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All those kinds of ceramic capacitor dielectrics.

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Introduction

This application note takes a look at all those kinds of ceramic capacitor dielectric, the objective being to make it clear which one to use for each particular application as an electronic circuit board designer.

What are those three characters?

Most of the ceramic capacitor are said to be X7R, NP0, ZU5, etc. These three characters are defined by the EIA-198 standard. These three characters do not dictate which ceramic is in the capacitor but its characteristics over temperature. The dielectric to be used is selected by the manufacturer.

My understanding is that the first letter identifies the lower temperature, the second the higher temperature and the third the capacitance tolerance. According to the Table 2 an X7R dielectric type ceramic capacitor operates in the temperature range of -55C to +125C and has a capacitance tolerance over that range of +/-15%.

Note that NP0 type capacitors are of lowest temperature dependence among the ceramic capacitor. NP0 are a type within CLASS 1, note that there are ceramic capacitor with different temperature coefficient such as shown in the Table 2.

Table 1, CLASS 1 TEMPERATURE COEFFICIENTS

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

These various temperature coefficient capacitors are often used to compensate temperature effect on the resonating inductor, note that if the inductor has a Tc of +200PPM and resonate with a capacitor of -200PPM the net temperature effect will be that the resonating frequency will not change with temperature!

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

Table 2, CLASS 2 EIA CODE

Percent Capacity Change Over Temperature Range	
RS198	**Temperature Range**
X7 X5 Y5 Z5	-55°C to +125°C -55°C to +85°C -30°C to +85°C +10°C to +85°C
Code Percent	**Capacity Change**
D E F P R S T U V	±3.3% ±4.7% ±7.5% ±10% ±15% ±22% +22%, -33% +22%, - 56% +22%, -82%
More details about these code can be founded on wikipedia: http://en.wikipedia.org/wiki/EIA_Class_2_dielectric	

These three characters did not tell the all story about the particular capacitor, there are lots of other specification to consider such as the dissipation factor, aging, ESR, ESL and leakage.

Buy doing a quick search on the web I found many types of ceramic capacitor available such as NP0, C0G, X5R, X7R, Z5U, Y5V, XR8, X7S, X6S and X7S. I am also sure that there are a lot more that can be found, but at least that shown that there are many types available out there.

TEMPERATURE CONSIDERATION

First if your application is military or automotive you have to select capacitor that has a temperature range from -55C to +125C, most CLASS 1 type will do the job and the X7R type too.

For industrial we stick on using X7 and X5 types, Y5 can be used if the unit is not located outside.

For commercial and consumer Y5 and Z5 are OK.

Do not forget to consider the temperature stability, so if you work on a commercial project, but that require greater stability you may need to use X7R.

WHAT ARE CAPACITORS CLASS

EIA-198 standard defines capacitors class as below:

Table 3, EIA CLASS DEFINITION

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. 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 those 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 are P = Irms^2 * ESR.

Apparent power is `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.`

So the lower is the ESR the lower is the dissipation factor. Note the DF varies with the frequency.

AGING

Aging is a very important factor to consider for selecting a capacitor. According to the manufacturer datasheet NP0 type capacitor did not suffer from aging, but the other dielectric suffer of aging by 2 to 5% per decade.

As example an X7R capacitor will loose 2% per decade hour, as example a 1uF capacitor will become 0.98uF after 10 hours, 0.96uF after 100 hours, 0.94uF after 1000 hours. If an X7R capacitor is used for a timing application, the frequency will rise with time. So for timing application it is better to use NP0 since they are by far more stable over time. Normally manufacturer gives the capacitor value after 1000h of life so that you can expect a drop of 2% after 10000h (a little more than a year).

MICROPHONIC EFFECT

To get large value capacitor in quite small package, very high dielectric ceramic shall be used. These very high dielectric ceramic 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 presents in microphone circuit amplification circuit since a large value ceramic capacitor is used for coupling. I also note by experience that surface mounted capacitors are more microphonic than leaded ceramic capacitor. This 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 was extracted from Wikipedia and simplify. This is useful to understand why ceramic are used for capacitor, their permittivity range from 86 to 10000, this is quite higher than the polystyrene used in film capacitor and a lot more than air and vacuum. Note the last fifth items are ceramics.

Material	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 20C
Titanium dioxide	86–173
Strontium titanate	310
Barium strontium titanate	500

Barium titanate	1250–10,000, (20–120 °C)
Lead zirconate titanate	500–6000

CONCLUSION

This note does not pretend covering all aspects of the ceramic capacitors but I hope it has brought some clarifications. Other important factors are the frequency range, the ESL (equivalent series inductance), resonating frequency, capacitance variation with DC polarisations, DC leakage, etc...

Personally I was confused about the three characters describing a ceramic capacitor to the point that I was believing the three characters were a name for each particular type of dielectric. This is note the case; the three characters specify the temperature range and the tolerance for CLASS 2 capacitors. Each manufacturer use the mixture of dielectric they want to fit their capacitor in the particular type of CLASS 2 capacitor.