

# **EIA STANDARD**



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## **Application Guide for Multilayer Ceramic Capacitors - Electrical**

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### **EIA-521-A** (Revision of EIA-521)

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## 1 Introduction

Ceramic capacitors are those wherein the dielectric material is a high-temperature, sintered, inorganic ceramic compound. As a general rule, these materials are based on mixtures of complex titanates or niobate compounds, i.e., barium titanate, titanium oxide, calcium titanate, strontium titanate, etc. Stannate and zirconate compounds are also used. Because of the great variety of electrical characteristics found in ceramic capacitors, the Electronic Component Industry Association (ECIA) has categorized ceramic capacitors into four separate classes.

### 1.1 Class I capacitors

Class I capacitors are those of the stable and temperature-compensating type. They are available in a wide range of temperature coefficients with relatively linear characteristics. They are suited for applications where low losses and high stability are required. The capacitance ranges available in Class I are much lower than in the other classes.

### 1.2 Class II capacitors

Class II capacitors are typically more complex in formulation. They may be ferroelectric compounds, often based on barium titanate, and possess a high dielectric constant (K). They are classified as having a semi-stable temperature characteristic and are used over a wide temperature range.

### 1.3 Class III capacitors

Class III capacitors are typically based on complex formulations. Like Class II, they may be ferroelectric compounds, often based on barium titanate, but Class III capacitors have a much greater dielectric constant (K). They are the most volumetrically-efficient of the standard ceramic dielectric types. They are used over a moderate temperature range in applications where high capacitance is required, but where significant dielectric losses and capacitance changes can be tolerated.

### 1.4 Class IV capacitors

Class IV capacitors are restricted to reduced titanate or barrier layer dielectrics. These capacitors have the highest apparent dielectric constant (K). Creating a thin re-oxidized dielectric layer, a PN semiconductor junction, and/or a thin grain boundary insulating layer develops the high dielectric constant. They exhibit the same temperature characteristics as the oxidized ceramic formulation.

### 1.5 Overview

All classes of ceramic capacitors are available in a variety of physical forms, ranging from disc or rectangular single layer and multilayer types, e.g. multilayer ceramic chip (MLCC), feed-through styles, and combinations of these. In all their variations, ceramic dielectric capacitors are used more than any other single dielectric family. High usage is the result of low cost, good volumetric efficiency, excellent high frequency capabilities, and inherent reliability.

## 2 Definition of ceramic capacitors

### 2.1 Mechanical

#### 2.1.1 Single layer

This type of device utilizes a single dielectric layer. The form of this dielectric may be a flat disc, rectangular block, or tubular shape. The single layer dielectric typically has a minimum thickness of 0.2 mm (0.008 in). These components are most often constructed with leads and coated with an insulating material. Multiple devices are often mechanically paralleled to increase the total capacitance.

#### 2.1.2 Multilayer (MLCC)

Multilayer ceramic capacitors utilize a number of thin dielectric and electrode layers, measured on the micron level. Because the layers are stacked in the unsintered “green” state, it is possible to achieve much thinner dielectrics than in the single layer type. This results in much greater volumetric efficiency. The multiple layers are sintered into a monolithic structure that has excellent mechanical strength.

MLCCs may be used in chip form in surface mount applications, or they may be assembled into encapsulated or unencapsulated axial or radial leaded units used in circuit boards or other circuit applications.

##### 2.1.2.1 Single and multilayer construction

Typical constructions are detailed in Figure 1.

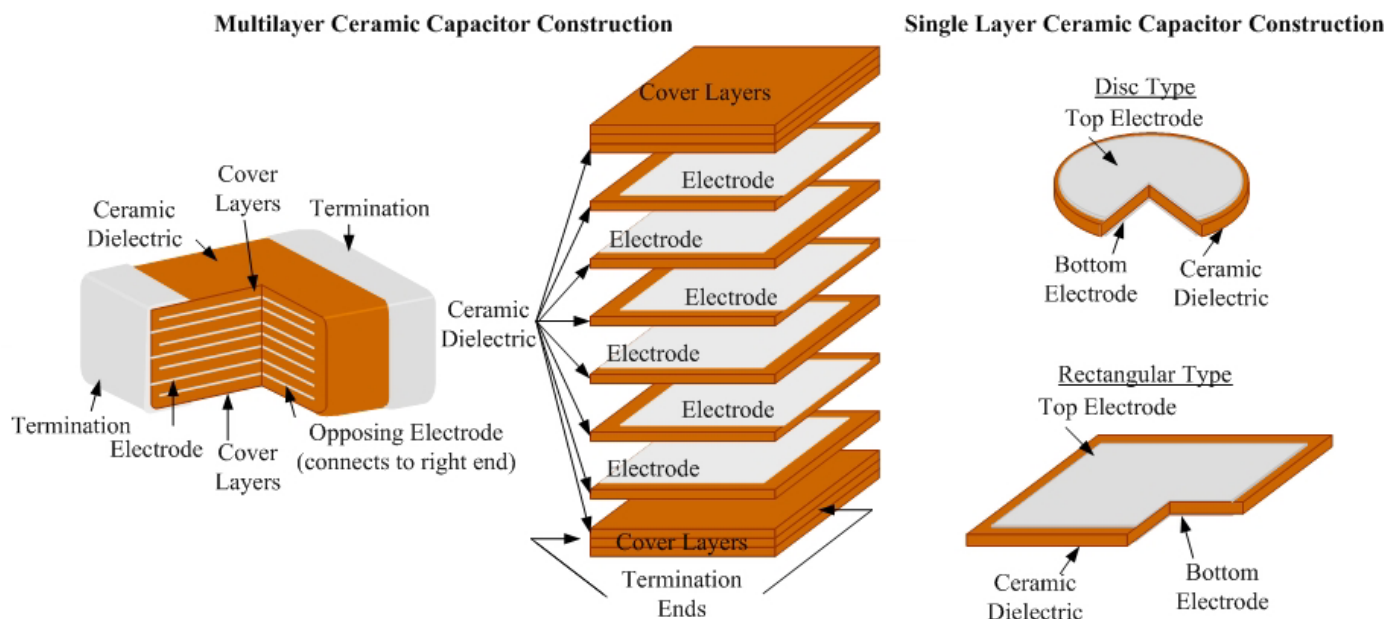


Figure 1—Single and multilayer construction

## 2.2 Electrical

### 2.2.1 Capacitance

Capacitors are electrical storage devices used in electrical and electronic equipment principally as energy storing, decoupling, coupling, bypassing or filtering, DC current blocking, voltage transient suppressing, and voltage multiplying applications. The capacitance (C) of a capacitor is determined by the relative permittivity of the dielectric material ( $\epsilon_r$ ), the absolute permittivity ( $\epsilon_0 = 8.85 \times 10^{-12}$  F/m), the overlap of the active plate area (A), and the thickness of the dielectric (d) between the plates, as shown in Equation 1:

$$C = \frac{\epsilon_0 \epsilon_r A}{d} \quad (1)$$

Note:  $\epsilon_r \epsilon_0$  is often called dielectric constant, or K value

In simplified form, capacitance is expressed as follows:

Single layer ceramics (equation 2):

$$C = \frac{0.00885 \epsilon_r A}{d} \quad (2)$$

where

C = capacitance (pF)

0.00885 = constant ( $\epsilon_0 = 8.85 \times 10^{-12}$  F/m)

$\epsilon_r$  = relative permittivity

A = overlap area of one electrode in square mm

d = dielectric thickness in mm

Multilayer ceramics (equation 3):

$$C = (N - 1) \left[ \frac{0.00885 \epsilon_r A}{d} \right] \quad (3)$$

where

N = number of electrode layers

NOTE—Typical dielectric constants are listed in Table 1.

### 2.2.2 Dissipation Factor and Quality Factor

The dissipation factor (DF) of a capacitor is the energy losses in the capacitor, and is the tangent of the angle by which the current lags the 90° vector of the voltage. The DF can also be expressed as an equivalent series resistor, R (equation 4):

$$DF = (2\pi fC) R \quad (4)$$

The dissipation factor is highly dependent upon frequency, voltage, temperature, and dielectric composition, and is listed as a dimensionless unit or as a percent, e.g., a dissipation factor of 0.010 is expressed as 1.0%.

Quality Factor (Q) is typically used as a measure of energy losses in higher frequency applications with Class 1 capacitors. A typical value for Q is 1000. Q is the reciprocal of DF (equation 5):

$$Q = 1/DF \quad (5)$$

Listed in Table 1 are typical dissipation factors for ceramic capacitors.

### 2.2.3 Insulation resistance

The insulation resistance (IR) is a measure of the ability of the charged capacitor to resist loss of charge through the mechanism of DC leakage current. Under the influence of a DC field, ions will move from one atomic interstitial site to another and will generate a DC current. With increasing temperature, the mobility of these charge carriers increases, causing a decrease in the insulation resistance. Other factors that influence the insulation resistance of a ceramic capacitor are dielectric composition, dielectric thickness, defect sites in the dielectric layers, and the number of dielectric layers (total plate area or capacitance value). For the latter reason, the IR limits are expressed as the product of IR (megohms) times capacitance (microfarads), yielding a minimum requirement expressed in megohms-microfarads (or ohm-farads, which is equivalent). Table 1 gives typical values of IR for the various ceramic characteristics.

**Table 1—Typical performance**

| Dielectric Class<br>(typical TC) | Typical K | Typical dissipation factor (DF) %<br>over Temperature |       |         |       |         | Typical insulation resistance (IR)<br>over Temperature |          |         |
|----------------------------------|-----------|-------------------------------------------------------|-------|---------|-------|---------|--------------------------------------------------------|----------|---------|
|                                  |           | -55°C                                                 | +10°C | +25°C   | +85°C | +125°C  | +25°C                                                  | +85°C    | +125°C  |
| I (C0G)                          | 65        | <0.1                                                  | <0.1  | <0.1    | <0.1  | <0.1    | >100 GΩ                                                | >50 GΩ   | >1 GΩ   |
| II (X7R)                         | 2,000     | 4-6                                                   | 2-2.5 | 1.5-2.5 | 1-1.5 | 0.7-1.5 | >2000 MΩ                                               | >1000 MΩ | >200 MΩ |
| II (X5R)                         | 3,000     | 4-6                                                   | 2-2.5 | 1.5-2.5 | 1-1.5 | —       | >2000 MΩ                                               | >1000 MΩ | >200 MΩ |
| III (Z5U)                        | 8,000     | —                                                     | 5     | 3       | 1     | —       | >1000 MΩ                                               | >500 MΩ  | —       |
| III (Y5V)                        | 10,000    | —                                                     | 3     | 1.5     | 0.5   | —       | >1000 MΩ                                               | >500 MΩ  | —       |
| IV                               | —         | 8                                                     | 6     | 5       | 2.5   | 1       | 5 MΩ                                                   | 2.5 MΩ   | —       |