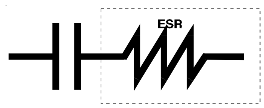
DOUGS TECH NOTES

By Doug Jones

Capacitor Wizard®
IN-CIRCUIT ESR METER

Capacitor Equivalent Series Resistance - Methods of Measurement



E = I x ESR

ESR would be easy to measure if it really existed as the single physical resistor represented by the drawing above! Unfortunately you can't just hang two test leads across the ESR resistor in the drawing above and measure the ESR! The drawing is just a ***symbolic representation*** of the total effect of the many physical quantities that make up ESR! This article is intended to give the reader an understanding of ESR and an introduction into the complexities of measuring ESR.

ESR is a DYNAMIC quantity of a capacitor. ESR does not exist as a STATIC quantity therefore it cannot be measured by a conventional DC ohm meter. ESR exists only when alternating current is applied to a capacitor or when a capacitors dielectric charge is changing states. ESR can be considered to be the TOTAL INPHASE AC resistance of a capacitor. INPHASE means the current(I) and the voltage(E) if measured across the resistive component ESR(R) of a capacitor are INPHASE with each other, just as if ESR(R) were pure resistance (no capacitive or inductive reactance). 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. 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®***!

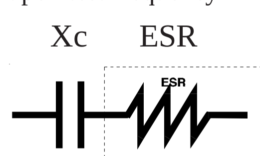
Before the formula E = I x R can be used to compute ESR, we must find a way to "ZERO OUT" or otherwise negate the effects of capacitive reactance. Here's why: Consider a series AC circuit that has an equal capacitive reactance (Xc) and resistance (ESR) of 10 ohms. The total value of these resistances when measured with an AC ohm meter will be the "VECTOR SUM" of the CAPACITIVE REACTANCE and the INPHASE resistance measured in ohms. In this example the total resistance measured by the AC ohm meter will be 14.14 ohms! This vector sum is always ***larger*** than the INPHASE resistance(ESR). For this reason an AC ohm meter is not a valid device to measure ESR ***unless a means of negating the effects of capacitive reactance is applied.*** Three equally valid basic techniques come to mind: (1) Raise the AC ohm meters test frequency so high that the capacitive reactance is so low compared to the expected ESR that the effects of capacitive reactance can be ignored. (2) Electronically subtract the capacitive reactance portion of the vector sum from the total measured AC resistance. (3) Use a sample/hold keying circuit and only "key on" the AC ohm meter when the PHASE ANGLE between the measured AC resistance and the test signal is at 0 or 180 degrees (INPHASE). Each technique has its advantages and disadvantages which will be explained below.

(1) Use a high test frequency: This is the technique the ***Capacitor Wizard®*** uses to "Zero Out" capacitive reactance.

Advantages: Will find open capacitors within the specified range of capacitance, Simple circuit, Reasonable Cost, no calibration required

Disadvantages : Only valid above a certain capacitance value, dependent upon test frequency

Xc = capacitive reactance
Zc = Total AC resistance (Vector Sum of Xc and ESR)
ESR = Equivalent Series Resistance
C = capacitance in Farads
F = Frequency in Hertz



Proof:

If $Xc = 1 / (6.28 * F * C) = 0$ AND $Zc = \sqrt{ESR^2 + Xc^2}$

THEN $Zc = \sqrt{ESR^2 + 0^2} = \sqrt{ESR^2} = ESR$

(2) Electronically subtract capacitive reactance from measured AC ohms:
Uses: Suitable for capacitor manufacturer
Advantages: Measure ESR of any capacitor, can also be adapted to measure capacitance
Disadvantages: Requires operator skills, not suitable for in circuit use, circuit complex, cost more, easily damaged, will not find open capacitors, requires periodic calibration

(3) Sample/Hold Keying:
Uses: Inexpensive method to measure ESR of any capacitor
Advantages: Measure ESR of any capacitor
Disadvantages: Not suitable for in circuit use, will not find open caps, keying must be highly accurate and short duration or ESR readings will be wrong, moderately complex, moderate cost, requires periodic calibration

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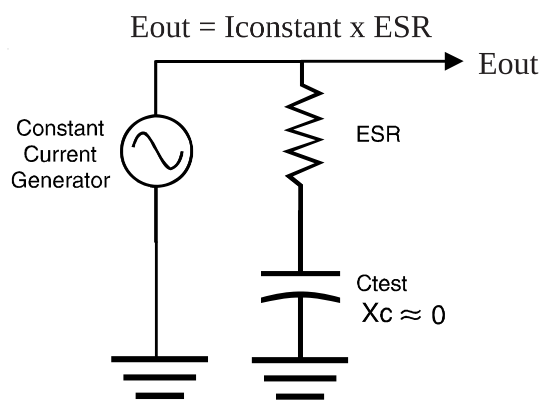
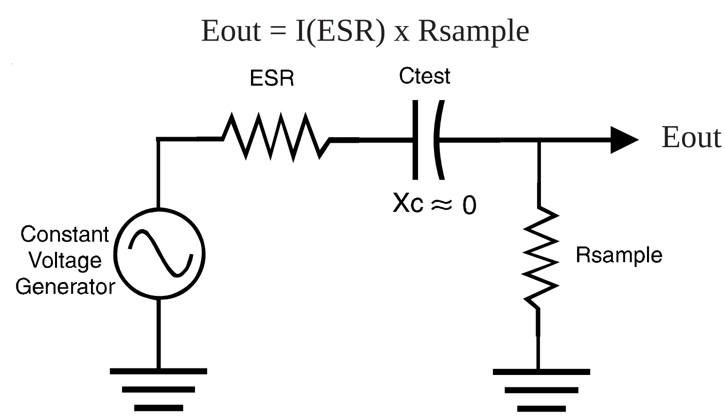
We now have a method to correct for capacitive reactance by using a high test frequency and a valid formula to compute ESR. Let's investigate our formula E=IR.

The formula E = IR has three unknown quantities and it is not usable until we get the formula into the form of ***two known and one unknown quantities***. The quantity we are trying to find is "R" so let's make it the unknown. We are left with "E" (voltage) and "I" (current) as the two variable quantities to be measured. Using conventional test equipment we can drive a capacitor with an ac 100khz signal, measure both "E" and "I" and, using the formula E = I x R, compute "R" (ESR). That method will work but it is clumsy, slow, and requires two pieces of test equipment - an AC volt meter, and an AC ammeter. If we were to hold one of the two variables in the test signal at a known CONSTANT VALUE we could measure the other variable with only one piece of test equipment! We could then calibrate its scale to represent the COMPUTED VALUE of "R"!! We could hold the test signals ***current(I) constant*** and measure the voltage(E) and then use the result to compute the value of "R". Or we could hold the test signals ***voltage(E) constant*** (the Capacitor Wizards method) and measure the test signals current(I). The result could be displayed on an analog or digital meter calibrated in ohms. These two methods of measuring resistance are well known by electronic measurement engineers as the "CONSTANT CURRENT" and "CONSTANT VOLTAGE" methods. Since the formula E = IR is a linear expression, both methods will yield an ohm meter with a ***linear*** meter scale. We could use either digital or analog meter displays.



Constant Current Method



Constant Voltage Method
The ***Capacitor Wizard*** uses this Method

Which Method to Use? Constant Current or Constant Voltage

Constant current has the advantage of conveniently measuring low values of ESR down in the milli ohm range. It however has the disadvantage of applying a theoretical infinitely large voltage across the test terminals to maintain its constant current. This voltage would turn on solid state devices when measuring ESR in circuit. For this reason the constant voltage method was chosen for the Capacitor Wizard.

For convenience we don't want a linear scale because it would require a Range Switch. I modified the basic constant voltage diagram above to include a resistor in parallel with the constant voltage generator that has the desirable effect of logging the ohm scale. It also serves to lower the output voltage to a level far below that required to turn on solid state devices.

Conclusion:

It should now be obvious that a DC ohm meter cannot measure ESR! A Capacitance meter is equally unsuitable for ESR measurements. ESR doesn't exist under the STATIC measurement condition of a DC ohm meter. Capacitance tells one nothing about a capacitors ESR. To measure ESR a ***controlled*** DYNAMIC test condition must be created. To create this test condition the engineer needs to consider a number of "Design Judgement Calls" based upon his experience and the desired end result. Electronic design is an exercise in compromise. There are many ways to design an ESR meter and each has its advantages and disadvantages. The quality of the end product is the result of wise choices made by the design engineer. Some of the important design considerations for an ESR meter are:

Which to use - constant voltage or constant current? At what magnitudes?
Test Signal - Sine wave or square wave? At what frequency?
Do you really want a linear ohm meter scale? How about a LOG scale? Analog or digital?
What are the ***reasonable*** good and bad limits of ESR? What range in ohms? How sensitive does it need to be?
Input - To protect or not protect? What about charged caps?
Power - Battery or A/C adaptor? Battery life?
Physical Size
Cost

All of the above choices were carefully considered in the design of the Capacitor Wizard®. The end product was to be easy to use, durable, small & lightweight, accurate, measure ESR in circuit and inexpensive. I think I have met these design goals with the Capacitor Wizard®!

Doug Jones, Designer of the Capacitor Wizard®