VERSATILE CONTINUITY TESTER

Checking continuity seems the most trivial of tasks until you try it. Sure as anything when you look at your multimeter a probe will slip. This project is designed for mere mortals and will even check circuits that include a light globe.

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A WHILE AGO I was faced with the job of checking out a large motherboard. I used the old trusty DVM and found that it's an incredibly tedious job as you have to wait for three or four readings before the display stabilizes. If there are hundreds of continuity checks to be made, then it literally adds hours to the job. Normal buzzer type continuity checkers often inject large currents and voltages into the board under test and can damage semiconductors. The actual resistance that most old style buzzers detect is also not too well defined.

It seemed to me that it'd be nice to have a little box with probe leads attached that beeped when the resistance between the leads was less than a set value. To complete the picture it'd be even nicer if the threshold resistance at which the beep occurred could be set to any desired value within limits. For example, if you were checking out the wiring of your car it would help if your continuity checker could tell the difference between a light bulb and a short circuit. With this in mind it became clear that the sort of sensitivity range needed was between 1 ohm and 20 ohms. Calibration didn't seem to be all that important and ±20% seemed to be a reasonable figure to work to.

While I can't speak for all readers I know that I personally have a genius for leaving battery powered equipment left on. I must get through about 10 batteries for my DVM in a year and they're usually flat when I want the DVM most (usually 11 pm on Sunday night when the job has to be delivered on Monday!). Clearly, the continuity checker should have some way of avoiding this aggravation.

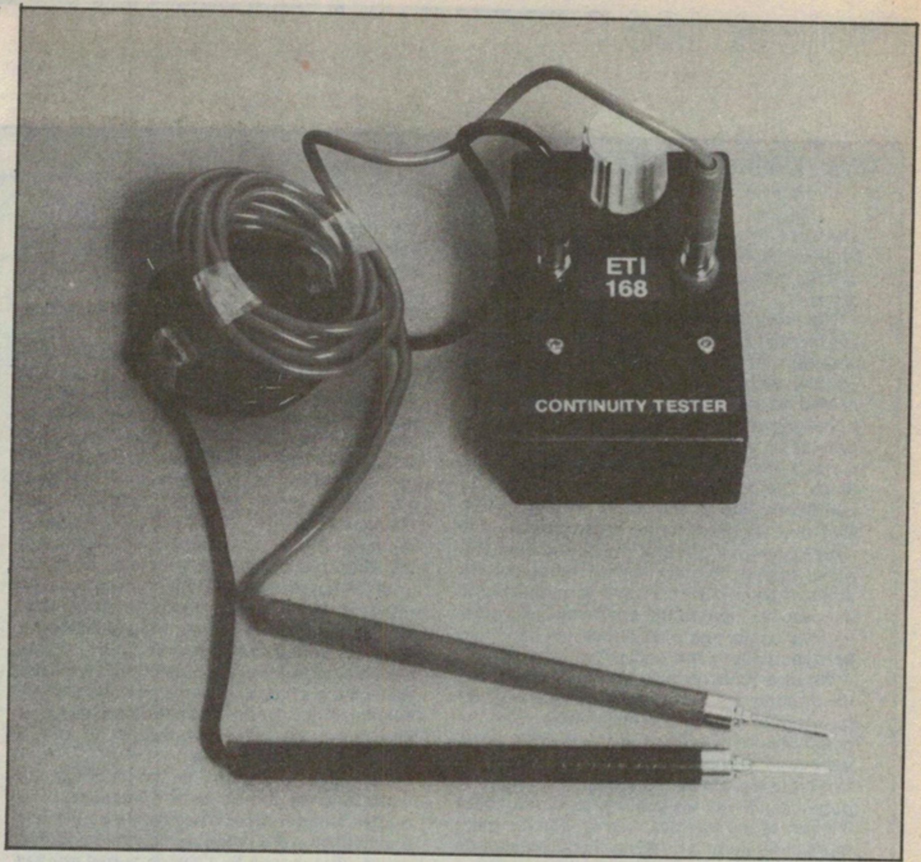
The neatest way to fix this problem is to make the device draw so little power that it *can* be left on and not go flat. A quick phone call to Union Carbide (they make Eveready batteries) told me that your basic AA cell has a capacity of about 0.7 amp hours and a shelf life of about five years before it flattens itself due to internal leakage. Now five years is equal to 43,800 hours so the internal leakage of the battery is equivalent to about 15 microamps. If the current drawn by the continuity checker was made less than this, then the life of the batteries alone would determine how often they needed to be replaced and the checker could be left on all the time — great!

Since I wanted the checker to be as small as possible I settled on two AA cells as the power supply, which gave me a three volt rail or ±1.5 volts and ground. Smaller batteries would probably be OK but they'd be hard to mount. The AA cells battery holders can be bought at almost any hobbyist shop.

For the beeper I chose one of the Piezoelectric transducers that are available from most of the bits and pieces shops. The actual model was an HPE127 from the ubiquitous Richard, that's nice and cheap and is very thin and convenient to mount in a box. These transducers have to have some sort of signal generator to drive them and the obvious way to do this is to use a CMOS oscillator. If the oscillator is gated off but power is left on then it only draws the leakage current of the CMOS gates which is measured in nanoamps. This certainly meets the current requirements. The oscillator is only used when the continuity checker is being used so the output load doesn't contribute to battery life at all (nobody works *that* hard!).

The sensing of the resistance across the probes wasn't quite as simple. The normal way to measure resistance is to inject a current through the resistance then measure the voltage drop caused by the current. Now as the battery must be treated gently, and we don't want to risk damaging any semiconductors that may be in the circuit, the current used must be restricted to a few milliamps. This means that the voltage drop to be measured must be only a few millivolts. This isn't absurdly small but it certainly prohibits the use of any simple transistor circuits.

Integrated circuit operational amplifiers have input offset voltages of only a few millivolts and would work very nicely as voltage comparators, but the normal TL082 type of op-amp draws about 5 mA — far too much for the battery life requirements. However, National Semiconductor makes an op-amp labelled the LM4250 the current consumption of which can be set by an external bias resistor. The total power used can be reduced to almost nothing but, as with all things, something has to be lost as the current drain is reduced. In this case it's the op-amp bandwidth. This means that when the op-amp is used as a comparator, the lower the power consumption, the



slower the output will switch. Experiment showed that at ridiculously low power consumption it still worked just fine. One nice property about the variable power drain op-amp is that as the total current used is reduced then the input bias current need is reduced as well. The whole device can be operated at higher impedances without generating offset voltages — better and better.

The bias current for the LM4250 is set by a resistor that bleeds current from the positive rail through what is effectively a diode. This sets up internal currents and determines the total device power. If an 11 megohm resistor is connected from the bias input to ground with ±1.5 volt rails then the total op-amp current drawn is *less than 1 microamp*. This seemed to be just what was needed. The input offset voltage wasn't specified for currents this low so I decided to use an offset adjust to null out any stray millivolts. The circuit given in the data sheet didn't work as the integrated circuit was operating at such low power. However, a simple resistor potentiometer arrangement from ground to the offset adjust inputs did the deed just fine.

I chose to ignore the fact that the offset null circuit drew half as much power as the IC, as it was still minute! This gave me a zero offset comparator to sense the voltage produced by the test current in the probe resistance and a very low power oscillator to drive the piezo-transducer. Even the price of the micropower op-amp isn't too bad: it can be bought for about $3.

Construction

I decided to fit the continuity checker into the smallest of the boxes that Dick Smith sells, the UB5. It isn't all that much bigger than the two AA batteries used to power it so it made for a rather cramped design, but everything fitted OK. The board layout shows that all the available area in the box is used — most of it by the batteries. All the components are mounted on the board with the exception of the threshold adjust pot. The batteries are mounted in a battery holder that's also available from our aviating adventurer's establishment but as the tester only uses two cells I had to modify a four cell holder.

I started by running a fine hacksaw through the battery holder to cut off one side. I didn't cut through the wire springs that make contact with the cells but only the plastic. The part to be kept is the side that has the clips to bring out the power, and the cut is made along the flat divider between the cells on the side away from the clips. After cutting the plastic I carefully drilled out the rivet on the cut-off piece to completely separate the two sections. The spring that's separated when the rivet is drilled out must be kept as it's needed later. Once the battery holder is completely separated, file off all the dags and rough edges so the bottom of the cut-down holder should be straightened out to form a long head to be soldered into the board later.

The printed circuit isn't all that complicated and shouldn't give you any trouble to make. Some of the tracks had to be made with 0.020″ tape which can be a bit fiddly to do as it is run between IC pins. When taping between pins it's very important to watch the spacing of the tape as there isn't a great deal spare. Of course the easiest way is to buy a ready-made board or buy a copy of the artwork from ETI. However you make it, the board dimensions mustn't be any bigger than those shown as it fills all the available space in the box.

To mount the battery holder on the board I made use of ye olde trusty Araldite. The two holes on the earth track must be drilled out to accept the straightened out springs that protrude through the bottom of the battery holder. The spring that was freed when the rivet was drilled out of the cut-off piece of battery holder had the rivet end straightened out and was reinserted into the holder in its original position. This left two leads protruding through the bottom of the holder. Mix up a small amount of glue and bond the battery holder onto the board with the straightened springs through the board and soldered onto the earth track. You have to be careful in positioning it so as not to cover any of the holes for components or accidentally fill them with glue. After the glue has set you can assemble the rest of the components on the board. Take care that both ICs are in the right way (CMOS ICs are instantly destroyed if they're put in reversed).

As there is *very* little spare space in the box it's necessary to cut away the top of the two battery terminals to allow enough free space for the potentiometer (see photo). A ▶

HOW IT WORKS — ETI-168

The continuity checker can be divided into three sections: the probe resistance sensing circuit; the oscillator; and the transducer driver.

The probe resistance sensing is done with the LM4250C operational amplifier. R1, a 390 ohm resistor, holds the hot probe input at the positive supply voltage. The hot probe is connected to the negative input of the operational amplifier through R2. R2 and C1 simply provide ac decoupling for the probe input so it won't pick up any rf signals or high mains fields. The operational amplifier dc operating conditions and power drain are set by R4, RV1 and R5. They draw approximately 100 nanoamps from pin 8 of the operational amplifier and set its quiescent operating current at about 600 nA. RV1's wiper is connected to the positive input of the operational amplifier and the dc voltage it produces can be varied between about 5 mV and 150 mV.

When a resistance is connected between the probes the external resistance and R1 form a potential divider that divides down the positive supply voltage. If the divided down voltage is less than the voltage on the positive input pin 3 then the operational amplifier output pin 6 will go positive to within about 0.6 volt of the positive supply. For the minimum potentiometer setting this corresponds to about 1 ohm and for the maximum about 70 ohms, which are the minimum and maximum resistance limits of the checker.

When pin 6 of the operational amplifier is negative (probes open circuit or greater than the threshold resistance) pin 1 of gate a is held low which holds the gate output high. When the gate input goes high it allows gates a and b to act as a free running multivibrator at about 7 kHz. This works in the following way:

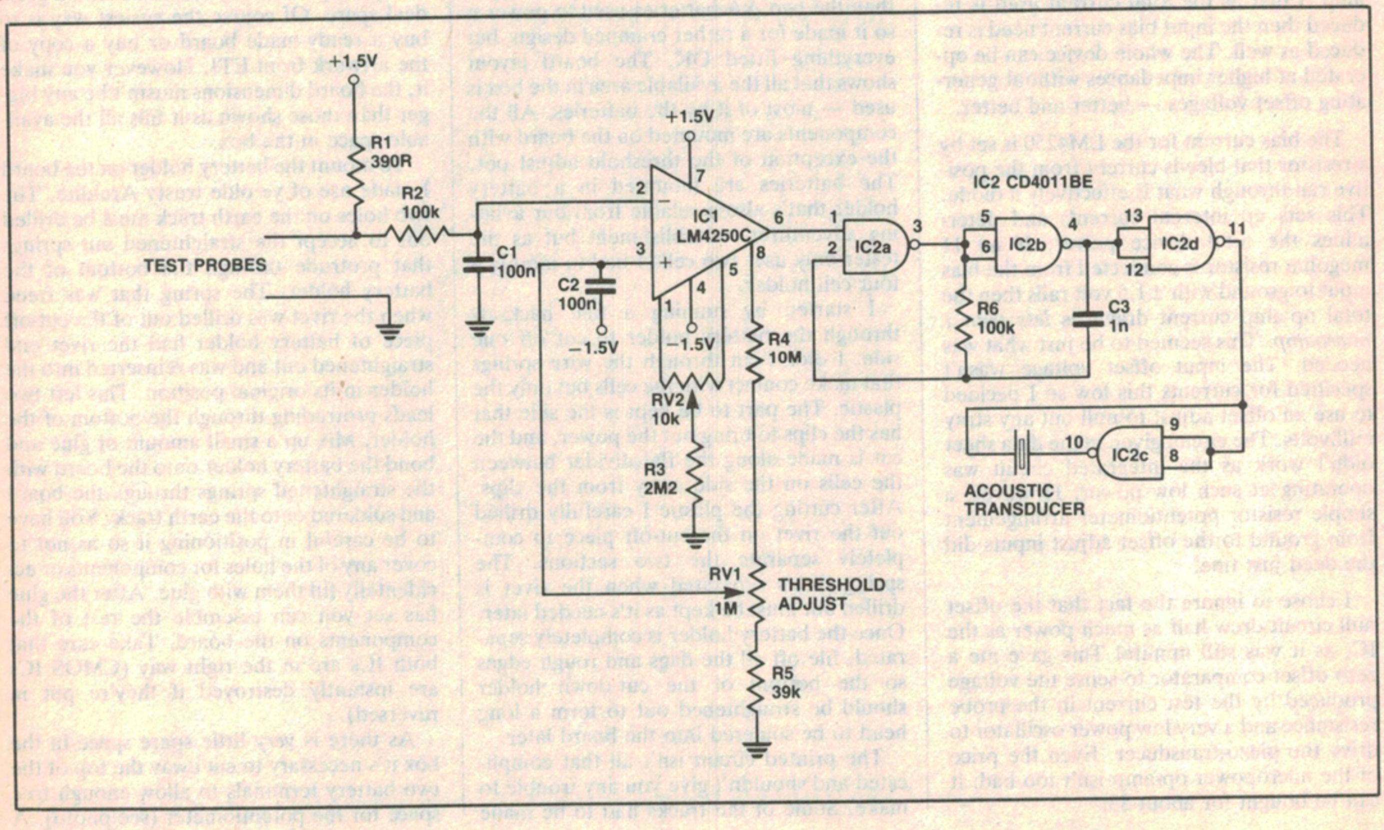
Imagine that the output of gate b has just gone positive. C3 couples directly to pin 2 of gate a and forces it high too. This means that gate a's output goes low. R6 then starts to discharge C3 and starts to pull pin 2 negative. After a few hundred microseconds pin 2 of gate a reaches the gate threshold and gate a's output goes positive. Gate b then changes state and its output goes negative reinforcing the transition of gate a through C3. Gate b's output then remains negative until R6 can recharge C3 when the process is repeated in reverse to force pin 6 positive again. This forms a free running oscillator to drive the transducer. However if pin 1 of gate a is held negative by the operational amplifier then gate a's output remains positive and oscillation stops. Under this condition the gates only draw the quiescent current of CMOS gates which is negligible.

The other two gates in the package are used to drive the acoustic transducer in a bridge configuration. When gate c's output is positive, gate d's output is negative and vice versa. This means that the ac signal applied to the transducer is effectively twice the supply rails and makes sure that the sound is clearly audible.

little discrete work with a hacksaw blade and sidecutters is needed to make sure it'll fit. When only the bottom quarter of the terminals is left solder two insulated pieces of wire onto the remnants of the terminals *but do it quickly* as the plastic of the battery holder will soften with the heat. Cut and strip the other ends of the two pieces of wire to a neat suitable length and solder them onto the pads on the board. This connects up the power supply and avoids any trouble with intermittent battery connections during the life of the checker.

Cut three pieces of wire about 70 mm long and strip the ends about 5 mm. It makes life a lot easier if you use different colours but it isn't essential. Solder them into position on the three terminals of the potentiometer and then solder the other ends into the board in the right place. Next cut two more pieces about the same length and connect them to the board for the probe inputs. Finally, connect the transducer to its two pads and the checker is ready to test before it goes into the box. Put two AA cells into the holder and try touching the probe leads together. You should hear a nice clear "peeeeep". If all is well, you're ready to adjust the op-amp offset.

Twist the probe leads together to form a semi-permanent connection (don't get carried away! — you've got to get them apart again) and temporarily solder a piece of wire between pins 2 and 3 of the op-amp.

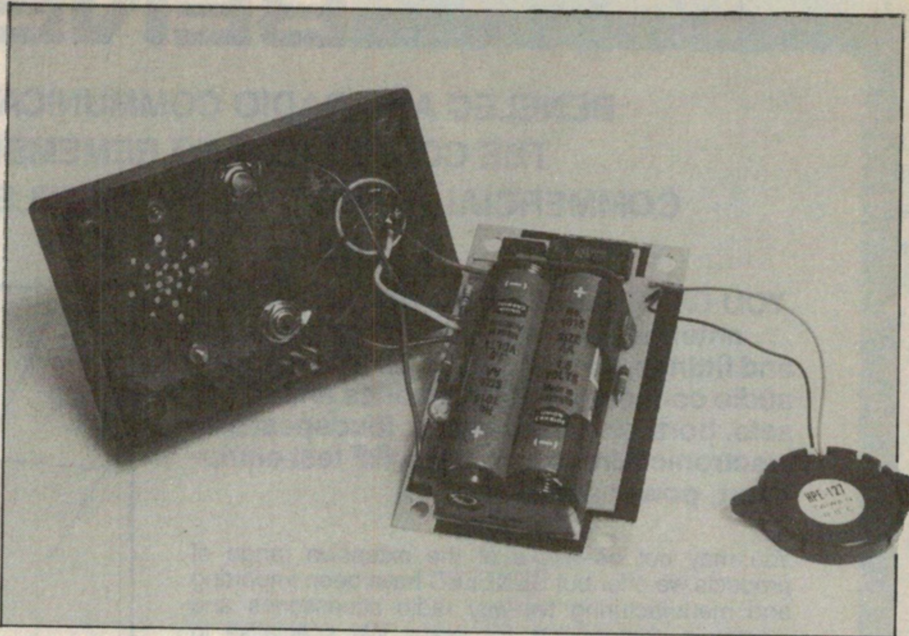


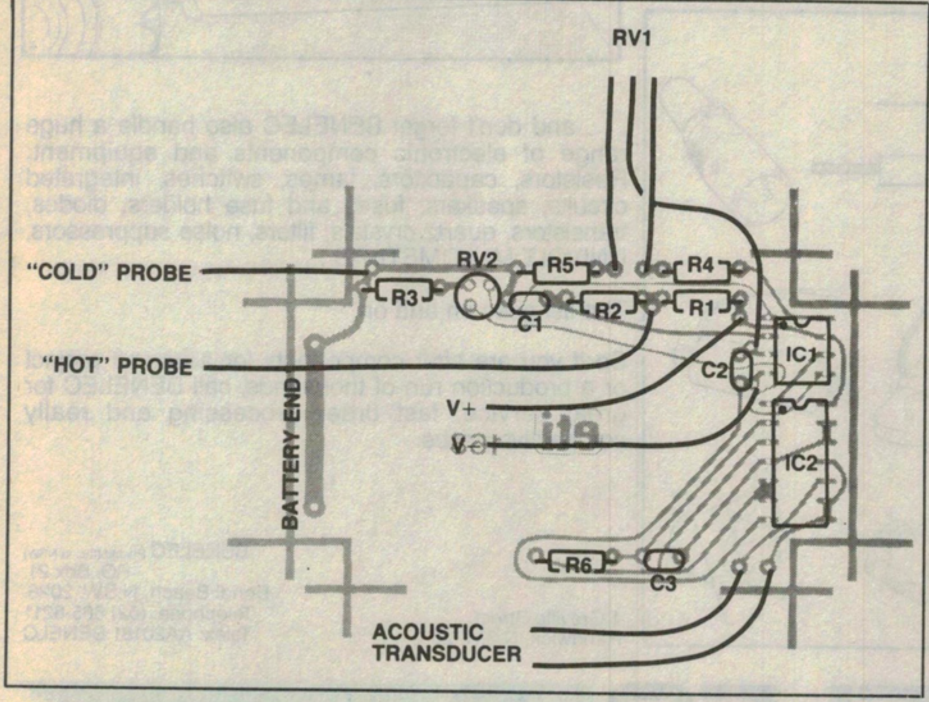
Then adjust RV2 until the peep just starts. Back the pot off a whisker and set it so that the tone starts and stops as you move your hands near the wires. The object is to set the pot so the op-amp is floating in the middle of its active region but there is so much gain that the minutest changes in circuit conditions will cause it to go one way or the other. When this is right remove the piece of wire from between pins 2 and 3. Finally, work over the bottom of the board cutting off all the component leads *as short as you can.* None of them should protrude more than a millimetre. It's a good idea to take the batteries out while you do this. Your soldering may need a little touching up here and there too.

The next step is to prepare the box. First place the transducer where you want it over the plastic box and mark off the two mounting holes, then drill them out to 2.5 mm. Next mark off the exact centre between the mounting holes and drill out a tasteful and artistic pattern of holes to let the peeeep out of the box. Feel free to let your mind run riot with regard to the pattern — the sound isn't fussy! Next insert two 2.5 mm x 10 mm pan head screws into the holes so the heads are on the outside and tighten two nuts onto each of the screws. This should nicely space the transducer away from the lid of the box when it's slipped over the free ends of the screws. Try it for size *but be careful of the leads from the transducer.* They're thin and easy to break off! The transducer isn't to be fixed in place yet.

Next mark off where you want the probe leads to come out. I used sockets that are specially made for this job, which I bought from Jaycar. Pull the sockets apart and use the plastic bushings to mark off the holes. The sockets *must* be as far over to the sides of the box as possible or they'll foul the batteries. To position them, hold the plastic bushings on the inside of the box where you want them, but hard up against the side of the box, and mark off the centre with a scribe or pencil. Then drill holes on the centre of the marks with the right size drill to clear the centre part of the bushings. Deburr the holes (be gentle here as the plastic's soft and if you're not careful the deburring tool will cut right through the box!). Assemble and screw the sockets into position with the solder tags between the two nuts, pointing away from the centre of the box.

Now carefully mark off where the potentiometer is to go in the box. Once again the body of the potentiometer must go hard up against the side (end) of the box so it doesn't foul the batteries. Drill out the hole to accept the potentiometer and check to make sure you've measured it right. If it's a little out a small amount of adjustment may be necessary with a rat tail file. Finally screw in the potentiometer and transducer and solder the probe leads (untwisted — see, I told you not to do it too tightly) onto the sockets. Put the batteries back in and test the unit again to make sure nothing was damaged during the lead cropping.





PARTS LIST — ETI-168

Resistors .... all ¼ watt, 5% unless noted
- R1 .... 390R
- R2,6 .... 100k
- R3 .... 2M2
- R4 .... 10M ±10%
- R5 .... 39k
- RV1 .... 1M **16 mm diameter** linear law pot
- RV2 .... 10k trimpot **6.3 mm diameter**

Capacitors .... all ±10% 63 volt
- C1, 2 .... 100 nF met poly
- C3 .... 1nF met poly

Semiconductors
- IC1 .... LM4250C
- IC2 .... CD4011BE

Transducer
HPE127 piezo resonator (Dick Smith cat #L7022)

Miscellaneous
ETI-168 pc board; 28 mm 54 mm x 83 mm box; battery holder; 2 x AA batteries; 2 probe leads; 2 x 4 mm panel mount sockets; 2 x 25 mm x 10 mm pan head screws and nuts; hookup wire; insulating tape; double sided sticky tape; glue.

Price estimate: $33.35

Finally, mount the board onto the metal bottom of the box in the following way. Cover one side of the lid completely with insulating tape so the tape just overlaps. The idea is to have a neat layer of tape over the whole surface. Cut away the tape with a razor blade so the holes are free. Then stick the board onto the lid with foam double-sided sticky tape. I used "Permastik Double Mounts" bought from BBC Hardware — it's pretty handy stuff to have around, in fact you probably already have some. Only cover the part of the board that's free of track — it's deliberately laid out that way. When you stick the board onto the lid make absolutely sure it's positioned so the battery holder only just misses the end of the box. This is so much easier than drilling screws holes and such. Last but not least, screw the works into the box and check once again that it works.

To pretty things up you can calibrate the knob you've attached to the pot by holding different value resistors between the probes and checking where the peep starts by rotating the knob. Mark off each value on the lid and the job's completed. This project's already saved me hours (and *many* dollars) in checking out the motherboard I already mentioned. I'm sure it'll help you too. ●