Elementary Electronics

An Electroscope

by Ross Tester

Most science students will be familiar with the 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.

We described a conventional electroscope in February, 1970 (File No 8/C/15). Copies of this article are available for those who may not have the issue. As well as describing how to construct the device, the article lists a number of experiments which can be conducted. This article would make good background reading for those who wish to construct this version of the electroscope.

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.

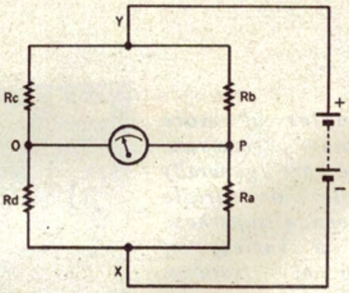
Since the indicating meter is connected between points O and P, and these two points are at the same potential, there will be no reaction by the meter. In this condition the bridge is said to be balanced. The important characteristic of this setup, as far as we are concerned at the moment, is that, even 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.

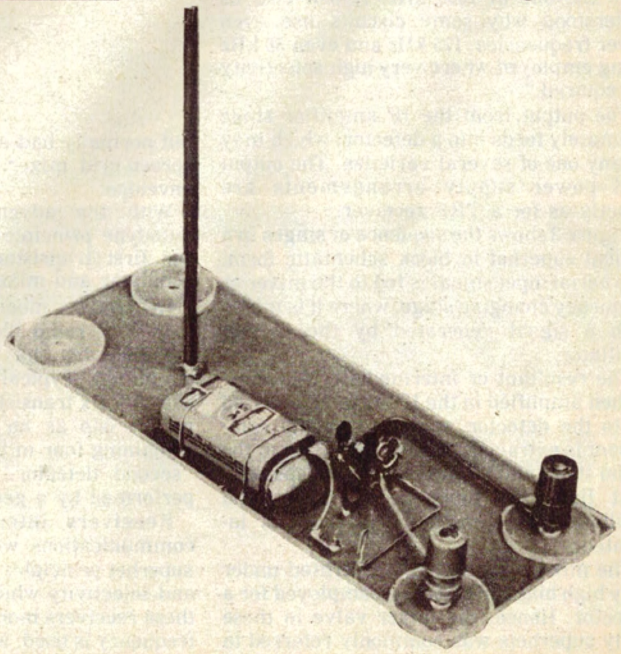
Now take a look at the circuit of our electroscope. Notice the similarity? In place of Ra and Rb we have a 47K pot which,, because of the tap provided by the moving arm, can really be regarded as two resistors, both variable. In place of Rc we have a 2.2K resistor, and in place of Rd we have the source/drain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



Above: The basic bridge circuit around which our electroscope is designed.



Right: The completed detector on its perspex base. The 2.2K resistor is obscured by the pot. Note our simple off-on switch; a loop of wire shaped to catch the battery lead when bent over it.

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 change 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 any body 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 charged 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 of the Elementary Electronics section 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.

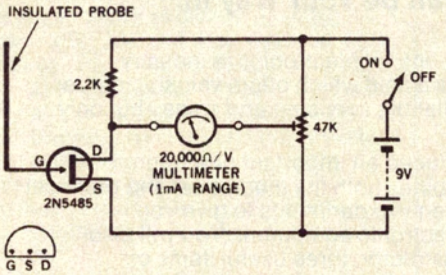
The ranges mentioned should enable you to obtain quite high sensitivity with your detector. If you do not have a multimeter, but do have a meter with an FSD current somewhere around 1mA, by all means go ahead and use it.

We built our detector on a piece of ⅛in 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 the 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 8in (203mm) by 3½in (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.



The circuit of the complete electroscope. Compare it with the bridge circuit on the opposite page.

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 1/16in. 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 straw 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 deflection.

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 ballpoint 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 electrons 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.