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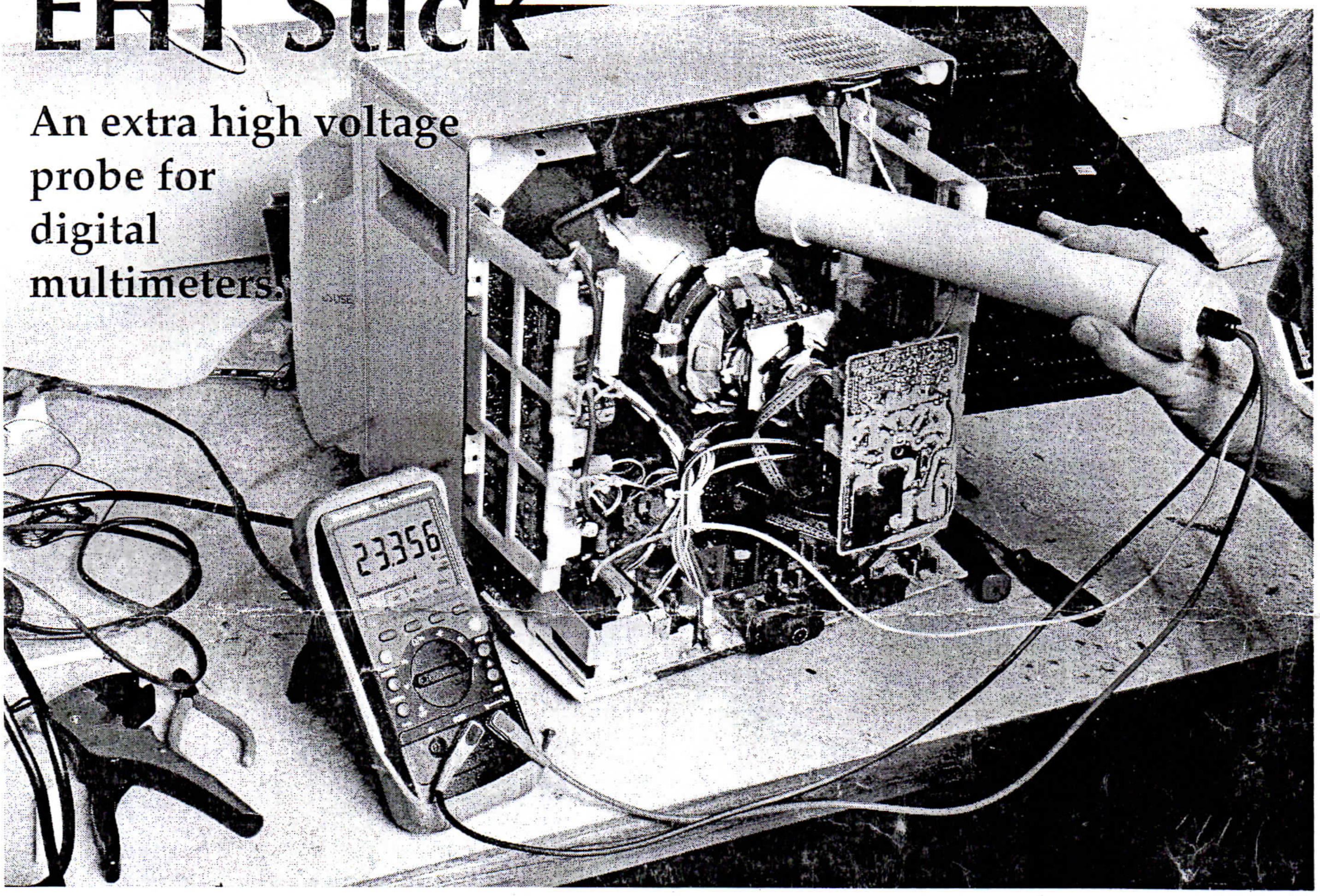
K 2559

EHT Stick

An extra high voltage probe for digital multimeters



Do you need to measure the EHT voltage in a CRT-based scope, computer monitor or TV receiver, or perhaps in a photocopier, laser printer or microwave oven? You'll need an EHT probe to suit your digital multimeter (DMM) to do this and you'll find they are pretty pricey. Not to worry though, because here's one you can build for less than $40.

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Measuring really high voltages is not something you can normally do easily or safely. So if you want to measure the EHT of CRT-based TV receivers or the corona voltages in photocopiers or laser printers, what do you do?

They are up around 22kV or more – far out of the range of a DMM. And if you want to measure the high voltage in a microwave oven – about 3kV or so – that's also way out of range of a DMM.

You can't make this kind of measurement just with a normal multimeter or DMM, because in most cases they have a maximum input voltage rating of 1000VDC or 750VAC.

The only way this type of meter can be used to make measurements on higher voltages is to connect a specially designed EHT divider probe between its input sockets and the source of high voltage. The probe divides down the voltage to be measured by a known factor (usually either 100:1 or 1000:1), to bring it within the voltage range which can be handled safely by the meter itself.

This type of EHT divider probe has been available commercially for many years, and they're still available if you hunt them down.

They've never been particularly cheap though and if you want to buy a brand-new probe nowadays you'll find they're priced from around $100 and upwards – not easy to justify if you only want to measure EHT voltages every now and again.

Our probe, which we've dubbed the "EHT Stick", has been designed to allow you to measure DC voltages up to around

23-25kV, using any standard digital multimeter (DMM) which has an input resistance of 10MΩ. It provides a division ratio of 1000:1, so kilovolts at the input are read simply as volts on the DMM.

Like many commercial EHT probes, it provides an input resistance of just over 800MΩ. So when it's connected across a circuit with a voltage of say 20kV (20,000V), the probe will draw a modest 'loading' current of only 25?A.

In their divider's crucial input leg, commercial EHT probes have always used special very high value 'long spiral' resistors rated to withstand very high voltages but these haven't been readily available for some time.

So instead, we have used 80 (yes, eighty!) high voltage (1.6kV) 10MΩ 0.5W metal film resistors in series to produce the 800MΩ input leg. The Farnell type number for the 10MΩ is 110-0295.

Because of the large number of resistors in series, the voltage drop per resistor is kept well within their maximum voltage rating.

Even when the EHT Stick is measuring a voltage of 25kV for example, the voltage across each resistor in the input leg is only 313V. The power dissipation per resistor will also be less than 10mW.

By the way, don't be tempted to substitute standard 0.25W or 0.5W resistors for the high voltage types specified. Most 0.25W and 0.5W resistors have a voltage rating of only 200-250V or so – certainly not enough!

Now before we move on to look at the probe's circuit and how it's built and used, please read the text in the safety warning box carefully.

Making measurements in EHT circuits inevitably presents an increased safety risk, because even in a CRT-based TV set or a microwave oven the EHT circuitry can provide a lethal shock.

So it's important – in fact, vital – that you not only build the probe exactly as we describe and that you follow the correct procedures when making a measurement. If you are careless, the measurement may be the last you ever make!

Safety Warning

In order to use EHT divider probes like the one described in this article safely, please note carefully the following points:

1. **The probe's ground return must always be connected** securely to the 'earthy' side of the EHT circuit in which you are making the measurement – BEFORE you connect the probe's measuring tip to the 'hot' side of the circuit. This is most important because if the probe tip is connected first, all of the probe's internal circuitry AND YOUR DMM will be 'floating' at the full EHT voltage and thus represent a very serious safety risk.
2. The probe's ground return lead and its connection clip must be regarded as a vitally important part of the probe itself. It is crucial to achieving correct probe operation, because it provides the only connection between the bottom end of the probe's voltage divider and the EHT circuit in which you are making the measurement.
3. NEVER connect the probe's ground return lead to the 'hot' side of the high voltage circuit, as this will also cause your DMM to be floating at the full EHT voltage. If you need to measure an EHT voltage that happens to be negative with respect to ground, simply reverse the polarity of the probe lead connections to the DMM input jacks. The probe's ground return lead should ALWAYS be connected to the 'cold' or earthy side of the EHT circuit.
4. If at all possible, turn off the power to the EHT circuit before you connect the probe's ground return lead and input measuring tip. Only turn the power back on when both connections are secure and your hands are safely withdrawn. This will help ensure that you don't receive a shock when the probe tip comes into contact with the 'hot' side of the EHT circuit, and also that a 'flashover' arc cannot develop.
5. Turn off the power to the EHT circuit again after you have made the measurement, and before you remove the tip and ground return connections (in that order).
6. If it is not feasible to turn off the power to the EHT circuit before making the probe connections and you have to hold the probe body in your hand while making the measurement, make sure you hold it down at the output lead end. Do not risk a flashover or punch-through by holding it closer to the tip end.
7. **Do not attempt to use this type of probe to make measurements in high voltage power distribution systems.** These can supply a huge amount of energy/power and in most cases cannot be turned off in order to make the probe connections. The risk of serious injury or death is therefore extremely high.

Circuit description

As you can see from the circuit of Fig.1, the probe is just a resistive voltage divider, with an input leg formed by the 80 10MΩ resistors in series.

The lower leg is formed by the 820kΩ and 30k? resistors in series with trimpot VR1, with the 10MΩ input resistance of the DMM itself in parallel.

When the value of this composite lower leg is adjusted using VR1 to have a resistance of 1/999 of the input leg (ie, nominally 800MΩ/999, or 800.801kΩ), the divider provides an exact division ratio of 1000:1.

Trimpot VR1 allows you to compensate for the within-tolerance variations in all of the other resistors, to give the probe maximum accuracy.

So while the circuit of the probe is very straightforward, the physical construction presented us with quite a challenge, in order to meet the somewhat conflicting needs of fitting no fewer than 82 0.5W resistors plus a trimpot into a case that would be compact enough to be handheld, yet provide a suitably high level of electrical isolation and safety.

Construction

The approach we came up with was to fit all of the resistors and the trimpot onto a long narrow PC board, measuring 228 x 37mm and coded 04104101. The 80 resistors in the divider's input leg are laid out in a long 'zig-zag' pattern over most of the

Test setup using the EHT Stick and a digital multimeter. Always ensure that the green grounding lead is firmly attached to a suitable ground point in the circuit under test BEFORE probing the EHT.

board's length, to provide the necessary spacing in a reasonably compact area.

The PC board, sleeved in 30mm heat-shrink tubing, is designed to fit inside a 250mm length of 43mm OD/39mm ID PVC-U conduit, with a 43mm ID PVC pipe cap at each end to complete the safety isolation.

The PVC-U conduit (the -U standing for unplasticised) is type DWV (stands for drain, waste & vent) and it and the matching end caps are made by companies such as Vinidex and Iplex. The conduit and the end caps can be obtained from hardware stores and plumbing supply outlets. Most will supply minimum lengths of 1 metre – a bit of a waste, if you'll pardon the pun – but our 1m length only cost us a couple of dollars. One of these days we're sure to come up with a use for the rest!

Or you might also try your friendly local plumber for an offcut. The plumber might also be good for a short length of 4mm brass rod (eg, brazing rod) to fashion a probe tip from.

The end caps are a (tight!) friction fit onto the conduit. This provides adequate physical security while maintaining good electrical isolation. We suggest you don't try to check the fit out before final assembly, because once on, they're not easy to get off again!

A 4mm banana socket is mounted in the centre of one end cap to provide the probe's 'hot' input, the idea being that whichever probe tip (or very short clip lead) you use plugs into the socket via a standard 4mm banana plug.

As we mentioned earlier, a short length of brass rod makes an excellent probe tip – we made ours from a piece of brazing rod about 50mm long (certainly not critical) with a point filed one end and soldered to a banana plug to mate with the banana socket.

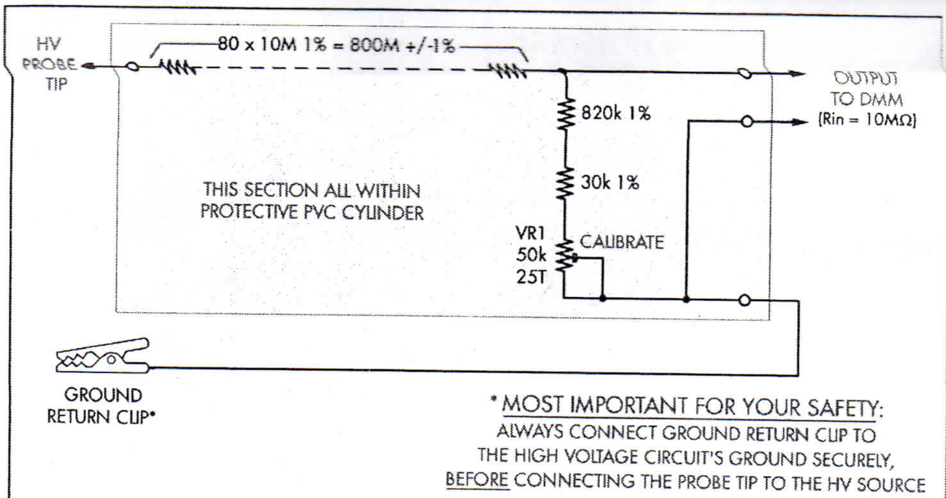
A cable gland is mounted in the centre of the other end cap to provide an exit for the probe's output leads and its ground return input lead.

Wiring up the probe board is not difficult but is a little tedious because of the large number of resistors to be fitted. The easiest part is fitting the four PC board terminal pins used to make the off-board connections – one at the input end to mate with the solder lug at the rear of the banana socket, and the other three at the output end to provide the cable connections.

Note that the single pin at the input end should be fitted from the copper side, with its 'top end' cut off flush when you have soldered it to the pad underneath.

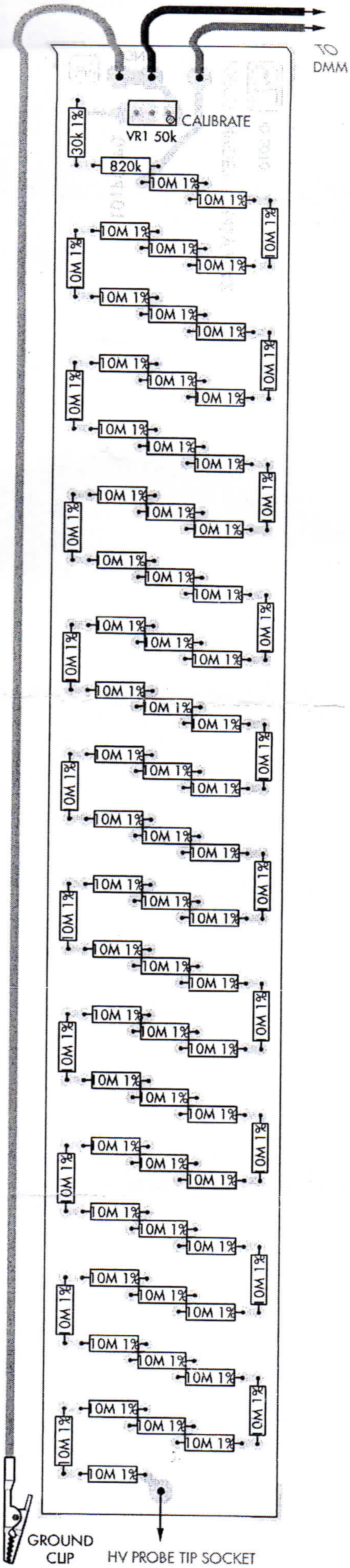
Once the pins have been fitted, you can proceed with installing the fixed resistors. They're fitted in the standard way, with the leads bent down at 90° quite close to the resistor body so that when they pass through the board holes, the resistor is lying flat on the top of the board.

The leads are then soldered carefully to the pads underneath, with just enough solder used to produce a nicely rounded joint. The excess leads are then cut off with sharp side cutters as close as possible to the joints, so that no sharp wire ends or 'points' are left.



SC EHT STICK (1000:1 HIGH VOLTAGE DIVIDER FOR DMMS)

Fig.1 (above): the circuit is simply a voltage divider giving a suitable output to measure on a digital multimeter.
Fig. 2 (right) shows the PC board component overlay. It's not difficult to build but it is quite tedious fitting and soldering 82 half-watt resistors. Note: do not substitute other resistors as their voltage rating may be insufficient.



This is quite important, because any sharp points on conductors carrying high voltage tend to concentrate the surrounding electric field and cause ionisation of the air – producing a 'corona' discharge.

The only other thing to watch when you're fitting the resistors is to fit the 820k? and 30k?resistors down at the output end of the board, as shown in the overlay diagram.

You might want to fit these first, to make sure they're in the correct positions. Then you can fit the remaining 80 resistors, happy in the knowledge that they are all of the same value.

With all of the fixed resistors installed, the only remaining step is to fit trimpot VR1 and your probe's PC board assembly will be complete. It can then be put aside while you prepare the probe's tube and end caps and assemble the whole thing.

Final assembly

Final assembly also involves calibration. This could be done now that the PC board is complete but it's better to wait until the unit is partly assembled (and therefore partly insulated) as it involves high voltages.

First cut your length of 43mm OD PVC-U DWV conduit to 250mm long. If necessary, square off each end with a flat file, using it to remove any burrs as well.

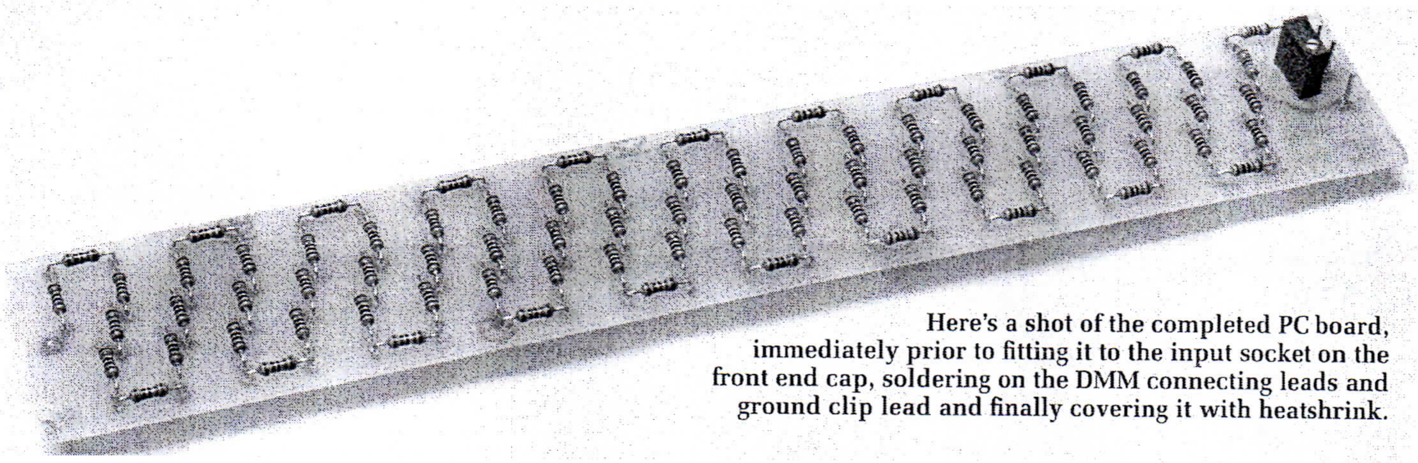
Parts List

1 PC board, code 04104101, 228 x 37mm
1 250mm length of 43mm OD/39mm ID PVC-U DWV conduit
2 43mm ID PVC pipe cap to suit conduit
1 230mm length of 30mm diameter heatshrink
1 4mm banana socket, red with matching double-adaptor banana plug
1 3.5-6mm cable gland
2 1.2m long 600V-rated test leads (one red, one black) with shrouded banana plugs
1 1m length of mains-rated flexible earth lead, with green insulation
1 32mm (medium) alligator clip, with black or green insulating shroud
4 1mm diameter PC board terminal pins
1 Nylon cable tie, 4mm wide
1 short (~50mm) length brass rod, around 2-3mm diameter (for tip) (not supplied)

Resistors

80 10MΩ (1.6kV rating)	1 820kΩ	1 30kΩ

1 50kΩ 25-turn vertical trimpot (VR1)



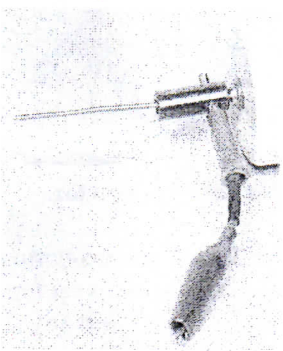
Here's a shot of the completed PC board, immediately prior to fitting it to the input socket on the front end cap, soldering on the DMM connecting leads and ground clip lead and finally covering it with heatshrink.

Next, drill the holes in the centre of each end cap to receive the 'hot input' banana socket and the output cable gland. These both need round holes of around 9mm diameter but the exact diameter will depend on the particular components you use – and the holes shouldn't be any larger than is necessary to receive them.

So it's probably best to drill a ~5mm hole in each cap first and then use a tapered reamer to enlarge it carefully until the socket or gland will just pass through. Then remove any burrs as before.

Mount the input banana socket securely in its end cap, using one of the two nuts supplied to fasten it in position. Next, fit the solder lug and the second nut, tightening this up so that the lug is securely attached to the back of the socket. Then bend the lug over against the side of the second nut. This will bring it into position where its end hole will be as near as possible to the input terminal pin on the end of the divider probe's PC board, when assembled. The bent lug will also help to hold the nut in position.

Now slide the PC board into the end cap so that the solder lug on the banana socket and the PC board input pin can mate. This is a little tricky but if you keep the solder lug and PC board parallel to each other, you should have success.



Once the pin does pass through the hole in the solder lug, you can solder the two together carefully to make the connection permanent.

Make sure that you apply enough solder to form a strong and nicely rounded joint – also take care not to burn the side of the PVC end cap with the barrel of the soldering iron. Your end cap and PC board assembly should now look very much like the photo below right.

Putting it together

Loosely fit the cable gland to the other end cap and pass the bare ends of the three exterior wires (ie, the two leads which go to the DMM and the ground lead) through the gland from outside to inside. Pull these three wires through as far as they will go so that the DMM plugs and ground clip lead are against the cable gland.

If necessary, cut the 30mm diameter heatshrink to length (~230mm, give or take) and either cut or drill a pot access hole. We placed a scrap of timber inside the heatshrink and drilled a 6mm hole, right in the centre and 10mm down from the end.

Pass the three external wires right through the heatshrink, from the pot access-hole end, all the way along the wires (you want to keep the heatshrink away from the heat of soldering in the next step).

Similarly, pass the three external wires through the PVC-U pipe and slide the pipe up the wire. Don't push the end cap onto the pipe, at least not yet!

Now solder the three external wires to their appropriate positions on the PC board, as shown on the overlay. Fit a small Nylon cable tie around the three wires to keep them together but not so close to the PC board that it causes undue strain on the wires.

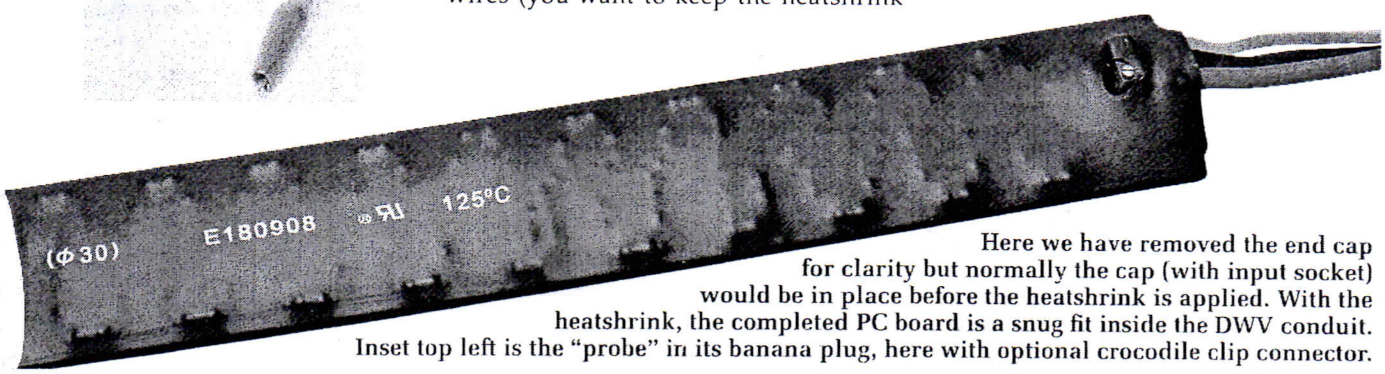
The final step before calibration is to slide the heatshrink back down the three wires and all the way onto PC board, locating the pot access hole over the pot and then shrinking the heatshrink onto the PC board. A hot air gun is best but a hair drier on a high heat setting will work – it just takes a bit longer.

Calibration

Before completing the Probe, now is the time to adjust trimpot VR1 for a division ratio of exactly 1000:1 – in other words, calibration.

Ideally, you'll need a convenient source of stable medium-high voltage to do this (say 750-950V DC).

If you don't have such a source your best plan would be to simply set VR1 to around the middle of its range, using one of your DMM's resistance ranges to do this. Simply connect the DMM leads



Here we have removed the end cap for clarity but normally the cap (with input socket) would be in place before the heatshrink is applied. With the heatshrink, the completed PC board is a snug fit inside the DWV conduit. Inset top left is the "probe" in its banana plug, here with optional crocodile clip connector.

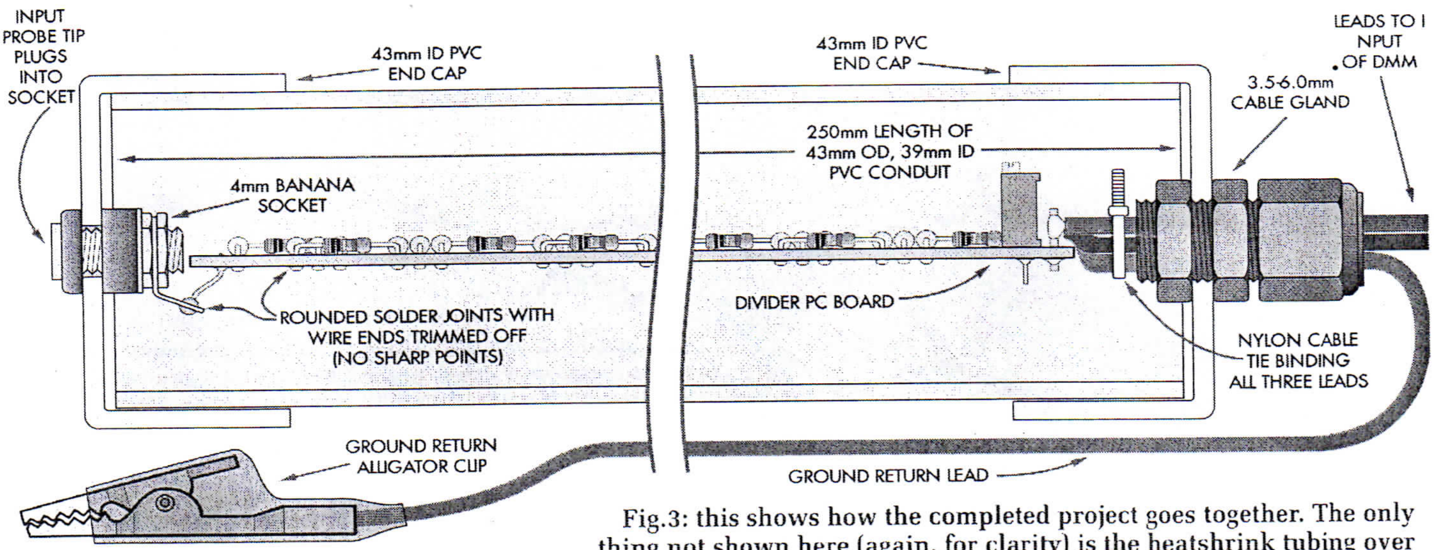


Fig.3: this shows how the completed project goes together. The only thing not shown here (again, for clarity) is the heatshrink tubing over the PC board. This provides extra electrical insulation.

directly across VR1, and turn its adjustment screw with a small screwdriver until you get a reading of close to 25k?. This should give your Probe a division ratio within about 3% of the correct figure.

If you do have a source of stable high voltage, calibrating the Probe is quite simple. You just need to be fairly careful, because high voltage can "bite"!

Having a banana socket with removable tip also makes it easier (and safer) to connect your high voltage to, as exposed metal is kept to a minimum.

You'll also need to connect the board's ground return lead pin (at the output end of the board) to the negative side of your high voltage source securely, before you start.

Measure and note down the voltage using your DMM directly, set to its top DC voltage range. Remove the DMM leads from the DC voltage source and connect instead the output leads from the Probe board.

Then connect the Probe's input socket to the positive side of the high voltage source, and you should be able to read the Probe's output voltage on the DMM. It should be very close to 1/1000th of the first reading and all you now have to do is adjust VR1 with a small screwdriver until it becomes as close as possible.

To end this procedure disconnect the probe tip from the positive side of the high voltage source, then disconnect the temporary ground return lead from the negative side and finally disconnect it from the ground lead pin in the rear of the Probe PC board. Your EHT Stick should now be calibrated, and ready for final assembly.

Give everything the once-over again, just in case – remember that once the end caps go on, they're rather difficult to get off again!

In fact, it's a good idea to loosely place the end caps as you follow the next steps and then make some trial measurements, just to make sure everything is still working.

It's complete!

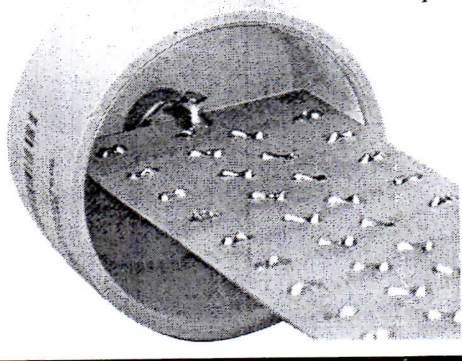
Slide the pipe back down the wires and over the heatshrink-covered PC board. It's a snug fit but it does go in.

Place the front end cap onto the pipe now and slide the other end cap right back down the wires to the cable tie.

Leaving a small amount of slack inside the pipe, tighten the cable gland and then push the rear end cap loosely onto the pipe.

If your test measurements look satisfactory, push both end caps hard onto the pipe. No screws (or glue) are necessary to hold the caps in place – they won't come off by themselves!

Looking into the end cap showing how the input socket solder lug connects to the PC board pin



Important Note:

Please note that we can offer a warranty only on the components supplied with this kit. Because we are unable to guarantee your labour, there is no warranty on either partially or fully built kits. We are able to offer a repair service, but once construction has commenced, this service is chargeable.

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