CIRCUIT DESIGNER'S NOTEBOOK

Capacitor ESR Measurement Technique

Equivalent Series Resistance (ESR) is the summation of all losses resulting from dielectric (Rsd) and metal elements (Rsm) of the capacitor. Dielectric loss tangent of ceramic capacitors is dependant upon specific characteristics of the dielectric formulation, level of impurities, as well as microstructural factors such as grain size, morphology, and porosity (density). Metal losses are dependent on resistive characteristics of the electrode and termination materials, as well as the associated frequency dependent losses in electrodes due to skin effect. ESR is a key parameter to consider when utilizing capacitors in RF designs. A reliable and repeatable test method must be implemented in order to establish valid capacitor ESR characterizations.

Measurement Methodology:

Measuring the ESR of high Q ceramic chip capacitors requires a test system with an inherent Q higher than the device under test (DUT). A high Q coaxial resonant line is most commonly utilized for these measurements. The coaxial line resonator is typically constructed from copper tubing and a solid copper rod for its center conductor. The DUT is placed in series between the center conductor and ground.

Before performing ESR measurements the unloaded characteristics of the resonant line must be established. This is accomplished by providing RF excitation to the shorted coaxial line and ascertaining the 1/4 and 3/4 lambda bandwidth. The line is then open circuited after which the 1/2 and 1 lambda bandwidth measurements are established. This data is used to characterize the unloaded Q of the resonant line, fixture resistance and resonant frequency. The unloaded Q of the line is typically in the order of 1300 to 5000 (130MHz to 3GHz) with a fixture resistance rfo in the range of 5 to 7 milliohms.

The capacitor sample is placed in series with a shorting plunger located at the low impedance end of the line. The generator is tuned for a peak resonant voltage, and then re-tuned to 6dB down from the peak voltage on both skirts of resonance. A loosely coupled RF millivoltmeter probe located at the high impedance end of the line (approximately at 1/4 wavelength from the shorted end) will measure RF voltage at the 6dB points.

The DUT perturbs the Q of the line changing the resonant frequency and bandwidth as compared to the unloaded line. The corresponding 6dB down frequencies referred to as fa and fb are used in the calculation of the capacitor's ESR. This process is referred to as the Q perturbation method. See Figure 1.

Note: Since the capacitive reactance of the test sample is in series with the line, it will shorten its electrical length depending on capacitor value. Values above 10pF will yield reasonable measurement accuracies however, as we approach 1pF the measured ESR may develop substantial errors. The small capacitance values exhibiting high Xc will cause the electrical length of the line to drastically change. The reactance of the line is equal and opposite to that of the DUT, at resonance.

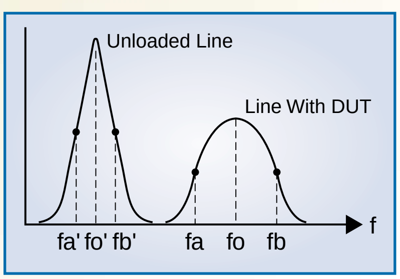


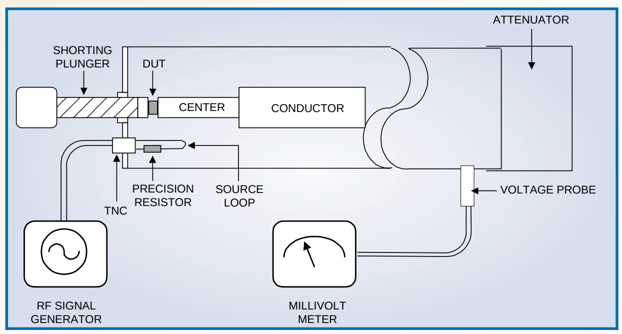
Figure 1: (Two Bandwidth Curves)

ESR Test System:

The test system most commonly used consists of a coaxial line (Boonton Model 34A) nominally (57.7cm) in length, with a resonant frequency of 130MHz and a characteristic impedance of 75 ohms. This impedance is chosen because it yields the highest line Q. Different line lengths may also be used for other frequency ranges.

A signal generator is connected to the low impedance end of the line and terminates in a non-inductive precision resistor. The resistor is mounted on a TNC connector and inserted into the DUT end of the line. It has an exposed loop that serves to loosely couple RF energy into the line. An RF excitation of 1 mw (0dBm) drives the shorted line through the source loop. The generator is swept until a peak resonant voltage is displayed on the RF millivoltmeter. The source loop is physically rotated until a 3 millivolt reference voltage is achieved at the high impedance end of the line. This procedure insures that the RF excitation does not load the line. See Figure 2.

An RF probe located at the high impedance end of the line is connected to a millivoltmeter to measure RF voltage at resonance. From these measurements the bandwidth and Q can be established. ESR is calculated by equating the change in bandwidth (BW) and Q, as compared to the initial unloaded shorted line condition. The BW data is put into an equation along with the initial line characterizations to calculate the ESR of the test sample. ESR measurements described here are performed in the series mode and can be achieved up to about 3 GHz.



See Figure 2: (Coaxial Resonator with DUT)

Factors Affecting ESR Measurement :

- Frequency measurement data for establishing BW require a minimum of four decimal places however, five places is desirable.
- Source and measurement probes must be loosely coupled to the line.
- The high impedance end of line should be shielded to reduce loss due to radiation to preserve Q. The shield is a cut-off attenuator offering16DB attenuation per radius.
- Placement of the DUT in the line fixture should be consistent.
- Keeping fixture contact surfaces clean is essential for good repeatability.

Richard Fiore
Sr. RF Applications Engineer
American Technical Ceramics Corp.