Frequently asked questions regarding:

# Temperature Characteristics of Multilayer Ceramic Capacitors

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*Abstract*

*All capacitors use a dielectric in their construction. This material could be a film, ceramic, or even air. With the modern trend for miniaturization, multilayer ceramic capacitors (MLCCs) continue to be a vital type of capacitor used today because of their volumetric efficiency. The material properties of the ceramics used to manufacture MLCC dielectrics can create very different DC-bias, permittivity, and temperature characteristics. These differences can drastically affect the design engineer's circuit performance.*

*This document will describe some common ways in which these temperature characteristics are categorized, graphically demonstrate temperature characteristic performance, and explain the physical reasons for the difference in temperature characteristic behavior between different ceramics.*

January, 2014

# TDK Guide to MLCC Temperature Characteristics

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**Q1. Why do some MLCC's capacitances change with temperature?**

This characteristic of the MLCC is based on the class of the ceramic with which the dielectric is made. There are two main classes of ceramics used today: class 1 and class 2.

Class 1 ceramics are non-ferroelectric ceramics based on titanium dioxide, also known as titania, ($TiO_2$), and frequently contain strontium titanate ($SrTiO_3$) and calcium titanate ($CaTiO_3$) as additives. Because they are paraelectric (non-ferroelectric), these ceramics are very temperature stable. Additionally, class 1 ceramics do not change in capacitance when under a DC-bias, and show almost no loss in capacitance over time.

Class 2 ceramics are ferroelectric and are usually based on barium titanate ($BaTiO_3$). Class 2 ceramics have significantly higher dielectric constants than class 1 ceramics. However, class 2 dielectric constants will fluctuate significantly with temperature, applied voltage, and over time. Their dielectric constants can vary significantly with temperature because the crystal structure of the ceramic will undergo phase changes within the operating temperature range of the MLCC. Class 2 ceramics also show a loss of capacitance when exposed to a DC electric field (DC-bias), and will exhibit a loss of capacitance over time (aging).

**Q2. Who creates the standards for temperature characteristics?**

The Electronic Industries Alliance (EIA) and the Japanese Industrial Standards (JIS) represent the two main governing bodies for MLCC standards, including the standards defining temperature characteristics. The JIS is referenced primarily in Japan, and the EIA is referenced in most other regions.

**Q3. Which Temperature Characteristic are commonly referenced?**

There are two different sets of code schemes used in the EIA standards. One set of codes is used to define temperature characteristics of class 1 capacitors (table 1), and the other is used to define temperature characteristics of class 2 capacitors (table 2).

Class 1 ceramics have many EIA codes, however C0G is the most commonly used. C0G is the EIA equivalent to the MIL NP0 (Negative, Positive, 0) specification. NP0 and C0G are specified to have capacitance tolerances of ±30ppm/°C over the temperature range of -55°C to +125°C. However, TDK uses both NP0 and C0G to differentiate operating temperature ranges for class 1 capacitors. TDK extends the operating temperature range of NP0 to +150°C.

| TDK Class 1 Ratings | |
|---|---|
| C0G | -55 °C to +125 °C ±30ppm/ °C |
| NP0 | -55 °C to +150 °C ±30ppm/°C |

*Table 1. TDK Class 1 Temperature Characteristics*

Unlike class 1, class 2 has many commonly used codes. In the class 2 set of codes, the first letter determines the lowest operating temperature, the number determines the upper operating temperature, and the final letter determines the maximum change in capacitance at any temperature within that temperature range. Common class 2 EIA codes include X8R, X7R, X5R, Y5V, and Z5U.

| EIA Class 2 TC Codes | | |
|---|---|---|
| **Lower Temp** | **Upper Temp** | **Tolerance** |
| X = -55°C | 5 = 85°C | F = ±7.5% |
| Y = -30 °C | 6 = 105°C | P = ±10% |
| Z = +10 °C | 7 = 125°C | R = ±15% |
| | 8 = 150°C | S = ±22% |
| | | T = +22% / -33% |
| | | U = +22% / -56% |
| | | V = +22% / -82% |

*Table 2. EIA Class 2 Temperature Coefficient Codes*

The two main JIS codes for MLCC temperature characteristics are CH, and JB. CH is the class 1 JIS code, rated for temperatures of -25°C to 85°C with a tolerance of ±60ppm/ °C. JB is the class 2 code, corresponding to a ±10% tolerance over the same temperature range of -25°C to 85°C.

**Q4. Do TDK's part numbers contain the temperature characteristics?**

TDK includes the TC in both the internal "item description", and the catalog number used in distribution channels. The section that is common to both is shown below.

```
(Commercial) C3216X7R1H105K*****
(Automotive) CGA3LX7R1H105K*****

(Commercial) C3216C0G2E223J*****
(Automotive) CGA3LC0G2E223J*****
```

**Q5. If X7R and C0G cover the same temperature range, how do I pick the one I need?**

Class 1 capacitors are good for RF matching, and resonant circuit applications, and are also used in applications requiring precise operation over wide temperature ranges and operating voltages.

Class 2 capacitors offer much higher dielectric constants and therefore have significantly higher capacitances than a class 1 of the same case size. This makes them suited for by-pass, bulk energy storage, and decoupling applications.

**Q6. Which temperature characteristics can be substituted for another?**

Temperature characteristics that cover the same range and offer tighter tolerances are drop-in compatible. X5R is a good replacement for Y5V and Z5U because of it's significantly tighter tolerances and superior DC bias performance compared to Y5V and Z5U. Because of this, TDK no longer offers MLCCs in Y5V or Z5U temperature characteristics.

X7R (-55ºC ~ +125ºC) can replace X5R (-55ºC ~ +85ºC) because the operating temperature range includes X5R's completely.

**Q7. How much change in capacitance with temperature can I expect?**

C0G and NP0 Class 1 ceramic temperature characteristics do not show significant changes in capacitance vs temperature.

Generally, heat lowers Class 2 MLCCs' capacitances, however around the Curie point (approximately 120ºC for $BaTiO_3$), the capacitance increases. This is due to an increase in the dielectric constant as the crystal structure of the ceramic changes from tetragonal to cubic.

The EIA and JIS standards state that within the operating temperature range, the change in capacitance will not exceed the specified tolerance. The chemical composition of the ceramic is not a part of the standard. Manufacturers of MLCCs use different additives to the dielectrics in order to change the performance of the MLCCs. These additives can shift the Curie point closer to room temperature (e.g. Z5U) or smooth the dielectric constant curve (e.g. X7R). The former have the highest unbiased dielectric constants, while the latter lower the maximum dielectric constant in order to achieve greater temperature stability.

These formulations are proprietary, and ensure that not all MLCCs are created equal.

Below is a graph of several MLCC's temperature characteristics.

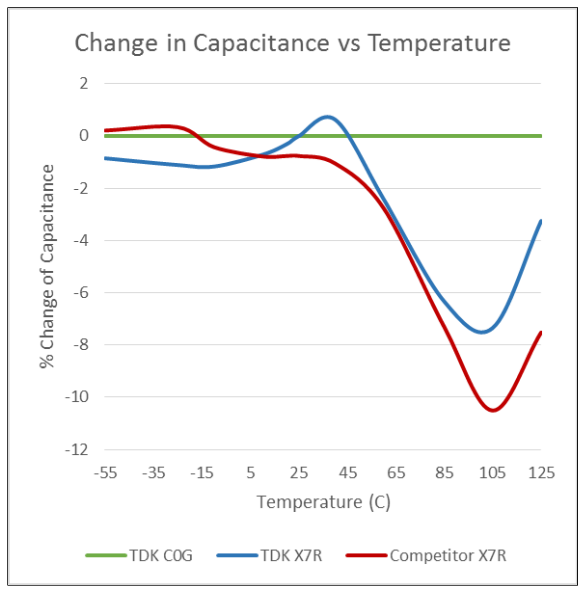


*Figure 1. A TC graph of three 10nF, 50V, EIA0603MLCCs*

Performance Data, including Temperature Characteristics curves, for TDK's MLCCs can be found on TDK.com.

# End of Report

Contact TDK for further information or visit our website at www.tdk.com.

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January, 2014