CAPACITOR BASICS IV – Ceramic Material Designations

Ceramic Dielectric Class Distinction

Electronics Industry Standard (EIA) 198 is a US Government document that categorizes various ceramic dielectric materials by their temperature coefficient (ΔTC). Classifications are organized into two basic groupings based on whether they exhibit either extremely stable Class I, or stable / semi-stable performance characteristics (Classes II, III and IV)

Classes I and II represent the more commonly utilized dielectrics, with Class III a distant third and Class IV limited to only a few remote applications where capacitor stability is not a critical component of the system design. For the purpose of this Application Note, information is limited to Class I, Class II and Class III capacitors as outlined below:

- **Class I "Ultra-Stable" Capacitors** – The general makeup for dielectrics utilized for Class I capacitors is a formulation that consists primarily of titanium dioxide (TiO_2) and their typical dielectric constants (K) are quite low, in the range of 150 or less. More importantly to the design engineer, these capacitors are also characterized by a low loss characteristic or dissipation factor (tan δ) in the range of 0.1 to 0.2%, minimal variation in capacitance due to changes in temperature, voltage and / or frequency and they exhibit no signs of aging over time. Applications such as timing or tuning circuits, filter networks and resonant circuits, generally require these type of capacitors because of their stability over temperature and high Quality Factor (Q) characteristics.

  Class I capacitors utilize non-ferroelectric materials and as such they exhibit a linear relationship between polarization and voltage. In addition, these materials also exhibit a near linear temperature coefficient and their formulations can be manipulated to have a predictable slope across their entire intended operating temperature range. These slopes can be positive, flat or negative with respect to temperature and they are often referred to as Temperature Compensating dielectrics.

  EIA-198 has developed an industry standard "letter – number – letter" designation code to define the ΔTC characteristics for ceramic capacitors and the most commonly recognized Class I dielectric is COG (0 ppm / °C ± 30 ppm / °C), which is often referred to as NPO (Negative – Positive – Zero)

  In addition, there is also a subgroup of materials that utilize small amounts of ferroelectric oxide dopants (additives) to achieve higher dielectric constants in the range of 150 to 500. By virtue of the fact that the Curie Point for these dielectrics is located well below -55ºC, they display near linear and predictable temperature coefficient characteristics in the range of N750 to N5600.

  Class I dielectric designations are shown below in Table 2, along with some examples:

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Alpha Symbol	Significant Figure of Temperature Coefficient of Capacitance (PPM / °C)	Numerical Symbol	Multiplier Applied to Signficant Figure	Alpha Symbol	Tolerance of Temperature Coefficient (PPM / °C)
C	0.0	0	-1	G	±30
B	0.3	1	-10	H	±60
L	0.8	2	-100	J	±120
A	0.9	3	-1000	K	±250
M	1.0	4	-10000	L	±500
P	1.5	5	+1	M	±1000
R	2.2	6	+10	N	±2500
S	3.3	7	+100		
T	4.7	8	+1000		
V	5.6	9	+10000		
U	7.5				

Table 2 - EIA-198 ΔTC Designations for Class I Dielectrics

Examples:

EIA Code	Industry / MIL Designation	Temperature Coefficient
COG	NPO (Negative-Positive-Zero)	0.0 ppm / ºC ± 30 ppm / ºC
U2J	N750	-750 ppm / ºC ± 120 ppm / ºC
P3K	N1500	-1500 ppm / ºC ± 250 ppm / ºC
R3L	N2200	-2200 ppm / ºC ± 500 ppm / ºC
P7G	P150	+150 ppm / ºC ± 30 ppm / ºC

- **Class II "Stable" Capacitors** – Capacitors defined by this classification are less stable than Class I capacitors and as such they are more readily affected by changes in temperature, applied voltage, frequency and time. The main advantage of this dielectric type is its volumetric efficiency and this classification is generally used in applications such as bypass and decoupling, where higher capacitance is critical and where there is less emphasis given to Temperature Coefficient and Quality Factor (Q).

  Dielectric materials utilized for Class II capacitors are comprised of ferroelectric formulations based on barium titanate (BaTiO3) as their primary ingredient. Consequently, unlike Class I dielectrics which exhibit linear polarization, the crystal structure of Class II formulations display a non-linear response with an applied field.

  In addition, when ferroelectric compositions are exposed to temperatures above the materials Curie temperature (≈ +120°C), the crystal structure of the dielectric transforms from a tetragonal to cubic symmetry. Upon cooling back down through its Curie temperature, the material begins a slow transformation back into a tetragonal structure. At the beginning of this transition the crystalline structure is distorted and over time there is a relaxation of this electrical stress with a corresponding loss in capacitance. Referred to as Aging, this rate of decay follows a logarithmic curve expressed as a percentage per decade hours. X7R, which is the most commonly utilized Type II dielectric, exhibits typical Aging rates of less than or equal to 2.5%.

  Class II dielectric designations (ΔTC characteristics A thru R) are shown below in Table 3, along with some examples:

- **Class III "General Purpose" Capacitors**

  Class III Capacitors are also ferroelectric formulations and as such they are very similar in performance to Class II dielectrics. They are distinguished by even higher dielectric constants and a resulting increase in capacitance levels per unit volume, but this increase in capacitance is offset by a more pronounced loss in stability and a further concession in performance characteristics.

  Across the board, ΔTC values are more pronounced, aging rates and dissipation factor levels are higher and insulation resistance limits tend to be lower at elevated temperature. As such, these parts are generally limited to those applications like filtering, decoupling or energy storage, where stability is not necessarily a prerequisite for proper system performance. The more recognizable Class III dielectrics would be EIA designations Z5U and Y5V.

  Class III dielectric designations (ΔTC characteristics S thru V) are shown below in Table 3, along with some examples:

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Alpha Symbol	Low Temperature (°C)	Numeric Symbol	High Temperature (°C)	Alpha Symbol	Max Cap Change Over Temp Range (%)
Z	+10	2	+45	A	±1.0
Y	-30	4	+65	B	±1.5
X	-55	5	+85	C	±2.2
		6	+105	D	±3.3
		7	+125	E	±4.7
		8	+150	F	±7.5
		9	+200	P	±10
				R	±15
				S	±22
				T	+22 to -33
				U	+22 to -56
				V	+22 to - 82

Table 3 - EIA-198 ΔTC Designations for Class II & Class III Dielectrics

Examples:

EIA Code	Low Operating Temp	High Operating Temp	Temperature Coefficient
X7R	-55°C	+125°C	±15%
X9R	-55°C	+200°C	±15%
X5R	-55°C	+85°C	±15%
X5U	-55°C	+85°C	+22 / -56%
Y5V	-30°C	+85°C	+22 / -82%
Z5U	+10°C	+85°C	+22 / -56%