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BY B. B. BABANI

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BY

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BERNARDS (publishers) LTD
The Grampians
Shepherds Bush Road
London W6 7NF

I.S.B.N. 0 900162 42 2

First published – February 1975
Reprinted – January 1977

Printed and manufactured in Great Britain by
C. Nicholls & Company Ltd

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AN ELECTROSCOPE

AN ELECTROSCOPE - A DEVICE USING VERY THIN METAL FOIL TO DETECT THE PRESENCE OF STATIC ELECTRICITY. HERE IS A MODERN VERSION - USING SOLID STATE TECHNIQUES AND A MOVING COIL METER.

Benjamin Franklin's famous kite flying experiment during a severe thunderstore is quoted in many elementary science texts as an introduction to the subject of static electricity. If Franklin had really understood the dangers he was courting, he might have been content with less spectacular experiments. Those of our readers who are interested in the subject will not need to do things the hard way, as Franklin did. They can build the simple electroscope described below. But first a word about the nature of static electricity.

Many readers will have experienced a slight, or possibly even unpleasant, electric shock when leaving a car. Many readers will have experienced the phenomenon of visible sparking when taking off a silk or nylon garment in a dark room, usually hearing at the same time a distinct crackle. Similar results are often obtained when dry hair, free from greasy preparation, is combed with a plastic comb. These are but three examples of static electricity. There are many others which individual readers will have experienced without necessarily knowing the cause of the phenomenon.

Static electricity of this type is brought about by friction. When you slide across the plastic-covered car seat, static electricity is generated. The nylon shirt rubs against the cotton or woollen garments and static electricity is generated. In hundreds of cases when two dissimilar materials rub together, static electricity is generated.

This static electric charge is in fact a shortage, or an excess, of electrons in the materials concerned. Some materials lose electrons readily to other materials, and thereby become positively charged when moved in frictional contact with such materials. Others acquire electrons readily from other materials, and become negatively charged.

By a suitable choice of materials, the maximum transfer of electrons can be induced. Plastic materials generally are greedy "swallowers" of electrons when suitably excited; other materials, such as wool, cotton and silk, are not so able to retain their quota of electrons from the electron grabbers.

The voltage which can be generated by such means are surprisingly large, and even rubbing a plastic ballpoint pen on your sleeve can generate a charge of hundreds of volts. However, the amount of actual energy stored is fortunately very small, so you are in no danger of being severely shocked by your charged-up ballpoint.

Glass is a material which gives up electrons fairly readily, and rubbing a glass rod with a piece of silk or nylon can induce in the rod a respectable positive charge.

Before the introduction of AC voltages, and the development of transformer theory, electrostatic generators were the only means available to science for the generation of high voltages for experiments, including those which led to the generation of X-rays.

The presence of electrostatic voltages can easily be demonstrated by the so called electroscope. A simple electroscope may be easily constructed from odds and ends and indicates the magnitude of static electricity of either positive or negative polarity by the movement of small pieces of metallic foil.

The foil pieces mutually repel each other when they acquire the same static charge. This action is a practical demonstration of the rule that like charges repel each other. The simple electroscope cannot, however, demonstrate the rule that opposite charges attract each other, as it is so arranged that the two pieces of metal foil will always have the same charge, of either positive or negative polarity.

A glance at the diagram will show how this is achieved. The foil pieces are attached to the same wire so any charge acquired through this wire will affect both pieces of foil identically.

To construct the electroscope, the first thing to acquire is a clear glass bottle with a capacity of about 10 to 20 fluid ounces, preferably with a rubber stopper; otherwise an ordinary cork stopper can be used. The type of bottle used by chemists for storage of liquid pharmaceuticals is very suitable. The only other requirements are a short piece of fairly substantial insulation sleeve, such as the inner sleeve of a coaxial conductor; about 6" of about 22 gauge non-insulated copper wire; and two pieces of very thin foil. With regard to the last named, it should be noted, to avoid disappointment, that ordinary domestic foil or foil used in chocolate and cigarette wrappers, is too heavy, and will not operate satisfactorily. Gold leaf is perhaps the best to use, but failing this, foil salvaged from an old paper-type capacitor will do very well.

The first thing to tackle is the copper wire which will support the foil pieces in the bottle. First, cut off about $\frac{1}{4}$" and shape it into a hook, as shown in the diagram. The end of the longer piece is then similarly shaped, and the two pieces can be soldered together, taking care not to put any solder on the hook section where the foil will be placed. Next, fit the insulating sleeve over the wire. The better the insulating qualities of this sleeve, the longer the electroscope will remain charged, as the purpose of the sleeve is to prevent the charge leaking away through the stopper. The sleeve should be a tight fit over the wire, to hold it firmly in position.

(It may seem curious to have to insulate something from a glass bottle. In fact, many types of industrial glass are very slightly conductive. Again, chemicals which may have been stored in the bottle could have left a microscopically thin conductive layer on the inner surface. Either way, a charge intended for the metal rod can distribute over the whole surface of the bottle, defeating the whole experiment. The real purpose of the bottle is to prevent the foil from being disturbed by air currents.)

Now a hole must be drilled or bored through the cork, in which the wire and insulator assembly must make a firm fit. When the wire assembly is fitted through the hole in the cork, the top of the wire may be shaped into a circle of about $\frac{3}{4}$" dia. and soldered.

The foil pieces can be prepared next and fitted on to the hooks. The size of the foils is not critical but about 1" long and $\frac{1}{4}$" to $\frac{1}{2}$" wide should give satisfactory results. Carefully make a small hole with a pin as close to one end of the foils as possible, and slip them on to the hooks. This completes the assembly, and the cork can now be carefully inserted into the bottle mouth. You are now ready for your experiment.

This will typically involve generating a static charge by rubbing a plastic pen or a plastic ruler on a dry shirt sleeve or coat sleeve whichever happens to produce the best result.

When a plastic pen or ruler is rubbed on a piece of cloth, heat is produced by friction where the two surfaces are in contact. The heat imparts extra energy to some of the electrons associated with the atoms in the two surfaces allowing them to move a little more freely from atom to atom or even leave the parent material altogether.

In fact, with certain materials such as a plastic pen and a garment containing cotton or wool, quite a lot of electrons may transfer from the cloth to the plastic surface. Areas of the plastic pencil which have been rubbed against the cloth may therefore end up with a large surplus of electrons and therefore a substantial negative charge. The charge will tend to remain on the surface for a significant period because the high insulating qualities of the plastic inhibit the charge from leaking away.

If the charge could leak away, it certainly would do so, as surplus electrons tend to exhibit a great deal of mutual repulsion. Not surprisingly, therefore, if the charged area is brought into contact with the wire protruding from the bottle, many of the electrons which can make their way to the wire will do so and these electrons will distribute themselves over the surface of the wire and of the two pieces of foil in contact with it. The pieces of foil will therefore acquire surplus electrons - or a negative charge - and will tend to repel one another.

In contrast with plastic, glass tends to lose electrons to cloth on which it is rubbed and areas on the surface of suitable low-conductivity glass tend to end up with a marked deficiency of electrons and therefore a positive charge.

If such an area is brought into contact with the wire in an electroscope it will attract electrons from the wire and foil, so that the two foils end up with a similar positive charge. Once again, they will tend to repel one another as a result.

Let us use this phenomenon for our first simple experiment. We take a plastic rod (an ordinary ball point pen can be used if nothing more substantial is available) and rub it briskly on a piece of cloth for a few seconds. If we now touch the loop of the electroscope with the rod or pen, the foil pieces will move apart to form an inverted "V". If we repeat the process, the foils will move further apart and will eventually form an angle rather more than 45 degrees. At some stage, a point will be reached when we cannot make the leaves move further apart for any length of time, although a slight kick will be observed each time we touched the charged rod to the loop. The reason for this is that the foils and support wire are capable of holding only a limited static charge at the charing voltage which can be produced. This is their "capacity", the same term used in connection with capacitors.

In fact, the degree of deviation from the vertical taken up by the charged foils is an indication of the voltage impressed upon them. In our own experiments, we were able to apply a voltage known to be of around 15KV, which moved the foils to about a 60 degree angle. A capacitor charged to 300V did not even move the foils when applied to the loop, whereas with a plastic handled screwdriver we were able to obtain an angle of more than 45 degrees, thereby proving that we were developing a pretty high voltage, well over 300 but short of 15,000.

If the insulating material you have used for the sleeve is good enough, the charged foils will remain in their "V" position for a long time in conditions of low humidity. On humid days it is virtually impossible to keep the charge on the foil for more than a minute. When the charge is holding well, you can demonstrate the eagerness of the electrostatically charged foils to give up their electrons, as the slightest touch of the finger on the loop will cause the foils to collapse.

We can now repeat the process with a glass rod instead of a plastic pen. The results obtained should be identical. Although the glass rod is acquiring a positive charge, whereas the plastic rod acquired a negative charge, the two foils will still repel each other, since they are both charged with the same polarity. If however, we make two electroscopes, and charge one positively, the other negatively, and we touch the loop of one to the loop of the other, the foils in both instruments will collapse. This is because the positive charge in one will cancel the negative charge in the other, and vice versa.

If you want to make a more elaborate electroscope to demonstrate the principle that opposite charges attract, this should be fairly easy to do by fixing two separate insulated wire assemblies into one bottle, each with a single foil. If one foil is charged negatively, the other positively, they will attract instead of repel.

At this point, we must leave our experimenters to devise further experiments for their electroscopes. Try different combinations of materials, try waving rods close to the top loop without touching it and so on. Have fun.

Our new electroscope is quite a jump from the simple concept of the original electroscope which, incidentally, was among the first primitive measuring devices with which the pioneers laid the foundations for our present electronic technology. This latest version uses one of the most recently developed solid state devices - the FET - in a simple bridge circuit to produce an extremely sensitive device.

The bridge circuit may be a new concept to many readers, but is a most important circuit configuration. Furthermore, it is not particularly difficult to understand. It has many uses, ranging from direct measurement of resistance, capacitance etc. to industrial control circuits. In our present circuit we make use of its balanced condition to balance out, or cancel, a heavy standing current, which would normally overload our sensitive indicating meter.

To understand this better let us look at a basic bridge circuit. 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 ratio between Ra and Rb is the same as the ratio 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 setup, 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 current.

Now take a look at the circuit of our electroscope. Notice the similarity? In place of Ra and Rb we have a 47K pot which, because of the tap provided by the moving arm, can really be regarded as two resistors, both variable. In place of Rc we have a 2.2K resistor, and in place of Rd we have the source/drain path of the FET. The meter and battery connections are as before.

From what we have already explained, it should not be too hard to visualise this circuit in a balanced condition. When the FET is in its "quiescent" state (no voltage between gate and source) its resistance is quite stable. When we adjust the tap on the pot so that the upper and lower halves of this arm have the same ratio as the 22K resistor and the source/drain resistance of the FET, the bridge is balanced and the meter reads zero.

Because of the balanced condition we can use the most sensitive indicating meter we like, regardless of the current required by the FET. For example, we could use a 50uA meter, even though the current through the FET is more likely to be around 15mA.

A meter of this sensitivity will detect an extremely small charge in the bridge. Because the change is likely to be an amount which is enough to send the needle hard FSD (full scale deflection), we suggest you use a lower sensitivity meter - around 1mA.

Now, how does the electrostatic charge upset the balance of the bridge? Whenever anybody or mass is charged, there will be an electric field associated with the charge. This field radiates from the body, getting progressively weaker as it moves further away.

If a capacitor is placed in this field, the capacitor will become charged. It will lose the charge as soon as it is removed from the field.

Our static electricity detector is virtually a capacitor. On one side we have the detection rod, on the other the wiring of the bridge. And between these two "plates" we have the gate and source electrodes of the FET.

Now bring a charges mass into close proximity to the rod. As the capacitor is now charged, there will be a potential difference between its two plates - and between the gate and source. This changes the resistance of the FET, upsets the balance of the bridge, and deflects the meter.

If we were to actually touch the rod with some charged objects, it is possible that quite a large current might flow into the gate. This current could, conceivably, be large enough to damage or destroy the junction of the FET by overheating it. For this reason, we have taken the precaution of covering the rod with PVC tubing, to prevent accidental touching.

In the interests of economy, we are not suggesting you buy a meter just for this project. Rather, we hope that by now most, if not all, of the readers will have obtained a multimeter. If you have not, now is a very good time. For here is one time when you can put the "uA" and "mA" ranges of your meter to work.

Most modern multimeters are of the 20,000 ohm per volt variety. That is, they have a basic movement of 50uA. Meter shunts are used to enable you to measure higher currents - some go as high as 10 amperes or more.

But we are more concerned with the ranges between 50uA and around 50mA. These will be the most useful in the bridge. To save "bashing" the meter, it is best to start on a high mA range, and work down.

The ranges mentioned should enable you to obtain quite high sensitivity with your detector. If you do not have a nultimeter, but do have a meter with an FSD current somewhere around 1mA, by all means go ahead and use it.

We built our detector on a piece of 1/8" perspex. We did this for two reasons: the first, perhaps the most important is that perspex has extremely low electrical leakage - in other words, it is very nearly a perfect insulator. If we built it on, say, a piece of wood, our sensitivity would be poor because a portion of our charge would leak away through the wood. This would be particularly so on a humid or rainy day.

The second reason was that clear perspex will allow those not familiar with electronics to see the wiring through the perspex. This will help to demonstrate electronics to others - especially if the builder is a science student or teacher who wishes to demonstrate the device to others.

If the second reason does not apply in your particular case, there is no reason at all why you should not build the detector on some other base. Just keep in mind our comments on leakage.

Our base measured approximately 8" (203mm) by $3\frac{1}{2}$" (89mm). We used four circles of perspex as feet, by glueing them to the underside. You could use four small rubber feet if desired. The FET, potentiometer, resistor and battery were all positioned at one end of the base. The rod as can be seen in the photograph is joined to the gate of the FET by a single piece of tinned copper wire.

We put our components on the perspex in the position we thought best, and then marked the positions of the leads with a fine tip felt pen. The position of the battery was also drawn, to enable us to make a battery holder later.

We then drilled the holes with a number 58 drill. This is the size which is normally used for printed circuit boards - component leads fit through easily. The holes for the potentiometer will have to be slightly larger - say 1/16". When the components are soldered, the heat on the leads causes some of the perspex to melt, thus holding the components in place.

One point we might make - when marking the positions for the holes to be drilled, do not use a pencil! This could leave a fine layer of graphite (pencil "lead") on the perspex. And since graphite is a conductor (one of the forms of carbon) the whole purpose of using perspex could be defeated. Two spring terminals were used to connect the detector to the multimeter. These were fastened in place by drilling two holes, each just smaller than the threaded shaft of the terminal, and then forcing the terminals into them. They cut a thread in the perspex as they screw in. The detector rod was made from a piece of 16 gauge tinned copper wire, bent double and soldered together. To fix it in place, we drilled a hole just large enough to fit the double wire, and forced it in. Then we turned the base over, and ran some solder over the ends of the wire. Once again, the perspex melted, firmly fixing the probe in place. We then cut off the excess protruding from the bottom, and soldered the wire from it to the gate.

To finish off the rod, we slid a length of insulating tubing over it, and sealed the top by touching it with a soldering iron. You could use any piece of plastic - even a drinking staw will do.

We made simple wire holders for the battery, by drilling four holes alongside it and then tightening some thin wire around it with a pair of fine pliers. Note that you will need a battery connector if you use the same battery we did.

We made a few experiments with our detector to determine how sensitive it was and were mildly surprised. A plastic bag, waved around from across the other side of our laboratory, caused a large deflection on the meter. If we moved any closer, we had to use a higher scale on the meter to stop it banging hard against the restraint at the end of the scale.

A comb, brushed through one's hair a few times will cause a full scale deflection, as will a piece of plastic rod rubbed on cloth.

As with a conventional electroscope, the weather has a marked effect on sensitivity. If it is a humid or rainy day, the readings will be less than those made in the same way on a dry, hot day. This is because the charge is able to leak away through the air, due to the amount of water vapour in it.

One fine, warm day, we turned the detector on, and found that nothing would induce the pointer to move from the stop at the bottom end of the scale. So we reversed the meter connections, and found that the pointer now pressed hard on the other stop. Turning the pot through its full range had no effect - it was not until the meter was put on the 50mA range that the pointer dropped a little.

We finally worked out that the author's shirt was causing the trouble. Apparently, the material, a synthetic, had developed a very high potential during the day and this potential was opposite to that of the other devices we had experimented with. For quite a few days before, it had been raining and this affected the detector. On this particular day, however, the meter registered a high negative delfection.

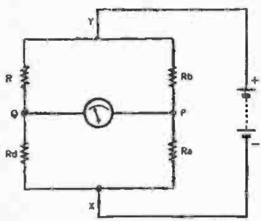
This brings us to an important point - if the meter deflects in the opposite direction you will have to change over the meter connections. The reverse reading indicates a reversal of polarity on the "capacitor".

When a plastic rod (or ball point pen or ruler) is rubbed on a piece of cloth, heat is produced by friction where the two surfaces are in contact. The heat imparts extra energy to some of the electrons associated with the atoms in the two surfaces, allowing them to move a little more freely from atom to atom. They may even leave the parent material altogether.

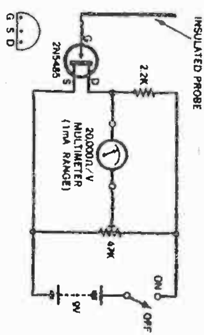
In fact, with certain materials such as plastic and cotton or wool cloth, quite a lot of selectrons transfer from the cloth to the plastic surface. The plastic, therefore, ends up with a large surplus of electrons and, therefore, a substantial negative charge. This charge will remain for quite a long period, because the insulating qualities inhibit the charge from leaking away.

By contrast, glass tends to lose electrons to a piece of cloth (particularly silk) on which it might be rubbed. Therefore, the glass acquires a positive charge and the cloth a negative charge. Even the human body can acquire a charge - but this is generally small and insignificant because of the leakage to the ground and to the air. You may notice though that the meter will deflect slightly when a person comes close to the pickup rod.

We could say a lot more on the experiments and observations possible with the electroscope. However, time and space does not permit this. We suggest that you try the things we have mentioned, and, if possible repeat the experiments with a conventional foil electroscope, to compare the results. You may be able to get a few hints from a science teacher or textbook.



The basic bridge circuit around which our electroscope is designed.



The circuit of the complete electroscope. Compare it with the bridge circuit

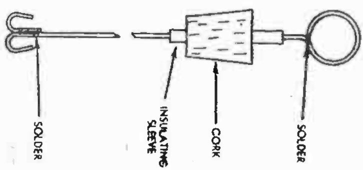


Diagram of the wire and foil assembly. The insulating sleeve and wire rod should both fit snugly, so that they do not slip down.

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BUILD YOUR OWN ULTRASONIC TRANSMITTER AND RECEIVER

HERE IS A GREAT OPPORTUNITY FOR THE HOBBYIST TO EXPERIMENT WITH ULTRASONIC SOUND WAVES. COMBINE THE COMPACT TRANSDUCERS WITH OUR SIMPLE TRANSMITTER AND RECEIVER CIRCUITS TO PERFORM A NUMBER OF INTERESTING TASKS SUCH AS BURGLAR ALARMS, REMOTE CONTROL COMMUNICATIONS AND EVEN A PISTOL RANGE. INTERESTED? JUST READ ON.

The transducers contain a ceramic piezo-electric element which resonates at around 40kHz. Signal connection to the element is made via phono socket. Measured capacitance of the element is of the order of 2000 picofarads.

To perform basic experiments with these ultrasonic transducers, you will need at least two of them. One used as the transmitter and the other used as the receiver or detector. In addition, you need a transmitter circuit, and a receiver circuit to close a relay or give some other indication that a signal has been received or interrupted.

Let us first describe the circuits we have developed and then we can list some of the possible applications.

We have developed two simple transmitter circuits using easily available cpmponents. The first of these is shown in Fig 1. It is a conventional mulivibrator consisting of two silicon NPN transistors. The output signal is coupled directly to the transducer from the collector of one of the transistors.

Since the signal developed across the transducer is a square-wave, albeit slightly rounded off, the amplitude has an effective value approximately equal to half the supply voltage. Thus for a multi-vibrator supply voltage of 9V, the effective signal voltage will be approximately 4.5V RMS.

Supply voltages to the multivibrator can be anywhere in the range from 6V to 18 VDC. Current drain at 9V is only 4 milliamps which means the battery would last a long time. Note that the circuit will work at below 6V, although the output may be so low as to be unusable.

A 10k preset potentiometer is provided to "tweak" the multivibrator frequency so that it is at the approximate 40kHz resonance of the transducer. In practice, the adjustment will be a compromise between maximum acoustic output from the transmitter transducer and maximum sensitivity of the receiver transducer, because the resonant frequency of each transducer differs slightly.

One problem with these transducers is that one side of the element is connected to the shell which is then automatically connected to the metal case of the device in which it is used. Because of this, both the wiper of the preset potentiometer and the aluminium box is connected to the postive supply line from the battery. With this arrangement, an access hole can be provided in the side of the case for screwdriver adjustment of the pot and there will be no risk of shorting out the battery by the shaft of the screwdriver.

The value of the potentiometer has been selected as a compromise between ease of adjustment, range of adjustment and ready availability If the higher supply voltages are used it may be necessary to add a resistor (say 4 7k or more) in series with the potentiometer to give it a suitable range of adjustment.

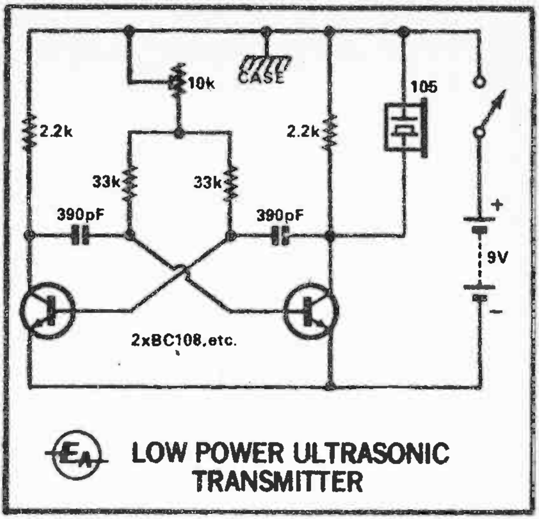


Fig 1: A simple multivibrator transmitter.

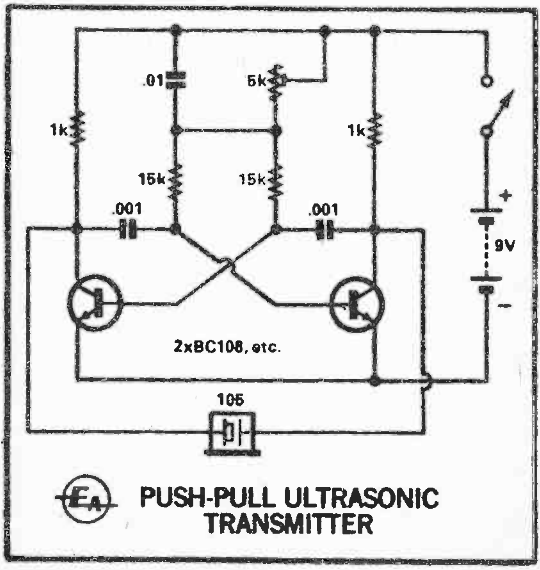


Fig 2: Push-pull operation of the transducer.

While the transmitter circuit in Fig 1 is very economical in terms of battery drain it is suitable only for low power applications such as monitoring doorways or narrow passageways. If higher power is required, the circuit in Fig 2 should be used. This circuit is fundamentally the same as Fig 1 but has the advantage that the voltage output to the transducer is doubled while the battery voltage remains the same.

Using the same transistors, the circuit has been redisigned with lower value collector load resistors (1k). This allows the transducer to be connected directly across the two collectors. Since the output waveform at each collector is a square wave with a peak value just slightly less than the supply voltage and the two waveforms are 180 degrees out of phase, our method of connection gives a "push-pull" operation to the transducer and doubles the amplitude of the waveform. The effective value of the output is almost equal to the supply voltage.

A 5k potentiometer provides adjustment of the frequency and it is shunted by a 0.01uF capacitor to improve the shape of the waveform and aid in reliable starting. Note that for supply voltages above 12V a resistor of 2.7k or so should be added in series with the preset potentiometer to give it the correct range of adjustment. As before the supply can range anywhere from 6V to 18V.

An interesting feature of this "push-pull" circuit is that once the preset potentiometer has been adjusted to give the resonance frequency of the transducer, the oscillator tends to lock in so that further manipulation of the potentiometer does not shift the frequency appreciably. It merely changes the waveform slightly.

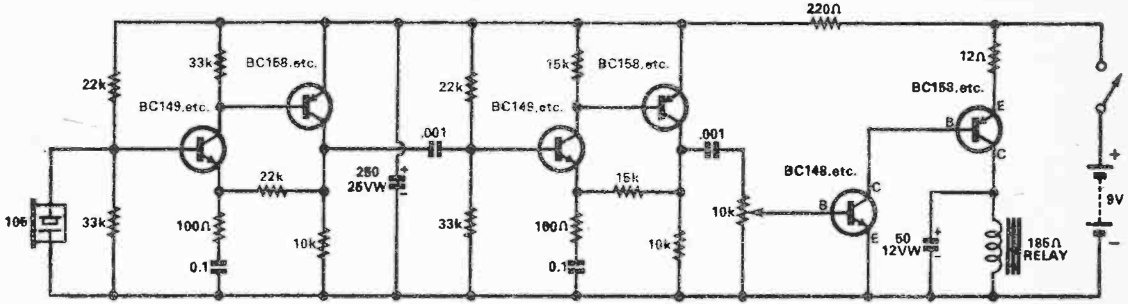
Current drain of the circuit with a 9V battery is of the order of 12 to 13 milliamps. This is higher than one would expect with the resistor values in the circuit but the loading effect of the transducer does increase the current.

Having described the transmitter circuits, we can give some details of their construction and then go on to describe the receiver circuits.

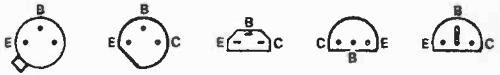
While both transmitter circuits were subject to quite a bit of experimenting we built the higher-powered circuit of Fig 2 into a standard over-the-counter aluminium utility box to present a suitable method of construction. The lower-powered circuit can use exactly the same method of construction. No doubt readers will have their own ideas in this regard and can rest assured the circuits are in no way critical apart from the few points noted above.

Outside dimensions of the aluminium box are approximately 103 x 62 x 60mm (4 x 2½ x 2⅜in) which allows plenty of space to mount the various components. We drilled and reamed a hole of approximately 25mm diameter in one end to accommodate the transducer. Those without a suitable reamer will have to cut the hole by drilling a circle of smaller holes and then filing the cut out to size, or perhaps by drilling a clearance hole and using a hand nibbler.

While we could have set the transducer in position with an epoxy adhesive we elected to hold it with a clamp made from a piece of aluminium measuring 50 x 30mm. A hole large enough to clear the phono connector (say ⅜in) is drilled in the centre of the aluminium and two additional holes drilled to take suitable screws to secure the clamp.

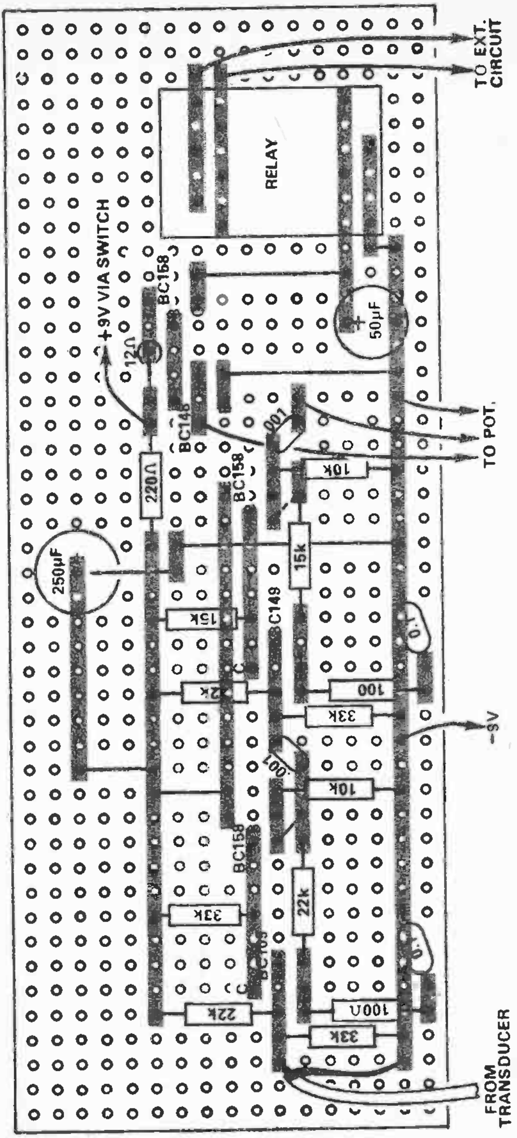


ULTRASONIC RECEIVER



Above is the layout of the receiver wiring board while below is inside view of the receiver case with the board held in the slots.

Fig 3: The receiver circuit uses two high gain DC-coupled pairs in cascade and a class-B detector driving the relay.


TO EXT. CIRCUIT
RELAY
+9V VIA SWITCH
BC158
12Ω
50µF
BC148
.001
TO POT.
10k
220Ω
BC158
15k
250µF
15k
BC149
0.1
2.2k
100
33K
-9V
.001
10k
BC158
22k
33K
0.1
22k
100Ω
33K
FROM TRANSDUCER

A short length of shielded cable carries the signal output to the transducer. Do not overtighten the screws on the transducer clamp otherwise it may cause intermittent behaviour in the transducer and perhaps distort the aluminium box.

All the circuitry is accommodated on a piece of Veroboard measuring 45 x 45mm approx and having 0.1in conductor spacing. The layout is not critical but note that several of the conductors are bridged together in the circuit. This is shown in the wiring diagram.

A miniature toggle switch is used for the on-off switch but this could be a "momentary-contact" pushbutton type if the particular application demands it.

Note that because of its construction, one side of the transducer is connected to case. This means that the screwdriver used to adjust the preset potentiometer of the push-pull transmitter will have to have an insulating sleeve fitted to its shaft, otherwise the multivibrator will stop when the screwdriver shorts the pot wiper to case. As noted above, this problem is circumvented in the low power circuit.

The battery is held in place by a clamp made from a scrap of alluminium. Note that if brass spacers are used to mount the Veroboard, the copper pattern should be cut away so that the circuit is not inadvertently connected to case.

Incidently one can get a weak but usable acoustic output from transducers over the audio range above 1kHz, by connecting them to an audio frequency generator with low impedance and output of 3V or more. The output is peaky, but it may possibly be useful in some situations.

Now we can go on to describe the receiver circuits, of which there are two. The first closes a relay when it receives a suitable signal. The second closes a relay when the signal it is receiving is interrupted. Refer now to the circuit in Fig 3.

One of the first problems we became aware of when designing a receiver around these transducers was the transducers have an appreciable response to sounds within the audio range. For example, with the transducer unloaded, one could whistle loudly close to it and get an appreciable output voltage. Clearly, this just would not do for applications such as burglar alarms or garage door openers. Every youngster in the street would soon be opening your garage by whistling at it!

Another problem is the very small output voltage from the transducer, which requires a lot of gain to enable a relay to be controlled. We calculated that the necessary gain is of the order of 10,000 times or more.

An initial suggestion from on of our staff was to use an operational amplifier integrated circuit to provide the necessary gain. These are available cheaply but a quick look at the specifications of the most commonly used type, the 741, showed that it was not anywhere near suitable for the job.

For a start, while the "open loop" gain (gain before negative feedback is applied) might be several hundred thousand, this only applies for DC and very low frequency AC signals. At the frequency we are interested in, 40kHz, open-loop gain is considerably less than 100 times. With feedback applied, it would be less again.

Our approach to obtain the necessary gain is to use two cascaded complementary feedback-pairs. Each feedback pair uses a PNP and NPN silicon transistor and gives a voltage gain of 150 times or more. When cascaded, the resultant gain is 20,000 or more.

Signal coupling from the transducer is made directly to the base of the first transistor in the first feedback pair. We can eliminate the usual input coupling capacitor because the transducer is itself a capacitive element and does not conduct direct current. Besides providing the correct bias for the input transistor, the 22k and 33k bias resistors are selected to load the transducer so that its response to signals below 40kHz is heavily curtailed.

The collector current of the first transistor is set by its 33k collector load to a suitably low value to minimise noise. A low noise transistor must be used here otherwise the very large overall gain will result in appreciable residual noise in the output of the preamplifier.

In theory, overall gain of the feedback pair is set by the ratio of the 22k (from the collector of the second transistor) to the 100 ohm resistor. However, unless the first transistor is one with particularly high beta, the actual gain will be somewhat less than the expected 220 times. Low frequency response is restricted below 40kHz by the 0.1uF capacitor in series with the 100 ohm resistor.

Output from the first feedback pair is coupled to the first transistor of the second feedback pair by a .001uF capacitor. This capacitor combined with the 22k and 33k bias resistors again helps to limit the low frequency response of the preamplifier.

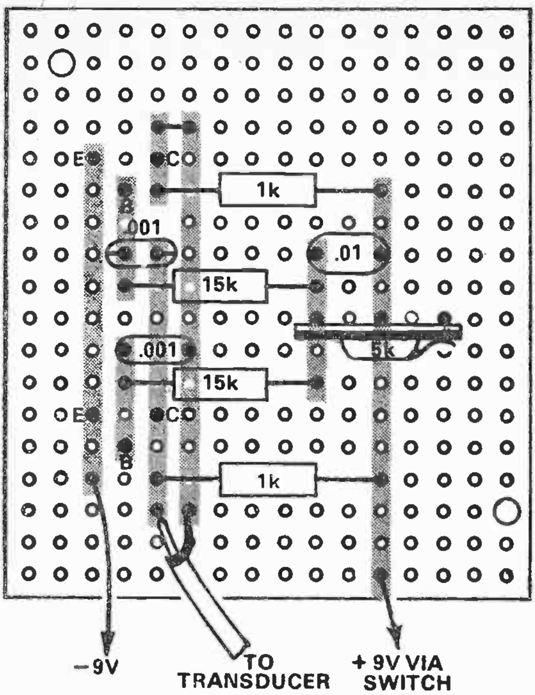
A low noise, high beta transistor is specified again for the first stage of the second feedback pair. Here it is specified not so much to give low noise performance but to assure high gain. Its collector current is set higher than in the first feedback pair by its 15k collector resistor. In practice, the gain of the second feedback pair will be close to the expected 150 times set by the ratio of the 15k and 100 ohm feedback resistors.

Readers may wonder why we have opted for the two feedback pairs with AC coupling between them instead of the 4-stage preamplifier (for example) with direct coupling throughout and one feedback loop. In practice, the arrangement we have used is more stable and is less complicated considering the high overall gain.

Out-put from the second feedback pair of the preamplifier is fed via a .001uF capacitor to a two-stage DC amplifier. The DC amplifier is really an NPN and a PNP transistor operating together as a high-gain class-B detector which drives the relay.

Since the class-B detector conducts only for positive excursions of the preamplifier output signal, substantial filtering of the detector output is required so that the relay will pull in and hold properly. Filtering is provided by the 50uF capacitor in parallel with the relay coil. This capacitor also does away with the need for a protective diode across the relay to protect the driving transistor.

We used a relay with a 185 ohm coil but any relay with a coil resistance of more than this can be used provided its "pull-in" voltage is within the supply voltage of the receiver. While we used a 9V supply for the receiver it could be run at 12V without any adjustment. Higher



Wiring layout for the transmitter board.

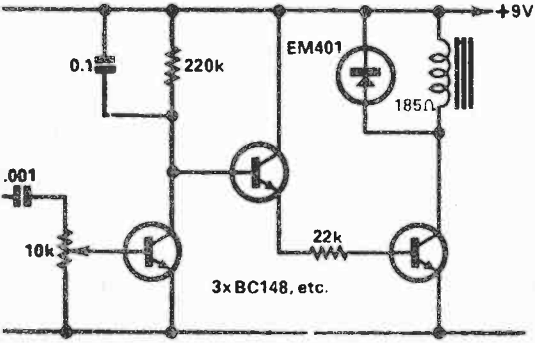


Fig 4: Another class-B detector circuit for tripping the relay if the beam is broken.

voltages could be used, up to to 18V, provided current drain through the relay is not a problem. If the higher voltages are used care should be taken not to exceed the ratings of the relay driving transistor.

Lower voltages than 9V are not recommended as the sensitivity of the receiver would be reduced.

Overall sensitivity of the receiver is controlled by the 10k potentiometer which adjusts the signal level to the class-B detector.

The receiver circuit of Fig 3 activates the relay when a signal of sufficient strength hits the transducer. If the opposite funtion is required, ie., the relay is activated when the signal to the transducer is interrupted then the detector circuit shown in Fig 4 should be used.

As with the transmitter circuits, we built one of the receiver circuits into a box to present a suitable method of construction. The receiver circuit of Fig 3 was housed in an STC diecast box measuring 120 x 95 x 55mm which has internal slots to mount a circuit board. We recommend this method of construction as it provides necessary shielding against strong RF signals, which could otherwise cause flase triggering of the relay.

All the circuitry is mounted on a length of Veroboard measuring 115 x 48mm with 0.1in conductor spacing. The circuit arrangement is shown in the wiring diagram. We have specified Veroboard with 0.1in spacing because it suits Lockfit transistors and the relay socket. Holes for the relay socket mounting must be enlarged a little to accept the pins. The relay we used has two sets of change-over contacts, although other relays may be pressed into service as noted above. Make sure you obtain a clip to hold the relay securely in its socket.

Note that the copper strips on the Veroboard should not make contact with the internal slots of the case - strip them back so this cannot occur.

The transducer is connected to the circuit via a male phono plug and a short length of shielded cable. The transducer is mounted in the same way as in the transmitter.

Wires from the contacts of the relay are knotted and passed out through a grommetted hole in one end of the case.

We used a 9V battery held in place by a clamp made from a scrap of aluminium. The snap-on connectors are each covered with a piece of insulation tape to prevent shorts to the case.

A word about transistor types is appropriate here and it applies also to those used in the transmitter. As noted in the parts list there are quite a few different types which suit each stage. While the older soon-to-be-obsolete types such as BC108 do not cause any problems as far as the lead configuration is concerned, the new TO-92 encapsulated types have two different lead configurations (on locally available devices).

On the TO-92 plastic encapsulated transistors with the leads in a straight line, the configuration is as follows: with the leads toward you and the flat portion facing down, from left to right the leads are collector, base, emitter. On those transistors with a cranked centre-lead, the leads are emitter, base, collector which is the same as for the Lockfit transistors. The various lead configurations are shown on the receiver circuit diagram. Just match them up with the transistor you get in your hot little hand!

And now to some of the interesting sidelights of the transmitter and receiver. One of the strange characteristics of the transducer is that it can resonate audibly while it is driven at 40kHz. Apparently it has resonances at sub-multiples of 40khz. But even stranger, the audible output changes when the supersonic input frequency changes. And this applies whether the input is a sine wave or square wave.

So if your have sensitive ears and hear strange tweets coming from the transducer you can stop worrying!

With the push-pull transmitter and receiver both operating from 9V batteries we found the effective range was about 6 metres (20 feet). At this range, we found the sharpness of the beam from the transmitter made it very difficult to aim. An improvement in range was gained by fitting a horn to the transmitter. This was made simply from cardboard. You can also fit one to the receiver. In fact, with horns fitted to transmitter and receiver and the transmitter running at 15V and tweaked for maximum range we achieved operation over a distance of 9 metres (35 feet).

Be warned though. It takes some fiddling to achieve this range of operation and whether it is reliable enough for some of the applications mentioned below is a matter for the constructor to make up his own mind about.

Let us now discuss some of the applications of ultrasonic systems. One of the most obvious applications is to monitor across a doorway or corridor and for this purpose the low power transmitter should be adequate. This could be the basis of a burglar alarm system, or as a simple "shop-minder".

Many remote control applications come to mind. The units described here could form the basis of a garage door remote opening system, or perhaps a television remote control. As a party novelty, one could have a lot of fun deceiving guests - your imagination sets the limit here.

An ultrasonic counting system would be useful on a production line instead of a light-sensitive system. It would have the advantage of not being affected by ambient light.

Educational emperiments could also be devised to demonstrate the behaviour of sound waves. It should not be too hard to set up an experiment to measure the wavelength of radiation at 40kHz. Here the receiver would drive a metering circuit instead of a relay.

Another worthwhile application would be a pistol range. Combine the push-pull transmitter in a "pistol" set up and use the receiver as the bulls-eye. One of the advantages of this set-up over a light-beam pistol range is that it is unaffected by ambient light - it can be used outside in broad daylight.

THE PARTS YOU NEED

Push-pull transmitter.

1 aluminium box 103 x 62 x 60mm
1 piece of Veroboard, 45 x 45mm, 0.1in conductor spacing.
2 silicon NPN transistors, BC108, BC208, BC548, BC148. RS276-2009
2 x .001uF polyester or polystyrene capacitors.
1 x 0.01uF polyester capacitor
1 x 5k preset potentiometer
2 x 1k, 2 x 15k resistors
1 ultrasonic transducer
1 miniature SPST switch
1 9V battery plus connector
1 male phono connector

Miscellaneous

Battery and transducer clamps, brass spacers, screws, nuts, lockwashers, hookop wire, solder.

Receiver

1 diecast box, 120 x 95 x 55mm
1 ultrasonic transducer
1 male phono plug
1 9V battery plus snap-on connectors
1 piece of Veroboard 115 x 48mm, 0.1in conductor spacing
1 relay.
1 printed board relay socket to suit above
1 miniature SPST switch
1 knob

Semiconductors
2 low noise silicon NPN transistors, BC109, BC149, BC209, 2N5088, BC549, SE4010. RS276-2009
1 silicon NPN transistor, BC108, BC148, BC208, BC548 RS276-2009
3 silicon PNP transistors, BC158, BC320, 2N3638, 2N3638A. RS276-2021

Resistors
(¼ or ½W rating, 10pc tolerance)
3 x 33k, 3 x 22k, 2 x 15k, 2 x 10k.
1 x 220 ohms, 2 x 100 ohms, 1 x 12 ohms.
1 x 10k (lin or log) potentiometer

Capacitors
(Voltage rating of plastic types non-critical)
1 x 250uF/25VW electrolytic
1 x 50uF/12VW electrolytic
2 x 0.1uF metallised polyester
2 x .001uF polyester or polystyrene

Miscellaneous
Battery and transducer clamps, grommets, screws, nuts, lockwashers, hook-up wire, solder.

NOTE: Resistor wattage ratings and capacitor voltage ratings are those used for our prototypes. Components with higher ratings may generally be used, provided they are physically compatible. Components with lower ratings may also be used in some cases providing ratings are not exceeded.

ARE YOU A SAFETY HAZARD WHEN DRIVING? TEST YOURSELF WITH A REACTION TIMER.

WE HAVE DESIGNED THE BUZZ BAR TO TEST YOUR CO-ORDINATION. NOW YOU CAN CHECK YOUR REACTION TIME. WHEN THE RED LIGHT COMES ON, GO FOR THE STOP BUTTON OR PEDAL AS FAST AS YOU CAN. THE TIME YOU TAKE COMES UP ON THE METER. FOR THE BUTTON YOU SHOULD BE LESS THAN 250 MILLISECONDS; FOR THE PEDAL, LESS THAN 400 MILLI-SECONDS.

When you are driving, your reaction time in an emergency can make the difference between rapid evasive action and possible fatalities. It is well known that reaction time is affected by the driver's physical condition and his psychological outlook at the time. In some cases, the driver does not register the emergency at all and drives straight into disaster.

Some people stoutly maintain that alcohol does not adversely affect their reaction time and may even improve it. Limited tests that the author has witnessed would indeed seem to indicate that a limited amount of alcohol does not affect physical reaction time to any extent. What is affected is judgement. But that is another story.

Eventually, reaction time testing may become part of the general driver licensing procedure. Even licence renewals may be conditional upon passing a reaction test and sight test. Who knows? In the meantime, we have produced a unit to measure reaction times up to one second. If your reaction time is longer than that you are disaster material anyway!

The unit presented here will enable a number of interesting reaction tests to be made. To perform the tests, two people are required. One acts as a starter and presses a button to light up an indicator on the tester. The other person is the one being tested, and must hit their button to turn off the light. The reaction time can then be read from the meter. The starter then has a reset button to zero the meter before the test is repeated.

An approach to measuring a short time interval of less than one second can take two general directions. First, logic circuitry can be used and the result displayed in digital form. All that would be required is a 100Hz square wave oscillator driving a couple of decade counters, plus the necessary decoder/driver integrated circuits to drive the neon or light-emitting diode digital display. The test would be merely starting and stopping the clock. The readout would be in the form of two digits which would be multiplied by ten to give the result in milliseconds. For example, a readout of 34 would represent 340 milliseconds.

While this concept is quite simple and easily extended to provide greater measuring accuracy down to 1 millisecond or less if required by the addition of more counter stages, it has drawbacks. The first of these is the power required. Unless CMOS logic circuitry was used, the unit could require the best part of 200 milliamps at 5 volts. This means that it would require a fairly large battery or be mains operated. And by the time the cost of all components was added up, it would not be a cheap project.

To avoid these problems we decided to see if we could achieve the desired result by an analogue approach. The obvious solution was to produce a steadily rising voltage and measure its value at the end of the given time interval which represents the reaction time.

But how do you produce a steadily rising DC voltage, ie., a voltage increasing at a constant rate for a maximum interval of one second? Actually, that is easy. All that is required is to charge a capacitor at a constant current. The resulting voltage across the capacitor will rise at a constant rate.

This can be shown by derivation from the fundamental relationship:

$Q = CV$

Where V represents voltage, Q represents charge in coulombs and C represents capacitance in Farads.

If we rewrite the above equation as $V = Q/C$ and then divide both sides by time in seconds, we get the rate of voltage change in volts per second is equal to the number of coulombs per second divided by the capacitance. But 1 ampere is equal to 1 coulomb per second, ie., current is the rate of charge flow. So dividing the capacitor charging current by the capacitance gives us the rate of voltage change. So the way to get a constant rate of voltage increase is to charge the capacitor with a constant current.

We can set the rate of voltage increase by selecting the value of constant current and the size of the capacitor. The capacitor must have a very low leakage current relative to the value of charging current. The capacitor we decided upon is a parellel combination of two 15uF 15VW tantalum electrolytics. Conventional aluminium electrolytics must not be used, because of their leakage. If we select a rate of voltage increase of 10 volts/second, the constant charging current is 0.3 milliamps.

Refer now to the circuit diagram (Fig 2). The constant charging current to the capacitor is provided by Tr3 and its associated components. The basic circuit of a constant current source using one transistor is shown in Fig 1. A reference voltage provided by a zener diode is applied to the base of the transistor and the emitter resistor is selected to set the collector current. The voltage across the emitter resistor becomes the reference voltage minus the base-emitter voltage of the transistor.

In the basic circuit we have shown a zener diode which provides a reference voltage of 4.7V. This would result in a voltage across the emitter resistor of 4.0V (allowing for a base-emitter voltage of 0.7V). The collector current is set at 0.4 milliamps by making the emitter resistor 10k. Any tendency for the collector current to increase would increase the emitter voltage by the same amount, which would bias the transistor off which would drop the current back to where it should be, and so on. The reverse process applies if the collector current tends to reduce.

Later on we will explain the component differences between Fig 1 and the current source Tr3 in the complete circuit diagram.

Having described how to obtain a voltage which increases linearly with time by using a constant current source to charge a capacitor, we can now discuss how to start and stop the current source. We do this an RS flip-flop consisting of Tr1 and Tr2.

The flip-flop has uneven collector loads. Tr1 has a 1k resistor in series with a light emitting diode while Tr2 has a 3.9k load. This means that when power is first applied to the circuit, Tr2 always turns on while Tr1

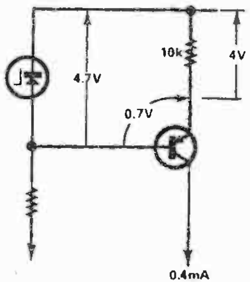
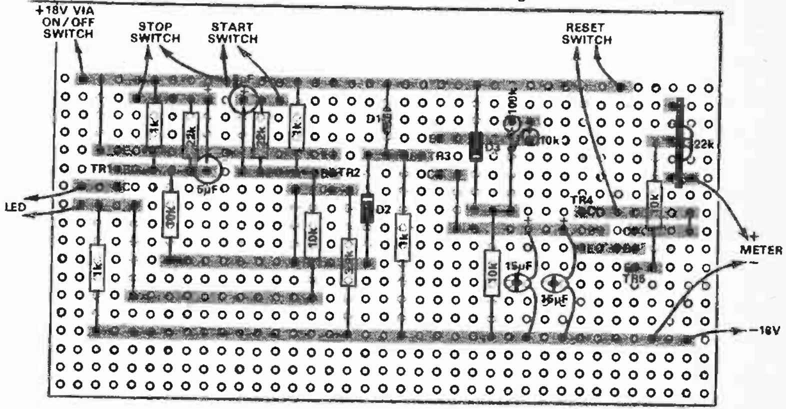
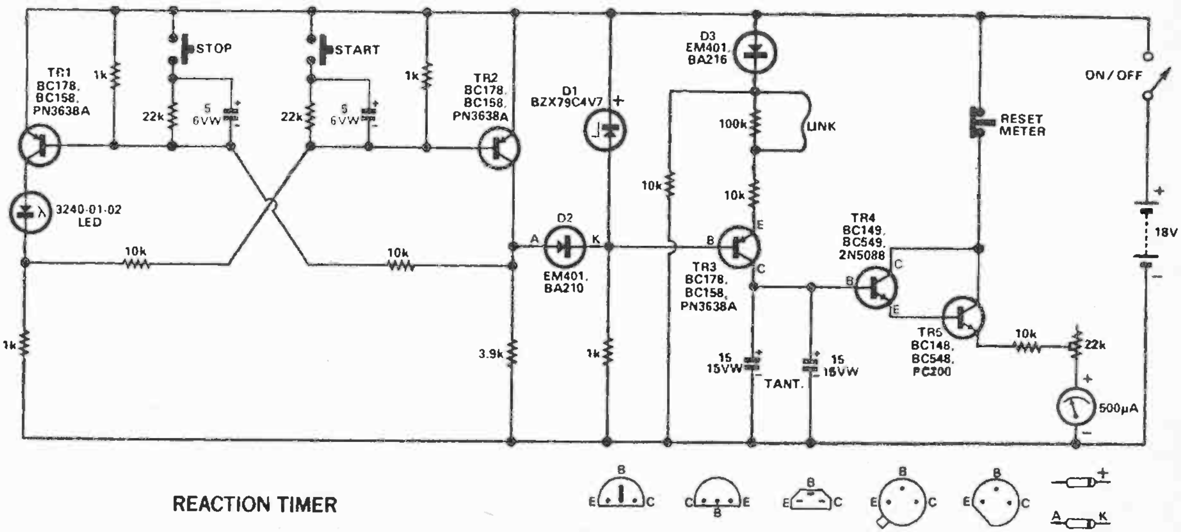


Fig 1. Basic constant current source.

Below is the component board diagram. Note the link shorting out the 100k resistor.





REACTION TIMER

An R-S flip-flop, a constant current source and a Darlington emitter-follower comprise the circuitry of the Reaction Timer.

is held off. Tr2 effectively shorts out the voltage reference zener diode D1 via D2 which turns off current source Tr3. Just to make sure that Tr3 turns hard off, diode D3 is connected in series with the emitter. The diode voltage is held constant by bias current from resistor R1.

So the situation at switch-on is that Tr2 is on, which holds Tr3 off, and so the voltage across the 30uF composite capacitor remains at zero. To start charging the capacitor, the START button is pressed, which momentarily removes the base voltage of Tr2. This turns Tr2 off and allows Tr3 to begin charging the capacitor at constant current.

At the same time as Tr2 goes off, Tr1 comes on and illuminates the light-emitting diode. The person being tested must then hurriedly press the STOP button which reverts the flip-flop to its original condition and turns Tr3 off. The voltage which then appears across the capacitor represents the elapsed time. All that remains is to measure this voltage while making sure that the capacitor's charge is not bled away so fast as to make the meter pointer drop rapidly. In other words, we have to measure the capacitor voltage but make sure that the current drawn off by the measuring circuit is as low as possible.

Our method of monitoring the capacitor voltage is to use a Darlington transistor pair to drive a 500 uA meter via appropriate resistors. With the high beta of the composite transistor the input current from the capacitor is very low - less than 1 microamp.

Other means could have been used to monitor the capacitor voltage, such as a FET source follower or operational amplifier "voltage follower", but these are not without drawbacks. Our circuit seems to have the advantages of economy and simplicity.

Several features of the circuit remain to be explained. First, the RESET button. This resets the meter to zero after a test so that it can be repeated. Notice that the capacitor is not discharged directly by shorting out. Rather, we remove the positive supply voltage from the Darlington, so that the capacitor discharges via the two base-emitter junctions and the meter circuit.

This effectively reduces the capacitor voltage to slightly less than the forward-bias base voltage of the Darlington pair, ie., slightly less than 1.2V. So instead of rising from zero at the start of a test, the capacitor voltage rises from approximately 1.2V. This means that as soon as the capacitor voltage begins to rise during a test, the meter pointer rises accordingly.

A simple, easy-to-reproduce calibration procedure presented a major problem in development of the project. No matter how ingenious or complex a circuit such as this might be, it is useless if it cannot be accurately calibrated by the would-be constructor who has a minimum of of test instruments at his disposal. We believe we have solved this in a neat fashion.

The calibration is performed by altering the setting of the current source so that it delivers a smaller constant current. This is done by temporarily removing the wire link shorting the 100k resistor in the emitter circuit of Tr3. This increases the total resistance in the emitter of Tr3 to 110k and thus reduces the capacitor charging current to one-eleventh of the normal value. Now, the meter takes eleven seconds to reach full-scale deflection instead of one second.

So to calibrate the reaction timer, proceed as follows. Remove the wire link to insert the 100k resistor into circuit. Press the START button, wait a few seconds and press the STOP button. Now press the RESET button to zero the meter. Now press the START button, wait exactly eleven seconds and press the STOP button. Now set the 22k preset potentiometer so that the meter reads full scale. This will have to be repeated a few times because the meter reading drops slowly.

Having set the 22k preset potentiometer so that the meter takes exactly eleven seconds to rise from zero to full scale, the wire link can be replaced to short out the 100k resistor and the unit is ready to perform testing. Ideally, the 10k and 100k resistors should be 1pc units, but in practice 5pc units will be close enough.

We specify a LED in the circuit because it has almost instantaneous response time, ie., light is emitted as soon as voltage is applied. The use of an incandescent lamp in this role would inevitably cause errors because of the thermal lag of the filament.

All the circuit components are mounted on a small section of Veroboard approximately 60 x 90mm. We used Veroboard with 0.1in conductor spacing to accommodate Lockfit or TO-92 encapsulated transistors. We raised all the resistors off the board by about 8mm as it makes them easy to remove if that is necessary.

Inevitably, constructors will be presented with a diverse number of alternative transistors to the ones we have specified and while this should present no problems, they will all have different lead configurations. Check the transistors you are supplied with against the appropriate base diagram on the circuit.

Take care to observe correct polarity of the diodes and tantalum capacitors. This is shown on the wiring diagram.

The two resistors, 10k and 100k, associated with the constant current source, Tr3 are wired "end-on" and a loop of hook-up wire soldered to their ends to short out the 100k resistor. The details are shown in the wiring diagram. The idea is to just "tack" the wire loop with your soldering iron so that it is easily removable for the calibration procedure.

We used a 500uA meter movement and made our own scale by erasing the existing scale with a typing eraser and lettering the new scale with Letraset. A 1 milliamp meter movement can also be pressed into service. The 22K preset potentiometer must then be changed to 10k and the associated 10 resistor reduced to 4.7k. No other changes are required and the calibration procedure is the same.

Notice that the 10k resistor in the base voltage divider for Tr2 is fed from the junction of the LED and the 1k resistor and not from the collector of Tr1. This is to avoid the small current flowing the 10k resistor from partially lighting the LED indicator.

Total current drain of the circuit varies from 27 milliamps in the STOP condition to 34 milliamps in the START condition. With an 18V supply rail, a fairly large battery is required.

Construction of the reaction tester is non-critical as far as layout is concerned. It can be built cheaply in a plywood box or dressed up to look the part of a fancy instrument. Our approach to the construction of the unit is shown in the photographs, but it is not at all mandatory.

The switches we used were all miniature types with normally closed and normally open contacts so they can be wired to perform any of the functions shown in the circuit. However, they are expensive and you will save money by buying the larger conventional switches. For the START and STOP switches you need pushbuttons with normally open contacts while the RESET switch has normally closed contacts.

The component board was stood off the rear panel of the tester with long screws and nuts while the battery was clamped to the bottom panel with a suitable clamp fashioned from a scrap of aluminium. The wires to the START and STOP switches were terminated on a strip of plastic terminal block to provide anchorage.

The LED stop light was mounted on the rear of our reaction timer so that the person being tested would not be distracted by the meter readings. But this is an optional arrangement and is inconvenient when the person being tested wants to see what time he has achieved.

We mounted the START and STOP switches in plastic pill cases for easy use. The STOP switch could be mounted in a floor jig with a brake pedal plus accelerator pedual to simulate actual braking procedure, ie., lifting the foot from the accelerator and on to the brake pedal. Here the stop switch would have to be protected from mechanical abuse.

With this set-up you will be able to verify that the driver in a car with automatic transmission will have a shorter reaction timer if he brakes with his left foot. This is a handy advantage even though it is frowned upon by some authorities.

Approximate cost of the timer, if you use all new parts, will be of the order of if you buy from one of the major kit suppliers. Go to it then. How fast is your reaction time?

PARTS LIST

1 chassis (see text).
1 meter movement, 500uA or 1mA sensitivity.
1 battery plus connector.
1 section of 0.1in Veroboard, 60 x 90mm approx.
2 pushbuttons with normally open contacts.
1 pushbutton with normally closed contacts.
1 SPST toggle switch.

SEMICONDUCTORS
3 silicon PNP transistor, BC158, BC 178, or 2N3638A, RS276-2023, SK3114-3118.
1 Silicon NPN transistor, BC149, BC549, BC109, 2N5088, RS276-2009 or SK3020
1 Silicon NPN transistor, BC148, BC548, BC208, BC108, RS276-2009 or SK3020
1 Zener diode, BZX79/C4V7 (BZY88/C4V7), SK3056.
2 silicon diodes, BA216, EM401.RS276-1139, BA219, 1N4002
1 light emitting diode or any other general purpose LED.

RESISTORS
(½W, 5pc tolerance)
1 x 100k, 2 x 22k, 1 x 3.9k.
4 x 1k, 1 x 22k preset potentiometer

CAPACITORS
2 x 15uF/15VW tantalum electrolytics.
2 x 5uF/6VW PC mounting electrolytics.

MISCELLANEOUS
1 three-way insulated terminal block, hook-up wire, Letraset, battery clamp, plastic pill cases, screws, nuts, lock-washers, solder.

AN ELECTRONIC GAS DETECTOR

IS YOUR AIR CLEAN? IS YOUR GAS LEAKING?

THE HUMAN NOSE IS PROBABLY STILL THE BEST GAS DETECTOR WE HAVE, YET THERE ARE MANY APPLICATIONS WHERE AN ELECTRONIC GAS DETECTOR WOULD BE VERY HANDY. NOW, FOR THE FIRST TIME, THERE IS AVAILABLE A SEMICONDUCTOR GAS SENSOR WHICH ENABLES US TO PRESENT THIS ELECTRONIC GAS DETECTOR.

The number of applications for gas sensors must be almost as long as the list of gases. But some of the more important applications are as an automotive exhaust analyser, petrol vapour detector for boats, gas leak detector, carbon monoxide detector, air pollution meter, paint dryness indicator and even as a breathalyser!

Of the above applications, perhaps the exhaust analyser and petrol fume detector for boats are the most often requested projects from our readers. But whatever the application, it has only recently become possible to design any circuitry to do the job.

Previously, exhaust gas analysers and other gas detecting instruments used the heat generation from catalytic reaction on a hot wire (platinum). However, these types of instrument are very expensive and have short life expectancy.

Our instrument is designed around a new type of semiconductor device known as a Taguchi Gas Sensor (TGS) developed by Mr N Taguchi of Japan and marketed by Figaro Engineering Inc of Japan. The TGS responds to certain gases, vapours and smoke particles. While it cannot distinguish between different gases it can record the relative concentration of a contaminating gas in air.

The TGS is a sintered n-type semiconductor device which is composed mainly of tin dioxide. Its conductivity varies widely when it comes into contact with a combustible gas such as hydrogen, methane, ethane, propane, alcohols, petrol, carbon monoxide and so on.

Embedded in the semiconductor chip are two heating coils made of an alloy of iridium and palladium and with a resistance of approximately 2 ohms. Only one filament is used to heat the chip, while the other is used merely to make electrical contact to the chip.

When a gas such as propane is absorbed by the surface of the chip, the chip resistance is reduced accordingly. The heat from the filament is required to convect the contaminant through the sintered porous structure of the chip and to drive the gas off (de-adsorb) when the source of contamination is removed.

Resistance change in the presence of a contaminating gas can be very marked. In clean air, the chip resistance may be anywhere from 10k to 50k but it will fall to less than a twentieth of this value when the concentration of propane in air is as little as 1000 parts per million. Similar changes occur for the other gases we have listed.

Refer now to the circuit. It is merely a simple bridge with the TGS forming one resistance leg. Normally, the bridge is balanced with the aid of the 10k potentiometer so that the meter indicates zero. When the chip resistance drops due to the presence of a contaminating gas, the meter indicates accordingly.

Our circuit uses batteries but the chip is not polarised so it can be connected either way around and the filament can be heated by AC. The heater consumes between 600 and 800 milliamps at 1.2 to 1.5 volts.

When the circuit is first turned on the meter pointer will move well up scale and then fall slowly back. This is because the sensor absorbs contaminating gases in the air while it is not in use and these must be driven off by the heater before the chip resistance rises to its normal "clean air" value.

The time taken for the contaminating gases to be driven off, or the effective "warm-up" time, varies according to the TGS type.

For detecting combustible gases such as coal gases, petrol vapour, alcohol and other hydrocarbon gases, type 308 is used. This has a fast warmup time and is ready for use in two minutes or less.

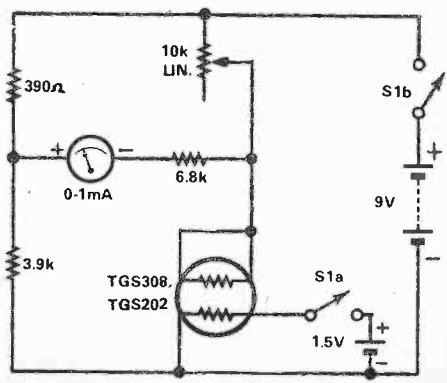
Type 202 will detect all the above gases plus carbon monoxide and smoke, but it has a long warm-up time of five minutes or more, depending on the length of time since it was last used.

Either TGS type may be used in the circuit described here without modification. It is possible to shorten the warm-up time of the type 202 by switching both its heaters in parallel at initial switch-on.

There are quite a few approaches that can be taken when building our gas sensor. We have taken a very simple approach in building the prototype.

The prototype is built on a simple L-shaped aluminium chassis 205mm wide, 100mm high and 100mm deep. Battery power is used.

Since we could not obtain a suitable battery holder at the time of writing we simply soldered the cells directly in parallel with hook-up wire. A clamp for five batteries was made from a length of aluminium bent to shape with the aid of a vice and an old battery as a former.



GAS DETECTOR

A small 1 milliamp movement serves as the meter. Other meters can be pressed into service if they are on hand. For example, a 500uA movement can be used if the 6.8k resistor is increased to 12k. We have not bothered to calibrate the meter, as a known gas mixture is required if the calibrations are to mean anything. But this could certainly be done if you have the facilities.

A 10k potentiometer is used to zero the meter in a "clean" air mixture. While we mounted the potentiometer on the front panel, there is no reason why a small preset pot cannot be used. Once the pot is initially adjusted to suit the sensor there should be little need to adjust it apart from a "tweak" every now and again.

Since there are two voltage sources in the circuit, a double-pole switch must be used. In the prototype, we used a miniature toggle switch wired for double-pole, single-throw operation. Since these small switches have a current rating of several amps, there is no problem in this regard.

For convenience, the three resistors in the circuit are mounted on a length of miniature tagboard on the back of the meter movement. The mounting holes of the tagboard were enlarged slightly to allow the board to be mounted on the back of the meter.

While we have made the prototype self-contained with its own batteries, it can be powered externally. For example, it can be run from a 12V car battery. In this mode, the bridge circuit may be run directly from 12V while the heater filament is powered via a 22ohm 10watt resistor.

Alternatively, the circuit can be powered from the 240V AC mains via a 6.3V transformer. The heater filament can be run directly from the 6.3 VAC via an 8.2ohm 5 watt resistor. At the same time, the 6.3VAC can be half-wave rectified by a single diode and then filtered with a 470uF 12VW electrolytic capacitor to provide 9 volts DC for the bridge circuit.

The TGA sensor for the prototype was mounted on the end of a suitably long cable. This enables it to be mounted remotely to the meter so that it can monitor the bilges of a boat, exhaust gases, poisonous gases and so on. It can safely monitor explosive gas mixtures, since the double 100-mesh gauze covering the chip is proof against explosions.

Spacing of the four pins of the TGS sensor enable it to fit neatly into a seven-pin valve socket, which is what we used. It can be supplied with a special four-pin socket but this is only suitable for mounting on a printed circuit board. We mounted the seven-pin valve socket and sensor on the end of an aluminium pill container.

The three wires from the socket run through a grommet in the lid of the pill container. The wires are twisted together to form a neat cable. At the chassis end they are firmly secured with the aid of the battery clamp.

Around the home, the prototype Gas Detector could have a variety of worthwhile applications. For example, it will respond very rapidly if a gas stove is turned on without lighting it - useful in a home where small children often turn on the gas taps. In this sort of application the Gas Detector would have to be mains powered to give round-the-clock monitoring.

A prime use for the Gas Detector would be as a petrol fume detector on a boat. The sensor can be mounted remotely in the bilge while the meter is mounted on the instrument panel. A routine would have to be followed though - always turn on the detector (using type 308) a few minutes before starting the engine. But it would be foolish to rely absolutely on this device as a defence against explosions - the bilge should be kept well ventilated.

The Gas Detector can also be a useful aid in setting the idling mixture of an automobile, although remember that it gives comparative results only. And the engine must be warmed up properly before the mixture can be adjusted.

At a party, the Gas Detector can be used as a novelty breathalyser. It gives a strong indication if a person has been consuming alcohol, even odourless drinks like vodka. It can give a false indication, though, when a person breathes hotly into the sensor as this raises the sensor temperature slightly which gives a slight change in its resistance.

At the same time, we do not suggest that you have a drink just to test out the Gas Detector.

PARTS LIST

1 chassis (see text)
1 meter movement, 500uA or 1mA sensitivity
1 9V battery plus connector
4 1.5V cells
1 seven lug length of miniature tagboard
1 DPST toggle switch
1 Figaro TGS 202 or 308 gas sensor
1 seven-pin valve socket
1 x 390 ohm, 1 x 3.9k 1 x 8.2k ¼W or ½W resistors
1 battery clamp (see text)
1 metal pill case (see text)
1 Grommet

MISC
hook-up wire, screws, nuts, washers, solder
Letraset.

AN EXPERIMENTAL HELIUM-NEON GAS LASER

THERE IS GOOD REASON TO BELIEVE THAT IN THE NEAR FUTURE, MANY INTRIGUING AND EDUCATIONAL EXPERIMENTS WILL BE PERFORMED IN SCIENCE CLASSROOMS USING A SMALL GAS LASER UNIT, SUCH AS THE ONE DESCRIBED IN THIS CHAPTER. THIS SHOULD THEREFORE BE OF CONSIDERABLE INTEREST, PARTICULARLY TO SCHOOLS, UNIVERSITIES AND TECHNICAL COLLEGES

<u>WARNING:</u> THE OPTICAL OUTPUT OF THE LASER UNIT DESCRIBED IN THIS CHAPTER, WHILE OF LOW POWER, IS CONCENTRATED INTO A NARROW BEAM POTENTIALLY CAPABLE OF PASSING FULLY THROUGH THE IRIS OF A NORMAL HUMAN EYE. THE INTENSITY WHICH WOULD BE PRODUCED AT THE EYE RETINA IF THIS OCCURRED IS REGARDED AS SUFFICIENT TO CAUSE PERMANENT SIGHT IMPAIRMENT, SO THAT INTENDING CONSTRUCTORS OF THE UNIT ARE STRONGLY WARNED AGAINST ALLOWING THIS SITUATION TO OCCUR.

A VERY WORTHWHILE RULE IS "NEVER TO LOOK A LASER IN THE EYE", EITHER DIRECTLY OR VIA A HIGHLY SPECULAR REFLECTIVE SURFACE SUCH AS A MIRROR OR A POLISHED METAL OR PAINT FINISH. ONLY ALLOW SUCH A BEAM TO ENTER THE EYE WHEN IN HAS BEEN WIDELY DIFFUSED, AS FROM A SCREEN OR WHITE CARD.

Although the laser has only been present on the technological scene for just on nine years, it has already made considerable impact. Most non-technical laymen know of its existence, if only from hearsay or as a result of the somewhat imaginative representation of such a device in the James Bond movie "Goldfinger".

Those with more technical background or inclination will no doubt have a somewhat more detailed and factual concept of such a device and its operation. In the past few years there have been many articles and news stories describing both the operation of the various types of laser, and their ever-growing applications.

Understandably, most of the laser applications publicised have been rather esoteric. Examples are extreme bandwidth optical communications links, optical rangefinders and other navigation aids, precision micro-machining, rapid hole-drilling in diamonds, 3-D "photography" or holography, and the welding of detached retinas inside human eyeballs. Some of these applications require the use of lasers of very high power, and correspondingly high cost; however, others may be performed using relatively low power and low cost units.

It may not always be realised that, in addition to their more esoteric applications, lasers are also very suitable and are in fact widely used for a variety of somewhat more mundane tasks. These include surveying, precision measurement of length, flatness and motion, and the simple and quite dramatic demonstration of many of the basic laws of optics. The last-named of these applications promises to ensure an ultimate place for lasers in every school, university and technical college physics laboratory.

The small helium-neon gas laser to be described is particularly suitable for demonstrations and experiments in optics, and should be found of considerable interest as a result. It is also capable of being used for simple interferometry and holography experiments, and possibly may also serve as the heart of an optical communications system. Despite its flexibility the unit is of relatively low cost in terms of laboratory equipment and construction is made very simple as a result of the use of a sealed and pre-aligned plasma tube.

The recent availability of the particular plasma tube used has in fact made the project possible. The tube used is the type EOA-9040, manufactured by Electro Optics Associates of Palo Alto, California and imported to this country.

The EOA-9040 is a compact tube measuring a nominal 7¾in long by 1in diameter. It is basically a hot-cathode discharge tube filled with a mixture of helium and neon gases at low pressures - approximately 0.4mM and 0.1mM of mercury, respectively. At these pressures the tube output is in the red region of the optical spectrum, with a wavelength of 6328 Angstroms (0.6328uM).

As may be seen from figure 2 the tube employs a novel double re-entrant or "co-axial" construction in which the outer envelope forms both the mechanical support for the pre-aligned resonator mirrors, and also provides the electrode chambers. The inner capillary tube provides the only plasma passage between the two electrode chambers, and therefore forms the actual oscillation cavity in which the "lasing" takes place.

Because of the integral construction employed, the tube has no need for the specially-angled "Brewster windows" used on external mirror tubes; as a result the ouput beam from the unit is unpolarised (but can be externally polarised if this is required). The use of so-called "confocal" combination of plane and spherical concave mirrors also ensures that the tube oscillates in its most basic transverse mode, producing an output beam whose intensity is substantially uniform in cross-section. The beam diameter on emerging from the output end of the tube is rated as 1.2mM.

Although of relatively short length, the output beam is quite highly collimated (formed into a parallel beam), having a rated maximum divergence of only 1.5 milliradians. This can be reduced by optics to a diffraction limited minimum of 0.15 milliradians.

Guaranteed minimum optical power output of the EOA-9040 tube is 0.5mW with a quoted typical figure of nearer 1mW. While this may seem a very modest figure it is in fact quite adequate for most experimental purposes, and is regarded as an attractive compromise between usefulness and operational safety.

DUE TO THE CONCENTRATED NATURE OF THE OUTPUT BEAM, THE FULL OPTICAL POWER OUTPUT OF THE TUBE COULD CONCEIVABLY ENTER THE EYE, PRODUCING AN INENSITY EXCEEDING THAT PRODUCED BY A DIRECT GLANCE AT THE SUN OR A HIGH-INTENSITY ELECTRIC ARC DISCHARGE - EVEN WITH AN OUTPUT LEVEL OF ONLY 0.5mW. READERS AND INTENDING CONSTRUCTORS ARE THEREFORE ADVISED TO TAKE CAREFUL NOTE OF THE SAFETY PRECAUTION GIVEN IN THE WARNING PANEL.

The directly heated cathode of the EOA-9040 tube requires a conventional heater supply of 6.3V at a nominal 0.6 amps. Anode ignition voltage is approximately 3KV, maintaining voltage approximately 1100V. Current-controlled operation is necessary because of the negative-resistance characteristic exhibited by plasma discharges, and the rated maximum continuous anode current is 7mA. The optical output in the tube is claimed to be substantially a linear function of anode current between the rated maximum value and near-extinction at approximately 3mA.

The following explanation of the nature of the light produced by lasers, and the operation of the He-Ne gas laser in particular, may be found of value both by intending constructors and also perhaps by those reading this article for general interest and background.

It is fairly common knowledge that light is a variety of electro-magnetic radiation, and as such is basically similar in nature to the type of energy radiated by radio and television transmitters, radar sets and X-ray tubes. The essential differences between these varieties of electro-magnetic energy are in terms of frequency - or its complement, wavelength.

Thus radio transmitters generally radiate electromagnetic waves whose frequency falls between 10 Kilohertz (KHz) and 100 Megahertz (MHz), television transmitters generally radiate waves somewhere between 40MHz and 800MHz, and so on. In comparison with these examples the frequencies of visible light radiation are very much higher, lying in a band between about 500 and 1,000 million Megahertz. The corresponding wavelengths are 0.7 and 0.4uM (micro-metres).

Although light and other forms of electromagnetic radiation may seem to consist of continuous waves, their behaviour in many situations has been found to suggest strongly that this is not the case. Rather it has been found necessary to conceive such radiation as consisting

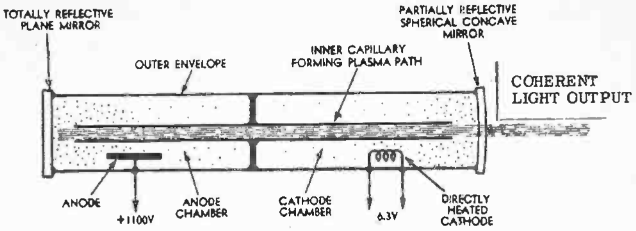


Figure 2 THE EOA-5040 He-Ne GAS LASER

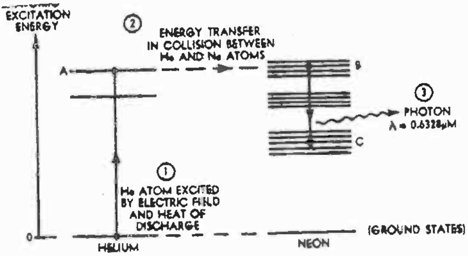
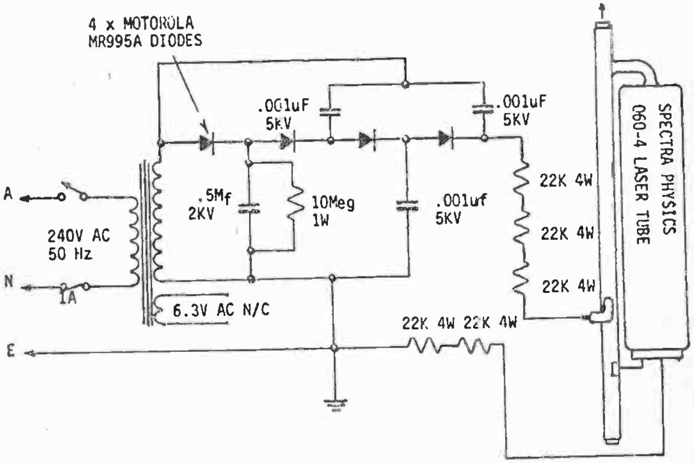


Figure 1



of a stream of "packets" of particles of energy. The name given to these particles is PHOTONS.

Probably the most common way in which photons of light are produced is when atoms of a material which have become "excited" by absorption of heat or other energy suddenly drop back either to a less excited state, or to their original unexcited "ground state." When an atom thus reverts to a less excited state, the energy is expelled and emitted as a photon of radiation.

The amount of energy which is expelled as a photon when an atom "relaxes" depends naturally upon the degree to which it was excited prior to relaxing, and the degree, if any, to which it remains excited after the relaxation. The expelled energy is simply the difference between the two. And the amount of energy expelled has been found to determine the FREQUENCY of the photon emitted - not, as one might perhaps expect, its "size."

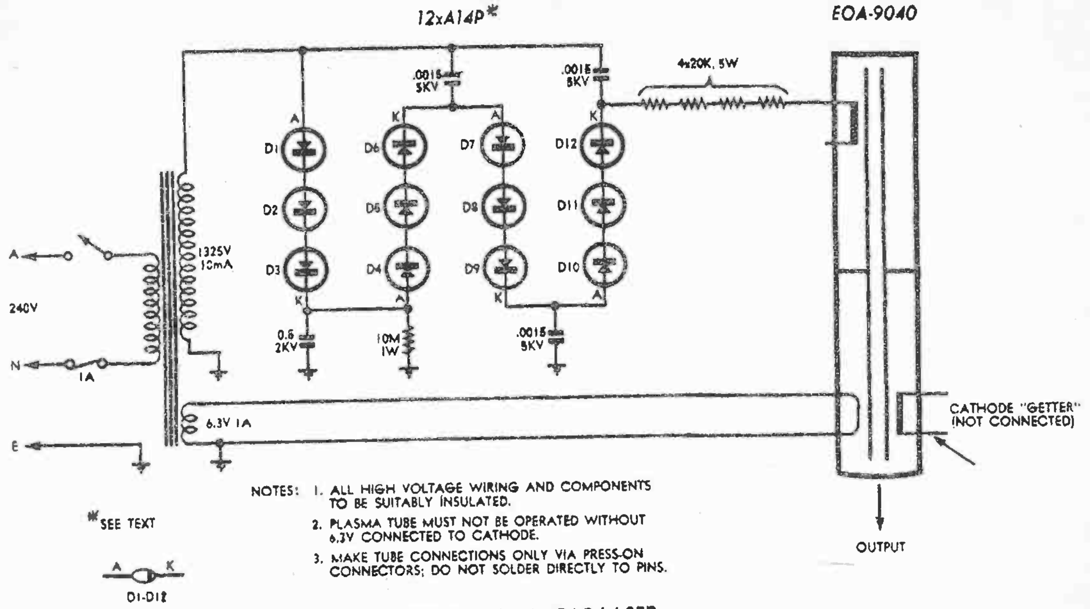
By their very nature, atoms can only absorb and expel energy in definite amounts or increments, called QUANTA. The size of the quanta also depends both upon the composition of the particular atom concerned, and also upon its degree of excitation at the instant concerned. Hence an atom of a particular element or substance, when it relaxes, can emit only those photons whose frequency correspond to the various possible transitions between the allowed energy levels of the atom concerned. This explains the characteristic "spectra" found by analysing the light radiated (or absorbed) by materials under suitable conditions.

In an ordinary flame, electric arc or incandescent lamp filament, many millions of atoms are constantly becoming excited to a greater or lesser extent, and similarly relaxing to a greater or lesser extent; the whole occuring in a completely random and haphazard fashion. The light which is produced by such sources therefore consists of vast numbers of independent photons, differing from one another both in terms of frequency and in terms of phase.

As such, this type of radiation differs considerably from that emitted by radio and television transmitters, because the latter radiate (ignoring modulation, for simplicity) a steady stream of photons all of the same frequency and synchronised with one another in terms of phase, such that together they effectively constitute a continuous wave-train. The term "COHERENT" is used to describe radiation which is in this more organised form.

In short, virtually all "normal" sources of visible light radiation produce light which is incoherent - composed of many frequencies, and lacking any significant synchronisation even between those photons having the same frequency. As such, the light emitted by such sources generally cannot be used for many of the potential applications which have long been known to exist for radiation possessing both coherency and the high photon energy of visible radiation.

The development in 1960 of the ruby laser provided the first known source of truly coherent light radiation, and for the first time enabled the potential applications to be realised. Since then a number of other types of laser have been produced, all possessing the ability to generate coherent light radiation, and all contributing to the current development of ever-exciting applications of such radiation.



LOW POWER He-Ne GAS LASER

The circuit diagram of the laser unit, which may be seen to consist essentially of a high-voltage power supply.

The name "laser" is itself a rather cryptic key to the way in which these devices operate. The name is really an acronym formed from the initial letters of the words Light Amplification by Stimulated Emission of Radiation.

As this suggests, the operation of lasers depends upon the effective amplification of light by a process known as "stimulated emmission."

Basically, stimulated emmission is not a difficult phenomenon to understand, although it may initially be found rather surprising. What it amounts to is this: if an atom is excited, and is therefore potentially able to relax by emitting a photon of a particular frequency, it can be stimulated into relaxing in this way by the occurrence of a collision with another photon of the same frequency. When this happens, the photon emitted by the relaxing atom is created in exact synchronism with the photon which triggered the event. At the same time the stimulating photon is not absorbed or otherwise disturbed, but is able to leave together with the second photon.

In other words, stimulated emission is the process whereby a photon of radiation collides with an excited atom to trigger the emission of a second photon identical in frequency and synchronised in phase; the two photons then leave together.

It should be fairly clear that this mechanism is a potential means of achieving light amplification, because a continuing and cumulative series of stimulated emissions can effectively result in the production of two photons from one, then four from two, eight from four, and so on. And it should also be apparent that because the stimulation mechanism in each case produces new photons which are identical in frequency and synchronised in phase with those triggering their production, the amplification process will result in coherent radiation.

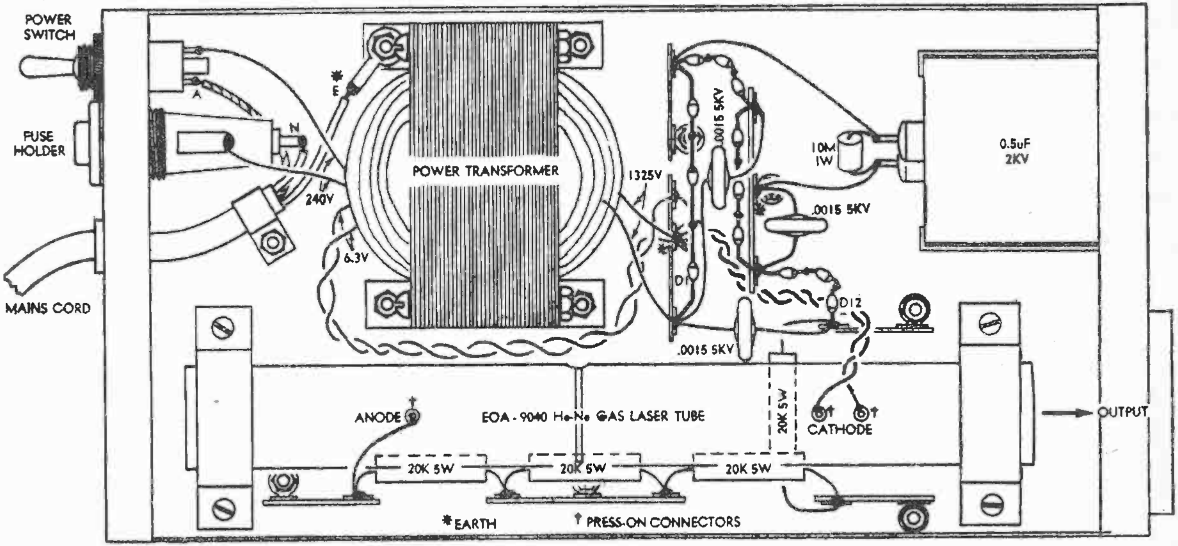
All lasers depend upon the mechanism of stimulated emission for their operation. The various varieties of laser differ mainly in terms of the material used to provide the excited/relaxing atoms, and the method used to "pump" or excite large numbers of the atoms into the excited state. Naturally enough, for cumulative light amplification or "lasing" to occur to any appreciable extent from stimulated emission, there must be a situation in which large numbers of atoms are in an excited state.

The helium-neon or "He-Ne" gas laser, of which the EOA-9040 is an example, is possibly the most common type of laser in use at the present time. In this type of laser it is actually the neon atoms which are associated with the stimulated emission mechanism; the helium atoms are used merely as an energy transer medium for "pumping" the neon atoms to the appropriate level of excitation.

The pumping system employed may be understood by reference to the excitation energy diagram of figure 1. There the solid horizontal lines represent the various allowed excitation energy levels or states for atoms of helium, on the left, and neon, on the right. The lowest lines in each case correspond to the ground states, and these have been aligned to show more clearly the relationships existing between the two types of atom in terms of excitation increments.

In passing it should perhaps be noted that although the diagram of figure 1 is somewhat similar in appearance to the electron-energy diagrams used in analysing electrical conduction and the operation of semi-conductor devices, it does not have the same significance.

complete wiring diagram of the laser unit,



The levels here do not correspond to specific allowed electron energy levels, but rather correspond in a more general manner to the levels of excitation available to the atoms considered as complete systems.

In the He-Ne gas laser the electric field and high temperature existing in the discharge plasma causes helium atoms to be ionised and accelerated, thereby exciting them to energy levels above the ground state. One of the allowed excitation levels for helium, shown on the diagram as "A," corresponds almost exactly to one of a number of closely spaced excitation levels of the neon atom. This level is shown on the diagram as "B."

Because of this level equivalence between the two types of atom, a collision between an excited helium atom and an unexcited neon atom almost inevitably results in a total transfer of excitation energy between the two. After such a collision the helium atom is almost always left in the ground state, while the neon atom is found to have acquired the excitation energy represented by level B. In the He-Ne gas laser system there is a high probability that this type of collision will occur, because the particular level "A" of the helium atom is meta-stable: once having absorbed the appropriate amount of energy, the helium atom connot spontaneously expel it to "relax." Hence there tends to be a high proportion of excited helium atoms in the discharge, and accordingly a high probability that collisions between excited helium atoms and neon atoms will occur frequently.

In effect, then, the helium atoms serve to "pump" large numbers of neon atoms to the level of excitation represented by the line "B." And it transpires that, if the pressure of the gases in the tube is adjusted to a suitable value, neon atoms which possess this excitation level exhibit a strong tendency to relax, either spontaneously or by stimulation, to a lower excitation level represented on the diagram by "C." From this level they may then drop to the ground state, at a later time.

The energy difference between levels "B" and "C" corresponds, as may be seen, to a photon of frequency equivalent to the wavelength 0.6328uM. Hence every neon atom which relaxes after colliding with an excited helium atom in the foregoing manner emits a photon of radiation of this wavelength. The excitation transition between levels "B" and "C" of the neon atom is thus that associated with the stimulated emission process in producing a coherent light output.

From the foregoing it may be seen that throughout the ionised gas mixture inside a He-Ne gas laser there will be excited neon atoms relaxing, either spontaneously or due to stimulation, and emitting photons of the appropriate frequency. Cumulative light amplification or "lasing" thus tends to occur everywhere inside the plasma tube, to a certain extent. However, in the case of a tube whose construction is similar to that of the EOA-9040, shown in figure 2, the lasing can only build up to significant magnitude and be maintained in a continuous manner in the narrow region extending though the central capillary tube and bounded at each end by the mirrors at the ends of the outer envelope.

One reason for this is that, in general, it is only inside the capillary tube that there are sufficient numbers of excited neon atoms to support the stimulated emission process in a continuous manner.

Because the construction of the tube forces the discharge plasma to "squeeze" through the narrow capillary, it is naturally inside the latter that the greatest degree of gas ionisation and excitation is produced.

Apart from this there are more fundamental reasons for the confinement of continuous lasing of the tube within the narrow central region. For coherent radiation to grow to a significant magnitude, the synchoronised photon "team" produced by the stimulated emission process must be able to accumulate a large "membership;" this implies a long optical path, as it is only over such a path that the stimulated emission process will be sufficiently cumulative. From figure 2 it can be seen that the longest unimpeded optical path existing in the plasma of the tube is within the capillary tube and aligned with its axis.
In itself, a long optical path could not result in continuous lasing. For coherent radiation to be maintained continuously after having built up, there must be some sort of positive feedback mechanism available whereby the stimulated emission process may be self-perpetuating. In the gas laser this feedback is provided by the mirrors at each end of the active optical path.

In effect, the mirrors form a resonant optical cavity, such that coherent radiation produced within the active optical path can oscillate back and forth to maintain itself. The reflection at the mirror surfaces is not entirely lossless, but the relection losses are compensated by the optical gain of the plasma path. In fact, one of the mirrors is intentionally desiged to be only partially reflective, and this is the means used to extract coherent light output from the laser. As shown in figure 2, in the EOA - 9040 tube it is the spherical concave mirror which is partially reflective, and therefore this mirror which forms the "output" end of the tube.

As may be seen from the circuit diagram, the EOA-9040 plasma tube forms the heart of the experimental laser unit. The remaining components are employed in a fairly simple power supply designed to provide the tube with the appropriate operating voltages.

The power supply employs a mains transformer having two secondary windings. One secondary is a conventional heater winding which supplies 6.3V at approximately 600mA for the plasma tube heater. The other secondary winding is designed for use with the rectifier circuit shown, to produce the anode voltage for the plasma tube; rated secondary voltage is 1325V at a nominal average current of 10mA.

The apparent complexity of the rectifier circuit arises from the fact that plasma tubes must be supplied initially with a voltage somewhat higher than the maintaining voltage in order to achieve reliable ignition. In the case of the EOA - 9040 the required initial voltage for reliable ignition is approximately 3.300V, while the maintaining voltage is approximately 1100V.

To satisfy the dual requirements concerning maintaining voltage and ignition voltage in an economical fashion, the power supply circuit combines a relatively well-regulated half-wave rectifier with a very poorly regulated voltage-multiplying rectifier. The half-wave section produces the plasma tube maintaining voltage, while the multiplier section produces the additional voltage necessary for reliable ignition.

The basic half-wave circuit consists of the three diodes: D1, D2 and D3, together with the 0.5uF/2KV reservoir capacitor. The 10M/1W resistor across the reservoir capacitor is a bleeder to promote rapid discharging upon switch-off, for operator protection, while the four 20K/5W resistors connected in series with the plasma tube anode provide the necessary current limiting. Three diodes are connected in series to provide sufficient peak inverse voltage rating.

The remaining nine diodes and three .0015uF/5KW capacitors form the voltage multiplying rectifier, whose output effectively adds to that of the basic half-wave circuit prior to ignition of the plasma tube. However, the low value reservoir capacitors used in this section provide very poor regulation with the result that immediately the plasma tube ignites and draws significant current, the total output voltage drops to the value determined by the half-wave circuit.

Three series-connected diodes are again used in each leg of the multiplier section, to provide sufficient peak inverse voltage rating.

The device type specified for all 12 diodes used in the power supply is a 1A/1000V peak inverse rating device which features transient overload protection. The special characteristics of this device permit the use of a simple series connection to achieve the required peak inverse rating, and also justify the use of only three diodes per leg, whereas four would be dictated from normal rectifier theory.

Although other types of silicon diode may be used in the circuit as it stands, and with possibly no ill effects, it would really be necessary to fit resistor-capacitor combinations across each device to ensure equalisation of both periodic and transient reverse voltages. Suitable values for most types of device would be a 470K resistor and .0047uF/2KV capacitor, connected in parallel across each device.

The 0.5uF/2KV main reservoir capacitor is a standard sealed paper type. The three.0015uF/5KV capacitors are standard high-voltage "button" ceramics.

As may be seen the physical construction of the demonstration gas laser is quite straightforward. The unit is housed in a small case measuring 10in x 5in x 2¾in, the case consisting of two complementary "U" sections. One section, forming the base and ends of the case, mounts both the plasma tube and the power supply components; the other section forms the top and sides of the case, and constitutes a removable lid.

The plasma tube is mounted along one side of the base, fixed securely but without strain on the glass envelope, by means of neoprene "O" rings clamped lightly between two metal clamps. The neoprene rings are of a standard type measuring 7/8in inside diameter and 1/8in thick. The base and lid of the case are provided with ventilation slots which align above and below the axis of the plasma tube when the case is assembled, to ensure adequate convection cooling. The power supply components are mounted inside the case beside the tube.

A circular aperture approximately 1½in in diameter is provided in the end of the case adjacent to the "output" end of the plasma tube, to provide adequate clearance both for the output beam and for manual cleaning of the external surface of the plasma tube mirror. From the photographs it may be seen that the prototype unit is also fitted with an accessory mounting ring on the exterior of the aperture; however, this is not really necessary except for serious research work.

The mains toggle switch and cartridge fuseholder are mounted on the "rear" end of the case, with the mains cord entry nearby. The mains cord is passed into the case through the usual rubber grommet, and is clamped securely upon entry to prevent strain on the terminations.

Immediately to the front of the switch and fuseholder is the power transformer, and in front of this again are four tagstrips mounting most of the minor power supply components. The large 0.5uF paper capacitor is mounted via the clamps supplied to the front of the case, with the 10M bleeder resistor connected directly across its terminals. The four 20K/5W current limiting resistors are below and adjacent to the plasma tube itself, supported by a further group of three tagstrips.

The tagstrips used in the unit are basically standard (not miniature) types, but with some of the original tags removed to improve the breakdown characteristics. In general every tag used to support a high voltage point of the circuit is isolated from the nearest earthed support tag by a blank hole corresponding to a removed tag from the original strip; this should be fairly evident from the illustrations. All components and wiring which are floating at high voltage are suitably protected by nylex or varnished cambric sleeving, and spaced at least ½in from the chassis and from other components.

In order to assist constructors in wiring the unit we have provided a complete wiring diagram, and this used in conjunction with the circuit diagram and photographs should render the task quite straightforward. Howver there are a few points which should be noted, particularly regarding the handling of the plasma tube.

PARTICULAR CARE SHOULD BE TAKEN WHEN HANDLING THE TUBE, AS IT IS BY FAR THE MOST COSTLY SINGLE ITEM IN THE PROJECT. TAKE CARE ALSO NEVER TO TOUCH THE SURFACE OF THE TUBE OUTPUT MIRROR WITH THE BARE HANDS, OR IN FACT WITH ANYTHING OTHER THAN A "COTTON BUD" USED FOR CLEANING. THE REMAINDER OF THE TUBE ENVELOPE MAY BE HANDLED, WITH CARE, ALTHOUGH IN THE INTERESTS OF SAFETY SUCH HANDLING SHOULD BE KEPT TO A MINIMUM.

Probably the most wise procedure when assembling and wiring the unit is to assemble all the power supply components in the case, and complete virtually all the wiring, before the plasma tube is mounted in position. This will protect the tube from most of the likely sources of danger arising during these operations.

Under no circumstances should the connections to the tube itself be made by soldering directly to the tube pins, as the resultant heating of the pins would almost certainly fracture the glass and ruin the tube. Instead the leads should be soldered separately to the small spring disc connectors supplied with the tube, the connectors then being pushed by hand on to the tube pins when they have cooled.

Each connector should be held in a pair of pliers while the soldered joint is made, and the joint itself should be made quickly to avoid overheating the connector and reducing its "springiness." However care should nevertheless be taken to ensure that the joints are sound; this is particularly important with the two cathode connections, as accidental loss of the 6.3V heater supply during operation could ruin the plasma tube.

When mounting the plasma tube in position take care that there is adequate clearance between the first 20K current limiting resistor and the pins of the electrically unused "getter" in the plasma tube cathode chamber. Unless there is at least ⅜in between these points arc-over may occur before the tube ignites properly, and both the tube and power supply components could be damaged as a result.

The manufacturers of the plasma tube recommend that, prior to the initial application of anode voltage to the tube, it is wise to make completely sure that the cathode heater is correctly and reliably connected to the appropriate 6.3 volts. Because simple disconnection of the tube anode lead could result in damage to the rectifier diodes and reservoir capacitor due to inadequate loading, the suggested procedure for this check is to omit connection of the "hot" end of the 1325V transformer secondary to the rectifier components. (Temporarily insulate the transformer lead with sleeving to prevent shorts.)

If everything is in order, switch-on will then simply result in the heating-up of the tube heater. If desired the voltage actually present across the heater pins may be measured with a suitable AC voltmeter, to ensure that the contact between the disc connectors and the tube pins is of low resistance. Then having made sure that the tube heater is being correctly energised, the power may be turned off and the final connection made between the transformer and the rectifier circuit.

Once this connection is made, the tube should begin "lasing" whenever power is applied. No further adjustments will normally be required, as a result of the sealed and pre-aligned mirror system used in the EOA-9040 tube. If desired, the tube current may be measured using a suitably insulated milliamp meter inserted in series with the anode lead, and should be no more than 7 milliamps. However, if the ciruit is wired as shown and all component values are unchanged, this measurement should be unnecessary

There are a wide variety of experiments which may be performed with the unit once it is operational, and for a full description of these the reader must be referred to one or more of the standard texts. However, a few examples will be given, both for the interest of those reading this article mainly out of curiosity, and also to whet the appetite of those intending to build the project.

Because of its coherence, the output beam of the laser may be used to demonstrate quite dramatically the effects of optical diffraction and interference. Thus a narrow vertical slip placed in the beam will cause it to diverge horizontally due to diffraction, and will result in a characteristic "dashed line" interference pattern on a screen placed in the path of the beam. The pattern was produced using a slit formed by two safety-razor blades clamped in a small holder fashioned from scrap aluminium.

Another quite impressive interference pattern is produced if the beam is passed through a small pinhole. Here diffraction causes the beam to be spherically divergent upon exit from the hole causing a pattern of concentric interference fringes to be produced on the screen. The pattern was produced using a small hole formed by passing a common dressmaking pin through a piece of blackened photographic film.

The third pattern is slightly more complex than the other two. It was formed by passing the beam throuch a very fine optical screen, of the type used in half-tone printing, and thus represents the effect of passing the beam in effect through a whole array of regularly spaced pinholes. A similar effect might be produced by a hand-made screen produced by scratching a series of closely spaced fine lines in a grid pattern on a sheet of blackened photographic negative.

A novel experiment may be performed by using a small lens to diffuse the output beam of the laser and project a suitably sized spot of light upon a screen or white card. If one allows the eyes to relax, it will be found the the spot of light appears to be composed of a large number of "grains". The interesting thing about the "grains" is that they appear to move if one moves about, and in a direction which depends upon the basic focal characteristics of the eye.

Hence if one is basically short- or near-sighted, the "grains" will appear to move in the opposite direction to any head movement. Yet those with normal or far-sighted eyes will find that the "grains" will appear to move in the same direction as the head. The experiment thus gives a simple test for the condition of one's eyes, although the results will fairly obviously be of little diagnostic value.

There are many more experiments which may be performed with the laser unit, but those briefly described above may serve to illustrate its potential applications. Perhaps it would be worthwhile stressing that, in seeking to discover the fascinating behaviour of the device, the experimenter snould always remember the possible injury which could result from direct entry of the full laser beam into the eye. In general, the rule should be "never look a laser in the eye," and the rule relaxed only with caution when the beam from the device has been well diffused.

A final note. The external surface of the output mirror of the plasma tube may from time to time collect sufficient dust to reudce the available output intensity. When this occurs, the surface may be cleaned carefully using a "cotton bud" dampened with medicinal quality acetone. Use a different part of the bud surface for each wipe of the mirror, to prevent scratching, and take care not to use an excessive amount of acetone because the mirror mounting cement is very slightly soluble and may be weakened.

Although the laser tube used in the original design was far from cheap - the project was a remarably popular one. A considerable number have been built up by schools, technical colleges, universities and by a small number of enthusiastic hobbyists.

Fairly obviously there is still a good deal of interest in do-it-your-self" lasers!

Now available is the type 060-4 from the Californian firm Spectra Physics. The 060-4 is very similar in its performance to the original tube, yet it costs only a little more than half the original price. Like the original tube it has a nominal light output of 0.5mW.

The main difference between the two is that the new tube is of the cold cathode type and does not need heater excitation. Apart from this the only circuit change required is an additional 22k/4W resistor in the ballast chain. We recommend that the chain be split in two, as shown, with two of the resistors in the cathode return. This is to reduce lead capacitance and assist in starting particularly when the tube gets very old.

We used a GE controlled-avalanche A14P 1000V diodes in the original circuit, with three in series per multiplier leg. These diodes are still available. However we suggest using four of the Motorola MR995A diodes, which are now also available. These are rated at 4kV PIV and 250mA average current.

The only other point of interest is that the 060-4 tube is physically rather different from the original tube, consisting of a narrow-bore laser resonator with a larger cathode tube alongside. This will call for a rather different method of tube mounting, and also for a slightly longer case. Overall tube length is 28.3cm.

FOR FURTHER READING:

BROWN, R., LASERS, 1968. Aldus Books Ltd., London.
PATEK, K., LASERS, 1967. Iliffe Books Ltd., London.

LASER PARTS LIST

1 Plasma Tube, Electro Optics Associates EOA-9040
1 Power transformer, 240V to 1325V at 10mA, 6.3V at 1A
1 Cartridge fuseholder, 1A fuse cartridge
1 SPST Toggle switch, 240V rating
12 Silicon diodes RS276-1114, BY127, 1S109, 1N4007-4249-4586, SK3033
4 20K 5 watt resistors
1 10M 1watt resistor
3 .0015uF 5KV ceramic capacitors
1 0.5uF 2KV sealed paper capacitor. (See text.)
1 Metal case, 10in x 5in x 2¾in, with plasma tube clamps
2 Neoprene "O" rings, ⅜in inside diameter, ⅛in thick.
7 tagstrips (modified - see text).
Nuts, bolts, connecting wire, mains cord and plug, insulating sleeving.

AN EXPERIMENTER'S HIGH-VOLTAGE GENERATOR

A SAFE SUPPLY FOR EXPERIMENTS AND DEMONSTRATIONS, DELIVERING LOW CURRENT AC OR DC AT HIGH VOLTAGE. ALMOST ALL THE PARTS MAY BE SALVAGED FROM A DISCARDED TV RECEIVER.

In technical colleges, high school science departments and similar educational situations there are often occasions when high voltage AC or DC is required for demonstration purposes. Typical applications are the operation of gas discharge tubes, small X-ray tubes, gas lasers and mass spectographs, potential plotting of electric fields, demonstration of corona, spark and arc discharges, and experiments concerning gas ionisation, plasma, and the measurement of mass and charge of electons and other atomic particles.

From considerations of operator safety there is strong motivation to make the source of the high voltage used in such applications as poorly regulated as possible. The lower the current which may be drawn from the supply, in general, the less will be the risk of injury due to burns, shock or heart disturbance in the event of inadvertent personal contact. Thus the poorer the supply regulation the "safer" the system of high voltage generation employed, although the effective risk of injury is also dependent upon such factors as the galvanic skin resistance, the body path involved and the condition of the operator's heart.

Fortunately, in most of the applications concerned the regulation of the high voltage supply is of relately minor importance with respect to actual operation, as the current drawn by the equipment is only a few micro-amps. Thus providing the supply has sufficient regulation to deliver the required voltage at the current drain imposed by the equipment, together with corona and insulation leakage losses, decay of output voltage at higher currents is unimportant.

Among the "classical" sources of high voltage for such applications has been - for AC - the induction coils of Ruhmkorff and Tesla, with so-called "electrostatic machines" such as those invented by Wimshurst and Toepler-Holtz being used for DC generation. Figure 1 shows etchings of equipment of this type reproduced from an early textbook; (a) shows a Ruhmkorff induction coil, which is essentially a high-ratio, step-up transformer with an integral buzzer-type primary current interrupter, while (b) shows a pair of rotary frictional machines which are essentially a mechanisation of the cat's-fur-and-ebonite-rod method generating an electric charge.

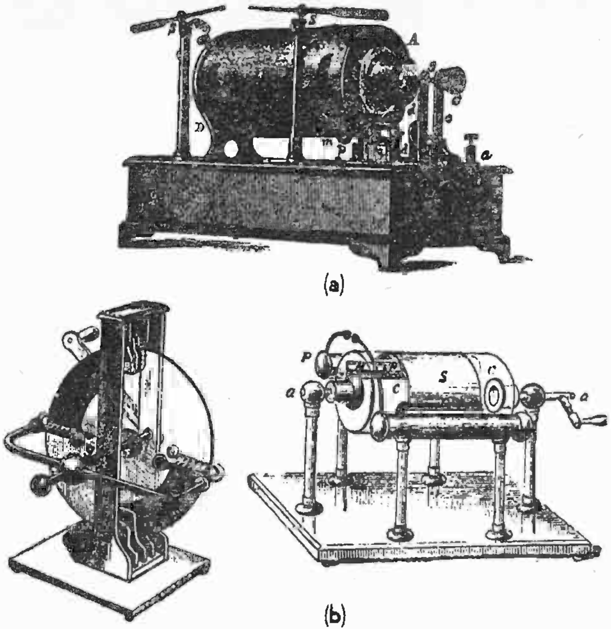
More recently a common source of high voltage DC has been the Van de Graaff generator, which employs the principle of electrostatic inudction to charge a metallic sphere continuously using an endless insulating belt. A diagram illustrating a generator of this type is shown in figure 2.

Although induction coils and frictional machines are capable of quite satisfactory results when well constructed and correctly adjusted, both types of machines tend to be some-what cranky and unreliable. The induction coil is critical of interrupter contact adjustment and is prone to develop shorted turns in the many-turn secondary winding due to moisture ingress and corona damage of insulation. Frictional machines are highly sensitive to humidity and dust and must be kept scrupulously clean and dry if appreciable output is to be obtained; they are also rather critical of mechanical adjustment.

The generator unit described in this article has been designed to provide high voltage AC or DC (alternatively) with a reliability and operating convenience considerably improved upon the earlier methods. In keeping with modern practice the unit is fully electronic and has no moving mechanical parts; it is powered from the AC mains. The output voltage is between 10 and 15kV (kilovolts) when lightly loaded, but is sufficiently poorly regulated to prevent serious injury in the event of personal contact. While a little more complex than induction coils or frictional machines, it is easily constructed from standard components, many of which may be salvaged from a discarded TV receiver.

As may be seen from the fircuit diagram, the generator consists essentially of a so-called "ringing-choke" inverter, using a standard horizontal flyback transformer of the type used in domestic TV receivers. The transformer is excited with current pulses delivered by a beam-power valve (type 6DQ6A or similar), the latter in turn being driven by a free-running or "astable" multivibrator using a double triode type 6SN7, 6CG7 or similar.

The multivibrator is of the cathode-coupled variety, both cathodes being connected to ground via a common 1k resistor. The first grid is grounded while the second is coupled to the first plate via a 390pF capacitor. The grid circuit resistance of the second stage is made variable to permit variation of the coupling time-constant, the variable resistor acting as a control of oscillator frequency. In operation the control is used to adjust the drive frequency of the output transformer-load-circuit, in which condition the generator produces maximum output voltage.



(a)

(b)

FIG. 1

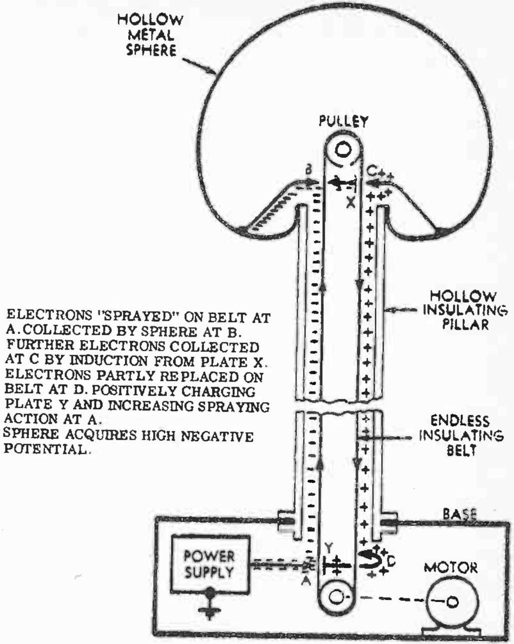
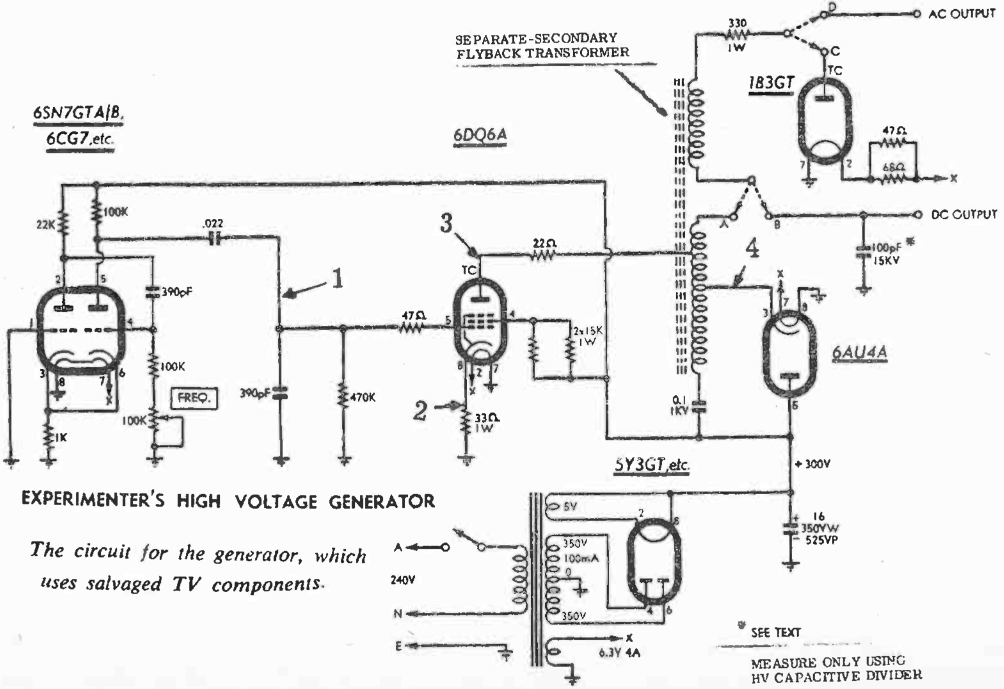


FIG 2 VAN DE GRAAFF GENERATOR



EXPERIMENTER'S HIGH VOLTAGE GENERATOR

The circuit for the generator, which uses salvaged TV components.

The output of the multivibrator is fed to the grid of the beam-power output falve via a 0.22uF blocking capacitor and 47ohm parasitic suppressor. A 390pF capacitor shunting the multivibrator output is used to partially integrate the essentially rectangular multivibrator output, producing an approximately sawtooth driving signal.

The output stage is quite conventional, with the plate of the beam-power valve coupled to a suitable tap in the flyback transformer primary via a 22ohm parasitic suppressor. The tap is selected so that the peak positive voltage applied to the plate is less than the rated 6.6KV.

Because the bias circuit allows the beam-power volve to draw grid current on positive drive peaks, and also because the drive amplitude is somewhat larger than the valve's grid base, the valve operates from cutoff. During the rising portion of the drive cycle the valve current rises from zero increasingly, and this current flows through the lower portion of the transformer primary. When the driving signal suddenly drops at the end of the cycle, the current tends to fall to zero - in response to which the transformer produces a sharp pulse in all windings. As the secondary winding has many turns, the amplitude of the pulse produced is high, producing the desired high voltage output.

The highest output from the unit is obtained by connected the lower end of the secondary to the top of the primary winding (links A, D on the circuit), this effectively connecting the two windings in series and making the full induced voltage available at the output terminal. As the output produced in this mode is in the form of the pulses, this is conveniently termed the "AC" generating mode.

A continuous or "DC" output could conceivably be provided in the manner normally used in domestic TV receivers, viz. by means of a series half-wave rectifier and filter capacitor connected to the top of the secondary winding. However, whereas with the conventional TV receiver EHT supply the rectifier heater may be powered by a small floating teriary winding on the flyback transformer, variable loading conditions would in this case preclude this method and the rectifier heater would have to be supplied by a battery supply floating at the full output voltage. Quite apart from the inconvenience and mechanical difficulty which would be involved in the latter, a rectifier circuit of this type would in any case be capable of supplying only a positive output with respect to ground - and in most cases a negative output is of somewhat greater use.

In order to provide a negative output and at the same time obviate rectifier heater problems the generator employs a shunt rectifier circuit connected only to the transformer secondary. A shunt diode (type 1B3 or similar) is connected from the top of the secondary to ground (link C), while the lower end of the winding connects to a 100pF reservoir capacitor (link B) and becomes the DC output terminal. Note that to permit this mode of operation the flyback transformer must be of the type having physically separate primary and secondary windings - preferably with the windings on opposite legs of the core - and the lower end of the secondary must be wll insulated from the frame.

The 33ohm resistor in series with the transformer secondary protects the transformer and power supply from damage in the event of accidental short-circuits.

As the flyback transformer winding inductance and self-capacitance together form a resonant circuit, modified slightly by loading conditions, the induced voltage following each pulse tends to swing negative and continue oscillation. If this were permitted to occur the plate of the beam-power valve would be driven highly negative, exceeding the valve ratings and hence reducing the life expectancy of the valve.

To prevent this from occuring, the output circuit is "damped" in a very similar fashion to that employed in a standard TV receiver EHT system, using a shunt diode (type 6AU4 or similar) connected as shown across the lower portion of the transformer primary and a storage capacitor (0.1uF 1KV) connected in series with the lower end of the winding.

Immediately the induced voltage across the transformer windings falls to zero and tends to go negative, the damper diode conducts. This effectively connects the 0.1uF capacitor directly across the lower section of the winding, whereupon the capacitor promptly draws charging current and takes almost all the energy stored in the transformer magnetic circuit. The negative voltage swing is therefore sharply halted.

The energy stored in the capacitor is not lost, but is returned to circuit during the early portion of the following cycle. The capacitor voltage is in series with and adds to the supply voltage applied to the lower end of the transformer primary, so that the capacitor returns its stored energy and helps in re-initiating the transformer primary current.

As may be seen the use of a damper diode both ensures that the beam-power valve operating conditions are within ratings, and also tends to improve the efficiency of the circuit as a whole.

Operating voltages for the generator are provided by a full-wave rectifier and a suitable transformer. The DC required is approximately 300V and 80mA, which is conveniently provided by a transformer having a 350-0-350V secondary rated at 80mA or higher. Transformers having a lower secondary voltage may be used with only slight reduction in the generator output. Transformers having higher secondary voltages may also be used, but in this case a resistor should be fitted between the rectifier and the reservoir electrolytic capacitor to limit the peak capacitor voltage at switch-on and maintain the DC output at 300V. For a 385-0-385V transformer the resistor value will be about 470ohms at 5 watts.

As mentioned earlier most of the components for the generator may be salvaged from a discarded TV receiver. This applies to the valves, the flyback transformer and most of the minor components. The power supply transformer and rectifier may either be salvaged from an old radio receiver or purchased new; any transformer and rectifier capable of delivering 300 volts DC at about 80mA and approximately 4A at 6.3V for the heaters is suitable. The chassis and EHT cage may also be salvaged from the same TV receiver used to supply the other components. Of course new components may be used throughout if this is more convenient.

As the pictures show, we built the prototype generator on a medium-sized utility chassis using an assortment of components salvaged from past projects. Although the layout we used may be copied if desired, the disposition of wiring is not particularly critical and may be arranged to suit the hardware to hand and the constructor's talents and desires. The main points to watch are that "hot" circuitry is kept well away from the chassis and the operator!

The EHT cage used for the prototype was sufficiently large to permit it to include the flyback transormer, EHT rectifier and damper diode. The latter were mounted to porcelain-type octal sockets bolted to the chassis in a fairly generous slot which provides both ample lug clearance and a measure of ventilation for convection cooling. The beam-power valve, multivibrator and power rectifier were mounted in a well-spaced line along the fron of the chassis, with the 6DQ6A close to the cage so that its plate lead is quite short (this helps keep radiation to a minimum). The latter lead enters the cage via a generous clearance hole. The 6DQ6A should preferably be fitted with an insulating top cap for operator protection.

The top and bottom of the flyback secondary, the top of the primary and the 1B3GT plate connection are each taken to four spring terminals which are mounted - suitably spaced - on a square of ⅛in plastic sheet screwed over a large hole in the top of the EHT cage. Spacing the terminals about 1½in part and 1in from the grounded metal of the cage obviates the risk of flashover. Wire links connected between appropriate terminals permit the circuitry to be arranged to deliver "AC" or DC as required.

The 100pF EHT reservoir capacitor must be connected to the lower end of the secondary winding for DC generation. As this capacitor must be capable of withstanding at least 10KV, a special type must be used. Epoxy insulated ceramic types are available with suitable ratings for this application, but they will be found relatively costly. As may be seen from the prototype photographs, we adopted an alternative course and one which is considerably less costly - a capacitor was "home-made" for the purpose using a construction rather similar to the "Leyden Jar" capacitors first used by early experimenters.

Our version consists of nothing more than a clean and dry office-paste jar (about 2½in dia. x 3in high), lined and enclosed with close-fitting tinplate cylinders. The outer cylinder forms a base which is bolted to the chassis and forms the earthed plate, while the inner cylinder (complete with disc bottom) forms the inner "hot" place and is connected to an axially mounted vertical electrode made from ⅛in brass welding rod. Measured on on R-C bridge, the "jar capacitor" was found to have a capacitance of close to 100pF, while the ⅛in glass dielectric has ample dielectric strenth to withstand the applied voltage.

The underchassis wiring of the generator is simple and non-critical, and may be provided using a straightforward point-to-point technique. We used only a single tagstrip near the power transformer, to anchor the transformer and mains leads. Tie points for the minor components were available on otherwise unused valve socket lugs.

When the generator is completed and switched on, the operation should ideally be checked using an oscilloscope to monitor the wave forms at the circuit points indicated by the circled numbers. The shape and amplitude of the waveforms is shown in the auxiliary diagram, together with allowed limits. Note that waveforms 3 and 4 should only be measured by means of a special high-voltage attenuator probe, which imposes a light loading on the circuit and protects the oscilloscope from damage. As the DC level of the waveforms is not critical and the usual type of capacitive divider probe is quite satisfactory for this purpose.

The operating conditions of the beam-power and damper valves may be altered if necessary by changing the flyback primary taps to which the valves are connected. In general the higher the tap to which the beam power valve plate is connected the higher will be the peak pulse voltage to which it is subjected, while lower taps will produce higher values of peak cathode current, as monitored by the cathode voltage waveform. For the damper valve, high taps tend to give excessive cathode voltage and current, while low taps will lower efficiency and allow the peak negative swing to increase.

If an oscilloscope is not available, a rough guide to the circuit operation may be obtained by taking a DC voltage measurement at the cathode of the beam-power valve. When the frequency control is adjusted for maximum output as indicated by the brightness of a small neon lamp held near the plate of the beam-power valve, the cathode should read approximately 2 volts positive if all is in order.

To conclude this article are some suggestions regarding simple demonstrations which may be performed with the generator. Some of these are illustrated by the accompanying photographs.

CORONA DISCHARGE: Connect the unit for DC output and attach to the out-put terminal a "star" electrode formed by soldering a number of common pins heads-in to a short length of stout wire. When the unit is operated in a dark room each point of the "star" will be seen to emit a bluish-mauve brush discharge produced by air ionisation at the high field intensity present at the points. Careful listening will reveal the characteristic hissing sound which accompanies the discharge, while after a few minutes of operation the smell of ozone will be detected. A finger placed near a point will feel the tiny "wind" produced by electrons and charged ions repelled by the point.

The presence of corona "wind" can be demonstrated quite dramaticlly by constructing a small pinwheel having peripheral points tangentially angled in a common direction. The wheel should be cut from thin brass shim using scissors, and provided with a central "dimple" such that it will balance on a pivot made from a common pin. With the pin attached to the output of the generator in DC mode and with an earthed metallic object nearby to pomote corona discharge, the wheel will be seen to accelerate and spin quite rapidly in the direction opposite to that of the points.

SPARK AND ARC DISCHARGES: With the generator delivering DC, an earthed electrode placed near the out-put terminal will draw a series of thin bluish-white discharges similar to miniature lightening strokes and accompanied by sharp "crack" sounds. These so-called sparks may be contrasted with the continuous mauve-coloured "arc" discharge produced under similar conditions when the generator is producing an AC output. Here the discharge generates considerable heat, tends to melt the electrodes and produces a loud whistling noise whose pitch may be varied by the generator frequency.

A phenomenon known as "Jacob's Ladder" may be produced by arranging for an AC arc discharge to be produced between two adjacent electrodes which are near-vertical and adjusted to be closer at their near-vertical and adjusted to be closer at their lower ends than at the top. When suitably adjusted and protected from air currents, this arrangement will produce a continuous series of arcs which are generated at the lower ends of the electrodes and move rapidly up to extinguish at the top. The movement of the arcs is usually explained as being caused by convection of air heated by the arc discharge.

GAS DISCHARGES: Small neon lamps held near the out-put terminals with either AC or DC output will glow, even with no direct connections to the electrodes. This is due to the high potential gradient present near the terminals. In similar fashion, a gas discharge lamp with one electrode connected to the AC output and the other electrode floating will glow quite brightly - partly because of the high potential gradient, and partly because of the slight current drawn by stray capacitance between the free electrode and the grounded chassis.

In the latter case, the lamp will be seen to glow considerably brighter if a finger is applied to the glass tube envelope - increasing the capacitance to ground significantly. In similar fashion, a small domestic fluorescent lamp may be lit quite brightly simply by holding it by the glass envelope and touching the connections at one end to the generator AC output terminal.

If the persons concerned do not find a mild shock unpleasant, a number of such lamps may be lit by forming a "chain" of people in rubber-soled shoes or standing on glass or other insulating platforms. Each person holds the electrodes of two tubes shared each with one of his neighbours, while the person nearest the generator touches one of his tubes to the AC output. Under dry conditions it is possible in this manner to light a number of tubes quite brightly.

ELECTROSCOPE: A simple version of the classic "gold-leaf electroscope" may be made by soldering a small strip of sheet metal axially inside the metal lid of a small screw-top jar (which must be clean). A small strip of metal foil is then fastened at the top end of the strip with cellulose tape. When the top of the jar is touched to the DC output erminal of the generator, the foil strip will immediately swing away from its support strip, being repelled from the latter by the similar charge polarity. Grounding the top cap will cause the foil to collapse - unless the operator has acquired a charge by induction of leakage in the glass, in which case it will only collapse if the operator is also grounded!

Many other experiments and demonstrations may be found in the standard texts on electricity and magnetism, particularly those of thirty or forty years ago. And, of course, the generator has a number of other applications including those mentioned at the start of this article. A further use would be as the "spraying" supply for a small Van der Graaff generator - and in this regard we may be able to give further information in a future issue.

THE PARTS YOU'LL NEED.

1 Chassis and EHT cage as available.
1 Power transformer, 350-0-350V at 80mA or similar, with heater windings to suit valves employed.
1 Horizontal flyback transformer, type having separate secondary winding.

Valves
1 6SN7GTA/B, 6CG7 or similar.
1 6DQ6A or similar.
1 1B3GT or similar.
1 6AU4A or similar.
1 5Y3GT, 5V4G or similar.

Capacitors
1 100pF 15KV working (see text).
2 390pF 400VW.
1 .022uF 400VW
1 0.1uf 1KVW.
1 16uF 350VW 525VP electrolytic.

Resistors
1 22ohm ½watt.
1 33ohm 1 watt.
2 47ohm ½watt
1 68ohm ½watt
1 330ohm 1 watt.
1 1K ½watt.
2 15K 1 watt
1 22K 1 watt.
2 100k ½watt
1 100K log potentiometer
1 470K ½watt.

MISCELLANEOUS

Valve sockets to suit valves, plate caps, nuts and bolts, knob for frequency control, mains switch, mains cord and plug, tagstrip to anchor transformer leads and mains lead, scrap of sheet plastic for output terminals, 4 spring terminals, connecting wire, solder, etc.

BUZZ-BAR

TRY YOUR HAND AT THIS GAME OF SKILL:

SO YOU THINK YOUR CO-ORDINATION IS PRETTY GOOD? HERE IS A LITTLE GAME WHICH YOU CAN BUILD TO TEST IT. ALL YOU HAVE TO DO IS MOVE A SMALL METAL LOOP ALONG A BENT WIRE WHILE TOUCHING IT AS LITTLE AS POSSIBLE. IF YOUR SKILL IS NOT UP TO IT, THE CIRCUIT SOUNDS A BUZZER OF LIGHTS A LAMP.

Most people tend to snort a little when they see this game. What could be more simple? Its just too trivial! Then they try it. And again. And again. It's certainly not as easy as it looks. And the "course" can be made easy to tortuous - just a few simple bends or maybe a couple of spirals to make it really difficult.

Our version of this game is simple but it can be made more complex. It has a light to tell when you've failed the course, a control to vary the amount of skill required and an on-off switch.

Let's talk about the circuit. Basically, it is a delay timer which adds up the time for which the metal loop is in contact with the bar. If the total time is more than that selected by the skill control, the timer lights a lamp or sounds a buzzer or bell.

The circuit can be built in two forms, using either a Philips OM802 or a Signetics NE555 integrated timer circuit. This should minimise any difficulty the would-be constructor may have obtaining parts for the project. Since the OM802 is the simpler device and is the one featured in our prototype Buzz-Bar, let us first describe the operation with this device.

Fig 1 shows the basic circuit of a delay timer using the OM802. There are two connections for the positive and negative supply lines. The load is connected between the positive supply line and pin 4. Initially, the voltage at pin 4 is almost equal to the positive supply so that no current flows in the load. Pin 2 monitors the voltage across the capacitor C which is charged from the positive supply via resistor R.

When the voltage across the capacitor rises until it is approximately equal to half the supply voltage, the timer applies almost all the supply voltage to the load, ie, the voltage at pin 4 falls to approximately zero. It stays in this condition until the capacitor is discharged by connecting pin 2 to pin 3.

During the time the capacitor is being charged to half the supply voltage, very little current, less than 10 nano-amps in fact, flows into pin 2. This means that pin 2 of the IC does not cause the capacitor charge to leak away and thus long time delays can be achieved with capacitors of a reasonable size.

Refer now to the complete circuit diagram of Fig 2. The timing capacitor we have used is a 50uF 6VW tantalum capacitor, which has very low leakage. The basic timing resistor is provided by a series combination of a 10k resistor and 100k potentiometer wired as a variable resistor. At the minimum setting of the potentiometer, the maximum time for which the metal loop can be in contact with the buzz-bar is approximatley 0.4 second. At the maximum setting of the potentiometer, the time is about 4 seconds.

It may be thought that if the player was to move the loop very slowly and carefully along the bar he would have less contact with the buzz-bar and thus more chance of traversing its length before the time could give an indication of his failure. But we have thought of that too. Resistor R1 sets the maximum time that can be taken to traverse the length of the buzz-bar. With the 270k resistor shown, the maximum traverse time is about 12 seconds.

Thus, there are two requirements placed on the player. He must touch the buzz-bar with the loop as little as possible, with a margin for error set ty the skill control, and he must traverse the course within a set time as set by R1. But while the maximum traverse time has been set at 12 seconds, each time the metal loop touches the buzz-bar the remaining traverse time is correspondingly reduced. So that the more the loop touches the bar, the less time left to complete the course before the light comes on!

R1 can be made variable to make the game more flexible or it can be left out so that there is less constraint upon the player. The 100k pot can be replaced by a 100k resistor, and different shaped buzz-bars used to challenge the skill of the players. So you have three possible variables: variable skill, variable traverse time and variable buzz-bar shape. Who would want more?

R2, the 10k resistor in series with pin 2 of the OM802, is to limit the current to a safe value when the device triggers. But in doing so it does not discharge the capacitor: this must be done by shorting out the timing capacitor with the on-off switch. The on-off switch is a DPDT type (double pole, double throw) with one pole switching the positive supply while the other pole shorts out the capacitor when the unit is turned off. When the unit is turned on, it starts with the capacitor fully discharged and thus the timing is always the same.

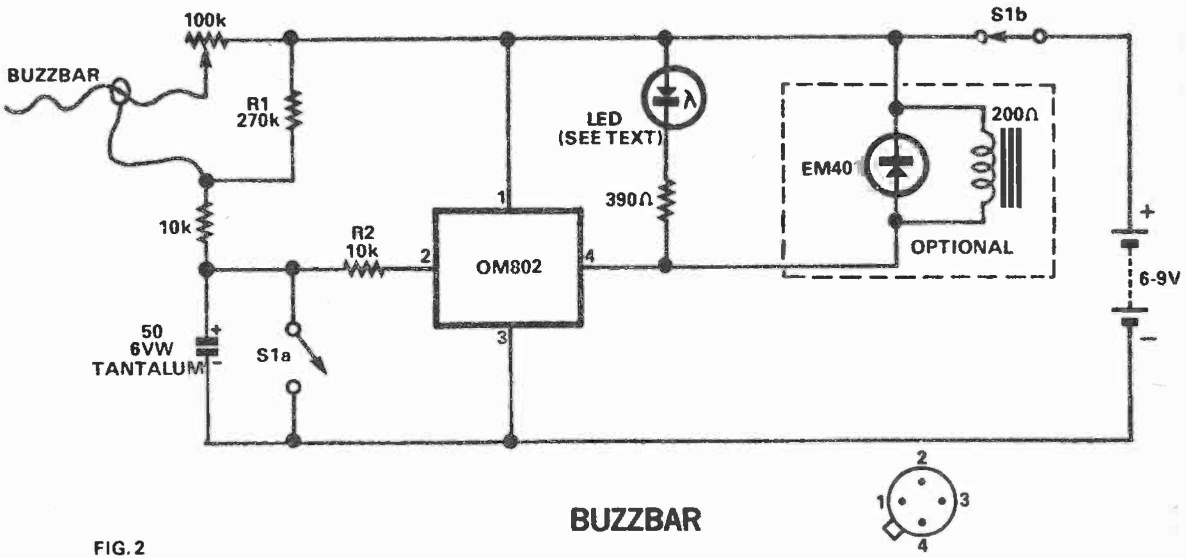
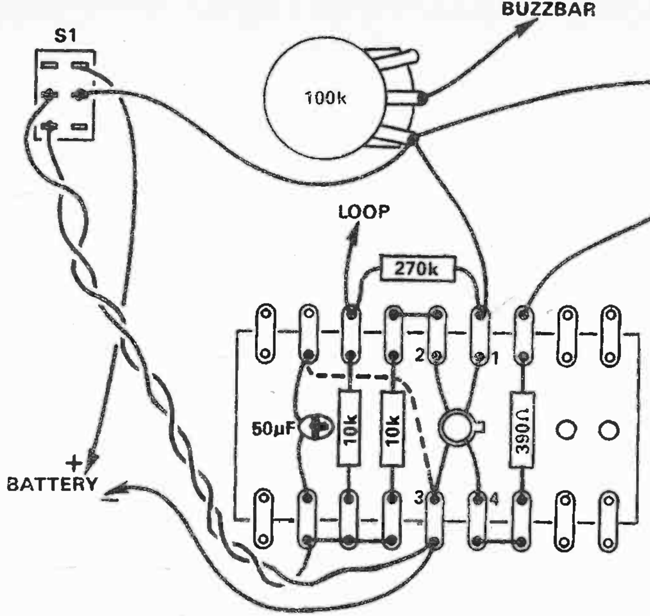


FIG. 2

A 4-pin integrated timer circuit is the heart of the buzzbar.



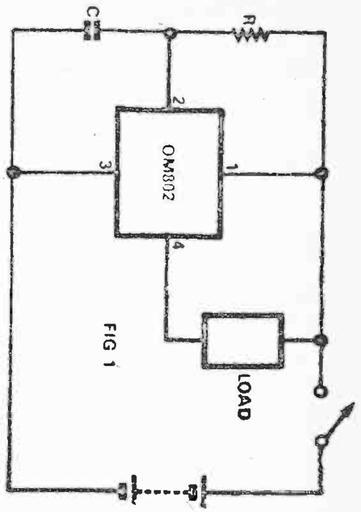


FIG 1

Wiring layout of the Buzzbar is not at all critical and it can be built in simple or complex forms.

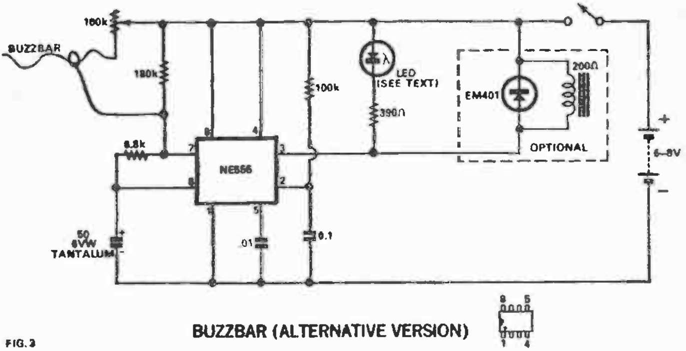
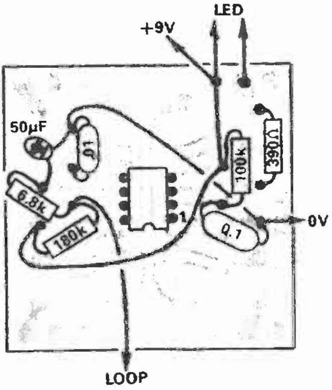


FIG. 3

BUZZBAR (ALTERNATIVE VERSION)

Above is the alternative circuit using the 555 timer IC and below is the wiring diagram.



The lamp we used to indicate "failure" is a light-emitting diode with a chrome bezel. It was supplied by McMurdo. The 390 ohm resistor in series with the LED limits the LED current to about 20mA which results in a total current drain of the circuit of 25mA. When the LED is off, the current drain of the OM802 is of the order of 150 microamps.

Also shown on the circuit of Fig 2 is a relay shunted by a reverse-biassed diode. The relay is necessary if a bell or buzzer is to be driven by the circuit. We left it out as the sound of a buzzer can be rather irritating, especially to those who are not involved in the game. Another good reason for omitting the buzzer is that their current drain tends to be heavy, requiring a large battery.

If you do decide to use a relay and buzzer, the relay should have a pull-in voltage of 6 volts or so and a coil resistance of 200 ohms or more.

A 60 milliamp incandescent lamp may be substituted for the LED and its limiting resistor, if the constructor has one on hand. The surge rating of the OM802 enables it to withstand the lamp surge without limiting resistors. Note that if a lamp is used, a larger battery than the Eveready 216 we used should be substituted.

A 6V or 9V battery can be used without any changes to the circuit but we chose the miniture 9V battery since it is compact and economical. Note that if the lower voltage is used, no timing inaccuracies occur since the circuit is largely independent of voltage.

Construction of our prototype was kept simple but undoubtedly it could be made simpler still. The circuit is not at all critical as far as layout is concerned. We used a piece of flakeboard measuring 210 x 160 mm as a base, and attached a U-shaped panel of aluminium to it to function as the control panel. All the components are accommodated on a 9-lug length of tagboard. Note that this has a spare pair of lugs to accommodate the diode if the optional relay is used.

Our buzz-bar was a length of 16-gauge tinned copper wire soldered to two banana plugs which are then inserted into sockets at the top of the panel. With this arrangement, the bar can be easily changed for more difficult shapes. The loop is also made of tinned copper wire, with the loop being of sufficient diameter to just fit over the insulated portion of the banana plug. We soldered our loop to a meter prod which is then connected by a length of hook-up wire to the appropriate point in the circuit.

Some readers may feel that the "failure" light could more appropriately be mounted on top of the panel so that it is more visible to the player. It may also be possible to substitute a SPST switch for the type specified and have the probe (loop) shorted to the negative supply line at the start and finish. This could be done using a different type of socket, say an RCA phono socket with the inner connector being the loop connection and the outer connection terminated to the negative supply.

Virtually any light emitting diode can be used in the circuit but the bezel mounting types do simplify the mounting arrangement.

The timing capacitor must be a low leakage tantalum type. The leakage of most conventional electrolytic capacitors will be too high to allow the circuit to function correctly.

As mentioned earlier, the buzz-bar can also be made using the Signetics 555 timer integrated circuit. Fig 3 shows the circuit arrangement. We use the same 50uF timing because the 555 trips at two-thirds of the supply voltage rather than half as for the OM802.

The 555 timer is a more complex device than the OM802 and it also functions differently. Initially, no voltage is applied to the load while the timing capacitor charges towards Vcc (the supply voltage). When the capacitor reaches 2/3Vcc the timer trips and applies almost the whole supply voltage to the load. It also discharges the timing capacitor via the 6.8k resistor. The circuit then stays in this condition, with voltage applied to the load until a negative trigger pulse is applied to pin 2. One way to do this would be to have a momentary contact push-button short out the capacitor at pin 2, but the same function can be achieved by switching off the supply and then on again.

Whenever the circuit is switched on, a negative pulse is effectively delivered to pin 2 and thus sets the timing cycle in motion. So, as with the OM802, the player switches off, then on, and tries his hardest to move the loop along the length of the bar while touching it is little as possible.

We have used the same load conditions as for the OM802. The 555 can drive the LED and/or the relay. The supply voltage can also be 6 or 9 volts. Note that if an incandescent lamp is used with the 555, in place of the LED, a suitable resistor must be connected in series with it to limit the surge current to 200 milliamps maximum. We recommend the LED version.

When wiring the 555 version you can use either Veroboard with 0.1in conductor spacing or a small printed board with type number 73d1 which we have entitled a DIP board. The DIP board is intended for lashing up circuits using dual in-line package (DIP) integrated circuits. All components are mounted on the copper side of the board. Most kitset suppliers will have the DIP board available, as we have used it in previous projects. If they don't you can always use Veroboard. An accompanying diagram shows the component layout for the DIP board.

Whatever way you build it, we think you'll find it an easy project and an intriguing game!

PARTS LIST

1 baseboard of particleboard, plywood or timber
1 piece of aluminium for control panel
1 calibrated knob
1 100k (lin) potentiometer
1 LED with chrome bezel
1 9V battery or equivalent
1 snap connector to suit battery
2 banana plugs and sockets
1 battery clip (made from scrap aluminium)
1 390 ohm ½W resistor
1 relay and EM401 silicon diode (optional, if buzzer used
or RS276-1139, BY201/500, 1N1119
Extra parts for OM802 version:
1 Philips OM802 integrated circuit
1 50uF 6VW tantalum capacitor
2 x 10k resistors (¼ or ½W)
1 x 270k resistor (¼ or ½W)
1 nine-lug section of miniature tagboard

1 DPDT miniature toggle switch
Alternative parts for NE555 version:
1 Signetics 555 timer integrated circuit
1 50uF 6VW tantalum capacitor
1 x 0.1uF low voltage polyester capacitor
1 x .01uF low voltage ceramic or polyester capacitor
Resistors (¼ or ½W):
1 x 180k, 1 x 100k, 1 x 6.8k
1 DIP printed board,
1 SPST toggle switch

MISCELLANEOUS
hook-up wire, screws, spacers for component board, solder

NOTE: resistor wattage ratings and capacitor voltage ratings are those used in our prototype. Components with higher ratings may generally be used provided they are physically compatible. Components with lower ratings may also be used in some cases, providing ratings are not exceeded.

ENCAPSULATION, POTTING, CASTING.

FROM THE EARLY DAYS OF "RADIO" THROUGH TO THE BROAD FIELD WHICH WE KNOW TODAY AS "ELECTRONICS", MANUFACTURERS HAVE BEEN GREATLY CONCERNED WITH THE SEARCH FOR SUITABLE INSULATING AND MOISTURE-PROOFING COMPOUNDS FOR THEIR PRODUCTS. THIS ARTICLE EXAMINES, BRIEFLY, THE HISTORY OF THESE COMPOUNDS AND LEADS ON TO SOME INTERESTING NEW MATERIALS WHICH HAVE RECENTLY BECOME AVAILABLE.

In the design of electrical and radio equipment it is a fundamental requirement that control of the flow of current through any part of the circuit be maintained at all times. This control rests upon the fact that some materials conduct electricity, whilst others (insulation) obstruct its flow.

In order more fully to appreciate why certain materials are insulators and why others are conductors, it is necessary to understand the molecular structure of these materials. It is not intended that this article should go deeply into this aspect of insulating materials, but the following brief review should serve to refresh the reader's memory on the subject.

All matter consists of atoms and molecules, atoms, comprising a central nucleus around which revolves one or more electrons in definite orbits. As the gravitational pull exercised by the sun on the planets holds our planetary system together, so electrical attraction existing between the positively charged nucleus and the negatively charged electrons holds the atom tegether. Since the electrical charges are equal in magnitude and opposite in polarity, an atom is electrically neutral.

A broad distinction between conductors and non-conductors may be explained by a consideration of the electron orbits of the two classes of material. The outer electrons of a metal such as copper travel in large, isolated orbits, so large and isolated, in fact, that electrons may come into the "zone of attraction" of an adjacent nucleus, leaving on atom to join another.

Since this involves all of the atoms all of the time, it will be apparent that a constant interchange of outer-orbit electrons is taking place between all the atoms throughout the material. However, the random movement of electrons within the material becomes a drift in one predominant direction (a flow of current) upon the application of an external electric charge to the material.

In non-conductive materials (insulators) free interchange of electrons does not take place anything like so readily. However, their orbits may be distorted by the application of an external charge. If the magnitude of this charge is increased sufficiently, it may force electrons to leave parent nuclei and to travel through the material as in the conductor. Insulating material which has suffered stress of this order is said to have "broken down" or been "punctured."

In practice, this may mean that a piece of insulating material has failed in service, causing a breakdown of the circuit or component involved.

The choice of an insulating material for any given application is not easy; electrical considerations have to be taken into account, while thermal and mechanical requirements also have to be met. In fact, the efficiency of an insulator depends to a large extent on its behaviour in varying atmospheric and service conditions. Mechanical properties are important because, in most applications, an insulator has to perform the dual function of providing electrical isolation and acting a part of a mechanical structure.

In the early days of electrical engineering the range of insulating materials was rather limited.

A compound of rubber and sulphur know as ebonite, introduced when the process of vulcanising rubber was commercialised in 1851, was the first mouldable material to be used to any extent.

Various bituminous compounds, known as cold moulding materials, were made available in the latter part of the nineteenth century.

Still later, a number of shellac compounds were moulded by processes bearing a resemblance to those used today.

While ebonite found extensive application, it discoloured badly in service, it lacked rigidity at any but comparatively low temperatures, and had poor mechanical strength characteristics.

The bituminous compounds proved cheap substitutes in the large quantities of turned and machined parts which were at that time being used in electrical apparatus but, again, their strength and permanency factors were not good.

Shellac mouldings possessed good electrical properties but lacked strength.

OTHER MATERIALS

Other insulating materials, porcelain, glass, paper, mica, etc., have been in use for many years but each of these is suitable only for restricted applications because of their well known physical characteristics.

With only a limited range of materials to choose from, designers of radio and electrical apparatus commonly had to arrive at compromises which satisfied electrical and mechanical requirements to only a a limited degree.

Fortunately, for the growth of the industry, a major breakthrough occurred in 1907 when Dr Leo H. Baekeland successfully made the first synthetic resin. This material was a phenol-formaldehyde plastic and was known by the trade name of "Bakelite." It was cheap, could be moulded to any desired shape and possessed excellent electrical and mechanical properties. Various grades designed to meet specific requirements are still available and anyone with any connection with the electronics industry will be aware how often the term "bakelite" is encountered.

However, before proceeding with our discussion of the various synthetic resins and their properties, it might be interesting if we diverged for a moment and took a look at another important aspect of the insulation of electrical components.

Form the earliest days of electricity and radio it was realised that there was not much point in having insulating materials on which to construct such things as coils, chokes, transformers, etc. (and to place between the plates of capacitors) if atmospheric moisture was later allowed to penetrate into the components as a whole.

For this reason it was not only necessary to develop insulating materials with good electrical qualities, which could be moulded and shaped, but it was necessary to develop further insulating compounds which could be used to "moisture proof" the finished component.

Because they have a low viscosity when hot and set relatively hard when cold, various forms of wax and bituminous compounds were first used for this purpose. In a coil, for instance, the wire - insulated by a layer of cotton or varnish - would be wound on a former. The assembly would then be dipped in a vat of hot wax and hung up to cool.

MODERATE SUCCESS

This process was only moderately successful, however, for waxes have rather poor temperature stability and tend to crack or run under adverse conditions. Either way the component could become faulty, after a time due to ingress of moisture.

To sidestep the temperature problems inherent in these waxes, various forms of varnish containing solvents which dry off on exposure to air were often used instead. If it had been possible to ensure that the solvents were dried off completely, such varnishes would have been more attractive but, unfortunately, quantities of the solvent were often trapped inside the component.

This happened because, after the components had been dipped, the varnish on the outside dried first, the drying process continuing inwards. This trapped the solvent from the varnish which had penetrated right inside the component, the solvent thereafter causing its own troubles.

These instances of the troubles encountered with waxes and air drying varnishes are only two of many similar problems which had to be faced in the earlier days of electronics.

DID THE JOB

Fortunately, the semi-natural and early synthetic materials were sufficient to sustain the industry until it had created such a demand for really good insulating and proofing materials that it became economical to undertake really intensive research into the subject of what could be broadly termed "plastics".

In fact, it might be said that the electronics and the plastics industries were a case of parallel development, similar to that which took place between the automobile and the petroleum industry, each sustaining and promoting the other.

Whether the reader is a newcomer to the radio industry or an "old timer" who has grown up with it, it is probable that the development of "plastics" has been taken somewhat for granted. If proof of their importance is required, it is only necessary to imagine a piece of modern electronic equipment being manufactured without any "plastics" whatsoever being used in its construction.

Have a look inside a modern TV set, for example.

A good many of the plastics used in th electronics industry require the application of heat and/or pressure to mould or extrude them into their final form and the machinery and processes required to achieve this are often very expensive and quite complicated. While they may therefore be practical for mass production, they are less so for small-scale production and quite impractical for the "one and two off" kind of requirement.

Fortunately, a new range of resinoid materials have recently been made available and it is with these materials that small concerns and homebuilders can now do many jobs which could formerly only be attempted on a quantity basis. Some knowledge of the new materials should therefore be valuable to all whose work in electonics is on a smaller scale.

Two of the commonest of these materials are polyester resin and the epoxy resin.

Before proceeding to examine the various properties of these materials it might be as well if we gave some dictionary definitions which will aid in an understanding of the materials, in the field we are considering.

RESIN - any of a class of solid or semi-sold organic products of natural or synthetic origin, generally of high molecular weight.

ROSIN - a resin obtained as a residue in the distillation of crude turpentine from the sap of the pine tree (gum rosin) or from an extract of the stumps and other parts of the tree (wood rosin).

ESTER - the reaction product of an alcohol and an acid.

POLYMER - a compound formed by the linking of simple molecules having functional groups which permit their combination to proceed to high molecular weights under suitable conditions.

CATALYST - a substance which markedly speeds up the cure of a compound when added in minor quantity, as compared to the amounts of primary reactants.

THERMOSETTING - undergoing a chemical reaction by the action of heat to arrive at a relatively infusible state.

EXOTHERMIC - characterised by the liberation of heat. Usually applied to a plastic which, after the addition of a catalyst, generates its own heat to become thermosetting.

THIXOTROPY - the property by which some compositions become solid at rest but liquefy again on agitation.

VISCOSITY - internal friction or resistance to flow of a liquid.

POLYMERIZATION - a chemical reaction in which the molecules of a monomer are linked together to form large molecules whose molecular weight is a multiple of that of the original substance. When two or more monomers are involved, the process is called copolymerization or heteropolymerization.

MONOMER - a relatively simple compound which can react to form a polymer.

PROCESSES

EMBEDDING - the complete encasement of a part, a component or an assembly, usually in some form of a "shaping" mould which is later removed.

ENCAPSULATION - the coating of a part, a component or an essembly; usually involves dipping of the part.

POTTING - the complete encasement of a part, a component or an assembly in a "pot" or case which is left around the object after the plastic has cured.

The polyesters (or polyester resins) are relatively low cost resins and have most of the properties required to maintain a strong, physical structure around an electrical assembly, while providing very good insulation. For this reason they were the first casting or potting resins widely used for the embedment of electrical assemblies.

Embedding and encapsulating, as we know them today, can be considered as improved design concepts for achieving such desirable things as mechanically stronger packages, modular construction, miniaturisation, and environmental resistance.

ADVANTAGES

The principal advantages of embedding an electrical or electronic assembly are (1)Hermetic sealing. (2)Components fixed in a matrix of known dielectric capabilities. (3)Mechanical strength and vibration resistance. (4)Space factor gain through the elimination of large air "clearance" spaces; in short, three-dimensional assemblies.

It would be very difficult for many products to be accepted for military use were it not for the advantages obtained by embedded electronic packaging. The heavy leads, the lacing, the clips and the tagstrips, once necessary to achieve ridity in electronic equipment, are incompatible with rising requirements of smaller volume, less weight and greater rigidity than ever.

From the home constructor's or small manufacturer's point of view, the biggest advantage of the polyesters is that they are supplied as a liquid which becomes thermosetting upon the addition of catalyst. They are 100 per cent reactive, ie., evolve no gas or liquid during cure; hence large articles can be moulded under low pressure with less expensive equipment than is required for forming solid, thermosetting resins.

The catalyst mostly used is of the peroxide group; the polyester is usually formed from dibasic acids and glycols which are blended with a reactive monomer such as methyl methacrylate. Under the action of heat and/or a peroxide catalyst the mixture copolymerises with the monomer cross linking the polyester to make a thermoset solid.

QUALITIES

Though the particular quality is of little importance for electronic embedding applications, polyester resins have good colour and may be light stabilised. Of more importance is the fact that they have excellent electrical properties and may be obtained in varying degrees of rigidity or with fire-retardant or high-temperature resistant characteristics.

Reinforced with fibrous glass cloth matting, the polyester resins are quite commonly used to manufacture such things as boat hulls, car bodies, laundry tubs, etc.

Because of their electrical properties and low cost, the polyesters have achieved a large measure of popularity, but they do have one major drawback - a high rate of shrinkage which sometimes causes cracking problems in curing the part. To a large extent this problem has been overcome with the newer epoxy resins.

Epoxy or epoxide resins, like the polyester resins, are liquid syrups available in a wide range of viscosities, and even as low melting point solids. They are exothermic and are cured or catalysed mainly by either an amino or an acid anhydride type of curing agent. Their high strength, low shrinkage, excellent adhesion and excellent insulating properties have given them an increasing field of use.

IMPROVEMENTS

When first introduced they were highly priced compared with the polyesters and had high viscosities, which made them rather difficult to work. However, these problems have been largely overcome in the materials available today.

Chemically, commercial epoxy resins are defined as special condensation products of epichloohydrin and a polyhydric phenol. The product is called an epoxide or epoxy resin because of the existence in the polymer of a carbon-oxygen chemical arrangement known as an epoxide group or an oxirane ring.

Epoxy resin adhesives and patching kits have been available to the do-it-yourself enthusiast for some time now, but just recently we were pleased to receive samples from Messrs W. J. McLellan of some new epoxy casting resins, coatings and adhesives, which they are going to make available to the "electronic" home constructor in "do-it-yourself" kits.

Similar materials are available from other sources, but these are the first we have encountered packaged specifically for the "odd job" type of application. They make it possible for experimenters to gain experience with modern adhesive, coating and casting materials without undue difficulty.

The kits are imported from the United States and are manufactured by Messrs Emerson and Cuming. Inc., a firm which has had a gread deal of experience in the production of special plastics and ceramics for the electronic industry. Some brief details and specifications on each of he epoxies are as follows:

STYCAST 2651: an easy to use, low cost, epoxy type casting resin with excellent adhesion to metals, plastics and ceramics. It has a low thermal coefficient of expansion and is stable over a temperature range of minus to plus 400 deg F. Its viscosity at room temperature is very low and if necessary, it can be thinned still further by elevation of temperature to plus 100 deg F. The material can be colour coded to specification but is normally available in black.

Specific gravity —1.55; tensile strength —9.000 psi (pounds per square inch); compressive strength —16.000 psi; fleural strength —15.000 psi; water absorption (7 days at 77 deg F) —0.1%; dielectric constant to 100Mc —4.4; dielectric strength (volts/millimetre) —455.

This particular resin is available in two packs, depending on whether room temperature or elevated temperature curing is required. The only difference is in the catalyst supplied with each one. At room temperature the curing time is 8 hours but the casting can be removed from the mould when hard, which is approximately one hour.

STYCAST 1090: low weight epoxide casting resin for electronic embedments. Has an extremely wide temperature range of usefulness, low shrinkage during cure and low thermal expansion coefficient. It cures at room temperatures to a black, rigid, opaque solid. Because of its low weight, it is particularly useful in airborne embedment applications.

When cured the material is completely unicellular and has, therefore, negative moistrure absorption. Its weight is much less than half that of other commonly used casting resins and the low dielectric constant means it has minimum effect on circuit operation.

Specific gravity -0.78; fleural strength -4.200 psi; water absorption -.1% in 24 hours at 25 deg. C; dielectric constant to 100Mc -1.9; dielectric strength (volts/millimetre) -300.

This material may be used over the temperature range of minus 100 deg. to plus 400 deg. F. without harmful results. At room temperature the material sets hard in less than 4 hours and a cure is fully completed in 24 hours.

STYCAST 2850 FT: epoxy casting resin for high temperature use. General specifications, etc., of this material are very similar to Stycast 2651 except that it is practically indestructible within its normal temperature range. Stycast 2850 castings can be subjected to temperature of 200 deg. C. without any ill effect.

ECCOCOAT VE: resilient, clear epoxide surface coating having adustable flexibility. This material has found use for coating electronic components, printed circuits and for generalised surface coating of plastics, metals and ceramics. Adhesion is outstanding. Resultant coatings are usable from minus 70 deg. F. to plus 300 deg. F.

Data taken on a 10 millimetre surface coating on metal: Hardness (shore Durometer) -80; weathering - unaffected in one year outdoors; salt spray - unaffected by at least 1,000 hours; flexibility - unaffected by 1-8in bend; thermal cycling - unaffected by 25 cycles - minus 70 deg. F. to plus 300 deg. F.; dielectric strength -460 (volts/millimetre); dielectric constant - approximately 3.0 (to 100Mc); dissipation factor - below 0.01.

Eccocoat VE is available as two liquids which can be mixed in varying proportions depending on the degree of flexibility required. Under normal conditions it cures tack-free in 6 hours at room temperature but with a suitable solvent and elevated temperatures it can be cured in 20 minutes.

ECCOBOND 45: a controlled flexibility epoxide adhesive designed for use where shock and peel resistance are desired. Eccobond 45 can be cured at room temperature (8 hours) or rapidly at elevated temperature (15 minutes at 220 deg. F.). The "pot life" of the mixed epoxy is approximately 3 hours.

As with Eccocoat VE the flexibility of the adhesive is variable and depends on the amount of catalyst which is mixed with the epoxy. Application is by brush, knife or roller and the clean-up solvent is trichlor-ethylene, toluene or lacquer thinner. The normally available colour is black, but other colours are available.

Temperature range for use, minus 70 deg. F. to plus 300 deg. F.; hardness (shore Durometer) -40; bond strength in shear at room temperature - 3200 psi; after 30 days soak in water - 2900 psi; fleural strength -5500 psi; dielectric strength (volts/millimetre) -410; dielectric constant to 10Mc -2.9.

ADHESIVES

The use of epoxide adhesives is rapidly gaining acceptance as one of the most versatile and practical methods available to the design engineer for joining materials. An outstanding example was the proposal to use epoxy resins to cement together the huge slabs which formed the roof the Sydney's new Opera House.

The history of use for "glues," or adhesives, goes back to biblical days, when ornamental pieces were attached to building columns by means of natural gums, pitch, or asphaltic substances. It has long been recognised that certain operations, such as applying labels to containers or laminating thin sheet materials, would be impractical without suitable adhesives.

Now that truly high shear strength compounds are available, more and more critical operations, even involving primary structural members, are being satisfactorily performed by these construction materials.

For applications where extrememly high bond strength is required or a joint has to be made between two impervious surfaces, the epoxide compounds are ideally suited.

As a practical test of just how effective and easy to use these new compunds were, we encapsulated the small transformer illustrated in Stycast 2651 and coated on of our 455 filter toroids in Eccocoat VE.

According to the instruction sheets which accompany the plastics it is necessary to mix 6 to 7 per cent (by weight) of catalyst 9 with the Stycast 2651 to accomplish a room temperature cure. Without some form of accurate chemical balance it is obviously impossible to mix small quantities of the materials in the exactly recommended proportions. However, our experiments showed that "near enough" was "good enough".

In our case, we mixed the materials in a small tobacco tin and simply "guesstimated" the amount of catalyst to be added. Some mixes we made took longer to cure than others and, depending on the amount of catalyst added, there appeared to be some differnce in the viscosity of the mixtures. Apart from this, we could detect no significant changes in the final product.

Although the materials appear to be rather "gooey" when first mixed, the actually have quite low viscosities and will flow to the shape of the most intricate mould before the chemical reaction, which causes them to harden, sets in. As supplied, the materials are suited to embedding, potting, or casting applications. Where encapsulating or dip-coating is the order of the day a special filler material is available for adding to the epoxy.

The Eccocoat and Eccobond materials are mixed in roughly one to one proportions with any variations simply altering the flexibility of the finished coating or adhesive.

After the required curing time had elapsed we subjected both the components we had treated to fairly extensive electrical and mechanical tests. Both were immersed in salty water for several days and then subjected to a naked flame for several seconds. In neither case could we detect any significant change in the component's electrical characteristics.

From our observations it would appear that these compounds are going to find many useful applications around the home constructor's workshop, now that they are available in reasonably economical quantities.

One application which springs to mind immediately is the termination of a coaxial line to a beam or other form of antenna. It has always been somewhat of a problem to satisfactorily seal the end of a coaxial cable against ingress of moisture.

By using a simple mould to form a casting of epoxy resin around the end of the coaxial cable and the connections to the antenna, the moisture problem should be most easily overcome. The high tensile strength of the epoxy should also do much to prevent breakage of the line at this vital point.

DAYLIGHT CONTROLS INTERIOR LIGHTING

WORRIED ABOUT BURGLARS RAIDING YOUR HOME WHILE YOU ARE ON HOLIDAYS? THE "AUTOLIGHT" WILL SWITCH YOUR HOUSE LIGHTS ON AT SUNSET, THUS DISCOURAGING SUCH UNWANTED VISITORS. WANT A GIMMICK TO IMPRESS YOUR VISITORS? THE "AUTOLIGHT" IS AN EXCELLENT EXAMPLE OF THE "MARVELS" OF THE ELECTRONIC AGE.

Many people going on holiday worry about the possibility of burglars raiding their homes while they are away. While a burglar alarm may be fitted, this does not discourage the potential burglar from making an attempt. The Autolight provides an additional safeguard and peace of mind by switching on your house lights at sunset, thereby giving the passerby the impression that someone is "home".

The Autolight will also serve a useful purpose by turning on your patio lights at dusk so that one has a pleasant transition from the fading daylight to artificial lighting. It could also control a nightlight in a constantly used passageway.

The Autolight takes the form of a compact diecast box with a light dependant resistor (LDR) protruding from one end. The box can be fastened to, or buried in a wall so that daylight has access to the LDR. A switch is fitted to the box so that any lights controlled by the device can be switched off if not needed.

The circuit of the Autolight is based on a phase-controlled Triac. The phase-control section of the circuit is rendered inoperative by the LDR whenever light falls upon it. As the ambient light becomes dimmer, the resistance of the LDR increases so that the phase control circuit comes into action to switch on the Triac.

For readers who may not be familiar with the operating principles of Triacs and phase-control circuits, the following explanation should be helpful. The Triac is closely related to the Thyristor (silicon controlled-rectifier) in that it is normally non-conducting until triggered into conduction by a gate signal, in the same way as a Thyristor. In fact, the easiest way to think of a Triac is as a pair of Thyristors connected in inverse parallel with a common gate electrode and a common case.

In essence, the Triac is a bidirectional switch which after being triggered into conduction, stays "on" until the supply voltage decreases to zero or reverses in polarity, when it turns off and can be switched on again. Used with AC, a Triac can be triggered into conduction at any point on either half cycle by a low voltage signal of either polarity applied between the gate electrode and terminal 1 (anode 1). Note that, since the Triac is a bidirectional device it has no anode or cathode as such. The two end terminals are normally referred to as "anode 1" and "anode 2" or "terminal 1" and "terminal 2".

As the Triac is a switching device which is either fully conducting or "off" the only means by which it can provide variable power control is to use it as very rapid switch which closes for varying portions of each half-cycle of the AC voltage waveforem - by adjusting the instant during each half-cycle when it triggers into conduction. If the Triac is triggered late in each half-cycle, low power is applied to the load and vice versa.

While there are many methods of varying the triggering point of a Triac, the most satisfactory one is known as "phase control". This involves applying to the gate electrode a sharp pulse of current whose phase, relative to the AC wave form, can be varied. This is done by means of a capacitor which is charged while the Triac is in the non-conducting state. The time the capacitor takes to charge will depend on its size, the resistance in series with it and the voltage supplied to it.

Referring to the circuit in figure 1 and ignoring for the moment, the function of the LDR, we have a basic power control circuit. In this circuit the 0.1uF capacitor is charged from 240VAC via the 22K resistor. The capacitor's charge is delivered to the gate of the Triac via a voltage sensitive device which conducts only when the voltage across it reaches a certain value. The voltage sensitive device used here is a Diac, a three-layer symmetrical breakover diode which is an open-circuit until the applied voltage rises to the breakdown rating, whereupon it breaks down to a negative resistance. The breakdown voltage is generally around 25 to 40 volts, in either direction.

The oscillogram shows the power applied to the load when the light dependant resistor is effectively out of circuit, i.e., when there is no light on it and, it is a high resistance. When light falls on the LDR, its resistance is in the region of 500 to 1000 ohms so that the voltage applied to it, and the capacitor, is less than the breakover voltage of the Diac and consequently the Triac is not triggered.

When the ambient light level falls, the resistance of the LDR rises to the point where the capacitor is able to charge to the breakover voltage of the Diac and the Triac is triggered, but late in the half cycle. At this point, a phenomenon familiar to designers of light dimmers becomes evident - that of "Snap-on".

"Snap-op" refers to the abrupt change in firing angle just after the initial triggering of the Triac. While the mechanism of this snap-on effect need not be explained here, it will suffice to say that it causes the lamp to initially light at somewhere between minimum and half-brilliance.

Asymmetry in the Diac/Triac combination will also cause another problem in that initially, the Triac fires on every second half-cycle so that it acts like a Thyristor. As the LDR rises to a sufficiently high value, the Triac reverts to normal bidirectional operation.

The combination of these two effects, snap-on and asymmetrry, conspire to effectively turn the lamp or lamps on in two steps instead of a gradual increase in brilliance. We did not feel that this was a drawback, however, since this device is intended essentially for applications where a light-operated on/off control is required.

The Autolight may be used to control just one light or a number of lights throughout the house. All that is required is that the unit be placed so that ambient light has access to the LDR. Note that the unit should be mounted so that the lights it is intended to control do not illuminate the LDR and cause the unit to "hunt".

Power consumption of the unit during the day when the lights are off, is small - approximately 3 watts, so that the cost of operating is governed almost solely by the number of lamps being controlled.

Figure 2 shows a similar circuit in which the Triac/phase-control circuit is actuated by an LDR. The major difference is that the lights or any other load are turned on when light falls on the LDR. This is included for those readers who may wish to experiment with such a circuit.

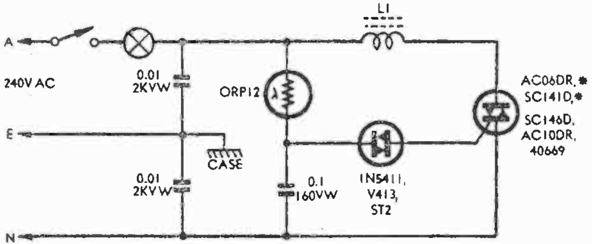
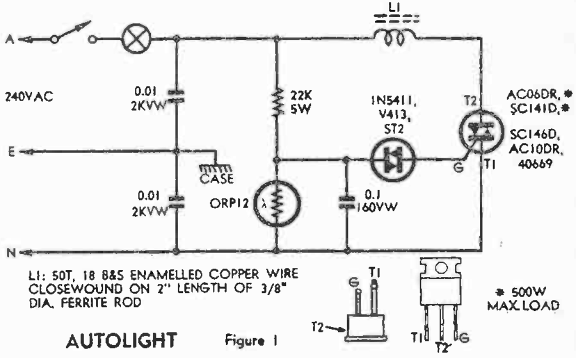


Figure 2

Right: The circuit for the unit described in this article. It switches on as incident light decreases. Above: An alternative version which switches on as incident light increases.



AUTOLIGHT

Figure 1

All but two of the Triacs specified may be used with incandescent lamp loads up to 1000 watts; The SC141D and AC06DR should not be used with loads in excess of 500 watts. This means that lights in several rooms of the house can be controlled with the one unit. While we have included a 2 amp switch to turn off the lights when not required at night, a higher rated switch must be used if loads in excess of 500 watts are to be controlled. The normal fascia-mounting light switches which have a rating of 5 amps or more suggest themselves as the most likely alternative.

While all the Triacs specified have adequate surge ratings to cope with their maximum specified loads, the individual incandescent lamps should not have ratings in excess of 100 watts. This is because the surge, which can occur when a high wattage lamp burns out and arcs over to the filament supports, can exceed 100 amps. While admittedly these circumstances are rare, a surge of this magnitude would mean destruction of the Triac.

As with other Triac circuits employing phase control, the two circuits presented here tend to radiate electrical interference when power is being applied to the load. This is due to the extremely rapid switch-on times of the Triac. The suppressor inductor L1 and the two .01uF capacitors bypassing the mains help keep the interference to a minimum. It is important that the Autolight should be housed in an earthed metal case, as the inductor is an efficient radiator of the electrical interference it is intended to suppress and it should be shielded.

Incidently, neither of the two circuits as presented are directly suitable for controlling fluorescent lights.

While the approach we have used is not mandatory, we do recommend that the unit be housed in a sturdy container, preferably a diecast aluminium box. The box we used measures 4-5/8 x 3¾ x 2 in and is available from most parts suppliers.

The Triac is mounted on a small heatsink measuring 2½ x 1½ inches, made from 18-gauge aluminium. Since the case of the Triac is at mains potential, the plate must be isolated from the case by two insulating pillars. The AC06DR and AC10DR are mounted using the clamps which are supplied at purchase while the other Tria-s specified are plastic pack units and mounted with a single screw and nut. If the power to be controlled is less than 300 watts the plastic pack units may be soldered directly into the circuit, with no additional heatsink required.

The interference suppression inductor L1 is not available commercially but is quite easily made. Start by winding a layer or two of thin insulation tape on a 2in length of ⅜in diameter ferrite rod. If a full length ferrite rod has been purchased it can be cut by filing a nick right around the circumference of the rod and then snapping it as if it were glass - do not try to saw the rod. Close wind 50 turns of 18 B & S enamelled wire over the insulation tape. Then wind insulation tape tightly over the rod in a couple of layers. This last step is important - if it is not wound tightly the inductor will make a buzzing noise due to currents being switched by the Triac.

A point about wiring is appropriate here. Note that the lamp is shown on the circuit diagram as a lamp symbol. Not shown directly on the circuit is the two core flex which carries power to the load. This can be in the form of ordinary mains lighting flex which will be sufficient for up to the maximum load specified.

The mains input and output cords should be passed through a grommetted hole in the case and securely anchored with a mains cord clamp. The earth wire should be connected to the case. Most of the circuitry is mounted on a suitable length of miniature tagboard. Layout is not critical but good wiring practice should be followed.

The LDR is mounted by drilling a suitable clearance hole in the case and securing the LDR so that it was slightly pround of the case surface.

Remember that this is a mains-operated device. In no circumstances should any work be carried out on it while power is applied.

PARTS LIST

1 diecast box 4-5/8 x 3-5/8 x 2-1/8 inches
1 2 amp mains switch
1 AC06DR RS276-1080 Triac.
1 1N5411 or equivalent Diac
1 ORP12. RS276-1081 LIGHT DEPENDENT RESISTOR
1 ferrite rod inductor (see text)
1 22K/5W resistor
1 0.1uF/160VW polyester capacitor
2 0.01uF/2KV ceramic disc capacitors
1 11-lug length of miniature tagboard
1 Heatsink for Triac
Insulating spacers, mains cord, mains cord clamp, solder lug, Araldite, screws, nuts hook-up wire, solder etc.

LSI DIGITAL CLOCK

HERE IS THE OPPORTUNITY TO BUILD A STATE-OF-THE-ART ELECTRONIC DIGITAL CLOCK, USING A MOS LSI INTEGRATED CIRCUIT AND A PLANAR SEVEN-SEGMENT NEON READOUT WITH BIG, BRIGHT DIGITS.

The clock presented here uses the 50Hz mains both to power it and to supply its timing pulses. It has a four digit display to give conventional 12 hour readout. An extra two digits can easily be added if desired to give seconds readout. Its time accuracy will be the same as for a conventional electric clock but it has the advantage of digital readout, visibility in the dark and completely silent operation. In addition, it is an interesting conversation piece.

Over the past year or so, great interest has developed in electronic digital clocks. This has been mainly as a result of increased availability of more complex digital integrated circuits and their continually reducing prices. Even so, the clocks made from conventional TTL integrated circuits have been fairly complex and power consumption fairly heavy.

Two developments have dramatically changed the situation, by greatly increasing the circuit complexity attainable on a single silicon chip and at the same time dramatically reducing the power consumption for a given circuit function. The first is large-scale integration, which is the title applied to integrated circuits having more than 1000 devices per chip. The second is the advent of metal-oxide silicon (MOS) technology, which has reduced chip space requirements per function compared with bipolar techniques and also reduced power consumption.

The clock described here takes advantage of these new developments. It is designed around a single MM5314N digital clock chip developed by National Semiconductor. A great deal of flexible electronics has been incorporated into the 24-pin plastic dual in-line package of this device.

It contains all the required logic to display time in four or six digits, will accept an input of 50 or 60Hz, and will operate in 12 or 24 hour mode. Decoding for seven-segment displays is performed on the chip, as is "multiplexing" of digit and segment data. This is explained later in the article.

The clock readout is a Sperry gas discharge device designated SP-332. It works on the same principle as a conventional neon numerical indicator tube, except that unlike the normal indicator tube, it uses seven segments to form any digit from 0 to 9 - in the same way as seven-segment LED readouts. It has the advantage over most LED displays, however, in that its digits are 0.5in high.

Now let us briefly describe the clock operation. First it has a divider-counter system. It takes half-wave rectified 50Hz, squares it up in a signal shaping circuit, and then divides it down to 1 pulse per second (1 pps). The 1pps signal is fed to a counter which cycles in BCD from 01:00:00 to 12:59:59 continuously (in 12 hour mode).

BCD output from the clock counter is decoded and multiplexed to drive the display via high-voltage PNP transistors.

In simple terms, multiplexing is a method of simultaneously transmitting more than one piece of information via the one path. In the case of the clock described here, it is necessary to display up to six separate numbers simultaneously. Each number has up to seven segments and therefore requires seven items of information.

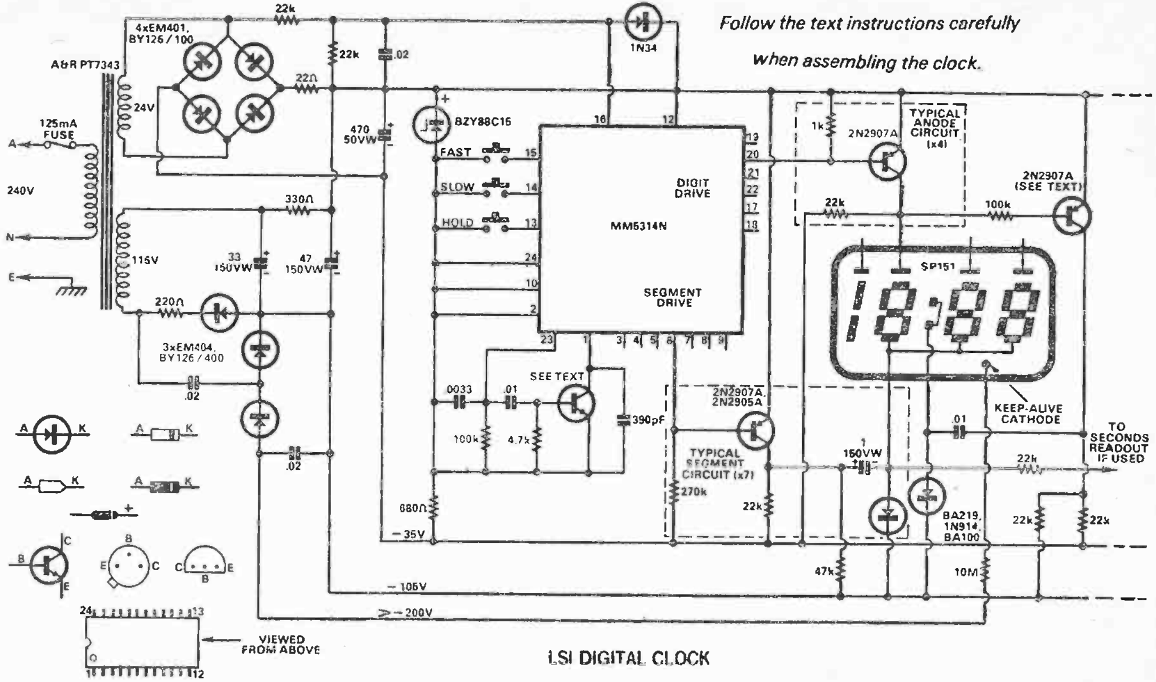
For a seven-segment display, eight separate lines are therefore required. Multiply this by six for a six-digit display, and we would need 48 lines, although when the clock operates in the 12-hour mode, the most significant digit is never larger than "1" and so will only need two segments; thus reducing the number of lines required to 43. If the clock chip used separate conventional seven segment decoding for each digit, it would thus require 43 output connections plus all the input, supply and control connections. Rather an unwieldy package!

Multiplex operation gets around the problem by not attempting to show all digits continuously. Instead the digits are flashed sequentially, at a rate of about 1kHz; at this rapid rate, they all appear to be on continuously.

All equivalent segments of the various digits are tied to seven common lines, each driven by a PNP "segment driver" transistor. The anode of each digit is driven by a PNP "digit driver" transistor. Thus there are only eleven separate output connections (13 for a six-digit display).

To display the various digits correctly, control signals are applied sequentially to the digit driver transistors, to apply anode voltage to each seven-segment readout in turn. At the same time the corresponding segment drive signals for each digit are applied to

Follow the text instructions carefully when assembling the clock.



LSI DIGITAL CLOCK

the common segment drivers. Each digit is thereby displayed at its appropriate position, but for only a fraction of the time; for four digit readout, one quarter of the time, and for six digits, one-sixth of the time.

Thus we use a relatively complex electronic time-sharing technique to drastically reduce the number of lines necessary to display all the digits. Three supply rails are provided for the clock operation and all are negative with respect to earth. A 35V rail powers the integrated circuit via a 15V zener diode stabiliser, 105V is provided for the "keep alive" cathode of the display. This last funtion is self-explanatory - it keeps the display quiescently "alive" for operation at the rather low voltage of 105V and allows reliable muliplex switching.

The low voltage rail is provided by a conventional bridge rectifier, while a voltage- multiplier arrangement supplies the higher voltages from the 115V secondary winding of the transformer.

Readers should note that while the circuitry is relatively easy to assemble, the finished unit will depend very much on the skill and patience expended on the physical form of the clock.

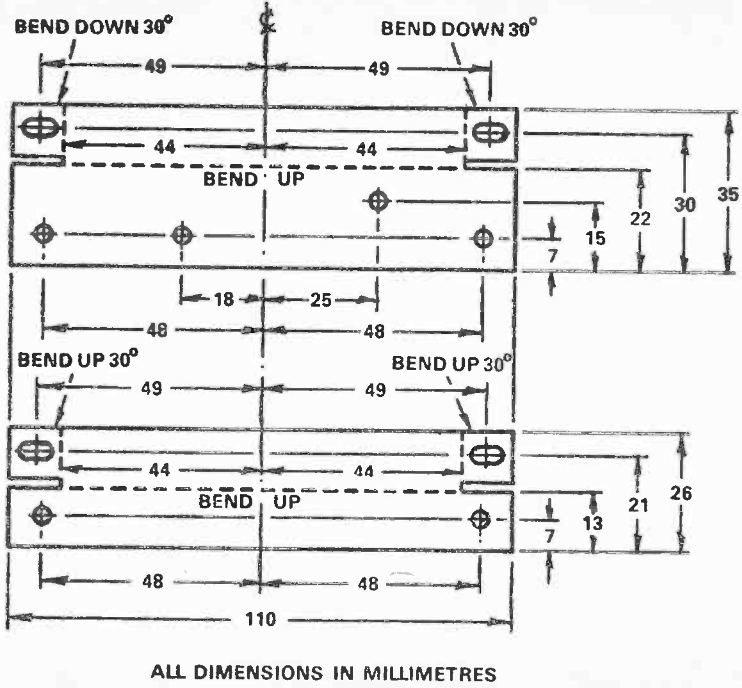
Our prototype uses two off-the-shelf diecast metal boxes, one standing upon the other. The larger of the two is inverted to become the base and the large printed board is mounted on the case lid. The smaller box is mounted upright so that its base becomes the front panel, with the lid used to support the readout board and the three time-setting switches.

Discussion of the construction procedure can start with the preparation of the diecast boxes and the associated hardware. The two boxes are attached together by two long screws passing through a shallow rectangular "tube". To make this, start with a piece of 16 SWG aluminium 18 x 1cm and bend it with the aid of a pair of electrician's pliers and a vice to form a rectangle approximately 7 x 4cm. The join should be in the centre of one of the long sides and faces the back of the clock.

Next, with the aid of suitable coarse and fine files, bevel one of the sides of the tube to match the bevel on the sides of the smaller diecast box, so that when supported by it, it stands up straight. Be careful when bending and filing the aluminium, not to scratch the visible surfaces.

Having cut your teeth, so to speak, on the aluminium tube, the brackets for the printed board can now be made. These hold the board by its corners, in slotted holes. Notice that the brackets are bent differently. One has its mounting screws underneath the board, to save space in the lid. Follow the dimensions shown in the diagram carefully. Aluminium or steel may be used, but aluminium is easier to work. Use 18 SWG aluminium or thicker.

Now the cases may be marked and drilled. Two ¼in holes are drilled on the major centre-line of the large case, space 5cm apart and equally spaced about the minor centre-line. Next, an elongated hole 1in by ½in is drilled and filed on the major centre-line between the two small holes, and displaced to the right of the case as far as possible so that it clears the power transformer. All the interconnecting wires pass through this hole, so make sure it is thoroughly de-burred. A matching set of holes is drilled in one side of the smaller case.



Two brackets are needed to mount the main printed circuit board. Make them of aluminium for ease of working.

Mark, cut and drill the aluminium and elongate the appropriate holes with a rattail file. Cut slots with a hacksaw where necessary to enable the aluminium to be bent correctly. Bending can be done easily with the aid of a vice and electrician's pliers. Note that the size of one of the board brackets is different from that shown in the prototype photograph.

All the holes may be drilled in the large lid using the printed board brackets as marking templates. File away the lip of the lid where the grommet and power cord are positioned, for clearance.

A 5/16in hole is drilled 15mm from the end of the larger case and 8mm from the edge, on the right-hand side looking from the rear. This is for the grommet. The hole is cut right to the edge with a round file or hacksaw so that the grommet slikes in easily. This is to allow the lid to be completely detached from the base.

A hole measuring 5.8 x 2.9cm is cut in the base of the smaller box to take the Digibezel, which is centred on the panel. It is best drilled roughly out and then brought out to size by filing. Three ⅛in holes with centres 15mm apart and 15mm from the lower edge are also drilled on the lid for the time-setting switches.

The readout board is mounted by two ⅛in screws, nuts and washers through the holes originally provided on the board for the HOLD and SLOW time-setting switches. We elected to have the switches on the rear panel because they would be both unsightly on the front panel, and an invitation to knob-twiddlers! Using ⅛in screws with flat washers in the large board holes allows sideways adjustment of the board to position the display precisely behind the Digibezel. The corresponding holes (⅛in) are drilled and countersunk with centres 8.2cm apart and 3cm from the top edge of the lid. The left-hand hole is centred 1cm from the edge of the lid.

Having drilled and de-burred all the holes in the cases, use a heavy wire brush to remove all the burrs, file-marks and swarf from the cases. If you have an electric drill and a circular wire brush, so much the better. It pays to carefully select the cases when purchasing them to be as free of imperfections as possible.

Now attach the cases with ⅛in screws and nuts and screw them up tightly. Attach the lids also, in preparation for painting. Use a well ventilated place, and make sure the work is dust and grease free. Follow the paint manufacturers' instructions carefully. Give the unit a coat of etch primer and then as many coats as necessary to the finish coat.

The colour of the clock case should match the decor of the room where it will be on display. We used a spray can of touch-up lacquer called "Chrysler Hot Mustard" which is currently a popular car colour. While the paint dries and hardens - let it stand over night - the boards can be assembled.

Start with the smaller board. With a hacksaw, carefully cut a piece off one end of the board. The cut should clear the hole marked "19" by 3 or 4mm. Don't worry about cutting the copper conductors to the left of this hole (looking at the copper side). They are for the time-setting switches, which we wire up directly rather than via the board. Now insert the pin connectors for the Sperry display. Note that five of the connector holes have no connection to the circuit, so they may be left out. They are for the AM and PM electrodes which are not used with the MM5314 circuit. Finally push a pin into each connector to open it up slightly.

With the pin connectors and the 10 megohm resistor soldered in, now start on the other board. It must be drilled to take the mounting lugs of the special A & R transformer. Drill the two holes carefully so that none of the essential copper pattern is damaged. Components may now be installed.

First, insert all the resistors and solder them. Ideally, ¼W resistors should be used wherever specified, as the board has been designed to take them, but ½W types will fit in - just. Do not bend the leads too close to the resistor body. Now insert the two integrated circuit connector strips and solder them. Snap off the top portion of each strip after soldering so that each little connector is now isolated from its neighbour. Having done that, remove the pin connector for pin 11 of the IC. This allows operation at 50Hz instead of 60Hz. Then push a pin into each connector to free them up slightly.

The intergrated circuit is supplied with the pins pushed through a black conductive foam material into a piece of polyurethane foam. This is to protect the MOS integrated circuit against build-up of static charges, which can do permanent damage. Do not unpack it or install it in the circuit until the rest of the circuit is complete, or the result may be very costly.

The next step is to solder in all the capacitors except the three large electrolytics. Metallised capacitors should be used where specified, as ordinary polyester capacitors are too large. The diodes may be installed at this stage, taking care to observe correct polarity. Again, do not bend the leads too close to the body, otherwise you'll end up with broken diodes.

Now solder in the transistors. In the place of "A20" on the board, next to the 390pF capacitor, install the TO-92 plastic encapsulated transistor marked with a green dot. In place of seven "H55" transistors in a line towards the top of the board immediately above the "Sperry" symbol, install 2N2905A or 2N2907A transistors. Similarly, the four "H55" transistors located in a line near the centre of the board (refer photograph) are replaced with 2N2907A or MPS3645. Do not use 2N2905A's here, as the spacing is too close for their larger TO-5 metal case.

Note that the two "H55" positions near the edge of the board and the associated 22k and 1k resistor positions are unfilled, unless the optional seconds display is required.

One 2N2905A marked with a red dot replaces the "H55" transistor located near the corner of the board, adjacent to the 470uF electrolytic capacitor. This transistor functions as the colon driver for the display. It is a specially selected device and cannot be replaced by an unselected device.

We soldered the fuse directly to the broad, with the aid of wire links. A more elegant method would be to use two McMurdo fuse-clips, with one of the solder lugs clipped off each. Alternatively, a length of appropriate fuse wire could be soldered directly to the board, but this is not recommended except as a temporary expedient.

The transformer may now be mounted. Take care when bending the six leads to suit the appropriate holes. Make sure the transformer is firmly bedded down on the board before twisting the lugs to secure it. Solder without applying excessive heat. Now solder in the 470uF electrolytic capacitor, which must be a printed circuit type (not pigtail type) if it is to fit in the case.

Now solder in the interconnecting wires. The active, neutral and ground connections may be ordinary insulated hook-μp wire, about 10cm long, while lighter gauge hook-up wire of as many different colours as possible should be used for the display connections. If you are limited in wire colours, use a repeating colour series, such as RBGRBG, to lessen confusion. Connections 8, 9 and 10 are made with dualshielded cable (figure-8), with both shields connected to "8". All these connections, 1 to 19 need to be about 20cm long. Leave out wires 12 and 13 unless the SECONDS display is required.

The remaining two large electrolytics present a problem in that the board was designed to take a dual-capactior printed circuit mounting can unit. The two electros to replace it are mounted horizontally with spaghetti sleeving on their pigtails, as follows: Remove the .02uF capacitor near the edge of the board and adjacent to the fuse. Now solder in the 47UF capacitor with the negative electrode connected to the vacated holde (for the .02uF) furthest from the fuse.

The 33uF electolytic capacitor is soldered to the appropriate connections marked plus and minus. Note that although values marked on the board are 50uF and 30uF, constructors are more likely to be supplied with the "preferred" range values of 47uF and 33uF. The tolerance on electros is so large that the nominal difference in value is unimportant.

Resolder the.02uF capacitor into position but on the copper side of the board. Carefully check the board for quality of the solder joints and breaks in the copper pattern. Assembly of all the components on the lid can now take place.

First, mount the "leads" end printed circuit bracket. It is secured with two screws which also hold the two rubber feet at that end. Insert the board into the bracket and mount the other bracket. Attach the mains cord with the aid of a cord clamp. The screw for the cord clamp also secures one of the rubber feet. The active and neutral wires from the mains cord and board are terminated in the two-way terminal block. The earth wires are attached to the solder lug.

Now solder the interconnecting wires to the display board, by passing each one, in turn, through the holes in the cases and soldering it. In this way, the job can be done systematically with no need to resort to a multimeter to find out which is which. Wires 8, 9, 10 and 11 are not soldered to the board but to the switches installed on the lid. Wires 12 and 13 have been deleted, as noted earlier. The shield of the figure-8 shield cable is a common connection for the three switches. If you have switches which have more than one set of poles, you will need to determine with a multimeter switched to the "ohms" range which pair of contacts are normally "open".

Note that while the FAST and SLOW timesetting switches should be normally open SPST push-button types, the HOLD switch can be a pushbutton, slide, rocker or toggle.

Having completed the interconnections, check them carefully and insert the integrated circuit into its socket. The notched end of the IC should be closest to the power transformer. Check that each individual connector is not touching its neighbour. The lid can now be screwed to the base.

When mounting the Digibezel, take care to install the polaroid filter with the right side facing out. The back clamping plate is installed with the large "knobs" putting pressure on the rear of the front panel. If you do it the other way around, the bezel will be a sloppy fit. The four push-on fasteners hold the bezel in place. They are installed with the aid of pliers. Take care to assemble the bezel correctly on your first attempt, because the push-on fasteners are very hard to remove without damage.

Some constructors may consider the polaroid filter cuts out too much light from the display. They may wish to substitute red perspex for the filter. However, we felt that the light output was adequate for most domestic situations and the polaroid filter is more attractive in appearance than perspex. It does not allow the un-illuminated cathodes of the display to be seen, whereas they may be visible with perspex.

Push the Sperry display carefully into the readout board connectors, taking care to see that each pin mates properly with its connector. Using nuts and washers either side of the board, mount it so that it is spaced approximately 8mm from the lid surface. Wires 1 to 7 can be laced loosely together, but wires 14 to 19 should be kept as far apart as possible from each other and from the shielded cable. The lid may be secured temporarily with two screws, making sure that none of the leads are pinched or interfere with the display. Now turn on the power.

The display does not light up instantly but in a few seconds will come on in a random fashion with some digits and or segments unlit. Sometimes the display does not light up at all but this is not necessarily a malfunction. Press the HOLD and then the FAST switch and the display should rapidly run forward. Set the time approximately and use the SLOW button to set the time exactly. Monitor the clock over a few hours to see that it does not gain or lose time. If it does it is generally because the interconnecting leads to the two boards are too close together, causing spurious "cross-triggering".

If one segment of a particular digit will not light up it is because of a bad connection on the back of the display. If one particular segment on all digits will not light up it will be because of bad connection or faulty "segment driver" transistor. This will usually be easily found by checking with a multimeter switched to the ohms-range across collector-emitter of the suspect transistor, which will most likely be shorted. Segment driver transistors are in a line towards one side of the board.

Similarly, if one digit does not light up at all, it may be because of a bad connection or faulty "anode driver" transistor. These are in a line near the centre of the board. At a pinch, if one of these eleven transistors has gone it may be possible to restore operation by replacing it with a TT800 though note that, strictly speaking, its voltage rating is insufficient. Other components substitutions should not be made unless there is no shadow of doubt as to their suitability.

Note that in normal operation the transformer will be quite warm to the the touch.

PARTS LIST

Sperry SP-151 12-hour clock display set of pin connectors for Sperry display. National MM5314 integrated circuit, integrated circuit socket connectors.

1 Transistor BC148.RS276-2009
7 2N2907A, 2N2905A, BC161/10, BCW80/16, SK3025 or RS276-2021 transistors (segment drivers)
4 2N2907A, MPS3645, BC161/10, BCW76/16, SK3114 or RS276-2023 transistors (anode drivers).
1 2N2905A, BC161/10, BCW80/16, SK3025 or RS276-2021 transistor (colon driver)
2 Printed wiring boards

Additional parts required:

1 diecast box, 12 x 9.5 x 3 cm
1 diecast box, 17 x 12 x 5.5cm
1 Digibezel
1 power transformer, printed board mounting
2 SPST normally open, push-button switch
1 SPST normally open, push-button, slide or toggle switch
8 Silicon diodes, 1N914, BA100 or BA219.RS276-1102.
1 germanium diode, 1N34. AA118-134-144. OA91/95. RS276-821. SD38.
4 silicon power diodes, RS276-1114, BY126-100 or equivalent
3 silicon power diodes, RS276-1114, BY126-400 or equivalent
1 Zener diode, BZY88-C15, (15V, 400mW)

RESISTORS
($\frac{1}{4}$ watt, 10pc tolerance unless otherwise noted)
1 x 10 megohm, 7 x 270k, 2 x 100k, 7 x 47k, 15 x 22k
1 x 4.7k, 4 x 1k, 1 x 680 ohm $\frac{1}{2}$ W 1 x 330 ohm $\frac{1}{2}$ W 5 pc tol, 1 x 220 ohm $\frac{1}{2}$W 5 pc tol, 1 x 22 ohm $\frac{1}{2}$W.

CAPACITORS
1 x 470uF 50VW printed board electrolytic
1 x 47uF 150VW electrolytic
1 x 33uF 150VW electrolytic
7 x 1uF 150VW electrolytic or metallised polyester
3 x .02uF 100VW metallised polyester
2 x .01uF 100VW metallised polyester
1 x .0033uF 100VW metallised polyester
1 x 390pF 100 VW polystyrene or ceramic

(Additional parts for optional SECONDS readout)
1 Sperry SP-151 display
1 Set of pin connectors for Sperry display
2 2N2907A, MPS3645, BC161/10, BCW76/16, SK3114 or RS276-2023 transistors (anode drivers)
1 x 10M $\frac{1}{4}$W, 9 x 22k $\frac{1}{4}$W, 2 x 1k $\frac{1}{4}$W (all 10 pc tol)
1 Digibezel kit to suit longer display

MISCELLANEOUS

Aluminium channel to attach cases, printed board mounting brackets (see diagrams and text) mains cord and plug, grommet, cord clamp, two-way terminal block, solder lug spaghetti sleeving, 4 rubber feet, 1/8A fuse, figure-8 shielded cable, hook-up wire, screws, nuts, washers, lock-washers, solder, can of suitable spray paint.
NOTE : Components listed here are those for the original design. Semiconductors should not be substituted unless they are direct equivalents. Passive components with higher ratings may be used in some cases provided space is not a problem (see text).

SIREN SOUND FROM A TRANSISTOR

THIS LITTLE DEVICE WOULD BE MOST EFFECTIVE AS A WARNING OR ALARM SIGNAL, FOR IT PRODUCES THE MOST IRRITATING SOUND MAGINABLE. IT JUST CANNOT BE IGNORED. THE WAVEFORM IS A SAWTOOTH WHICH IS MODULATED - INCREASING IN AMPLITUDE AND FALLING IN PITCH. IT CAN BE BUILT WITH ITS OWN SELF-CONTAINED AMPLIFIER OR USED AS A SIGNAL GENERATOR TO FEED A MORE POWERFUL AMPLIFIER.

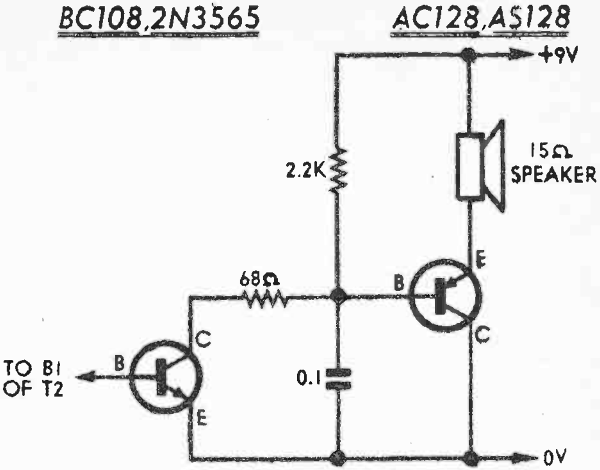
The unit actually consists of two relaxation oscillators, each using a unijunction transistor. One runs at a relatively high frequency in the middle of the audio range while the other runs at a sub-audio frequency which is varied by a potentiometer. The slow running oscillator modulates the former by means of the NPN transistor. Before we describe how the modulation is achieved it would be an idea to describe the operation of unijunction transistor (UJT) oscillators.

As far as use in a relaxation oscillator is concerned, the important characteristic of a UJT is as follows: In UJTs with N type bases, virtually zero current flows through the reverse-biased diode from the emitter to base-1, which is normally fed through a resistor connected to the negative side of the supply, until the emitter voltage rises to a certain value between the B1 and B2 voltages. B2 is normally connected to the positive side of the supply.

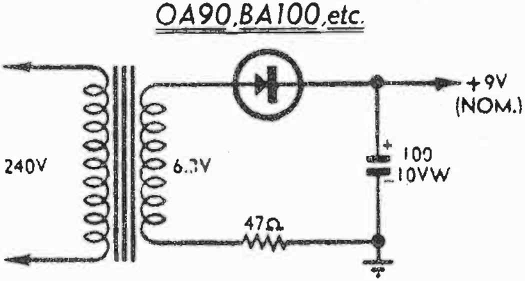
Referring to the circuitry to the left of the dotted line on the schematic diagram will show how this characteristic is employed to obtain a relaxation oscillator. The 2uF capacitor connected from the emitter to the negative side of the supply is charged through the resistance consisting of the potentiometer and the 10K resistor. When the voltage across the capacitor rises to a certain value, as described above, the emitter base-1 resistance decreases suddenly (i.e., the UJT is forward biased) and discharges the capacitor. The cycle repeats for as long as the circuit conditions are maintained. Thus a sawtooth waveform is generated across the capacitor. A train of pulses at the same repetition rate appears simultaneously across the base-1 load resistor.

The other relaxation oscillator consists of the circuitry to the right of the dotted line.

Initially, as the switch to the supply is closed, both the 2uF and 0.1uF capacitors will begin charging up via their respective resistors. The NPN transistor T3, in series with base-2 of T2 will be biased "off" by the 100K resistor connected to the junction of the 2uF capacitor and the emitter of T1. As the voltage across the 2uF capacitor rises, T3 will begin to conduct so that the relaxation oscillator formed by T2 can begin to function.



A switching mode amplifier which could be used with the siren oscillator

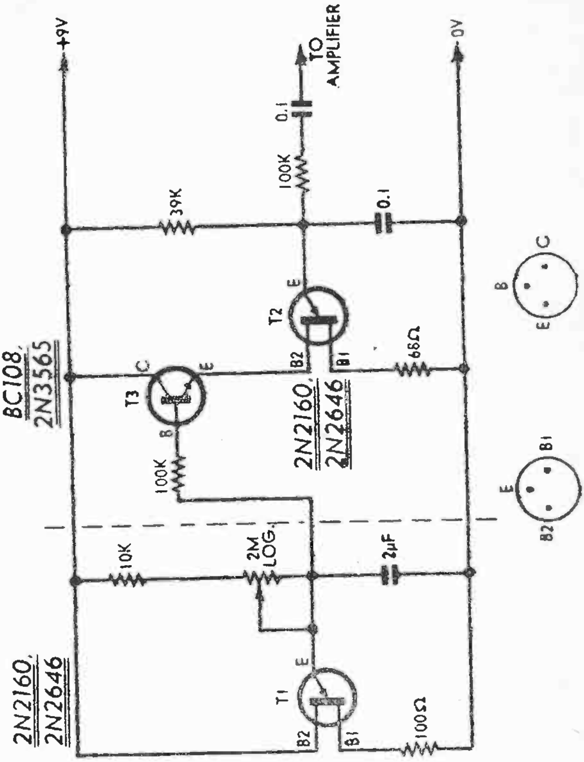


A simple 9V supply which could be used to power the oscillator and/or amplifier

AC128=RS276-2004/5

OA90=RS276-1102, BA100

2N2160=RS276-2029, 2N2646
BC108=RS276-2009, 2N3565



the circuit of an oscillator capable of producing a siren-like signal.

In normal operation the signal from T1 modifies the conduction of T3 and changes the voltage across the bases of T2. In so doing, it effectively changes the "peak-point" of UJT and thus varies the frequency as well as the amplitude. The so-called "peak point" of a UJT is when the emitter voltage rises above the base-1 voltage by an amount sufficient to cause conduction in the emitter/base-1 junction. This explains why the T2 relaxation oscillator starts out with a relatively high frequency which then decreases - simply because the 0.1uF capacitor charges up to a low voltage faster than to a higher voltage.

The rate of modulation is controlled by the 2 megohm potentiometer which provides a wide variation. At the high end of the pot the "slow" oscillator will not function due to leakage effects in T1. Thus a continuous tone will be emitted.

The output of the oscillator can be taken from the emitter of T2 via a 100K resistor and a suitable blocking capacitor, say 0.1uF. Connecting the amplifier will cause a change in the operating frequency but this would be of little consequence in a case like this.

Alternatively, the device can be built up as a self-contained unit with its own amplifier and 15-ohm speaker. The amplifier consists of a silicon NPN transistor followed by a medium power germanium PNP transistor. The transistors are operated in a "switching" mode. The base of the NPN transistor is connected directly to base-1 of T2. The germanium power transistor, AC128, is fitted with a flag heatsink to improve heat dissipation. Although the transistors are operated in the "switching mode, the amplitude of the signal at the beginning of the cycle of the "slow" oscillator is insufficient to drive the transistors into saturation. Thus, the power dissipation in the power transistor is higher than if it merely alternated between "cut-off" and saturation.

The tone from the speaker can be "muted" by increasing the value of the 0.1uF capacitor. This will tend to reduce the amplitude of higher order harmonics which contribute so much to apparent loudness. There is no practical way in which a volume control could be fitted to a switching mode amplifier unless it took the form of a variable resistor in series with the loudspeaker. The impedance of the speaker must not be reduced below 15 ohms but it can be higher if you have one on hand.

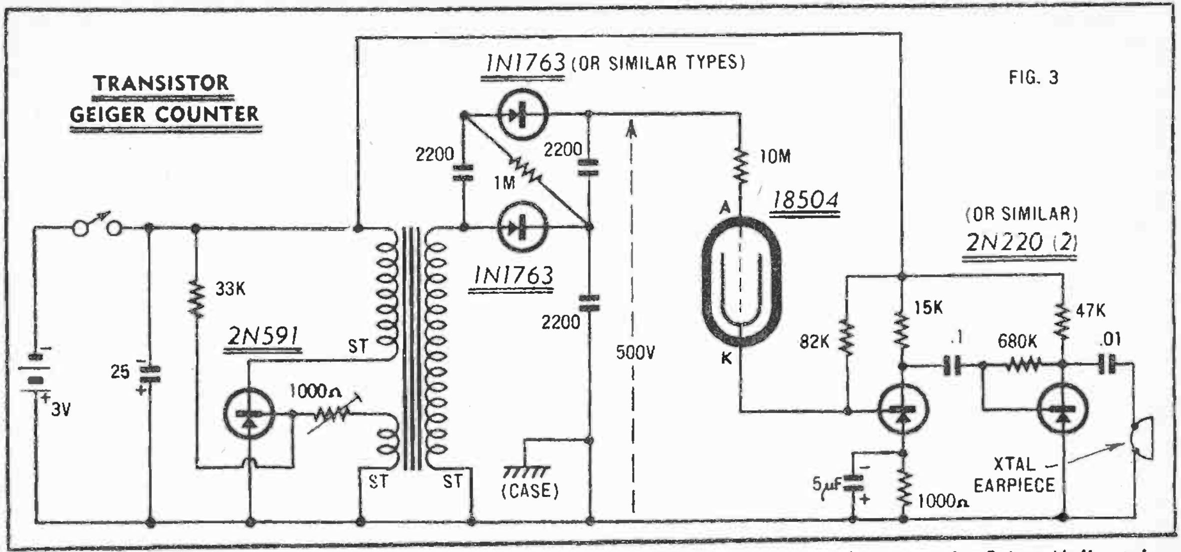
TRANSISTOR-CONVERTER POWERED GEIGER RADIATION COUNTER

Having examined the basic design of the ringing-choke converter we now consider a practical application of the circuit - that of a transistorised Geiger counter. Discussion of such a device will not only provide us with an example of the design of a ringing-choke converter, but will also provide readers with a practical project, a photograph of which appears above.

The circuit for the device is shown in Figure 3. As you can see, it is simply a 3-to-500 volt ringing-choke converter supplying the Geiger-Muller tube, followed by a two-stage transistor amplifier delivering the output pulses to a crystal earpiece.

Here, briefly, is the design procedure for the converter.

Firstly, it is known from the data that the Geiger tube requires a supply voltage of about 500V to place it in the centre of its "plateau". It also requires a load resistance of 10 megohms. From consideration



The circuit of the unit reveals that it comprises a transistorised 500-volt power supply to run the Geiger-Muller tube, followed by a two-stage transistor amplifier to increase the magnitude of the output pulses. A crystal earpiece serves as an indicating device.

of the load resistance and the tube characteristics, this means that about 20 microamps of output current may be taken as a design figure for the converter. This gives a required output power of 10 milliwatts.

For this value of Pout and the required Vin of 3 volts, the peak input current will be approximately 13 mA.

Due to the large voltage step-up ratio involved, a voltage doubler circuit for the output rectifier has already been selected, as the circuit shows. As the ringing-choke circuit develops only uni-directional output pulses, it is of the Cockcroft-Walton type.

The voltage step-up ratio is still rather high so it is wise to select a transistor for the converter which has a fairly high Vcb (max) rating. From an examination of data books, the type 2N591 seems very suitable, as it has a voltage rating of 32 volts. Its emitter current rating lies substantially above the 13mA we have calculated for Ipk and its dissipation is also well above a value of 0.2 times Pout, so it seems a good choice.

Now for the transformer. First, the required value of Lp is found, and this works out to be 50 millihenries. Using this value, it is now possible to select a suitable core shape and material, and to calculate the number of primary turns required. See our book No. 160 entitled "Coil Design and Construction Manual".

In this case, the core material selected is type "H" Ferramic material. After some experiments to determine the best compromise between core size and shape and necessary turns, the final core selected comprises two of the manufacturer's type F4016 - ¼ in Ferramic "E" cores. For this core, the required primary turns is 170 wound with 28 S.W.G. enamelled copper wire.

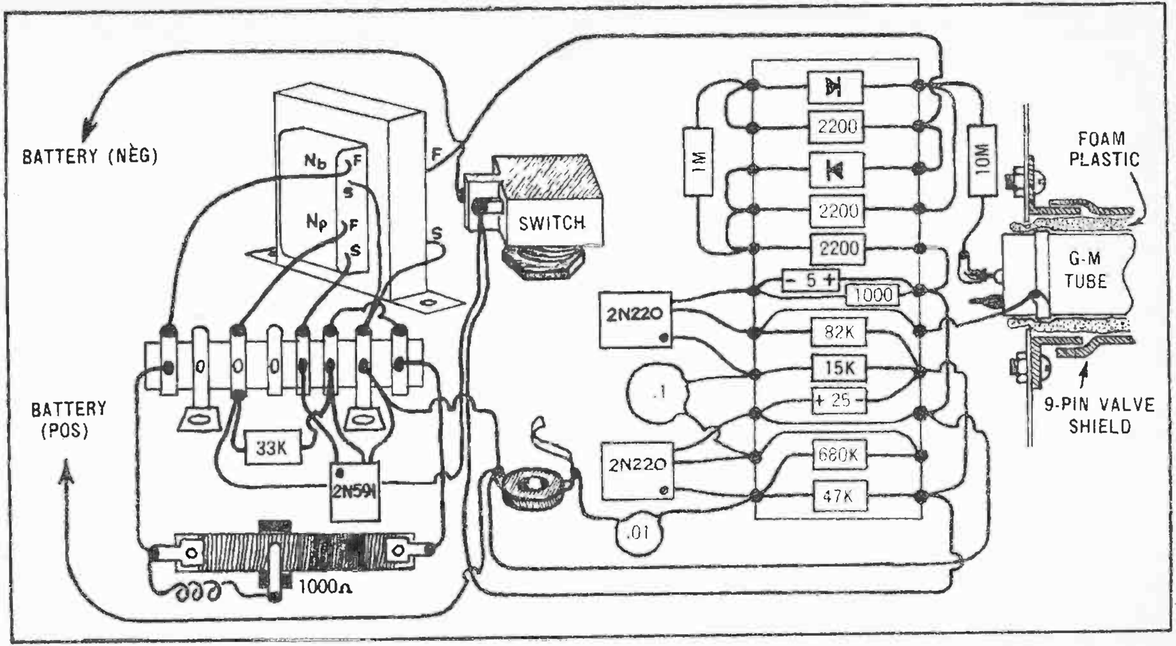
From the transistor data, it is learnt that, to produce bottoming at all currents up to about 13mA with the 2N591, an input voltage of about 0.3 volts is required. Multiplying this by about 2 to allow for transistor spread, this means that the required base feedback winding is 30 turns. This winding may be of the same wire as used for the primary winding.

What about the secondary winding? Well, the turns ratio required is equal to 250/(32-3), or 250/29. Thus the secondary winding must have 250/29 times (170 plus 30), or near enough to 1700 turns of 42 S.W.G.

Now for some minor points of interest concerning the final converter circuit. You will notice that a 33K resistor is wired from the negative battery terminal to the 2N591 base (via the switch). This is to supply a small amount of "starting bias" to ensure reliable initiation of oscillations with low battery voltages or transistors having low gain, etc. The value shown is a compromise one, selected to suit most conditions. However, under unusually adverse conditions it may not provide enough starting bias, and may be reduced slightly.

VOLTAGE DOUBLER

As was mentioned before, the high voltage rectifier is a voltage doubler using the Cockcroft-Walton circuit. In effect it consists of two half wave rectifier circuits paralleled as far as AC input is concerned, but connected in series as far as DC output is concerned. This circuit operates quite satisfactorily with the positive-pulse output wave of the converter transformer, and does not affect the ringing-choke operation.



Here is the complete wiring diagram of the counter.

The Geiger-Muller tube used in the counter is a Philips type 18504, a small end-window halogen-quenched tube which is intended for the counting of Beta (electron) and Gamma radiation.
The tube is connected in series with the recommended load of 10 megohms across the 500-volt output of the converter. Also, in series with the tube is the base-emitter circuit of a 2N220 transistor, which is followed by a further amplifier stage using another 2N220.
The first 2N220 is normally conducting, having a forward bias impressed on the base by the 82K resistor. When radiation ionises the Geiger-Muller tube, however, its impedance drops considerably for a brief period (until the halogen filling cuts off or "quenches" the tube). Thus a positive pulse is delivered to the transistor base, cutting it off for the approximate period of the pulse.
A negative pulse thus appears at the collector of the transistor, and this is fed to - and amplified by - the second 2N220. The output of the second transistor is fed to the crystal earpiece, which registers a "click".
The higher the radiation level experienced by the counter tube, the greater the number of times it will ionise in a certain time, and the faster the repetition of the clicks in the earpiece. When a fairly high level is present, the clicks tend to blend into a deafening "roar" in the earpiece.
You may have noticed the 25 mfd electrolytic capacitor connected across the supply; this is to lower the supply impedance. Owing to the pulse nature of the converter input current any common supply impedance causes ripple to appear in the audio amplifier supply voltage, and a whistle is heard in the earpiece along with the desired clicks.
By wiring in the bypass capacitor, this effect is almost eliminated. A small amount of whistle may usually be heard but not enough to cause listening fatigue or reduce the "click-detecting ability." In fact, it serves as an indicator that the converter is functioning correctly.
Mechanically, the unit is quite simple. It is built into a small metal box measuring 6" x 3" x 2" with a chromed rod handle on the top.
The G-M tube is quite small yet must be mounted without stress and so that the sensing window is not shielded to radiation. We solved this problem by using a shielded miniature 9-pin socket assembly - minus the actual socket moulding. The tube is wrapped in foam plastic to provide a stress free mounting. In addition to providing electrical insulation for the cathode (outer cylinder).
Incidentally, the cathode shell is provided with a little strap to facilitate connection. The connecting wire should be lightly soldered to the free end of the strap, using no more heat than is necessary for a good joint. Do not try to solder directly to the shell, for this will destroy the tube.
The anode electrode is provided with a removable clip connection, which should be soldered to the 10 meg. load resistor WHEN UNCLIPPED FROM THE TUBE. This is for the same reason as above - Geiger tubes are not cheap!
The top of the case has the two panel fittings - the on-off switch and the phone socket (a miniature type). These are grouped close to the handle, for easy operation.
Inside the case, we have the main wiring panel at the tube end. This is followed by the converter transformer and circuitry in the centre, and the batteries at the opposite end.
Wiring of the unit should present no problems, as we have prepared a

complete wiring diagram. For ease in assembly, we suggest that the wiring board be wired prior to fitting into the case. Two components must be left off to allow for screwing the panel into place, but these are easily added later.

The batteries used are "penlight" cells, which will last for a considerable period at the 14 milliamp-or-so drain required by the counter. We made up a little two-cell holder from bakelite and brass sheet scraps, but we understand that imported cell-holders are available which may prove suitable, or at least adaptable.

With the unit completely wired and assembled, set the base slider potentiometer to maximum resistance and switch on. If the converter circuitry is functioning, you will be greeted by a small whistle due to the usual magnetrostriction effects in the ferrite core of the transformer. If no sound is evident at first trial, switch off and reverse the base winding or the collector winding. Note, however, that as the secondary winding MUST have its start earthed, there is ONLY ONE correct combination of the base and collector windings. Oscillations will occur with the other combinations but the secondary will produce little or no output.

With the converter operating correctly, the final step is to set the base slider potentiometer so that the converter output is 500 volts. As the supply is quite poorly regulated, the measurement must be performed on an electrostatic meter or a VTVM fitted with a television type EHT probe - otherwise the voltage read will be much lower than the actual value.

As the photographs show, the slider will be about midway along its travel - which may serve as a rough guide to those not possessing suitable measuring gear.

PARTS LIST

1	Converter transformer as per text
1	Geiger-Muller tube, type 18504
1	Sheet metal case, 6"x3"x2" with lid. Handle to suit.
1	Panel mounting toggle switch
1	Miniature 9-pin socket and shield
1	11-tag length of miniature resistor strip
1	8-lug miniature tagstrip
1	Miniature crystal earpiece
1	Plug and socket assembly for above
2	1.5 volt penlight cells

TRANSISTORS AND DIODES

1 x 2N291 or RS276-2007. GE2. HEP629. SK3004. 2N4106. OC74. AC117-128-153. 2SA219. NKT224

2 x 1N1763. 1N4004. RS276-1103. RS276-1138. RS276-1114. BY137/400 BY151N. BY201/400

2 x 2N220 or RS276-2005 or HEP254 or SK3004. GE2. OC71. AC107-122-126-163

RESISTORS

½ watt 5% types; 1K, 15K, 33K, 47K, 82K, 680K, 1M

1 watt 1% H.S. type: 10M

Wirewound slider; 1000 ohm

CAPACITORS

3	2200 pF 600VW plastic
1	0.01 uF 100VW ceramic
1	25 uF electolytic, 6VW
1	0.1 uF 100VW ceramic
1	5uF electrolytic, 6VW

MISCELLANEOUS
Connecting wire, screws and nuts, scrap bakelite and brass for battery holder, foam plastic sheet for G-M tube mfg., solder etc.

BERNARDS & BABANI PRESS RADIO AND ELECTRONICS BOOKS

BP1	First Book of Transistor Equivalents and Substitutes	40p
BP2	Handbook of Radio, TV and Ind. & Transmitting Tube & Valve Equiv.	60p
BP3	Handbook of Tested Transistor Circuits	40p
BP4	World's Short, Med. & LW FM & TV Broadcasting Stations Listing	60p
BP5	Handbook of Simple Transistor Circuits	35p
BP6	Engineers and Machinists Reference Tables	30p
BP7	Radio and Electronic Colour Codes and Data Chart	15p
BP8	Sound and Loudspeaker Manual	50p
BP9	38 Practical Tested Diode Circuits for the Home Constructor	35p
BP10	Modern Crystal and Transistor Set Circuits for Beginners	35p
BP11	Practical Transistor Novelty Circuits	40p
BP12	Hi-Fi, P.A., Guitar & Discotheque Amplifier Handbook	75p
BP13	Electronic Novelties for the Motorist	50p
BP14	Second Book of Transistor Equivalents	95p
BP15	Constructors Manual of Electronic Circuits for the Home	50p
BP16	Handbook of Electronic Circuits for the Amateur Photographer	60p
BP17	Radio Receiver Construction Handbook using IC's and Transistors	60p
BP18	Boys and Beginners Book of Practical Radio and Electronics	60p
BP22	79 Electronic Novelty Circuits	75p
BP23	First Book of Practical Electronic Projects	75p
BP24	52 Projects using IC741 (or Equivalents)	75p
BP25	How to Build Your Own Electronic and Quartz Controlled Watches & Clocks	85p
BP26	Radio Antenna Handbook for Long Distance Reception & Transmission	85p
BP27	Giant Chart of Radio Electronic Semiconductor & Logic Symbols	60p
BP28	Resistor Selection Handbook (International Edition)	60p
BP29	Major Solid State Audio Hi-Fi Construction Projects	85p
BP30	Two Transistor Electronic Projects	85p
BP31	Practical Electrical Re-wiring & Repairs	85p
BP32	How to Build Your Own Metal and Treasure Locators	85p
BP33	Electronic Calculator Users Handbook	95p
BP34	Practical Repair & Renovation of Colour TV's	95p
BP35	Handbook of IC Audio Preamplifier & Power Amplifier Construction	95p
100	A Comprehensive Radio Valve Guide – Book 1	40p
121	A Comprehensive Radio Valve Guide – Book 2	40p
126	Boys Book of Crystal Sets	25p
129	Universal Gram-Motor Speed Indicator (Combined 50 & 60 ∞ model)	10p
138	How to Make Aerials for TV (Band 1–2–3)	25p
143	A Comprehensive Radio Valve Guide – Book 3	40p
150	Practical Radio Inside Out	40p
157	A Comprehensive Radio Valve Guide – Book 4	40p
160	Coil Design and Construction Manual	50p
161	Radio TV and Electronics Data Book	60p
170	Transistor Circuits for Radio Controlled Models	40p
177	Modern Transistor Circuits for Beginners	40p
178	A Comprehensive Radio Valve Guide – Book 5	40p
183	How to Receive Foreign TV Programmes on your Set by Simple Mods.	35p
196	AF–RF Reactance – Frequency Chart for Constructors	15p
200	Handbook of Practical Electronic Musical Novelties	50p
201	Practical Transistorised Novelties for Hi-Fi Enthusiasts	35p
202	Handbook of Integrated Circuits (IC's) Equivalents and Substitutes	75p
203	IC's and Transistor Gadgets Construction Handbook	60p
204	Second Book of Hi-Fi Loudspeaker Enclosures	60p
205	First Book of Hi-Fi Loudspeaker Enclosures	60p
206	Practical Transistor Circuits for Modern Test Equipment	60p
207	Practical Electronic Science Projects	75p
208	Practical Stereo and Quadrophony Handbook	75p
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211	First Book of Diode Characteristics Equivalents and Substitutes	95p
213	Electronic Circuits for Model Railways	85p
214	Audio Enthusiasts Handbook	85p
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216	Electronic Gadgets and Games	85p
217	Solid State Power Supply Handbook	85p
218	Build Your Own Electronic Experimenters Laboratory	85p
219	Solid State Novelty Projects	85p
220	Build Your Own Solid State Hi-Fi and Audio Accessories	85p
221	28 Tested Transistor Projects	95p
222	Solid State Short Wave Receivers for Beginners	95p
223	50 Projects using IC CA3130	95p
224	50 CMOS IC Projects	95p
RCC	Resistor Colour Code Disc Calculator	10p

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