Chroma
Advancing Excellence

APPLICATION NOTE

Multi-layer Ceramic Capacitor (MLCC) Application Note

December 2021
Chroma ATE Inc.

Table of Contents

(1) Purpose

Multi-layer ceramic capacitor (MLCC) is a type of ceramic capacitor with a capacitance value that is proportional to the surface area of the product and the number of ceramic film stacks. Its physical properties make an MLCC resistant to high voltage and high heat as well as operable under a wide temperature range. MLCCs are widely used in electronics, since they can be shaped into small chips with large capacitance, good frequency characteristics, low loss rate when used under high frequency, applications for mass production, low price, and high stability. This application note will illustrate how to effectively verify the quality of MLCC products.

(2) Capacitor Working Principle

In vacuum, a voltage is applied between the conductor parallel plates without dielectric. The electromotive force induces electrical charge between the conductor parallel plates.

$Q_0 = C_0V$: C_0 is the scale factor, which is the vacuum electrostatic capacity of this conductor parallel plate. C_0 is also proportional to the area S of the parallel plate, and inversely proportional to the parallel plate gap spacing d.

$C_0 = \varepsilon_0 S/d$: ε_0 is the scale factor, which is the vacuum dielectric coefficient.

$\varepsilon_0 = 8.854 \times 10^{-12}$ [F/m]

After the space between the parallel plates is filled with homogeneous dielectric, the dielectric gives a polarization reaction. The electromotive force induces electrical charge between the conductor parallel plates.

$Q = CV$

$C = \varepsilon S/d$: ε is the dielectric constant after the dielectric is inserted, relative to the vacuum dielectric coefficient ε_0.

$\varepsilon = \varepsilon_r \varepsilon_0$

ε_r is the relative permittivity.

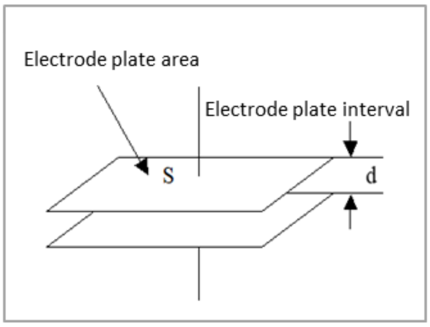


Figure 1 – Vacuum Electrostatic Capacity

(3) Basic MLCC Parameter Test Methods

3.1 Basic Parameters

All DC energy storage components have the following three basic parameters:

① Basic energy storage capacity

② AC loss

③ DC insulation leakage

In MLCC, these are:

① Electrostatic capacity (C, [μF])

② Loss factors (D or tanδ in %)

③ Insulation resistance or leakage current (IR [Ω] or LC [μA] @ rated voltage)

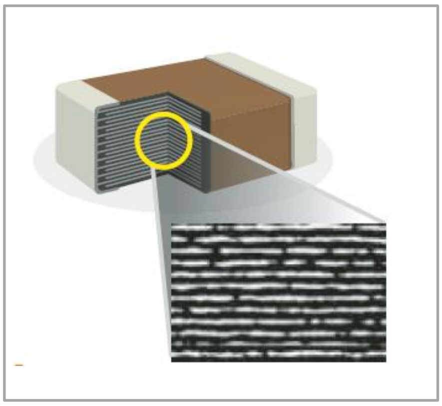


Figure 2 – MLCC Structure

3.2 MLCC Electrostatic Capacity (C, [μF])

Because an MLCC uses insulating material with a high dielectric constant, when in a low-voltage field, it will begin to show nonlinear phenomena and the measured capacitance will vary with the voltage applied to the capacitor. For this reason, the JIS C 5101-1-1998 standard regulates the test signals.

Nominal capacitance	Test Frequency	Test Voltage
C ≦ 10μF (10V min.)	1 ± 0.1kHz	0.1 ± 0.2Vrms
C ≦ 10μF (6.3V max.)	1 ± 0.1kHz	0.5 ± 0.1Vrms
C > 10μF	120 ± 24Hz	0.5 ± 0.1Vrms

Table 1 - Test Conditions

Notice:

Common LCR meters are designed with an internal output current-limiting resistor. Therefore, you need to carefully select the voltage setting on the instrument; choose a lower output resistance mode (≦ 10ohm) or use the automatic level compensation (ALC) function.

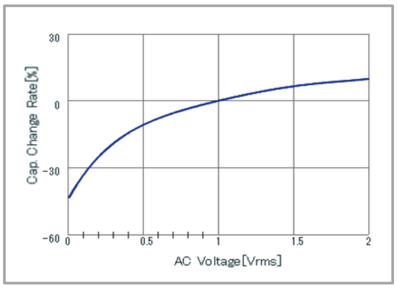


Figure 3 – AC Voltage Versus Capacitance

3.3 Loss Factors (D or tanδ in %)

The loss factors refer to the ratio of the loss in the AC state to the apparent power.

$$D = \frac{i^2 Rs}{i^2 Xc} = \frac{Rs}{Xc} = \omega CsRs$$

Rs: Series equivalent resistance

Xc: Capacitive reactance

Cs: Series equivalent capacity

- The lower the D-value, the smaller the loss. This will sometimes be expressed as a percentage, which is convenient for converting apparent power into loss power.
- The D-value and the measurement of C generally use the same test frequency (example: 1kHz 1V); but the main variables of loss in high and low frequencies are different. Sometimes, the ESR (Rs) is tested at a frequency close to or higher than the actually used frequency to detect specific defects (example: very small surface area of the internal electrode, high frequency electric conduction has small effective surface and high resistance).

3.4 Insulation Resistance or Leakage Current (IR [Ω] or LC [μA] @ rated voltage)

Both IR and LC are converted from the measured LC.

$$IR = \frac{Vt}{LC}$$

Vt: Test voltage; general specifications are tested with rated voltage.

- Common production inspections on MLCC is labelled with IR. However, the insulation characteristics of dielectric materials are generally based on the relationship between leakage current and test voltage (I-V curve).

(4) Other MLCC Dielectrics Verification Methods

MLCCs of the same specification will perform differently in use. The following sections describe special verification methods used to discern higher-quality MLCCs.

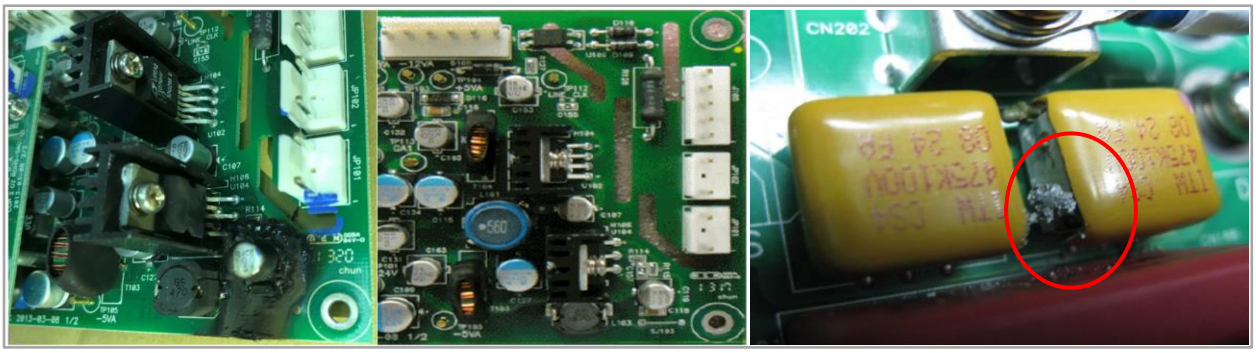


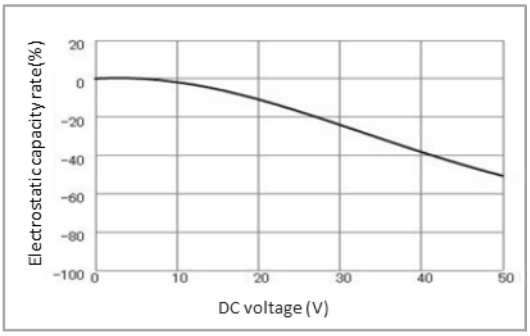
Figure 4 – Practical Examples of MLCC Damage MLCC

4.1 Breakdown Voltage

4.1.1 MLCC Breakdown Voltage: Withstand Voltage Margin

There is a considerable difference between the rated withstand voltage of the MLCC and the breakdown voltage of the actual product. For example, an MLCC with nominal 50Vdc rated voltage may only have 50% capacitance left when used at 50Vdc but the electrical breakdown may be 5 times as high at 250V. This difference is the margin of the product's withstand voltage. Manufacturers will usually perform a flash test at the production line to ensure this margin and set a magnification that varies depending on the product's withstand voltage or the company's quality considerations, between about 1.5 to 5 times. The most common and severe issue for MLCCs is a short circuit fault after use that causes the product to act abnormal or the PCB to ignite, so it is sensible to choose a good MLCC product based on the actual withstand voltage margin.

- General rated voltage refers to the voltage at which the nominal capacity remains within the usable range.
- Breakdown voltage refers to the voltage at which the insulation of the dielectric material



collapses into a conductor or the dielectric is unable to recover.

Figure 5 – DC Voltage and Capacitance Rate of Change

4.1.2 MLCC Breakdown Voltage: Test Method

Effectively identify the insulating ability through either one of these concepts:

- Poor insulation: Electrical breakdown or electrical flashover occurred during a certain voltage test.
- Turning point of insulator and conductor characteristics (I-V curve).

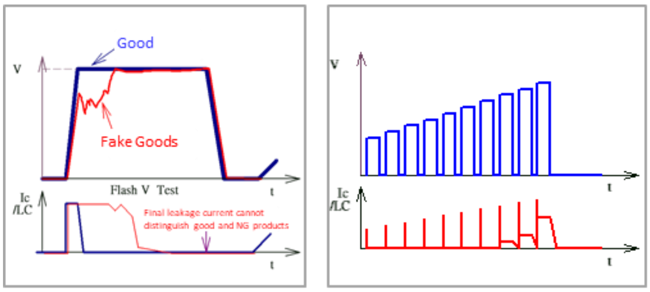


Figure 6 – Electrical Breakdown or Flashover

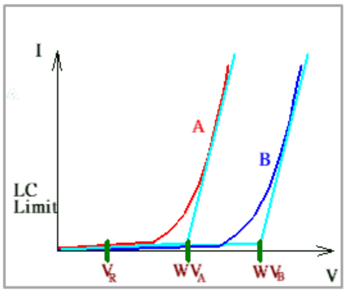


Figure 7 – Turning Point

Since the leakage characteristics will rise quickly once the insulation starts to deteriorate, the two above methods generally do not differ too much. We recommend you to set the target for the breakdown voltage sweep to 10 times the rated voltage of the MLCC or the maximum value of the device.

4.1.3 MLCC Breakdown Voltage: Actual Test Case

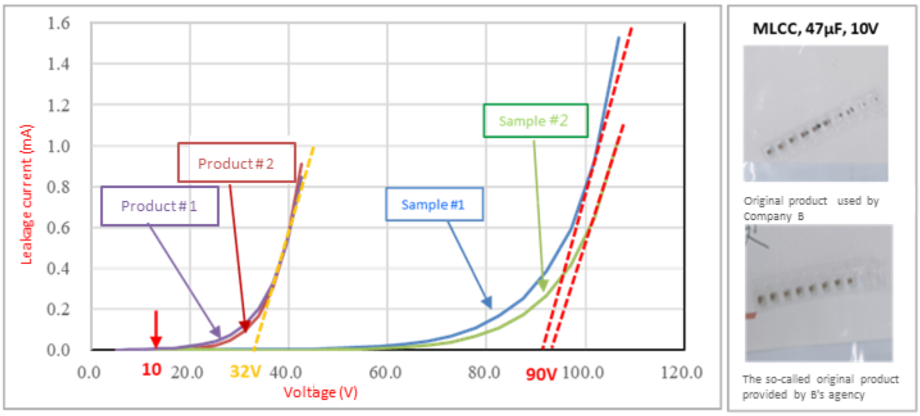


Figure 8 – Actual MLCC Test Case: 47μF, 10V

4.2 AC Withstand Current/Ripple Current

Factors that cause the MLCC to heat up in actual AC/DC combined applications:

- Heat generated by the polarization change caused by the AC voltage in the dielectric material.
- Active power generated by the AC current on the external electrode and the internal electrode silver-plated conductors.
- Active power generated by the DC voltage and its leakage current (V * I).

The heat generated by the polarization change caused by the AC voltage in the dielectric material is correlated to the active power generated by the DC voltage and its leakage current (V * I) because of the influence of the DC voltage polarization ability. Therefore, to evaluate the heating quality of an MLCC, usually a rated voltage is superimposed (the so-called ripple current test), and then an AC current is applied to test its temperature rise.

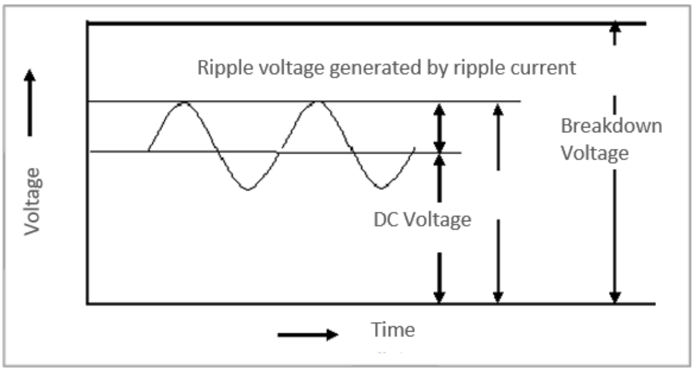


Figure 9 – MLCC AC Withstand Current Versus Ripple Current

MLCC specifications should provide the maximum tolerable ripple specifications, but not all manufacturers are able to test and analyze each specification.

Basic practices provided by common MLCC products:

- Using CC (constant current) to test the temperature rise for each current
- Generally specified not to use over +20°C
- Fixed-point frequencies: 10kHz, 100kHz, 500kHz, 1MHz
- Medium voltage (100V~500V) and low capacitance (<10nF) products are instead tested with CV (constant voltage) at 100kHz, 500kHz, 1MHz due to low current and high voltage.

For verification of heating quality differences in MLCCs of different manufacturers, in addition to referring to their nominal ripple current MLCC specifications, we recommend you to also separate severe conditions to compare temperature rise differences between capacitor brands, which can shorten the time required for comparison.

Example: Product with 4.7uF, 50V, 3.5A max. specifications ➔ Test the temperature rise difference with 50V DC Bias, 7A @ 1MHz.

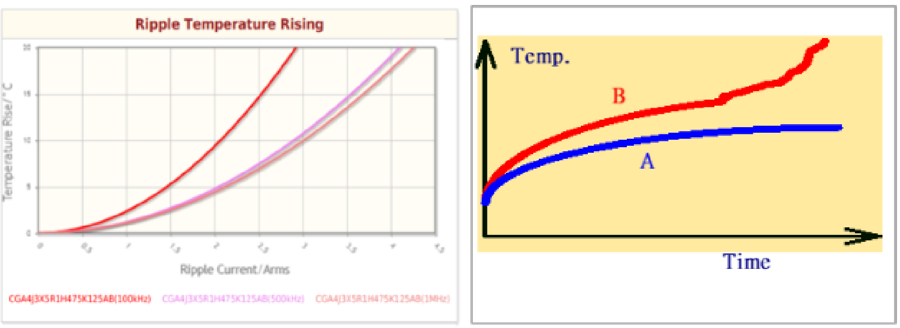


Figure 10 – MLCC Ripple Current Capacitance Temperature Rise Differences

(5) Chroma Test Solutions

5.1 Chroma 11050-5MHz HF LCR Meter

5.1.1 Test target: C/D/ESR for MLCC

5.1.2 Product specifications:

- Test parameters: L/C/R/Z/Y/DCR/Q/D/θ
- Test frequency: 60Hz ~ 5MHz (can be selected as you wish)
- Test level: 10mV ~ 5V
- Basic accuracy: 0.1%
- Test signal automated level compensation function
- Compare & bin-sorting functions
- Standard Handler, RS-232C, USB storage
- Optional 1GPIB or LAN interface

5.2 Chroma 11210 Battery Cell Insulation Tester

5.2.1 Test target: IR (insulation resistance) / LC (leakage current) / BDV (breakdown voltage) for MLCC

5.2.2 Product specifications:

- Test level: 1KV, high-speed CC charging 0~50Ma
- High-speed testing: > 10mS
- Contact check function
- Breakdown voltage (BDV) test function, I-V curve output
- Flash voltage Instantaneous flashover (+Flash) test function
- Partial discharge (PD) at all periods [PD option: PD degree and frequency recording]
- Partial discharge (PD) analysis [PD analyzer option: + waveform recording]

Notes on waveform recording function: Part of the insulation burrs or dielectric defects will be restored during the insulation test, due to the strong electrical discharge. Cells judged as defective may not reappear after retesting, which could influence the quality assurance tracking.

Figure 11 – Waveform Record

5.3 Chroma 1820 Capacitor Test System

5.3.1 Test target: Ripple current for MLCC

5.3.2 Product specifications:

- High-frequency sine wave current: 1kHz~20kHz, 10kHz~20010kHz
- DC bias voltage: 5000V max.
- Capacitor endurance & temperature rise test
- Capacitor withstanding current test (frequency sweep)
- Software control supported
- Customized test modules

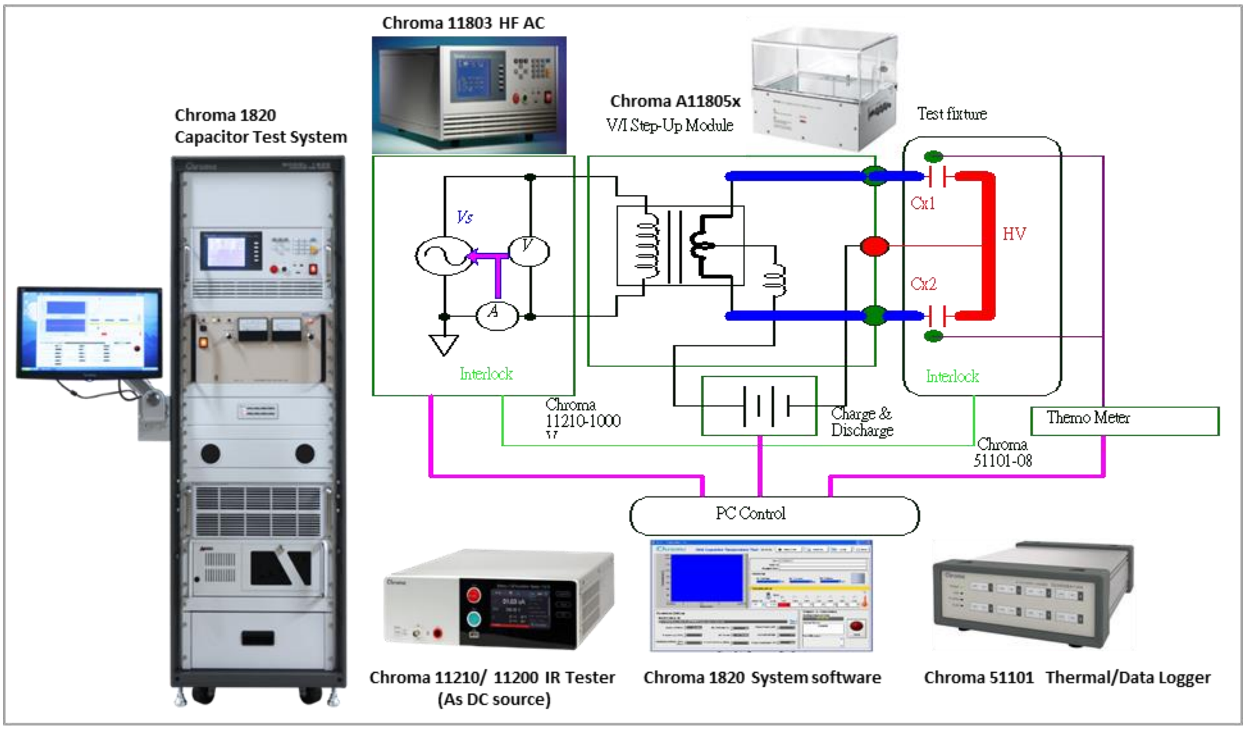
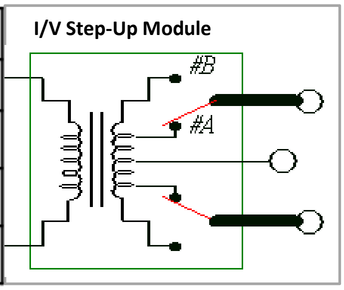


Figure 12 – Chroma 1820 Capacitor Test System

5.3.3 MLCC ripple current: voltage/current rise test module: 800VA 10k~1MHz

- A118053 @ < 20kHz output voltage specification *50%

Model		V output (V)	I output (A)	Applicable Test
A118053	#A	15+15 (Note 1)	27	Low voltage High capacitance CC
A118052	#A	125+125	4 (Note 2)	
	#B	250+250	2 (Note 2)	Middle voltage Low capacitance CV
	#C	500+500	1 (Note 2)	



A118052 @ > 200kHz Output Voltage Specification *80%

5.3.4 Recommended test fixtures for MLCC ripple current:

5.3.4.1 SMD capacitor test board:

MLCCs are usually surface-mount, we recommend soldering the capacitor under verification onto the PCB for testing.

- Test results are less affected by the temperature rise due to contact resistance.
- Temperature monitoring is less affected by mechanical interference of the fixture
- After testing, the desoldering may not be subject to C/R, ESR, and IR tests.
- Covers a standard size and characteristic requirements such as solderability, heat dissipation, PCB creepage voltage, and insulation.

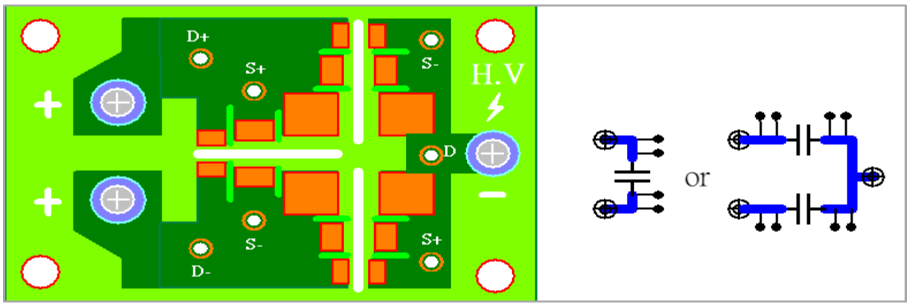


Figure 13 – SMD Capacitor Test Board Application

5.3.4.2 Multiple SMD capacitor series test board:

When comparing the ripple resistance specifications of the MLCCs from different manufacturers, it is more efficient to test multiple samples with the same specifications at once, for example, using a serial test board.

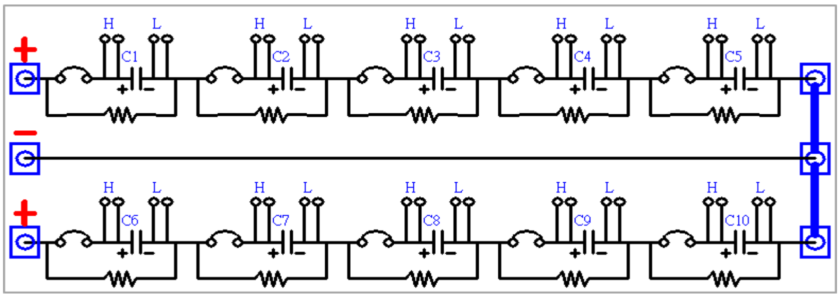


Figure 14 – Multiple SMD Capacitor Series Test Board Application

(6) Technical Description

6.1 Flash Power Test Requirements

Some capacitor applications will encounter transient overpower (for example: cold cathode tubes, hot cathode tube startup capacitors, SMPS snubber capacitor). Few test equipment can provide continuous full power or complete simulated load waveforms for testing. Therefore, it is up to the test personnel to recognize whether the test requirement serves to verify (1) insulation degradation caused by high voltage or (2) overheating caused by load current?

6.1.1 Insulation degradation caused by high voltage (CV test)

- Set a longer interval time (t2) to minimize heat generation.
- Taking the voltage level as the main parameter, choose a test frequency that is close to the actual application but within the power range of the high-frequency AC tester.

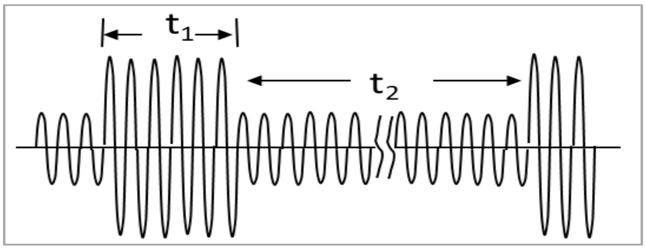


Figure 15 – High-voltage Flash Power Durability Test

6.1.2 Overheating caused by load current (Note 1)

- Primarily consider that the generation of "heat" is close to the evaluation target.
- Taking the current root mean square (RMS) value as the main parameter, also consider the ACR difference between the actual equivalent application frequency fa and measureable frequency fm.

$$Im' = Im * \sqrt{\frac{R\ (@fa)}{R\ (@fm)}}$$

Note 1: Certain low-capacity, medium- and high-voltage ceramic capacitors do not fit a CC test due to low current, and require a CV test.

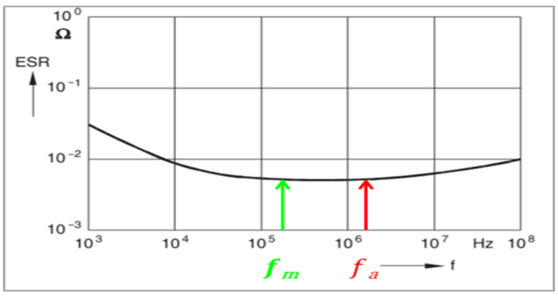
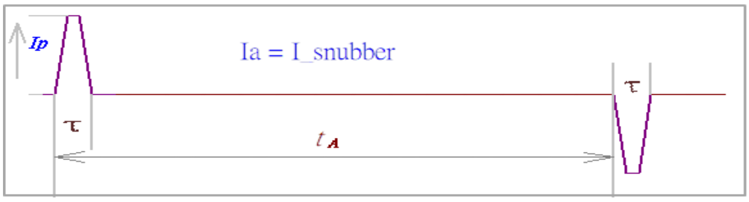


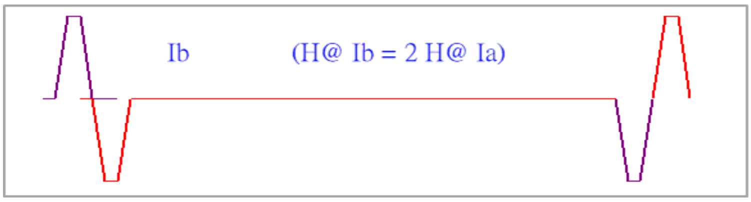
Figure 16 – ESR vs Frequency (CC Durability Test)

6.2 Frequent Errors in Requirement Specifications – Snubber Circuit Pulse

For the heat H that occurs on the capacitor: H@ Ic = $\frac{tA}{\tau}$ * H@Ia

If the pulse width of Ia is τ, then the period of Ic is 2τ, the equivalent application frequency is $fa = \frac{1}{2\tau}$





Use $Im \equiv \frac{Ip}{\sqrt{2}} \frac{1}{\sqrt{\frac{tA}{\tau}}}$ [rms] @ fa to find the appropriate heat generated by Ia.

Means: the actual measured maximum load current RMS, but the frequency is determined by the pulse width.

Ex: τ = 0.3μS, tA = 15 μS, Ip = 20A

Im = 2.0Arms @fa = 1.66MHz

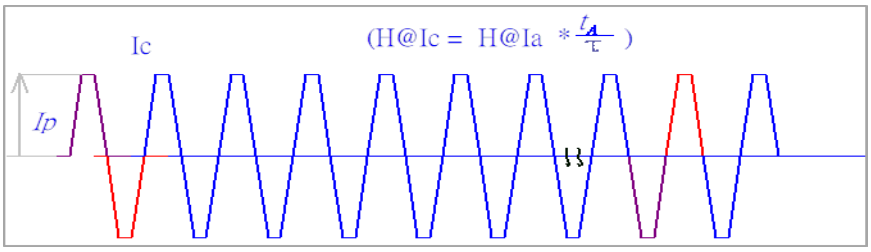


Figure 17 – H@ Ic = $\frac{tA}{\tau}$ * H@Ia

(7) Addendum: MLCC Flash Voltage Test

7.1 Possible Causes for MLCC Short-circuit Degradation

- Cracks induced during MLCC production or assembly
- Insufficient effective distance of the insulation in the ceramic insulation layer due to metal burrs or local insufficient thickness of the ceramic.
- Dielectric ($BaTiO_3$) defects

7.2 Prevention of Insulation Deterioration in Common MLCCs: Flash Voltage Test

In general MLCCs, a pulse test with a voltage of 2~5 times above the rated withstand voltage is applied for a short time. This impact can cause products with weak withstand voltage to become damaged products, which then can be screened out by a normal IR test or C/D test of rated voltage. Or it could be that the low-insulation path is destroyed after high voltage aging and is repaired to be "good" with acceptable withstand voltage, although that often becomes a potential “fake” that will continue to deteriorate into a short-circuit product or substandard product with low deformation resistance.

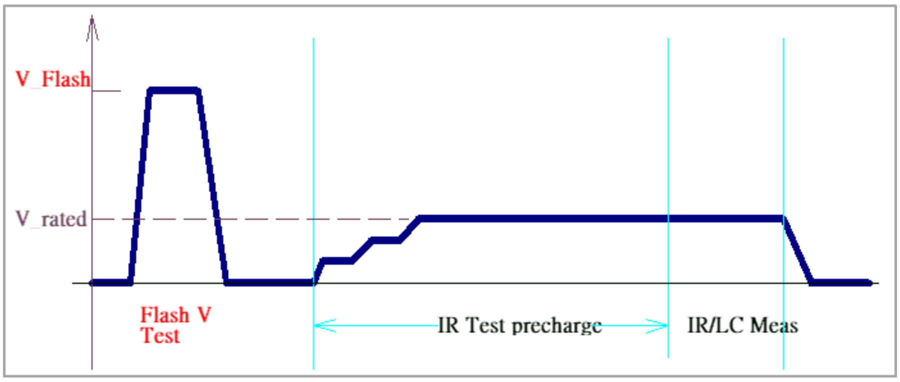


Figure 18 – Flash Voltage Test