Measure Capacitance of Class-II and Class-III Ceramic Capacitors

This application note addresses proper capacitance measurement techniques of Class-II (X7R/X5R) and Class-III (Y5V/Z5U) ceramic capacitors and identifies common errors that are made upon incoming inspection or after board assembly. The methods outlined below highlight these errors and provides instruction for better electrical measurements and results.

Measurement Method for Capacitance

Overview

There are many instruments that can be used to measure the electrical properties of a capacitor. Instruments that measure capacitance, measure the impedance of a capacitor using a known AC voltage and frequency. The capacitance value is then extracted from the impedance measurement. Table 1 illustrates the voltage and frequency parameters recommended for measurement of Class-II and Class-III ceramic capacitors.

In this application note, the capacitor under test may also be referred to as a device under test or DUT.

Capacitance	Voltage	Frequency
$\leq 10\,\mu$F	1.0 Vrms	1 kHz
$>10\,\mu$F	0.5 Vrms	120 Hz

Table 1. Voltage and Frequency for Class-II and Class-III capacitance measurements

Output Impedance of the Instrument

All capacitance measurement equipment will have a known output impedance greater than zero. The output impedance will vary based upon the model and/or capacitance measurement range of the equipment. Impedance is a critical factor in the measurement of capacitance, especially when the impedance of the DUT approaches the impedance of the instrument. Figure 1 shows the general schematic of a capacitance measurement with the instrument source impedance.

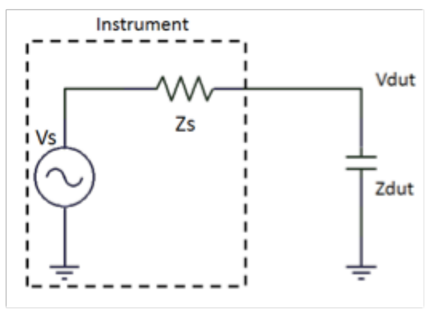

Figure 1. Schematic of Capacitance Measurement with Source Impedance

Instrument Voltage versus Actual Voltage on DUT

When a DUT is being measured for capacitance, the source voltage of the test equipment must be set to the desired measurement voltage. In the case of a 10 μF capacitor, the source voltage would be 1.0 Vrms based on Table 1. If the instrument's output impedance is high enough, it will cause a voltage divider and reduce the actual test voltage across the DUT.

Equation 1 shows the voltage across the DUT during the measurement. From the equation, as the source impedance (Zs) approaches the impedance of the DUT, there will be a voltage drop across the part.

$$Vdut = Vs * \frac{Zdut}{Zdut + Zs}$$

Equation 1. Voltage across the DUT during measurement

Electronic Components KEMET CHARGED.

Using this equation, we can plot the percent voltage drop across the DUT during measurement as a function of capacitance. Figure 2 shows this plot which illustrates a drop in voltage at around 100 nF with only 15% of the voltage at 10 μF. The voltage steps up to around 80% just after 10 μF, due to the change in frequency.

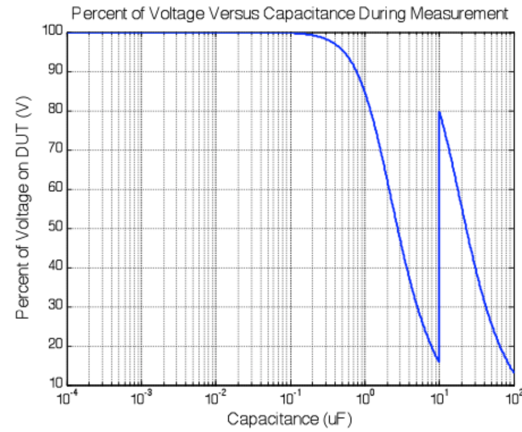

Figure 2. Percent of Voltage across DUT versus Capacitance

Example 1:

Agilent E4980 LCR meter measuring capacitance of a 10 μF 10% X5R capacitor.

From Table 1, the desired voltage and frequency are 1.0 Vrms and 1 kHz, respectively. In this example, the output impedance of the test meter is 100 ohms based on the meter's specifications. At 1 kHz, the DUT impedance will be j*15.91 ohms. Using Equation 1, the voltage across the DUT will be approximately 157 mV. Thus, only about 15% of the output voltage is actually applied to the DUT. Because of the resulting voltage drop across the DUT, the capacitance measurement is invalid since it does not meet the test specifications outlined in Table 1. It is important to maintain a constant test voltage while measuring capacitance. Figure 3 shows an actual measurement of a 10 μF capacitor using the Agilent E4980 LCR meter. The measured AC voltage across the capacitor is only 186 mV, far below the 1 Vrms specification. The result of the test falsely indicates that the capacitor does not meet its rated specification. The next section will show how to correct for this anomaly and limitation.

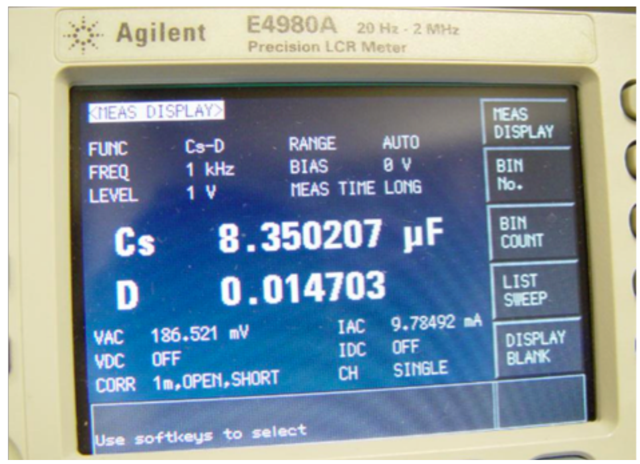

Figure 3. Capacitance measurement of 10 μF capacitor.

How do we correct for the voltage drop?

To ensure the voltage across the DUT is maintained at the desired level, the output voltage must be increased on the test meter to adjust for the voltage divider. Some capacitance measurement equipment will have a function called Auto-Level Control (ALC) which does this automatically. This feature enables the instrument to automatically increase the source voltage to meet the set voltage. When considering the case in Example 1, without the ALC function, the voltage across the DUT was 186 mV with a set voltage of 1.0 Vrms. If we enable the ALC function, the instrument will automatically raise the source voltage to achieve the desired 1.0 Vrms across the DUT. Figure 4 shows a measurement of the same 10 μF capacitor using the Agilent E4980 LCR meter with the ALC feature set to ON. The result of the test shows the capacitor measures within the 10% tolerance range.

Figure 4. Capacitance measurement of 10 μF capacitor using ALC function.

Aspects of Class-II and Class-III Dielectrics

Capacitance with Applied Voltage

The measured capacitance of Class-II (X7R, X5R, X8R, etc.) and Class-III (Y5V, Z5U, etc.) devices will change when the applied voltage is increased and decreased. The relative permittivity of these dielectric materials are affected by both AC and DC voltage. The severity of the change depends on the magnitude of the voltage, dielectric type, and thickness of the dielectric. Figure 5 illustrates typical capacitance change versus AC voltage of a Class-II capacitor. Figure 6 illustrates typical capacitance change versus DC voltage on a 16VDC rated part. Based on the plots in Figures 5 and 6, it is important to note that both AC and DC applied voltages must be considered when making a capacitance measurement.

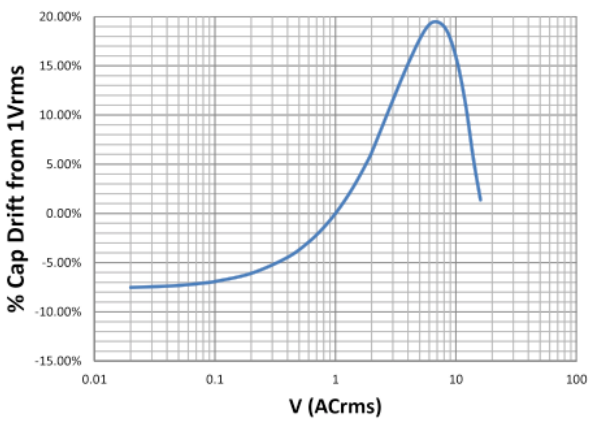

Figure 5. Capacitance versus AC Voltage

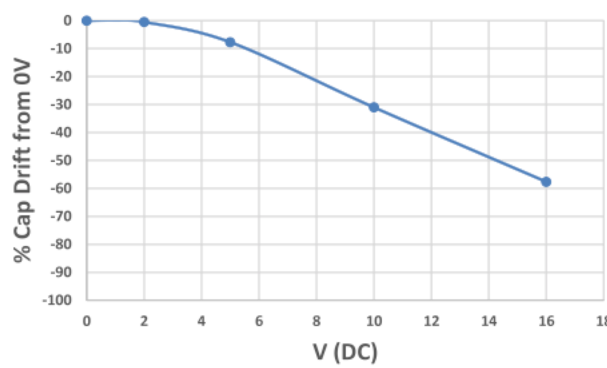

Figure 6. Capacitance versus DC Voltage

Aging

In addition to changing capacitance with applied voltage, Class-II and Class-III ceramic capacitors exhibit a predictable change in capacitance over time, known as aging. Most Class-II and Class-III capacitors are constructed of ferroelectric dielectric materials. The aging phenomenon is an intrinsic and natural property of these dielectric materials, and is commonly reported in terms of a percentage drop in capacitance per decade of time. Ceramic capacitor manufacturers identify the aging rate of their ceramic materials in catalogs and/or product documentation. Aging rates typically range between 0.5% to 5.0% for Class-II dielectric materials and higher for Class-III. Manufacturers utilize the aging rates to set factory test limits, which bring the capacitance within the specified tolerance at future time (also known as referee time) to allow for customer receipt and use.

De-aging

The reversal of the aging process is often referred to as de-aging. It is achieved by heating the dielectric material above its Curie temperature. The amount of de-aging depends on both the elevated temperature and length of time at that temperature. After a period of time, the capacitor will regain the capacitance lost during the aging process.

It is important to consider the effects of de-aging when measuring capacitance after board assembly. The Curie temperature of the dielectric material is typically exceeded during the soldering process. Immediately following a de-aging event like soldering, the capacitance will often measure high. Following a de-aging event, capacitance measurements should be indexed to the manufacturer's established referee times.

Manufactures assign referee times based upon the aging properties of their dielectric materials. These times typically coincide with the last de-aging event that occurs during the manufacturing process (often referred to as "last heat"), and identify the period of time that must pass after the last heat before the capacitor is deemed to be "within tolerance." In other words, capacitors are shipped to be within tolerance at this specified time. KEMET's assigned referee times are part number specific at either 48 or 1000 hours.

For reference, the Curie temperature for Barium Titanate (BaTiO3), which is used in the manufacturing of most Class-II and Class-III capacitors, is about 125°C. To achieve adequate de-aging, KEMET recommends heating the capacitors to 150°C for one hour.

Note on Class-I (C0G)

Class-I ceramic capacitors (e.g., C0G) are made using non-ferroelectric ceramic dielectrics, which is not affected by the aging phenomena and only slightly affected when voltage is applied to them. The C0G capacitors exhibit ≤30ppm/°C change in their capacitance over a broad temperature range from -55°C to +125°C, which is why they are also referred to as "temperature compensating capacitors."

Conclusion

Capacitor manufactures specify voltage and frequency parameters for measurement of Class-II and Class-III ceramic capacitors. In order to determine whether a capacitor meets its rated specification, it is critical to measure the part under the conditions provided by the manufacturer. It is equally important to choose measurement instruments with: (1) a low enough source impedance so that the device impedance does not affect the measurement, or (2) a feature which allows for the automatic adjustment of source voltage to account for the voltage divider.

Bibliography

[1]. "Why that 47 μF capacitor drops to 37 μF, 30 μF, or lower," John Prymak, Mike Randall, Peter Blais, Bill Long, CARTS USA March 2008, 28th Symposium for Passive Electronic Components, Newport Beach, CA.

About KEMET

KEMET Corporation is a leading global supplier of electronic components. We offer our customers the broadest selection of capacitor technologies in the industry, along with an expanding range of electromechanical devices, electromagnetic compatibility solutions and supercapacitors. Our vision is to be the preferred supplier of electronic component solutions demanding the highest standards of quality, delivery and service.

For more information on this product go to
http://www.kemet.com/an1005 or scan the QR code: