DOUGS TECH NOTES

By Doug Jones

Capacitor WIZARD®
IN-CIRCUIT ESR METER

Using the Capacitor Wizard for the First Time

E = I x ESR

This article is in response to new customer feedback. It was brought to my attention that the Capacitor Wizard® operating manual needed a "getting started" section for first time users. I decided to write a whole article on the subject. Measuring for ESR (Equivalent Series Resistance) may be new to many techs so lets briefly review ESR and its detrimental effects on various electronic circuits.

ESR is the DYNAMIC pure resistance of a capacitor to an AC signal. High ESR can cause time constant problems, capacitor heating, circuit loading, total circuit failure etc. A switching power supply may not reliably start - or start at all. Slight hum bars appear in the video of a VCR or monitor. A TV may be pulled in from the sides/top/bottom. Partial loss of a color, intermittent operation, diode and transistor failure over a period of time. These problems and many more are often caused by capacitors with normal capacitance ***but high ESR!***

Why do I need the Capacitor Wizard®? - why not use a standard capacitance checker or a DC ohm meter?
ESR does not exist as a STATIC quantity therefore it cannot be measured by a conventional capacitance meter or a DC ohm meter. ESR exists only when alternating current is applied to a capacitor or when a capacitor's dielectric charge is changing states. ESR can be considered to be the TOTAL INPHASE AC resistance of a capacitor. ESR includes the DC resistance of the leads, DC resistance of the connections to the dielectric, capacitor plate resistance, and the INPHASE AC resistance of the dielectric material at a particular frequency and temperature. ESR is affected by every capacitor physical quantity - so any problem with a capacitor (except a short) shows up as an increase in ESR! The combination of components that make up ESR are symbolized by a resistor in series with a capacitor as shown above. This symbolic resistor does not really exist as a physical entity so direct measurements across the ESR resistor are not possible! However, if a method of correcting for the effects of capacitive reactance is provided, and considering all ESR resistances are INPHASE, ESR can be calculated and measured by using the basic electronics formula E = I x R! This is the ***Basic Electronics*** foundation used to design the ***Capacitor Wizard®***!

From the above definition of ESR you should now understand that ***any capacitor failure mode*** will cause the ESR of that capacitor to ***increase in resistance*** (except shorts). If a capacitor has dried out, is open, or otherwise has suffered DRASTIC failure, ***the measured ESR will be near infinity***. If a capacitor has changed capacitance slightly, it has a problem and that problem will show up as a ***several ohms increase in the ESR***. For this reason a standard capacitance meter that does not measure ESR could lead you to conclude that a bad capacitor is actually good!! I have had many reports from Capacitor Wizard® owners that have found bad caps using the Capacitor Wizard® that other cap testers found good - and proved it by replacing the cap!

Get experience measuring known bad caps:
OK, lets test some caps. As a new user of the Capacitor Wizard® I highly recommend that you test some known bad caps to see how they respond and build your confidence in the instrument. The Capacitor Wizard® probes are ***nonpolar*** so don't worry about polarity. You will probably have mostly open capacitors and they will barely move the meter. Get a 100 ohm resistor and put it in parallel with a bad open cap. Notice that the meter still just barely moves! Try different values of resistance and see how the meter responds. Get a transistor or a diode and try to measure across the junctions. You will notice the Capacitor Wizard® does NOT respond. That is because the Capacitor Wizard® test signal is only about 5 millivolts RMS. It takes 300 to 600 millivolts to turn on solid state devices. Get a transformer or a choke similar to what you expect to find in the equipment you repair. Measure across the primary, secondary or anywhere you like. You will notice that the Capacitor Wizard® does not respond. That is because the INDUCTIVE REACTANCE at the 100 khz test frequency of the Capacitor Wizard® is many orders of magnitude larger than the resistance range of the Capacitor Wizard®. A high percentage of your bad caps will fall into this category - OPEN. This demonstration proves that open caps are very easy to find IN CIRCUIT and the associated circuitry has little effect on the Capacitor Wizard® operation IN CIRCUIT.

You probably noticed that not all of your bad caps checked open. I'm sure that some of the caps probably rang the "Cap Good" beeper (ESR less than 1/2 ohm). Those caps are more than likely GOOD. Every shop accidently replaces a good cap now and then. Just to make sure they aren't shorted, check them with a standard ohm meter. Check them on your standard out of circuit capacitance reading meter. You'll probably find that they are all good. Shorted caps are pretty rare. I've got boxes of bad caps from repair shops around town and have yet to find a shorted cap.

Well, finding those open caps and good caps was easy. Now lets look at other bad caps that require a little more experience with the Capacitor Wizard® and some knowledge about capacitor TYPES and USES. You probably found caps from 1 to 30 ohms ESR in your bad box. How do you tell the good caps from the bad??

Whether the ESR of a particular capacitor is correct or too high can always be determined ***by comparing*** the suspicious capacitor to a known good one of the ***same value, voltage rating, and type***. Unfortunately one doesn't always have another capacitor to compare against. Experience is the best teacher here, however there are some general guidelines:

The higher the rated working voltage, the higher the normal ESR.
Capacitors used in Power Switching applications need to have really LOW ESR - less than 1/2 ohm
Nonpolar Caps are normally less than 1/2 ohm

The next logical question about ESR is "How HIGH is TOO HIGH"? Thats a judgement call that can only be based on experience or comparison to a known good cap (or access to the engineering data from the capacitor or equipment manufacturer - ha ha!). Over 10 ohms is certainly too high for most applications. Over 3 ohms is too high for Horiz/Vert switching applications. Over 1/2 ohm is too high for ***power*** switching applications. By comparison you will gain experience and know when to be suspicious. These are my opinions. Here are some actual repair situations:

Example: 47uf @50vdc measures 25 ohms ESR in circuit - BAD CAP
The suspect capacitor is a 47uf @50vdc in a switching power supply for a VCR. The Capacitor Wizard® has measured 25 ohms ESR in circuit. That is higher than 15 ohms and much to high for any quality cap. A new capacitor measured 5 ohms ESR. The new capacitor fixed the VCR. In my opinion the new capacitor was not of the highest quality (5 ohms is too high) however it did fix the VCR. The use of these low quality inexpensive import capacitors is probably the reason we see so much capacitor failure in consumer electronic equipment! A higher quality cap with a lower ESR of the same kind costs more money but will measure less than 1 ohm and be more reliable.

> Conclusion: This is a higher voltage capacitor and can be expected to normally measure higher than 1/2 ohm. In my judgment any "switch mode" capacitor that measures more than 3 ohms ESR is suspect no matter what the voltage rating. However you may obviously get by with the 5 ohms ESR in that ***particular*** circuit. For comparison, the bad part was checked "out of circuit" on a well known competitors $2000 Cap analyzer and it determined that the cap was GOOD - even though the ESR measured 25 ohms! That manufacturer made a huge mistake by trying to calculate good and bad ESR from entered and measured data. It can't be done reliably. That is why we don't simply have a good/bad indication on our meter scale. Any cap over 3 ohms is suspect. This is my Experience.

Example: 1000uf @6vdc measures 1.5 ohms in circuit - BAD CAP
This is a little brown 1000uf 6vdc cap used in lots of VCR switching power supplies. The Capacitor Wizard® measured 1.5 ohms in circuit. Because the capacitors operating voltage is so low (6vdc) and its used in a switching power supply, I would expect a normal ESR reading of less than 1/2 ohm. Comparison to a known good cap confirmed it should measure less than 1/2 ohm. Replacing this cap cured the trouble. This particular cap goes bad often as I have many in my box of bad caps gathered from local repair companies. If you work on VCRs, I bet you have some too.

Summery:
Measuring ESR is a very good indicator of capacitor failure. For switch mode circuits it is the ***ONLY*** reliable capacitor test, IN or OUT of circuit!. Open caps and caps with really high ESR (over 10 ohms) are easy to find in circuit and need to be replaced. Marginal caps that measure between 1 and 10 ohms ESR require some experience with the Capacitor Wizard® and/or comparison to a known good cap of the same voltage, value, and type. Caps above an operating voltage of 35vdc have a normally higher ESR (around 1 to 3 ohms) than caps of a lower voltage (less than 1/2 ohm ESR).

I know of no perfect formula or rule that can always tell normal ESR from marginal ESR other than comparison to a known good part. The obvious solution is to obtain the capacitor manufacturers data manuals on the EXACT capacitor measured but that is not normally practical. As a technician myself I always follow this rule: ***"If in doubt, replace".*** You will eliminate a lot of recalls and cure many weird and undefinable intermittent problems if you follow this rule.

Doug Jones, Designer of the Capacitor Wizard®