pen-like holder, such as the plastic case of a ball-point pen. Suitably cleaned, and with the components soldered to it, the metal part housing the actual ball-point becomes the probe tip with which to pick up signals whilst a flying lead may be taken away and connected to chassis, thus giving a compact and easy to handle unit. The same idea could also be used with a pen light torch case.
The combination of RF probe and amplifier allows RF signals in radio receivers to be traced by merely connecting the probe between any desired point in the circuit, and chassis. In most cases it should be possible to trace the RF signal path for any discontinuity up to the output of the converter. In fact, it is possible to detect strong local stations at the input of the converter.
As can be seen from the photograph, the components comprising the amplifier are easily accommodated on a piece of sample Veroboard. The drawings illustrate the layout used, and the soldered connections necessary to form the circuit in conjunction with the copper strips and components.
The circuit is connected to the negative supply of the battery via the switch on the potentiometer. The positive supply lead is taken straight to the board.
A rigid mounting for the potentiometer is achieved by soldering a piece of $\frac{1}{4}$" long tinned copper wire to each of three tags, these extensions then being soldered into their respective holes on the board. The remainder of the construction is perfectly straightforward.

Nevertheless, a test with this simple instrument would be a most instructive experiment.
This multivibrator is of the free running type, and a look at the circuit diagram will show that the collector of T1 is capacitivaly coupled to the base of T2 and the collector of T2 capacitively back coupled to the base of T1. This cross coupling results in a circuit that will oscillate due to positive feedback, oscillation being sustained because the loop gain is greater than unity.
The actual operation of this circuit is that one transistor is cut off while the other one conducts fully, this condition alternating between them at a rate determined by the vlaue of associated components.
In order to understand how the multivibrator works, it is necessary to appreciate that the method of connection produces a condition whereby any change in collector current in one transistor, will result in an opposite change in the other transistor. Thus, if one collector current is increasing the other one will be forced to decrease and vice-versa.
When voltage is initially applied to this circuit, and due to very small differences in component value, one transistor tends toward full conduction and forces the other toward cut-off. Because this is a regenerative loop circuit, this action takes place extremely quickly culminating in one transistor being cut off and the other conducting fully.
However, this condition cannot be maintained, because the coupling capacitors can transfer only the CHANGES which occur at each collector, and not the steady state represented by either cut-off or full conduction. Once this point is appreciated we can follow the sequence of events through a complete cycle.
Assume that T1 is cut-off and that T2 is conducting fully. This condition makes the collector side of C1 less negative than the base side, which causes C1 to charge and drive the base of T1 negative, thus bringing it into conduction from its cut-off condition. This is regenerative, causing T1 to conduct fully and T2 to be cut off. To complete the cycle, C2 now charges driving the base of T2 negative, and the cycle is repeated but this time, in relation to the other transistor. The circuit continues subsequent cycles in this manner, and therefore oscillates by switching from one transistor to the other.
The pulse repetition frequency (prf), or speed of switching between the transistors, is determined by the time it takes C1 to discharge through R2 and for C2 to discharge through R3, and therefore the time constants of these components. Due to base leakage currents and there being a discharge path through the bases of the transistors for C1 and C2, temperature also has some bearing on the prf.
Using the values shown in the circuit diagram our multivibrator oscillated at approximately 7KC. By feeding its output into the aerial of a communications receiver we found that the frequency range covered was from the broadcast band to 20 MC, after which, the signal dropped off rapidly.
If the values of C1 and R2 equal those of C2 and R3, the mark/space ratio or the on and off times of the square wave output, are equal and would be as shown in the circuit diagram. It is possible to alter this ratio by unbalancing C1, R2 and C2, R3 but if this unbalance is made too large the circuit will not function as a multivibrator.
The construction of a multivibrator on a sample piece of Veroboard is quite simple, as can be seen from the photograph which also shows the general layout used. The accompanying drawing of the underside of the

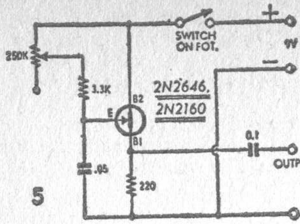
4 - AUDIO - RF MULTIVIBRATOR

In the following paragraphs we describe a free-running multivibrator, which, as well as being an intersting project to build, may also be put to a number of uses.
As a multivibrator produces an essentially square wave output, and it can be shown that a square wave comprises a fundamental sine wave plus odd order harmonics to infinity, the output of such a circuit is abundant in these harmonics.
In practice it is impossible to achieve a perfect square wave output so the number of harmonics produced is finite. Nonetheless, output wave shapes very nearly square are possible, and the harmonics from an audio frequency fundamental will extend well into the RF region.
Thus, the harmonic output of a multivibrator may be used for testing or fault-finding, in either radio or audio equipment. In this role, it is used as a simple signal generator and with its output connected to the input of the equipment being examined, will produce an audible tone in the loudspeaker, or headphones, if all is in order.
To trace faults in radio receivers and audio amplifiers, the best method is to start at the loudspeaker end of the equipment and inject a signal into the final stage. If a signal is heard in the loudspeaker, work toward the input, stage by stage, until no signal is heard. This shows at which point the equipment is faulty and a more localised and thorough examination around the stage should reveal the fault.
Square waves are also very useful for testing performance characteristics of audio amplifiers. If we start with a "perfect" square wave, pass it through an amplifier, then display it on a CRO, the resultant pattern will tell us quite a lot about the amplifier's behaviour.
Naturally, a perfect amplifier will reproduce our square wave exactly as it was generated, but this is unlikely in practice. However, good quality amplifiers will come very close to this ideal. In general, there are three main amplifier characteristics which our square wave will check; high frequency response, low frequency response and stability.
The frequency response may be only a rough check, since there are better through more time consuming, ways of doing this. The stability check, however, can be most important. Where an amplifier has poor high frequency response, the "corners" of the square wave tend to be rounded and an experienced observer can get quite a good idea of the degree of loss from the amount of rounding.
Poor low frequency response will be shown as an inability to preserve a level "top" to the wave, this being presented as an inclined plane. Once again, experienced observers can quickly deduce the approximate order of loss.
Even assuming that these faults do not occur, it is most likely that there will be some "ringing" present. This takes the form of a small damped oscillation at one or both "corners" of the square wave, and indicates a degree of instability, or tendency to oscillation which, while not enough to make the amplifier oscillate continuously, is nevertheless sufficient to seriously degrade its ability to handle sudden wave fronts, or "transients", which form a significant part of musical sounds.
Unfortunately, we need a considerably more refined square wave generator than this simple device, in order to conduct these tests properly. For one thing, the square wave must be really square, or as nearly as we can make it, and must also be variable over a wide frequency range in order that we can select the best fundamental frequency for each test.

board shows the soldered connections necessary to form the circuit in conjunction with the components. The multivibrator functions quite well from a 4.5V battery.

5 - AUDIO FREQUENCY OSCILLATOR

There are several uses for an audio oscillator, apart from the Morse practice role dealt with in detail elsewhere. One application is for fault finding in audio amplifiers. By applying its output to the input of the equipment being tested, then to the grid of the first stage and so on through to the loudspeaker, a defective stage can be located.
This oscillator can also be used to modulate an RF signal generator but, due to its non-sinusoidal output wave form and, therefore, high harmonic content, it is most definitely NOT recommended for modulating transmitters.
Since originally presenting this circuit, another type of unijunction transistor, the 2N2646, has become available which operates equally as well as the 2N2160 in this application, and probably more important, is less expensive. For this reason, we have specified the 2N2646 as a first choice, if available.
A comprehensive description of the construction and action of a unijunction transistor is not within the scope of this article, However, and very simply, it is a "relaxation" circuit in which the .05uF capacitor charges through the 250K potentiometer and 3.3K series resistor, discharging through the unijunction and the 220 ohm resistor in B1. Due to an "inbuilt bias", which the unijunction provides for itself the capacitor has to charge sufficiently to overcome this bias level to bring the unijunction into conduction in order to discharge.
Therefore, the frequency with which the events are repeated as an oscillation, depends mainly on the time taken for the capacitor to charge to the inbuilt bias voltage of the unijunction - in other words, on the time constant of the resistor and capacitor. The larger the resistor, or capacitor, the slower the charging and the lower the frequency of oscillation. Conversely, the frequency may be increased by reducing the value of resistor or capacitor. In this circuit, we maintain a constant value of capacitance and alter the value of resistance by means of the potentiometer to achieve a change in frequency. Using the values specified, our little oscillator has an approximate frequency range of 100 cycles to 6KC. As too low a value of resistance will prevent oscillation by keeping the unijunction "on" all the time, a 3.3K resistor is included in series with the potentiometer as a safe minimum value for maintaining oscillation with the potentiometer wound out of circuit.
The type of potentiometer, and the "way wound" it is connected, needs to be considered if we are to get a reasonably smooth and well-spaced frequency control.
First, let us consder what would happen if we used a linear pot in this position. Due to the manner in which the circuit functions, the highest frequency is produced with minimum resistance in circuit. Since the total resistance is low, a small increase in resistance represents a significant percentage change, resulting in a significant frequency change for a small movement of the control knob. Conversely at the low frequency end, where a lot of resistance is involved, a large change is needed for the same percentage change and the knob movement is well spread out.
This would be the case if we used a linear pot. but if we use the more conventional and readily available "log" pot we find that the situation is



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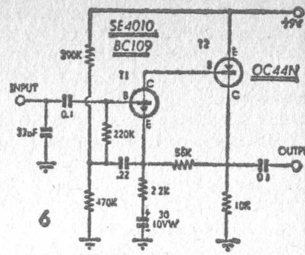


6

1 2N2646 unijunction transistor.
1 250K log switch potentiometer.
1 3.3K ½ watt resistor.
1 220 ohm ½ watt resistor.
1 0.1uF capacitor.
1 .05uF capacitor.
1 piece sample Veroboard 1¼in x 1⅜ in, 1 9V battery, signal and battery wires, sleeving.

1 SE4010 transistor
1 OC44N transistor
1 2.2K ½ watt resistor
1 10K ½ watt resistor
1 56K ½ watt resistor
1 220K ½ watt resistor
1 390K ½ watt resistor
1 470K ½ watt resistor
1 33pF capacitor
2 0.1 capacitors
1 .22 capacitor
1 30uF 10 volts working electrolytic capacitor
1 piece sample Veroboard 1¼in x 1⅜in, 1, 9V battery, signal and battery wires, sleeving

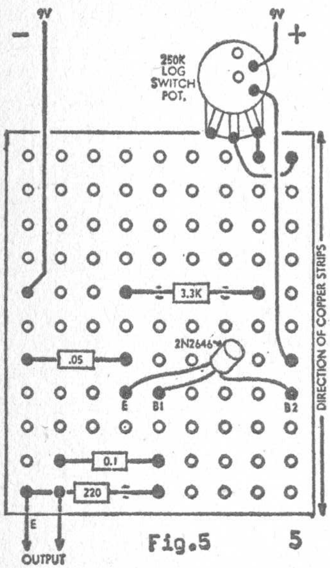


Fig.5 5

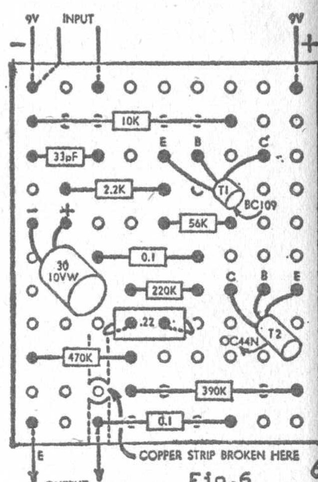


Fig.6 6

even worse if we wire it to produce the conventional increase in frequency with clockwise rotation of the knob. The ideal, then, would be an "anti-log" pot or one having just the reverse characteristics of a log pot. Such devices are available, but not always "off the shelf" at the nearest store.

However, we can achieve much the same result by simply wiring a conventional log pot. in reverse; the only objection being the minor one that the frequency will be highest at the anti-clockwise or "switching-on" position, decreasing as the knob is rotated clockwise.

Construction of this unit is straight forward, the necessary details regarding component layout and underside soldering points being given in the drawings. Potentiometer mounting is achieved by soldering its bottom end tag to the copper strip holding the top end of the 3.3K resistor, with the slider connected to the positive supply by a flying lead. The positive supply lead from the battery is taken via the switch potentiometer, the negative lead being taken straight to the board.

At the time of construction, we were unable to acquire a miniature 250K log switch potentiometer and were forced to use the standard type, as seen in the photograph, being larger than desired for this type of project. However, readers may be able to obtain a smaller version of this component for their unit.

The oscillator operates well from a 9V supply and is capable of driving either a 15 or 33 ohm loudspeaker, or a set of high impedance head phones, at a clearly audible level.

6 - CRYSTAL MIC. PREAMPLIFIER

Sooner or later, most radio enthusiasts have need of a microphone circuit, a facility not always available even in many elaborate amplifiers. The reasons for this need are many and varied.

Since cost often has to be considered, it is natural to ask whether an existing receiver or amplifier can be used for this purpose, either by adding something to it, or by selecting a suitable microphone. Depending on the individual's pocket, the microphone used could either be a crystal, dynamic, or even ribbon type, but since the crystal type is capable of quite good performance at a very reasonable cost, it is a very popular and logical choice.

However, regardless of the type finally selected, the output will be very much lower than, say, that of the conventional crystal pickup, and will require considerable amplification before it is strong enough to be fed into the pickup terminals of a standard audio amplifier.

Furthermore, if we do select a crystal type, it is essential that the input circuit to which it may be connected provides a high impedance ideally about 5M but certainly not less than 1M. Otherwise, the bass response of the microphone will be seriously attenuated. Our simple pre-amplifier is designed to satisfy both these requirements.

The circuit may appear a little unconventional at first, and it may be helpful to discuss briefly some of it s more important features. It is a two stage directly coupled amplifier, using a NPN (SE4010 or BC109) first transistor and a PNP (OC44N) second transistor.

Apart from the direct coupling, the main feature is the input circuit to T1, designed to provide the high input impedance necessary for the crystal microphone.

The 220K resistor and the .22uF capacitor, connected as shown between the emitter and base, is known as a "bootstrap" arrangement, which has the effect of increasing the input impedance to a much higher value than that of the 220K resistor, by decreasing the normal shunting effect of this resistor.

This circuit functions, broadly, something along the same lines as the emitter follower, in which negative feedback is used to increase the apparent input impedance, by using the amplification of the stage to develop what might be termed a "bucking" voltage across the input load so that very little current can flow through it from the signal source. Thus, the source "sees" what appears to be a very high resistance. To understand how this is achieved, we have to consider an input signal applied to the circuit. This signal appears at the emitter of T1 at nearly its full magnitude, due to the amplification of the transistor, and is applied via the .22uF capacitor to the lower end of the 220K resistor. This now means that there is very little difference in the signal present at either end of the resistor, and it accordingly passes very little current. Thus as fara s the input circuit is concerned, its impedance has been effectively raised. In fact, the effective input impedance is raised to greater than 2.2M. This is one method of conveniently increasing the input impedance of a transistor stage, using only one extra resistor and capacitor.

The 56K and 2.2K resistors provide both negative feedback and thermal stabilisation for the transistors, the latter being dealt with more fully in our Two Stage Audio Amplifier project. The 30uF capacitor supplies the AC path to chassis. The 10K to chassis is the collector resistor for T2, and the output developed across it is extracted via the 0.1uF capacitor.

This little unit performs very satisfactorily from a 9V supply.

Although there are a larger number of components to be accommodated on our sample piece of Veroboard, the project is simple to construct and presents no problems. The component layout is illustrated and it should be noted that it is necessary to cut the input/output copper strip at the point indicated in order to maintain the correct circuit and mount all the components on the one board. A special tool is available for cutting the copper strip, but in its absence, a razor blade or 1/8" drill will do the job nicely.

When it has been built and the equipment set up for test, don't be surprised if the whole thing screams it's head off as soon as the volume control is advanced. This will be due to acoustic feed back, caused by the microphone picking up signals from the speaker and feeding them back into the system. This is quite normal, and it is best to place the microphone as far away from the speaker as possible. Indeed, to turn the system up for testing it would be best to locate them in separate rooms.

The tendency to feed back will be aggravated by any peak in the system, since the system will spill over at this frequency before a useful leve is reached at other frequencies. Many of the cheaper crystal microphones have a tendency to peak badly, and these types should be avoided if possible.

Where such peaks exist, due to the microphone or any other cause, it is sometimes possible to minimise their effect by limiting the top response of the system with a conventional "tone control". Naturally, there is a limit to the amount of top cut that can be tolerated, but it is often possible to select a degree which is a suitable compromise between feed back and top response.

UNDERSTANDING MULTIMETERS

ONE OF THE FIRST TECHNIQUES A BEGINNER IN ELECTRONICS MUST LEARN - ESPECIALLY FOR TRANSISTOR CIRCUITS - IS HOW TO USE A MULTIMETER. THIS CHAPTER EXPLAINS HOW MULTIMETERS ARE MADE AND HOW TO USE THEM.

When testing a piece of electronic equipment, a designer or experimenter or serviceman will commonly want to measure three quantities :

THE VOLTAGE or potential across various components or between various points in the wiring while the equipment is operating. The measurement is made in volts and requires the use of a voltmeter.

THE CURRENT flowing through various portions of the circuitry when the equipment is operating. In ordinary receivers and amplifiers, the current is most commonly measured in milliamps and requires the use of a current meter - most commonly referred to as a milliammeter.

THE RESISTANCE across components or between various points in the circuitry, normally measured when the equipment is not operating. Resistance is measured in ohms or its decimal multiples and involves what is normally referred to as an ohmmeter.

In the early days of radio, separate meters were used for these three basic measurements. But good quality meter movements are relatively expensive and test instrument manufacturers began to devise circuit arrangements involving switching and/or multiple plugs which allowed the one basic meter movement to indicate volts, milliamps and ohms.

The result of their efforts to devise multipurpose instruments gave rise, logically enough, to the term "multimeter", and this is the name you will encounter most commonly in literature.

However, particularly in overseas literature, you may encounter the three letters "VOM" which stand for volt-ohm-milliammeter. VOM means the same as multimeter.

Till the late fifties, multimeters were relatively expensive and largely out of the reach of newcomers to hobby electronics. In fact, the construction of a multimeter was often something of a milestone for hobbyists and would-be servicement, home construction being tackled partly as an educational exercise and partly to save money.

Over the last decade the position has changed dramatically, mass production of multimeters, particularly in Japan, has brought the price down and pushed the quality up. There is not much point these days in trying to build up a multimeter at home.

On the contrary, enthusiasts can reasonably plan to buy an instrument and put it to use quite early in their hobby activities.

Assuming that you may be thinking along these lines, one purpose of this articles is to explain what is inside a typical multimeter and to show how it performs its basic tasks of measuring voltage, current and resistance.

THE METER MOVEMENT

The heart of any multimeter is the meter movement itself. Its basic construction is illustrated in Figure 1.

A permanent magnet, two pole pieces and a central core create a cylinder-shaped air gap across which there is a strong magnetic field. Suspended on pivots in the air gap is a small coil of wire wound on a rectangular-shaped former. Small spiral springs adjacent to the two

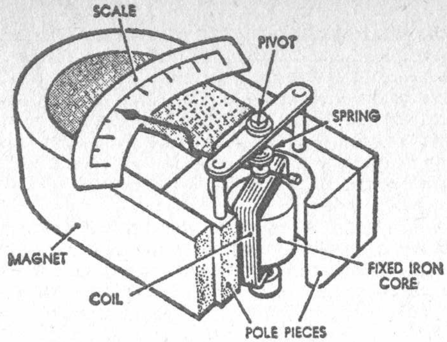


Figure 1. Basic construction of a meter movement.

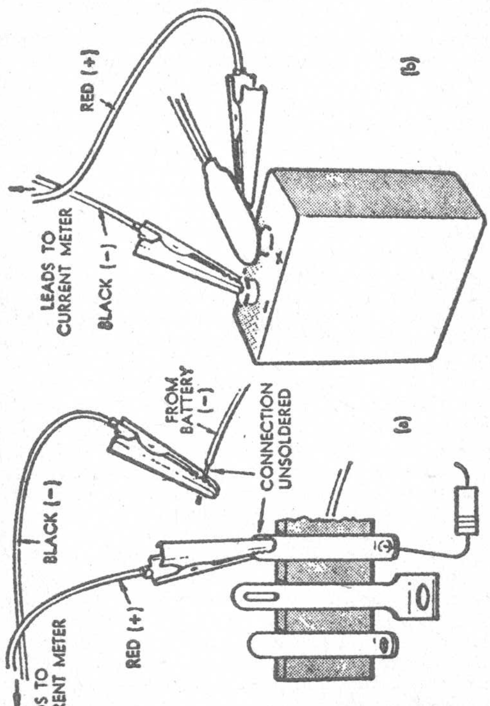


Figure 2. Two ways of breaking into a circuit to measure battery current.

pivots hold the coil in a suitable initial position and also provide a metallic path by which an electric current can be passed through the coil. When a direct current is passed through the coil, it generates a magnetic field around the coil, in the manner of an electromagnet. This field interacts with the fixed radial field from the magnet structure with the result that the coil tends to rotate on its pivots. The rotating action is resisted by the springs and the end effect is that the coil moves until the resistance due to the springs exactly balances the rotational force due to the magnetic fields.

Attached to the coil is a light pointer and counterweight system, the pointer being arranged to seep across a reference scale. This scale can be calibrated in terms of the current flowing through the coil, so that the current can simply be read off at any time. All readings taken with a multimeter, no matter how the scales are marked, are actually readings of the current flowing through this coil.

Some of the less sensitive meter movements require several milliamps of current through the coil to deflect the pointer right across the scale. Such meters are not suitable for use as the basis of a general-purpose multimeter.

Until a few years ago most general-purpose multimeters were built around meter movements having a full-scale deflection (commonly abbreviated to FSD) of 1 milliamp.

However, improved mass production techniques have made it possible to build multimeters around much more sensitive meter movements having an FSD of, typically, 100 microamps (0.1 milliamp) or even 50 microamps (.05 milliamp). For a number of reasons, multimeter using these more sensitive meter movements are to be preferred.

CURRENT MEASUREMENT

To measure current flowing in a circuit it is necessary to break into the circuit so that the current will also flow through the meter. Frequently this involves unsoldering a lead or one end of a component and clipping the meter between the separated connections so that the current flows through the meter.

Assuming the normal situation where the current to be measured is DC (direct current) the meter must also be connected so that the pointer reads forward across the scale. If the meter is connected the wrong way round, the coil and pointer will try to move backwards.

Figure 2a is based on the simple transistor amplifier. It shows how a milliammeter could be interposed to measure the current drawn from the battery; it involves unsoldering one lead.

Occasionally, it is possible to avoid unsoldering by interposing the meter at a point where there is a mechanical connection. Figure 2b shows the meter leads interposed between the negative terminal of a battery and the negative side of the connector. Current flowing from the battery to the device under test will pass through the meter and will produce an appropriate reading on the meter scale.

When measuring current, there is a seeming difficulty that a milliammeter could only be used to read currents up to a figure equal to its natural full-scale sensitivity. How can one measure 10 milliamps or 100 milliamps, for example, if the meter pointer goes hard over on anything more than 1.0 milliamp?

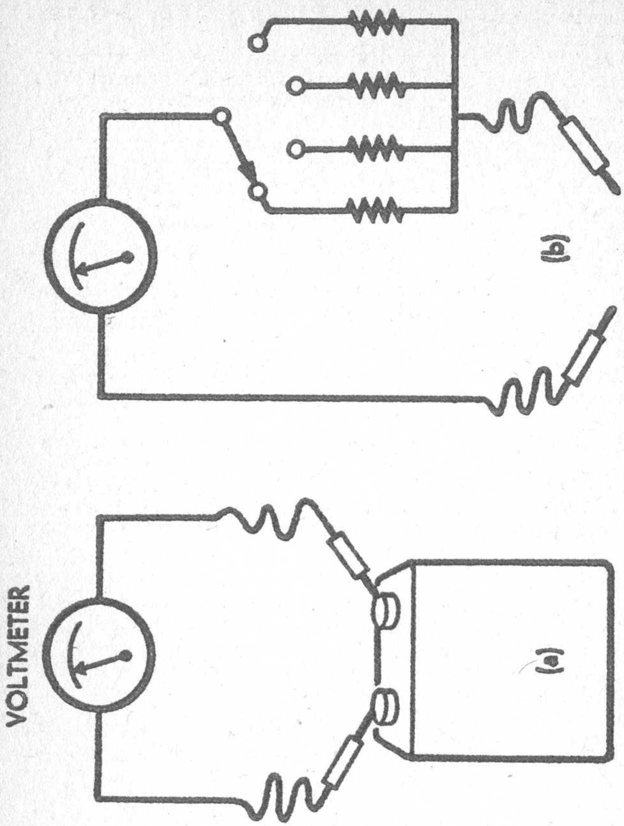


Figure 4. (a) Measuring battery voltage. (b) Voltage multipliers are added in series with the meter movement to increase the useful range of a voltmeter.

Figure 3 shows how the designer of a multimeter normally overcomes this problem. He provides a switch or a plug and socket system so arranged that carefully selected resistors can be connected in parallel with the meter movement. Resistors used in this role are described as "current shunts" or just "shunts".

With the switch in the bottom position, there is no shunt in circuit and all the current flowing via the test leads passes through the meter. The meter will therefore read current up to but not beyond its full-scale sensitivity - let us say 1 milliamp.

Let us say, however, that in the next switch position a resistor is introduced across (or in shunt with) the meter movement. Some of the current flowing between the test leads will now pass through the meter, some through the resistor.

If the shunt resistor is selected to have one-ninth of the resistance of the meter movement, the current will divide in the ratio of nine units of current through the resistor for every one unit of current through the meter. For them to read full scale, a current of 10 milliamps must flow between the test leads, 9 milliamps through the resistor and 1 milliamp through the meter.

The meter and shunt combination will thus behave as a 10-milliamp instrument. The scale may have a separate set of calibrations for 0-10 milliamps or the user may mentally multiply the 0.1 milliamp scale by 10 whenever the 10 milliamp shunt is used.

By using shunts of progressively smaller resistance, the meter can be made to provde still higher current ranges. In the past, multimeters have conventionally provided for measuring current up to 250 milliamps DC. Current ranges beyond this present difficulties to multimeter designers but there is an advantage in having a higher current range available.

DC VOLTAGE

To measure DC voltage it is necessary only to touch the test prods on the respective points between which the voltage is to be measured. This is depicted in figure 4a, where a voltmeter is shown connected across the terminals of a battery. We will assume that the positive side of the voltmeter is connected to the positive side of the battery so that the meter will read forward, as intended.

But how can a current-sensitive meter, as in figure 1, be made to serve as a voltmeter? The answer is contained in figure 4b. Here, carefully selected resistors are introduced in series with the meter by suitable switching or by a plug and socket system. Resistors in this role in a nultimeter are commonly referred to as "voltage multipliers" or simply as multipliers".

To make it easy, let us assume that the meter has a full-scale sensitivity of 1 milliamp; further, that the multiplier resistor which is shown switched in to circuit has a value such that its resistance plus that of the meter movement adds up to 10,000 ohms. If you are familiar with Ohm's Law you can work out the next step for yourself; if you are not, you'll have to take our word for it.

If 10 volts DC is applied between the test prods, the resulting current through the 10,000 ohms of resistance will be 1 milliamp and the meter will read full scale. If only 5 volts is applied across the test prods, the current would be 0.5 milliamp and the meter would read half scale.

In other words, the particular combination of a current meter and as series multiplier resistor would function as a 0.10 voltmeter. Once

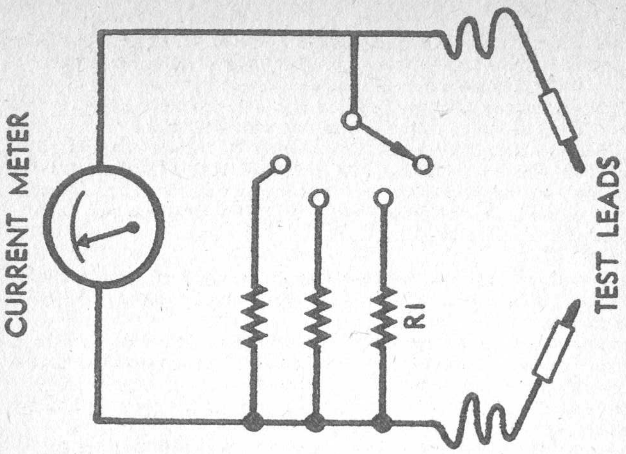


Figure 3. Current shunts are connected in parallel with the basic meter movement to increase its useful range.

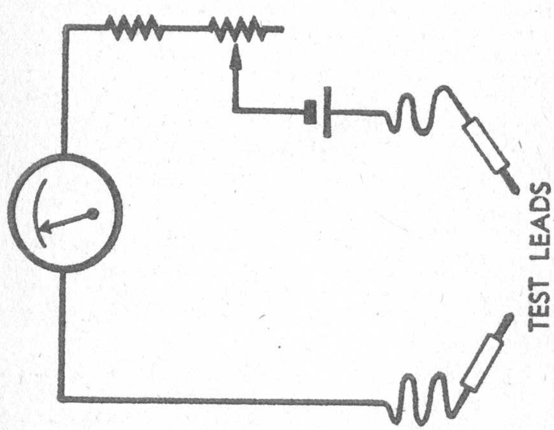


Figure 5. How a basic meter movement is used to measure DC resistance.

again, the scale could be calibrated in terms of 0.10 volts, or a basic 0-1 scale could mentally be multiplied by 10 and called volts whenever a voltage range was selected.

Fairly obviously other voltage ranges can be covered in similar fashion by selecting other suitable values of multiplier resistor.

Ordinary commercial multimeters provide DC voltage ranges up to about 500; with a few going to 1000. Beyond this, difficulties arise because the internal insulation of the instrument and the spacing of switch contacts may be inadequate to cope with high voltages.

IMPORTANCE OF SENSITIVITY

A most important point emerges from the example we have just used, involving a 1 milliamp meter and 10,000 ohms of resistance for a 10-volt scale.

When such a meter is connected across a circuit to read the voltage, it is equivalent to connecting a 10,000 ohm resistor between the particular points.

If the meter happened to read full scale, it would be drawing 1 milliamp from the circuit under test.

When reading the voltage of a battery, as in figure 4a, neither the resistive loading nor the current would be especially significant.

However, there are plenty of circuit situations within electronic equipment where the connection of a 10,000 ohm resistor, and a load current of up to 1 milliamp would upset the operation and give an entirely false reading.

The use of a more sensitive meter movement eases the problem to some extent because, for any given voltage range, the value of the multiplier resistor is much higher, and of course the current drawn by the meter from the circuit under test is much lower.

The sensitivity of meter movements is usually indicated in small type on the meter face. A 1-milliamp movement would normally carry the endorsement: FSD 1mA. There may be an additional note along the lines "Sensitivity 1000 ohms/volt". This means that the internal resistance as a voltmeter is equal to 1000 ohms multiplied by the particular voltage range in use. On the 10V range it would be 10,000 ohms, on the 250V range it would be 250,000 ohms.

Nowadays, a large number of multimeters are built around 50-microamp meters (50uA or .05mA) which yield an internal resistance 20,000 ohms per volt. A multimeter offering this order of internal resistance has a very clear advantage over the older 1mA, 1000 ohms/volt variety.

AC VOLTAGE

Most multimeters, these days, also have provision for measuring volts AC-perhaps surprising in one sense because the kind of meter illustrated in figure 1 will not read on AC. Multimeter designers get around this by bringing a small rectifier into circuit whenever an AC range is selected. The rectifier changes the current flowing in the meter circuit from AC to DC and allows the meter to give a meaningful indication. Presence of the rectifier modifies the behaviour of the circuit as a whole and reduces the sensitivity. It is therefore quite common to see a notation on the meter face indicating that the internal resistance as an AC voltmeter is lower than as a DC voltmeter.

Another point worth mentioning is that the length or shape of the AC schels, particularly on the lower voltage ranges, may be different from that of the DC ranges. Anyone using a multimeter to measure AC volt-

age should therefore be on the alert to identify the exact set of calibrations against which particular AC voltage readings should be taken. So much then, for the voltmeter function.
Figure 5 shows an elementary circuit which allows a meter to measure DC resistance. As we have already indicated, the measurement is presented as so many ohms and, in this role, the instrument is commonly described as an ohmmeter.
It can equally indicate whether the circuit through a component or a wiring sequence is "continuous" or "open". From this cam an older term, which is still heard on occasions: a "continuity" meter.
Figure 5 shows a meter, a battery, a fixed resistor and a variable resistor in series one with the other and with the test leads.
If the test leads are not touching, no current will flow through the circuit and there will be no reading on the meter.
If the test leads are touched together, current will flow and the meter will read. The variable resistor may be adjusted so that the meter will read exactly full scale when the leads are touched.
Thus, with the test leads not touching, or touching points between which there is no electrical circuit, the meter will not read; the indication will be "open circuit" or an infinite number of ohms between the test points.
With the test prods touching, or connected to a common electrical conductor, the meter will read full scale, indicating "short circuit" or zero ohms between the test points.
If the test prods are connected across a component having significant electrical resistance (being neither an open nor a short circuit) the meter will give some intermediate reading.
As we have already indicated, DC resistance measurements must be taken when the unit or circuit being examined is not operating and preferably is completely disconnected from the power source.
In practice, DC resistance measuring circuits within a multimeter are most complex than suggested by figure 5 and there is usually provision by switching to obtain a more meaningful reading on resistances of different magnitude.
Having a sensitive meter movement has the additional advantage that it makes it easier to achieve measurement of a wide rang e of resistance values, particularly those values above about .22 megohm.

SCALES ON A TYPICAL METER

A variety of low priced multimeters are available on the British market, many of them through mail-order radio parts suppliers.
The bottom positions on the range selector scale offer three ranges for the measurement of direct current: 0.1, 25 and 250 milliamps. Pointer indications would be read against the scale sector marked "V-mA"
When reading to 0.1mA, the 0.10 figures on the scale would be used but would be mentally translated as .02, .04, .06, .08 and 0.1mA. On the 25mA setting, the 0.25 figures would be used directly. On the 250mA setting, the same figures would be used but multiplied mentally by 10. The significance of the scale subdivisions would have to be worked out in each case, being a more or less straightforward excerise in reading graduations.
In practice, the 0.1mA scale would not be used a great deal but it is handy to have for special test situations.
Where it is anticipated that the current to be measured would lie above 0.1mA but below 25, the 25mA range would have to be selected.

An here a limitation of the particular multimeter would become apparent. A current of the order of 1 milliamp would produce only a very small deflection of the pointer, involving two of the smallest graduations. Measurements of current between 0.1mA and about 2.5mA would therefore be quite unprecise. More elaborate - and more costly - meters are likely to offer a greater number of ranges and would avoid an awkward gap like this.
What about the measurement of alternating current as distinct from direct current? Very few miltimeters provide any facility for measuring AC milliamps, partly because it is difficult to provide in a budget-priced instrument and partly because it is a facility that most enthusiasts can do without if they have to.
On the left hand side of the switch are five voltage ranges covering from 2.5 to 1000 volts. This is, in fact, a very good coverage and probably reflects a trend to rely more on voltage measurements than current to analyse the performance of solid-state circuitry. And certainly it is easier to measure voltages around a printed wiring board than to unsolder connections to measure the current.
The figures on the scale 0-25, 0-10 and 0-5 provide the basis for reading off the appropriate voltage, either directly, or by inserting a decimal point or adding noughts. Thus, the 0-25 scale can also be read as 0-2.5.
The AC voltage ranges on the right hand side of the selector switch also give good coverage. Note that the 10V AC range has its own scale which is different from the 10V DC sclae, for reasons already referred to.
The two switch positions immediately under the meter are for the measurement of resistance. They are used in conjunction with the topmost scale on the meter face. Using the selector position "R x 10", the "5" graduation would represent 50 ohms, the "10" graduation would represent 100 ohms and so on. The "2K" mark at the extreme left of the scale would represent 20,000 ohms.
To read values above about 2000 ohms, the "R x 1K" position could be selected to advantage. With this range selected, the "5" graduation would represent 5000 ohms, while the "2K" graduation would represent 2 megohms. This is a quite useful range of resistance measurement but more comprehensive - and expensive - multimeters would permit more accurate measurement of very high value and very low value resistors.
Incidentally, the "Ohms Adj." control serves the purpose of the variable resistor in figure 5. With the test leads shorted together, the adjustment should be set so that meter pointer reads exactly full scale, or zero ohms.
There are other ranges and markings on the scale but these are best relegated to another chapter, where space is at less of a premium. One major objective in this chapter has been to talk about the basic functions of measuring current, voltage and resistance.

OPERATING PRECAUTIONS

In using a multimeter, the one thing above all others that the operator must be alert to is the risk of damaging the instrument by failing to use the proper scale.
When checking voltage, always set the meter to a range which you know will be adequate for the equipment under test.
With a transistor receiver operating from a 9-volt battery, you would

never need to use higher than the 10V range.

With a valve receiver, you would have to be prepared for voltages in excess of 250; therefore, you could start with the 1000V range and only switch to a lower range when you know that the voltage AT THE PARTICULAR POINT you wish to measure is less than 250.

Similarly, when measuring current drain, start with the highest current range and only reduce the range when you are sure it is safe to do so. But, of course, it would be quite foolish to attempt to measure current flow in, say an automotive electrical system with a simple multimeter. In such a system, the current flow is reckoned in amps, not milliamps (thousandths of an amp).

However, the "standard" method of accidentally ruining a multimeter is not just to use it on the wrong voltage or current range. That can be bad enough.

The most common method is first to use the meter for resistance tests and to leave it set to one of the OHMS ranges.

Then, intent on measuring a voltage, the user forgets to select the appropriate voltage range. Instead, he connects the meter straight across 250 volts and wham! The meter pointer flies across so violently that it bends into an arc, maybe sticks, maybe jumps out of the pivots. The instrument may even suffer damage to other parts of the circuitry. Just about everyone who has ever used a multimeter has been through this kind of experience but the knowledge is of little comfort as you view the results of your own personal effort.

So try to educate yourself NEVER to take a meter reading without first stopping to look at the range selector.

And here's another safety hint: Having taken a reading of current of resistance, flick the switch around to the 250V or 1000V setting, either AC or DC. That way you won't do any harm if you forget to check the range switch before touching the meter on an active circuit.

In recent years, multimeter designers have adopted a scheme called "diode protection" to minimise the effect of meter overload. The diodes are connected across the meter movement and tend to act as automatic shunts, should the voltage across the meter ride too far beyond what it should be.

Diode protection will usually protect a multimeter from damage arising from quite severe overloads, provided the overload condition is not sustained.

However, very severe overloads, particularly if sustained, can damage other parts of the circuitry, even if the meter remains intact. Multimeters with diode protection usually sell for a little more than meters without protection but in general it is well worth spending the extra amount.

A MODULATED LIGHT COMMUNICATION SYSTEM

WE HAVE DEVELOPED A COMMUNICATION SYSTEM USING MODULATED INCANDESCENT LIGHT, TO GIVE SATISFACTORY SIGNALS UP TO 300 YARDS BY NIGHT AND 70 YARDS BY DAYLIGHT.

The principle of light modulation is very simple, and I first tried out the idea using a photo-electric cell.

The results were very distorted. Further investigation suggested that the lamp would have to be biased so as to operate at some suitable "mid point" on the luminance characteristic curve, so that positive and negative halves of the audi AC would casue equal changes in luminance above and below this reference point. Unbiased, the lamp caused frequency doubling and gross intermodulation distortion.

A battery was therefore connected into circuit to provide a DC bias, see figure 1. The best results in this early experiment were obtained with a 2.5V lamp energised by a 3V battery, with the modulation kept below the point where the lamp could be seen to flicker. These conditions still apply. The voltage at the lamp was the battery voltage less the voltage drop across the transformer secondary winding, and was somewhat less than 3V.

This rather crude set-up gave really surprising results, and a plotted response showed the -3dB points at 45Hz and 5KHz. The limited high frequency response is due, in the main, to the thermal inertia of the lamp filament, it being obviously impossible for the filament to heat and cool rapidly enough as the frequency increases. It was also considered that some loss may have been due to core magnetisation caused by the rather heavy DC current (300mA) through the transformer secondary.

Futher experiments were carried out when a germanium junction photoelectric cell - an STC type P50A - was substituted for the original "Lumatron" cell. The same supply and amplifier were used. A condenser lens was used to focus the light on to the small area of the cell, and a 7" parabolic mirror was placed behind the lamp. Both lens and mirror were from theatre picture projectors. With this equipment, it was possible to send quite good quality music over a distance of up to 70 or 80 yards and intelligible speech up to 300 yeards.

More recently, attention has been given to solid state circuitry using phototransistors, but results were marred by the everpresent hiss from the light-sensitive cells. The greater sensitivity, however, allowed the use of much simpler and cheaper optics still with a useful range of up to 250 yards.

Some experimenting was done to see if amplifier output matching was critical. For this purpose a transformer was made up with design characteristics which allowed for the 300mA DC in the secondary and which matched the 3-ohm output of the amplifier to the approximate 8 ohms of a 2.5V pea lamp drawing 300mA, see figure 2.

It was found that, for the frequency range required and the level of dis tortion acceptable (voice only), the parallel feed system of figure 3 was quite satisfactory. The mismatch of the amplifier load had little or no effect due to the small amount of audio power being involved. It is possible to reduce the voltage across the lamp to a point where the filament is a mere red spot with the modulation causing the very slightest flicker, and still receive a good signal over a distance of more than 60 yards.

Although the main circuit shows the lamp biased from a separate battery, it may derive its power from the main amplifier battery or power supply, byadding sufficient resistance in series with the 10W variable resistor

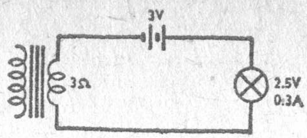


Figure 1

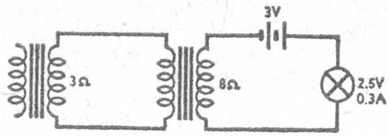


Figure 2

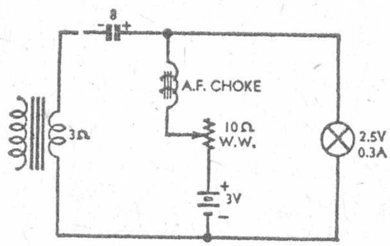


Figure 3

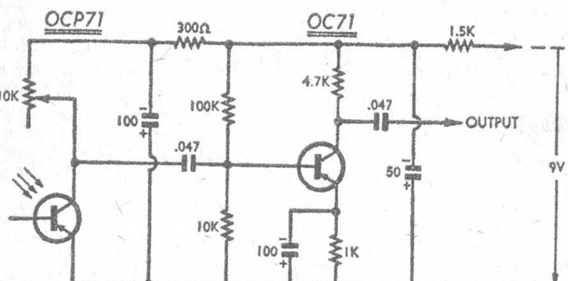


Figure 4

The receiver circuit

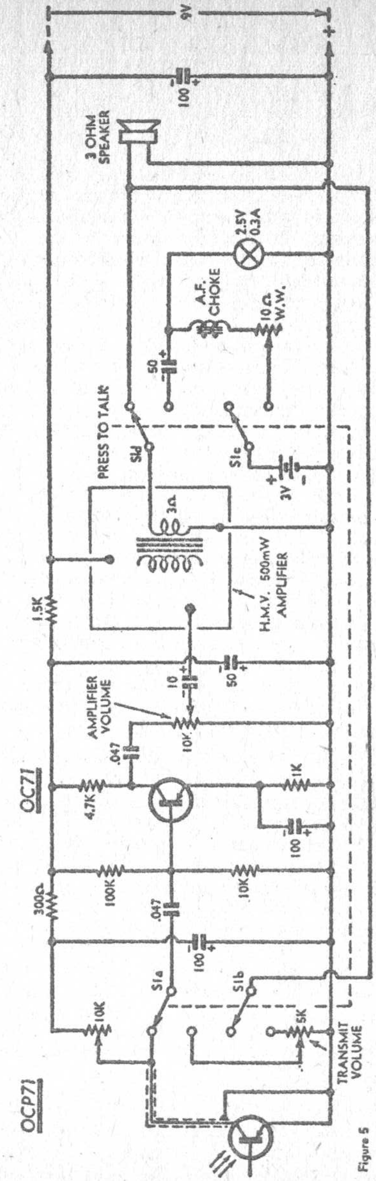


Figure 5

shown in the lamp circuit.
The reciever, figure 4, starts with an OCP71 phototransistor which has an ordinary 3" reading glass to focus the incoming light on to the tiny sensitive area. These are arranged in a tube made by soldering three jam tins together to provide a mounting for the lens and keep extraneous light away from the cell.
The OCP71 is quite sensitive to variations in the light intensity of what could be termed the carrier. It is possible to vary the sensitivity over a wide range by adjusting the collector load resistor to give maximum signal. Too high a light intensity can easily drive the OCP71 to cut-off, and the adjustment caters for this. With the receiver set to maximum sensitivity and with careful focusing of the lens, it is possible to pick up the pea lamp, without reflections, across a 12 ft room or up to 20 ft with a fairly high hiss level.
If a reflector of any kind is used behind the pea lamp and the distance is less than about 40 yards, a lack of signal strength from the cell is more likely to be due to too much light than to too little! Reducing the light intensity by shading and/or adjustment of the cell sensitivity control should create optimum conditions. Reducing the lamp intensity by means of the pot in the lamp circuit will also have the desired result provided that modulation depth is also adjusted to prevent distortion.
The amplifier which follows the phototransistor is a pre-amplifer stage using an OC71 transistor with comparatively small coupling capacitors to cut low frequencies. The main amplifier can be any type, valve or transistor, with a sensitivity of approximately 100mV. This is used for transmitting as well as receiving as it is only necessary to connect the output to the lamp circuit instead of the loudspeaker.
This is the method used in the complete circuit, figure 5, which shows one of two units used as a communication system. Using ordinary good quality torches as light sources and cheap lenses they provide telephone quality communications usable to more than 250 yards. Distances obtainable depend on the quality of lenses and reflectors and the care with which they are set up.

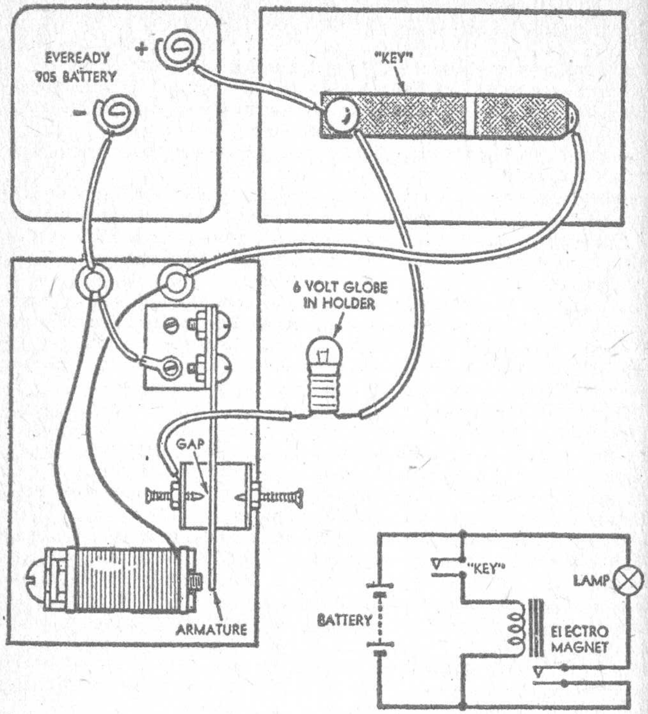
Using the original equipment first class communication was set up over a distance of 70 to 80 yards in broad daylight. Alignment of the beams is a little more difficult than in darkness, and there is an increase in hiss level due to the ambient light. However, the signal level indicated that a much greater distance should be possible before the signal disappears in the noise. Test distances greater than 70 to 80 yeards were prevented by practical limitations such as buildings, trees, traffic, etc. The hiss due to ambient light can be reduced by painting the inside of the lens mounting tube with a flat black paint, such as chartboard black.
By using an old car headlight instead of a torch head, i.e. only increasing the reflector size, a readable signal was received at a distance of considerably more than one mile along a main road at night. Above this distance distortion became a pertinent factor due to heat haze and air movement above the road surface. The total power required to transmit and receive a readable signal over this distance was only 1.1 W!

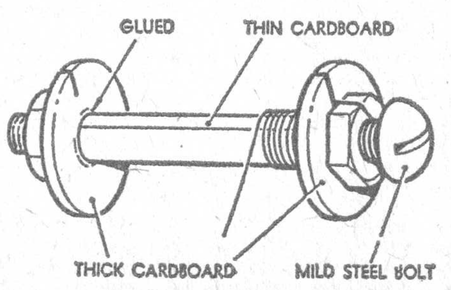
HOW TO BUILD, USE AND PUT TO WORK AN ELECTROMAGNET

The electromagnet is very much a part of our modern life - and has been for some time. Doorbells and telephones use them in their ringing systems. Cars and trucks use them extensively. In this chapter we describe how to build and electromagnet and do a few simple experiments, and will show you how to put your electromagnet to work controlling electricity.

First of all, we had better explain exactly what an electromagnet is, and how it works. Basically, an electromagnet is a coil of wire wound on to a soft iron core. The core becomes magnetised when an electric current passes through the winding, the strength of the magnetic pull depending largely on the magnitude of the current and on the number of turns.
For professionally made electrical equipment, the strength of the pull can be worked out mathematically. However, in a do-it-yourself situation, it is sufficient to find an acceptable gauge of wire which will allow sufficient turns to be put on, and which will cause a suitable current to flow from the battery to be used.
When a current flows through a wire, a "magnetic field" is set up around the wire. This field may be thought of as "lines of force" surrounding the wire. When the wire is wound into a coil the field becomes concentrated. If the coil is wound on to an iron core, the field tends to concentrate in the iron, and the core exhibits the properties of a magnet.
When current ceases, the flux, as the magnetic field is called, begins to diminish. Just how fast this flux dies away depends on the material used in core. If hard steel had been used, this flux would take some time to die away; in fact, some of it would always remain. The amount of flux left with no current is described as the "remanence" of the core. The ability of the magnet to retain the flux is defined as the "retentivity".
However, if a solft iron core is used, the rententivity is very much closer to zero; in other words, most of the flux would disappear immediately. This is the type of core most often used in such devices as relays where an immediate response is required when current is initiated and interrupted. This is the type of core we shall use in the electromagnet to be described.
All you will need to make this electromagnet is a 2" fully threaded mild steel bolt and two nuts to fit on to it; some thick and some thin cardboard; some glue; and of course, the wire.
The exact gauge of the wire is not critical. We used 32 B & S but calculation has shown that any gauges between 28 and 34 should be satisfactory. The wire should be insulated, that is, having an enamel coating to prevent adjacent turns from "shorting" each other.
If the wire was not effectively insulated, current would not have to flow around the coil but would travel between the turns - jumping from turn to turn - where they touch each other. Electrically, the current would "see" the coil as a solid mass of copper, and hence no significent magnetic properties would result.
The first step in the construction of the electromagnet is to "soften" the core. This is done by a process called "annealing". The purpose of this softening or annealing is to make the cor's retentivity as low as possible. Why we do this will be obvious later, when we attempt some experiments. To anneal the bolt it is necessary to heat it red hot, hold it at this temperature for a short time, and then cool it as slowly as possible.

Figure 1. Electromagnet connected for use as a relay. The circuit which lights the lamp is separate from the one which operates the electromagnet — except that in this case we have used the same battery to energise both circuits.





The way we did ours was to hold the bolt over a gas flame for about 10 minutes, using a piece of stiff wire and a pair of pliers. After 10 minutes or so the bolt was glowing bright red all over, and then it was slowly removed and allowed to cool.

Next, we must make a bobbin on which to wind the coil. A bobbin is necessary for two reasons: First, it prevents the sharp grooves of the bolt biting into the wire and cutting it or damaging the insulation: and second, it makes the coil easier to handle.

First, wind one nut on to the bolt as far as it will go. Then cut two circles of fairly thick cardboard approx $\frac{3}{4}$" dia, with a hole in the centre just wide enough to fit on the bolt. Put one of these on to the bolt hard up against the nut.

Next cut a strip of fairly thin cardboard, 1 $\frac{1}{4}$" wide, and wind one layer of this around the bolt. Cut off the excess and secure the tube with adhesive tape. Push this tube firmly against the circule and nut, and then put the other circle and nut on the bolt in that order.

Tighten the nut until the whole assembly is firm, and then glue the end cheeks (circles) to the tube. Use a good PVA glue (eg "Aquadhere") and do not use too much.

Also, take care that you do not glue the bobbin to the bolt or either nut, as you will want to be able to move this later.

Once the bobbin has been glued it must be left to dry. The bobbin may be left in this position on the bolt while the wire is wound on. While it is possible to wind the coil by hand, it is a slow and tedious process.

A much more satisfactory way is to insert the end of the bolt into a hand drill chuck, and use the drill to wind on the coil. One hand may be used to wind, and the other used to guide the wire. Or better still, have someone else wind, to leave you free to guide the wire.

Begin by cutting a slit in each end of the bobbin approx. $\frac{1}{4}$" deep. After winding about 6" of wire on to the head of the bolt, pass it through this slit, and you are ready to begin winding the coil. Make certain, however, that the wire left at the start is secure on the bolt and will not move around, as fine wire is very easy to break. If necessary, put some adhesive tape over the head of the bolt to stop the wire from moving.

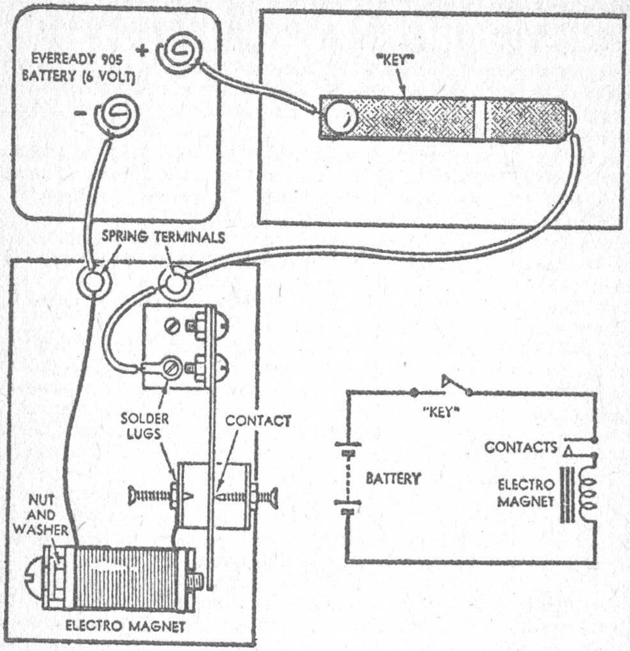
While the wire does not have to be wound on side by side, the layers should be neat and no part of the coil should be allowed to build up more than another. Just wind on smoothly and evenly, going back and forth across the bobbin keeping the wire reasonably firm in the hands while guiding. You should continue winding until the bobbin is almost full.

Then terminate the wire in the same way as the beginning. Leave about 6" or so of wire at each end. When completed, put a daub of PVA glue on the wire in the slits to anchor it properly in place. There should be around 2,500 turns on the bobbin - give or take a few hundred.

You have now completed your electromagnet. All that is necessary to operate it is a voltage source. We would suggest that you buy a large lantern-type battery, as it will last much longer than a bank of torch batteries. An Everready No. 509 would be ideal. It has spring terminals on the top to make easy connections and it has quite a long life, considering the relatively large currents which some projects may draw.

Now that we have constructed an electromagnet, there are a few simple experiments we can carry out to observe the properties of magnetism. One thing we can do is determine the north-seeking pole and the south-seeking pole of the electromagnet with the aid of a permanent bar magnet. You should be able to obtain one at a hardware

Figure 2. Electromagnet connected for use as a buzzer. Wired in this way the electromagnet turns itself on and off hundreds of times per second, thus producing an audible tone.



or large chain store. But you will need to know the poles of the permanent magnet.

Most magnets will have either a dent or an "N" punched in the metal, or have a band or spot of paint on them. This end will be the north-seeking pole. If the poles are not marked, the following experiment will enable you to find them out. You may even care to do it just to prove to yourself that the poles are correctly marked.

Tie two loops of cotton around the ends of the magnet. Then tie a 1-foot length between these loops. At the exact mid-point of this piece (i.e. when the susspended magnet is exactly (horizontal) tie one end of a much longer piece of thin cotton - at least 6 feet. Tie the other end to some high point, perhaps a fitting on the ceiling, away from walls and out of draughts. If you leave this for long enough (until it stops spinning) you will notice that the magnet is aligned along a north south axis.

Check this against a local map. The end pointing to the north is, logically enough, called the north-seeking, or simply "north" pole.

You may wonder why the pole of a bar magnet marked "N" or "North" is attracted by the north pole of the earth. This seems to conflict with one of the basic laws of magnetism; opposite poles attract and like poles repel.

We have here a language problem, not a technical problem. One of the earliest uses of magnets was in the compass, and people came to use the term "north" or more accurately "north seeking" to describe the end of the compass pointer which pointed to the north magnetic pole. This word usage has been passed down through the years and remains the conventional way of marking magnets.

Just keep in mind that the words "north" and "south" when used in reference to magnetism, are really an abbreviated way of saying "north-seeking" and "south-seeking".

Connect the battery to the wires leading from the coil, preferably with one side through a switch, so that you can switch the electromagnet on and off as you need it, and so save the battery. Make sure that the insulating enamel is scraped off around the wire wher you make the connections. You can scrape this off carefully using a knife or razor blade.

Switch on the current. You should find that the electromagnet attracts any iron object (nails, tacks, etc.) in close proximity. Switching off the current should cause anything attracted to the end of the electromagnet to fall away. If the core was not soft enough, the bolt might remain magnetised, and the objects would not release.

Again switch on the current and bring one end of the permanent magnet near the shaft end of the bolt. You should find that it either is attracted to the bolt very strongly, or is repelled. Depending on the number of turns you have wound on, this repulsion will either be weak or strong. In some cases it may be barely noticeable. In any case, a marked difference will be noted between the two ends of the magnet. Note which end of the magnet produces which effect.

Reverse the connections to the battery, and note what happens when you repeat the experiement. You should find that exactly the reverse has happened, in other words, where you had a north pole, you now have a south pole, and vice versa. Mark one end of the coil with a "+" so that you will always have the same pole at the same end if the battery is connected with the "+" terminal to this point. If the end of your

electromagnet attracted the north pole of the bar magnet, it is the south pole of your electromagnet. If the end of your magnet was repelled by the north pole of the bar magnet, it is its north pole.
Nexy, we will examine the magnetic field of our electromagnet, and tha t of the permanent bar magnet. Obtain some iron filings (almost any machine shop will be only to glad to get rid of some) and thoroughly dry them by leaving them spread out in the sum on a piece of paper. Next, cut two pieces of thick paper or thin cardboard about 1 foot square. Tape the electromagnet to the centre of one and the bar magnet to the centre of the other. Also, it is not a bad idea to tape the connections to the electromagnet down on to the card as well, in order to prevent damage to, or breaking of the leads.
Turn the cardboard over, and from a height of about 6 to 8 inches, sprinkle some iron filings lightly over each piece of cardboard. As you can see from our photographs, the filings form a pattern, lying end to end. This pattern corresponds to the magnetic field of the magnet in that particular plane. Actually, the field extends right around the magnet and electromagnet, but we have been able to "see" it in one plane.
If you wish to make a permanent record of this pattern for future use (for example in a project or for a teach or lecturer to use) it is very easy to do if you have photographic facilities available. If you haven't then someone you know may have. All that is needed is a sheet of bromide photographic paper (at least 8 x 10 inches) and normal developer and fixer.
The pattern of iron filings should be made as before, but this time on the bromide paper under darkroom safelight conditions. The paper should then be exposed to normal light for about five seconds and then iron filings should be removed and the paper developed and fixed in the normal way. The pattern will appear as white lines on a black background.

A relay and a buzzer are very similar in theory of operation and can be built from nearly identical parts. The major difference is in how the circuit is wired. We describe here a simple device that can be used for both purposes.
All you will need to make this project is your electromagnet, a few scrap pieces of aluminium, two spring terminals, a piece of wood to use as a base board, an old (but not rusty) hacksaw blade, six small wood screws and four nuts and bolts - two 1/8" and two 3/16". You should have some wire already attached to your electromagnet. (If you don't have a 1/8" Whitworth tap, you will need an extra two 1/8" nuts. We will explain this later.)
Start by drilling and cutting out the four pieces of aluminium from the patterns given. The holes and solts are best drilled before you cut out the pieces. It is much easier to hold a larger piece of aluminium!
Where slots are shown, simply drill two or three holes close together and form them into a slot using a fine file.
Next, make some holes in the base board for the woodscrews, using the pattern shown. You can do this with a small drill, or by hammering in a small nail and removing it.
The holes in the vertical sections of the "U" bracket may be ordinary 1/8", or preferably tapped 1/8" Whit. If the hole is tapped only one fastening nut is necessary but if it is not, two nuts, one each side of the bracket will be required to hold the contact screw steady.
The screws mentioned in the last paragraph should be pointed. This may be done by first winding a nut on to the screw, then filing the end to a

point with a fine file. Once the point has been made, the nut can be wound off to rethread the screw.
The reason for pointing the screw is that we want to make good electrical contact between the screw and the blade and a point has a much better chance of making contact than a flat end. You will have to polish the blade as well at the point where the screw makes contact. We use a piece of hacksaw blade rather than an ordinary piece of steel, because the "armature" (which the blade becomes) relies on a spring action for its operation.
If you use the end of a hacksaw blade there will be one 3/16" dia hole already drilled in it. If not, you will have to drill two holes. Use the holes in the largest bracket as a guide for drilling the holes in the blade. The holes should match up exactly, as mechanical rigidity at this end is important if the buzzer is to operate correctly. Both these holes should be 3/16" dia.
After you drill the holes, you can snap the required length of blade off. It is easiest to fasten the required length into a vice and then snap the blade by bending it close to the jaws of the vice. You need approximately three and a half inches of blade. Do not worry if it is slightly more than this, but don't use less. Sufficient blade movement may not be realised if you do.
Once cut, the blade (or armature) may be screwed to its mounting bracket.
All brackets may now be screwed to the base board. The screws holding the armature bracket are not completely tightened, to allow it to be moved around to get the optimum position for operation.
Attach the spring terminals in the positions shown. You can screw the terminals directly into the wood by making holes for them slightly smaller than the screwthread, and screwing them in under pressure. Although the thread is not intended to be used as a woodscrew, it works quite satisfactorily.
Place the electromagnet in its mounting brackets, and tighten it with the nut on the "head" end. There should be a short length (approx. 1/16") protruding at the shaft end. This may be seen from the accompanying drawings. The flat of the hacksaw blade should be another 1/32" away from the end of the bolt. Once you have all the pieces in the correct position, tighten up all screws.
Now take the two pointed contacts, and insert nuts all the way on to them. Place a solder lug under one of them, and put them into the holes in the "U" bracket. If you do not have tapped holes, put another nut on the contact to hold it in position. Screw the outer contact into the hole until it just touches the blade when it is at rest. Hold the contact in this position, and tighten the nut(s) hard against the bracket. Repeat for the other contact, but this time hold the blade against the electromagnet, and adjust the screw until it just touches the blade in this position. Then tighten the nut(s).
Now all you have to do is wire the components together, and this will depend on whether you want to make a relay or a buzzer - or both!
The relay is probably the most simple, so we will explain it first. By wiring the electromagnet directly into a source of current (a battery), the coil is energised and the bolt becomes a magnet. This attracts any ferromagnetic material in close proximity - in this case, the blade. By making the blade part of another circuit, we can control the other circuit without actually touching any of the components in it.
In practice, a relay is usually used for the control of a high voltage or high current circuit by means of a low power circuit. In an automobile,

for example, horns and starters are operated by relays to avoid having to route heavy wiring carrying high current to the inside of the car.
To make the relay work, you must loosen the outside nut and remove the screw far enough to make sure that it will not touch the blade in any way. Then connect the circuit up as shown in Figure 1. When you are sure that everything is correct, connect the battery.
If the circuit is correct, the lamp should be out. If it is on, check to see that the screw you just loosened is not touching the blade. If this is not the case, something is wrong with your wiring.
When you get it operating correctly, examine the circuit diagram and note that the circuit which lights the lamp is completely separate from the electromagnet circuit except for the battery connections. We use the same battery for convenience, but the lamp could be connected to another battery of a different voltage or to another power source without affecting the operation of the electromagnet-and-key circuit.
Now we will show how the electromagnet can be used as a buzzer. All you need do is replace the screw you loosened before, and loosen the other screw you were using as the relay contact. Connect the circuit as shown in Figure 2. It will help if you have some kind of key between the battery and the coil. Besides saving the battery, you will be able to experiment with Morse code. If you haven't got a proper key, you can fashion one from tinplate by following the simple diagram in Figure 4.
However, we must point out that using such a key will certainly be detrimental if you seriously try to learn Morse code. A proper hand action must be developed, and this can only be learnt by much practice, on a proper key. Good keys are available quite reasonably from disposals sources. Such a key is a "must" if you are to develop good Morse technique.
First, let's see how a buzzer works. As in the relay, the electromagnet is operated by connecting it to a battery via a switch. When the switch is turned on, current flows through the armature and contact, through the electromagnet, and back to the battery.
Suppose, however, that at the instant we turned the electromagnet on, contact was broken. Current would stop flowing, the bolt would no longer be magnetised, and the armature would immediately spring back to its rest position.
This is exactly what happens with the buzzer - the armature breaks contact with the contact screw, current stops, and the armature sprints back. Butwhen it springs back, it makes contact, and once more is attracted towards the bolt. Contact is broken and the armature springs back. This process is repeated hundreds of times per second, and this movement, pushing against air in its way, produces the audible "buzz".
Once set up, briefly touch the key. A buzz, naturally enough will indicate that the buzzer is working properly. However, it is more than likely that it will not work first time. There are two things which will probably require adjustment. One is the set screw for the contact, and the other is the distance of the blade from the bolt. First of all adjust the screw with a screwdriver, holding the nut(s) with a pair of pliers. If this doesn't work, then try moving the blade closer to the bolt. If none of these work, try adding another battery in series with the other(s). If this doesn't work, then there is probably something wrong with your wiring.

Our buzzer worked quite satisfactorily down to four and a hlaf volts (three cells in series) but was much better on a single six-volt lantern type battery (Eveready type No. 509). It may be necessary to go as high as seven and a half volts or even nine, but this is unlikely.
One final point we might raise about this buzzer. You may notice, particularly if you have moist fingers, that the buzzer gives you a tingle when you touch certain parts of the wiring. We can already hear the questions: Where does this tingle come from? It is dangerous? What is the voltage and current?
We can assure you that it is not dangerous. The current flow would be in the order of one to 10 milliamps, and the amount of current at which danger starts is over 10 milliamps, according to electricity supply authorities.
The tingle you feel comes from the coil, or more precisely, from the collapsing magnetic field and the coil. What happens, briefly, is this : When the contacts break, current from the battery stops and for an instant of time there is no current flow, but there is still a magnetic field around the core. Then this field rapidly dies away. When this happens, we have a changing magnetic field cutting across the coil of wire.
This changing field cutting across a coil "induces" an emf (electromotive force) into the coil. Believe it or not, this emf can be well over 200 volts. In our buzzer, for example, we know that it was well over 120 volts. How did we know?
An easy but novel way to determine the order of magnitude of the voltage is to use miniature neon bulbs. Connect the neon in series with a 1000 ohm resistor, and connect it across the buzzer, that is, between the armature bracket and the contact bracket.
Press the buzzer key, and note what happens to the neon. It should be glowing brightly. As it takes at least 60 - 70 volts to turn the neon on, we can reasonably assume that the emf induced is at least 60 volts. More neons connected in series would also light up until the number of neons multiplied by roughly 60 - 70 exceeded the emf induced. Our buzzer lit two neons, but not three.

WARNING : ON NO ACCOUNT SHOULD THIS SIMPLE RELAY BE USED TO CONTROL ANYTHING OTHER THAN A FEW VOLTS FROM A BATTERY. DO NOT ATTEMPT TO USE THIS AS A CONTROL FOR MAINS VOLTAGE. STICK TO BATTERIES - THEY ARE MUCH SAFER.

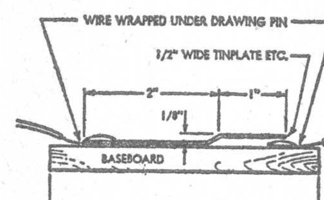


Figure 4. A simple key for experimenting with Morse code can be made from a strip of tinplate and two drawing pins as shown above.

LET'S TALK ABOUT SOLDERING

It is our intention to discuss soldering for beinginners.

Before any soldering operation can be carried out, it is obvious that certain basic facilities must be available, including a bench or table on which to work. It is a good idea to place a protective covering on the table top to prevent accidental burning.
The list of necessary tools is headed by a good soldering iron, the right kind of solder and flux for the job, pliers and wire cutters. From the outset, it cannot be too strongly emphasised that tools of a high grade always pay good dividends and are well worth the extra expense.
The bit of a soldering iron is not iron at all, but a piece of copper. Copper is used because it is a particularly good conductor of heat and it may be tinned readily. In days gone by, many of us had only a smaller version of the familiar plumber's iron. This consisted of a lump of copper pointed at one end fitted with a length of steel rod terminating in

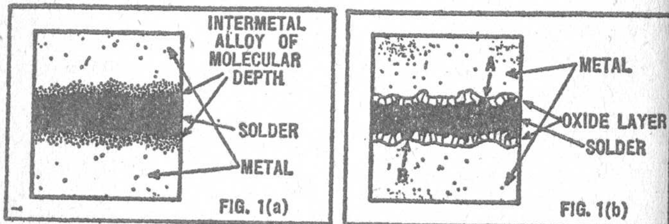


Fig. 1. (a) Diagrammatic representation of a good soldered joint, showing alloy formation between metal and solder. (b) A poor joint with no intermetal alloy and random contact at a few points only.

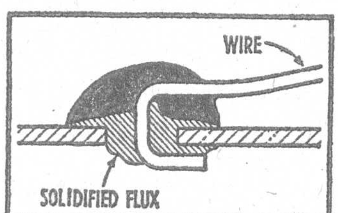


Fig. 2. Another poor joint in which solidified flux gives the joint a deceptive strength which may pass casual inspection. It will inevitably fail in service.

a wooden handle. The copper bit was heated in a gas flame, primus stove, or even an open fire!
At the same time, the solder may well have been a large stick of unknown composition, perhaps 50/50. The flux was usually a paste, or if you were really on the ball, some powered or solid resin.

DISADVANTAGES

Such a set-up had serious short comings. Apart from the fact that the iron was rather clumsy for radio work, the large stick of solder took a lot of heat from the iron, in addition to that required to melt the needed blob. Very soon the iron had to be put back into the fire to be heated again. Added to all these trials, the paste or resin was messy to use.
Later, thinner sticks of solder became available, which made the job easier and did not cool the iron so quickly. When the electric soldering iron made its appearance, it was a rather large unit compared with those of today, but it was a big step forward. The temperature of the bit remained at a useable level continuously and so made soldering quicker and easier.
With the advent of resin cored solder and, later, activated flexes, the process became so much easier again, and we often wonder just how we managed in the bad old days. However, improvements are still going on in order to keep pace with modern electronic requirements.
If you have one of the older style electric irons, then it should be quite alright for general radio work. It would be less suitable for compact transistor radio and similar applications, but may be pressed into such service provided care is exercised and tooverheat the joint and components.
On the other hand, if you wish to purchase a new iron for radio and similar work, then there are many good products on the market from which to choose. A small modern iron rated at about 20 watts would be suitable for normal work but would not be big enough to make a joint to a chassis. One rated at 100 watts or higher would be necessary for this application.
There is also an iron of the instantaneous variety which operates at a lowe voltage. It has a carbon element which is brought into operation only when needed. A control on the handle is pressed forward to complete the electrical circuit. The bit heats in from four to six seconds when it is ready for use. This iron is very versatile but requires a little skill in its use. It is most useful for service jobs and other intermittent applications. For a straight wiring job, the constant heat type may be just as desirable.

TYPICAL TYPES

In order to give the reader some idea as to what is available on the local market, the standard type is available in 40, 60, 75, 100, 150 watts and higher. A similar type but somewhat smaller is available in four models, 240 volts, 19 to 27 watts.
Getting down to the miniature types, we have various models for 6 and 12 volt operation, rated from 10 to 40 watts. Also among this type is the "Oryx" available in a wide variety of low voltage and wattage ratings.
Typical quick-heating models are marketed. The larger types are capable of soldering to a chassis and down to light radio joints.
All irons designed to operate on low voltages must be used in conjun-

ction with a suitable step down transformer. This is a good feature as it makes for added safety. Alternatively, in an emergency, they may be operated from a suitable tapping on a car battery.
Before any soldering can be done, the bit of the iron must be properly tinned. If the iron is an old one and the bit is pitted or dirty, it should be filed to give a clean and even surface. This is best done with the iron hot. Immediately apply resin cored solder until a thin layer flows over the cleaned surface. In the case of a new iron, it is only necessary to tin the bit as soon as it comes up to temperature.
As time goes on and the iron has had considerable use, the bit will become corroded or pitted. When this occurs, it should be put back in order by filing and tinning as before. The copper in the bit is actually dissolved by the tin in the solder. Some solders are "loaded" with a small percentage of copper which has the effect of reducing this nuisance.

(In the case of some irons a new bit may be purchased for a few pence and is easily screwed into place. It is seldom worthwhile attempting to "dress" such a small bit.)

PRACTICAL SOLDERING

The art of soldering is no longer confined to the expert craftsman as it was in days gone by. With the coming of radio and its rapid development, then television and the vast electronics field, the soldering process has been considerably improved and simplified, as already discussed.
What makes a soldered joint so important?
Although it is not always easy to quote actual figures, there would be between one and two hundred soldered joints in a radio receiver, while a local manufacturer quoted a current television receiver as having about 600 soldered joints (This is not counting the joints in prefabricated components). Any one of these joints could be a potential source of trouble if not made correctly.
What is worse, faults due to faulty soldered joints are frequently intermittent; the kind that may cost pounds in a serviceman's time before being tracked down and cleared. And it doesn't take many such faults to ruin a manufacturer's reputation.
Here is a list of important points vital to the success of soldered joints:
(1) The parts to be soldered must be mechanically and reasonably chemically clean.
(2) Solder having the correct ratio of tin to lead should be selected to suit the particular application.
(3) Similarly, a suitable flux should be used, dictated by the job in hand.
(4) The temperature of the iron must be high enough to ensure efficient "wetting" of the metals.

POINTS IN DETAIL

Let us consider these points in turn:

(1) CLEANLINESS

Much already has been said about this but it is important enough to bear repetition, with particular emphasis on the practical aspect.
Untinned or unplated metal should be scraped with a knife or rubbed with an abrasive cloth. It is not sufficient to make a few streaks, the surface must be made bright all over. If the part has been plated and is dirty,

it should be similarly cleaned.
Having cleaned the parts, they should then be tinned. In fact, it is desirable to tin all parts where possible, before making the actual joint. Tinning is carried out by applying the soldering bit to the part for sufficient time to bring the temperature up to that of molten solder. Just enough resin cored solder is applied to the part to provide a thin coating over the surface required for the joint.

(2) (3) CORRECT SOLDER AND FLUX

In radio and similar work, 60/40 solder is the most suitable, with activated resin as the flex. These two requirements are met with resin cored solder. The gauge of solder should be selected in accordance with the size of soldered joints to be made. For normal radio work, 16 or 18 gauge will be satisfactory.

(4) IRON TEMPERATURE etc.

The application of heat to the soldered joint is possibly the most important single aspect of soldering. It is certainly as important as cleanliness and in some ways more so. After all, a good flux will do some of the cleaning for you - even though one should not depend on it - but there is no substitute for heat.

The whole situation may be summed up in the following statement:

IN ORDER THAT A SOLDERED JOINT BE PROPERLY MADE, IT IS ESSENTIAL THAT THE TEMPERATURE OF THE JOB, i.e. THE PIECES OF METAL TO BE JOINED, SHALL BE HOT ENOUGH TO MELT SOLDER.

That may sound a simple statement but it is well worth while reading again and thoroughly digesting. Once this point is fully appreciated, the beginner is well on the way to making successful joints.
More specifically, we cannot have molten solder in contact with a piece of metal which is below the temperature at which the solder melts. Although most of the solder may still appear molten, that portion actually in contact with the cooler metal must be solid. And in this condition, none of the processes whereby the solder combines with the metal can take place.
This is the reason why, when solder is first applied to a joint, the metal appears to repel it, much as a greasy surface repels water.
After a few moments - if all is well in other respects - the solder will suddenly "flow" or "wet" the surface, indicating that the temperature of the metal has finally reached that of the molten solder.
Because this requirement is so important, many authorities insist that the solder should never be applied to the iron, but only to the job. In that way there can be no mistake that the job is hot enough because the solder will not melt until it is. Unfortunately, while this is sound reasoning for large jobs, there are very good reasons why it cannot always be applied to delicate electronic components.

OVERHEATING

While it is true that we can apply the iron to the joint and heat it - eventually - to the required temperature there is a serious risk that this will take far too long, with the result that the heat will be conducted along the pigtails and into the body of the component where it can cause damage.

One reason for this is that the iron may not make intimate contact with the irregular shape and small area of the job. However, if a small amount of solder is fed to the bit while it is in contact with the job, this will develop the joint and assist materially in conveying the heat quickly. When it "flows" indicating correct temperature, more solder may be applied if the size of the job requires it. While on the subject of applying solder to the job, we should make another point. Solder should not be conveyed from the stock to the job as a molten blob on the tip of the iron. In the time needed to transfer the solder, most or all of the flux will have been burnt or vaporised, most likely resulting in a dry joint.

However, there are times when three hands are necessary to carry out a particular function, and sticking to these rules may be difficult. In cases where both parts are already well tinned and it is only necessary to apply solder to the joint, this rule may often be broken by an experienced solderer.

Strictly speaking, an experienced operator is not breaking a rule at all. He will have checked that there is still some flux on the joint and will move quickly in transferring the solder from the stock to the job, so that some of the flex picked up with the solder will still be active. This last point in soldering can be quite contentious and who knows, may become a subject for "Argument".

HOW HOT?

Reverting to the subject of heat, just when is an iron at the right temperature?

Provided the iron is in good condition and is operated at the correct voltage, the temperature should be right almost automatically. In cases where the bit is adjustable, the temperature may be varied somewhat by sliding the bit in, to make it hotter, or out, to make it cooler. Low voltage miniature irons, operated from transformers, often have a voltage adjustment provided for the same purpose.

The quick heating type of iron, on the other hand, must have its temperature adjusted by the operator. This is done by releasing the switch when sufficient heat has been generated. This calls for a certain amount of skill and judgement, but is soon acquired after a little practice.

Should the iron temperature be too low, the solder will not melt properly, resulting in a "putty" which produces a messy looking dry joint. Also, the iron may need to be applied for an abnormal time. This leads to overheating of components with a serious risk of damage. Polystyrene capacitors may be melted, resistors can change considerably in value and transistors may even be rendered useless, just to mention a few possibilities.

If the iron is too hot, the bit will burn and corrode excessively and will be difficult to keep properly tinned. Again, there is the risk of damage to components due to overheating, unless the operator is very quick and careful. To sum up on this point, have the iron at a temperature which will melt the solder immediately it is applied, but not so hot that it loses its "tin" rapidly or tends to corrode.

Several times in our discussion, so far we have mentioned a "dry joint" and it may be helpful to enlarge on this term a little. Fig. 1a portrays a section of a soldered joint magnified. The process has been carried out properly and the solder has "wet" the metal. The intermetallic compound is shown dotted and is continuous throughout.

Fig. 1b illustrates a "dry" joint. A layer of resin and oxide forms a barrier between the solder and the metal. The barrier may be penetrated at one or more points. The result is a high resistance union with little mechanical strength and which may be easily shaken loose.

Fig. 2 shows another dry joint where a wire has been fixed to a solder lug which has not been previously tinned. The solder has taken to the wire, but the greater part of the space between the wire and lug is occupied by resin, with only a token contact of solder to the lug. The unfortunate part about a dry joint is that it may look quite normal.

Although a good soldered joint is quite strong in its own right, it should not be relied upon for any great mechanical strength. Where the equipment is subject to vibration or heavy components are used, the leads should be made mechanically secure by twisting them around the terminating point before being soldered. Where vibration is not a problem wire leads and small components need only be rested against the lug and soldered.

It will now be assumed that the necessary equipment is available, including some 60/40 resin cored solder and that you are ready to start soldering. Most components used in electronics, which are to be soldered are already tinned or plated. This makes the job quite easy.

For the purpose of illustration, a unit will be considered consisting of octal type valves, all glass miniature type valves, a printed board, a germanium diode, and a transistor. Such a case is purely hypothetical and is not likely to be met in practice, but it will serve to illustrate the treatment of various types of components.

It is a good idea, when wiring valve sockets, particularly the glass base miniature types, to insert a valve in the socket being wired. This avoids the possibility of the socket lugs becoming mis-aligned, with apossibility of cracking and estroying the valve when it is plugged in later. The writer has sad memories of such an accident occurring to an expensive valve which had been brought back from overseas.

It is often -convenient to run filament leads directly from the power transformer to an octal socket. This may well be 16-gauge enamelled wire with a PVC sleeving over it. The wire is cut to length, about $\frac{1}{4}$" of sleeving removed from the end with a razor blade and the enamel scraped from the piece thus exposed. Be careful when using a razor blade to remove insulation from any wire. Even a small nick in heavy solid wire will weaken it and may lead to a breakage. It is also quite easy to cut through some strands of stranded wire.

It is important to note that the PVC insulation will not stand much heat before it melts and spoils the appearance of the lead. So, using a minimum of heat, tin the exposed end of the wire and make sure that it is tinned all round.

The other lugs on the valve socket should also be tinned. Use as little solder as possible so that the holes in the lugs are not filled. If they are filled, surplus solder may be drawn off with - the bit it the latter is stripped of all free solder. Wiping the bit with a cloth or "flicking" it quickly, will achieve this. In extreme cases, surplus solder may be removed from the lugs by inserting a scrap of wire while the solder is molten.

Lead ends, previously tinned, may now be pushed through the holes in the apprbpriate lugs, with about 1/16 inch protruding. The iron tip is placed against the junction for sufficient time to bring it up to temperature. Solder is fed to the junction in just sufficient quantity to ensure a neat blob. When the solder has flowed and wetted the joint, the iron is removed immediately.

While the solder is cooling to the solid state, make sure that the parts are not moved. If movement takes place, the solder will take on a dull appearance and may form a high resistance joint. If so, it must be reheated and a little more solder applied to provide fluxing. A shining, neat joint should be the result. By the way, any resin covering the joint may be left there. It will do no harm, and is often regarded as a protection against corrosion.

Should the octal socket be for a rectifier, it is likely that a rather large electrolytic capacitor will connect between filament and chassis. Although the capacitor is heavy, it is quite in order to wire it direct to the socket, which should be strong enough to support the weight.

Do not wire in any components using more length of pigtails than is really necessary, as the result is usually an untidy mess.

CHASSIS JOINTS

Next we may consider connections to the chassis. This presents some problembs, and several factors must be considered. In the case of zinc or cadmium plated steel it is possible to solder direct to the chassis, provided a 100 watt or larger iron, or one of the larger "quick heating" types, is available.

With brass or copper, either plain or plated, it is still possible to solder to the chassis but another factor makes the job more difficult. Brass is a much better conductor of heat than steel and copper is even better. As a result, it is difficult to supply enough heat to raise the temperature to that of molten solder. It can be done with a large and very hot iron but care must be taken not to damage other components in the process.

A better method for brass and copper, and also for aluminium, where we have little choice is to provide a solder lug, screwed TIGHTLY to the chassis in the appropriate position. This method may be used in almost any circumstances and is perhaps the most popular.

Before a lug is fitted to a painted chassis, an area of paint must be removed in order to make a good electrical connection. When soldering direct, the paint will almost invariably be burnt on the opposite side as well as around the joint leaving an unsightly appearance.

The foregoing considerations with respect to octal socket wiring apply more or less to 7 and 9 pin miniature sockets, scaled down in proportion. It would not be wise to connect 16 gauge wire or heavy electrolytics direct to the socket lugs but 18 guage wire and other normal components are quite in order. Don't forget to plug a valve, preferably an old one, into the socket before wiring. This applies particularly in cases where the socket lugs are bent and soldered to the centre spigot or to the chassis.

Care should also be taken not to apply too much heat to the socket which could crack the valve. Also excessive solder should be avoided as it may run down into the socket contacts or short to adjacent lugs. This may sound involved, but after a little while these precautions are taken automatically.

In circumstances where it is necessary to use heavy gauge leads and

heavy components with miniature sockets, this is best done by terminating the leads on a nearby tagstrip. Ordinary hook-up wire may be then used to complete the connection.

Perhaps the most fascinating type of unit to "wire up" is the printed board. Actually, the "wiring" has already been done by etching a copper pattern on an insulating board. Holes are drilled at the appropriate positions to allow a components pigtail to be passed through and soldered. The deposited copper strips then perform the function of hook-up wires.

After bending the component leads so that they match the relevant holes in the board, push the leads through these holes and cut off the excess, leaving about 1/16 inch to bend over slightly. All components may be mounted this way and then soldered.

It is not necessary to cram the components hard against the board. This practice may result in the leads being unnecessarily short or even being bent sharply close to the component in question, which should be avoided unless really necessary.

The trend with these boards is to miniaturisation. Considerable care must therefore be exercised to avoid over heating the components and burning the board. Unless you are a practised and fast solderer, and even then, it is desirable to use some form of heat sink. A good idea is to hold the pigtail with a pair of pliers between the component and the point to be soldered.

Whether or not you use a heat sink during soldering of general components, we strongly advise that you do so when dealing with germanium diodes. When soldering transistors a heat sink is an absolute must because damage is almost inevitable if they are overheated.

A worthwhile procedure is to cut the pigtails to the required length and to tin the ends before mounting the components. This helps to prevent dry joints, as was pointed out previously. Sometimes component leads which are supposed to be pre-tinned are very difficult to solder. A rub with fine emery cloth or a scrape with a knife or razor blade usually fixes the trouble. This also prevents the components or board from getting too hot while trying to make the solder "take".

Transistor leads need not be cut at all, since they are self-supporting on the lengths provided and this will reduce the risk of heat damage. Some spaghetti tubing may be slipped over the exposed leads to avoid the possibility of short circuits.

Do not use an excessive amount of solder, just enough to make a neat blob. Care should also be taken during the soldering process not to allow a "dag" of solder to fall across adjacent copper leads on the board and so short them together.

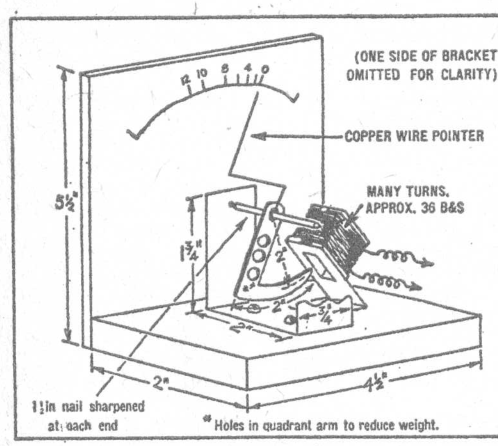
All the foregoing sounds rather involved but it is much easier to make a soldered joint than it is to write how to do it! Remember, skill and proficiency come with practice.

A DO-IT-YOURSELF LESSON ON METERS

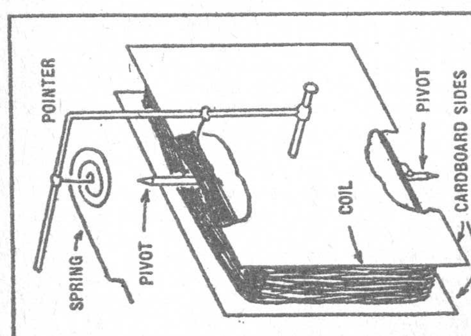
Beginners often find difficulty in understanding the operation of the various measuring instruments used in electrical and radio work. This chapter attempts to aid newcomers by explaining the operation of some common types of meters from first principles. Details are given to enable simple meters of each type to be constructed from common workshop materials.

When a source of electromotive force (EMF) such as a battery, is connected across a conducting circuit such as a coil of wire, electrons drift around the circuit. This drift of small negatively charged electronis is called a "current flow".
According to the well-known rule of schoolday physics, "like charges repel, while unlike charges attract". Thus the direction in which the electrons drift around a circuit is away from the negative polarity of the applied EMF and toward its positive polarity. The rule for the direction of current flow is thus "electrons flow from minus to plus".
When currents were first observed, however, they were thought to be due to the flow of small POSITIVE charges around a circuit.
When the direction of current flow as decided upon, it was accordingly the opposite of the present day idea - namely, "current flows from plus to minus"
The old idea of current being a flow of positive charges has remained with us, and is the basis on which the operation of various devices is explained. Thus, we find that many electronics people still use the "plus-to-minus" convention of current flow in discussing circuit operation. In the following discussion, we will point out the differences produced by the two conventions wherever ambiguity is likely.
(Really, it matters little which way we imagine current, for a flow of negative charges in one direction is effectively the same as a flow of positive charges in the opposite direction. Either may be used to explain circuit operation. It is clear to all concerned whether we are speaking of "conventional" current flow or electron movement).
Electrons find a certain amount of difficulty in drifting through a circuit, (1) because they tend to colide with electrons and atoms of the material of which the conductors are made and (2) because they are subject to thermal (heat) energy which tends to accelerate them in random directions.
To make a certain required net number of electrons flow around the circuit in a given time, a certain order of "pressure" in the form of EMF must be applied. In fact, as found by Mr. Ohm, the current which flows - in the form of so many electrons per unit time - is directly proportional to the size of the applied EMF. Twice the applied EMF results in twice the current, and so on.
To describe the value of EMF which must be applied to a given circuit to produce unit current flow, a characteristic of the circuit known as its RESISTANCE is defined. A circuit requiring a high value of EMF to produce unit current is said to have a high resistance. If "I" represents the current produced and "E" the EMF necessary to produce it, then "R" the circuit resistance is given by E/I.
In the "Rationalised M.K.S." system of units, the resistance of a circuit in OHMS is given by the applied EMF in VOLTS divided by the current produced in AMPS.
Because EMF is expressed in volts, it is fairly common practice to use the term "voltage" in place of "EMF".
We often require to know what is happening in an electrical circuit, whether voltage and current are present, for example, and their size and direction. None of our senses is able to supply us with this information directly and satisfactorily, so it is necessary to use instruments which "translate" electrical goings on into visual or audible indications.

These instruments, called measuring instruments play a big part in electrical and ratio work, since they provide a measure of phenomena which are otherwise rather intangible. An understanding of the operation of measuring instruments is thus essential for people concerned with the building and servicing of electrical equipment.
Many measuring instruments use, or are built around, devices known as "meters". These are simply devices which translate a certain electrical quantity into a visual indication, usually in the form of the position of a needle or "pointer" along a calibrated scale.
We will consider one such device in this chapter.
The type of meter whose operation is probably the most easy to understand is the so-called "moving iron" meter. This type is used mainly for the measurement of heavy alternating current in power stations, switchboards, etc.



A sketch of the moving iron meter, giving the main details of its construction. Built from some scraps of wood and brass and a few yards of wire, it is easy to assemble.



A diagram showing the construction of the moving coil assembly used in the meter described on these pages. This part of the meter is also shown in the photographs on page 51.

The moving iron meter, in common with other types which we shall be discussing later, relies for its operation on the fact that a current flowing through a wire causes a magnetic field to appear around the wire. The direction of the magnetic field produced is given by the well-known "right-hand grip rule". If the wire is gripped with the right hand in such a way that the thumb points in the direction of the current flow, then the fingers of the hand show the direction of the magnetic field.

NOTE ON FLOW

(Note that this "right-hand grip rule" is based on the convention mentioned earlier, that current flows from positive to negative. The direction of the field is based on the further convention that it represent the direction in which a hypothetical "free" north pole would move.)
When a wire is wound into the shape of a solenoid coil, and a current is passed through it, the magnetic fields produced by all the sections of the wire add together. The resultant or total field produced is very similar to that which would be produced by a bar magnet placed inside the solenoid, along its axis.
In other words, the resultant field passes through the centre of the solenoid in concentrated form along its axis, then curls out, around and in again at the other end. The field at one end of the coil behaves as the north pole of a bar magnet, at the other end, the south pole.
The direction of the field may be determined from the previously mentioned right-hand grip rule, providing one knows the direction in which the current is flowing and the direction in which the coil was wound. The strength of the field can similarly be calculated from a knowledge of the current and of the coil dimensions.
For the purpose of this discussion, however, it is sufficient to know that there is such a field produced and that its strength is directly proportional to the size of the current flowing in the wire. Twice the current produces twice the field strength and so on.

MEASUREMENTS

Because of this proportional relationship, a solenoid of wire may be used to measure the current flow in a circuit. The current to be measured is passed through the solenoid, whereupon a magnetic field is produced whoe strength is proportional to the currents magnitude. The magnetic field is used to operate an indicating pointer in the following manner: A piece of magnetic material such as iron, nickel or cobalt is placed near the solenoid so that it may be attracted by the magnetic field. It is mounted on a shaft which has pivots allowing the piece of material to move toward or away from the solenoid, in the direction of the total field.
An indicating pointer is attached to the same shaft, to indicate the position of the moving piece of magnetic material. The pointer is made to move over a scale or dial which may be calibrated directly in units of current.
The mechanism is so arranged that the piece of magnetic material normally occupies a position some distance from the solenoid. It is held in this "at rest" position by a maintaining or restoring force, in the form of gravity, another magnet or a spring.
When a current is passed through the solenoid, magnetic attraction

tends to pull the piece of magnetic material towards and into the solenoid. To move the magnetic material, however, the magnetic field has to overcome, to some degree, the force which wants to hold the mechanism in its "at rest" position.
The restoring force is arranged to be of a magnitude proportional to the distance of the piece of material from the rest position. In other words, the further the magnetic field tries to put it from the rest position, the larger the opposing force it has to overcome.

PROPORTIONAL READING

It is this proportional -to-amount-pulled nature of the restoring force which makes the device give a position reading proportional to the strength of current passing through the solenoid. Consider, for example, what happens when a current "I" is passing through the solenoid.
Due to the current, a magnetic field proportional to "I" will appear around the solenoid. This will attract the movable piece of magnetic material toward the solenoid, with a force proportional to "I".
Under this attraction, the piece of material, accompanied by the indicating pointer, will move toward the solenoid UNTIL the restoring force - which increases with the distance moved - just equals the attractive force. There is then no resultant force on the moving system, and it will remain stationary until the current is changed in value or removed.
If a current of "2I" is passed through the solenoid, there will be twice the force of attraction acting on the moving system. It will thus come to rest at something like twice the distance from its rest position, since it will have to move that far for the restoring force to euqal the attractive force.
It should thus be clear that the "moving iron" meter so formed will give pointer positions corresponding to the current passing through the solenoid. Accordingly, once it has been calibrated with known currents, it may be used to measure unknown currents.

FOR DC OR AC

The moving iron meter may be used for either direct or alternating current measurements, for its principle of operation does not involve constant polarity effects. On alternating current, the pulsating nature of the attractive force causes the meter to read effectively the root-mean-square or R.M.S. current.
A simple moving iron meter is easily constructed along the lines shown in the photograph. A solenoid is made by winding as many turns of enamelled copper wire (approx. 38 s.w.g.) as possible on a hollow "former" made from scrap brass.
The coil former is made from two small strips each bent into a shallow "U" and soldered to a small brass bracket having a rectangular hole corresponding to that formed inside the solenoid coil. Before the coil is wound, the former should be insulated by winding a strip of paper around the brass strips, fastening the end with adhesive tape. The former support bracket is screwed to a wooden block serving as the base of the meter. A quadrant arm is cut from sheet iron, having a hole at one end through which the suspension shaft passes and is soldered.
The shaft for the prototype was made by cutting the head off a two-inch nail, and then sharpening the ends to a smooth, sharp point. At

the centre the quadrant arm is soldered, and here too a few inches of copper wire are soldered to serve as the pointer.
The moving assembly thus formed is supported by a bracket made from a strip of aluminium. The strip is bent into a "U" and is given a centre-punhhed "dimple" near the inside top of each upright arm to receive the bearing points of the spindle shaft.
The support bracket is screwed to the base block in a position such that the end of the bent arm of the quandrant is close to and able to enter, the hollow former of the solenoid. Thus, when attracted by the field of the solenoid, the quadrant can enter the solenoid freely.
The indicating scale is drawn on paper, and is glued to a piece of panel board or plyboard fastened to the base block.
What provides the restoring force?
Gravity, in this case, for the natural position of the quadrant arm assembly will be as shown in the photograph. When pulled away from this position by the field of the solenoid, the quadrant will try to return to its rest position, seeking to place its centre of gravity directly below the pivot axis. The further it is pulled, the greater the restoring force will be so that our proportional-to-position force is provided.

ONE POSITION

You may have realised, however, that this places a limitation on the simple moving iron meter, for it cannot be used in any position other than that shown. Unless, of course, a different construction is used or a spring is used to provide the restoring force rather than gravity.
The moving iron meter shown is calibrated in voltage, rather than in current as we were previously considering. The voltage calibration is possible because the solenoid coil has a certain resistance. Thus, for a certain voltage applied to it, there is a corresponding current according to Ohm's Law. The meter responds to the current, but we can calibrate the scale in voltage simply by marking the deflection produced when various voltages are applied to the solenoid.
In this simple form, the meter may be used to indicate the voltage available from batteries delivering up to a few volts. It may not be highly accurate and it will draw a fair amount of current from the battery being tested, but it will teach you some basic facts in such a way that you will not readily forget them.
Of all electrical meters, the moving coil instrument is perhaps the most common. It is the type normally envisaged when the word "meter" is heard, and is used in multimeters, vacuum-tubes voltmeters, valve testers, and countless other devices.
The moving coil meter depends for its operation on the fact that a current carrying wire, when placed in or surrounded by a magnetic field, experiences a force. The force is proportional to three things - the size of the current, the strength of the field, and the angle between them. The direction of the force is at right angles to both that of the current and that of the field, and its sense is given by the classic "left-hand motor rule". This rule may be stated as: "If the thumb and first two fingers of the left hand are extended so that they are all at right angles to each other, and if the first finger is made to point in the direction of the magnetic field while the second finger points in the direction of current flow, then the thumb points in the direction of motion. That is, the direction in which the force is experienced and in which the wire

will attempt to move".
One way of remembering this rule is to simply remember "First Finger - Field" and "Thumb - Motion", stressing the "f's" in the first case and the "m's" in the second. With the thumb and forefinger correctly placed, one can hardly go wrong! Unless, of course, one uses the wrong hand, or uses electron flow rather than conventional current flow - whereupon the world seems to act rather queerly!
To demonstrate the force which acts upon a current-carrying conductor in a magnetic field, it is possible to construct a very simple piece of apparatus. This is shown in the first and second photographs.
As you can see, the apparatus consists of a battery, a push button and a magnet-conductor device constructed in the following way:
Firstly, a block of wood 4" x $4\frac{1}{2}$" is prepared as a base. Near one corner of the base, a piece of wood 2" x 1" x 1" is screwed on its end to form a support piller. To the top of the pillar is screwed a small piece of sheet metal (1" x $\frac{1}{2}$"). The piece of metal overhangs the side of the pillar by about 3/8" and has a centre-popped "dimple" in the underside of the overhanging section.
A similar piece of metal is screwed to the base in such a position that its dimple is directly below that of the piece mounted on the pillar.
Wires are connected to the two pieces of metal for connecting to the push button and battery (a 22 ohm resistor should be wired in series with the battery to limit the current.)
The moving conductor is then made, by bending a $5\frac{1}{2}$" length of copper wire, which has been stiffened by stretching into a "U" shape with small outward bent sections at the end of each leg. The conductor is then sprung into the space between the two fixed contact plates so that its ends sit in the dimples. The conductor is thus able to pivot, using the dimples as bearings.
A magnet from an old telephone magneto (many of these are available from disposals sources) is placed on a small square piece of plywood so that its poles are on either side of the vertical centre section of the movable "U".
When the push button is depressed, current will flow. The "U" will experience a force and will swing either into or out of, the magnet. The direction in which it swings will depend upon the direction of the current and which way round the magnet is placed. You can check the various combinations and directions for yourself, verifying them with the rule given above.
Now for the next step.
When a wire is wound into a coil, placed in a magnetic field as before and a current passed through it, the coil experiences a couple or "turning moment" (torque). This is due to the fact that conductors on one side of the coil, having current flowing in the opposite direction to that of the other side, experience a force in the opposite direction. The coil thus tends to turn in the field.
As one would expect, the strength of the torque experienced by the coil is proportional to the current flowing through it. Thus the principle can be used to produce a current measuring meter.
If we place such a coil in a magnetic field and arrange for it to be able to pivot under the induced torque while carrying current, it will simply swing around in one direction or the other. To make it stop in a position proportional to the size of the current, we must provide a proportional-to-distance-moved restoring torque to oppose the induced torque.

This will function in exactly the same fashion as the restoring force in connection with the moving iron meter. The higher the current, the further the coil will have to swing from the rest position to balance the induced and restoring torques and reach equilibrium. The reading will thus be directly proportional to the magnitude of the current in the coil. As before, a pointer is attached to the moving coil system, and arranged to move along a scale. The scale may then be calibrated directly in units of current, etc.
A simple moving coil meter may be constructed using a magnet, some wire and some scraps of wood and metal. The one shown in the third and fourth photographs was built up in about an hour and a half, and should present beginners with few problems should they wish to duplicate it as a tuitional exercise.
The size of the device will depend to a large extent upon the size of the magnet used, so it is advisable to procure the magnet before commencing the construction. Obtain a horse-shoe shaped magnet having poles about $2\frac{1}{2}$" apart, and with as high a field strength as possible.
Prepare a piece of 3/8" plywood so that it is in the shape of a square approximately 3/8" smaller (side-to-side) than the distance between poles of the magnet. Cut two squares of thin card so that they are about 1/8" smaller than the distance between the magnet poles, and glue or staple them to the square of plywood, one to each side.
Next, drive a small nail halfway into the centre of two opposing edges of the wooden square. Cut the noid heads off, and sharpen the ends, which will become the pivots on which the coil will swing.
In the coil former so formed, wind on 50 or so turns of 26 S. W.G. gauge enamelled copper wire. Before winding, solder one end of the wire to one of the bearing nails, which will become the lower hearing-cum- contact.
Next, partly drive a small noil into the centre of one side of the coil block. To the nail solder a $6\frac{1}{2}$" length (approx) of 16 gauge tinned copper wire in the manner shown bending it at right angles about $2\frac{1}{4}$" from the nail. To the wire also solder the remaining end of the coil.
Next, a baseboard should be prepared of a size suited to that of the magnet. To the base, and near the centre of it, screw a wooden pillar about $1\frac{1}{2}$" higher than the side-to-side dimension of the coil.
Two small bearing brackets should now be made, having dimples to receive the pivots of the coil. One bracket is fastened to the wooden pillar near the top, and the other to the base with its dimple directly below that of the first. Arrange the two so that the coil will fit between the dimples and swing freely.
Next, make a spiral spring by stretching three or four inches of approximately 20 gauge tinned copper wire and bending it freehand into a spiral of outside diameter about 1". Bend the inside end up at right angles as shown and solder it to the pointer wire of the coil system at a point as close as possible to that directly on the pivot axis.
We suggest stretched copper wire for the spring mainly because it should be most readily available and easy to solder. If you can easily substitute wire with better "spring" qualities, it will be all to the good.
With the coil mounted between the pivots, solder the free end of the spring to a solder lug screwed to the supper support bracket in such a way that the rest position of the coil is as shown. The coil is thus provided with a restoring torque. The spiral spring is also used for the top connection to the coil.

Make a dial and scale from a piece of aluminium and a square of paper or card, screwing the dial to the top of the support pillar. Then, with the magnet placed on the base with the coil between its poles, the moving coil meter is complete. It may be calibrated by passing known currents through the coil and marking the deflections produced.
The unit shown in the photographs, which uses a magnet from an old telephone magneto (of different style to that used before), gives a full scale deflection with about 700 milliamps passing through the coil. The actual figure obtained will depend upon the strength of the magnet, the size of the coil, the number of turns and the way in which the home-made spiral spring behaves!

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