X-Ray Pictures of High Voltage Capacitors

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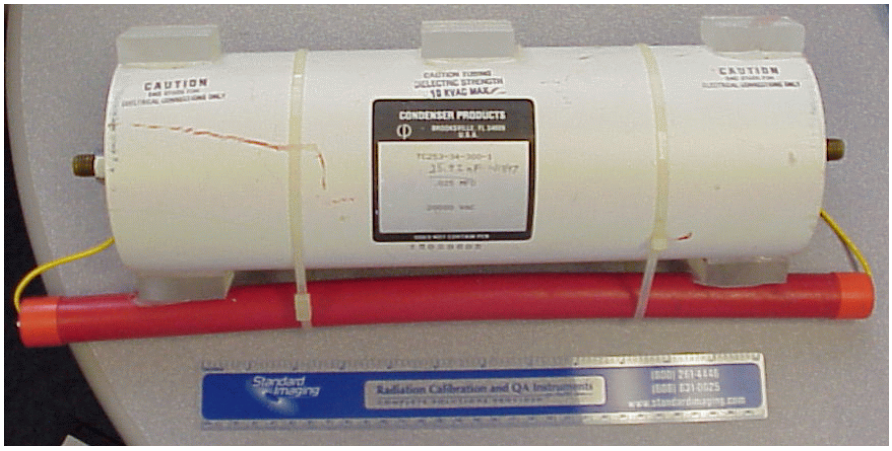
Ever wonder what's inside a high voltage capacitor? This document may help a bit. While acceptance testing a new x-ray C-arm unit recently, I took the liberty of x-raying some of my high voltage capacitors to illustrate what's inside. All of the figures shown here are of actual functional capacitors. The extraneous metallic particles you may observe are part of the normal manufacturing process and do not seem to cause harm (probably because they are outside the individual capacitor modules). In the images, black indicates a highly attenuating material (like metal), and white means the object is transparent. Plastics are less attenuating than aluminum, and appear lighter in color than the metal attachments. It is actually a negative of the true x-ray image. However, the geometry of the insides is shown fairly well.

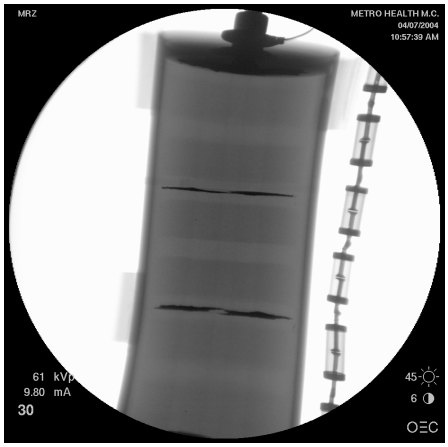
I have lots of high voltage capacitors, some of which are shown below. At surplus stores and hamfests, I tend to buy all the capacitors and pretty much any other component that has a voltage rating of two kilovolts or higher, provided that: 1) They are cheap enough, and 2) I can get them into and out of my small car. That rules out pole pigs and the like.

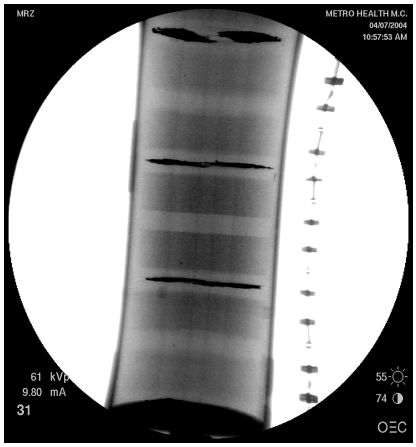
In the pages that follow, I will briefly discuss several capacitors I routinely use in tesla coils and other high voltage experiments.

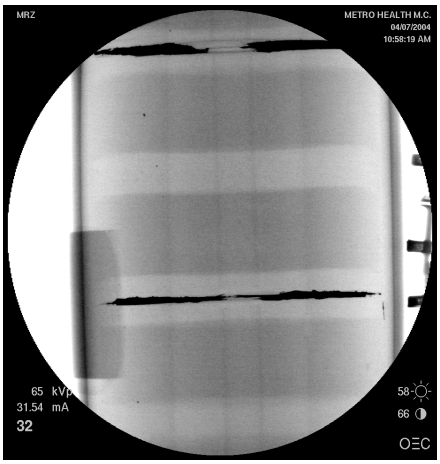
Condenser Products (CP) makes a number of excellent energy discharge capacitors, some of which are well suited for tesla coil use. In 1997, a group of tesla coil enthusiasts purchased 25 nF capacitors rated at 20 kilovolts AC RMS from CP. Over time, most of these units have failed. In 1997, many coilers were not aware of resonant rise effects which can result in approximately 3 x 1.414 x the RMS applied kilovoltage to appear on the capacitor. For a 15 kV NST, that amounts to as much as 60 kV across the cap, which will easily cause failure. These days, we hopefully use larger-than-resonant (LTR) capacitance values, and we use safety gaps across the caps to protect our investment. I was part of the original group purchase, and photos of my cap are shown below. I have always run my unit with a safety spark gap directly across the cap and have only used 7-9 kV supplies. As a result, my capacitor is still working well after 6 years of heavy use. These are the same style of caps Ed Wingate uses in his large coil systems. He often runs them for 2-5 minutes at a time, and has put several hours of running time on them over a single weekend without a failure. Unfortunately, Condenser Products no longer sells caps to private individuals for tesla coil use. They do appear occasionally in the surplus market.

The cap below consists of five pairs of cylindrical capacitor sections connected in series. The red tube contains Victoreen 2 kV spark gaps connected in series to protect the capacitor from overvoltage. For reference, the blue ruler is 12" long. Note the black metal interconnects between the cap modules.

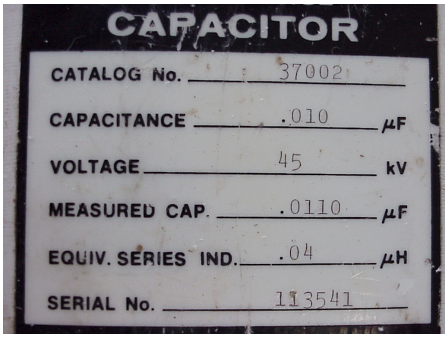


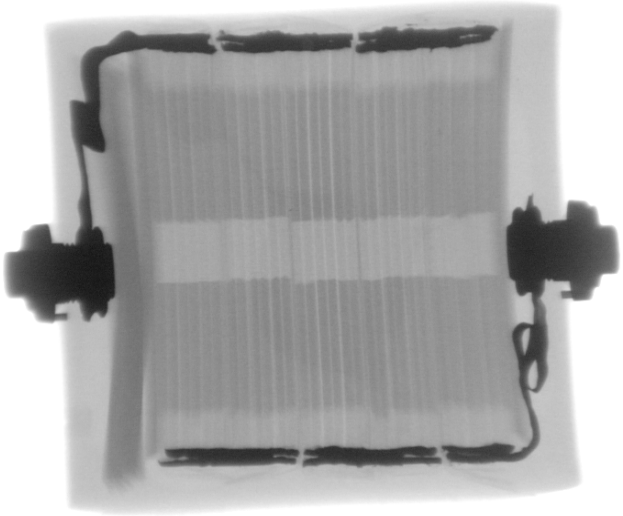




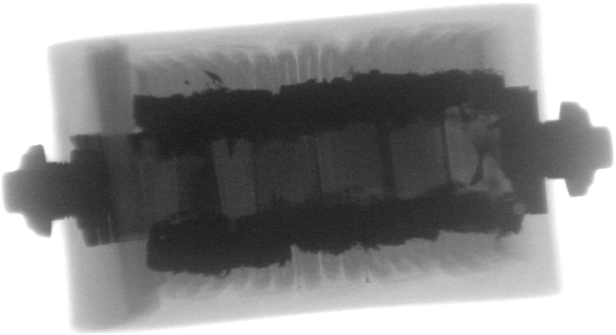


Another popular commercial capacitor vendor is Maxwell. They make a number of great pulse discharge capacitors. Their 37xxx series is often used by coilers. Below are photos and x-rays of two of my Maxwell units. There are five capacitor modules connected in series in the 37002 model, shown below. Note the flattened individual modules which are in parallel groups of three. These are then connected in series using alternating end plate interconnections. This geometry results in low internal inductance, like the Condenser Products caps.



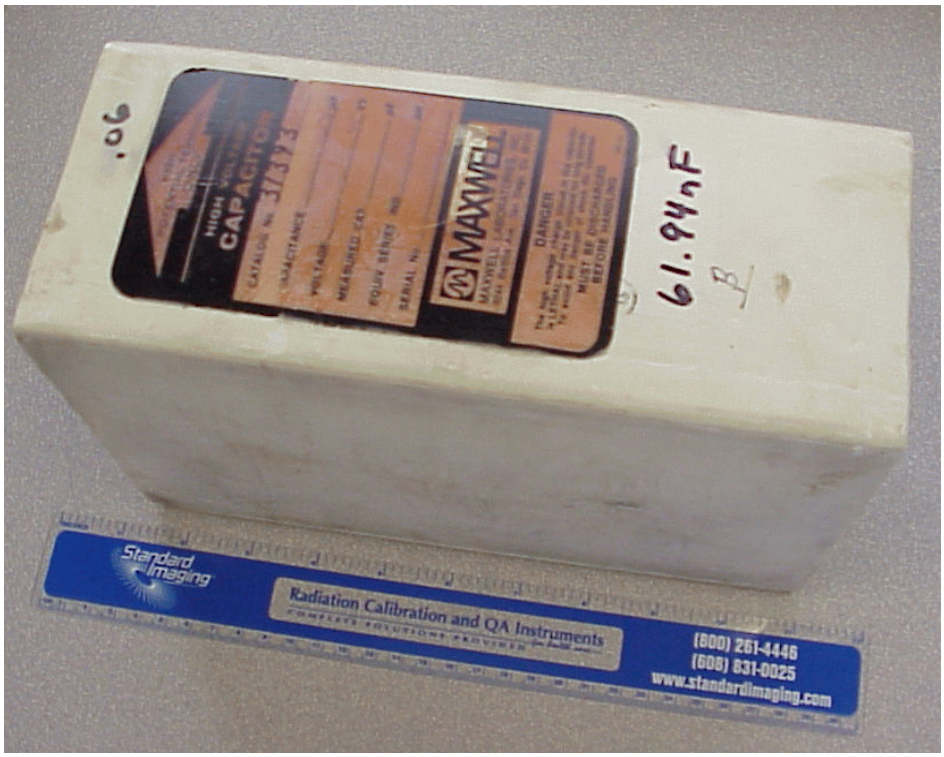


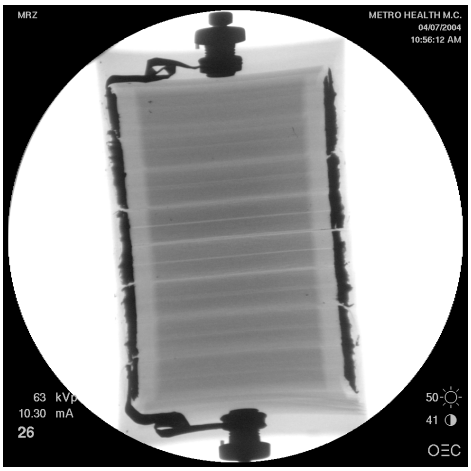
Side X-Ray view

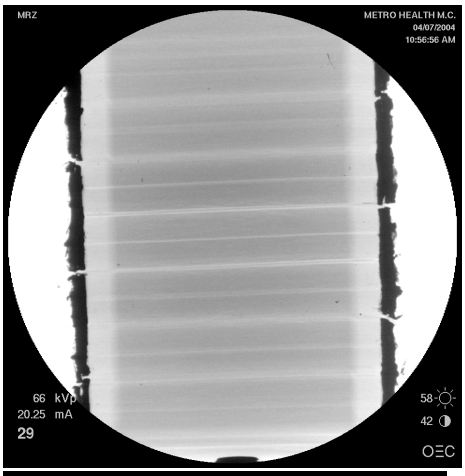


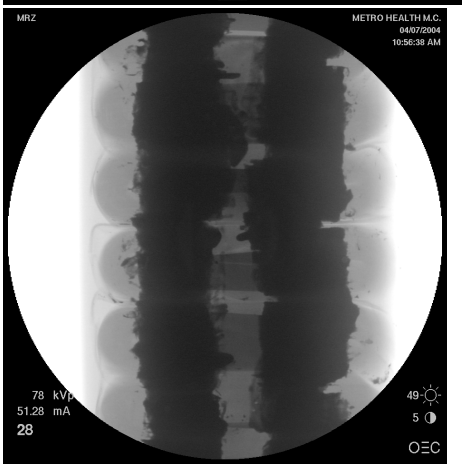
Top x-ray view

Another popular Maxwell model is the 37393, rated at 40 kV and 60 nF in this example. I have never blown a Maxwell, but I always use safety gaps directly across the caps and I try not to overvolt them. This model is about 12" (30 cm) long. There are eight capacitor modules connected in series in this 40 kV capacitor. The black represents the metal connections at the ends of the capacitor stacks. These are extended foil designs like the Condenser Products caps. However, these units have a flattened coil geometry instead of the the cylindrical geometry used in the CP caps.





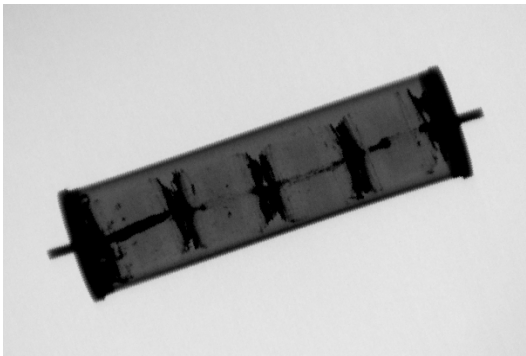




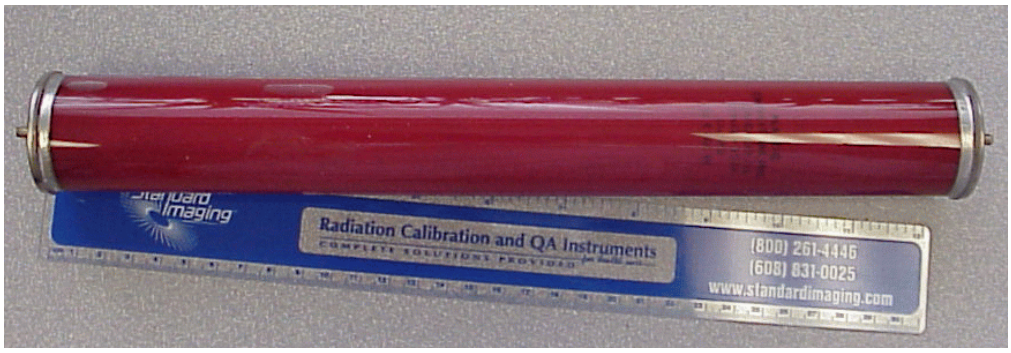
Another capacitor vendor is Plastic Capacitors Incorporated (PCI) out of Chicago, Illinois. Visit their factory if you ever get the chance. They make a wide variety of high voltage capacitors, pulse forming networks, transformers and high voltage power supplies that are of interest to the high energy enthusiast.

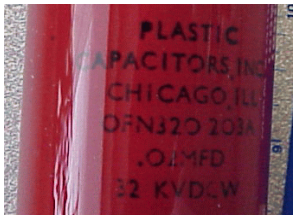
Their high voltage supplies are usually sealed in metal cans and look like transformers or metal capacitors. Look for the big insulators. They are coded HVxx-yyy and may have the letter “M” after the “yyy” to denote that they are in their compact series. The “xx” is a number representing the voltage output and the “yyy” is a max current indicator. For example, model HV150-502 will produce 0-15 kV at 5 mA when powered from a variac. These supplies provide 1.5 - 15 mA, depending on the model (-152 = 1.5 mA, -502 = 5 mA, -103 = 10 mA, -153 = 15 mA). They come in models producing 1 to 100 kV. These show up surplus frequently. Look for the Plastic Capacitors label. They usually have four or six terminals on top. The example shown is a model HV25-103M, producing 0-2.5 kV at 10 mA. It is designed to be operated directly from a small variac.

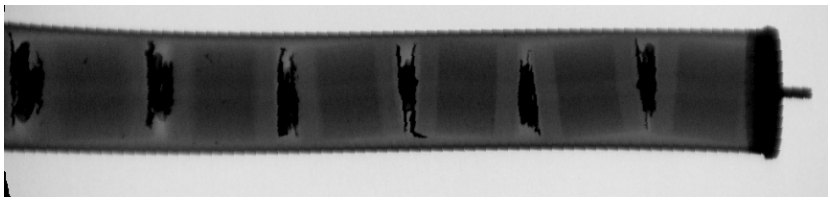
PCI also makes many high voltage capacitors. Most models are designed for DC filtering. However, their BNZ series are designed specifically for RF use and make great tesla coil caps. In addition, their LK-ND series are energy discharge caps which are useful for single-shot experiments (strobe, can-crusher, quarter shrinker, etc.). I have used the BNZ series for tesla coils, and they perform well. I have not had any problems with reliability. You usually see the OF, LQ, LJ, LK, and LR series on the surplus market. These are designed for DC filtering and are not suitable for tesla coil use. They use either paper or mylar for the dielectric, which is very lossy at RF frequencies. As a result, these caps heat up quickly in tesla coil use. They also cannot handle the high currents due to small interconnections inside. They are great for high voltage power supplies, however. Here’s an example of their custom BGX series, which are plastic film caps suitable for vacuum tube tesla coils. Note the four sections in this glass shell, metal end 3 kV 400 kHz AC rated capacitor.



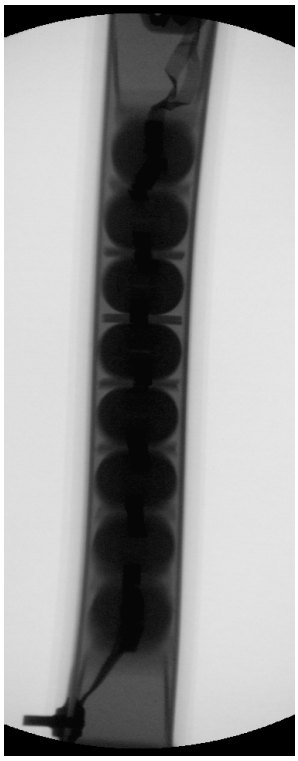
A mylar film OF series DC filtering capacitor from PCI is shown below. It really heats up under tesla coil use due to the high loss of mylar at radio frequencies. There are 8 series-connected sections in this 32 kV DC filter capacitor at .02 uF (20 nF). They are great for HV DC supplies.



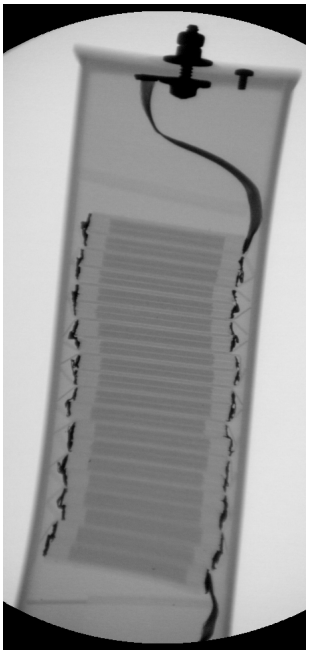




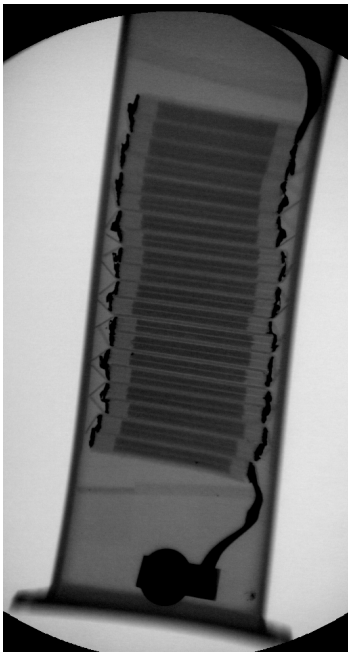
Here's another DC filter capacitor, this time the LN series, made from a series of paper-foil capacitor sections. This unit is rated 0.01 uF at 80 kV DC and is used in mammography x-ray equipment. It is unsuitable for use at tesla coil frequencies. It has high internal resistance due to the thin leads interconnecting the 8 flattened, rolled paper-foil capacitor sections. There is a flat piece of plastic between each cap to help stand off the 80 kV. Like all of the above caps, it is oil-filled. PCI uses anhydrous mineral oil in most of their caps.



Here is PCI's tesla coil compatible BNZ series capacitor in the same phenolic case as used in the previous LN model. This cap consists of a series of stacked capacitors, much like the Maxwell designs. There are 20 capacitors in series in this 0.005 uf, (5 nF) 15 kV RMS AC rated unit.

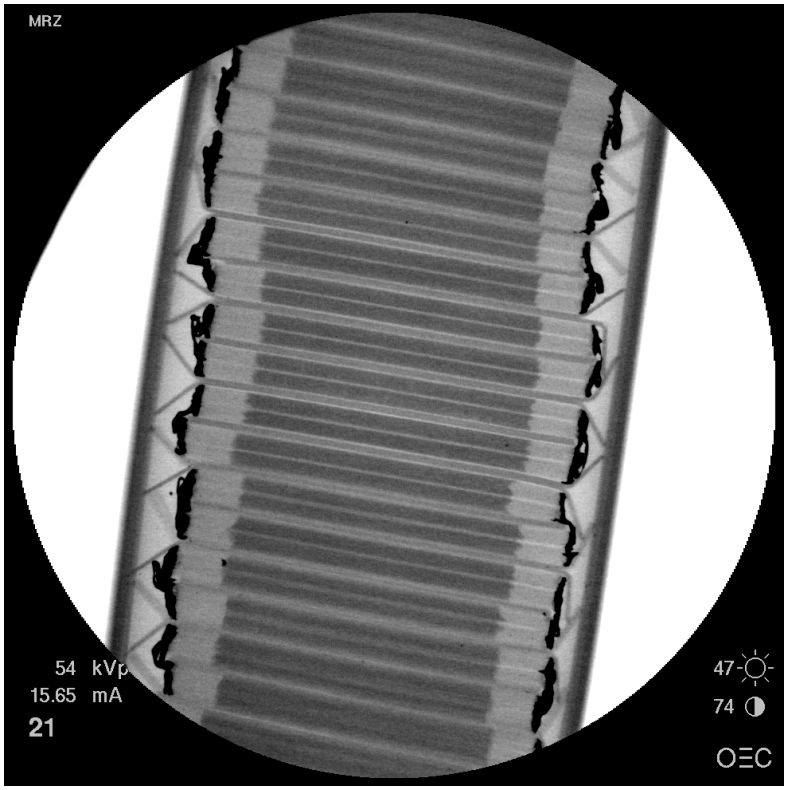


Top ½



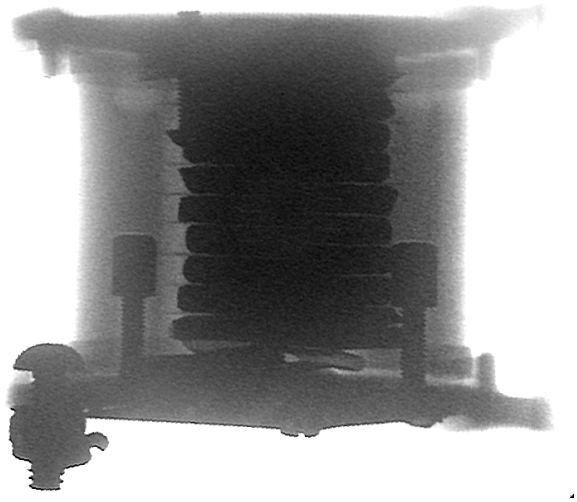
Bottom 1/2

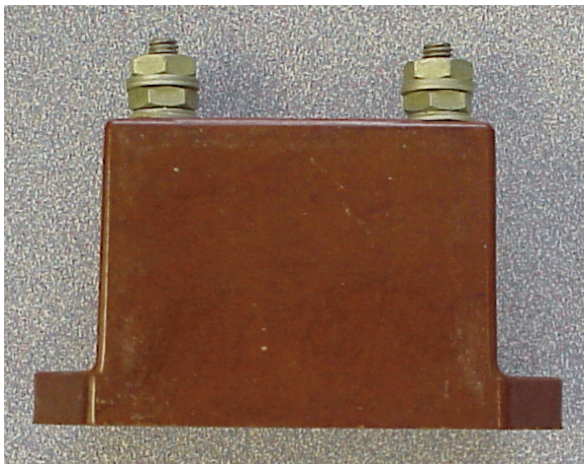
Side view

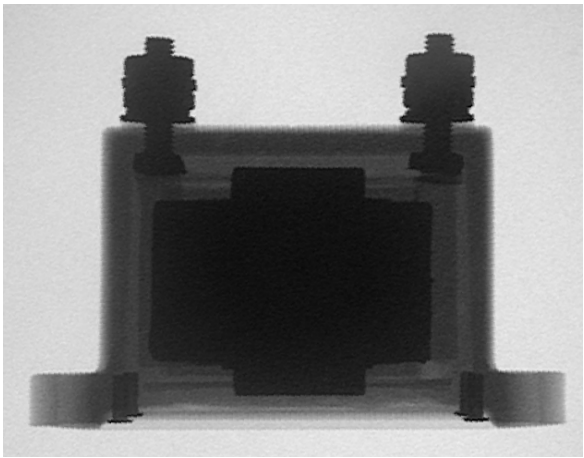


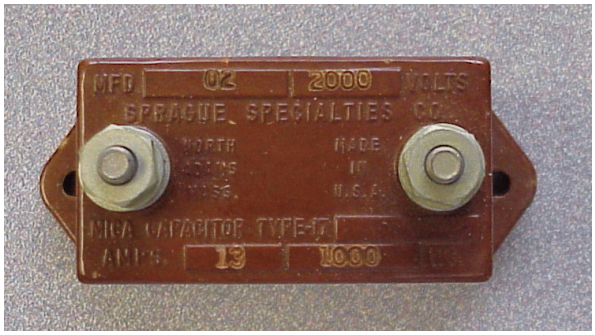
magnified view

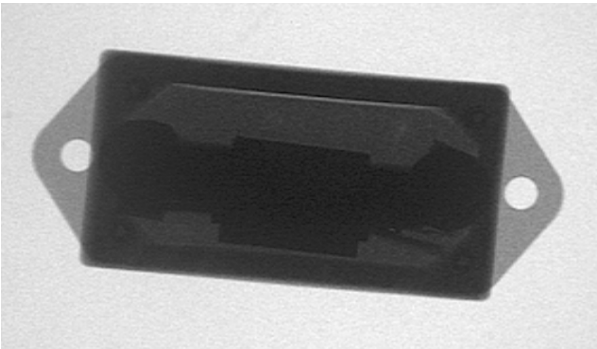
Another capacitor useful for tesla coils is the mica cap. Mica has very low loss at tesla coil frequencies and, until recently, was often used in vacuum tesla coils (now often replaced with MMC's). Mica capacitors come in a variety of sizes and shapes, as illustrated here. Large transmitting types are often cylindrical in shape, as shown in the first pair of images. High voltage mica caps require multiple plates in series, just like the plastic caps shown earlier.



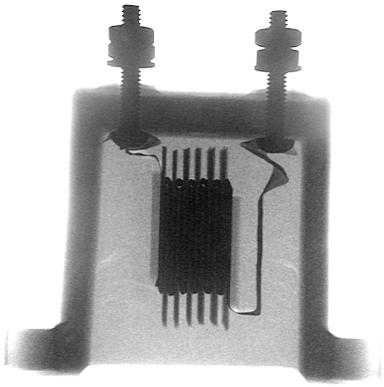


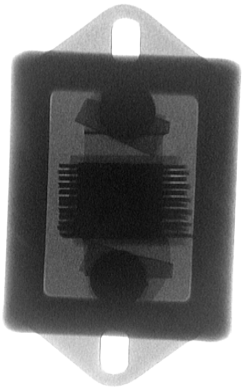


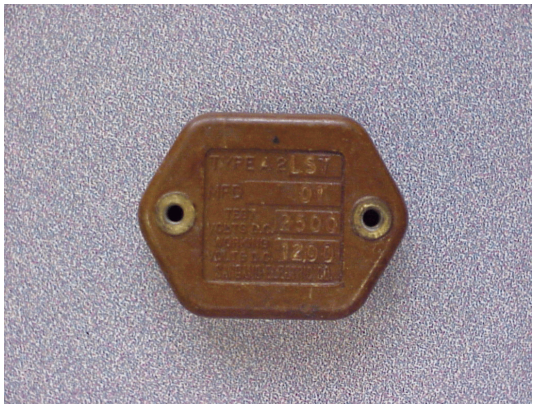


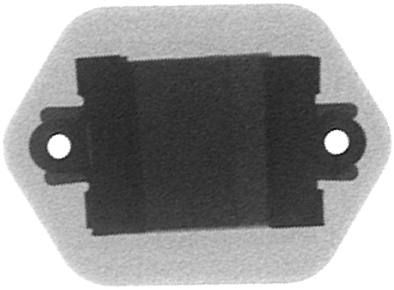


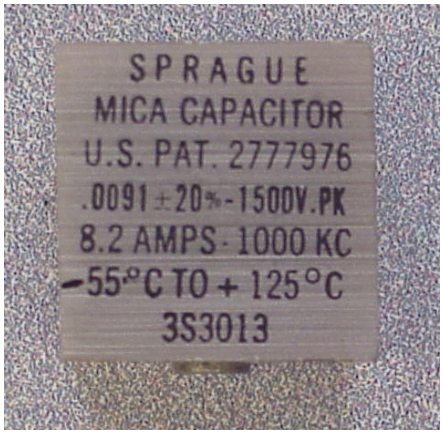

AEROVOX
MICA CAPACITOR
TYPE PEAK VOLT MFD
1996 12500 .0001
5 AMPS 15000
4 AT 7500
3 KCS 3750
2 1875
MADE IN
NEW BEDFORD, MASS. U.S.A.

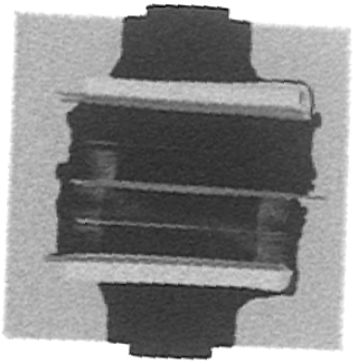




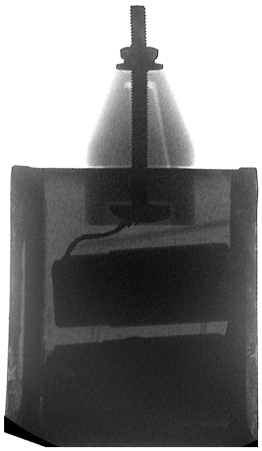


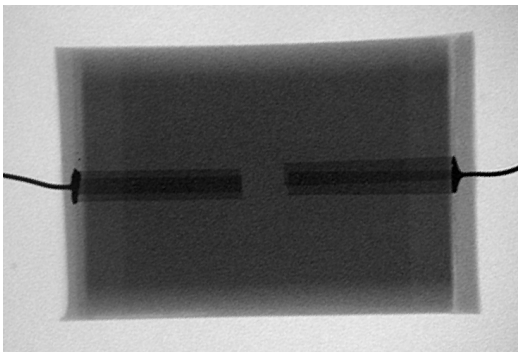



SPRAGUE
MICA CAPACITOR
U.S. PAT. 2777976
.0091 ± 20%-1500V.PK
8.2 AMPS-1000 KC
-55°C TO + 125°C
3S3013

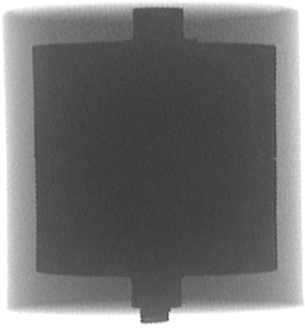



.01 MFD.
8 AMP. 110 M. C.
8000 V.D.C. TEST
SK - 1464
MICAMOLD RADIO



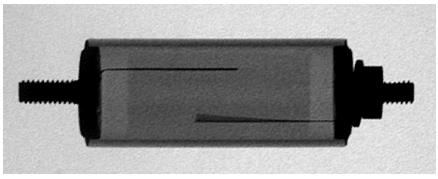


The above capacitor is made from a composite mica material and is about 4 inches (10 cm) long. They are lossy at tesla coil frequencies, and I find they often fail when used in tesla coils. Your mileage may vary, of course.



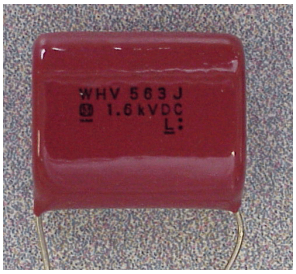
This is a 1.05 nF 10 kV AC barium titanate capacitor. They also come shaped like hockey pucks. They are very lossy at tesla coil frequencies but are useful for transient suppression purposes. They do not work well as bypass caps in tube coils, either.

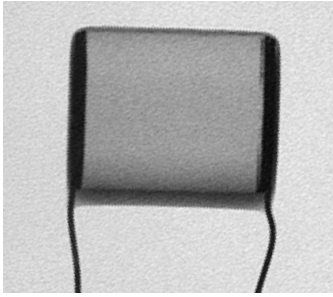
The capacitor shown below is a filter cap. Note the tiny connecting leads internally (right x-ray image). As a result, these caps cannot be used as MMC capacitors due to their low peak current carrying capacity.



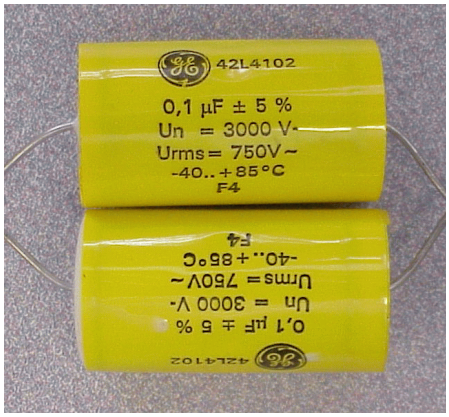
Next, I'll show a number of capacitors which many people have connected in series/parallel fashion to produce a mini-multi-capacitor (MMC) module. These capacitors tend to be constructed with end foils which extend to the ends of the caps, where solid connections can be made. They are wound with polyethylene or polypropylene, which are excellent low-loss plastics at tesla coil frequencies. They provide a means for tesla coil enthusiasts to construct a high voltage capacitor with relative ease. In addition, the metal is deposited as a film on the capacitor, so any punctures due to overvoltage have a tendency to heal, albeit with a slightly reduced capacitance afterwards. They afford the amateur a simple

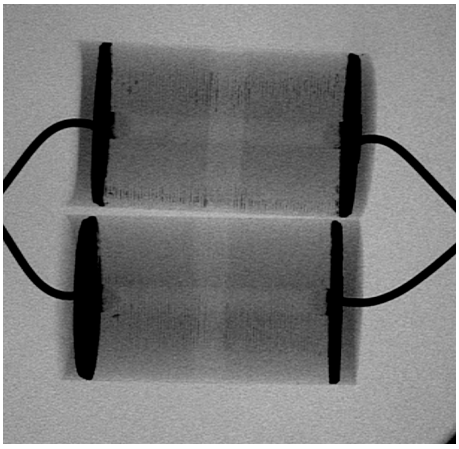
method for building a high voltage capacitor. However, they do not have anywhere near the current carrying capacity of the commercial capacitor units described previously (as I have shown in previous measurements - see tcbor01.pdf). I don't have any Geek Group caps yet, so there are no pictures of their products yet. However, I have included pictures of the units Terry used to sell, some G.E. snubber caps and some of the WIMA series, all of which are used in MMC construction.



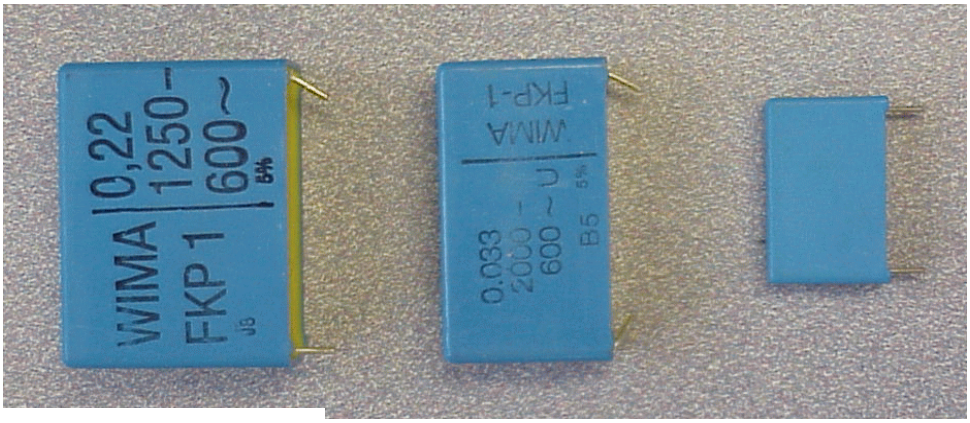


Look at the solid end-foil connections to the exterior leads on these capacitors! (Terry Fritz used to sell these!)





G.E. Snubber caps



WIMA Caps