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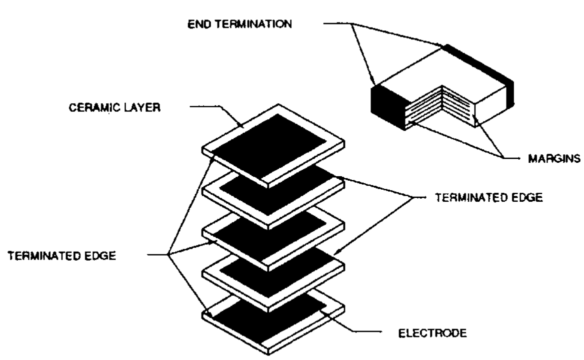
HIGH VOLTAGE CERAMIC CAPACITORS

I. FUNCTION

A Capacitor is a component that stores electrical charge. In its simplest form it consists of two conductive surfaces separated by an electrical insulator or dielectric. The stored charge is determined by the dielectric constant of the insulator material and the geometry of the construction.

Figure 1 shows the internal structure of a typical monolithic ceramic capacitor.

Fig.1 CAPACITOR CONSTRUCTION



II. BASIC PROPERTIES

(Electrical, sizes, configuration)

A. Electrical

1. **Capacitance.** Table 1 compares the dielectric constants of air, glass, mica, and paper with three of the commonly used ceramics. As can be seen the crystalline ceramics have extememly high K in comparison to the others. Barium Titanate is the basic material used in the manufacture of ceramic dielectric. It is produced by reacting barium oxide with titanium dioxide under controlled conditions. Barium Titanate has ferroelectric properties. As a dielectric it exhibits strong hysteresis. Capacitance varies widely over a fairly narrow temperature range which limits use of Barium Titanate as a ceramic dielectric in its pure form. By adding other oxides the basic characteristics can be modified to make the dielectric more desirable electrically and flatten its response over the operating temperature range. These additives are variously referred to as shifters, depressors, fluxes, or stabilizers, depending on how they effect the Barium Titanate characteristics

Table 1 DIELECTRIC CONSTANTS

MATERIAL	"K"
AIR	1.0006
GLASS	7.0 - 10.0
MICA	5.0 - 7.0
PAPER	4.0 - 7.0
NPO (Class I-A)	25 - 100
X7R (Class II-A)	300 - 1800
Z5U (Class II-B)	2500 - 15000

As noted in Table 1, there are three basic ceramic formulations available in capacitors. They are NPO, X7R, and Z5U. Mathematically capacitance can be described as $C = \frac{n(0.224KA)}{t}$.

Where C is capacitance in picofarads
n is the number of capacitors in parallel,
K is the dielectric constant
A is the area of opposed conductors in inches squared
0.224 is the dimensional constant, and is the dielectric thickness in inches.

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Capacitance then is directly proportional to dielectric constant, K.

2. **Dissipation Factor.** The dissipation factor is an overall measure of losses in the capacitor. It is related to dielectric type temperature and frequency. Figure 2 shows typical values for X7R. NPO is nearly unchanged with temperature.

B. TEMPERATURE EFFECTS

Barium Titanate is cubic above 120°C. As it is cooled through this temperature (the Curie temperature) the structure becomes tetragonal and disorted such that electric dipoles exist. Additional transformations occur at about 0°C and -85°C. The dipoles produce a large dielectric constant due to their ability to respond to an electric field and store energy. The transformation at 120°C produces an anomolously large dielectric constant (up to 160000). Commercial ceramics are made by adding chemicals which shift or surpress the Curie point to some degree (Z5U and X7R) or squash it entirely by eliminating the cubic to tetragonal transformation (NPO). Figure 3 shows the typical responses of commercial bodies to temperature.

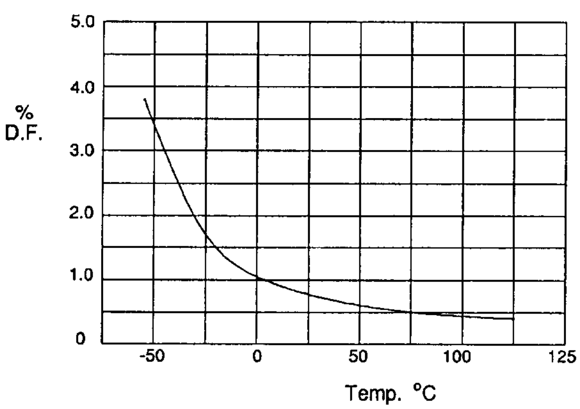
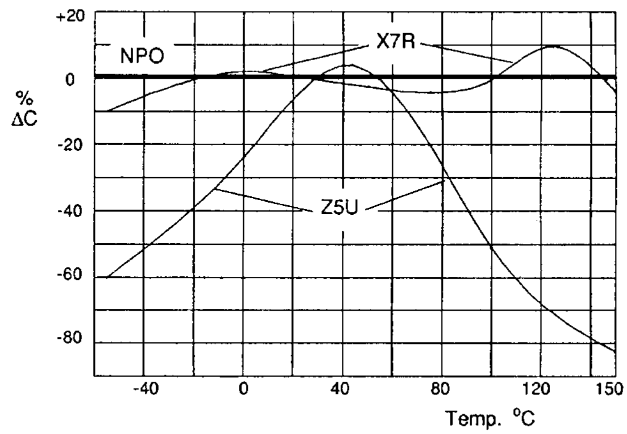


Fig 2. Typical Dissipation Factor vs Temperature

C. Voltage Effects

When voltage is applied the capacitance shifts considerably as shown in Figure 4 and Table 2. The overall volume efficiency of capacitors also change as shown in Table 2. Here, dielectric constants are assumed to be 70, 1250, and 7000 for NPO, X7R, and Z5U respectively.

Figure 3. Temperature Coefficient



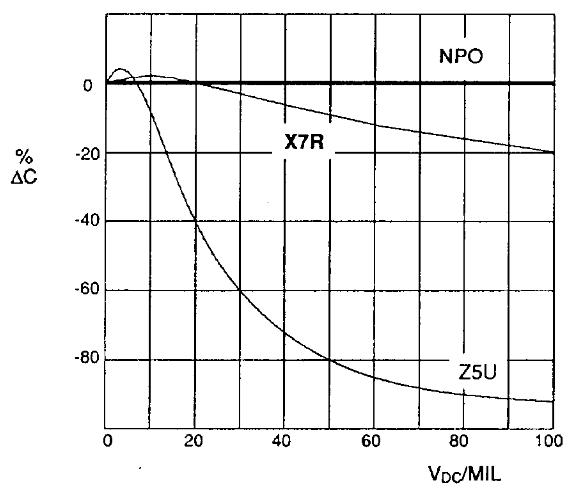


Figure 4. DC voltage Coefficient

Table 2. Volume Efficiency Comparison, Applied Working Voltage

DC Volts	0	2000	4000
DC/MIL	0	50	100
NPO	0.513/14.25	0.513/14.25	0.513/14.25
X7R	**4.24/120**	**4.00/111**	**3.47/96**
Z5U	5.26/156	1.12/31.1	0.592/16.4

Legend: (CAP/EFFICIENCY) nF/(nF/in^3)

Fig 3 TEMPERATURE COEFFICIENT

For the same part size, say 0.45 x 0.40 x 0.20, and voltage rating, say 5KV the required dielectric thickness would be about 25, 37, and 80 mils for the three materials. The capacitance for such parts is shown in Table 2 as a function of the applied voltage.

The efficiency of X7R for high voltage comes from a combination of good voltage withstanding properties, modest capacitance loss with voltage, and a relatively high basic dielectric constant. Another parameter to consider is break-down voltage or dielectric strength of a capacitor body. For any given thickness there a is maximum stress that can safely be applied to a dielectric before breakdown occurs (Figure 5). For example, a 6kV flash breakdown requirement for Z5U dielectric would result in a dielectric thickness of about 80 mils. An X7R dielectric of about 37 mils would easily meet the 6KV requirement. The Z5U part does not have adequate volumetric efficiency at high working voltages. The flash voltage, or over-rating as it is sometimes referred to, is a value which should be based on potential transient voltages that a capacitor may encounter. Instead the flash voltage is often determined by an arbitrary safety factor of 1.5 to 2 times the working voltage. Safety factors are mandatory for

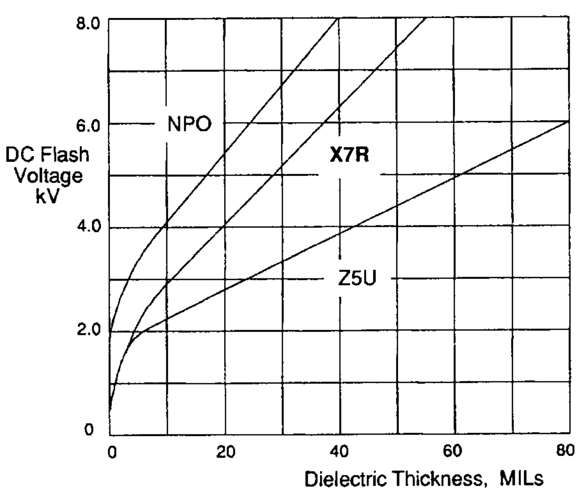


Figure 5. Relative Flash Test Voltage

reliable operation, however excessive over-rating creates problems for designer and user alike.

An X7R unit with a dielectric strength requirement of 4kV is 22 mils thick. If a traditional 50% safety margin is used, flash voltage increase to 6kV and the dielectric thickness increases to 40 mils. This in turn reduces capacitance and volume efficiency by 50%. Unnecessary over-rating similarly effects all type of dielectrics. When voltage is applied to a ceramic dielectric, the degree of polarization, and thus the capacitance, will vary as a function of voltage stress. (Figure 4). This property is known as the voltage coefficient of capacitance. The amount of variation is determined by the specific dielectric formulation, consequently each dielectric type has a distinct characteristic voltage coefficient curve. At 100 V/Mil, for example, NPO is virtually unaffected by the voltage, while Z5U has only 10% of its 1VDC biased capacitance. It is important to note that capacitors are normally specified at zero or 1V DC bias even though they do not operate at that bias level. The circuit designer should have access to data that reflects the true capacitance at operating voltage.

D. Frequency Effects

Frequency effects are like voltage effects in that NPO is less affected than X7R which is less affected than Z5U. NPO shows virtually no capacitance change up to 1MHz and although the DF may double between 1 KHz and 1 MHz the values are typically 0.02 to 0.04%.

E. Aging

When a ceramic capacitor is fired to a solid monolithic its internal grain structure is permanently set. When the ferroelectric types are cooled through the Curie point the grains divide into domains which reduces the strain energy of the body. With time these domains continue to divide until a balance is reached between stress relief and the energy required to form additional domain walls. The result is a decrease in capacitance with time. X7R bodies age at 2% per decade hour (depending upon type). Z5U ages at 3 to 4% per decade hour and NPO does not age as it is not ferroelectric. The aging cycle restarts every time the capacitor is heated above the Curie temperature such as during a soldering operation or a high temperature burn-in.

III. APPLICATION NOTES

A. Capacitor Mounting Techniques

Some Semtech High Voltage Ceramic Capacitors are supplied without leads. Because they are high voltage rated, connections should be solid and large in proportion to the termination area. Soldering is one of the strongest of the bonding methods and is the least electrically resistive. To prevent catastrophic thermal shock, the chip should be slowly elevated in temperature to approximately 120°C prior to soldering. A good hot plate will provide an even temperature surface. Solder connections shoud be made quickly removing the soldering iron as soon as the connection is made to prevent leaching of the electrodes. Silver bearing solders are recommended to prevent leaching.

B. Surge Current

Charge and discharge currents are directly proportional to voltage. Exessive charging current can trigger a piezoelectric effect and result in destruction of the part. Excessive rate of discharge is not critical in terms of piezoelectric effect, but can result in loss of metallization during the discharge arc.