

Measuring Insulation Resistance of Capacitors

A common use of high resistance measuring instruments (often called megohmmeters or insulation resistance testers) is measuring the insulation resistance of capacitors. Such tests are useful to quality engineers in the production of capacitive components, by design engineers to determine suitability for a particular application or at incoming inspection. By the proper application of a megohmmeter type instrument a capacitor's dielectric material can be tested and evaluated in two ways.

First, the DC value of its impedance (resistance) can be determined. This is an important parameter in some types of capacitors such as ceramic or film, where a high value of insulation resistance is a primary reason in choosing them for an application. It may be that a design engineer has determined that his circuit will not work well below a certain value of insulation resistance. In addition, the DC resistance of a capacitor tells something about its quality. Wide variations from unit to unit or consistently low values may indicate a quality problem.

Second, the measurement of the capacitor's insulation resistance with high voltage is an excellent way of detecting flaws in the dielectric material, which might not otherwise make themselves known until long after installation in the user's equipment. Ceramic dielectrics are subject to cracking (as are all ceramic materials), and often these cracks will not be noticed at normal voltages. However, with the application of 500 or 1000 volts, breakdown along the crack edges often occurs resulting in an abnormally low value for DC resistance.

Why are Capacitors hard to Test?

When a capacitor with high insulation resistance is attached to the measurement terminals of the typical high resistance meter, the user may notice some very strange behavior of the instrument. Resistance readings will fluctuate widely in continuous mode, and never settle down. If a pure resistor of similar value is substituted for the capacitor, the readings usually settle down and the instrument measures the device perfectly. This situation can be exhibited on most megohmmeters, whether the instrument has the older analog display or the newer digital display. What is interesting is that, although the variation of readings may be greater on the analog meter, it may be less evident. This is because the resolution on these older instruments is less than those designed today. To the casual user the analog readout that covers one or two decades from zero to full scale will not appear to waiver much for values changing by 2:1. On a digital display even though the readout may be more representative of the actual results in many cases it can be annoying and make readings unreliable to difficult. This phenomenon is caused by the way that megohmmeters measure resistance.

What Does That Look Like?

Figure 1 is a standard way of building an operational amplifier gain stage used in the detector circuit of many types of instruments. The input resistor (R_{in}) is actually the unknown (DUT). The feedback resistor (R_f) is a range resistor selected by a range switch or software when auto ranging is employed, to match the level of current flowing into the detector. This range resistor is very stable and its value must be known precisely or measured during the calibration of the instrument. The voltage out of the detector then depends upon the input voltage and the value of R_{in} (the unknown). The value of V_{in} is known and accuracy verified when the instrument is calibrated, so R_{in} is the only variable.

The best way to understand all this is to assume a set of test conditions, with the instrument set to its more sensitive range (1nA full-scale) and a feedback resistor of $2G\Omega$ ($2 \times 10^9 \Omega$). If the unknown value was $200G\Omega$ ($2 \times 10^{11} \Omega$) and 100 volts applied to it, the current flowing would be 0.5nA or half scale. This results in an output voltage of 1V since the gain of the detector is $R_f/R_{in} = 2G\Omega/200G\Omega = 0.01$.

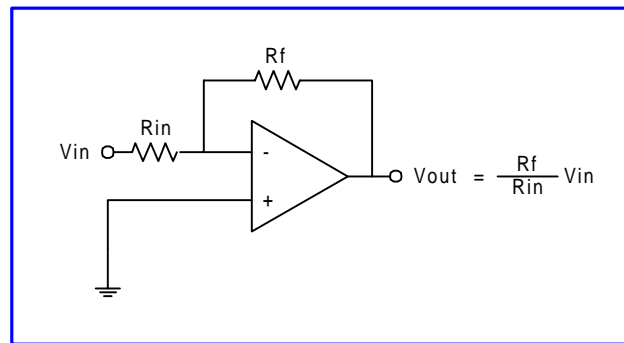


Figure 1: Typical Op-Amp Circuit

If the unknown is a capacitor, however, things get a little more complex.

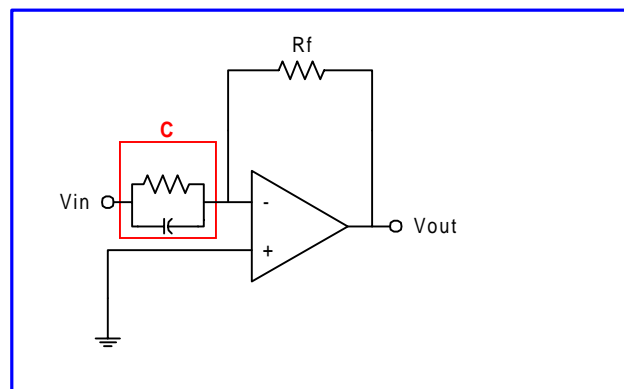


Figure 2: Capacitor Equivalent Circuit

A Real Capacitor

A "real" capacitor consists of an ideal capacitor in parallel with its insulation resistance. This ideal capacitor has infinite resistance at DC. As frequency goes up, however, its reactance decreases according to:

$$X_c = \frac{1}{2\pi f C}$$

where f is the frequency in hertz, and C is the capacitance in farads.

Notice that we use the symbol Xc for the reactance of the pure capacitor, to distinguish from its insulation resistance, R.

In this example we'll consider a ceramic capacitor of 2.2uF (2.2x10⁻⁶ farads) with a typical minimum insulation resistance of 2GΩ. If a capacitor is tested at 200V and measures a dielectric leakage current of 10nA the insulation resistance must be 20GΩ. For 10nA the instrument would be on the 100nA full-scale range with a feedback resistor of 20MΩ. In this case the gain of the detector is 20MΩ/20GΩ, or .001. The output voltage would then be [(0.001) • (200V)], or 200mV.

This all assumes DC. As soon as we consider AC, things change. At a frequency of 1Hz, the "ideal" capacitor in this unit will have a reactance, Xc, equal to:

$$\frac{1}{6.28(1)(2.2 \times 10^{-6})} = 7.2 \times 10^4$$

The AC gain of the detector would be:

$$\frac{20 \text{ Mohms}}{7.2 \times 10^4} = 270$$

The source of 1Hz voltage on the input could be any one of several things. It could be room noise picked up by the meter leads, or small fluctuations in the instrument power supply. Even moving the leads (as on an automatic handler) can induce low frequency AC on them. Generally, the induced AC voltage will be small perhaps 1mV, but the detector would multiply this by 270 to give an output of 270mV. This is higher than the "true" reading of 200mV. The noise from this 1mV source can cause the result to vary by 135%.

So What Do You Do?

This situation could be improved by shielding the device under test (DUT) and the test leads from the AC noise. Indeed, at high values of resistance (above 1GΩ) low noise shielded cables are highly recommended. The real solution to the problem of capacitor testing comes from remembering the cause - high AC gain. If we can reduce the AC gain, we can eliminate the problem.

AC Gain Compensation

Recall that the AC gain is R_f/X_c . If we were to add a compensation resistor, R_c of $1M\Omega$ in series with the DUT, the AC gain would become:

$$\frac{R_f}{R_c + X_c} = \frac{20 \text{ Mohms}}{1 \text{ Mohm} + 7.2 \times 10^4} = 18.65$$

This is a lot better than 270! With the same 1mV of noise in, we get only 18.65mV out compared to the "true" signal of 200mV. The series resistor, R_c , has reduced the AC gain to 9.35% of the DC gain, a tolerable level.

DC Errors

At this point, one might worry that, although we've solved the instability problem, we've introduced an error term of $1M\Omega$. We have! But, so what? Remember, we're in the business of trying to measure $2G\Omega$ versus an induced error of $1M\Omega$ ($=.001G\Omega$). The error is .05%.

At lower values of DC resistance, a $1M\Omega$ resistor may be significant, so a smaller compensation resistor should be used. Capacitors with a dielectric leakage current greater than 10uA are simply too "leaky" to exhibit the fluctuations of readings in the first place. Lastly, the addition of series R_c will increase the charge time somewhat. This is unavoidable, but in most cases will be inconsequential.

Procedure Using QuadTech 1865 Megohmmeter/IR Tester

The QuadTech 1865 is supplied with two quieting resistors that can be placed in series with the DUT when measuring low leakage capacitors.

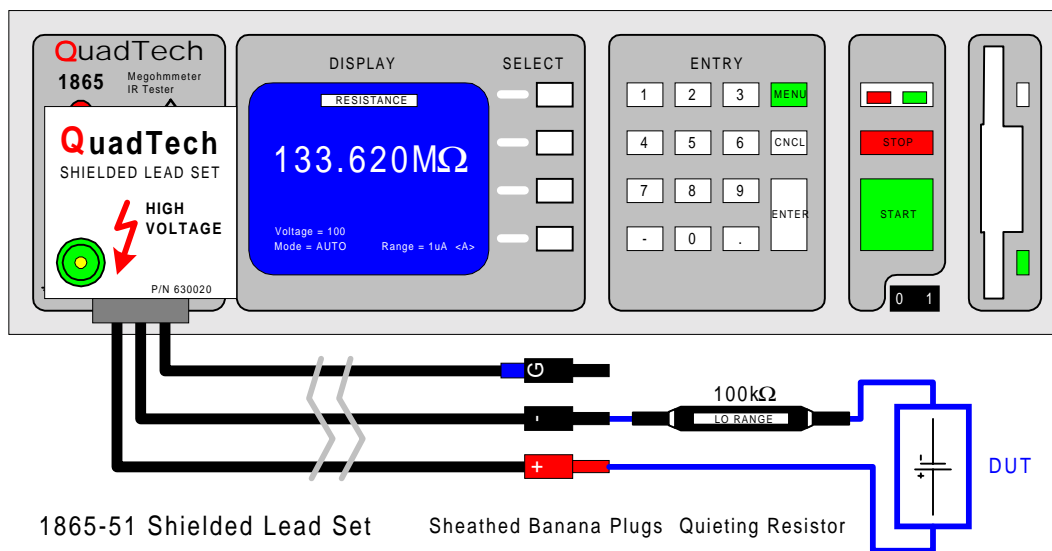


Figure 3: 1865 Megohmmeter with Quieting Resistor

Conclusion

To determine the proper adapter to use, simply measure several devices on the 1865 with Auto Range selected. Generally, no resistor is required for the 100uA and 1mA ranges. This can be confirmed by looking for instability in the readings over a measure time of, say, ten seconds. Note that, during this time, the readings on a non-charged capacitor will change as the DUT charges up. But the reading should increase steadily, not fluctuate up and down. If the readings seem to fluctuate, a quieting resistor may be required. Refer to Table 1 to help select the proper resistor for the measurement range being used.

There may be cases (hard to predict) where a higher value compensating-resistor is required on the low current range (1nA). In general, the two resistors supplied with the 1865 unit should suffice. The Current Range is calculated by dividing the Test Voltage by the Resistance Limit.

$$I_{\text{RANGE}} = V_{\text{TEST}} / R_{\text{LIMIT}}$$

Table 1: Choosing the Correct Quieting Resistor

Current Range	Quieting Resistor	(QR) Value
1nA	HI RANGE	1MΩ
10nA	HI RANGE	1MΩ
100nA	LO RANGE	100kΩ
1μA	LO RANGE	100kΩ
10μA	LO RANGE	100kΩ
100μA	Not Required	N/A
1mA	Not Required	N/A

For complete product specifications on the 1865 Megohmmeter/IR Tester or any of QuadTech's products, visit us at <http://www.quadtech.com/products>. Call us at 1-800-253-1230 or email your questions to info@quadtech.com.

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