K9AXN SERVICE NOTE 022h
IMPORTANT CAPACITOR INFORMATION

One of the most frequent errors when restoring vintage radio equipment is removing the paper capacitors and indiscriminately replacing them with Ceramic caps. This seems to be a universally held notion. It is also a fairly sure way to transform a radio that could have performed to factory specs to a mediocre performer. Sound like finger nails scratching on a black board? Sure, but indulge me and read on because the world is not flat.

A great case and point is the Hallicrafters SR-2000, SR-400, and SR-150 transceivers as well as the HT-44 transmitter. The popular first thing done is turn the radio over and check for paper caps. If you find any, replace them --- they are evil --- NOT SO!! They are not paper capacitors but expensive very high quality NON-INDUCTIVE film capacitors manufactured by General Instruments. The SR-2000/400/400A/150 transceivers implemented poly-film capacitors that resembled paper caps. They were used in ANALOG CIRCUITS rather than Ceramic capacitors, e.g. the source and sink for the balanced modulator, key click filter, AGC, AALC, and noise blanker time constants, as well as the side tone generator circuits where linearity and stability are a design requirement. **Ceramic class 2 and 3 capacitors are not a proper design choice for these functions.** This note will provide comprehensive explanations, research papers, and test methods to help you choose the right capacitors for the right functions in your radio.

Note: When I refer to ANALOG, I am speaking to a circuit whose components participate functionally in combination with other components to perform a common task i.e. --- a Tuned resonant circuit, Time constants, Key click filter, coupling to and from the low impedance balanced modulator, and band pass filter circuits that demand linearity in the presence of varying voltage.

Low impedance components that are used to couple high impedance end points are not considered analog participants. The low impedance of the coupling capacitor does not allow a significant AC voltage differential between the plates of the capacitor when coupling high impedance end points.

Low impedance components that are used to couple low impedance end points are considered ANALOG because the coupling capacitor will be exposed to varying voltage.

The film caps used in the SR-2000, SR-400, SR-150, and HT-44 must not be replaced with Ceramic caps. Read on, it will become apparent.

TYPES OF CAPACITORS AND DIFFERENCES IN BEHAVIOR

CERAMIC CAPACITORS:
There are three major classes of Ceramic capacitors; Class 1, 2, and 3, each having different characteristics.

The following is an overview of research data. Please read the included research papers for details --- no point in repeating the data. (www.k9axn.com Service note 23 for links)

Class 1 Ceramic (Low K):

The class 1 Ceramic capacitors are comparable to Mica capacitors; the best there are. They are stable in the presence of varying voltage, very low Dissipation factor, very low Dielectric absorption, very low Hysteresis effect, and they are temperature stable or predictable, and they do not age. They are the C0G, NPO, and Temperature compensating i.e. N150, N750 etc. The higher the Negative number in the temperature compensating version, the closer to the class 2 capacitor behavior they become.

Class 1 Ceramic capacitors are generally used in circuits that require temperature, capacity, Hysteresis, and age stability. Critical ANALOG circuits!

Class 2 Ceramic (Medium K):

The class 2 Ceramic capacitor covers a variety of performance characteristics that begin from the very low end Class 1 to the high end class 3 behaviors. Several undesirable characteristics begin to appear in the Class 2 caps and become progressively worse in the Class 3capacitor.

1. The capacity varies significantly with applied voltage and varies differently for AC or DC.
2. Capacity varies wildly with temperature.
3. The Hysteresis effect becomes problematic.

4. They age, losing capacity over time.

These first three vulnerabilities cause distortion, harmonics, IMD, and unpredictable behavior. See the harmonic chart in the Clifton paper.

These capacitors can be used for Bypass as well as coupling provided the impedance of the coupling capacitor is significantly lower than the termination.

Class 3 Ceramic (High K):

The class 3 Ceramic capacitor displays all four of the undesirable characteristics of the Class 2 but much more profound.

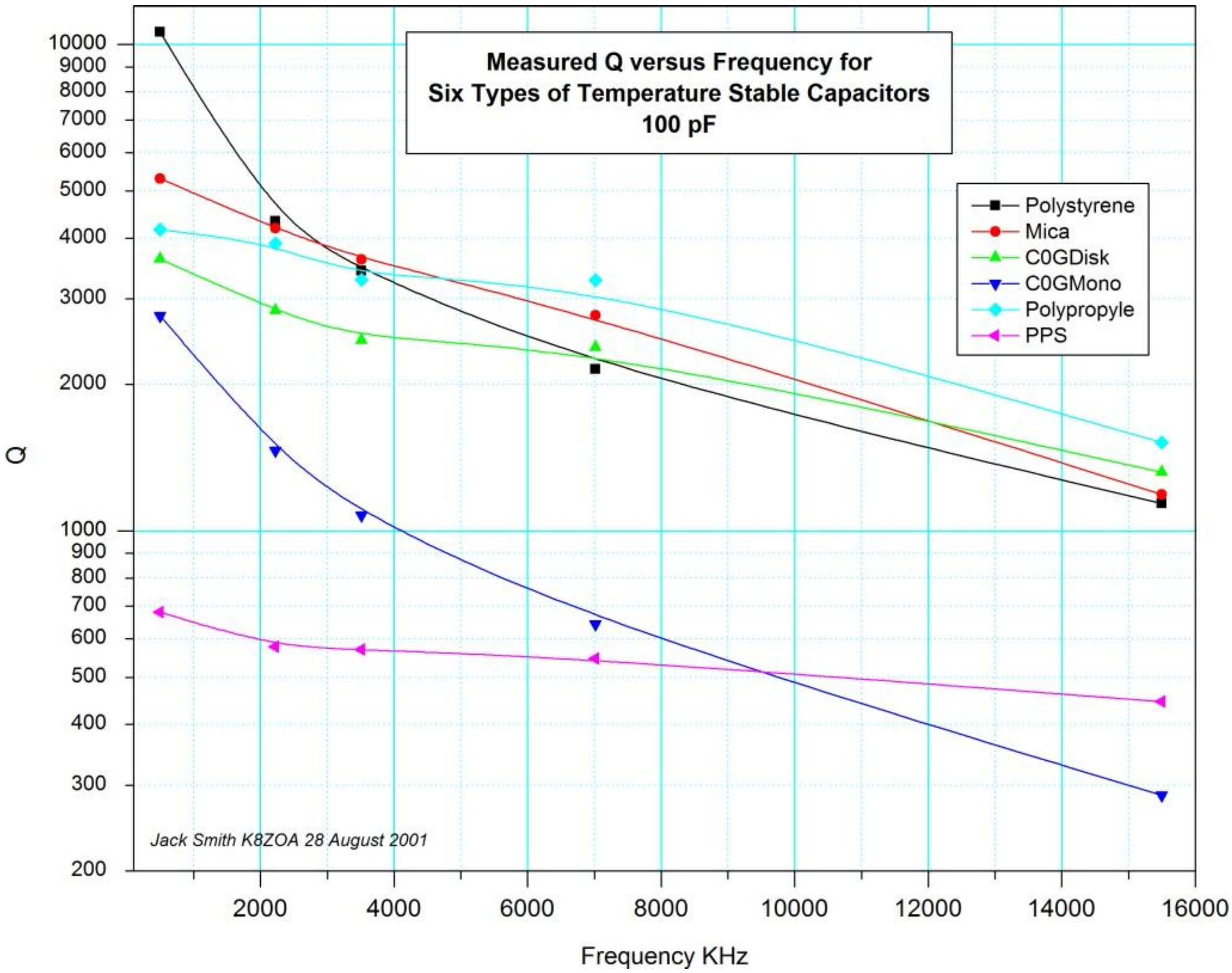
They can be used for Bypass, and with great care coupling, provided you do not care about linearity.

Polypropylene film/foil:

Polypropylene capacitors are acknowledged by some manufacturers as the new Class 1 Ceramic replacement. The electrical characteristics of the leaded Polypropylene, Ceramic class 1, and Mica capacitors are very close to the same.

1. They are non-inductive.
2. The capacity does not vary with applied voltage.
3. They display extremely low Hysteresis effects.
4. The dielectric properties regarding stability and loss are much the same as Class 1 Ceramic capacitors.
5. All work well through the VHF range.
6. They do not age.
7. The dielectric is efficient to well into the VHF range. We measured the apparent Q to 205Mc. http://www.k9axn.com/_mgxroot/page_10833.html

The following chart represents the Q of a variety of temperature stable capacitors. Pay special attention to the close comparison between the Mica, Polypropylene, and C0G class 1 Ceramic capacitors.



Details regarding proper circuit usage:

The capacity of a Polypropylene film capacitor does not vary with applied voltage, age, or exhibit Hysteresis effects as do the popular class 2 (X7R) or class 3 (Z5U) Ceramic caps. The capacity of class 2 and class 3 Ceramic capacitors begins to increase as the voltage is increased, then lose as much as 40% of the original value. The capacity of the class 3 Ceramic cap varies the most.
There is almost immeasurable capacity shift with varying voltage in the class 1 caps.

The varying capacity of ceramic class 2 and especially class 3 capacitors in the presence of more than a fraction of a volt **AC** will create distortion in an analog application and is a universally inappropriate design. The variation in capacity with voltage is different for AC and DC. In the presence of AC, the capacity begins to vary at less than 1 volt. Why the difference with AC? Because the Hysteresis effect is present beginning with very low AC levels and the general voltage effect at higher levels. Check the research papers, --- any research paper, --- specifically the charts in the Kemet paper. I provided a link to their paper as it is copy right.

Class 3 Ceramic capacitors should be relegated to bypass operations:
Contrary to the universally held notion that they are the best there is for bypass ---- truth be told, that is the only function that they are capable of doing well.

Class 2 Ceramic capacitors can be used for the following configurations:

Bypass:

Coupling: From the plate to the output tuned circuit --- because the AC voltage across the capacitor is significantly lower than the plate voltage swing --- about 1/10th. Use a cap with a voltage rating 5 to 10 times the expected voltage swing.

Coupling: In the Pi section output. The voltage is approximately 230vac for a 2000W transmitter and 400vac for a poor SWR. Again, use a cap with a voltage rating 5 to 10 times higher than the expected voltage. Remember, the % of capacity variation with voltage is spread across the full voltage rating of the cap but be aware, it is not linear. A 10 volt variation in a Ceramic 50 volt cap will have a much more pronounced effect on capacity than the same variation in a 500 volt cap.

Low level timing: A timing circuit where you don`t care about linearity.

Note, the SR-2000 uses 280v on most plate and 150v on most screen circuits. At 280VDC the capacity of a 500v class 3 capacitor can be up to 30% lower, however, I believe the designers selected component values based on that knowledge.

The characteristics of high K Ceramic capacitors were well known in the early 60's and before. None of this information is new --- just forgotten.

The final compartment SR-2000:

Class 1 and 2 --- no class 3 caps are used.
The coupling from the plate to pi-section is a high quality Centralabs class 2 X5U 5000v door knob cap. The low capacitive reactance of the coupling capacitor limits the AC voltage differential between plates, which is essentially a low

impedance coupler to high impedance load. This is appropriate use of the class 2 cap.

For the 3.5Mc and 7Mc caps that are switched in the plate side of the final tuned circuit, a class 1 100pf N750 door knob is used; Yes, a class 1 cap. Class 1 caps include the C0G, NPO, and temperature compensating caps. They used a class 1 cap because the voltage swing is over 2000v in the tuned circuit which is an ANALOG function by any definition. A class 2 or class 3 capacitor, because they behave like voltage variable capacitors, would have added unacceptable distortion and harmonic content into the final pi-section; remember, the capacity of a class 1 cap does not vary with applied voltage. You will not find a class 2 or 3 Ceramic capacitor that carries circulating current attached to the plate side of any final tuned circuit. Check your transmitter, you will find this to be correct.

The 50 ohm, antenna side of the pi section sees approximately a 225 volt swing at 1Kw out with a good match and maybe 400 volts with a poor SWR. Here they use a high quality, high voltage X5U Class 2 cap. A class 2 capacitor in an analog circuit? They used a 5000v X5U in the output side of the final tuned circuit where the voltage swing is a maximum of approximately 400v. This particular capacitor because of the 5000 volt rating displays very little change in capacity in the 0vac to 400vac range and is an acceptable design.

Do not arbitrarily grab a ceramic capacitor from your stock to replace a paper or what looks like a paper capacitor thinking it has to be the right choice.

Bypassing a screen, or plate RF cold side with a class 2 or 3 ceramic cap is OK because there is no AC voltage swing to speak of as the cap provides a low impedance path to ground for RF. One caveat, a .01uf Z5U 500v used as a bypass for a circuit that has 280vdc will likely result in a .006uf to.008uf capacitor, not .01uf. The X7R will vary somewhat less than the Z5U. If that satisfies the design criteria, all is good. You will not find a class 2 or 3 Ceramic cap participating as a major Q contributor in the circulating current of a tuned circuit for all of the above reasons!

A common example of paper capacitor terror is the misguided replacement of the **band pass** caps with Ceramic in the SX-100 and other 50kc I.F. systems: bad choice, use film.

FACT: Polypropylene caps do not have the frailties inherent to class 2 and 3 Ceramic caps. The capacity varies **insignificantly** with voltage, and they are not plagued with Hysteresis effects like the class 2 and 3 ceramic caps.

The notion that the Polypropylene dielectric is lossy at high frequency is absolutely absurd. I have tested the Q of Polypropylene caps to over 200Mc and find their Q to be => than Ceramic class 2 or 3 caps and stability superior; See the video.

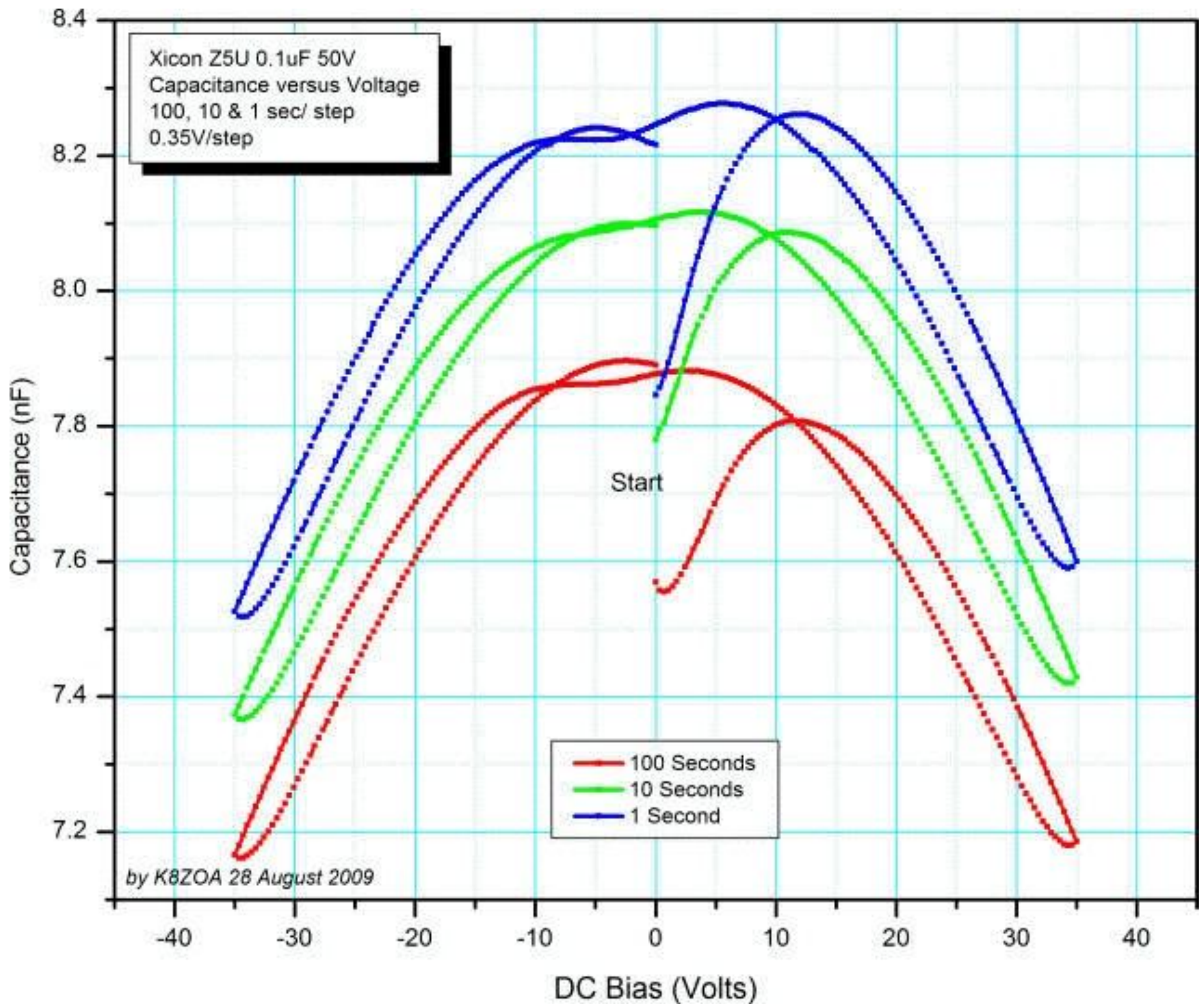
The manufactures data sheets for polypropylene caps specifically state that they are non-inductive and can be used to their self-resonant frequency just like any other cap.

The inductance that they present is actually =< to that of a straight length of wire. A one inch length of #22 wire exhibits about 22nh of inductance. If you short the leads of a capacitor using a flat copper strap 1/8 inch wide, 1/4 inch long to minimize the connection inductance of a .001uf Polypropylene metal foil cap, it is self-resonant at approximately 76MC. Calculate this, it represents approximately 6.0nh ---- the total inductance of a 1/4 inch length of #22 wire. We tested several .001uf Ceramic caps shorted in the same manner; the result --- self resonant, but at approximately 65Mc. See the video and repeat the test yourself --- you will find it interesting.

Comparing the apparent, not measured Q at 65Mc for both gives the Polypropylene caps a 130/100 advantage over the Ceramic caps. The Polypropylene dielectric outperforms the class 2 and class 3 Ceramic capacitors regarding stability and Q to well above their series resonant frequency, where BOTH, the Ceramic and Polypropylene film caps become inductive albeit no more so than a straight length of wire. A 500pf Polypropylene metal foil cap is series resonant at approximately 105Mc and continues to display an => Q than Ceramic caps

Is the Q important? Of course! The Q of a capacitor is the opposite of Dissipation factor i.e. Admittance and resistance. The dissipation factor limits the maximum frequency that is usable.

Dissipation factor is composed of two properties, ESR and Dielectric Absorption. The ESR is simply the combined resistance of the connections. Dielectric Absorption is a result of the dielectric charges lagging in their return to their natural state --- like an old soggy rubber band compared to a new one. Dielectric absorption results in energy being expended to force the charges back to their natural position generating heat and is defined as the Hysteresis effect which is insidious for linearity.



You will find this butterfly chart and narrative at the end of the Clifton Labs research paper clearly displaying the Hysteresis behavior of Ceramic class 2 and 3 caps. The capacity at a particular voltage varies radically. Please pay close attention to this chart. The hysteresis effect is as old as Ceramic capacitors. If you have not seen or heard of the effect, we will provide a simple test procedure and video that you can use to compare two capacitors to determine which has the better Dielectric Absorption factor. You will find this a very interesting exercise!

Here is an interesting story. Everyone has heard about the carbon dating of some object. We also know that the resistances of vintage carbon composition resistors are universally quite high over time. What we tend not to know is that ceramic capacitors age as well. The class 2, X7R age at approximately 2% per decade and the class 3 Z5U approximately 5% per decade. Don't believe this? Clip a cap out of an SR-2000/400/400A or any vintage radio and measure the capacity. You will find them down from 10% to 25%+ depending on the age and class. Check your inventory. Take it a step further and restore them to their original state. Place them in a coffee cup and bake them at 150C degrees for 1/2 hour or 125C degrees for 1.5 hours let them cool for 24 hours and re-measure. The crystalline structure is now recovered and their values are as new. One caveat, the aging process begins again. Note, that not one of the film capacitors is degraded.

No, the baking process does not hurt the capacitor! What temperature is Ceramic fired, what temperature does solder melt, and one further note; the baking process was used by some manufacturers to adjust the values to tolerance --- CHECK THE KEMET OR ANY OTHER RESEARCH PAPER AS TO WHETHER THIS PROCEDURE IS HARMFUL

Note: The Class 1 NPO/C0G or temperature compensating ceramic caps do not display varying capacity with applied voltage, the aging problem, or profound Hysteresis problems as do the class 2 and class 3 ceramic caps.

Seems to require a million words to express a concept, and it's easy to warp the meaning of the written word; as you have read in the frequent diatribes on the various reflectors. The fundamental reason for this service note is the flawed notion that any time you find a tubular or what you believe to be a paper capacitor in a vintage radio, replace it with a disc Ceramic cap. Use polypropylene if you are not sure.

Review the circuit and if it has an analog personality, or you care about linearity and stability, use Polypropylene film, Mica, or class 1 (NPO, COG, or any of the temperature compensating Ceramic capacitors). Would you use a voltage variable capacitor, which is the behavior of class 2 (X7R etc.) or class 3 (Z5U etc.) disc Ceramic capacitor as a major component of a tuned circuit? The people who designed the radios didn't think so. If you must use a disc Ceramic capacitor, use the class 2 cap with a voltage rating as high as you can find that will fit. TEST it`s personality first. These capacitors vary radically even within a batch. They should be tested before use. The test methods and setup are included in video format in these notes. You will be stunned by the vast variations between Ceramic class 2 and 3 capacitors with the same values marked.

We will provide a video of a new disc Ceramic cap that measures great for capacity but has almost no Q, and when subjected to 50% of its rated voltage has lost 90% of its capacity. This is a must see! If you have purchased some of the new Blue caps, watch this one!

NOTE: See photos of the tests and instrument setups (service note 23a) that can be used to verify these findings and review any of the numerous research papers including the links at the beginning for more information.

Do the calculations and measure the self-resonant frequency of a .01uf capacitor --- IT CANNOT BE SELF RESONANT AT ANYWHERE NEAR 30Mc, THEORETICALLY OF PHYSICALLY WITH ½" LEADS OR WITH A DEAD SHORT! There is an old and very misguided myth that a .01uf Ceramic leaded capacitors with ½ inch leads is self - resonant at over 30Mc. Do the math. Test it yourself, and check the research papers. Best you can do with the leads shorted directly together is 21Mc and with ½ inch leads maybe 11Mc. This is confirmed in any research paper.

Do the self-resonant measurement as viewed in the video.

Do the measurement for capacity change with voltage variation test: you can tell a good deal about a capacitor with it.

Do the hysteresis comparison test.

Do the Dissipation comparison test.

They are simple and you can prove to your satisfaction that you can choose the right capacitor for the right application without having to depend on Myths, legends, hysterical campfire talk.

I will provide videos of the tests and setups. They are incredibly simple and interesting.

I will be happy to respond to any courteous question and hope you find this interesting. If it is unclear, please send a note describing the content and we will fix it.

Thanks and a good day to you. Kindest regards Jim K9AXN