

A simple ESR meter

Gord Rabjohn, 2010

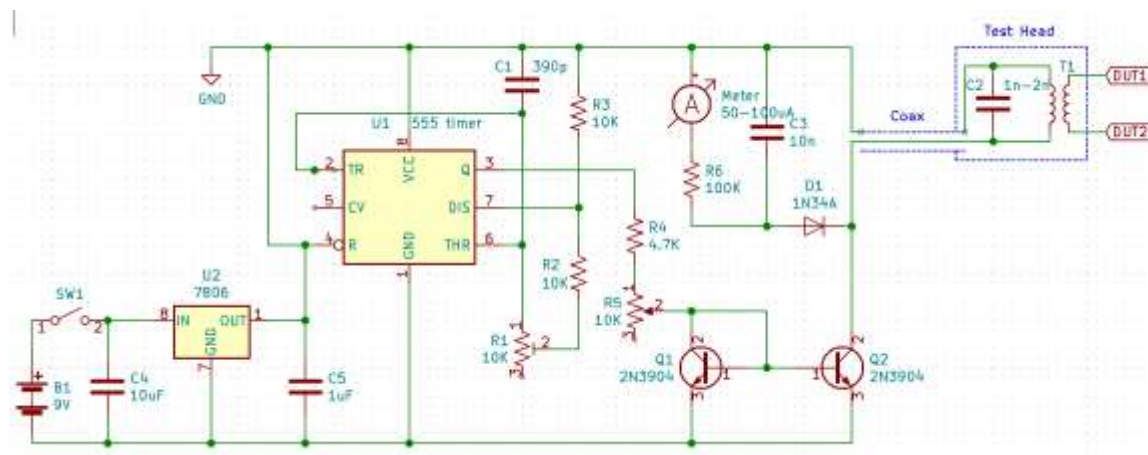
This article describes the construction of an analog meter for measuring the ESR (Equivalent Series Resistance) of an electrolytic capacitor. A version was originally published in the Ottawa Vintage Radio Club newsletter in 2010.

This ESR meter is essentially an ohmmeter capable of resolving a few ohms, but rather than operating at DC, it operates at a high frequency, typically 10-100kHz. At this frequency, most electrolytic capacitors should look like a short (An ideal 1uF capacitor looks like 1.6 ohms reactive at 100kHz). Any series resistance is therefore easier to resolve than at, say, 60Hz (a 1uF capacitor looks like about 3000 ohms at 60Hz, so measuring a few ohms in series with such a large reactance is difficult). So, this meter is useful for capacitors of roughly 1uF or more.

The meter I describe here is an “Analog” design, using a hand-calibrated meter movement. As long as you are comfortable with that, its unique design gives it some desirable features:

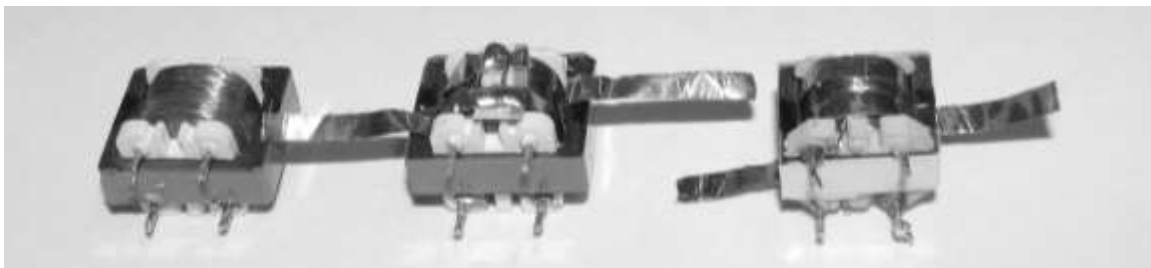
- It is cheap and simple and can probably be made from parts you already have.
- You can discharge a fairly large capacitor into it without damaging it.
- The wire from the meter to the “test head” (that has the test port) is at a high impedance, so the inductance of this wire does not introduce error (a few microHenrys of inductance at 100kHz looks like a large reactance compared to 1 ohm.)
- The test head is small enough to fit into corners of a chassis or circuit board.
- The test head can accept pins of various separations to mate with a variety of capacitor sizes without adding appreciable wire length.
- There is no DC on the test port, so it can usually check capacitors in-circuit.
- The open circuit voltage is low, under 0.1V RMS, but the short-circuit current is quite high, over 50mA; this makes it sensitive to small resistances.

The schematic of the meter is shown below:



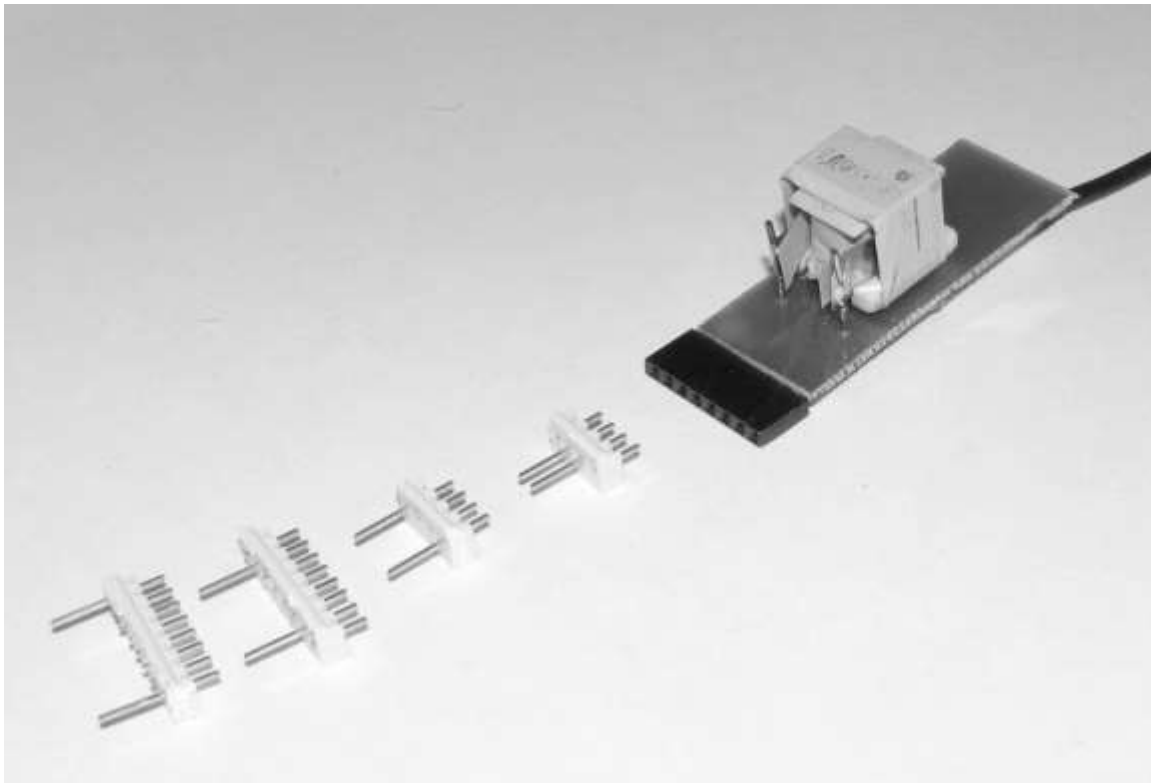
The 555 timer provides a stable 50-100kHz square wave. The output of the 555 drives a current mirror that turns the square wave into current, which is fed to an L-C tank. The 555 oscillator works at the resonant frequency of this tank. The inductor in the tank is coupled through a low impedance winding to the device under test (DUT). The AC voltage across the tank is detected and displayed on an analog meter. With an open circuit at the DUT port, there is a maximum voltage across the inductor. Resistance on the DUT port causes this voltage to decrease. With a short on the DUT port, there is almost no AC voltage remaining.

The only critical parts are the transformer T1, and the capacitors that determine the frequency of operation, C1 and C2. This design requires a transformer that is compact, low loss at 100kHz, and readily available. I first looked at output transformers, but their iron core gives them terrible loss at 100kHz. I found an ideal solution in the power supply for a Compact Fluorescent Lamp (CFL). When your CFLs expire, take them apart, because they are a good source of useful parts. There are 400V diodes or a bridge rectifier, power transistors, a 10-50uF 200V electrolytic, and various inductive components. Most CFL supplies have a large inductor (1-4mH), which forms the basis for this project. (One I opened had a multi-winding transformer, and I haven't evaluated it for suitability, but all other had a simple inductor). Figure 2 shows some examples of these (some with a 2-turn secondary that I added). These inductors are usually held together with glue. Hopefully they were not too generous with the glue so that there is room in the core for another winding. If there is glue that gets in the way, I found that a jeweler's saw with a medium-fine blade can be used to cut through the glue and make room for the secondary. The secondary (which goes to the device under test) is made with 1 or 2 turns of copper foil, the type used for stained glass. 1mH inductors need a 1 turn secondary and 0.002uF resonating capacitor (C2). 3mH inductors require 2 turns, and 0.001uF capacitor. Instead of foil, you can use solder braid, braid from a coax cable, or several strands of magnet wire in parallel for the secondary. Because the impedance is so low, the secondary must have a reasonably wide cross-sectional area, however it needs to be flat to fit into the inductor.



I built the main part on a piece of copper clad board in dead-bug style. I elected to use a positive ground, because this allowed the braid of the coax that goes to the test head to be grounded. Q1 and Q2 can be any NPN low power silicon transistors, but they should be identical. R6 should be selected so M1 registers about full scale when 5V is present at D1. Though I used a 78L06 6V regulator, a 7906 negative regulator (with appropriate circuit changes) might make more sense.

The test head was also assembled on a piece of copper clad board. It consists of the transformer, capacitor C2, and a connector. I used a 3-foot length of fine 50 ohm coax, but the length is not critical. I surrounded it with heat-shrink tubing for protection. I used a multiple position female circuit board connector as shown in Figure 3. It allows me to plug in various needles that are useful for testing various sizes of capacitors on circuit boards. Capacitor leads or test leads can also be plugged directly into this connector.

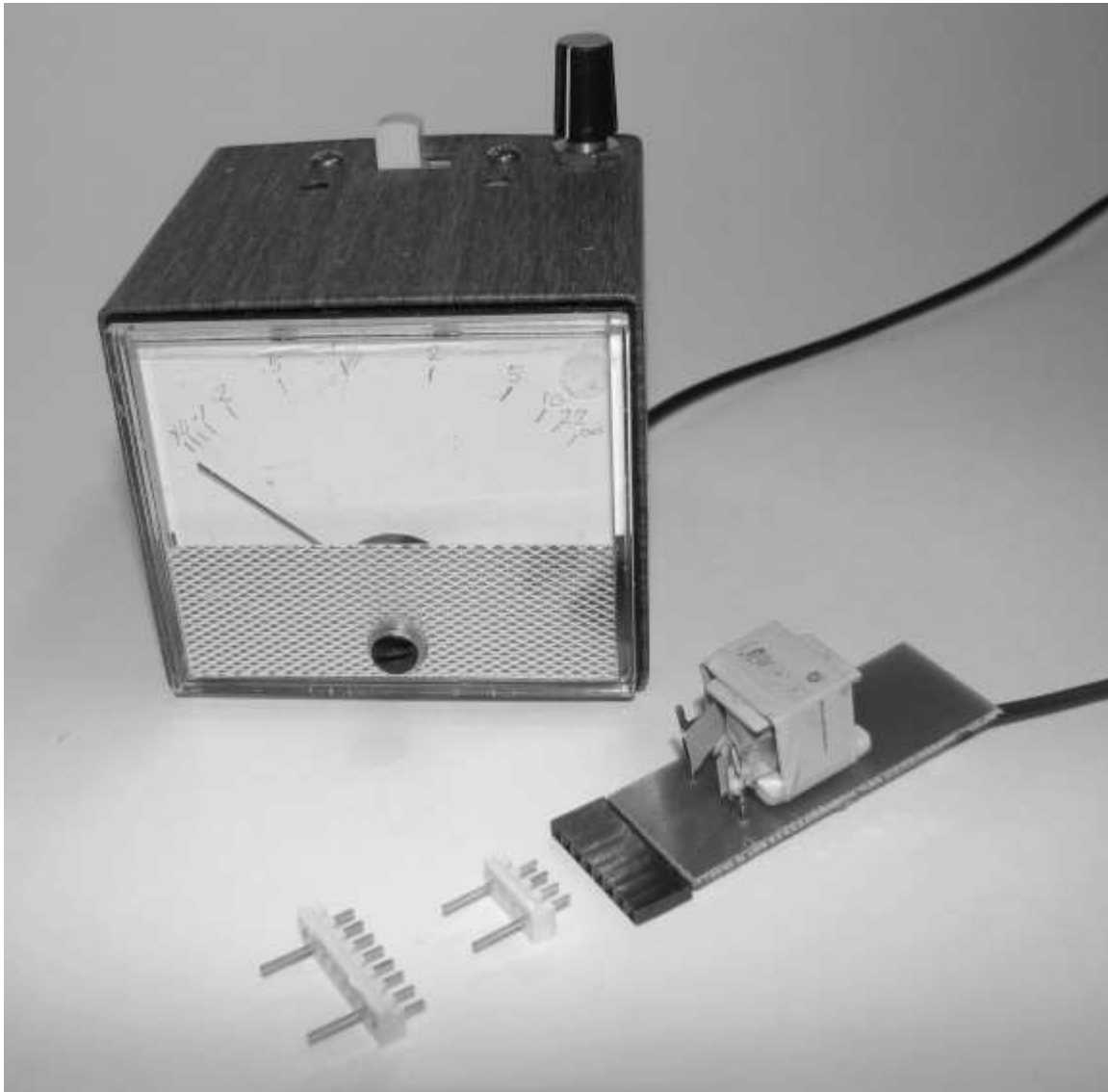


B1	9V battery
C1	390pF high quality capacitor (NPO or mica)
C2	1000-2000pF high quality capacitor (see text)
C3	0.01uF capacitor
C4	10uF capacitor
C5	1uF capacitor
D1	1N34A or similar germanium diode.
M1	50uA-100uA meter
Q1, Q2	2N3904, or any low power silicon NPN
R1	10K trimmer, 10 turn preferred
R2, R3	10K resistor
R4	4.7K resistor
R5	10K pot (with knob)
R6	100K (for 50uA meter, select so that M1 reads full scale at 5V)
S1	Power switch
T1	Transformer, see text

U1	555 timer IC
U2	7806 6V voltage regulator
	0.1, 1, 10 ohm resistors for calibration
	Coaxial cable, RG174 or similar.
	Connector and header pins.

Table 1: Parts list

The finished unit is shown in Figure 4.



To calibrate the unit, first adjust the frequency of the oscillator using R1 until the meter reading peaks. Increase R5 if the meter pegs. (If you cannot get R5 large enough to “unpeg” the meter, then you may need to increase R4). If a peak is not found, then the resonating capacitor, C2 may need to be changed. Try adding 220pF capacitance in parallel. If adding capacitance causes the meter to increase, then a larger capacitor is

required, try doubling C2. If adding capacitance causes the meter reading to decrease, try halving C2. Once R1 is set, it should never need adjusting. Next, adjust R5 until the meter reads full scale (which will be infinite resistance). Again, it may be necessary to change R4 until this can be done. Placing a short across the measurement terminals should cause the meter to drop to almost 0, this will be zero ohms. (If it does not drop to almost zero, then the transformer secondary probably needs to be made of thicker copper.) Connect a 1 or 2.2 ohm resistor to the DUT terminals. The meter should read between a quarter scale and three-quarter scale. If the meter is too close to full scale, then increase the number of secondary turns on T1. If it is too close to zero, decrease the number of turns. I have tried several transformers, and all needed either 1 or 2 turns on the secondary. Now, use several 0.1, 1.0, and 10 ohm resistors in various series and parallel combinations and mark resistances on the meter face in a 1-2-5 progression.

Before every use, adjust R5 until the meter reads infinite ohms without anything connected. Connect the capacitor under test with minimum length leads (this meter is quite sensitive to series inductance). A good high voltage 10uF capacitor should usually be under 2 ohms. (As an experiment, I added a 10 ohm resistor in series with the 10uF filter cap of a recently recapped radio, and could hear more buzz (not hum, but buzz) with the resistor in place. I find the sensitivity depends on the radio design. Radios with capacitors from the B+ line to a signal path will tend to pass the higher harmonics that may be poorly filtered by a low ESR capacitor.) Though I use this meter when I'm working on old radios, I find it most useful for troubleshooting modern equipment, stuff that tends to be laced with electrolytic capacitors on a circuit board. At least half of all problems with old equipment can be traced to a defective capacitor. A good electrolytic capacitor of more than 100uF should have less than an ohm of resistance, and the larger the capacitor, the less resistance you would expect. The needle probes are especially good for testing capacitors on circuit boards. I also have test leads for testing loose capacitors. Note that generally capacitors can be tested in-circuit, that is, without removing them from the circuit.