Testing Method to identify Counterfeit Multilayer Ceramic Capacitors

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Abstract

Due to the high-volume production of mobile phones and computer tablets, the demand for MLCCs (Multilayer Ceramic Chip capacitors) has started to outstrip supply, especially for custom MLCCs. This is particularly true for Class I MLCCs with special specifications such as high voltage and frequency stability, and for such stringent applications as automotive, military and aerospace. Under these conditions, the opportunity for counterfeit OEM and replacement capacitors to enter the supply chain continues to grow. This is especially true as the majority of MLCCs have no marking and cannot easily be distinguished from their package, which gives unscrupulous vendors opportunities for fraud.

This paper introduces several test methods for MLCC compliance verification, namely 1) The effect of DC bias on capacitance, 2) Capacitance temperature characteristics, 3) High voltage testing of DCW (Dielectric withstand voltage) and IR (Insulation Resistance), 4) Cross section (Dielectric layer and terminal comparison for flex types), and 5) electron microscopy (EDS) material analysis to match with known good device chemical composition.

1. Introduction

Capacitors are passive electronic components that are used in high quantity in modern electronic circuits. In order to reduce printed circuit board (PCB) size and cost, these ‘chip capacitors’ have been scaled down to the sub-mm dimension and are surface mounted to the PCB. **Figure 1.** shows an example of a MLCC mounted on an iPhone-7 PCB which demonstrates the challenges of easily identifying counterfeit parts during production.
There is one important step we must perform before testing Class II capacitors. This is referred to as the ‘capacitor Precondition test’. The standard way to do this, according to Murata, is to perform a heat treatment at 150+0/-10°C for 1hour and then let the part sit for 24±2 hours at room temperature, then measure its electrical characteristics.

The reason to perform this precondition test is due to the characteristics of $BaTiO_3$, which is a typical metal-oxide dielectric used in MLCCs and is the base material of Class II MLCCs. A decay in dielectric permittivity has been observed over time with these formulations whereby the molecular structure of $BaTiO_3$ changed with time. Initially it displays a galvanic molecular structure which gradually transitions to a chaotic couple structure. The chaotic couple structure of the dielectric molecules has a lower ability to store charge than the galvanic molecular structure thus causing the capacitance value to decrease. In general, we refer to this phenomenon as the **aging** process.

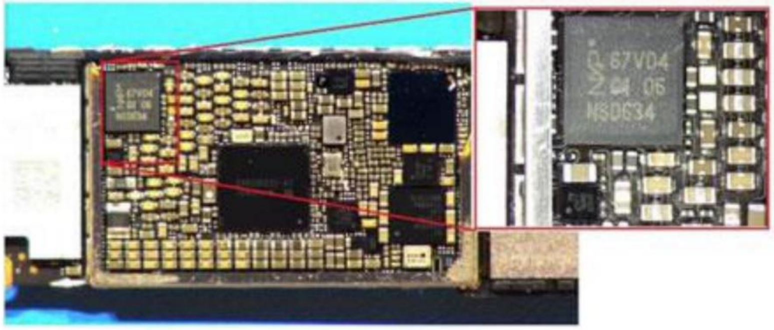


Fig1 iPhone 7 PCB showing numerous MLCCs and a higher magnification of a typical Class I MLCC (right inset). Note these are surface-mounted parts and, due to their very small dimensions, have no manufacturers markings ruling out inspection as an easy means to determine MLCC authenticity.

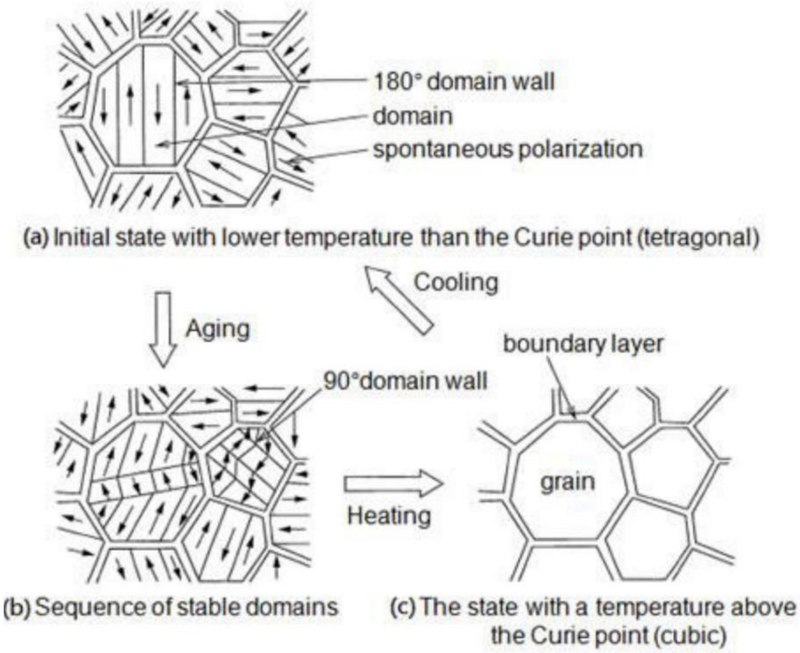


Fig2 Material characteristics inside MLCC devices. (a) initial electric dipole orientation, which explains how capacitors store charge, with galvanic molecular structure while (b) shows the chaotic couple structure. The rotation of the dipoles is how capacitors lose charge storage over time. (c) Structure when temperature is above the curie point.

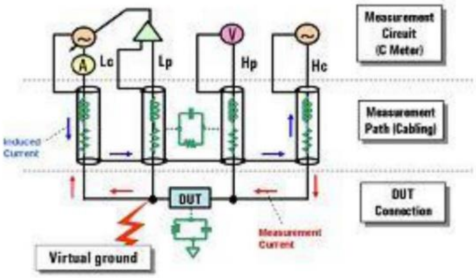


Figure 4 Measurement of MLCC capacitance using the 4TP measurement method.

The Hp and Hc terminals are often referred to as the CMH (Capacitance Meter High) terminal, and the Lp and Lc terminals are commonly referred to as the CML (Capacitance Meter Low) terminals.

There are some residual inductance and resistance in the cables, along with parasitic capacitance between the cables, or between the DUT and ground. When we perform the measurement, we must perform parasitic compensation and calibration to eliminate these parasitic elements otherwise the accuracy of the measurement will be greatly reduced.

Fig. 5 Photograph of the Keysight E4990A and test fixture 16034G used to make the capacitance test.

Compensation and Calibration:

There are 4 types of compensation and calibration steps we usually perform:
1) Open correction, 2) Short Correction, 3) Cable length calibration, and 4) Load correction.
The Open/Short Correction (Figure 6) is used to compensate for stray admittance and residual impedance due to the test fixture.

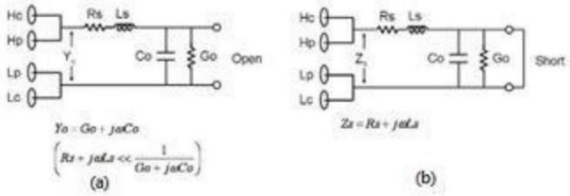


Fig. 6 Use open(a) / short(b) correction to calculate residual impedance and stray admittance of the test fixture.

With these two corrections then we can extract Z of text fixture.

$$Z = \frac{Z_m - Z_s}{1-(Z_m - Z_s)Y_o}$$

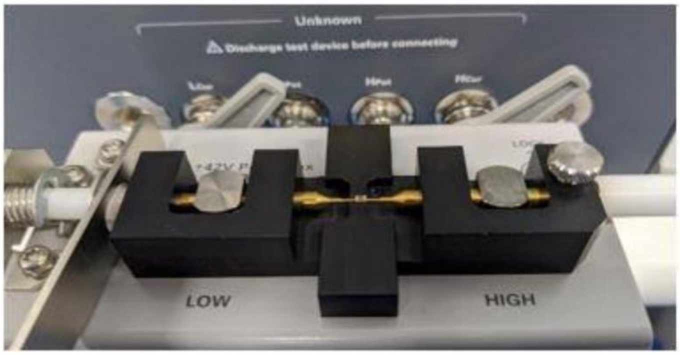


Fig 7 MLCC in 4TP measurement and compensation test fixture

Cable length calibration improves bridge balance stability at high frequencies, and it compensates for any phase drift induced from cable length and high frequency. Phase compensation should be performed before open / short cable compensation to achieve the best calibration condition for the test.

Load correction is usually performed if the testing frequency is greater than 5 MHz. Since the MLCC test frequencies are all below 1 MHz we do not need to discuss this further in this paper.

Test Frequency:
Test frequency can be a useful means to detect counterfeit MLCCs, especially in the common case where type Class II capacitors are substituted for Class I capacitors.

The frequency test characteristics of Class I capacitors are very stable since the capacitance does not change with frequency. On the other hand, Class II capacitors display a well-known drop in capacitance at high frequencies, thus it is easy to determine if the MLCC is Class I or Class II by simply doing a frequency sweep. Figures 8 and 9 compare Class I and II capacitance during a frequency sweep from 20 Hz to 10 MHz:

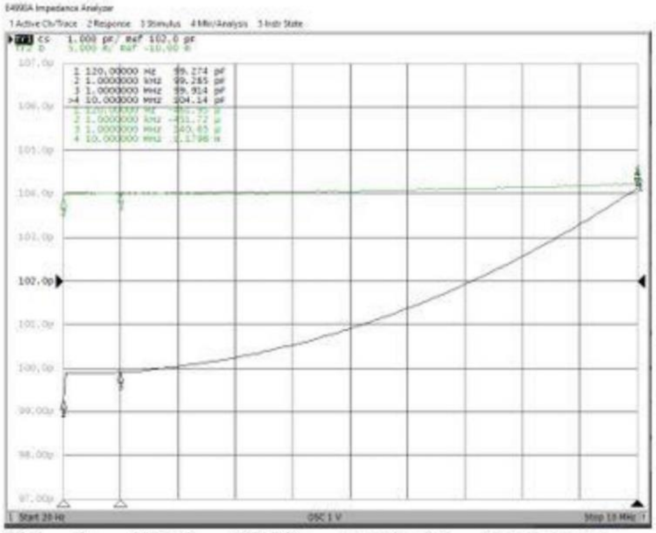


Fig 8 Class-I MLCC capacitance measurement. C0805C101F1GACTU Capacitance change vs. Frequency (20Hz to 10 MHz).

Fig 9 Class-II MLCC capacitance measurement. C0805C152KDRACAUTO Capacitance change vs. Frequency (20Hz to 10 MHz)

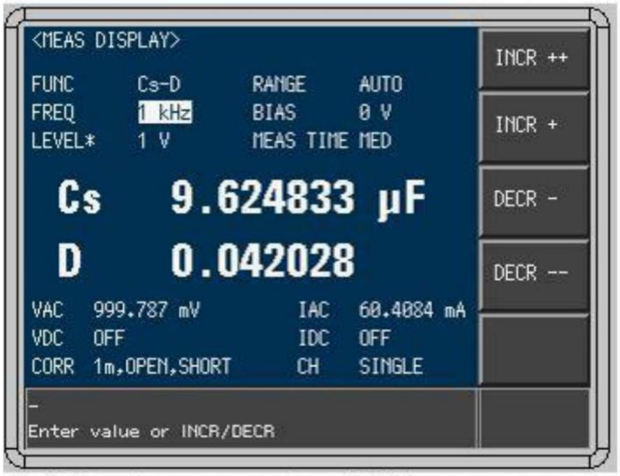
Frequency Sweep in these two samples:
Sample 1: C0805C101F1GACTU
Rated: 100 pF, 100V, C0G (class I) 1% tolerance
Sample 2: C0805C152KDRACAUTO

Rated:1500pF,1000V, X7R (class II) 10% tolerance.
Frequency Sweep 20Hz to 10MHz, E4990A Keysight Impedance Analyzer, Test fixture: Keysight 16034G
Table 2 Class I and II Capacitor capacitance change vs. frequency

<MEAS DISPLAY>
FUNC Cs-D RANGE AUTO
FREQ 1 kHz BIAS 0 V
LEVEL 1 V MEAS TIME MED
Cs 8.593258 µF
D 0.025452
VAC 181.864 mV IAC 9.81619 mA
VDC OFF IDC OFF
CORR 1m,OPEN,SHORT CH SINGLE
Enter value or INCR/DECR

Fig 11 Capacitance measured *without* ALC. The Testing level set to 1.0V, however the Voltage monitor showing only using 181.864 mV

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 12 shows a measurement of the same 10 µF capacitor using the Keysight E4980 LCR meter with the ALC feature set to ON.



<MEAS DISPLAY>
FUNC Cs-D RANGE AUTO
FREQ 1 kHz BIAS 0 V
LEVEL* 1 V MEAS TIME MED
Cs 9.624833 µF
D 0.042028
VAC 999.787 mV IAC 60.4084 mA
VDC OFF IDC OFF
CORR 1m,OPEN,SHORT CH SINGLE
Enter value or INCR/DECR

Fig 12 Capacitance measured *with* ALC on. The Testing level set to 1.0V, and the Voltage monitor also showing using 999.787mV

For some cases we saw where general Class II capacitors were used to replace Automotive MLCCs. Both are class II. Therefore, the frequency method or temperature method are not able to detect the counterfeit part. However, the AC characteristic can be used in this case.

The Automotive grade MLCC capacitance is more stable vs. AC voltage variation. Fig. 13 shows the AC voltage characteristics of the GCM32EL8EH106KA07 Class II capacitor:

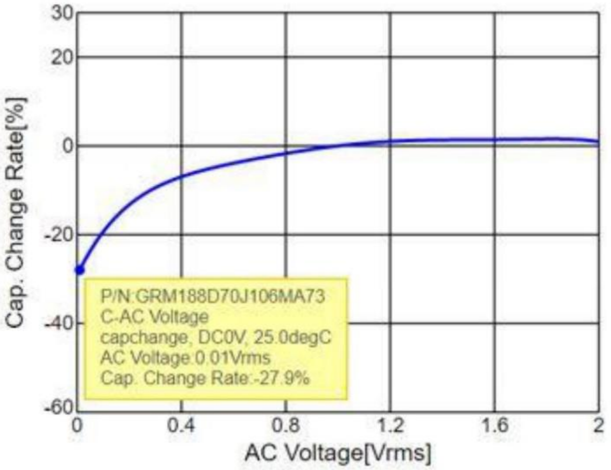


Fig. 13 General rating class II capacitor- GRM188D70J106MA73, capacitance loss (-27.9%) at 0.01 Vrms. Data provided from Manufacturer.

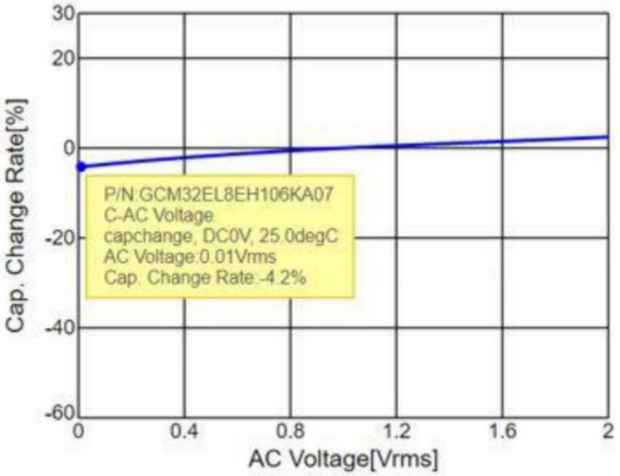


Fig14. Automotive rating class II capacitor- GCM32EL8EH106KA07 capacitance loss (-4.2%) at 0.01 Vrms. Data provided from Manufacturer.

Compared to the general MLCC, GRM188D70J106MA73 capacitance change (loss) vs. AC voltage was 27.9% at 0.01 Vrms (Fig. 13) while the GCM32EL8EH106KA07 and GCM32EC71H106KA03 experienced only a 4.2% loss (Fig14, Fig 15).

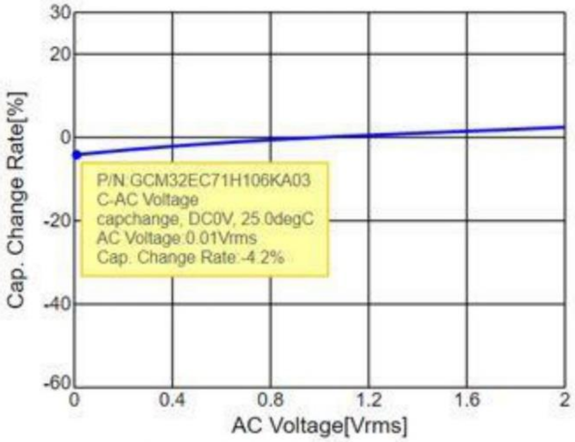


Fig. 15 Automotive rating class II capacitor - GCM32EC71H106KA03 capacitance loss (-4.2%) at 0.01 Vrms. Data provided from Manufacturer.

III. Insulation Resistance and Leakage Current

Insulation resistance is one of the important parameters used to identify counterfeit multilayer ceramic capacitors, MLCCs. The different MLCCs have different insulation resistance, which depends on the application. From experience, one of the common methods to counterfeit MLCCs is to place low specification chips into high specification packages, and then claim it as a high specification part. For some applications the MLCC must have a higher insulation resistance. If the user chooses the counterfeit MLCC the device/circuit performance may initially seem fine, but over the time leakage current and break-down voltage will degrade adversely affecting circuit performance and possibly leading to device/circuit failure. This is particularly the case where low insulation resistance affects the operation of circuits intended to be isolated. Unexpected high leakage currents can eventually lead to deterioration of the insulation by heating or by direct current electrolysis. Consequently, knowing how to measure MLCC insulation resistance is one of the important methods to identify counterfeit MLCCs.

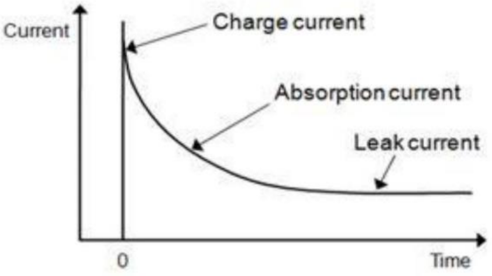


Fig 15 Behavior of MLCC current vs. charging time. Note three distinct current levels: charge current (peak MLCC current), absorption current (exponential decay due to device RC time constant) and steady-state leakage current.

The Insulation resistance values for MLCCs are usually very large, generally in the Mega-Ohms (MΩ) range. In terms of the RC time constant the product is typically in the Ohms-Farads (ΩF) range or larger. For example, if the MLCC capacitance is 10µF and the minimal insulation resistance is 500ΩF the insulation resistance equals 500ΩF/10µF or 50GΩ. This value cannot be measured by a conventional ohmmeter as those instruments are only accurate up to ~ 1 GW. We thus need to measure the insulation resistance using the Electrometer/High Resistance Meter and follow the procedure outlined in MIL-STD-202-302 [3].

For instance, for the Keysight B2987A Electrometer/High Resistance Meter, the capacitance resolution is 0.01 fA with a maximum resistance measurement of 10 PΩ. On the other hand, there are two basic ways to measure leakage current: the series method and the parallel method. In the series method an electrometer is placed in series with the capacitor and voltage source. (Fig. 16). For the parallel method a voltmeter is in parallel with a resistor, and then connected in series to the capacitor and voltage source. (Fig. 17). In the series method we measure the leakage current for the MLCC. From the MLCC datasheet, we need to apply the rated voltage to the capacitor for 60 – 120 seconds depending on the capacitance. Because, while we apply a DC voltage to the capacitor terminals, current will start to charge the capacitor and, after charging is complete, the current will decrease and then level off (Fig. 15). From this steady state current we can identify it as the leakage current. In this measurement, we determine the voltage applied to the capacitor and leakage current passing the capacitor after it is fully charged. Then we can calculate the insulation resistance of MLCC by ohm's law, R = V/I.

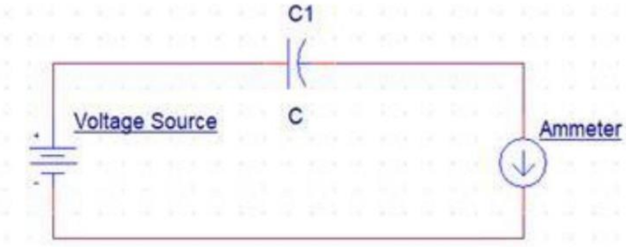


Fig 16 Series Method for Insulation Resistance Measurement

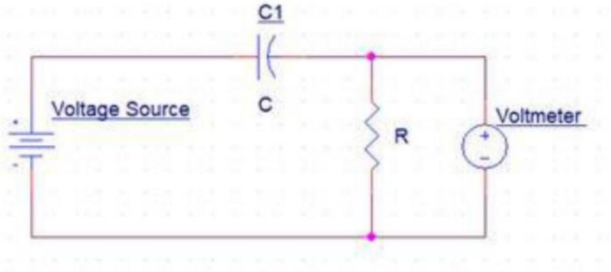


Fig 17 Parallel Method for Insulation Resistance Measurement

Since the MLCC is made using a real dielectric material with a non-zero loss tangent, which is not a perfect insulator, there will always be leakage current present. Additionally, MLCCs have a different value of insulation resistance because it is composed of different materials or combinations of materials. Therefore, there are a many reason for low MLCC insulation resistance or high leakage current, such as: device temperature and moisture, dielectric contamination, oxidation, loss of volatile materials, and material cracking. Insulation resistance measurement is especially helpful in determining the extent to which the insulating properties have been affected by deteriorative influences and also to determine if the MLCC is counterfeit or of low quality.

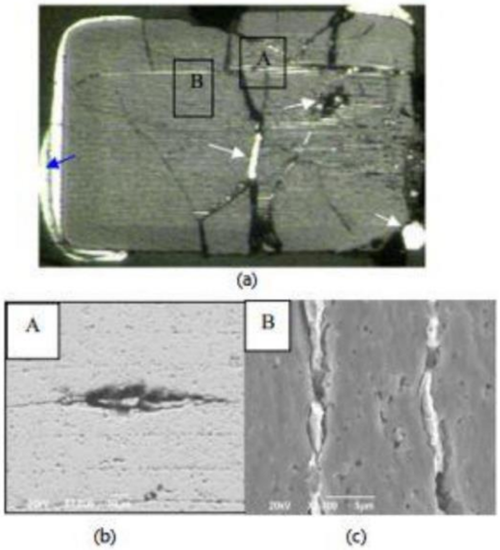
Fig 18 Insulation resistance measurement of a qualified MLCC using the B2987A Electrometer/High Resistance Meter.

Fig 19 Insulation resistance MLCC failure using the B2987A Electrometer/High Resistance Meter. Note the decay in resistance vs. time.

For example, the MLCC part no. C2012JB1A476M125AC, manufactured by TDK, has a nominal capacitance of 47µF. We used the B2987A Electrometer/High Resistance Meter to measure its insulation resistance by the series method (Fig. 16). We set the voltage source of the meter to 10V, which is its rated voltage. From the datasheet, we found the voltage application time for the insulation resistance measurement is 60 seconds and the minimum insulation resistance is 2MΩ. In Figure 18, we can see a stable measurement of 59.8444 MΩ, which is higher than the datasheet spec. Therefore, we can identify the device under test as matching the manufacturers specification. On the other hand, in Fig. 19, we observed that the insulation resistance was lower than the specification and kept decreasing as we charged the MLCC for 60 s. Therefore, we can identify this device under test as having failed the insulation resistance measurement and can designate it as a counterfeit MLCC.

IV Dielectric Withstanding Voltage

The purpose of the dielectric withstanding voltage test is to assess the reliability and expected lifetime of an MLCC. Failure during a dielectric withstanding voltage test results in short circuits caused by a decreasing insulation resistance and increased current, which will damage other chips on the board. The typical breakdown voltage for an MLCC is much greater than the rated voltage. But a voltage less than the breakdown voltage may permanently damage the insulation and thereby reduces its safety factor. For an MLCC, dielectric withstanding voltage failures lead to internal damage by electrical overstress cracking as shown in Fig. 20.



(a)

(b) (c)

Fig. 20 MLCC dielectric withstanding voltage test. (a) Dielectric breakdown by EOS (electrical overstress). (b,c) SEM morphology of dielectric showing a local stratification phenomenon [4].

The manufacturer uses the dielectric withstanding voltage test to determine the voltage rating and verify that the MLCC is capable of operating at its rated voltage without material degradation. It is also used to assess if the device can withstand a momentary overvoltage event due to switching spikes or surges. In other words, the dielectric withstanding voltage represents the maximum level of continuous voltage that can be applied across an MLCC. There are different dielectric withstanding voltage tests depending on the voltage applied or stress condition. According to military [5] and manufacturer specifications, the dielectric withstanding voltage for Class I MLCCs is usually 3 times the rated voltage. For Class II MLCCs, the dielectric withstanding voltage is 2.5 times the rated voltage.

To implement the dielectric withstanding voltage test we used a Vitrek V73, which is an AC/DC/IR Hipot tester. It can provide 5kVAC/DC with a 20 mA source current. As mentioned, the dielectric withstanding voltage is a test to measure the MLCC breakdown voltage and confirm that the MLCC can safely operate at the manufacturers rated voltage. When an MLCC fails the dielectric withstanding voltage test, the application of the test voltage will result in a disruptive discharge such as a flashover, sparkover, or breakdown. Additionally, MLCC deterioration due to excessive leakage current may change the device electrical parameters or physical characteristics.

For example, from the datasheet for the C2012JB1A476M125AC MLCC tested in the last section, the rated voltage is 10V, has a JB temperature characteristic and, is Class II. That means the dielectric withstanding voltage of the device under test is 2.5´10V = 25V, and the voltage application time is 1 second. In Fig. 21, we observed that there was no breakdown when 25V was applied to the device. The rated voltage of the device under test matches the manufacturer's specification and passes this test.

Fig 21 Dielectric Withstanding Voltage Testing using the Vitrek V73 AC/DC/IR hipot Hipot tester showing that the device passed the 2×Voltage rating for the Class II MLCC part no. C2012JB1A476M125AC.

V. MLCC DC Bias Effect

MLCCs use dielectric materials which makes them different from other capacitors, such as electrolytic. Their materials provide a high dielectric constant that changes according to environmental factors.

MLCCs are divided into classes based on the dielectric materials used. Two of the most common types of MLCCs used in the industry are Class I which is temperature compensating, and Class II, which has a high dielectric constant. Class I capacitors tend to have lower capacitance values and are more stable than Class II capacitors.

Class I MLCCs contain a low-loss dielectric and are very stable as shown in the measured data of Fig. 22. These measurements were taken at room temperature at a frequency of 1 MHz under various DC bias applied voltage ranging from 0 V to 40 V.

Class II MLCC permittivity depends on the applied electric field. Therefore, with different applied voltage, the MLCC capacitance varies accordingly. The following measured data, shown in Fig. 23, shows that the capacitance changed after performing the DC bias sweep. These measurements were taken at room temperature at 1 kHz and under various DC bias applied voltage ranging from 0 V to 10 V.

Fig. 22: Effect of DC bias on Class I MLCC capacitance for a 270 pF, C0G. Note that the capacitance did not change as the DC bias was swept from 0 to 40 V, which is expected for this class of MLCC.

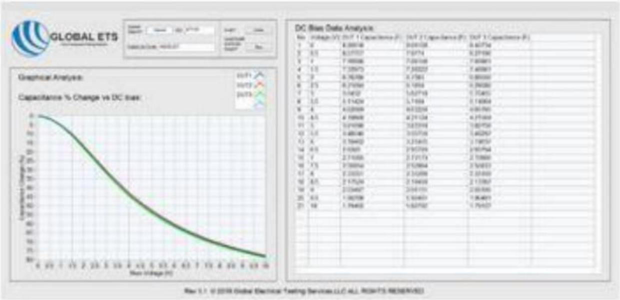


Fig. 23: Class II MLCC capacitance for a 10uF, X5R. Note that the capacitance changed value as the DC bias was swept from 0 to 10 V, which is expected for this class of MLCC.

As shown above for a Class-2 MLCC, as the applied voltage increases the change of capacitance becomes more significant. For Class I MLCCs, however, different voltage ratings hardly affect how they perform. With this knowledge, we can tell if a part is a legitimate Class I MLCC or not based on its DC bias capacitance profile.

VI. MLCC Temperature characteristics Testing

As we mentioned in the section above, Class II MLCCs tend to have a larger capacitance compared to Class I MLCCs. The capacitance value of Class II MLCCs change greatly with temperature, yet for Class I MLCCs this is not the case. The following research results show how to measure the difference between these two kinds of capacitors based on temperature cycling.

The following test on Class I capacitors was performed at 25°C, -55°C and 125°C at a frequency of 1 kHz.

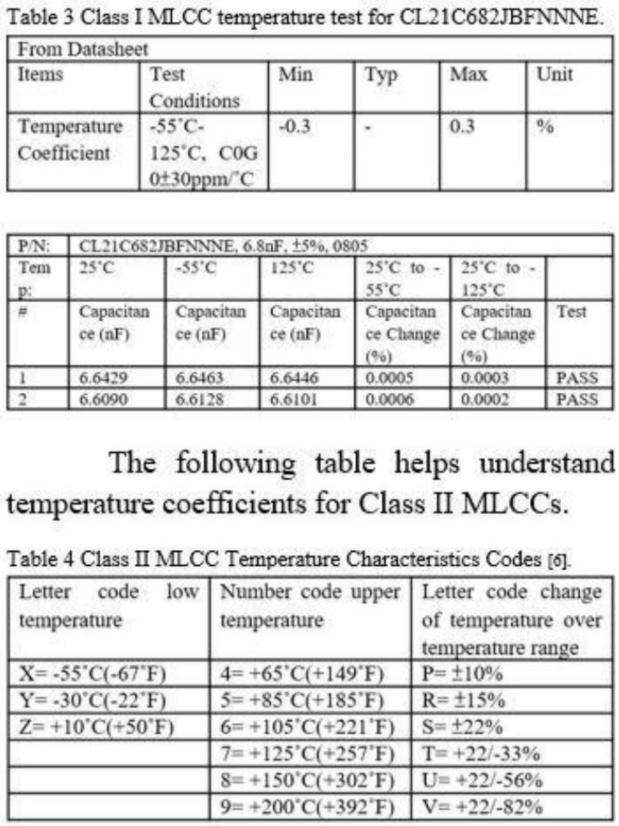


Table 3 Class I MLCC temperature test for CL21C682JBFNNNE.

From Datasheet					
Items	Test Conditions	Min	Typ	Max	Unit
Temperature Coefficient	-55˚C-125˚C, C0G 0±30ppm/˚C	-0.3	-	0.3	%

P/N:	CL21C682JBFNNNE, 6.8nF, ±5%, 0805					
Temp:	25˚C	-55˚C	125˚C	25˚C to -55˚C	25˚C to -125˚C	
#	Capacitance (nF)	Capacitance (nF)	Capacitance (nF)	Capacitance Change (%)	Capacitance Change (%)	Test
1	6.6429	6.6463	6.6446	0.0005	0.0003	PASS
2	6.6090	6.6128	6.6101	0.0006	0.0002	PASS

The following table helps understand temperature coefficients for Class II MLCCs.

Table 4 Class II MLCC Temperature Characteristics Codes [6].

Letter code low temperature	Number code upper temperature	Letter code change of temperature over temperature range
X= -55˚C(-67˚F)	4= +65˚C(+149˚F)	P= ±10%
Y= -30˚C(-22˚F)	5= +85˚C(+185˚F)	R= ±15%
Z= +10˚C(+50˚F)	6= +105˚C(+221˚F)	S= ±22%
	7= +125˚C(+257˚F)	T= +22/-33%
	8= +150˚C(+302˚F)	U= +22/-56%
	9= +200˚C(+392˚F)	V= +22/-82%

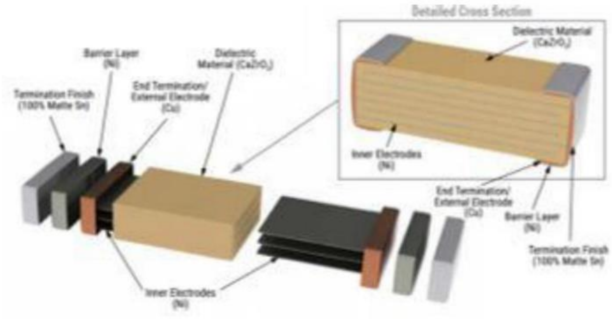
As we notice, the capacitance change rates (around 10% under -55° C) of Class II MLCCs are more obvious than Class I MLCCs. Thus, by looking at the capacitance change rate versus temperature, we can tell if a part belongs to Class I or Class II.

VII Energy-dispersive X-ray spectroscopy

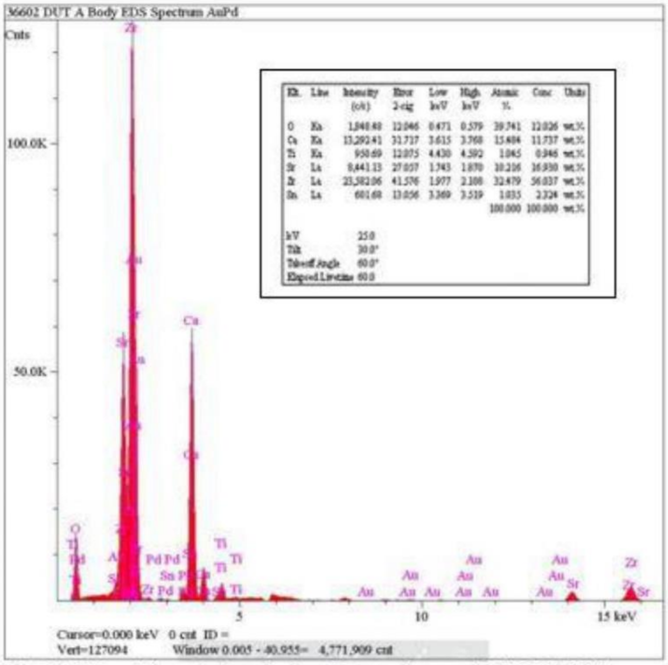
Energy Dispersive Spectroscopy (EDS) is a chemical micro-analysis technique used with scanning electron microscopy and widely applied to research of elemental analysis and material characterization.

The fundamental principle is based on the interaction between an excitation source and the specimen. Different elements have their own unique structure and x-rays are emitted with unique peak energy forming an energy spectrum for each sample. It is a similar, but opposite, principle behind element identification using X-ray fluorescence (XRF). In both cases photon energy is emitted; with EDS they are stimulated using electrons while in XRF x-rays do the job.

In EDS, the specimen is illuminated with an electron beam and transfers its energy to the atom which changes the electron state in the atom. When the electron then relaxes back to its original state energy is released in the form of an X-ray photon. The energy and the number of X-ray photons, called counts (cnts.) can be measured by EDS. Thus, we can identify the elemental composition of specimen but the sensitivity of the analysis depends on both the atomic number of the element and the matrix that is resides in.



Fig, 24. Material composition of class I capacitor from KEMET. Dielectric Material $CaZrO_3$.



El.	Line	Intensity (c/s)	Error 2-sig	Low keV	High keV	Atomic %	Conc	Units
O	Ka	1,840.48	12.046	0.471	0.579	39.741	12.026	wt.%
Ca	Ka	13,292.41	31.737	3.615	3.768	15.604	11.737	wt.%
Ti	Ka	950.69	12.075	4.430	4.592	1.045	0.946	wt.%
Sr	La	8,441.13	27.057	1.743	1.870	10.216	16.930	wt.%
Zr	La	23,582.06	41.576	1.977	2.108	32.479	56.037	wt.%
Sn	La	601.68	13.056	3.369	3.519	1.035	2.324	wt.%
						100.000	100.000	wt.%

kV	25.0
Tilt	30.0°
Takeoff Angle	60.0°
Elapsed Livetime	60.0

Fig 25 Material analysis of class I capacitor - C0402C0G500-470JNP. Note the dominant peaks are for Au, Ca, Ti, Pd, Sn, etc. Inset: relative count percentage for each element.

VIII. Cross-section & Metallography

The physical cross-sectioning of an MLCC can always provide essential information to aid in understanding electrical testing of the device. It physically shows the device structure and allows for easy material characterization of the metal and dielectric components. Cross-sectioning is not a means, but a goal. It is a destructive metallographic technique to show the internal structure for material analysis whereas x-ray inspection only provides information on device geometry.

Metallography was originally used on metal alloys but has since been applied to a variety of materials such as plastics and ceramics. In the IC industry, metallographic techniques are often applied during failure analysis because they can reveal the internal structure of the PCB board, joint terminals, and electronics inside the component package. In the failure testing of MLCCs, it is important to check if the capacitor is soldered to the PCB board properly when cross-sectioning is used. For example, open cracks may be found in the solder joint(s) but appear during electrical testing as a device failure resulting in a false positive result.

Besides electrical functionality tests, the other testing method to identify counterfeit MLCCs can be binned into two types: structural component and material composition characterization. These methods are more likely to allow observation of the entire capacitor from its external to its internal structure. The choice of tools and equipment are vital when performing material structure analysis. X-Ray, X-ray fluorescence spectroscopy (XRF), optical microscopy or scanning electron microscopy (SEM) are the most common tools used to perform material analysis. However, each has their limitations and, often, complimentary methods are used to properly evaluate an MLCC structure and material composition.

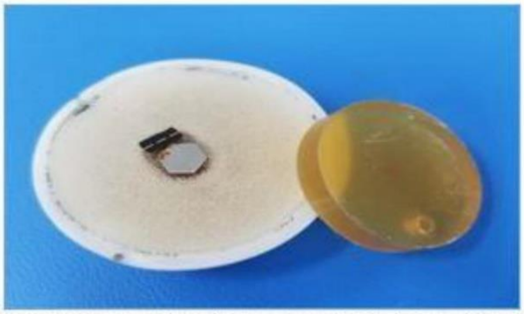
X-Ray and visual inspection by optical microscopy are typically non-destructive methods used to observe the sample; however, they are limited in the details they reveal. X-ray analysis can only show the rough structure and visual inspection is limited to only exterior information, such as the package and leads. In both cases they cannot tell us more about the materials used in the construction of the device. Therefore, cross-sectioning provides another tool to explore details of the device more completely and allows access to the internal material composition, such as the dielectric compounds used, which is critical to ascertain if an MLCC is legitimate or counterfeit. Cross-sectioning reveals the material grain structure and internal boundary conditions between the metal layers and the gap spacing. It is therefore an important technique to analyze the structure of MLCCs, with the proviso that it is a destructive test

Method of Metallography

Metallographic specimen preparation can be broken down into a few steps – device mounting, sectioning, grinding, polishing, and then etching. Preparation of the sample is vital to preparing a suitable cross-sectioned device as improper specimen preparation can cause contamination of the various device components making elemental chemical analysis impossible.

Mounting

The purpose of mounting the specimen is encapsulating the sample in an epoxy, acrylic or polymer compound (Fig, 25). This mechanically fixes the specimen within the compound to be held easily during the grinding and polishing processes and reduces contamination caused be debris migration across the sample.



Fig, 25. Specimens mounted in both epoxy and acrylic for cross-section processing.

Additionally, the orientation should be considered when mounting the specimen. Fig. 26 shows the cross-section of an MLCC we want to study and the mounting orientation.

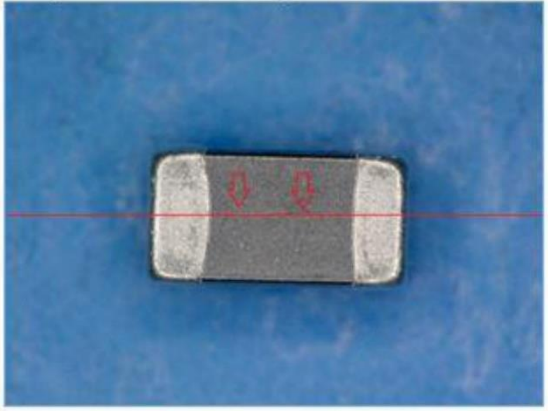


Fig. 26. Photograph of an MLCC before mounting in epoxy or acrylic compound. Red line and arrows show where the device is to be sectioned. (Sample Dimensions: Length=1.75mm, W=0.98mm, Thickness=0.95mm).

Sectioning

There are a variety of methods to section the specimen such as hacksawing, diamond blade cutting or using a hot flame blade for larger specimens. In the metallography for small specimens, often an abrasive or precision cutter is used. As a result, mechanical and thermal damage cannot be avoided during this type of process, but if done properly it is possible to minimize damage. This allows more precise steps that follow to accurately reveal device material with minimal contamination.

Grinding

During the grinding process, silicon carbide or alumina grit sand paper is widely used. The grinding process is always performed using water since it helps reduce heat damage and removes impurities during the process. The main purpose during grinding is to remove damage caused from the sectioning process.

Polishing

Polishing is the final step needed to finish preparing the specimen for material analysis. With proper polishing, a fine, flat surface without scratches and deformation results. The choice of polishing abrasives are usually diamond, aluminum oxide and silicon dioxide. Polishing cloth is also used when performing gel polishing. Generally, low nap cloth is used for coarse polishing and medium or higher nap cloth is used for final polishing.

Etching

After polishing a chemical etching step is used to complete specimen preparation. The different metal elements in the part have different resistance levels to chemical solvents. After the etching process, the micro-structure of the metals (and ceramic) parts are more obvious. Proper etching during metallography can be used on IC terminals which are made of alloys. In the MLCC case, we care about the chemical composition of the materials that can only be obtained from part cross-sectioning. Therefore, we don’t need to do the etching in this case.

Case Study

Below is shown an as-received original part before cross-sectioning (Fig. 27) and after cross-sectioning (Fig. 28). Fig. 27 also shows the proper orientation of the MLCC during cross-sectioning.

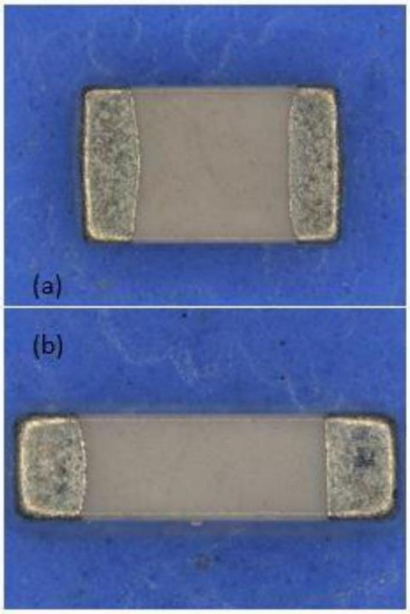


Figure 27 MLCC prior to sectioning. (a) Front view of capacitor under test, (b) top view of capacitor under test. (Sample Dimensions: Length = 2.04 mm, Width = 1.21 mm, Thickness = 0.59 mm).

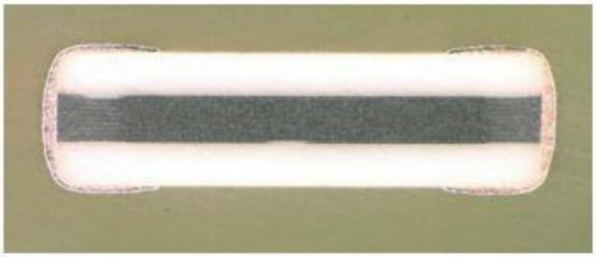


Fig. 28. Cross-section view showing proper orientation of sample after cross-sectioning. Note metal alloy package leads (left and right) and capacitor plate layers imbedded in dielectric (white material). (Magnification: 100x).

We use one known good device and one unknown sample device to do the comparison. The figures below (Figs 29 and 30) show the terminal on the left side, ceramic body and the intermetallic boundary.

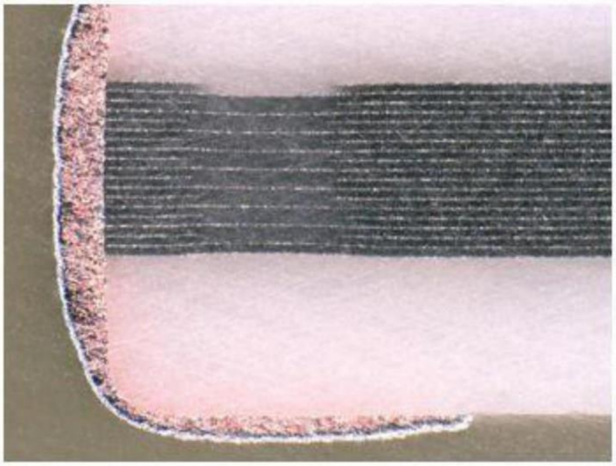


Figure 29. Optical micrograph of a known good device - intermetallic boundary. (Magnification: 400x).

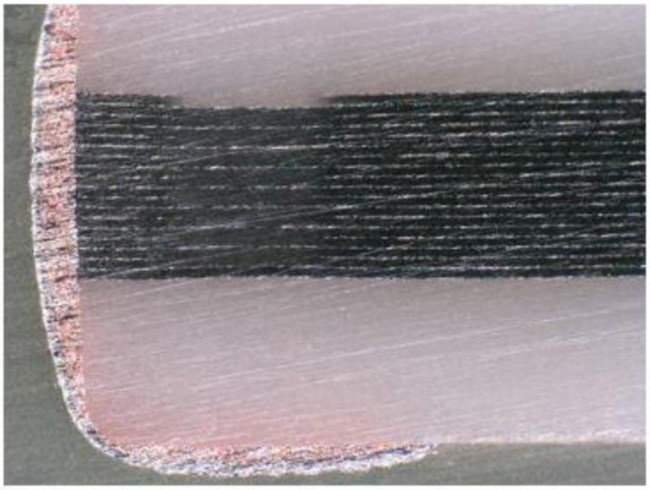


Figure 30. Higher magnification optical micrograph of the unknown sample device - intermetallic boundary. (Magnification: 400x).

The Figures below (Figs 31 and 32) show the dimensions of the MLCC and intermetallic boundary.

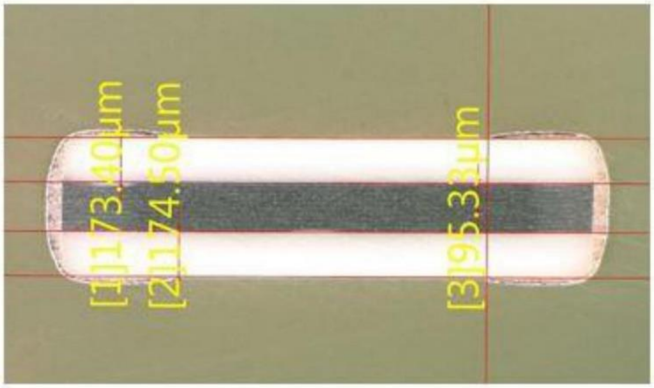


Figure 31. Optical micrograph of the known good device - dimensions of structure. (Magnification: 100x),

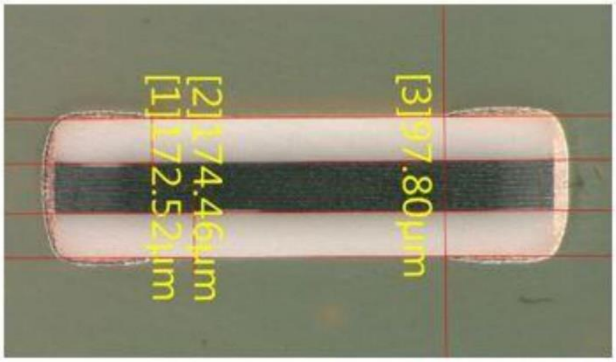


Figure 32. Optical micrograph of the unknown sample device - dimensions of structure. (Magnification: 100x).

From this case, we can see that the composition and structure are the same for the known good device and test device which indicates that the unknown device is an authentic, i.e., non-counterfeit, part.

IX.Conclusion

Identification of a counterfeit MLCC is very challenging. With the development of 5G technology, the need for high quantities of MLCCs will face new challenges in preventing counterfeit parts from entering the supply chain. There are only a few papers or articles focusing this issue. Even the manufacturers not able to provide an effective way to identify counterfeit parts. We have contacted many major manufacturers in this industry and they only provide the service to verify part authenticity via the label on the parts reel which clearly does not solve the counterfeit MLCC issue.

In this paper, we have introduced some counterfeit MLCC case studies and several methods to help to identify counterfeit MLCCs. These methods are not only based on their electrical characteristics but on their physical characteristics as well. Based on the electrical characteristics of the target device such as High frequency RF capacitance, we can use a test frequency sweep. Using the MLCC High Voltage rating we can use the Dielectric withstand voltage test and insulation resistance test; For Soft terminal MLCCs (vibration-proof) we can use cross section testing based using metallography methods.

Using MLCC physical characteristics, this provides a golden sample will helps to identify counterfeit capacitors, especially during physical comparison (EDS and cross section).

By using a combination of these testing methods, we can successful identify 80% – 90% of counterfeit MLCCs. Our future research will focus on the capacitor mechanical characteristics, (such as bent testing, vibration and mechanical shock, etc.) and Lifetime testing such as Moisture Resistance, Operational Life (at high temp), and Thermal Shock(temperature-cycle) to keep counterfeit MLCCs out of our supply chains.

Reference:

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[4] Wei Jiang; YongDa Hu; ShengXiang Bao; Song Lijie; Zheng Yuwei; Yongqiang Cui; Li Qiang"*Analysis on the causes of decline of MLCC insulation resistance*" *in Proc.* 2015 16th International Conference on Electronic Packaging Technology (ICEPT), Changsha, China, 11-14 Aug. 2015.
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[6] *Ceramic Dielectric Capacitors Classes I, II, III and IV*, EIA-RS-198, November 1983