Capacitance and Dissipation Factor Measurement of Chip Multilayer Ceramic Capacitors

Innovator in Electronics

muRata

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1. Introduction

When you measure a high dielectric MLCC capacitor (X7R-characteristic or Y5V-characteristic) using a LCR meter, there may be a case you can not obtain a reasonable capacitance value within its nominal range.

As capacitance and dissipation factor of these Temperature characteristic MLCC capacitors significantly change according to the measurement temperature, voltage (AC, DC) and frequency. One of the reasons of such a failure to obtain a reasonable capacitance can be that your have not performed the measurement correctly using specified measurement conditions. Another reason may be an incorrect meter setting or use of measurement equipment that does not have the capability needed for accurate measurement.

Solutions for the former issue is to fully understand characteristics of MLCC capacitors and the appropriate “three (3) measuring conditions”, i.e. measuring temperature, voltage (AC and DC) and frequency. The actual measurement conditions of capacitance and dissipation factor of high dielectric ceramic capacitors are shown in Table 1 below.

The temperature used for these conditions is 25 degree:

Table 1 Measuring Conditions

Nominal Capacitance	Measuring Frequency	Measuring Voltage
C ≤ 10μF (10V or greater)	1 ± 0.1kHz	1.0 ± 0.2Vrms
C ≤ 10μF (6.3V or less)	1 ± 0.1kHz	0.5 ± 0.1Vrms
C > 10μF	120 ± 24Hz	0.5 ± 0.1Vrms

The solution for the second issue is to understand the capability of the measurement equipment to be used and to confirm that it meets the measurement conditions listed in Table 1.

In this brochure, we will first describe the characteristics of the MLCC capacitors that can affect capacitance and dissipation factor measurement. Next, the measuring principle of the LCR meters used for actual measurement is described, then an example of the correct method used to measure the capacitance and dissipation factor of the MLCC capacitors is explained.

2. Characteristics of the MLCC (Multilayer Ceramic Chip) Capacitors

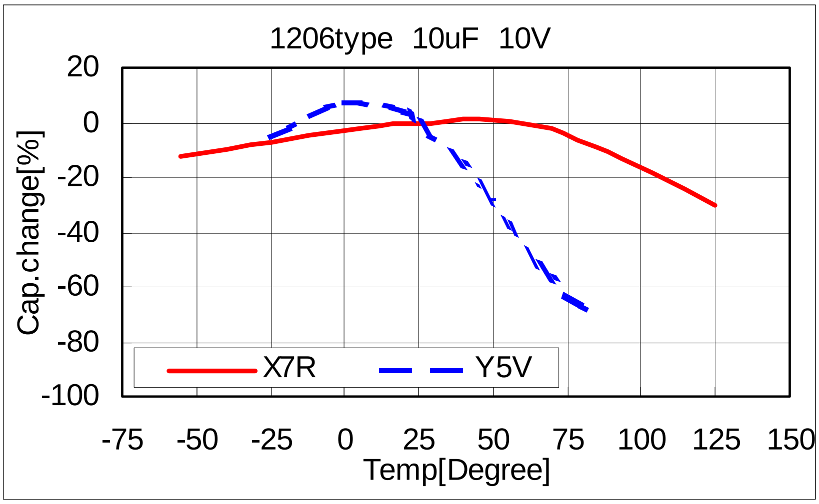
The MLCC capacitors have excellent features such as small size, high reliability, low impedance and no-polarity, etc., but on the other hand, they have demerits such as capacitance change with temperature or voltage change.

In the following sections, measurements of 1206 type 10μF X7R-characteristic and Y5V-characteristic MLCC capacitors are taken up as examples to explain the various characteristics that can affect the measurement of capacitance and dissipation factor.

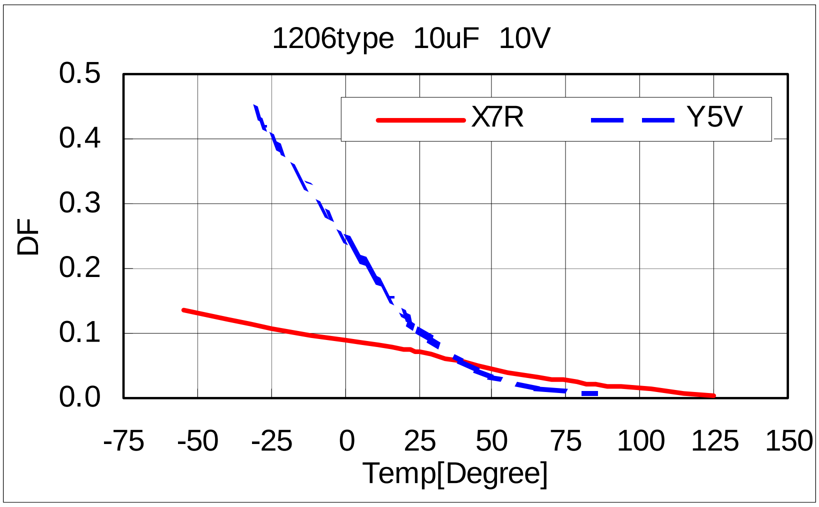
2-1. Temperature Characteristic

Temperature characteristics of MLCC capacitors are shown in Fig.1 below:

At the measurement conditions of 1kHz, 1Vrms, whereas capacitance change ratio of the X7R-characteristic is within ± 10% at maximum, The Y5V-characteristic capacitor is allowed to over a wider range of + 30% / -80%. Dissipation factor also changes according to measurement temperature, which tends to go up in lower temperatures for both X7R- and Y5V- characteristic capacitors.



(a) Capacitance Change Ratio



(b) Dissipation Factor (DF)

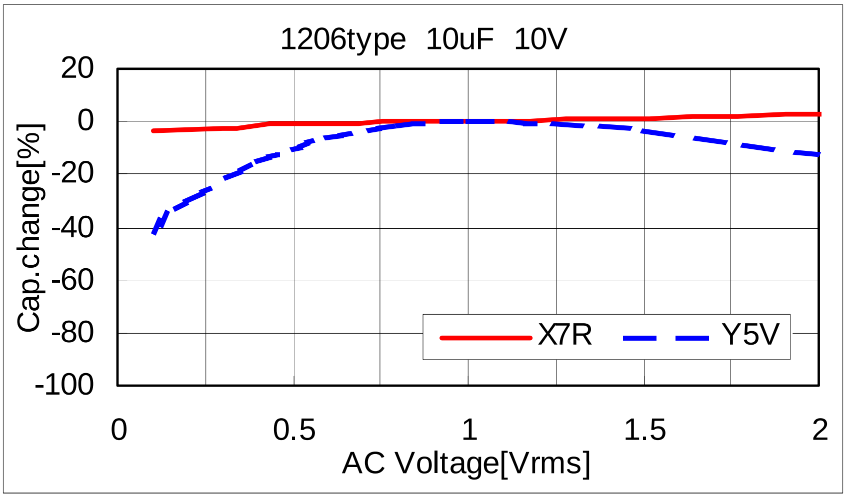
Fig.1 Temperature Characteristic

2-2. Voltage Characteristic

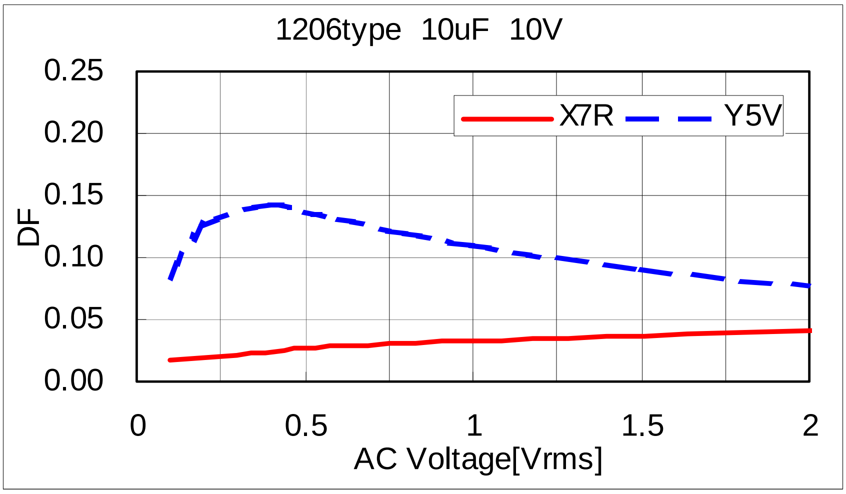
(1) AC Voltage Characteristic

The AC voltage characteristics of X7R- and Y5V-characteristic MLCC capacitors are shown in Fig.2 below:

At the measurement conditions of 25 degree, 1kHz, while capacitance change ratio of the X7R-characteristic capacitors is within ± 5% at maximum, the capacitance of Y5V-characteristic capacitors drops by 50% at the maximum and changes according to applied AC voltage level. Although the dissipation factor of Y5V-characteristic capacitor also changes significantly according to the measurement voltage, the X7R-characteristic capacitor shows very little change.



(a) Capacitance Change Ratio



(b) Dissipation Factor (DF)

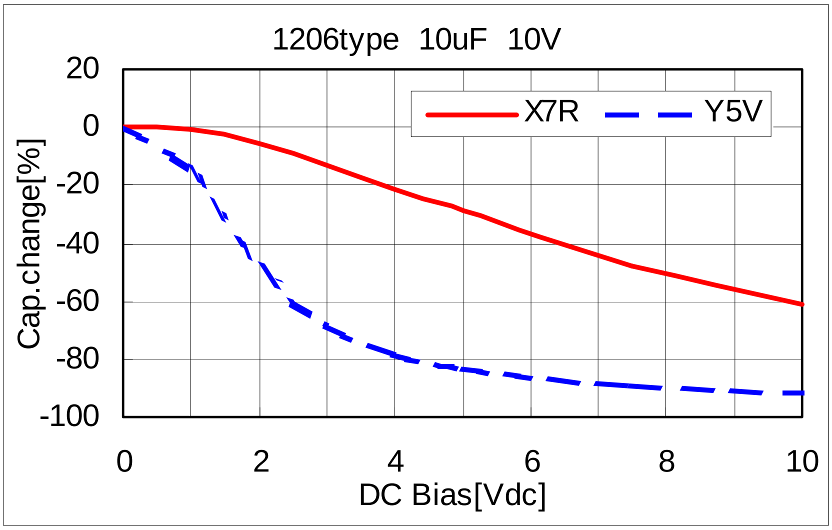
Fig.2 AC Voltage Characteristic

(2) DC Bias Characteristic

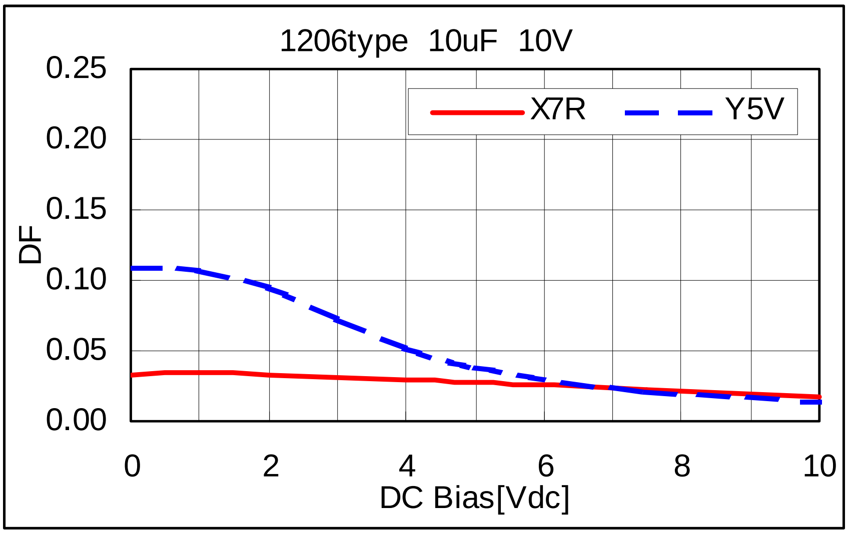
The DC bias characteristics of X7R- and Y5V-characteristic MLCC capacitors are shown in Fig.3 below:

At the measurement conditions of 25 degree, 1kHz, 1vrms, the capacitance of the X7R-characteristic capacitor drops by a maximum of 60% according to DC bias voltage applied, while the capacitance of the Y5V-characteristic capacitor drops as much as 90%.

The capacitance of MLCC capacitors decreases as applied DC bias voltage increases. Also dissipation factors of those capacitors comes down as DC bias voltage goes up.



(a) Capacitance Change Ratio



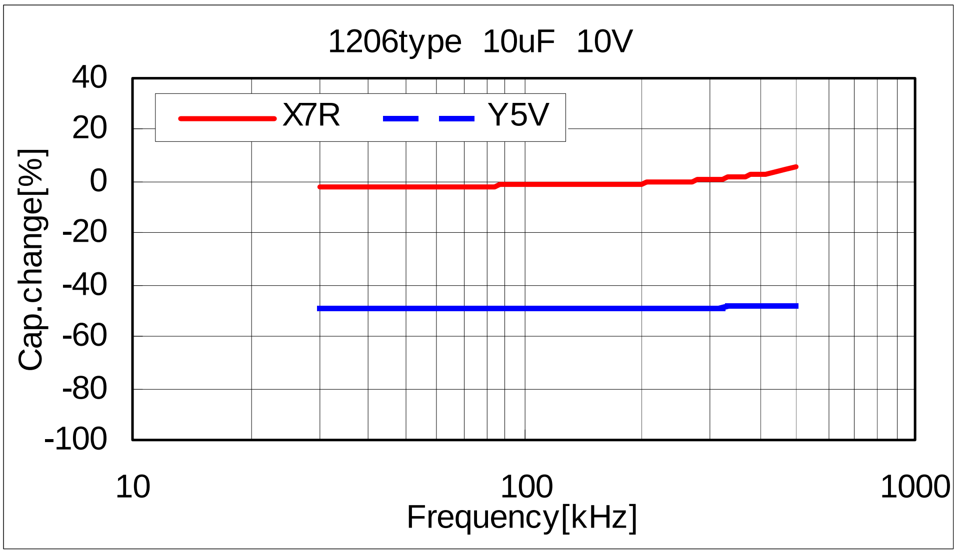
(b) Dissipation Factor (DF)

Fig.3 DC Bias Characteristic

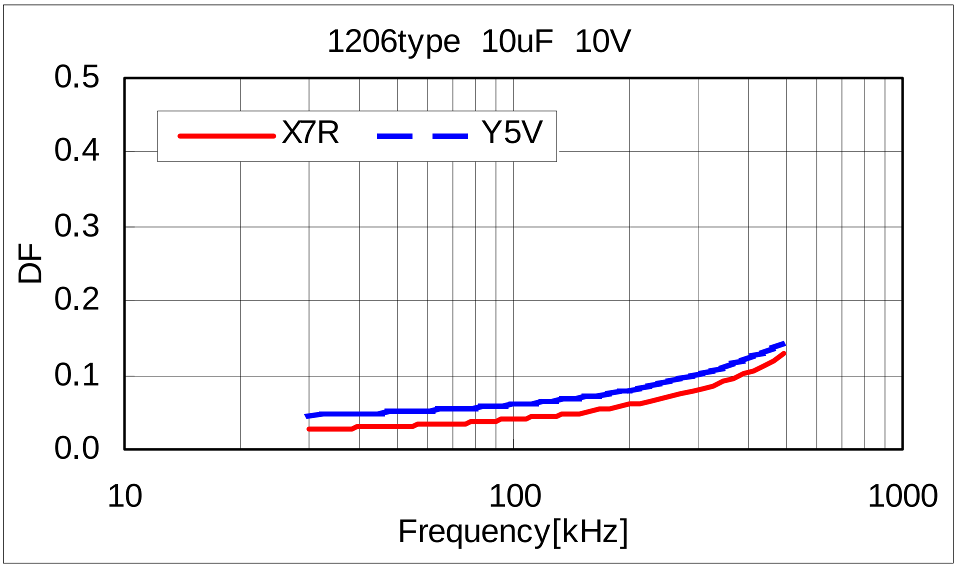
2-3. Frequency Characteristic

The frequency characteristics of X7R- and Y5V-characteristic MLCC capacitors are shown in Fig.3 below:

Although capacitance of both X7R- and Y5V-characteristic capacitors changes little as the measurement frequency is altered, their dissipation factors change substantially according to the measurement frequency. The reason the Y5V-characteristic capacitor's capacitance drops lower than 50% is that generally it is not possible to apply 1Vrms with the usual impedance analyzer (e.g. LCR meter) to the Y5V -characteristic capacitor at these (shown) frequency steps and 0.1Vrms is used instead. At the AC measurement voltage of 0.1Vrms, the capacitance of Y5V-characteristics decreases by 50% as shown in Fig.2 (AC Voltage Characteristic.)



(a) Capacitance Change Ratio



(b) Dissipation Factor (DF)

Fig.4 Frequency Characteristic

2-4. Summary

As described above, the capacitance and dissipation factors of MLCC capacitors change according to the measurement temperature, AC voltage, DC bias and frequency. Therefore, the capacitance and dissipation factor of these capacitors shall be measured after specifying the three measurement conditions, “temperature”, “voltage (AC & DC)” and “frequency”. When you design an electronic circuit using these capacitors, use them after carefully considering their characteristic values at the intended environment and operating conditions.

3. LCR Meters and Measuring Jigs

Typical LCR meters and measurement jigs are introduced in this section.

3-1. LCR Meters

LCR meters are generally used for measurement of the capacitance and dissipation factor of capacitors. Typical LCR meters include 4284A, 4278A and 4268A by Agilent Technologies Corp. as shown in Fig.5. As there are some measurement instruments that do not meet the measurement conditions specified in Table 1, please review the measurement principles in Section 4 and measurement methods in Section 5 and 6 before performing any tests.

(a) 4284A

(b) 4278A

(c) 4268A

Fig.5 Exterior Photographs of LCR Meters

3-2. Measuring Jigs

It is necessary to select a measurement jig appropriate the LCR meter to be used. Typical measurement jigs used for MLCC capacitors are shown in Fig.6 below:

(a) 16034E (b) 16334A

Fig.6 Appearance Photographs of Measuring Jigs

There are two types of measurement jigs, a type on which a chip capacitor is placed and measured by applying a pin to one-side of the electrode terminal, such as 16034E of Agilent Technologies Corp. and another type that is shaped like tweezers to catch a chip capacitor by its terminals to measure it such as 16334A also from Agilent Technologies Corp.

4. LCR Meter Measurement Principle

The basic issues necessary for LCR capacitor measurement such as the LCR meter measurement principle and measuring voltage, etc. are explained in this section.

4-1. Measurement Principle

The typical “measurement system” of LCR meters is the “automatic balancing bridge method”, which is shown in Fig.7.

In Fig.7, a high gain amplifier automatically adjusts the gain level so that an eclectic current is drawn through a resistor. R is always equal to the current flowing through the DUT (Device under Test), that is, the L-side end potential of DUT (lower voltage side) always equal to virtual ground level (electric potential =0). At this condition, impedance value of the DUT can be determined from the out put voltage E2, feedback resistance R and input voltage E1 as follows:

$$Zx=R*E1/E2$$
$$E1=|E1|\angle\theta1=|E1|\cos\theta1+|E1|\sin\theta1$$
$$E2=|E2|\angle\theta2=|E2|\cos\theta2+|E2|\sin\theta2$$

At this moment, phase angles of E1 and E2, $\theta1$ and $\theta2$, are measured at the same time, and the “resistance component Rx” and “reactance component Xx” can be calculated from the above phase angles and Zx value, from which capacitance and dissipation factor are determined.

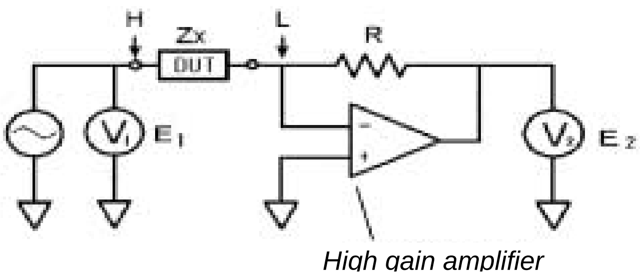


Fig.7 Principle Diagram of Automatic Balancing Bridge

4-2. Measuring Voltage

LCR meters generally provide internal resistances to protect their own power supply circuits. Depending on the value of this resistance, the actual voltage differential between the electrodes of a capacitor being measured drops excessively which prevents correct measurement of capacitance and dissipation factor of the capacitor. Depending on type of LCR meter used, measurement of a ceramic capacitor with large capacitance such as 10μF at an assigned voltage may be impossible due to extremely low impedance of such capacitor.

This mechanism is explained using the simple equivalent circuit model shown in Fig.8. Measuring voltage is applied to DUT, E_{dut} is a partial potential of power supply voltage E_O divided by impedance of DUT, Zx = R + jX, and the LCR meter's internal impedance R_{in}.

The measuring voltage applied to DUT, E_{dut}, is determined by:

$$E_{dut}=E0*\frac{\sqrt{(R^2+X^2)}}{\sqrt{\{(Rin+R)^2+X^2\}}}$$

$$X=1/\omega C=1/(2\pi fC)$$

Thus, the measurement voltage of capacitor is different from the power supply voltage. Therefore, we recommend using a LCR meter that automatically maintains the "measurement voltage" at a preset voltage (ALC function). When using a LCR meter not providing such function, you have to manually measure actual voltage applied between the terminals of the capacitor being measured, etc. and manually adjust it.

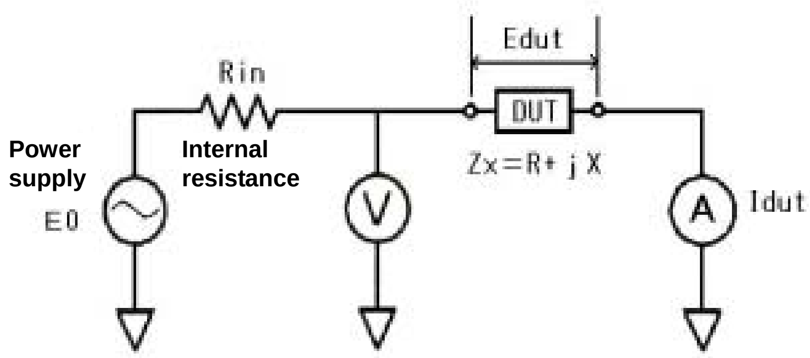


Fig.8 Measuring Voltage Applied to DUT

4-3. Capacitance Measurement Circuit Mode

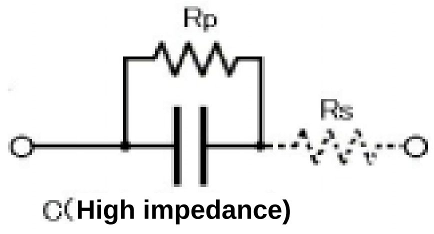
Capacitance measurement circuit mode generally includes two types of circuit modes. These are; parallel equivalent circuit mode and serial equivalent circuit mode.

(1) In case of small capacitance (see Fig.9):

A small capacitance has a large reactance, i.e. high impedance, which causes the influence of parallel resistance Rp on the measurement to be far larger than that of the serial resistance Rs, thus Rs can be neglected and measurement circuit provides a parallel equivalent circuit mode.

(2) In case of large capacitance (see Fig.10):

A large capacitance has a small reactance, i.e. low impedance, which makes the influence of serial resistance Rs on the measurement far larger than that of parallel capacitance Rp, thus Rp can be neglected and measurement circuit provides a serial equivalent circuit mode.



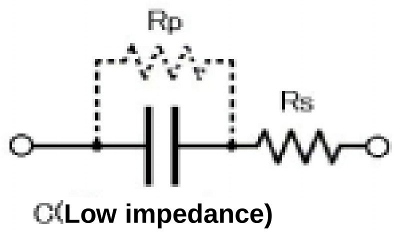


Fig.9 Small capacitance (Parallel equivalent circuit mode)

Eig.10 Large capacitance (Serial equivalent circuit mode)

(3) The measurement circuit mode is determined according to impedance value of a capacitor to be measured, which is switched at about 10Ω in relation to internal impedance of LCR meter. The relationship between capacitance and impedance is shown in Fig.11. The "Electric Capacitance" (4.7) and "Dielectric Dissipation Factor" (4.8) sections of the public standard JIS C 5101-1-1998 define measurement frequency to 1kHz for 10μF or lower capacitance and to 120Hz for capacitance higher than 10μF. Therefore, the impedances of all these capacitance values become 10Ω or greater, which are measured by the parallel equivalent circuit mode. However, for a capacitance exceeding 10μF, the serial equivalent circuit mode is used, as its impedance is lower than 10μF.

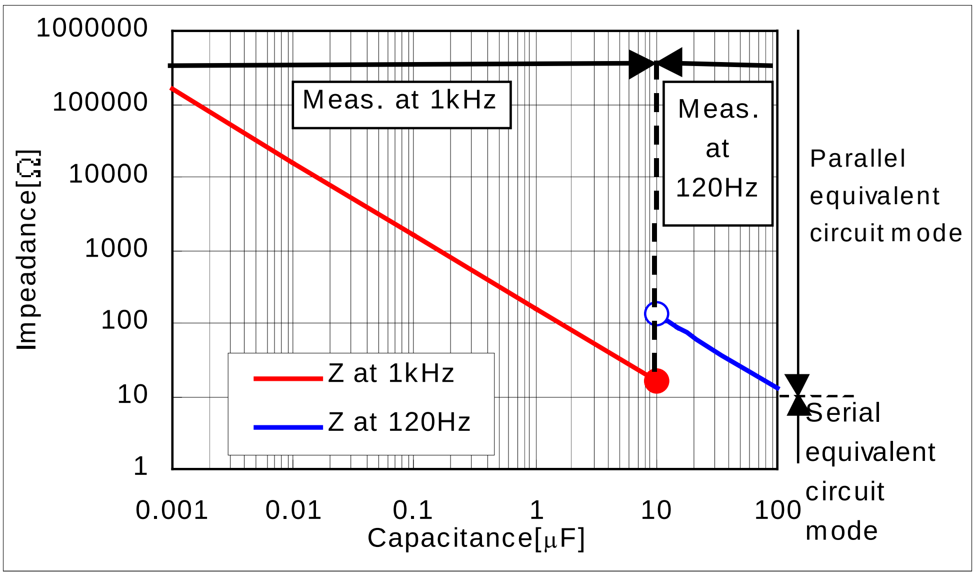


Fig.11 Relation between Capacitance and Impedance

5. Capacitance Measurement by LCR Meter 4284A

The correct capacitance measurement method using a typical LCR meter 4284A and measurement jig 16034E is described in this section.

5-1. Turn on the power of LCR meter

This measurement equipment requires warm-up time. Turn the power on for the meter 30 minutes before starting actual measurement.

5-2. Installing the measuring jig on the meter

Install the measurement jig on the meter as shown in Fig.12.

5-3. Setting the LCR meter

Setup measurement conditions using “Measure Setup” screen (see Fig.13).

(1) FUNC → Cp-D,

(2) FREQ and LEVEL→ See Table 1.

Fig.12 LCR Meter with Jig Installed

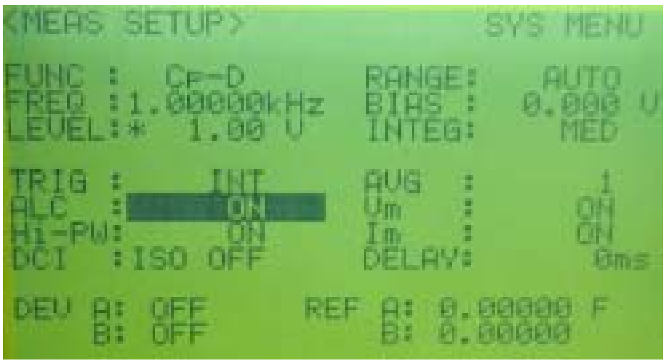
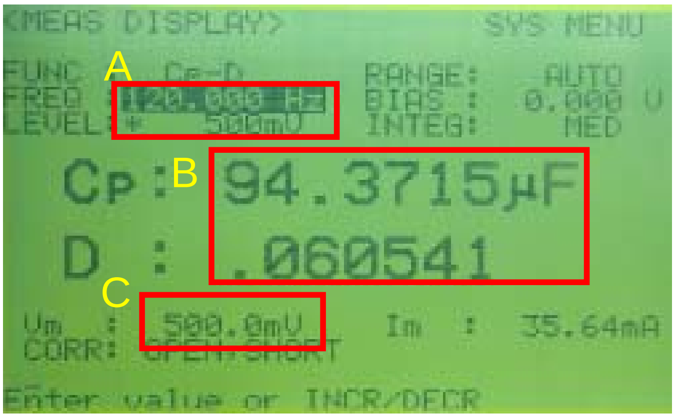


Fig.13 Measure Setup Screen

Note 1: If FREQ and/or LEVEL is not correctly set, you will not be able to correctly measure the capacitance. These settings are explained in the following example:

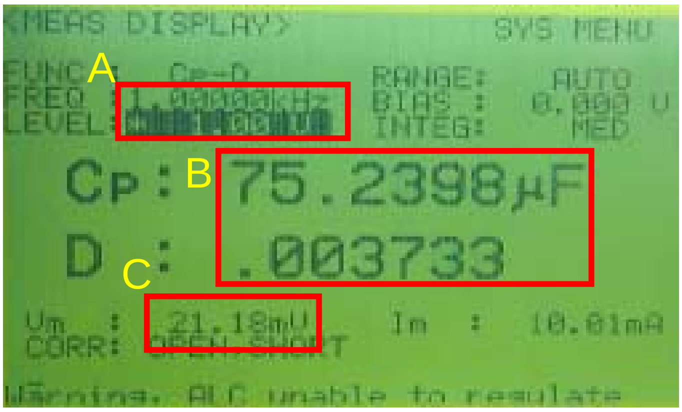
Example: Sample capacitor 1812 type X5R-characteristic 100μF

Correct settings for the frequency and AC voltage are “FREQ: 120Hz” and “LEVEL: 0.5Vrms” respectively (see Fig.14). If capacitance is measured using different conditions, such as1kHz and 1Vrms, the capacitance will be incorrectly displayed, as being 20% lower than if measured using the correct conditions as shown in Fig.15.



"A" field in the above figure is set to measurement frequency and voltage required. This field is correctly set to "FREQ: 120Hz" and "LEVEL: 500mV" according to the specification. "B" is a field that displays the values of measured capacitance and dissipation factor. The capacitance is about 94µF is compared against the nominal value of 100µF of the sample capacitor, this is within the specified capacitance tolerance. "Vm" in "C" field indicates actual the measurement voltage monitored by the meter, which shows 500mV applied to the sample.

Fig.14 Measuring Conditions : 120Hz, 0.5Vrms



"A" field in the above figure is set to "FREQ: 1kHz" and "LEVEL: 1V", both of which are different from sample's specification. The capacitance indicated in "B" field above is very low, about 75µF against nominal value of 100µF of the sample capacitor, which is 20% lower than that measured by the correct conditions. "Vm" in "C" field indicates the actual measurement voltage monitored by the meter, which shows only about 21mv against set value 1V.

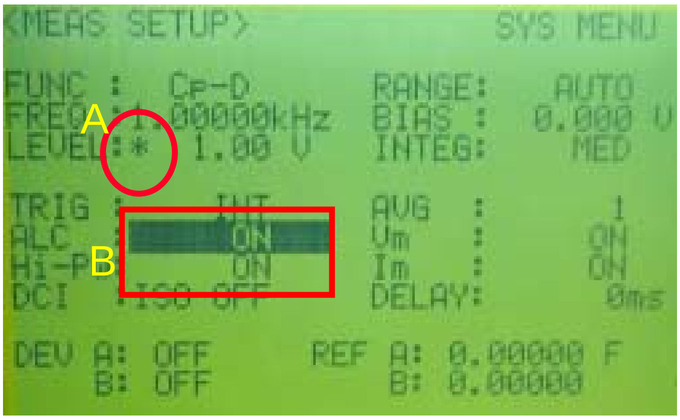
Fig.15 Measurement Conditions : 1kHz, 1Vrms

(3) Hi-PW (High Power) → ON, and ALC (Automatic Level Control) → ON

When "Hi-PW" is set to "ON", the capacitance can be measured with the Power Supply voltage within set to a range of 1Vrms to 10Vrms. ALC is used to maintain the measurement voltage at the designated voltage and shall be always set to "ON". Even if you set the measurement voltage to 1Vrms, you cannot obtain the correct capacitance value unless the actually monitored value is 1Vrms. This setting is explained using the following example:

Example : Sample 1206 type X7R-characteristic 10µF

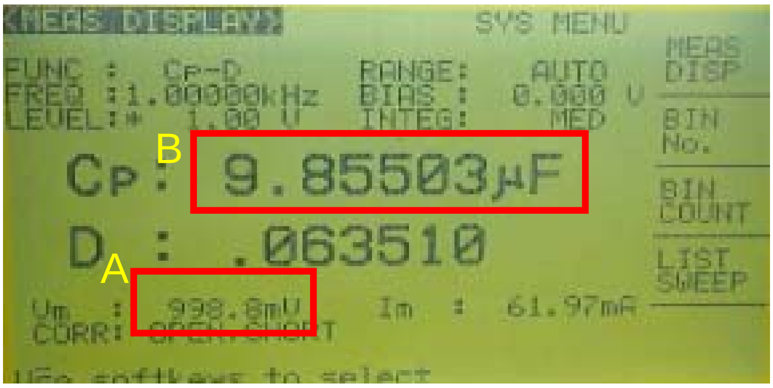
By setting the ALC and Hi-PW to "ON", you can apply 1Vrms measurement voltage to a sample to be measured, and obtain a correct capacitance value, which is about 9.86µF in the example (see Fig.16 and 17). When ALC is set to "OFF", measurement voltage becomes low 184mV in the example figure below, which makes apparent capacitance low, showing about 8.43µF.



"A" field in the above figure indicates both ALC and Hi-PW being set to "ON".

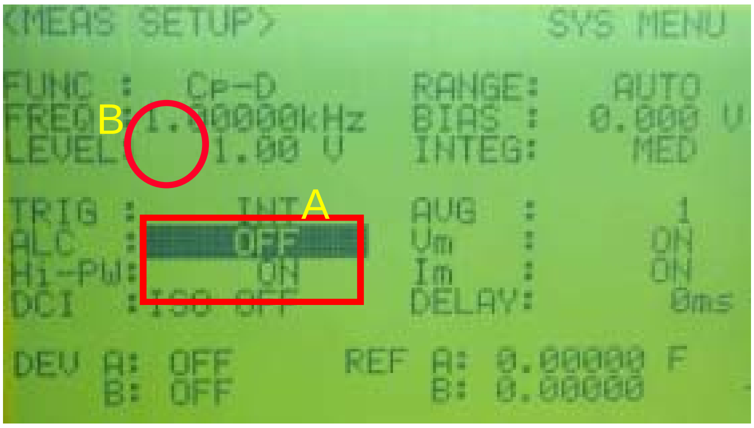
An asterisk mark at "B" field in the figure means ALC being on.

Fig.16 Measure Setup Screen Showing ALC ON



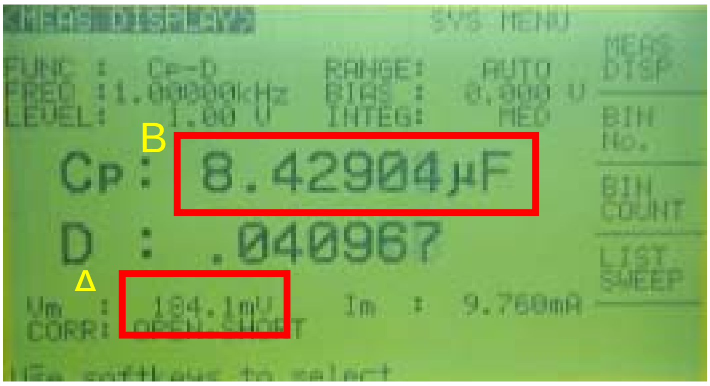
"Vm" in "A" field in the above figure indicates actual measurement voltage monitored by the meter, which shows 1V being applied to the sample. "B" field shows the capacitance of a 10μF product, which is about 9.86μF which is within the specified tolerance.

Fig.17 Measure Setup Screen Showing ALC ON



"A" field in the above figure indicates ALC being set to "OFF" and Hi-PW being set to "ON". No asterisk mark at "B" field in the figure means ALC is off.

Fig.18 Measure Setup Screen Showing ALC OFF



"Vm" in "A" field indicates actual measurement voltage monitored by the meter, which shows 1V is applied to the sample. "B" field shows a capacitance of a 10µF product, which is about 9.86µF which is within the specified tolerance.

Fig.19 Measure Setup Screen Showing ALC OFF

Note 2: Check Method of Measurement Voltage Applied to Capacitor Under Test

One method to check the measurement voltage actually applied to a capacitor under test is to apply plus and minus probes of the tester to both terminals respectively of the capacitor set into measurement jig, and read the indicated voltage.

A photograph in which "measurement voltage" of Fig.17 above is checked is shown in Fig.10. It shows it indicates a value of 998mVrms.

Also, a photograph in which the "measurement voltage" of Fig.19 is checked is shown in Fig.21. It shows the tester indicating 187mVrms and low capacitance due to the AC measurement voltage being less than 1Vrms.

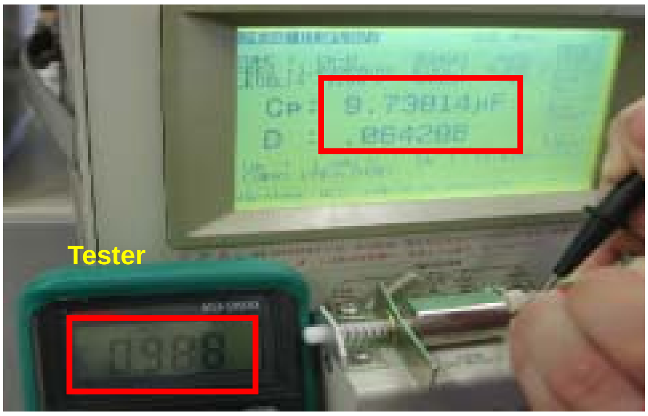


Fig.20 Tester Measurement Example for ALC ON State

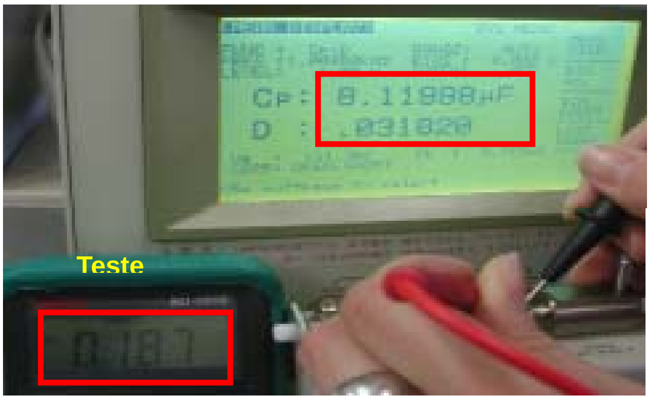


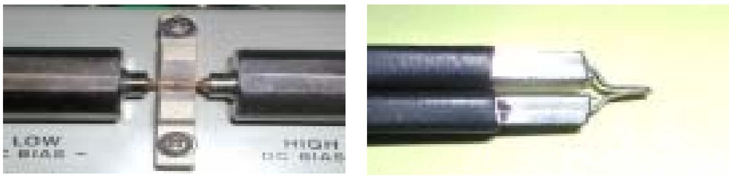
Fig.21 Tester Measurement Example for ALC OFF State

5-4. Calibration

You implement the measurement calibration using COMPEN in the MEAS SETUP screen. The are two types of calibration “Short Calibration” and “Open Calibration”,
The order in which you preform the calibration is optional.

(1) Short Calibration

For “short” condition, see Fig.22. Confirm that Rs is 0.03 Ω or less at this point. When Rs does not come down to 0.03 Ω or less, then wash the terminal using acetone, repeat above as necessary to obtain a Rs reading of 0.03 Ω or less.



(a) 16034E (b) 16334A

Fig.22 Short Condition

(2) Open Calibration

Adjust “open” distance to a size of chip capacitor to be measured. See Fig.23 for “open” condition.

(a) 16034E (b) 16334A

Fig.23 Open Condition

5-5. Measurement

You measure the MLCC capacitors after completing these calibrations.

6. Capacitance Measurement by LCR Meter 4278A

In this section, A correct capacitance measurement method using the combination of a typical LCR meter 4278A and measuring jig 1603A is explained.

6-1. Turn on LCR Meter Power

The equipment requires a warming-up time, always turn on its power 30 minutes before starting your actual measurement.

6-2. Meter with Measuring Jig installed on

Install the measuring jig on the measuring equipment as shown in Fig.24.

Fig.24 Meter with Measuring Jig installed on

6-3. Meter Setting

Set measurement conditions on the meter using ”Menu” screen shown in Fig.25.

(1) Setting items to be measured:

MENU → MEAS, PARAMETER → Cp-D

(2) Setting measuring frequency and voltage :

MENU → SIGMAL, SOURCE → FREQ → 1kHz

→ OSC → 1.0V

Note 4: 4278A provides two types frequencies, 1kHz and 1MHz. Therefore, it cannot measure a capacitor having a capacitance greater than 10μF because such capacitance requires a measurement frequency of 120Hz. Use 4284A or 4268A for the measurement of a capacitor greater than 10μF.

Fig.25 Menu Screen

Note 5: Check Method of Measurement Voltage Actually Applied to a Capacitor

Even though you set the measurement voltage to 1Vrms, if “1Vrms” is not actually applied to the capacitor to be measured, you won’t be able to correctly measure capacitance.

Check whether the measurement voltage set is actually applied to the capacitor by applying plus and minus probes of a tester to both terminals of the capacitor set in measuring jig and read a indicated voltage.

Fig.26 shows the check operation of the measurement voltage of a 1206 size X7R-characteristic 10μF chip capacitor, in which measurement frequency is set to 1kHZ and measurement voltage to 1Vrms. Actual measurement voltage is about 1.0Vrms and measured capacitance is about 10.4μF.

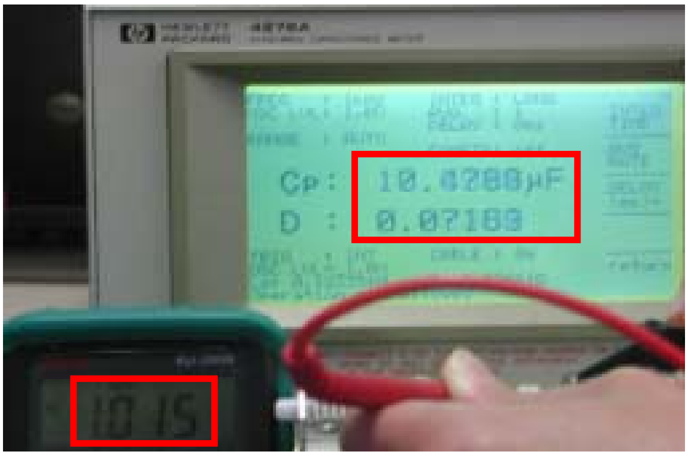


Fig.26 Measurement Voltage Check by Tester

(3) Cable Length

When using measurement jig 16034E, set CABLE LENGTH to “0 (zero)”m.

MENU → NEXT → CABLE LENGTH → 0m.

6-4. Calibration

Use “screen” displayed after pushing MENU → NEXT → COMPEN for the calibration.

The calibration at this point shall be performed for OPEN, SHORT and TEMP COMP. See LCR meter 4284 measurement procedure in Section 5 herein for OPEN and SHORT calibration methods.

OPEN COMPEN → OPEN ON

SHOT COMPEN → SHORT ON

STD OFF

TEMP COMPEN

6-5. Measurement

You can start the measurement of the MLCC capacitors after completing the TEMP COMPEN above.

Note 6: Capacitance Change by Aging Characteristic

Although the “aging characteristic” of high dielectric MLCC capacitors is not directly related to the capacitance measurement, as it reduces capacitance of the MLCC capacitors, you must take it into consideration when designing a circuit using those capacitors.

High dielectric MLCC capacitors (typically represented by X7R / Y5V temperature characteristic of which main composition is $BaTiO_3$) have an attribute that their capacitance decreases as time elapses. This attribute is called “aging” of capacitance.

Capacitance aging is a phenomenon inherent in dielectric ceramics having spontaneous polarization. When a ceramic capacitor of this type is heated up over its Curie point and left at a temperature lower that the Curie point with no load, the rotation of its spontaneous polarization is gradually inactivated as time elapses, which is observed from outside as “capacitance decrease”.

This phenomenon is not limited to our products but generally observed in all high dielectric MLCC capacitors (with $BaTiO_3$ system). Some public standards have an appendix for supplemental explanation about the aging of electric capacitance (Multilayer Capacitor: IEC 384-10 Appendix X7R, etc.) If a MLCC capacitor with aging-reduced low capacitance is again heated up over its Curie point, its capacitance is restored to nominal again the aging process from the time point it is cooled down to a temperature lower than the Curie point starts again.

Generally, using a capacitance value reading 24 hours after heat-treatment at 150 degree or higher as a baseline, the capacitance linearly decreases according to logarithm time scale.
See a typical example of a capacitance aging characteristic graph decreasing with time shown in Fig.27.

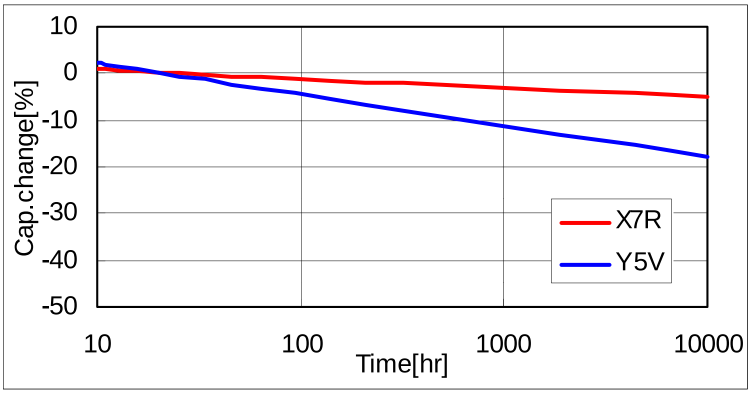


Fig. 27 Aging Characteristic, Capacitance Change with Time

When you use high dielectric MLCC capacitors, please carefully consider the capacitance change of these capacitors arising from their aging characteristics, and particularly when you need a stable capacitance, check capacitors using your actual appliances. However, temperature compensating type MLCC capacitors have no such aging characteristic.

7. Closing

In order to correctly measure MLCC capacitors, it is necessary to fully understand the product characteristics that affect the measurement of those capacitors and using LCR meter performances.

This brochure explains key points in the measurement that are likely to be mistaken or overlooked. We hope that this brochure is useful for your capacitor measurement.

References

- 4284A Operation Manual, Agilent Technologies Corp.
- 4278A,Operation Manual, Agilent Technologies Corp.
- Impedance Measurement Handbook, Agilent Technologies Corp. Second Edition, 2001
- Basics and Applications of Ceramic Capacitor, Ohmsha, First Edition, 2003

Document Prepared: September 2005