Homebrew ESR Meter
By David "Yorkie" Taylor

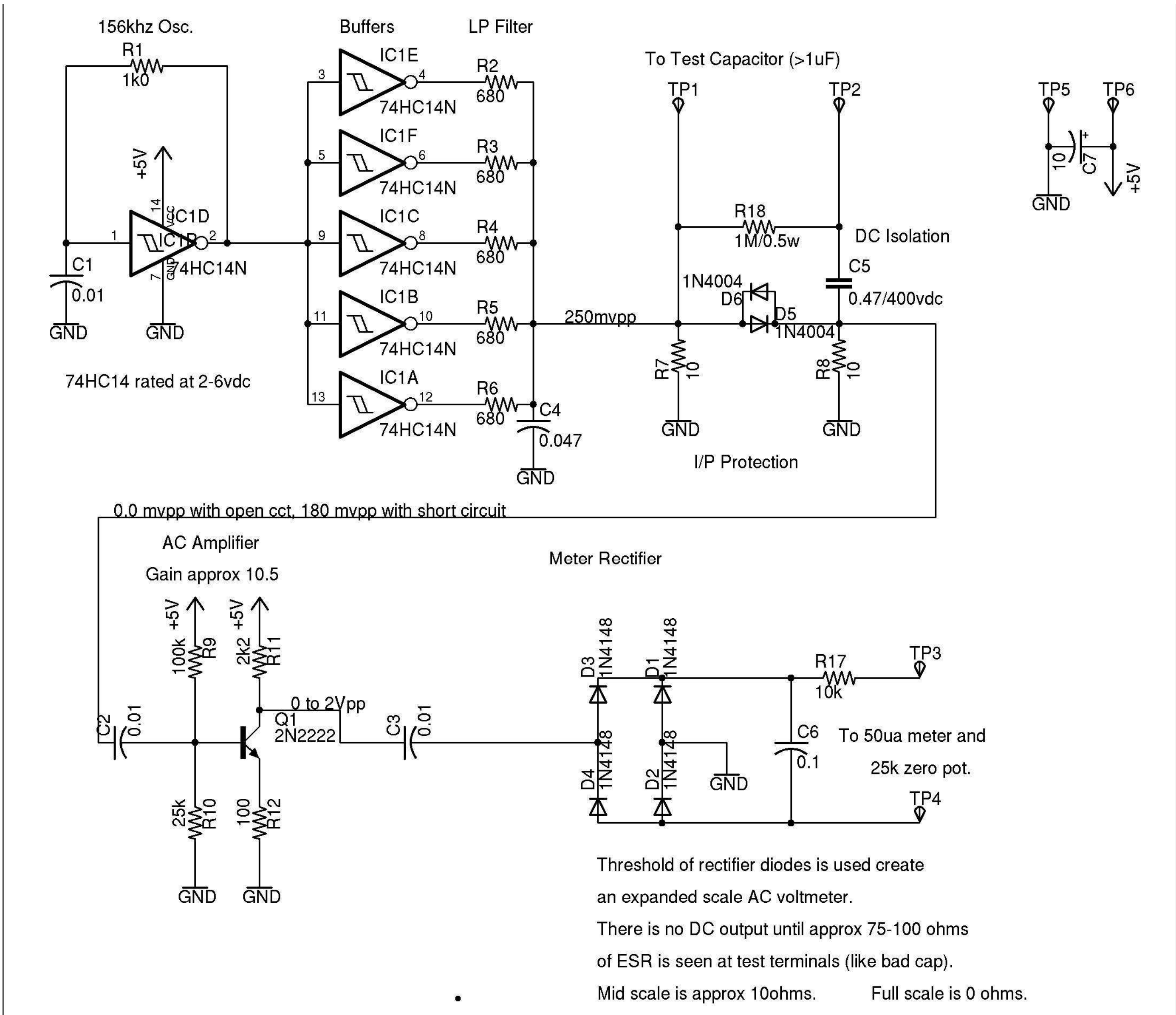
One of the most useful items of test gear for renovation vintage radios and other electronic gear is an ESR Meter for testing electrolytic capacitors. It should be said though, that valve radios generally have few electrolytics – generally, just a smoothing and reservoir capacitor, and a cathode bypass capacitor in the output stage, often 25uF 25 Volts, and often duff. TVs, transistor radios and other solid state equipment on the other hand, often have many physically small electroytics which dry out over time and develop a high ESR. Hence, except for valve radios perhaps, an ESR meter is a worthwhile thing to have, and can be made for less than a tenner.

Several years ago I one from a design in the now defunct 'Television' magazine, which has given a good account of itself, but I've long since lost the copy of the article and PCB artwork.

I decided it was time to make another, as I work in a spare bedroom and also an outside workshop, so it's handy to have two of most items. I looked around for designs on internet and opted for is at this link. I favoured it because it is built on a PCB, uses easily obtained components, and there's no transformer to wind:

http://www.members.shaw.ca/swstuff/esrmeter.html

Original Schematic:



This circuit functions by applying a small 150khz AC voltage
to the electrolytic capacitor being tested. The AC resistance of the cap is
measured by an expanded scale A/C ohm meter circuit.
Caps can be tested live in circuit (not recommended).
The maximum AC voltage applied across the test cap is 250mv pp.
This will not turn on any solid state devices.
Caps tend to measure either full scale (good),
or no deflection (esr > 75 ohms... bad).

Cap	Good ESR
0.1	10
1.0	1
10	0.1
100	0.01
470	0.002
1000	0.001
4700	0.0002

Polarity of test leads does not matter.
The input will survive 400vdc (C5 rating).
Meter Powered by 4 Nicads

Capacitor Checker - Measures Equivalent Series Resistance (ESR)
(c)2005 Lawrence P. Glaister VE7IT, Nanoose Bay BC, Canada

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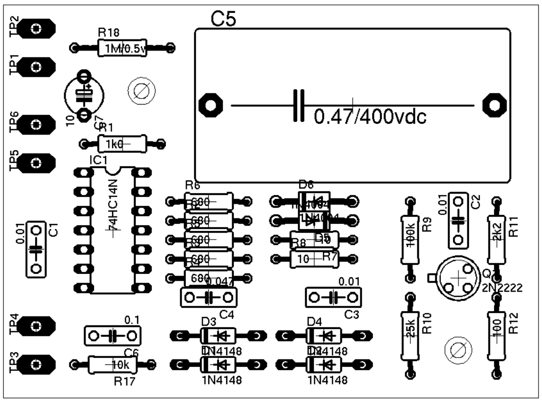
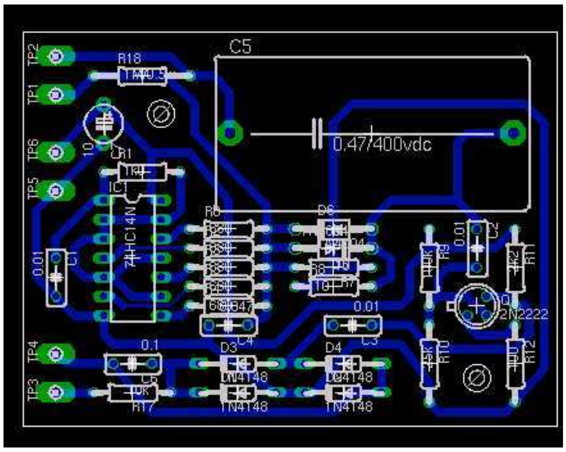
Original Parts Layout:



Original x-ray of parts placement:



I claim no credit for the design, which was the work of VE7IT, but in the sprit of homebrew and experimentation I've adapted the original design to my own requirements.

The designer used four rechargeable batteries to provide the 5 - 6 Volts needed, but rechargeables soon self-discharge if not used. Fine for radios is use regularly, but unsuitable for use in low current devices which are used infrequently, and then only for a few minutes at a time.

I preferred to feed the 74HC14N IC, (which is rated at 2 - 6V), with a regulated 5V from a 9V PP3 battery, which will last for ages. 5V+ regulator so I could power the unit from a 9V PP3. I therefore modded the PCB artwork to incorporate a cheap and simple 5V+ regulator, the TS78L05, which will provide a fixed 5 Volts until the PP3 voltage falls to just below 7 Volts. This regulator is no larger than a transistor, needs no heat sink, and fits easily on the PCB. As the meter only draws no more than 25mA, a PP3 will last a long time.

R10 - shown on the circuit as 25k - is not a preferred value, so I used a 22k, which seems fine. The same goes for the pot which is used for adjustment to get FSD on the meter, in series with R17. The pot was specified as 25k, but I used 22k, (now a preset on the PCB). R17 is shown as 10k on the circuit, but I found I had to reduce it to 3k3 to enable the meter to adjust to FSD.

Either or both of these values may need to be altered by experimentation depending on which type of 50uA meter is used, if a different one is fitted from the one that I used from ESR Electronics Ltd. The values aren't critical, so long as you can achieve FSD with the test prods shorted.

When the meter is built and working, to calibrate the meter dial requires only four low value resistors - eg, two 1R in parallel = 0.5R, one on its own = 1R, the two in series = 2R. Then 2 x 10R in parallel = 5 R, then added to the 1R resistors, = 6R, 7R, and a 10R on its own = 10R. (8 & 9 R can be inferred between 7 -10). I calibrated the scale on my meter up to 15R, which took up about two thirds of the scale but most good caps will have an ESR of just a few Ohms. (The scale isn't linear).

The only reason to have the zero adjustment pot on the front panel was to adjust the meter for full scale deflection as the battery voltage gradually ran down. Because I incorporated a fixed 5V+ regulator, this pot can be a preset one mounted on the PCB, so I modified the PCB layout accordingly, making wiring-up more straightforward.

In my experience capacitors either have a high ESR and hence are useless, or a very low ESR and are good, so the precise value isn't all that important. The easiest way to check a capacitor about which you are doubtful is to see how it compares with a known good one. The meter scale works like an Ohmmeter such as an AVO – with zero resistance when meter is full scale deflection. Thus, when the test prods shorted, the needle move right across to the RH side of the scale, and is then adjusted for zero. The scale then reads backwards to the left. 75% full scale deflection is about 2 Ohms, 50% FSD is about 5 Ohms, and 25% FSD is about 15 Ohms.

I felt that some of the component pads on the original PCB were a little small, so I beefed them up. I made a couple of other minor alterations to the tracks, and I also provided an extra hole at the RH end of C5 on the PCB to allow for different sizes of .47 400V caps used for C5. Some 0.47 caps have radial leads, others, axial. Whichever hole is best for the cap that you find should be used. I re-routed one of the tracks (Pin 6 of the IC to R3) as there was little clearance from adjacent tracks. I also moved the position of C1. All of these mods are highlighted on my diagram of the component overlay, which should be compared with the original.

I added a series limiting LED resistor and two pins on the PCB to supply a Power On LED.

I also added what is often (perhaps unkindly!) referred to as an 'idiot diode' to protect the meter from accidental polarity reversal should a constructor decide to use a 'wall wart' to power the unit rather than a PP3 9V battery. I don't personally see the need to use a wall wart as the meter is only used occasionally and for a few minutes, and draws only a few mA is use. It only requires a 5V supply, via the TL805, so a PP3 can drop by a few Volts before it ceases to power the unit correctly. That said, it is a fact that some constructors prefer to use a wall wart, and have inadvertently reversed the polarity, which will destroy the TL805, the 74HC14N IC and 2N2222A transistor. Not the end of the world – all three will cost no more than a pound in total, but the addition of a protection diode – a 1N4007 say, costing just a few pence, will obviate the risk. (Such diodes are now routinely included in all designs in Everyday Practical Electronics).

There are only 8 off-board connections:

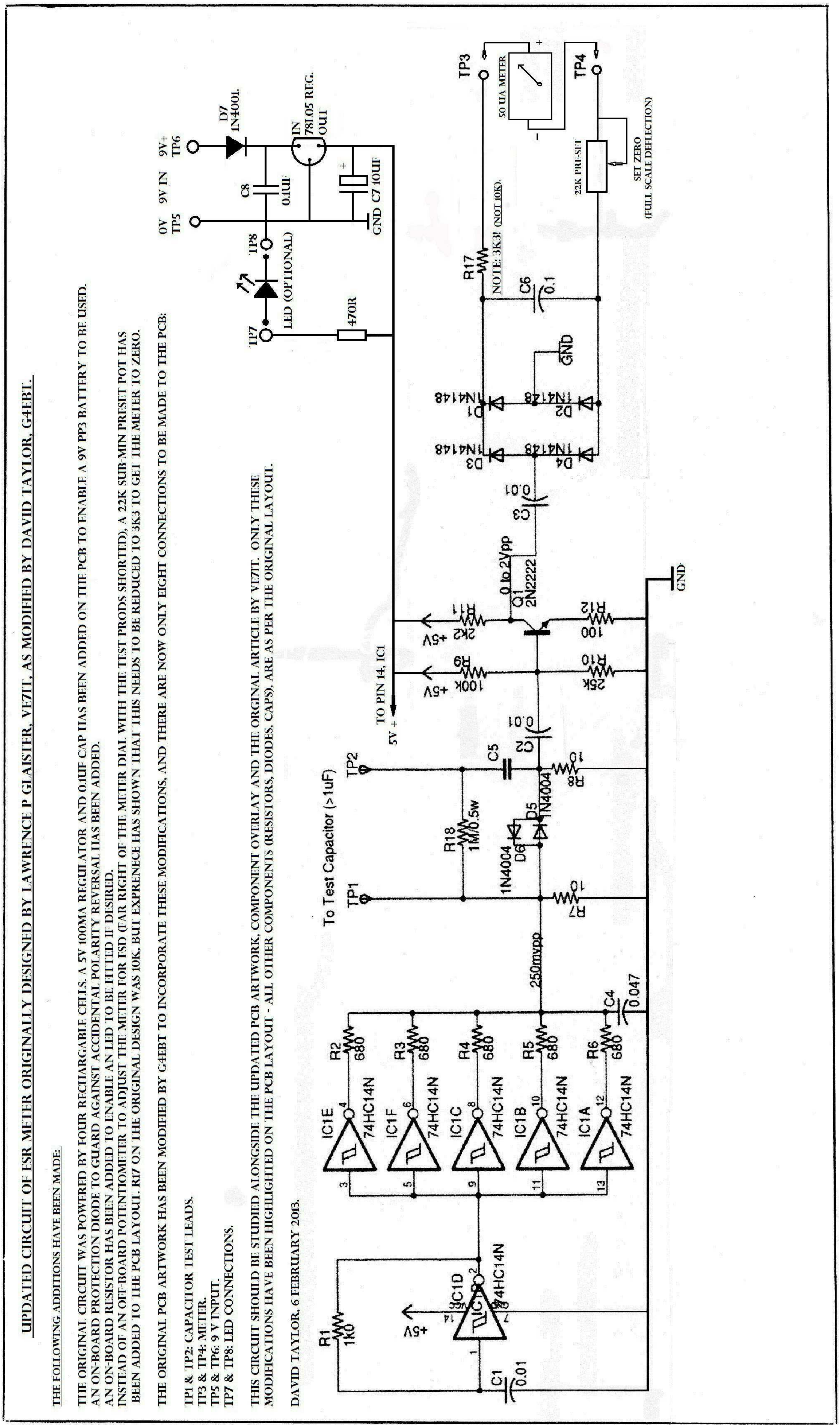
meter +/-;
cap test leads;
9V +/- battery leads (via a switch);
LED.

The only off-board items needed layout are an on/off switch, an LED (which can be omitted if desired), a battery, the meter movement, and the test leads. I've attached the PCB artwork, and an x-ray of the PCB showing the updated layout with the changes made. All other component placements that I've not mentioned on that updated PCB layout, (capacitors, resistors, diodes) are as per the original layout, and to make any sense, the original and updated layouts and the original circuit must be studied alongside each other. I've also attached some pics of the completed PCB, and how it's mounted inside the case.

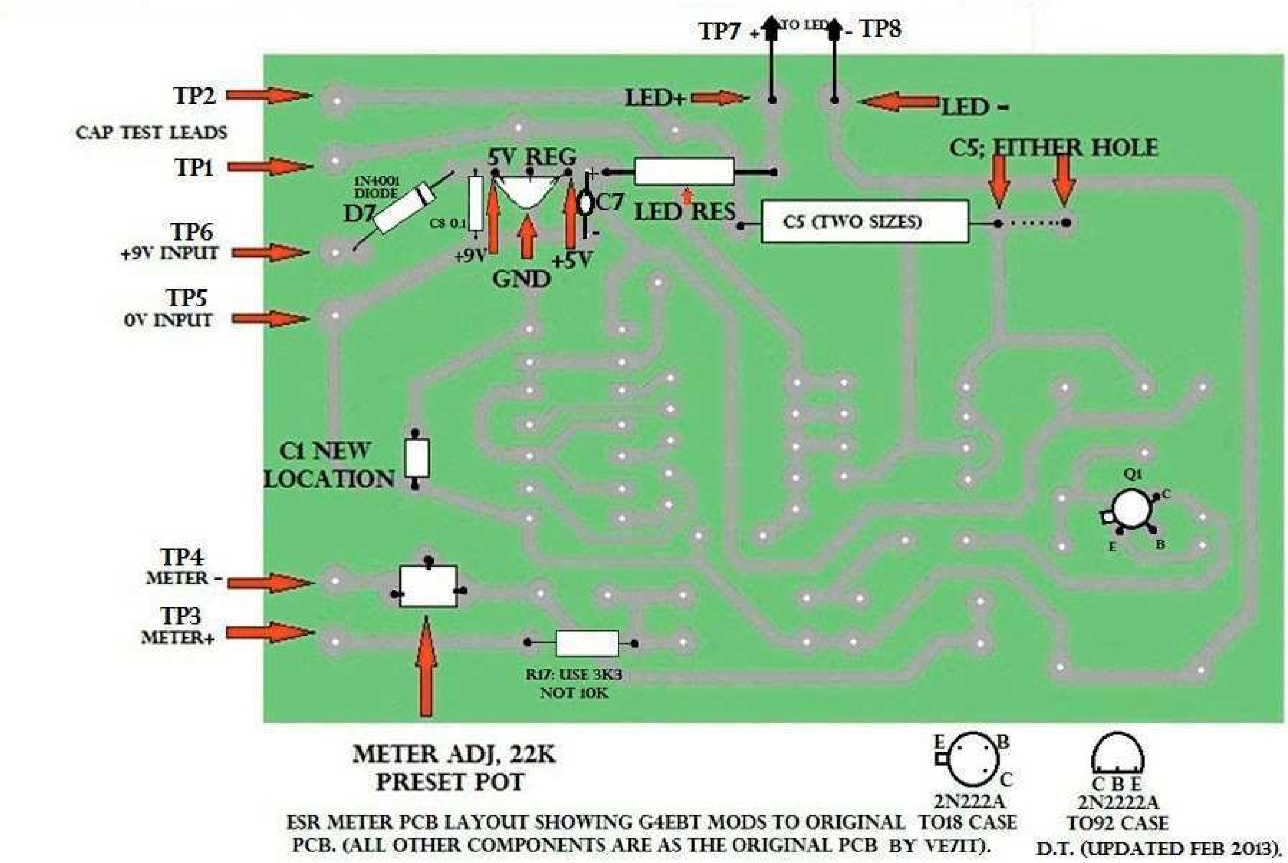
The layout isn't critical, and can be built on plain matrix board rather than a PCB if desired, by following the lines of the PCB, wiring components beneath the matrix board.

The meter can be housed in a small diecast or ABS project box, but I've taken to making my own enclosures from oak offcuts, with comb-jointed corners, as they cost me nothing to make and are evocative of crystal set days - at least I think so! You can either fit 4mm test sockets, into which test leads can be plugged, (as with a multimeter etc), but I preferred directly wired short test leads fitted with croc clips.

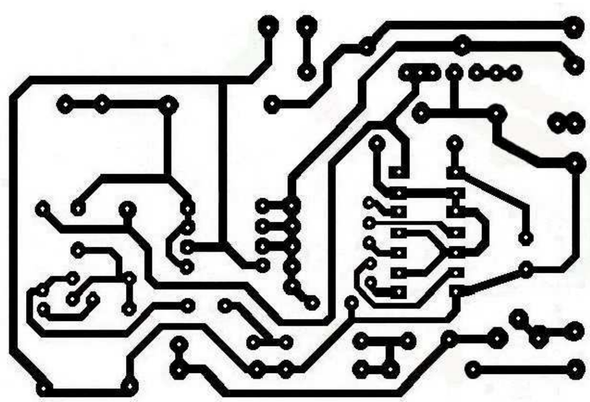
Revised Schematic:



Revised Component Layout:



Revised PCB Artwork:



Parts List:

Resistors:

R1 – 1k0
R2, R3, R4, R5, R6 - 680R
R7, R8 - 10R
R9 - 100k
R10 - 22k (25 k specified)
R11 - 2k2
R12 - 100R
R17 - 10k
R18 - 1M0 0.5W
LED Series resistor, if LED to be fitted: 330R
All 0.5 Watt metal film or carbon film resistors (as sold in the UK by ESR and others).

Zero pot to set FSD: 22k vertical sub-min preset. (25 K specified – see note below)

Note: There are no resistors marked R13 – 16 in the circuit, which uses a total of fifteen resistors if an LED is to be fitted, as listed above. I can only assume that the prototype had more resistors, and the author didn't re-number the resistors in the final version.

Capacitors:

C1,C2,C3 - .01uF
C4 – 0.047uF
C5 - 0.47uF 400V DC (280V AC) Isolation Cap. See note below.
C6 - 0.1uF
C10 - 10uF Tantalum 16V

C5 is there to protect the meter from the stupidity of a user who might connect the prods to an un-discharged high voltage electrolytic cap, such as a smoothing or reservoir cap in a valve radio, on a cap in a TV, and zap the meter. It goes without saying that for personal safety, anyone working on high voltage equipment - even when disconnected from the mains - should always discharge electrolytics before delving into the set. Should this not be done, at least the ESR meter will be protected, if not prying fingers.

The other caps can be miniature resin-dipped ceramics, which are usually rated at 100V, but anything over 10V should be fine. (As with the resistors, there are some gaps in the list – there are no caps C7, 8 & 9).

IC1 – 74HC14N (NOT 74HCT14N!)
Q1 – 2N2222 NPN transistor.
D1,D2,D3,D4 – 1N1418
D5, D6 – 1N4004.
78L05 5V+ 100mA regulator

Note re the IC: The 'N' suffix simply denotes a 14 pin DIL package. Any prefix denotes the ID of the maker. In the family of the '74' series of ICs the 'HC' stands for High Speed CMOS with CMOS-compatible inputs.

Other bits:

M1 – 50uA analogue panel meter. New 50uA meters can be found cheaply on internet, though often with a small face.
PCB (or plain matrix board).
IC socket
Red LED
Croc clips for test leads
Case
On/off switch.
PP3 battery connector.
Project box, wire etc.

All of the above items are available from many UK suppliers, including ESR Electronics, who have no minimum order level or minimum pack size, and charge only £2.50 P&P.

http://www.esr.co.uk/

The total cost of components - including the meter movement, should be no more than £10.

Principle of Operation

Over time, electrolytic capacitors can develop a high series resistance, and though they may read OK on a capacitance meter and exhibit low leakage, will act as though there is a resistance in series with the capacitor. (From experience, small, low voltage electrolytics seem prone to developing a high ESR - cathode bypass caps etc, and I've cured a dim LED display in a VCR through changing a cap found on test to have a high ESR). As well as helping to find caps with a high ESR, the meter will of course exonerate those that are good, pointing to faults elsewhere on the equipment under investigation.

All ESR meters work on a similar principle - the application of a low amplitude AC signal usually of a frequency of between 100kHz - 200kHz to the capacitor under test, and measuring its ESR. Most electrolytic capacitor values have an ESR of much less than 10 Ohms which means good caps test at very close to full scale, (zero ESR) and bad caps test at little or no deflection – very high ESR.

To make any sense, the following comments need to be read alongside the circuit diagram above.

The square wave oscillator is as simple as an oscillator can be – just one, cap (C1) one resistor (R1) and one gate of the 74HC14N IC (a hex Schmidt trigger, widely available for just a few pence). At pin 2 of the IC - the output of the oscillator - there should be square wave of 100kHz or thereabouts - the actual frequency isn't important. (I've tried various 74HC14N ICs in this design and the frequency of the square wave oscillator has ranged from 100 – 105 kHz).

Pin 2 of the IC goes to the input of the other gates at pins 3,5,9,11 & 13. The outputs of those five gates at pins 4,6,8,10 & 12 go to the five 680 Ohm resistors R2,3,4,5 & 6, and form a buffer and low pass filter. At the junction of those resistors, which are all coupled together on their outputs, there should be a waveform of approximately 250mv peak to peak at about 100KHz. This low amplitude AC signal is fed to the AC amplifier - a 2N2222 transistor. The next stage is the input protection stage (D5, D6, C5 etc) which protects the meter from damage should it get zapped with an un-discharged capacitor attached to the test leads. From the junction of R8, D5, D6 and C5, there should be a waveform of about 180mV peak to peak, but it's important to note that this is only when the test leads are shorted, or a good cap with a low ESR is connected to them.

This AC waveform then passes via C2 to the base of the 2N2222A which is an AC amplifier with a gain of approx 10.5. Its role in life is to raise the 180mV p-p input at the base to nearer 2 Volts p-p at the collector. This then passes to the meter rectifier D1,2,3 &4, for the meter movement. Note: Without the test leads shorted, or a known good electrolytic cap with a low ESR attached to the test leads, there will be zero Volts at the input of the 2N2222A, nothing at its output, so no deflection on the meter.

The meter rectifier enables the meter to function as an expanded scale AC voltmeter. Full scale is zero Ohms, midscale is approx 5 Ohms. There is no DC output until approx 75 Ohms of ESR is seen at the test terminals, (ie, a bad cap), at which point the meter will barely deflect.

When observed on a scope, at the base of that transistor there should be 0.0V p-p with the test terminals OPEN circuit, and about 180mV p-p 100 kHz (or thereabouts) when the test terminals are SHORT circuit. (You can't measure this on a normal multimeter without an RF probe, as multimeters on the AC range are for 50 Hz). This amplified AC signal passes from the output of the transistor (the collector) via C3, to the meter rectifier, which rectifies the AC voltage to DC and presents it to the 50uA meter, via the sub-min preset 22k pot, which is adjusted to zero the meter at FSD. There is no DC output at all until approx 75 Ohm (equivalent to a very high ESR from a duff cap), or below, is present.

The test leads aren't polarity sensitive – they work either way around on the cap under test.

Testing Caps in Situ, or Not?

There is a debate about this, and one school of thought is that at least one end of a cap under test should be unsoldered and lifted, as some say that the testing of a capacitor while still in circuit can be tricky.

A table written by ESR meter guru Bob Parker, of approximate worst-case (highest) ESR values for new electrolytic capacitors at 20 degrees C (68'F) can be found at this link:

http://www.your-book.co.uk/design/esrchart.htm

Or here:

http://members.ozemail.com.au/~bobpar/2003esrchart.txt

As a footnote, the designer referred to the oscillator (gate 1 of IC1) frequency 150kHz, and the circuit shows 156kHz, though neither of these are correct, given the values of C1/R1. As far as I can determine, the formula for calculating the oscillator frequency of the 74HC14N is 1/C1*R1= f MHz, where C1 is uF and R1 is Ohms.

Hence: 1000*.01 = 10. and 1/10 = 0.1MHz = 100kHz.

Having tried several 74HC14 ICs from more than one maker, they all come out at around 100kHz. The actual frequency has no bearing on the accuracy of the meter, and in fact 100kHz is the frequency that many designs seem to operate at. (Using this formula, a frequency of 150 KHz would require R1 to be 665R, and at 156 KHz, 640R)

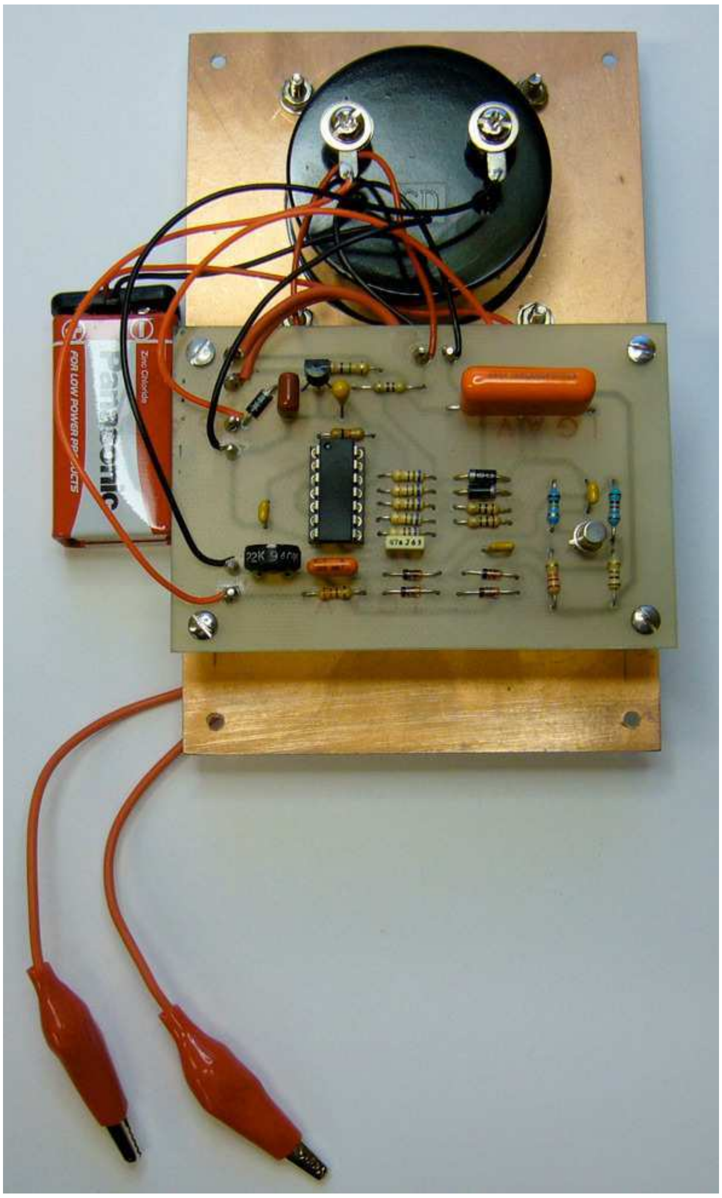
I mention this only in the event that a curious constructor with a frequency counter might decide to check the actual frequency at pin 2 of the I.C., and finding that it's near enough 100kHz rather than 150/156 kHz, might wonder if it's faulty.

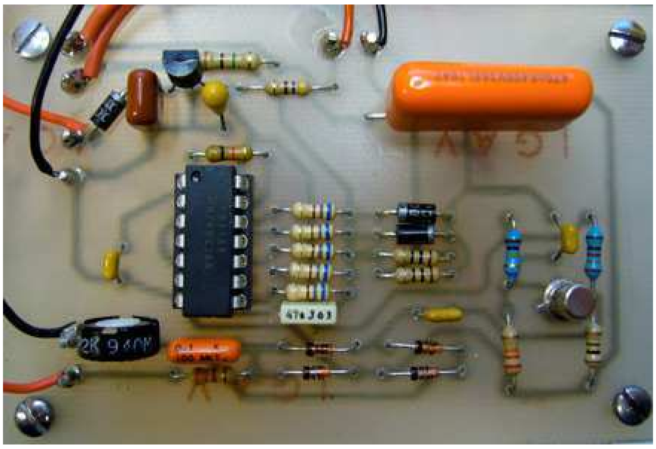
ESR Meter Construction, Testing, Setting Up and Troubleshooting Notes.

As with all projects it's important to check that components are the correct value, particularly those which have obscure markings. Even resistor markings aren't so straightforward these days - often using the 5-band marking code, as at Maplin for example. Also, ensure that diodes are connected the right way round.

The 2N222A transistor comes in two case styles, the more common of which is the metal 'TO18' style case. It also comes in the plastic TO92 case. On the 'x-ray' picture of the updated PCB, I've shown the pin-outs of each case style.

A word of warning though – there are less common TO92 cased 2N222A transistors in which the emitter and collector are reversed. It's therefore wise to use a metal cased one, or to check the connections on a transistor tester to be sure.





Initial tests and setting up:

On completion of the project, set the meter adjust pre-set pot on the PCB to midway position, and before inserting the IC, switch the meter on, and check that there is 5V present at pin 14 of the IC socket. (Black test prod to pin 7 of the socket – red to pin 14). If all's well, insert the IC, clip the test prod leads to each other, and the meter needle should deflect to the right. If so, adjust the preset pot on the PCB until you get full scale deflection on the meter. It should not need adjusting again.

Calibrating the dial:

Having zeroed the meter with the pre-set pot so that with the test prods shorted it shows full-scale defection - zero Ohms, you can begin calibrating the dial using a few low value resistors as follows:

Two 1 Ohm resistors in parallel = 0.5 Ohm, one on its own = 1 Ohm, two in series two Ohms, then more 1 Ohm resistors up to 10 Ohms, and so on. On the 50uA meter that I used 1 Ohm was about 80% of full scale, 5 Ohms mid-scale, 15 Ohms about 30%. Really, any cap approaching 10 Ohms is highly suspect, so it's the low Ohms end we're interested in, at the RH end of the scale.

What if it doesn't work?

Carefully check all the components, especially the correct orientation of the diodes, Q1, the voltage regulator, the IC and C7 (the only polarity sensitive capacitor). Using a magnifying glass, check for any solder bridges - for example between the pins of the IC socket. Check that you have 5V+ at pin 14 of IC1. If not, is there 9V at the input of the voltage regulator? If so, suspect the regulator. Check that you've used the right IC - 74HC14N. (Not 74HCT14N). It helps if a scope is to hand to check the waveform at various points, and to gain an understanding of the various elements of the circuit.

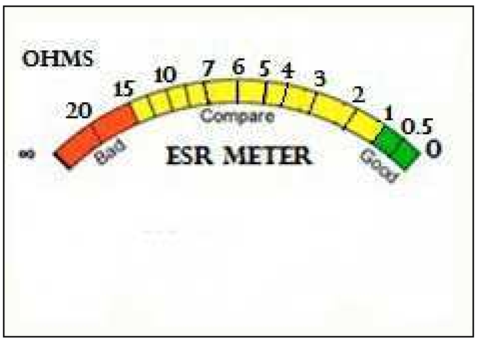
Getting the meter to read Full Scale Deflection:

The original circuit specified a 10k resistor for the 50 uA meter shunt, (R17) though the designer refers to having to reduce that to 4k7. I found that I needed to reduce it still further to 3k3. Make sure you've used a 3k3 resistor for R17 - not a 10k resistor for R17 as was in the original design.

Though the elements of the circuit aren't complex, it does help in troubleshooting if a scope is to hand, but it's worth stressing that when testing and setting up the device, unless the test leads are shorted out, there will be no deflection on the meter and 0.0mvpp at C2 into the AC amplifier (Q1) etc.

If the meter doesn't work, it's unlikely to be the transistor or IC that are at fault as they're not especially delicate. But as the ICs are just a few pence each, it's easy enough to swap one to see if the original is indeed dud.

A larger 50uA meter than the one from ESR Electronics Ltd (which is 60mm x 45mm) is available from Rapid Electronics at a similar price and is 70mm x 60mm and hence, the dial is less cramped and clearer to read. With my limited artwork skills, I've managed to enlarge and re-calibrate the dial to suit this meter. The dial can be printed onto photo paper, and if the scale-plate of the meter is carefully removed, can be stuck on the rear of the plate and the plate fitted back again. Removal of the dial only involves two crews, and the scale-plate, another two crews.



The link to the Rapid 50uA 70mm x 60mm meter is here:

http://www.rapidonline.com/Electrical-Power/Moving-Coil-Meter-50UA-SD-670-48-0300