Bob's TechTalk

Number 48
by Bob Eckweiler, AF6C

Choosing Disc Ceramic Capacitors:

Recently I was ordering some replacement disc ceramic capacitors to restore an old tube receiver. On a distributor website I had a large choice to select from. One column gave the dielectric choices. From years past I remember NP0, Z5U, X7R, N750 and others, but to my surprise one capacitor was marked S3N. That was a totally new notation to me. So let's look at those letters and see what they mean.

Regular Parameters:

What parameters need to be specified to designate a common disc ceramic capacitor? The three obvious ones are capacitance, tolerance and working voltage. Others that may be important are physical size, RoHS status, temperature range and the temperature coefficient (capacitance change with temperature). If you 'homebrew', you are probably familiar with all except possibly the last three. Let's look at them:

RoHS (Restriction of Hazardous Substances):

RoHS compliancy is fairly recent. For a component to be RoHS compliant it must meet specific requirements as to the materials in its makeup. Full details may be found on the web; just Google "RoHS". However the predominant banned substance is lead. Sometimes RoHS components are also marked as lead-free. Lead is one of the major ingredients in common solder. Today, most commercial electronics manufacturing is done with lead-free solder.

[Operating] Temperature Range:

This is the temperature range that a capacitor was designed to operate at. Operating outside this range may cause damage to the capacitor or more likely cause its performance to fall outside its specifications.

Figure 1 - A class 1 disc ceramic capacitor 5 pF 1KV C0G (NPO)

Temperature Coefficient:

For one class of ceramic capacitor temperature coefficient specifies how much, and in what direction, the capacitance will change for a given change in temperature. These capacitors have a linear response to changes in temperature. For other classes of ceramic capacitors the capacitance change is not linear, and a temperature range is specified along with a ± tolerance over that entire temperature range. The temperature characteristics for both classes are given in a code like those shown in the first paragraph. For capacitors that change temperature linearly, the change is given in parts-per-million per degree change in Kelvin (ppm/°K). The Kelvin temperature scale has the same magnitude as the Celsius scale; however, the Celsius is based on the freezing point of water and the Kelvin scale is based on the absolute zero temperature. 0 °K = -273.15 °C.

Disc Capacitors:

We will hold our discussion to the common disc capacitors found in radios since the fifties (See figure 1). However much of this information relates to current ceramic capacitors. You will find the characteristic nomenclature is

Temp. Coef. 1st Letter		Multiplier Number		Temp. Tol. 2nd Letter	
C	0.0	0	–1	G	±30
B	0.3	1	–10	H	±60
M	1.0	2	–100	J	±120
P	1.5	3	–1,000	K	±250
R	2.2	5	+1	L	±500
S	3.3	6	+10	M	±1,000
T	4.7	7	+100	N	±2,500
U	7.5	8	+1,000		
Less Common Parameters					
L	0.8	4	–10,000		
A	0.9	9	+10,000		
V	5.6				

Table I - Class 1 Ceramic Capacitors EIA Codes - All values in ppm/°K

used even on today's surface mounted ceramic chip capacitors.

To make things a little more difficult, disc ceramic capacitors come in different classes and since it is human nature to complicate things, each class has its own standards. Yes, that's plural!

Class 1 Ceramic Capacitors:
Class 1 consists of smaller value capacitors such as might be used in resonant circuits. They offer stability, low loss and known temperature coefficients with good linearity. The upper capacitance range is on the order of one nF (1,000 pF or 0.001 µF). Their capacitance is independent of, and does not change due to applied voltage. Temperature characteristics are determined by the dielectric material used, and may be expressed in at least two formats, the newer EIA code or the older name code. Dielectric material of different formulas set the temperature linearity and characteristics. These dielectrics have low volumetric efficiency; thus limiting their capacitance for a given size (volume). They remain stable showing no aging tendencies.

Table I gives the EIA codes for type 1 capacitors. The code consists of a letter, followed by a number, followed by a second letter. The first letter specifies the temperature coefficient in ppm/°K. The number specifies a multiplier for the first letter. Multipliers of ±1, ±10, ±100 and ±1,000 may be specified. The second letter specifies the overall tolerance of the value given by the first two characters, and varies between ±30 ppm/°K and ±2,500 ppm/°K.

As an example, the S3N capacitor mentioned in the first paragraph will have a temperature coefficient of (3.3 times –1,000) or –3,300 ppm/°K with a tolerance of ±2,500 ppm/°K. Thus an S3N capacitor will change capacitance at least

Name	Temp. Coef.	Temp. Tol.	Equiv. EIA Code
P100	+100	±30	M7G
NP0	±0	±30	C0G
N33	–33	±30	S1G
N75	–75	±30	U1G
N150	–150	±60	P2H
N220	—220	±60	R2H
N330	–330	±60	S2H
N470	–470	±60	T2H
N750	–750	±120	U2J
N1000	–1000	±250	M3K
N1500	–1500	±250	P3K

Table II - Class 1 Ceramic Capacitors
Name Codes - & EIA Equiv. Values in ppm/°K

-800 ppm/°K, but no more than -5,800 ppm/°K. On the other hand a C0G capacitor will change capacitance between +30 and –30 ppm/°K.

Looking back in a 1963 Arrow Electronics catalog, other codes were used to specify ceramic capacitor tolerances. Old-timers know what NP0 and N750 mean. These are the older "names" tolerances. They are often still used often today. Table II gives the a list of them. Note that their tolerance is set by their name, and their temperature coefficient is given as the number in the "name". The letter(s) tell the direction of change "P" equals positive and "N" equals negative. The exception "NP" represents negative/positive and represents a temperature coefficient of zero (with a tolerance). Table II shows the "names" coefficient specifications along with their EIA code equivalent.

One might wonder why there are all the different temperature coefficients. Getting an LC oscillator to limit its drifting during warmup and normal operations can be accomplished by using capacitors that drift in a way that is opposite the drift resulting from the other frequency determining components. This may be considered a black art by some, but in the fifties and sixties companies like Collins, National Radio, Hallicrafters, Hammarlund, Heathkit and others did a good job of using these capacitors to compensate for drift.

Other features of type 1 capacitors are that they are stable with age and their capacitance remains stable over a large voltage range. Their ratings are specified over a temperature range of 25 to 85 °C. However NPO (C0G) capacitors perform well between -55 and 125°C with a capacitance change of just over 0.5% or less. Figures 3 and 4 are charts of Class 1 capacitors vs. temperature.

Class 2 Ceramic Capacitors:

Class 2 consists of the mostly larger value capacitors from 0.002 µF up to 2 µF or so. Figure 2 shows a typical class 2 capacitor. These capacitors are normally used for bypass and coupling and are not used in frequency determining sections of a circuit. These capacitors are less stable temperature-wise and some even have microphonic tendencies. Neither of these tendencies is a problem in most bypass or coupling uses. Class 2 capacitors perform well at high frequencies and have reasonable capacitance changes with temperature. They also change capacitance with age and with changes in applied voltage. The dielectric material used in type 2 ceramic

Figure 2 - A class 2 disc ceramic capacitor 0.022 µF 500V Z5U

Low Temp. 1st Letter		High Temp. Number		Tol. in Range 2nd Letter	
X	–55 °C	4	+65 °C	P	±10%
Y	–30 °C	5	+85 °C	R	±15%
Z	+10 °C	6	+105 °C	S	±22%
		7	+125 °C	T	+22/–33%
		8	+150 °C	U	+22/–56%
		9	+200 °C	V	+22/–82%
				F	±7.5%

Table III - Class 2 Ceramic Capacitors EIA Codes

capacitors is chosen for its better volumetric efficiency resulting in a lot higher capacitance for its size. However these dielectric materials vary with temperature in a non-linear manner. Figures 5 and 6 are charts showing the capacitance change vs. temperature for some of the common class 2 types. The capacitance changes with frequency as well as applied voltage. Figure 7 is a chart of the change in capacitance vs. percent of rated voltage for nine common type 2 styles.

If one were designing a filter or oscillator requiring larger values of capacitance (thus at lower frequencies - audio, ULF and VLF ranges) one of the many types of film capacitors should be used instead of a type 2 ceramic capacitor.

Like the type 1 capacitors, the type 2 capacitors also have an EIA three character code. It is even made up similarly: a letter, followed by a number followed by a second letter. However, it is completely different from the type 1 specifications. The first digit specifies the minimum operating temperature, the number specifies the maximum operating temperature and the second letter specifies the capacitance tolerance over the range of temperatures from the minimum to the maximum temperature. Table III shows the specifications over the range that is of interest to most radio amateurs.

An example is the capacitor shown in Figure 2. It is clearly marked as Z5U. This signifies a low temperature of +10 °C and a high temperature of +85 °C; over that range the capacitance may vary between +22% and -58%. Thus a 0.022 µF Z5U capacitor will be within the range of about 0.027 µF down to about 0.010 µF over the temperature range of +10 to +85°C (+50 to +185 °F).

Likewise an X7R capacitor will be in the range of ±15% of its marked value over a temperature range of -55 °C to +125 °C (–67 to +257 °F).

Common type 2 capacitors are X5R, X7R, X8R, X7S, Y5V and Z5U.

Capacitance Change			Temperature	
CODE	∆C/Co V=0	∆C/Co V=R	CODE	Range
2B	±10%	+10/–15%	1	–55 to +125 °C
2C	±20%	+20/–30%	2	–55 to +85 °C
2D	+20/–30%	+20/–40%	3	–40 to +85 °C
2E	+22/–56%	+22/–70%	4	–25 to +85 °C
2F	+30/–80%	+30/–90%	5	–10 to +70 °C
2R	±15%	—	6	+10 to +85 °C
2X	±15%	+15/–25%		

Table IV - Class 2 Ceramic Capacitors IEC Codes

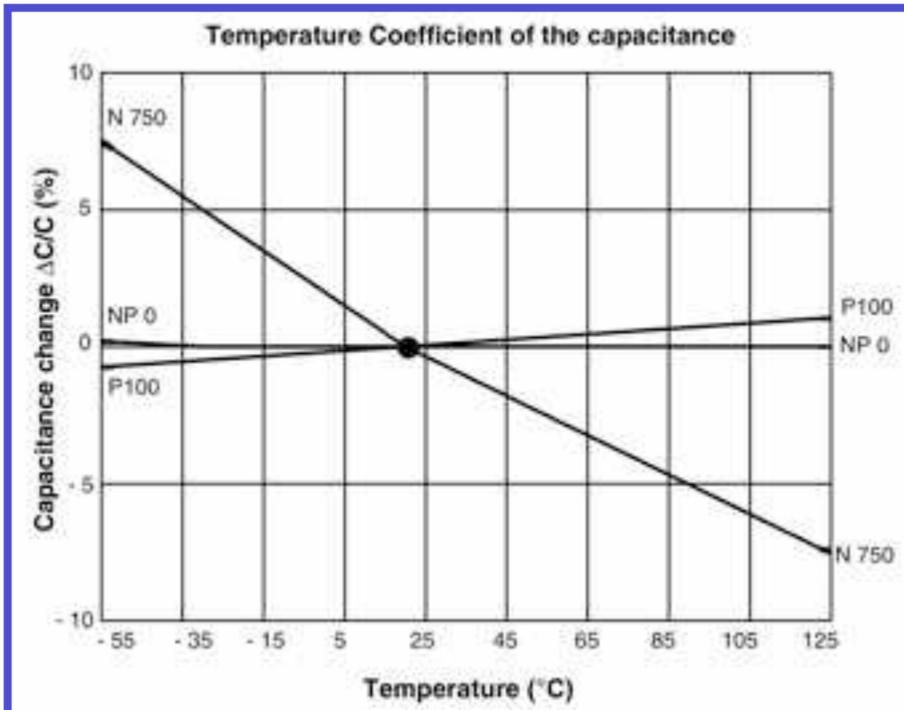

Figure 3: ∆C/C vs. °C for Class 1 N750, NP0 and P100

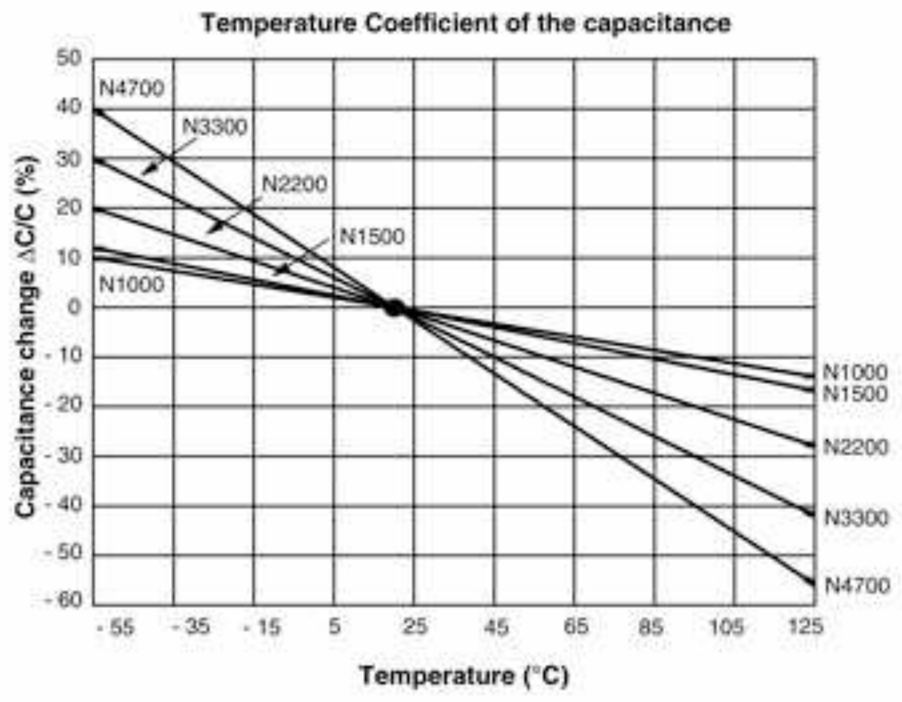

Figure 4: ΔC/C vs. °C for Class 1 N1000 through N4700 Capacitors

A second coding system for specifying type 2 ceramic capacitors is published by the IEC under standard EN 60384. I have not come across capacitors so marked, but one should be aware of its existence as it could be encountered at any time. Table IV shows the specification of this coding system. It consists of the number '2' followed by a letter and a second number. The letter designates the maximum capacitance change as a percentage of the nominal marked value (ΔC/Co) over the given temperature range. The actual temperature range is specified by the second number. Two different (ΔC/Co) ranges are given for each letter; one with an applied voltage of zero and one with the rated DC voltage applied.

Not all EIA codes can be directly translated to IEC codes. The EIA Z5U capacitor of Figure 2 matches IEC's 2E6, but the EIA X7S is only close to the IEC 2C1. No IEC code exists for X8R.

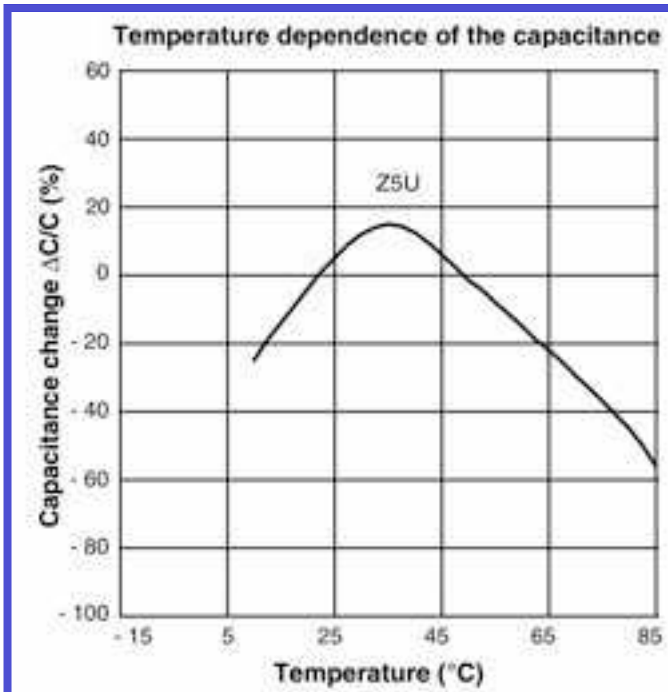

Figure 5: ΔC/C vs. °C for Class 2 Z5U Capacitor

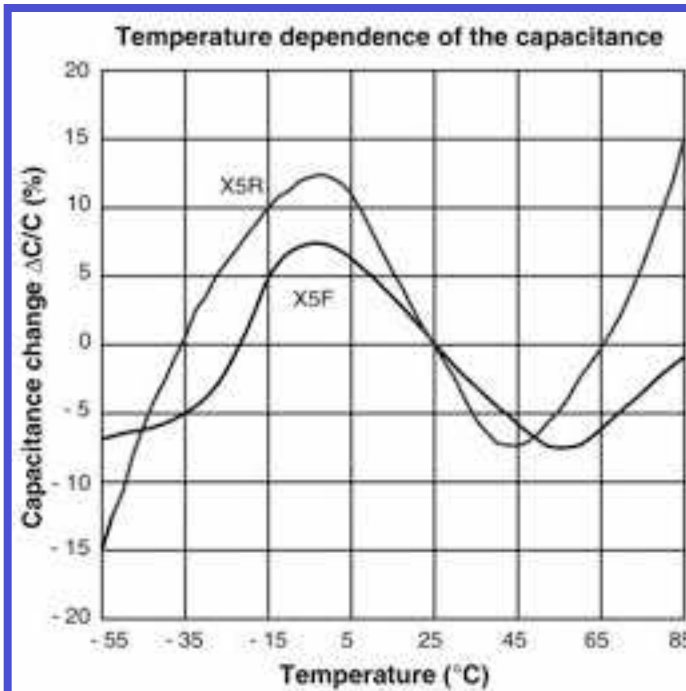

Figure 6: ΔC/C vs. °C for Class 2 X5R & X5F Capacitors

Code	Tolerance
C [1]	± 0.25 pF
D [1]	± 0.5 pF
J	± 5 %
K	± 10 %
M	± 20 %
Y	+ 50/– 20%
Z	+ 80/– 20%
P [2]	+ 100/– 0%

[1] Only for capacitors up to 10 pF
[2] Often designated GMV

Table V: - Standard Tolerances

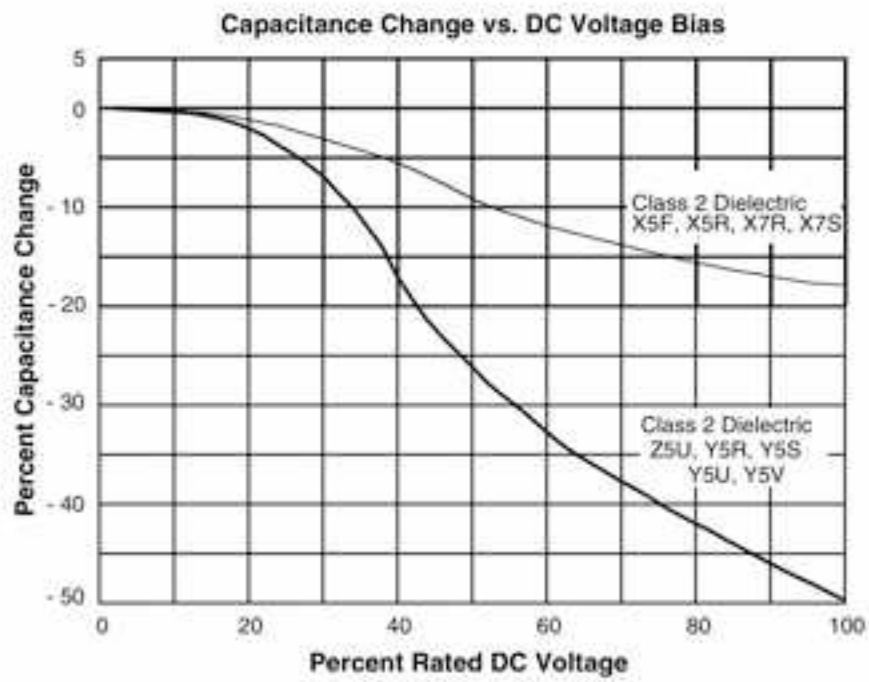

Figure 7: ∆C vs. Applied Voltage for numerous Class 2 Capacitors

Capacitor Tolerance:
Besides temperature dependent tolerances, capacitors also are rated for their tolerance at a particular temperature (usually at or near 25 °C). This represents the maximum deviation the capacitance will be from the marked value at the measuring temperature. The code is usually given by a single letter code as shown in Table V. These tolerance codes are the same as used on many other types of capacitors

Summary:
So next time you are choosing a ceramic capacitor, keep this article in mind and spend a little time choosing the right capacitor for the job it will do. As usual, there is a trade off involving cost vs. selection.

Comments:
Back in Bob's TechTalk #43 and #44 I began a series on magnetism, coils, and inductance. It is hard to imagine that was back in 2010. I do plan to finish the series soon; I have already written the next installment, but need to refine it. Perhaps next month it will be ready and included in that issue of RF.

Previous articles in the Bob's TechTalk (Originally, just TechTalk) may be downloaded in PDF format from the OCARC website:

http://www.w6ze.org/btt/BTT_Index.html

I hope you find these articles useful and educational. I know I've learned a lot writing them. It is one thing to know something and it is another to know it well enough that you can describe it to others.

73, from AF6C

This article is based on the TechTalk article that originally appeared in the June 2015 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.