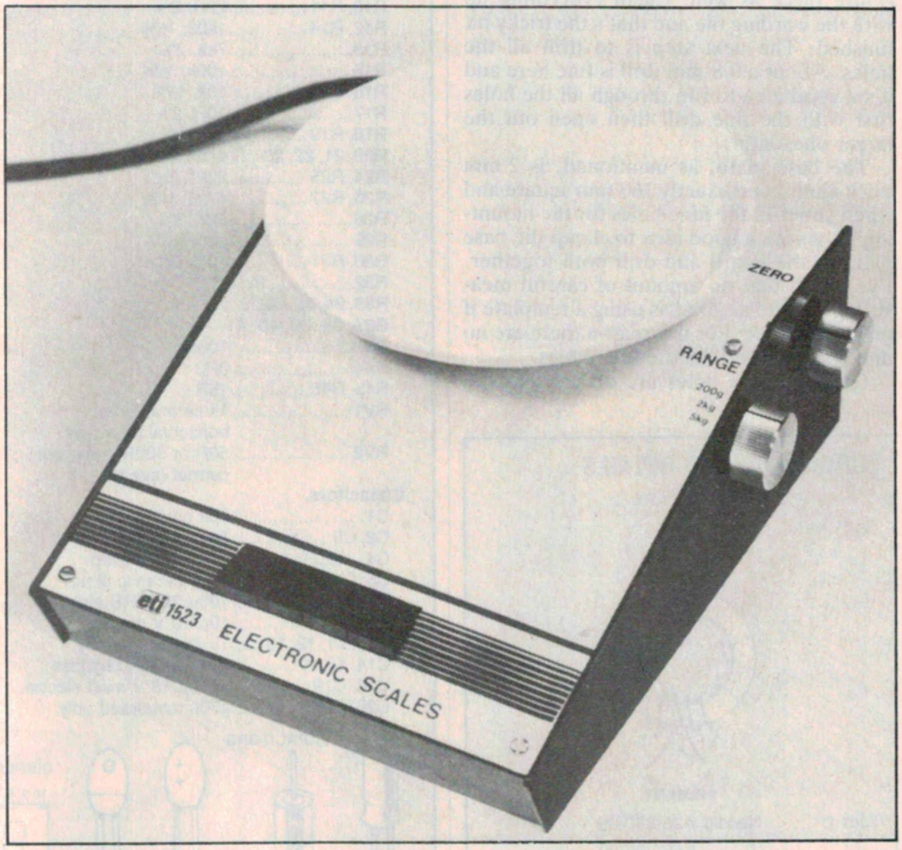
Digital readout electronic scales

Part 2

Ian Thomas



Now we get down to the 'nitty gritty' of constructing the instrument. No fancy tools are needed, but a fret saw or small jig saw makes cutting the pc board to shape easy.

THE FIRST PROBLEM with this project is getting the printed circuit board made. With all due respect to readers' undoubted skills in photo-lithography, the strain gauges really are just about out of reach of 'kitchen sink' technology. When I made the first simple one-beam test board I had no end of trouble with

(a) taping up 20 thou tracks at 15 thou spacing to generate the artwork

(b) making sure the photoresist had no pinholes and

(c) trying to etch the board evenly on both sides.

As it was I managed to scratch the resist which cut about four tracks in the meander line pattern. I can say from experience it's a sod of a job trying to bridge the gaps with solder. Just the taping is a tedious enough job.

If you want to make your own board *I strongly recommend* that you do the artwork at twice full size and have it reduced. This way you can use '40-thou' tape and interleave it with '30-thou' tape for the spaces. When the complete strain gauge is taped, the 30-thou tape is removed and gives a very even pattern. The ends are then joined to give the meander line. This was exactly how I made the prototype artwork.

Since I didn't fancy taping separate artworks for both sides I used the same strain gauge artwork for both sides and overlayed it with the pattern for the electronics during photography. Dick Roodenberg of Gladesville (Sydney) was very helpful here and is *most* reasonably priced. You could probably photograph the artwork at the back of this article OK too, but really, it's not the sort of thing to be taped up one-to-one and have come out successfully. (Transparencies of the artwork are available — see 'Shoparound' this issue.)

Much the same argument applies to the board etching. Life really is too short to spend hours fiddling with chemicals to have a damn great scratch across the strain gauge grid and a ruined board. It's also absolutely essential to use '½-ounce' copper to increase the strain gauge resistance.

Most of the ready resist-coated boards use '1-ounce' material which is not good. Probably the easiest way is to buy a ready-made board and cut it out yourself or photograph the artwork and have a board made.

Needless to say it absolutely, totally, utterly *essential* that you use glass epoxy board. If you tried to use paper phenolic the cantilevers would probably break off the first time you sneezed at them. They just would not be strong or springy enough (don't forget the base material of the board is the "reference spring" of the whole scale).

Once you've got a board, by whatever means, the first thing is BE CAREFUL OF THE STRAIN GAUGE PATTERNS. You've got to be continually aware that *they are easy to ruin.* If you've just got a board with the outside guillotined off square the first thing is to cut out the load beams and, in the centre, the piece of board that is used to mount the weighing pan. I used a piece of hacksaw blade with a handle made from masking tape for this job. To separate out the three beams there are three triangles with 30°, 30° and 120° vertices to be cut out, each of which requires three cuts.

To start each cut, drill five 3 mm diameter holes using the pads provided. The holes may not run together completely so, using fine long nosed pliers *gently and carefully* break out the material between them. Then, holding the board between two pieces of softwood in a vice, cut along the copper tracks that delineate the edge of the board. You should leave most of the track in place with the hacksaw. After you've made the three cuts for one triangle and the bulk of the excess board has been removed, then dress the cut edges back with a fine warding file. You've got to cut right into the corners to ensure that all the strain gauge is flexed; for this I bought a fine needle file shaped in a shallow wedge.

During all this, never hold the board directly in the jaws of the vice or you will ▶

cut through the strain gauges. Repeat the process for the other two triangles and when you're dressing them off be sure to dress back the centre bit as well. When this is finished you should have removed all of the copper track that marks the edge of the board *but no more.*

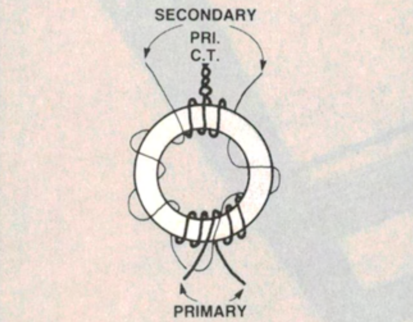
The last step is to cut along the ends of the beams to free them up and also free the centre piece as well. Clean everything up with the warding file and that's the tricky bit finished. The next step is to drill all the holes. About a 0.8 mm drill is fine here and it's a good idea to run through all the holes first with the fine drill then open out the larger ones later.

The base plate, as mentioned, is 2 mm thick aluminium exactly 160 mm square and when you drill the nine holes for the mounting pillars it's a good idea to clamp the base plate to the board and drill both together. I've found that no amount of careful measuring is quite as good as using a template if one is available. For this reason there are no dimensions given for the nine holes.

Once the fine holes are drilled you can open out the nine mounting holes with a 9/64″ drill and while you're there, drill the holes in the mounting plate as well. The last step is to cut out the notches for the box mounting pillars if you're using the same box I did (Jaycar Cat. Nos. HB-6240/1/2).

Unless you're fortunate enough to have a split rail power supply, the first thing you'll have to build is the power supply board for the scales, so you've got something to work with. This is pretty straightforward though. Just drill all the holes to about 1.6 mm (1/16″), except for the mounting holes which are, once again, 3.6 mm (9/64″).

TOROID WINDING DETAILS



Toroid:	Neosid #28-680-36 or #28-080-36
Primary:	4 m of 0.33-0.35 mm enamelled copper wire, closewind on 120 turns, centre-tapped.
Secondary:	10 turns of 0.5-0.64 mm enamelled copper wire, wound over primary.

Take the 4 m of primary wire and double it in half. Twist the fold for a good 30-40 mm to make the centre tap. Commence winding from the centre tap, laying on 60 turns winding in one direction. Then wind on the other half — winding *in the same direction.* Lay the turns close to one another on the inside of the core and the windings should fit neatly. Use sticky tape to hold down the two ends when you're finished.

Tackle the secondary next. Start the winding adjacent to the primary centre tap. Wind on 10 turns *in the same direction* as the primary. Distribute the turns evenly around the circumference of the toroid.

Note that, in the drawing above, the primary winding has been shown in a thicker line than the secondary for reasons of clarity. The secondary winding actually uses a heavier gauge wire.

PARTS LIST — ETI-1523

Resistors .... all ½W, 5% unless noted

R1	33k, 2%
R2	1M
R3, R4	390R
R5, R6	2k2, 2%
R7	47k, 2%
R8	22k1, ½%
R9	22k6, ½%
R10, R11	22R, 2%
R12, R14	1k00, ½%
R13	7k5, 2%
R15	100k, ½%
R16	10k, ½%
R17	10R, 2%
R18, R19	47k, 2%
R20, 21, 22, 23	475k, ½%
R24, R25	22k1, ½%
R26, R27	47k5, ½%
R28	8k2, 2%
R29	200R, 2%
R30, R31	100k, 2%
R32	39R
R33, 34, 35, 36	1k
R37, 38, 39, 40, 41, 42, 43	100R
R44	3R3
R45, R46	15R
RV1	1k cermet trimpot, horizontal pc mount.
RV2	50R or 500R linear pot., cermet (see text)

Capacitors

C1	6p8 ceramic plate
C2, C3	1n metallised film
C4	10µ/16 V electro.
C5, C6	470p ceramic plate
C7, C16	100µ/25 V RB electro.
C8, C9	10µ/10 V electro.
C10, 11, 12, 13	1µ metallised poly.
C14, 15, 17	100n ceramic bypass
C18, C19	2200µ/16 V axial electro.
C20, C21	470n metallised poly.
C22	220p metallised poly.
C23, C26	39µ/10 V tant.
C24, C27	100n ceramic bypass
C25	330µ/6 V tant.

Semiconductors

Q1, 2, 3, 4, 5, 6	BC337
IC1	4001B
IC2	4013B
IC3, 5, 6	CA3240E TL082 etc.
IC4	4053B
IC7	MM74C935N, ADD3501
IC8	7805
DSP1-4	FND500, HDSP-5503 or equiv.

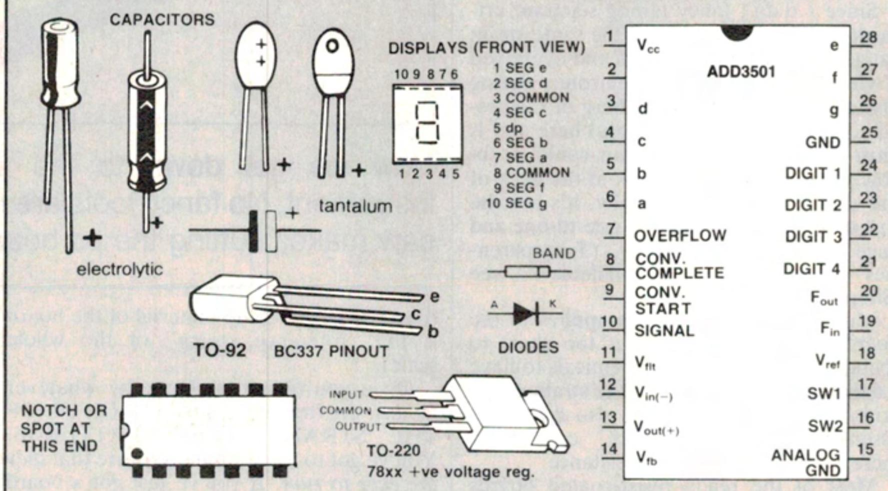
Miscellaneous

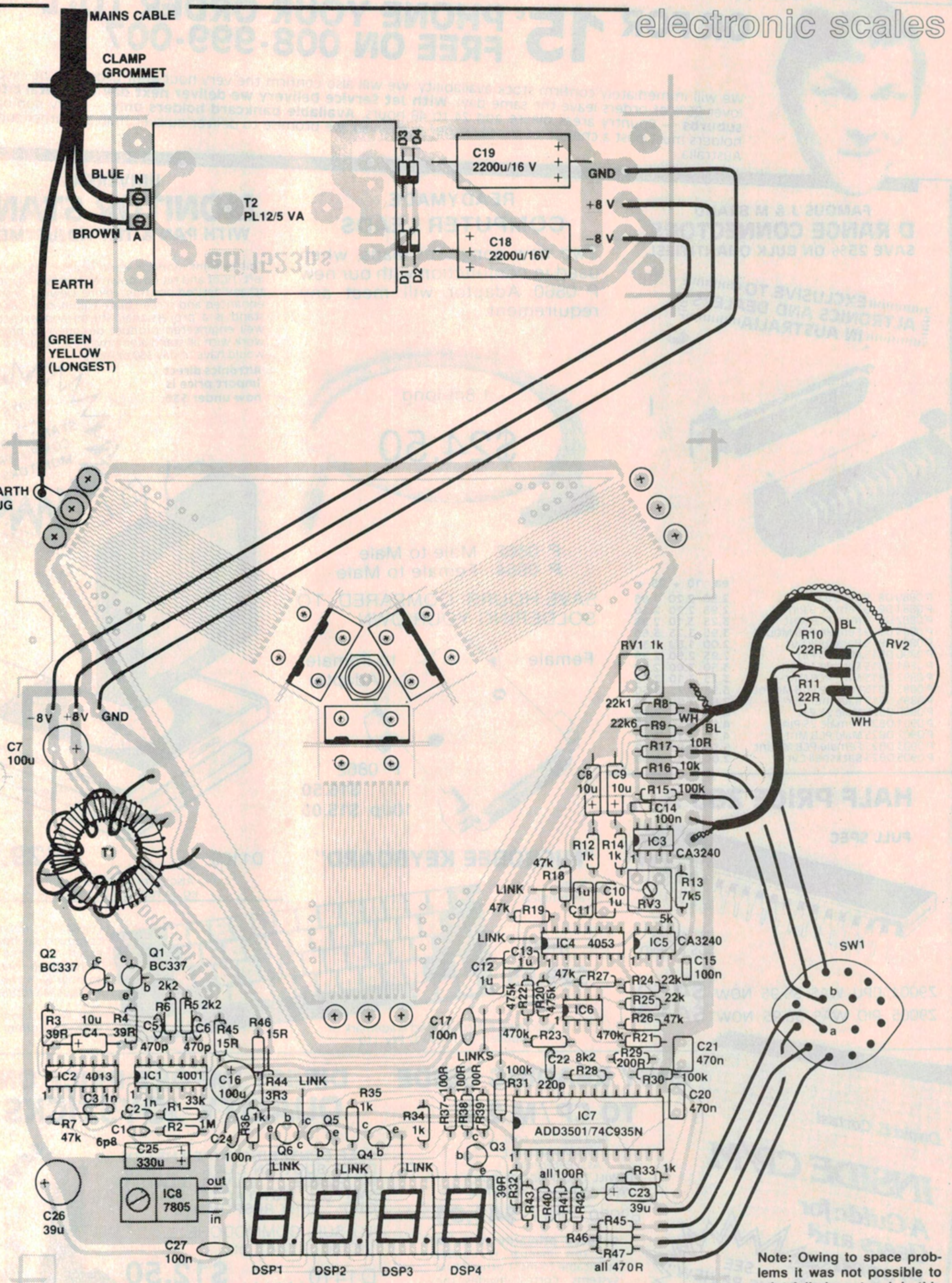
TR1	Neosid toroid core type 28-680-36 (nylon coated) or 28-080-36 (plain) wound with about 4 m of 0.33-0.35 mm enamelled copper wire, plus sec.
TR2	Ferguson PL12/5 VA pc mount transformer

ETI-1523 (double-sided) and '1523ps (power supply) pc boards; case — Bimbox model 6007 (Jaycar Cat. No. HB-6240); Scotchcal front panel; 6 mm or 8 mm dia. by 80 mm long bolt with two nuts; six 30 mm wide brass hinges; 150 mm dia. 'Decor' pot stand; 2-way pc mount terminal block; mains cable, cable clamp grommet and mains 3-pin plug; two knobs; hookup wire; heavy gauge aluminium plate, 160 mm square; nine brass standoffs, 25 mm long, tapped 4 BA; bolts to suit (18 off); 100 mm shielded cable and 100 mm of twin shielded cable; four 12 mm long tapped spacers with bolts to suit; etc.

NOTE: The main, double-sided, pc board requires **½-ounce** copper, not the usual one-ounce variety.

Price estimate: $105-$120





Note: Owing to space problems it was not possible to print full size artwork in this issue. (See Shoparound page 154)

LOW NOISE EARTHING

It can't be emphasised too much how important a proper approach is to earthing in sensitive instruments. Books could be written about it (and almost certainly have). If it is done correctly things work pretty painlessly, but if the rules are broken you've got Buckley's chance of sorting out all the problems. To give you an idea of how this design was approached, it's interesting to look at the layout of the board and explain why certain things were done.

One of the first rules is that if you have a known crud generator (here we have three beauties!) then the crud must be contained and not allowed to insinuate itself on supply lines. In this case the three are the CMOS oscillator and divider (not so bad), the inverter itself (a truly magnificent spike generator) and the digital part of the DVM chip (a true recipe for disaster!)

If you look at the layout you will see that positive and negative rails for the inverter feed nothing else but the inverter and are run straight to a large filter capacitor before going anywhere else. This means any high level ac currents are contained within the inverter area itself and aren't allowed to impose themselves on the supply rails for the rest of the circuitry. The inverter was deliberately run from the positive *and* negative rails so no spikes had a chance to get onto earth lines.

Much the same applies to the CMOS oscillator except that the supplies are decoupled by resistors and have their own massive bypass capacitor. To be quite candid I whoopsed here in the prototype and didn't bother with the resistors but the electrons have absolutely no respect and the spikes from the oscillator got everywhere. The decoupling resistors went in!

The third and worst noise generator is the DVM chip itself. National know their stuff so there are *two* earths on the chip to enable all the bad things to be kept in their place. You will see on the layout that the earth for the digital section of the DVM starts at the input to the whole board and runs down the side of the board away from any sensitive areas to the 5 V regulator and display. It is connected to *nothing* except the digital circuits and their associated filter capacitors. This earth can be thought of as the "dirty earth" and it is unthinkable to take it anywhere near any analogue circuitry (the term "unclean" is totally appropriate!).

Even with all this care it was still necessary to bypass the 5 V rail with a monster 330 µF tantalum capacitor plus a not-so-monster one on the 8 V input to contain the crud. National Semiconductor recommend a special 5 V regulator with very good high frequency attenuation to get away from the expansive tantalum capacitor but they aren't easy to get.

The "clean" earth starts from the common node of the two strain gauge bridge arms and runs straight around to the linear section of the circuit. It's kept as far away as possible from all the bad, dirty digital stuff and is connected to one point which is the reference earth for the high gain ac amplifier (that's where the two 10 µF capacitors are connected).

The secondary of the inverter is floating and connected only to the resistors which form the other half of the bridge via two tracks that run parallel, and as close as possible to the "clean" earth. Even here it is not assumed that the two ends of this earth are at the same potential; it is merely hoped that the potential difference is the same for the signal lines as for the earth line.

As the two gain blocks in the amplifier have nearly the same earth (they are only 5 mm apart) no contaminating signal should be able to get in here. The amplified ac signal is not considered to be referred to any earth but is only a voltage difference between two capacitors. It would probably work OK to not connect the "earth" ends of the capacitors to anything but I didn't try it. The voltage difference between the two capacitors is then connected to the differential amplifier discussed earlier whose reference earth is — lo and behold! — the reference earth for the DVM.

There are no absolute earths at all in the system but only local earths which tie things together where they matter. If you decide to build the scale and want to see that this isn't all theoretical, just try shorting the analogue and digital earths of the DVM together and watch the whole thing fall in a heap (it isn't destructive, just educational!).

Assemble all the bits being sure to get the diodes and capacitors in the right way. I think it's an investment in good health and long life to use a mains screw-type connector to get mains onto the board — they're readily available at Jaycar and other electronics suppliers — and could save a nasty accident with frayed bits of copper.

After you've completed assembly of the power supply board *tape-up the tracks that have mains on them* or cover with Araldite, Silastic, or the like. Then connect a three-core mains lead to the input connector and power it up to test. The Ferguson mains transformer gives out more than its rated voltage under no load but this is normal — I found I got about ±10 volts. Turn the mains off and pull out the plug as well; I have little faith in electricians putting the switch in the active lead!

The next step is to wind the toroidal transformer. The core is a Neosid type 28-680-36 (nylon coated) or 28-080-36 (plain) and either will do. You will need about four metres of 13 or 14 mil (0.33 to 0.35 mm, say 28 B&S) enameled copper wire for the primary winding. Try and get 'Solder-eze' or 'Leumex' enamel which can be stripped with a soldering iron to make things easy. Some stores that have high expenses like helicopter fuel sell wire that has to be stripped with emery paper and it's a damn nuisance. Fold the wire double and twist the fold tightly for about 20 mm or so to form the centre tap.

The actual winding should be done in a room where there are no dogs, cats, rabbits, guinea pigs or small children as you'll have wire all over the place and things just love to get tangled in it! Thread one end of the wire through the core until you reach the centre tap. then commence winding turns through the core and laying them *neatly* hard against each other. As there is only just enough space for the required 120 turns you must make absolutely sure that each turn is hard up against the next and that each is nice and tight. It's easiest to wind one half of the toroid completely first then wind the second half. Once the wire has been partly wound onto the core it gets easier to handle but always be careful not to allow the wire to kink. This is particularly prone to happen just as the last bit of a winding is being pulled onto the core and once kinks are in they are very hard to get out.

If by some terrible miscalculation you wind 60 turns on one side then find that you can only fit on 55 or so on the other side don't despair. A few turns more or less doesn't matter. The important thing is that there must be *exactly the same number of turns both sides of the centre tap*. Not even one turn difference is allowable.

As a matter of interest, the toroid I wound (or to give credit where credit's due — my wife) did have a one turn difference and it produces a very noticeable assymetry in the output waveform. As an aside, this is because each side of the winding is switched on for exactly the same time and if the number of turns is different the only way the core magnetising current can balance up is for the core to partially saturate on one side; which is exactly what happened.

After the primary winding is completed solder the twisted centre tap right up to the winding (if you do it before it makes it too easy to break the wire), then tin the two ends of the wire up to where they go onto the core.

Winding the secondary is rather more tricky but a lot easier. It is very important that the secondary be wound in the correct polarity. People hold toroids in all sorts of ways when winding them so it's hard to know just how the primary was wound, but the important thing is for the secondary to be wound in the same sense as the primary. That is, if you wound the primary with the wire through the toroid towards you, do exactly the same for the secondary. The transformer is tested before it can do any damage but it's nicer to get it right first time (up yours, Murphy!)

The secondary is only 10 turns of somewhat stouter wire than the primary, 20 to 25 mil (0.5 to 0.64 mm, say 22-24 B&S) wire is fine. At a pinch you could use the same size wire as the primary but it makes things awfully hard to tell apart. Start the winding a few millimetres away from the primary centre tap and wind away from it evenly distributing the 10 turns around the core so that the last one puts you a few mm on the other side of the centre tap. Tin both ends of the secondary and that's the end of the tedious stuff.

In order not to have any spectacular and expensive accidents it's best to assemble and test the board in sections. Before you start soldering on the board though, a word of warning. This is only ½-ounce copper on the board so it's a lot easier to damage than normal 1-ounce boards. Take it easy with the soldering iron.

Starting with the strain gauge drive circuit, ICs 1 & 2, assemble the complete circuit up to the two toroid drivers, Q1 and Q2. Also assemble the input filter capacitor C7 and don't forget the driver power supply filter resistors and capacitor. Then connect up the power supply board you've already built via three pieces of suitably-coloured wire about 200 mm long, taking care that you get the polarity correct. Then check that the polarity of the electrolytics and ICs are correct (both will tolerate reverse polarity for about five nanoseconds!).

Then plug in your carefully tested and *mains protected* power supply and turn it on. Quickly test that the supply rails are both up OK and that nothing has burst into flames. Then, if you have a CRO, check that there is a square wave at about 5 kHz on the two input pins, 12 and 13 of IC2 (the CD4013). If you don't, then check that the voltage on both pins is 0 ± about 1 volt. If so, then probably all is well. You should get the same answer on pins 10 and 11 of IC1, the transistor drive gates.

Now comes the interesting bit, namely, connecting up the drive transformer. At this stage it is prudent to leave the leads long until you are sure that all is well. First, insert a piece of wire, about 30 mm long, and solder it to join the earth point which is common to the two strain gauges. Leave most of it sticking out the top of the board as a convenient earth test point. This point is about 30 mm South-West of the power input if the centre of where the display goes is due South and right on the inside edge of the board.

Next, using your trusty ohmmeter, check that you don't have trouble with the strain gauges. They should measure between 10 and 12 ohms for each side, an open circuit means you've got trouble. If by some horrible mischance you do have an open circuit then you'll have to find it by visual inspection (a magnifying glass will almost certainly be necessary). Try to repair the damage with a piece of fine wire and solder. On the first test board, I did have an open (read several) and I found it almost impossible to bridge the gap with solder. The gaps that I bridged went open circuit under load (both tensile and current). A bit of wire is safer.

If all is well, connect the centre tap of the transformer to the point nearest to the earth point and the two ends of the primary to the pads connected to the transistor collectors (solder on the wiring side — the top don't go nowhere!).

Then power up the board again and listen carefully *(really!)*. You should hear a faint but distinct whistle from the toroid due to magnetostriction as it is cycled. If not, there is something wrong with the transformer or drive transistors. If all is well proceed to make sure that the polarity of the drive to the strain gauge is correct.

IAN THOMAS — a short biography

He was raised in Sydney's outer western suburbs (Penrith) in the days before the urban sprawl had reached out that far and Penrith still retained some of the character of a country town. After completing high school at Penrith High he went on to Sydney University to study Electrical Engineering in 1963. After two successful years he took the obligatory year off and transferred to the Science faculty to obtain his B.Sc in 1965. He transferred back to Engineering in 1966 and in 1967 completed his Engineering degree.

In 1968 he was employed by AWA in their Research Laboratories at North Ryde as a design engineer. Since then he has been working at North Ryde in various areas and has made full use of the vast opportunities for obtaining experience in almost all fields of electronics. His experience includes 18 months designing integrated circuits (actually laying out the emitters, bases, etc which is invaluable in explaining some of the less desirable unpublished characteristics of commercially available ICs!).

Since his boyhood Ian has been fascinated by electronics and from the day he actually heard noises from his first crystal set (using a real piece of galena — he's a purist at heart) he was doomed to his current career. He's always felt that his work should be a source of fun as well, so his home has strange machines readily available to perform menial tasks.

His approach to design is the same as his approach to life — decide what is really needed then do it with no consideration to the currently accepted norms and fashions. This is well illustrated by his attitude to a tidy work area (it isn't). When he can't find something he tidies up until he finds it, then stops and carries on with what he was doing. This system forms a self regulating arrangement where the exact optimum time is spent maintaining order so things are neither so chaotic that all progress ceases nor so neat that flicking solder from the iron becomes a major crime.

After nine years at AWA Ian decided enough was enough so far as working was concerned, so he emptied out his bank account and took off overseas for a year wandering around the world. For the whole year he saw nothing whatever of electronics (there isn't a great demand for remote controlled toilet flushers 15 000 feet up in the Himalayas). After he returned he was drawn as if by some horrible fascination (and the dollars!) back to AWA North Ryde.

Since then, he has continued to learn new tricks and further develop old ones with AWA's backing. Last year he decided that all the toys he'd built for himself owed him something, so he approached Roger Harrison to ask about the financial rewards for becoming a part time writer and project developer. After a ritual period of sordid haggling (Roger, you didn't stand a chance — you were up against skills developed in Indian bazaars!) an agreement was reached and the first article was written which appeared in last month's ETI (Project 275, Bathroom Strip Heater Time-out).

Since his return to Australia, Ian has spent most of his time developing microprocessor-based audio test equipment for the broadcasting industry, which introduced him to the principles of active filter synthesis. This interest has remained as a hobby and he often spends a recreational evening playing with such wonders as Jacobian elliptic integrals on his calculator. More recently he has become involved with RF power amplifier design, and has already designed a 25 watt 440 MHz amplifier for ETI. He is now toying with a 100+ watt aether bender on the same band.

Ian's pet peeves include non-cooperative public servants, Australian electronic component suppliers who don't carry stocks and editors who delay payment for articles (hint!). His deep loves include a nice cold schooner with condensation running down the side, Mel Brooks movies and, most of all, his beautiful Thai wife.

If you have a CRO this is dead easy. The output of Q1 (the inside transistor) and the top input to the strain gauge should be in *antiphase*. Measure the polarity of the two secondary leads and label them "IN" and "ANTI" or somesuch. If you don't have a CRO, a high impedance voltmeter set to ac will do fine. Measure the voltage between the collector of Q1 and the two secondary outputs. One should measure about 15 V and the other about 18 V. The higher voltage lead is in antiphase and the lower is in phase. Solder the two secondary leads onto the board and make sure that there is no problem, then shorten up all the wires and mount the toroid tidily on the board. It's a good idea to stick it down with some silicone stickum (e.g: Silastic) so things can't move around and break wires.

Having survived this, you can assemble the ac amplifier area of the board. Insert ICs 3, 4, 5 and 6, making sure they are in the right way and then assemble all the components around them. The type of op-amps you use isn't that important just as long as they're FET-input devices. Make sure that the polarity of the two electrolytics is correct, not so much because reverse polarity will damage them (it's only about 5 mV) but because the cans may capacitively pick up noise if you reverse them.

Wire in the trimpot RV1 and then connect up the two 22 ohm resistors R10 and R11 between the centre tap of the pot and the two ends. Alternatively, if you can get one, use a 50 ohm cermet pot, whereupon R10 and R11 are unnecessary. Connect the pot to the board using about 100 mm of two-core screened lead (this prevents capacitive pickup to the input).

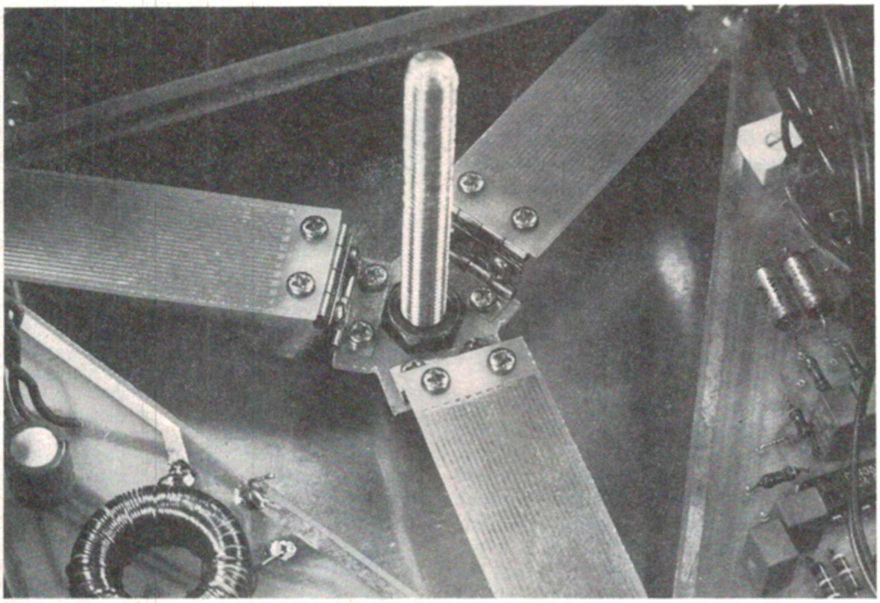
You're now ready to see if you got the polarity of the drive transformer secondary correct. Power up the board again and make sure that all is well then measure the dc volts on the output of IC6 pin 1. If it reads about +2 V all is well, but if it reads −2 V then you blew it and got it backwards!

Before you start reversing windings from the drive transformer it's a good idea to check that the ac amplifiers are working OK by monitoring pin 7 of IC6. You should be able to adjust this to zero by adjusting the trimpot RV1; RV2 will give fine adjustment. ▶

As a last check, hold the board firmly and bend one of the strain gauges away from the components. The output of pin 7 should go positive (fast and far!). If pin 1 is negative and pin 7 moves negative, then merely reverse the secondary winding of the drive transformer and all is well. If you can't zero the output try shorting the input to the ac amplifier, this should bring pin 7 of IC6 close to zero. If not, you've got problems with the amplifier or synchronous switching circuit. Find and fix is all I can offer.

If all is OK, then turn off the power and carry on to assemble the DVM part of the circuit. Start by assembling the 5 V regulator and all its associated capacitors. Turn it on and check that it works OK before assembling the rest of the DVM section (the DVM chip is relatively expensive and it would be so aggravating to cause one to discorporate). Then carry on and assemble the rest of the board including the displays.

Now turn it on and see the pretty numbers come up! It'll probably come up with '000' or '0FL' depending on whether the zero set is too low or too high. At this stage it isn't worth bothering with the decimal point or gain switching as there's plenty to do yet. Check that you can in fact adjust to zero OK, just to be sure then you can start on the mechanical stuff.



View of load assembly. Showing how the pc board centre piece and the cantilevers are coupled via the brass hinges.

Mechanicals

The first thing to do is prepare the case to accept the board. You will find that there are six totally useless little mounting pillars moulded into the bottom of the case. Remove them. I used a wood chisel and hammer, which worked fine. Clean the bottom of the case off smooth then take the piece of sheet aluminium and measure out the notches needed to clear the mounting posts in the case. The two pairs of groups-of-three holes go in the rear corners of the case. Cut out the notches and make sure that the plate fits comfortably and flat in the bottom of the case then hold it so there is about 2 mm clearance along the sides and at the back and drill three or four holes right through the plate and case. Anywhere will do as long as they don't come within 5 mm of the holes already drilled for the mounting pillars. Use a drill the right size so self-tapping screws will cut a thread properly, then open out the holes in the case to clear the self-tappers.

Next, countersink the nine board mounting holes deeply on the opposite side to that of the board and mount the nine 25 mm spacers on the mounting plate. Make sure that the screws are tight and you've finished that bit.

The next thing to assemble is the mounting for the weighing pan and post. Open out the six holes at the ends of the cantilever beams with a 3 mm (1/8") drill and repeat the process with the epoxy glass centre piece. Also enlarge the hole in the centre piece to clear the centre post that supports the weighing scale. Next come the hinges. Screw the hinges together in pairs back-to-back, as shown in Figure 5, with 6 BA x 1/4" or 2.5 mm x 5 mm screws.

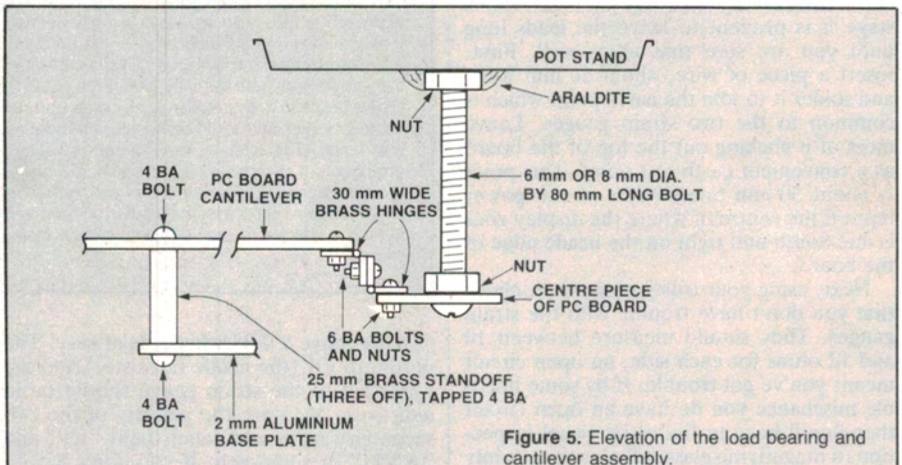


Figure 5. Elevation of the load bearing and cantilever assembly.

Now comes a rather tedious job, namely, freeing up the hinges. Put plenty of oil on them and, holding them by the ends, work them back and forward as far as they will go. Keep this up until they're completely free and will just hang under gravity.

This is important because if it isn't done properly then the final scale will show stiction effects and will not return to zero all the time.

Finally, screw the three pairs of hinges to the bottom of the three cantilever beams and the centre piece to the ends of the hinges (see photo) using twelve more of the small machine screws. Last of all the whole board can be mounted on its nine spacers and it's ready to start testing.

Testing

Before you're able to test and calibrate the scale you'll need some accurate or accurately measured weights. If you have access to an accurate balance then you can weigh some convenient objects and use them. I used small food cans for the light weights but however you get them, you will need weights of about 180 grams, 1.8 kilos and, if possible, about four kilos. One possible answer is to go down to your friendly local butcher or greengrocer and ask to weigh them on his scales (if he gets all twitchy you know where not to shop in future!).

If you turn on the scales you will find that the zero adjust is hopelessly unstable and moves if you even wave your hand near it, but fear not, this is normal. It is because air currents over the strain gauges change their temperature and hence their resistance. To fix this, wrap all three gauges completely in cotton wool at least 5 mm thick. The scale should then settle down after a few minutes and the zero will only change by 0.1 gram every minute.

With the electronics out of its case, even air currents over the bridge balance resistors will cause some drift but when everything is finally in its box these problems disappear. If you want, you can prepare the actual weighing pan before testing (I didn't bother).

I used a base from a plastic flower pot which was just the right size (and price!) and glued a nut, which fitted the threaded post, onto the centre of the bottom with Araldite (*lots* of Araldite). Don't use Araldite with brass nuts though — it doesn't like copper or copper alloys. Also, be sure that the nut has absolutely no grease or oil on it before glueing it.

Finally, the testing. Turn on the scale and give it a few minutes to warm up then adjust the zero set until it flickers between 000 and 001 (it can be −5 kg and still read 000). Then place the 180 gram weight on it and adjust RV3 until the scale reads correctly. The scale is now calibrated (there, wasn't that easy!) RV3 should be fairly close to the centre setting and if you can't get a correct reading at all, then there's a problem with the strain gauges or gain setting resistors R15, R16 and R17.

The scale is now 90% operational and all that remains to be done is to connect the range switch up and mount the whole thing. The range switch is a two (or more) pole, three-position rotary switch which selects R16, R17 or nothing to vary the gain of the second gain block between 100, 10 and 1 (actually 101, 10.1 and 1.01, but who cares!).

A second section of the switch is used to select the appropriate decimal points on the display. Use about 100 mm of ordinary insulated hookup lead to connect the gain switching resistors to one section or the switch. The common terminal of the switch is connected to pin 6 of IC3 and the 10k resistor R16 goes to the centre terminal of the switch to select the middle or 2 kg range. Resistor R17, the 10 ohm resistor, selects the high or 5 kg range and the terminal that selects the 200 gram range is left open circuit.

Also, wire up the decimal point resistors using lengths of hookup wire about 150 mm long. The common contact of this switch section goes to the +5 volt rail (there's a pad provided near the decimal point pads and resistors).

If you can't follow the wiring diagram, rather than laboriously explaining which pad selects which decimal point, the easiest way is for you to select each gain range in turn and try the terminals on the switch to get the right ones. For the 200 gram range the display should show '00.0', for 2 kg '.000' and for 5 kg '0.00'. Connect the appropriate leads and things are almost ready to finally go in the box.

First, drill the two holes in the side of the box to accept the switch and zeroing pot then assemble the main board and mounting plate into the case with three self-tapping screws into the holes already drilled.

Tighten it down then carefully locate the power supply board on the inside of the rear of the case as far up as it will go without fouling the top of the case when it is put on. The power supply transformer must not interfere with the cotton wool insulation on the strain gauges at all. Mark the position of the four mounting holes and drill them with a 3.6 mm (9/64″) drill. Attach four 6 mm (¼″) spacers to the four corners of the board and then screw in the power supply itself.

Next, cut an appropriate hole to the left of the power supply board and run in the mains lead you intend to use. To abide by the law you must have some way of clamping the flex so it can't be pulled out.

Use a 'clamp grommet'. Strip off about 40 mm of the outer cover from the flex you are going to use and feed it through the hole and clamp it. Then bare about 5 mm of the active and neutral leads and screw them into the cable clamp. Solder a lug onto the earth lead and screw it tightly under the centre screw, holding down the main board. That's the power connected. Then put in the zeroing pot and range switch with the zeroing pot towards the back (as far away as possible from the crud from the display).

Now all that remains to be done is to cut out the holes in the top cover and attach it and you've just built yourself a set of scales. Measure off exactly where the display comes through the top cover and cut a hole about 62 mm x 19 mm (but measure it off the case carefully — don't guess it) to clear the display. You also need a hole about 20 mm in diameter to clear the weighing pan shaft. Attach the front panel label to the top cover or label it as you see fit and the mechanics are completed.

Before sealing things up it's time for final calibration. Power up the project and give it a minute or so to settle down then select the 200 gram range and adjust the zero exactly. The display should be flickering between '700.0' and '00.0'. Place the accurate 180 gram weight on the pan and ensure that the display reads correctly. Adjust RV3 if necessary to pull it right into line and it's finally calibrated. Change ranges and check with the heavier calibrated loads if you have them.

Remove the weighing pan, screw on the top panel and replace the pan and your electronic weighing scales are complete!

The scales will always take a minute or so to warm up and settle down as the two strain gauges must be equal in temperature to about 0.001°C, or at least steady in temperature. Also, the zero set will have to be used often as temperature variations do occur. Loads over 5 kg may cause the scale to hit bottom but this does not damage. It may be necessary to recalibrate the scales every few months if you really want accuracy. Happy weighing, people! ●