Helpful Tips On Measuring Capacitance

Capacitors are one of the many components used in electronic circuits. The basic construction of a capacitor is a dielectric material sandwiched between two electrodes. The different types of capacitors are classified according to their dielectric material. Figure 1 shows the general range of capacitance values according to their dielectric classification. Capacitance C, dissipation factor D, and equivalent series resistance ESR are the parameters usually measured. Capacitance is the measure of the quantity of electrical charge that can be held (stored) between the two electrodes. Dissipation factor, also known as loss tangent, serves to indicate capacitor quality. And finally, ESR is a single resistive value of a capacitor representing all real losses. ESR is typically much larger than the series resistance of leads and contacts of the component. It includes effects of the capacitor's dielectric loss. ESR is related to D by the formula ESR $=D/\omega C$ where $\omega = 2\pi f$. These parameters are discussed in more detail in QuadTech's, "A Guide to LCR Measurements."

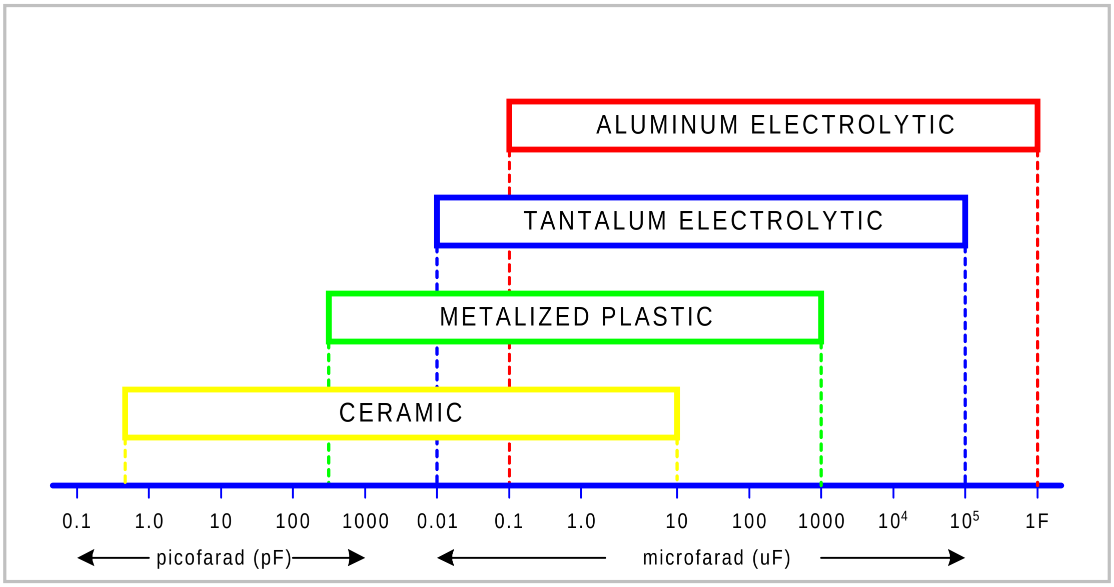

Figure 1: Capacitance Value by Dielectric Material

Series or Parallel Measurements

New capacitor applications, manufacturing techniques and advances in impedance measurement instrumentation have changed capacitor testing into what might be considered a complex process. A typical equivalent circuit for a capacitor is shown in Figure 2. In this circuit, C is the main element of capacitance. Rs and L represent parasitic components in the lead wires and electrodes and Rp represents the leakage between the capacitor electrodes.

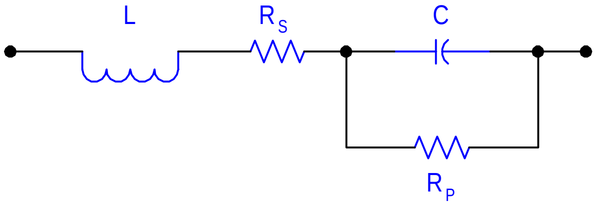

Figure 2: Capacitor Equivalent Circuit

When measuring a capacitor these parasitic components must be considered. Measuring a capacitor in series or parallel mode can provide different results. How the results differ can depend on the quality of the device, but the thing to keep in mind is that the capacitor's measured value most closely represents its effective value when the more suitable equivalent circuit, series or parallel, is used. To determine which mode is best, consider the impedance magnitudes of the capacitive reactance and Rs and Rp. For example, suppose the capacitor modeled in Figure 3 has a small value. Remember reactance is inversely proportional to C, so a small capacitor yields large reactance that implies that the effect of parallel resistance (Rp) has a more significant effect than that of Rs. Since Rs has little significance in this case the parallel circuit mode it should be used to more truly represent the effective value. The opposite is true when C has a large value. In this case the Rs is more significant than Rp thus the series circuit mode become appropriate. Mid range values of C requires a more precise reactance-to-resistance comparison but the reasoning remains the same.

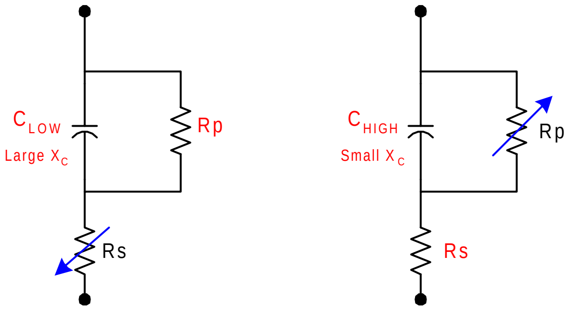

Figure 3: Capacitance Reactance: R_S and R_P

Connection to DUT

The rule of thumb for selecting the circuit mode should be based on the impedance of the capacitor:

- Above approximately 10 kΩ - use parallel mode
- Below approximately 10 Ω - use series mode
- Between these values - follow manufacturer's recommendation

Translated to a 1kHz test: Use Cp mode below 0.01 µF and Cs mode above 10 µF; and again between these values either could apply and is best selected based on the manufacturer's recommendation. The menu selection on the QuadTech 7000 Series Meters makes mode selection of Cs, Cp or many other parameters easy with results clearly shown on the large LCD display.

High values of capacitance represent relatively low impedances, so contact resistance and residual impedance in the test fixture and cabling must be minimized. The simplest form of connecting fixture and cabling is a 2-terminal configuration but it can contain many error sources. Lead inductance, lead resistance and stray capacitance between the leads can alter the result substantially. A 3-terminal configuration, with coax cable shields connected to a guard terminal, can be used to reduce effects of stray capacitance. This is a help to small value capacitors but not the large value capacitors because the lead inductance and resistance still remain. For the best of both worlds a 4-terminal configuration, shown in Figure 4, (often termed Kelvin) can be used to reduce the effects of lead impedance for high value capacitors. Two of the terminals serve for current sourcing to the device under test and two more for voltage sensing. This technique simply removes errors resulting from series lead resistance and provides considerable advantage in low impedance situations.

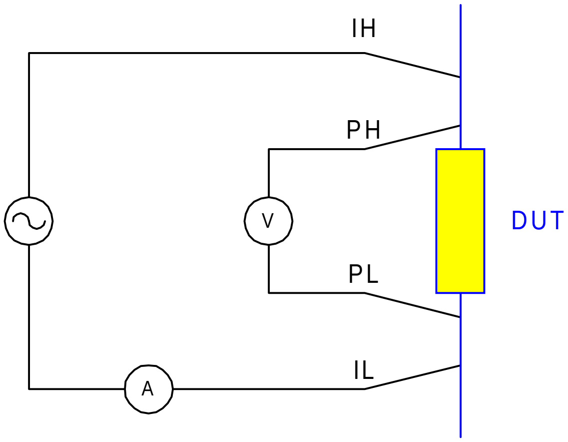

Figure 4: Kelvin (4-terminal) Connection

Besides a 4-terminal connection made as close as possible to the device under test, a further enhancement to measurement integrity is an OPEN/SHORT compensation by the measuring instrument. The open/short compensation when properly performed is important in subtracting out effects of stray mutual inductance between test connections and lead inductance. The effect of lead inductance can clearly increase the apparent value of the capacitance being measured. Open/Short compensation is one of the most important techniques of compensation used in impedance measurement instruments. Through this process each residual parameter value can be measured and the value of a component under test automatically corrected.

Other Factors to Consider

One of the most important things to always keep in the forefront is a concerted effort to achieve consistency in techniques, instruments, and leads/fixtures. This means using the manufacturers recommended 4-terminal test leads (shielded coax) for the closest possible connection to the device under test. The open/short compensation should be performed with a true open or short at the test terminals. For compensation to be effective the open impedance should be 100 times the DUT impedance and the short impedance 100 times less than the DUT impedance. Of equal importance, when performing open/short zeroing, the leads must be positioned exactly as the device under test expects to see them.

Charged Capacitors

For safety sake of the user and the measuring instrument to which capacitors are connected, make sure capacitors are fully discharged before proceeding with measurements. It is important to remember that once a capacitor is charged it gives up its total charge reluctantly because of the phenomenon termed "dielectric absorption." High value capacitors are the most likely candidates for charge buildup. If stored unshorted for a long time then they should be discharged before handling or connection to the measuring instrument.

Test Cables

If test cables are extended from an instrument to the DUT without regard to their length it will cause an error. Any precision instrument must be calibrated under known conditions. That's not to say that user fabricated or custom cables are not possible. Should a custom cable length become necessary make sure a cable with equivalent electrical specifications is used and the instrument properly calibrated. QuadTech makes available an optional 7000 Series Calibration Kit (NIST traceable) for this purpose and for periodic on-site calibration.

Temperature

Temperature is another factor that can affect the measured value of a capacitor. One needs to keep in mind that the temperature difference between a controlled environment (calibration laboratory) and an uncontrolled environment (production area) can differ by several degrees C. A device is also subject to temperature rises due to extensive component handling or even excitation from the measurement test signal.

Frequency

When measuring almost any component, frequency dependency is common because of the existence of parasitics. Parasitics are a combination of impedance elements that may be made up of unwanted resistance or inductance in capacitors. There is no such thing as a pure component.

Test Signal Level

The AC test signal applied during testing of a capacitor may also affect the measurement result. This dependency varies based primarily on the dielectric material used to make the capacitor.

One More Factor to Consider

Shielding or Guarding

Some of the various measurement techniques allow for shielding or guarding and there is a difference between the two. Shielding minimizes the amount of interference induced into a measurement circuit as the result of electromagnetic fields. In simplest terms a shield consists of an enclosure around the component being measured and this enclosure is usually connected to ground. Measurements referenced to ground are subject to influence by what is generally called common-mode sources (potential differences between the measured device and the measuring reference). Guarding techniques help minimize the effects of these common-mode sources. A measurement instrument is termed "guarded" when it has an additional shield between its LOW terminal and ground, as shown in Figure 5. This effectively increases the leakage impedance between the LOW and ground. The guard shunts common-mode currents around the measuring circuit, thus minimizing measurement errors caused by ground loops.

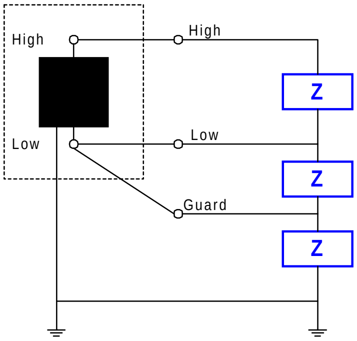

Figure 5: Guard Terminal

Putting It All Together

Today's instrumentation has made component testing easier, faster and provided measurement results that are more reliable. The QuadTech 7000 Series LCR Meters provide that all-important consistency of fixturing, including 4-terminal connections, (guarded or not), and open/short compensation. The 7000 units have 321,000 programmable frequencies to 2 MHz and a wide selection of AC test voltage and current. Depending on the specific capacitor testing application, units are also available with added protection from charged capacitors or for high speed production testing.

For complete product specifications on the 7000 Series Precision LCR meters 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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