The Many Ceramic Capacitor Dielectrics

Matching the right one to the correct application

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This application note takes a look at the wide array of ceramic capacitor dielectrics in order to determine the best selection for use with each application, while clarifying the usage of the characters for identification.

What are those three characters?

Most ceramic capacitors are usually accompanied by three characters –defined by the EIA-198 standard– which tend to take the following form: X7R, NP0, ZU5, etc. These three characters don't dictate which ceramic is used in capacitors but rather its characteristics over temperature. The first character identifies the lower temperature, the second the higher temperature and the third the capacitance tolerance. As an example, we can note that, as shown below in Table 2, an X7R dielectric type ceramic capacitor operates in the temperature range of -55 °C to +125 °C and has a capacitance tolerance over that range of ±15%. Another example shown in Table 1 is that NP0 type capacitors, which are a type within Class 1, are of lowest temperature dependence among ceramic capacitors, which can have different temperature coefficients.

Type	Temperature Coefficient (ppm)
P100	+100
NP0	0
N150	-150
N220	-220
N470	-470
N750	-750
N1500	-1500

Table 1: Class 1 Temperature Coefficients

These various temperature coefficient capacitors are often used to compensate temperature effect on the resonating inductor. In circumstances where the inductor has a TC of +200 ppm and resonates with a capacitor of -200 ppm, the net temperature effect will be that the resonating frequency will not change with temperature.

You can consider putting in parallel and/or in series various temperature coefficient capacitors to match the coefficient of the inductor you need to compensate.

Class 2 capacitors are labelled according to the change in capacitance over the temperature range.

Similarly to the EIA-198 standard, the EIA RS-198 standard uses a three characters where the first character is a letter:

- The first character is a letter that indicates the lower operating temperature.
- The second is a number and indicates the higher operating temperature.
- The letter at the end indicates capacitance change over that temperature range.

Following are some common examples:

- X7R (–55/+125 °C, ΔC/C0 = ±15%)
- X5R (–55/+85 °C, ΔC/C0 = ±15%)
- X7S (–55/+125 °C, ΔC/C0 = ±22%)
- Z5U (+10/+85 °C, ΔC/C0 = +22/–56%)
- Y5V (–30/+85 °C, ΔC/C0 = +22/–82%)

Note, however, that these three characters do not tell the whole story about a particular capacitor, as there are numerous other specifications to consider such as the dissipation factor, aging, ESR, ESL and leakage, some of which we address below. Ceramic capacitors are readily available over the web and come in many types, which include NP0, C0G, X5R, X7R, Z5U, Y5V, XR8, X7S, X6S and X7S.

Temperature Consideration

In circumstances where the application is military or automotive in nature, a capacitor that has a temperature range of -55 °C to +125 °C must be selected. Most Class 1 types, as well as the X7R type, would be appropriate choices. For industrial applications, a selection amongst X7 and X5 types should be made, in addition to the Y5 types if the unit will not be located outside. In commercial and consumer applications, Y5 as well as Z5 would be good options. It is important to consider the temperature stability, therefore if your project is of commercial nature but requiring greater stability, then use of X7R may be a better option.

EIA-198 Standard Capacitors Classes

CLASS I

Components of this type are temperature compensating ceramic dielectrics, fixed capacitors of a type suited for resonant circuit applications or other applications where high Q and stability of capacitance characteristics are required.

Letter code low temperature	**Number code upper temperature**	**Letter code change of capacitance 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)	L = ±15%, +15/-40% above 125 °C
	7 = +125 °C (+257 °F)	S = ±22%
	8 = +150 °C (+302 °F)	T = +22/–33%
	9 = +200 °C (+392 °F)	U = +22/–56%
		V = +22/–82%

Table 2, Class 2 EIA RS-198 Code

CLASS II

Components of this classification are fixed, ceramic dielectric capacitors of a type suited for bypass and decoupling application or for frequency discriminating circuits where Q and stability of capacitance characteristics are not of major importance. This classification is further defined as those capacitors having temperature characteristics A through S. Class II ceramic dielectrics exhibit a predictable change with time and voltage. Compensation for the aging effect is made by referencing capacitance limits to a future time deemed to be most useful to the buyer; 1,000 hours is normally chosen, but other arrangements may be negotiated between the buyer and seller. Voltage will also cause a temporary capacitance change, and the test sequence should be such that capacitance measurements are not affected by previous voltage tests.

The aging rate of a dielectric is essentially constant over many decades of time, i.e., 10 h to 100 h, 100 h to 1,000 h, 1,000 h to 10,000 h, etc., when measured from the time of the last heat of depolarization in manufacture. Restoration of the original capacitance at time of manufacture will occur on heating to 150 °C for one hour, after which normal aging will again commence. Capacitors measured prior to 24 hours may exhibit temporarily high capacitance values that will age downward.

CLASS III

Components herein standardized are fixed ceramic dielectric capacitors of a type specifically suited for use in electronic circuits for bypass, decoupling or other applications in which dielectric losses, high insulation resistance and capacitance stability are not of major consideration. This classification is identical to that of class II, except that it is restricted to those capacitors having temperature characteristics T through V.

CLASS IV

This classification is restricted to components utilizing reduced titanate or barrier layer type construction. While basically fitting the descriptions of class II and class III, certain other electrical differences can be noted, as described in EIA-198-3-F of this specification.

Dissipation Factor

The DF/PF of a capacitor tells what percent of the apparent power (Irms*Vrms) input will turn to heat in the capacitor. The dissipation factor is related to the ESR in such a way that the current circulating in the capacitor causes loss in the ESR.

The loss and apparent power are calculated as follows:

Loss:
P = Irms^2 * ESR

Apparent power:
Irms^2 * Xc,
Irms^2 * sqrt (1/ (2 * PI * F * C) ^2 + ESR^2)

DF = (Irms^2 * ESR) /
(Irms^2 * sqrt (1/ (2 * PI * F * C) ^2 + ESR^2))

= ESR / sqrt (1/ (2 * PI * F * C) ^2 + ESR^2)

From the equation above, the denominator at very low frequency is 1/2*PI*F*C, we can then write DF = 2 * PI * F * C * ESR.

Therefore, the lower the ESR, the lower the dissipation factor. Note that the DF varies with the frequency.

Aging

Aging is a very important factor to consider for selecting a capacitor. NP0 type capacitors tend to not suffer from aging, but other dielectrics suffer of aging by 2 to 5% per decade.

For instance, a X7R capacitor will lose 2% per decade hour, while a 1uF capacitor will become 0.98uF after 10 hours, 0.96uF after 100 hours and 0.94uF after 1,000 hours. In circumstances where a X7R capacitor is used for a timing application, the frequency will rise with time, making a NP0 type capacitor a better option because of its stability over time. Manufacturers tend to normally provide the capacitor value after 1,000h of life; it can therefore be expected to notice a drop of 2% after 10,000h, which is approximately a little more than one year.

Microphonic Effect

Very high dielectric ceramics should be used in order to obtain a large value capacitor within a limited space. These very high dielectric ceramics are often also piezoelectric, which means they act as transducer. Mechanical pressure on the ceramic causes a voltage difference on its surface. As stated by AVX:

"**Effects of Mechanical Stress** – High "K" dielectric ceramic capacitors exhibit some low-level piezoelectric reactions under mechanical stress. As a general statement, the piezoelectric output is higher, the higher the dielectric constant of the ceramic. It is desirable to investigate this effect before using high "K" dielectrics as coupling capacitors in extremely low-level applications."

This problem is often present in microphone amplification circuits since a large value ceramic capacitor is used for coupling. Additionally, surface-mounted capacitors are more microphonic than leaded ceramic capacitors, which is possibly caused by the looser mechanical coupling between the printed circuit board and the dielectric due to the capacitor wires acting as vibration absorber.

Permittivity of Some Dielectric

The table below, a simplified excerpt from Wikipedia, is useful in understanding why ceramic is used for capacitors. Ceramic permittivity ranges from 86 to 10,000, which is quite higher than polystyrene used in film capacitors and a lot more than air and vacuum. Note the last five items are ceramics.

Materials	Permittivity
Vacuum	1
Air	1.0006
Teflon	2.1
Polystyrene	2.4–2.7
Paper	3.5
Silicon dioxide	4.5
Pyrex (Glass)	3.7–10
Silicon	11.68
Water	80 at 20 °C
Titanium dioxide	86–173
Strontium titanate	310
Barium strontium titanate	500
Barium titanate	1250–10,000 (20–120 °C)
Lead zirconate titanate	500–6,000

Conclusion

Not exhaustive as covering only certain aspects of ceramic capacitors, the main objective of this application note was to provide clarifications on some important related factors for an optimal selection. Some additional significant factors not covered here include frequency range, ESL (equivalent series inductance), resonating frequency, capacitance variation with DC polarizations, DC leakage, and more.