A simple ESR meter

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Electrolytic capacitors are one of the major causes of failure in electronic equipment of any vintage. And, they can fail many different ways. We have all seen the “leaky” capacitor (both electric leakage, and leakage of the physical contents of the capacitor). We all know to verify that a capacitor has low leakage current (especially if it feeds the grid of a tube!). Many of us attempt to reform electrolytic capacitors. Once reformed, we may check the capacitance to see how close it is to specification. Yet, there is one more test required to ensure that the capacitor is good: one should confirm that the Equivalent Series Resistance (ESR) of the capacitor is low.

The ESR gives you some idea about how much current the capacitor can supply into a load. I have seen capacitors that appear to have the correct capacitance, are not leaky, and yet somehow did not seem to be performing the power supply filtering function we have come to expect. These capacitors had excessive series resistance.

High ESR capacitors are not found just in old equipment. I find that even modern capacitors can degrade. In fact, I suspect that modern capacitors are probably constructed even more poorly than old style Drylitic capacitors. Note that many modern electrolytic capacitors are rated for only 1000 hours (about a month) of operation at 85C.

There are a large number of ESR meters available; just do a Google search for ESR meters, and you’ll find many. There are nice plans at these web sites:
http://www.members.shaw.ca/swstuff/esrmeter.html
http://ludens.cl/Electron/esr/esr.html
Probably, most of them are better than the one I describe in this article, but this one cannot be beat for simplicity and ruggedness.

An 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 dead short (An ideal 1uF capacitor looks like 1.6 ohms 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 has a unique design that gives it some desirable features:
-It is cheap and simple!
-You can discharge a fairly large capacitor into it without damaging it.
-The leads from the meter to the “measuring head” are at a high impedance, so the inductance of these leads does not introduce error (a few microHenrys of inductance at 100kHz looks like a large reactance compared to 1 ohm.)
-There is no DC on the probes, 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 in Figure 1.

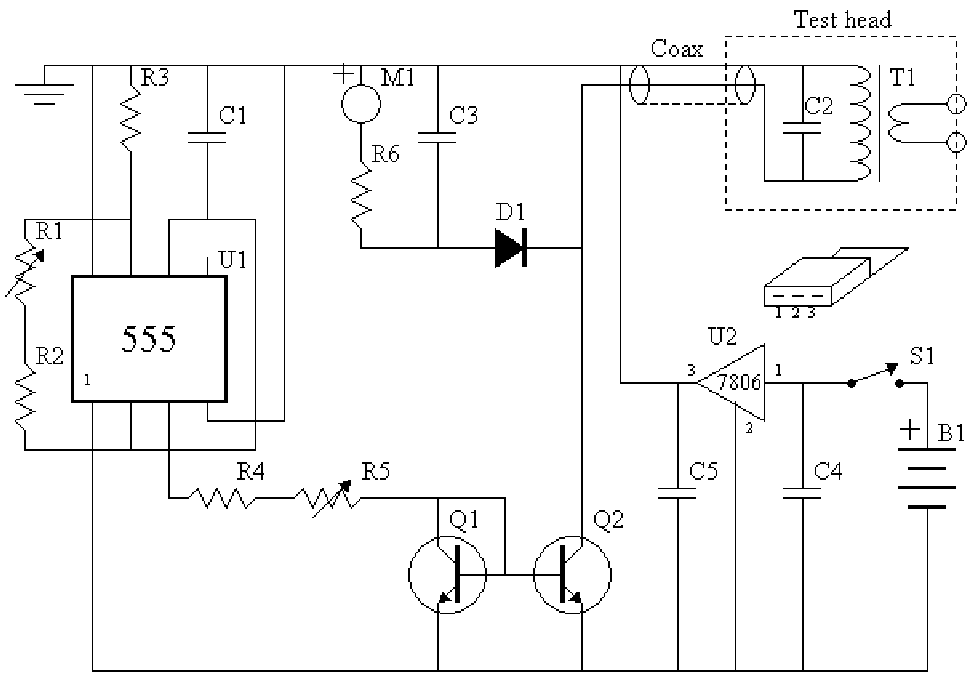

Figure 1

The 555 timer provides a stable 50-100kHz square wave.. The output of the 555 drives a current mirror, which turns the square wave from the 555 into current pulses, which are fed to an L-C tank. The 555 oscillator works at the resonant frequency of this tank. The inductor in the tank is coupled 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 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). Many of us have been lured to use these products on the promise of saving energy and money. I find that their promised lifetime of 10000 hours is seldom reached, usually because something in the power supply has failed. When they expire, I 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 capacitor (which is good for fixing up AC-DC sets), 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 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 small 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.

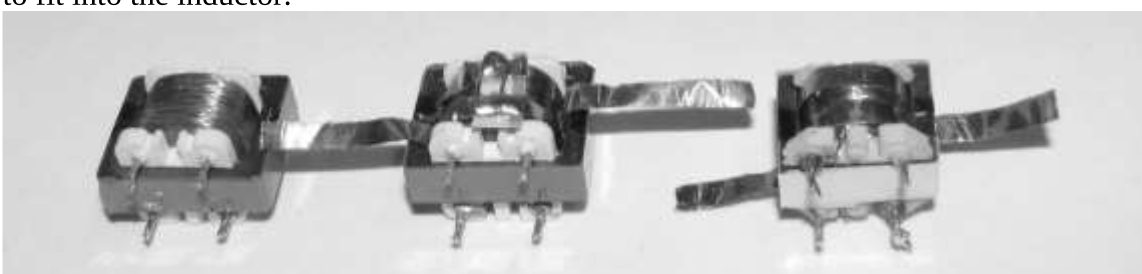

Figure 2

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 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.

The sensor head was also assembled on a piece of copper clad board. It consists of the transformer, capacitor C2, and a connector. 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 electrolytic capacitors on circuit boards, as shown in Figure 3. Capacitor leads can also be plugged directly into this connector.

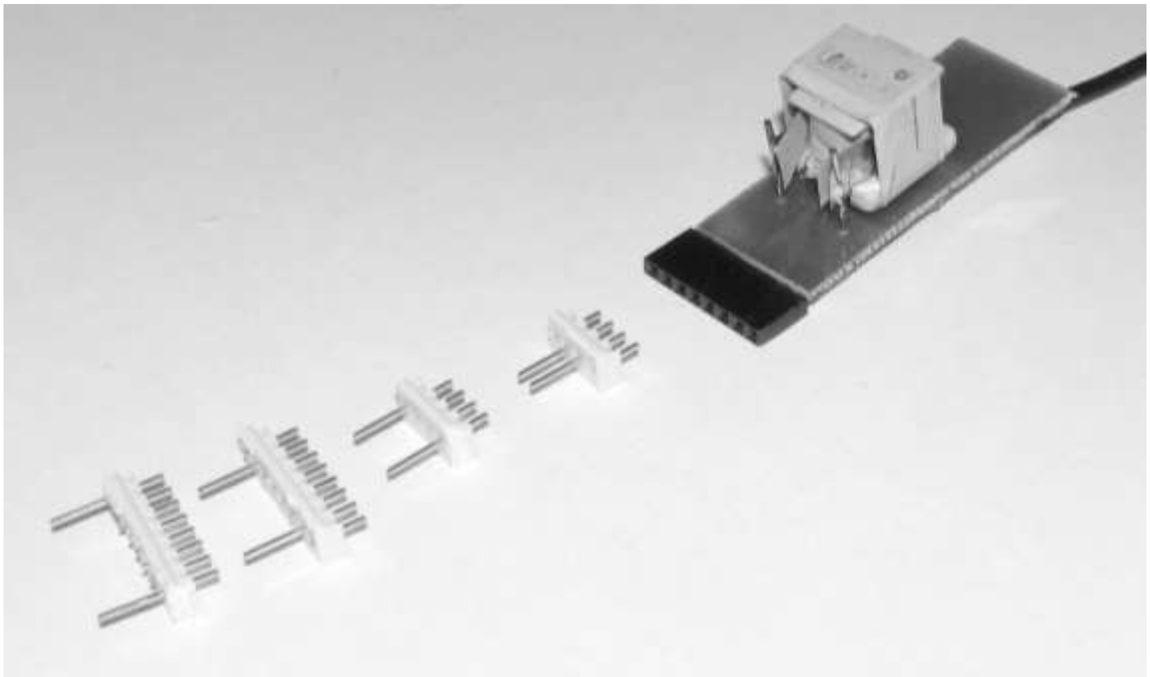

Figure 3

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 looks something like what is shown in Figure 4.

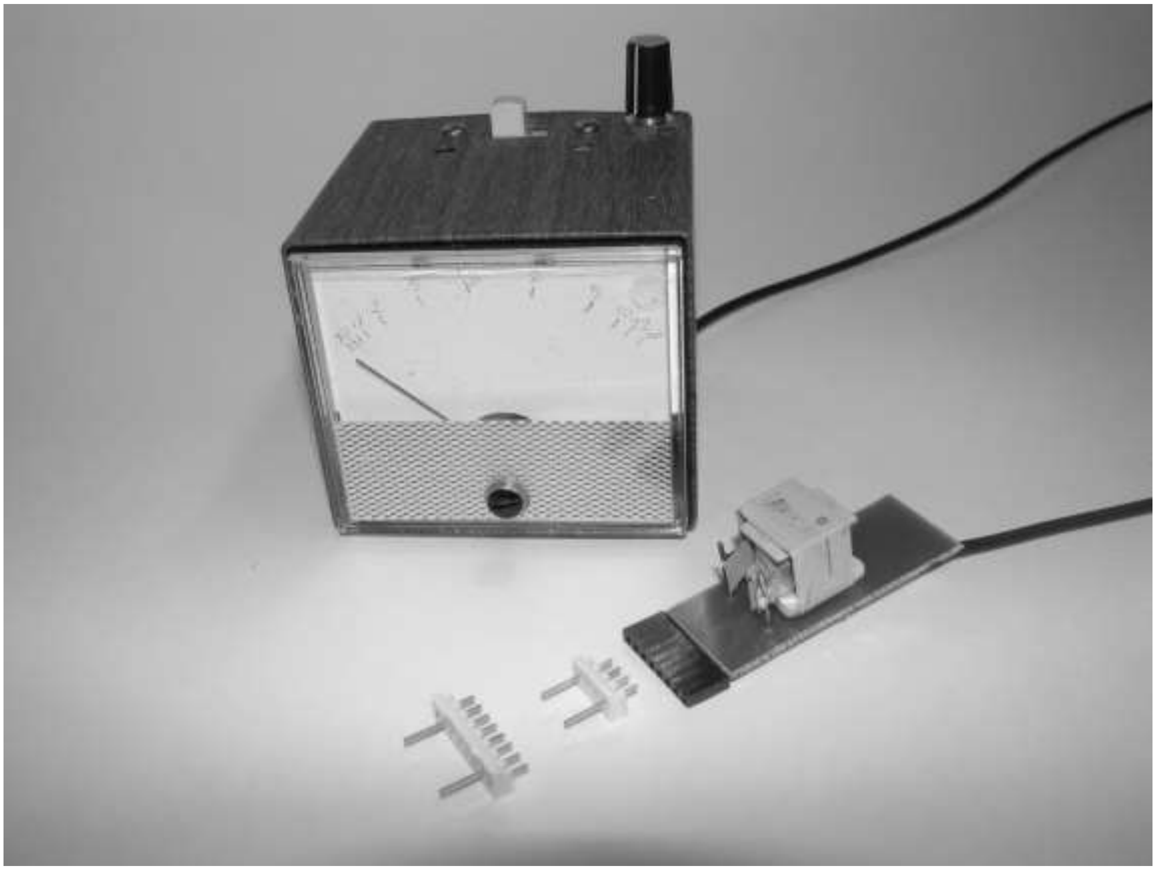

Figure 4

To align 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 measurement 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, 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 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. Note that generally capacitors can be tested in-circuit, that is, without removing them from the circuit.

List of figures