EMI Filter Company

Dielectric Types and Low Pass Filter Performance

For optimum performance over expected and unexpected temperature ranges, EMI Filter Company recommends users of low pass filters to specify them with either a X7R or NPO type temperature range/stability characteristic. Other dielectrics, i.e. Z5U and especially Z5V, vary too much over their shorter temperature ranges, and performance drops precipitously outside of stated ranges. Trying to find a way to live with this variability, some filter customers mistakenly specify capacitance tolerances tighter than the industry standards (+100/-0% and +80/-20%) rather than specifying a better dielectric. Demanding special tolerances is expensive and can impact delivery times. Some filter manufacturers use dielectrics with poor temperature properties to make tubular capacitors; they are cheap, but require high dielectric constant (at room temperature) dielectrics to achieve significant capacitance. By their nature, multilayer ceramic discoidal capacitors offer higher capacitance and can thus be made with of more temperature stable formulations. EMI Filter Company only uses discoidal capacitors with either X7R or NPO type dielectrics in its miniature bulkhead mounted filters. Below is a brief discussion of dielectrics used in low pass filter construction and why and how the affect performance.

Dielectric Review

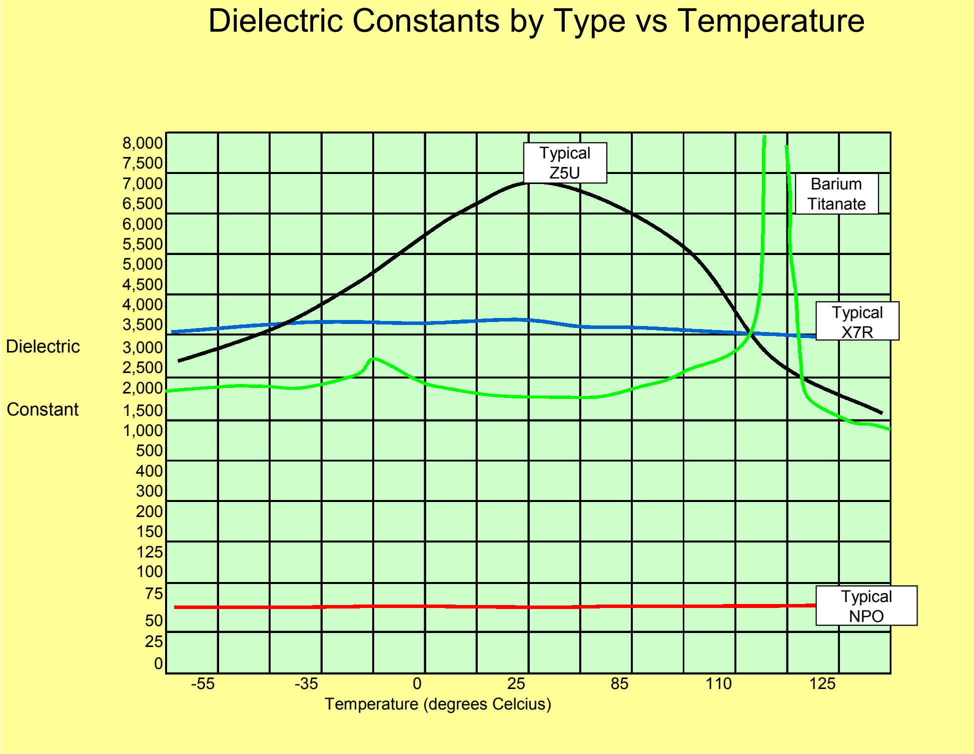
Class I dielectrics, which exhibit low dielectric constants, usually under 150 (air is 1), are usually modified TiO_2 formulations. The most common NPO/COG type has a dielectric constant of about 60. Most miniature low pass filters with a capacitance of less than 500pF use Class I dielectrics. Class I dielectrics are the most stable and are generally specified to not vary more than +/-30ppm/°C. The deviation from stated capacitance with temperature (TC) change from the standard 25°C value to –55°C to +125°C is negligible and is nearly linear.

Class II Dielectrics, are generally used for any value at or above 500pF and are modified $BaTiO_3$ based formulations. Class II dielectrics offer much higher dielectric constants than Class I dielectrics, but with less stable properties with changing temperature, voltage, frequency, and time. The change in capacitance with temperature is characterized as varying by +/- some *percentage* from the 25°C reading over a given temperature range. The most common Class II dielectric is the X7R/BX type with a dielectric constant of up to 4,000 with capacitance varying no more than +/-15% from –55 °C to +125 °C. The Z5U type has a higher dielectric constant upwards of 8,000, but offers significantly poorer temperature stability than the X7R type. Z5U can vary +22% to –56% from +10 °C to +85 °C. Y5V, another high dielectric constant material, has a broader temperature range (-30 °C to +85 °C), but the actual capacitance can vary even more (+22% to –82%). Table 1 summarizes the EIA designations for Class II dielectrics:

(A)	**(B)**	**(C)**	**(D)**	**(E)**	**(F)**
Low temperature requirement	Letter Code for (A)	High Temperature Requirement	Numerical Codes for (C)	Max (+/-)% Change over Temp. Range	Letter Code for (E)
+10	Z	+45	2	1.0	A
-30	Y	+65	4	1.5	B
-55	X	+85	5	2.2	C
		+105	6	3.3	D
		+125	7	4.7	E
				7.5	F
				10.0	P
				15.0	R
				22.0	S
				+22-33	T
				+22-56	U
				+22-82	V

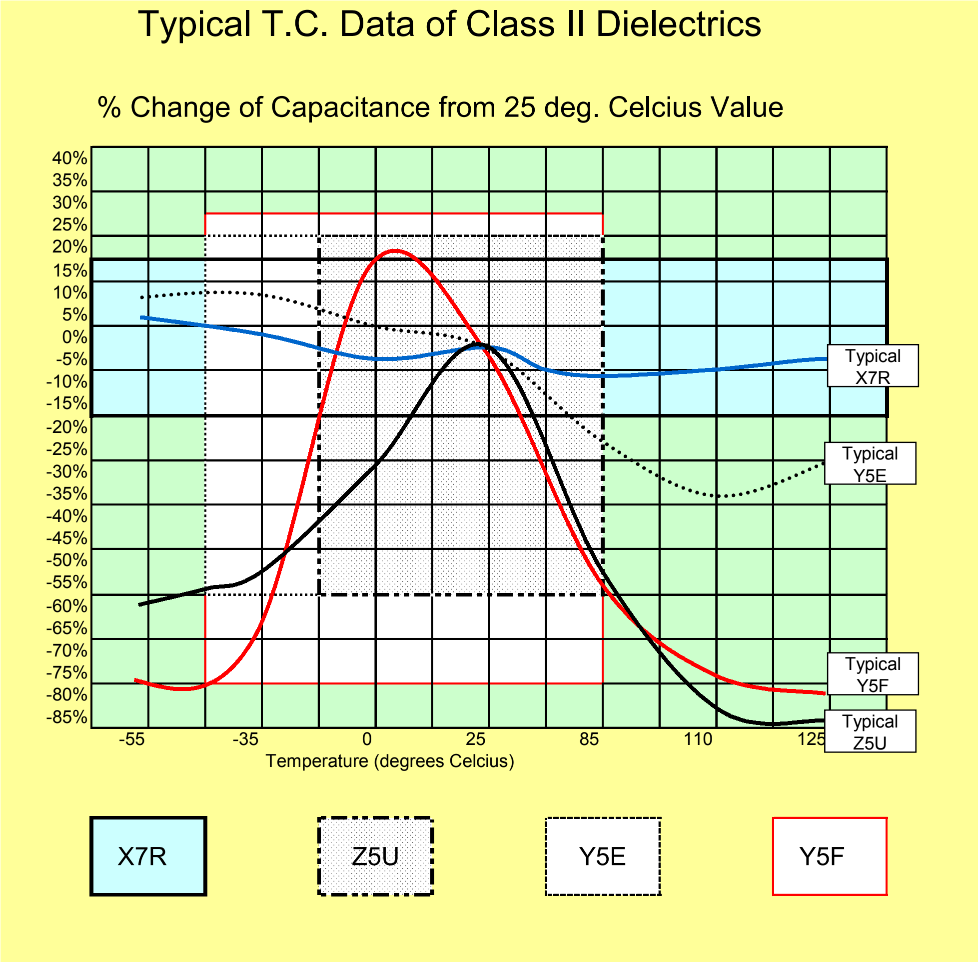
Table 1

Generally speaking, the lower the dielectric constant at “room” conditions, the more temperature stable the dielectric is over a broader temperature range. The graphical interpretation of Class II dielectrics is a curve with the peak usually being around 25 °C. Graph 1 shows the change in dielectric constant (capacitance) for different dielectrics over a temperature range. It is easy to see the relationship between temperature stability and dielectric constant over a given temperature range. For Class II dielectrics, the dielectric constant peak (Curie Point) for barium titanate is broadened and moved by additions of other materials such as $CaZrO_3$ and $SrTiO_3$. The mole ratio between Ba and Ti is often modified to increase or decrease the dielectric constant.



Graph 1

Graph 2 illustrates actual measured capacitance change of commercial formulations with the individual operating temperature ranges overerlayed. Notice how poorly Z5U performs outside its normal temperature range. Y5E varies considerably over a very tight temperature range. Only X7R and NPO handle temperature extremes well.



Graph 2

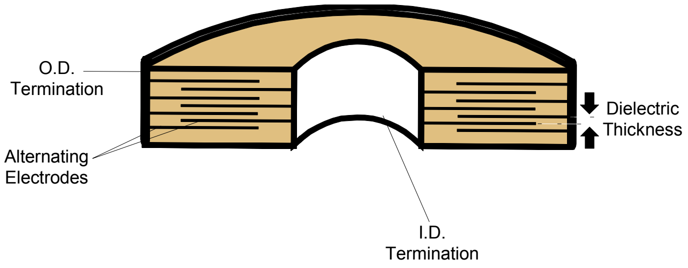
Why would any one use Z5U and other limited dielectrics? It all comes down to the design of the capacitor inside the filter. Miniature “C”, “L”, ands “Pi” filters are either built with discoidal or tubular capacitors. Each has its own distinct advantages. Tubular capacitors are simpler and cheaper, but are limited in capacitance. The formula for capacitance of a parallel plate capacitor is:

$$C = \frac{0.224K\,(A)}{T}$$

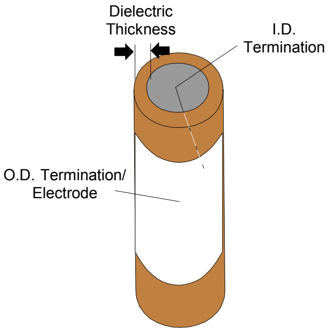
C = Capacitance in picofarads $=10^{-12}$ farad
A = Overlap area of two parallel plates (inches^2)
T = Thickness (inches)

One can see that as the dielectric thickness goes up, the capacitance goes down. A tubular capacitor is usually a single parallel plate capacitor device with an extremely high dielectric thickness. Discoidal capacitors, while more complex to manufacture, are more durable under temperature and physical stress and offer capacitance orders of magnitudes higher than tubulars. Tubular capacitors are deemed so unreliable due to physical flaws they are forbidden under MIL-PRF-28861. The higher capacitance ability of discoidal capacitors is from the multitude of parallel plate capacitors in each capacitor. Discoidal capacitors, a form of multilayer ceramic capacitor, offer the highest capacitance to volume ratio of any capacitor. Ceramic tubular capacitors are limited by the size constraints of the filter body and thus are much more likely to use dielectrics that exhibit poor temperature stability over a narrower temperature range than discoidal capacitors. The construction of a discoidal multilayer capacitor is illustrated in Drawing 1 and the tubular capacitor in Drawing 2.

Drawing 1: Discoidal Cross Section



Drawing 2: Tubular Capacitor



The number of conductive plates (electrodes) and dielectric layers and how thick the dielectric layers are controls the capacitance of a discoidal capacitor. Dielectric thicknesses for discoidal capacitors range from .004” to less than .001” and the overlap area of each electrode pair remains constant. 200 VDC/.001” dielectric thickness for an X7R dielectric is traditionally expected, so for a given voltage rating capacitance, control is as simple as adding or subtracting a few electrode/dielectric layers. In the tubular capacitor, the dielectric thickness is also the tube wall, so dielectric thicknesses over .020” is often used to impart some physical strength. This means the length, and thus the overlap area, is the primary method employed to control capacitance in a tubular capacitor. With such a high dielectric thickness, tubular capacitors can usually handle very high voltages, but with so much 5 and 24 volt circuitry now bieng employed, additional voltage handling capability is superfluous. Tubular capacitor construction techniques have not changed much at all in the last 50 years, they are usally extruded, dry pressed, or rolled. These processes impart innate physical weaknesses. Discoidal capacitors are an outgrowth of multilayer chip capacitor technology, of which trillions have been made and whose quality is proven.

Temperature Impact on Filter Performance

Consider the simple “C” circuit low pass filter. Capacitance directly affects insertion loss and capacitance is affected by temperature change. Performance for a “C” circuit can be predicted using the classic formula for attenuation:

$$IL = 20 \log_{10} \sqrt{1 + (50\pi fC)^2}$$

A perfect “C” low pass filter rises with a slope of 20dB per decade for any given capacitance. For example, a 1,000pF low pass filter would provide 23.9dB of attenuation at 100MHz and 43.9dB at 1GHz. However, if one takes into account the change in capacitance due to temperature variation of some typical dielectrics one would expect to see significant variation as seen in Table 2 below:

Dielectric	*Operating Temp. Range (°C)*	*Allowed Capacitance Change*	*dB Range (Max-Min Capacitance) In Operating Temp. Range*	*dB Range (Max-Min Capacitance) From –55 to +125°C*
Perfect Capacitor	-	-	0	0
X7R	-55 to +125	+/-15%	3	3
Z5U	+10 to +85	+22/-56%	9	12
Y5U	-30 to +85	+22/-56%	9	12
Y5V	-30 to +85	+22/-82%	12.5	13

Table 2

Conclusion

It becomes very apparent that dielectric selection alone has a significant impact on filter performance. Performance can be drastically impacted by temperature excursions beyond intended ranges. No one can anticipate what environments the end user will subject modules and systems to. As in any business, there is a gap between perceived problems and complaints. A lack of complaints does not mean a lack of problems for the end user, but it may cause a customer to start to look elsewhere. You don’t complain about the cheapest paper towel because it is cheap, you just move on and buy better quality next time. The old axiom is true: quality is its own virtue. X7R and NPO may cost a few cents more, but the temperature and performance stablility is worth it.