**1st Lighten The Load Inc**
*'World Changing Technologies'*

# Electrically Enhanced Ceramic-Polymer Capacitor Dielectric

By: David Kelly, President 1st Lighten the Load Inc.

## Introduction:

Capacitor dielectrics composed of ceramic-polymer or polymer-polymer capacitors fail to optimize the unique properties of each material of which they are constructed. The two most important properties they are unable to optimize are the working voltage and dielectric constant. The first problem is the result of electric field concentration and subsequent corona erosion of the matrix surrounding the dispersed or conglomerates of particles with the highest dielectric constant. The second problem is that when different dielectric materials are mixed, such as high k with lower k, the resulting dielectric constant is a logarithmic ratio not a proportional relationship. For a simple two-phase composite in which the ferroelectric filler is well dispersed in a polymer matrix, the effective dielectric constant can be calculated from Eq. (1):

$$\log \varepsilon'_{composite} = \log \varepsilon'_{matrix} + \varphi_{filler} \log(\varepsilon'_{filler} / \varepsilon'_{matrix}) \quad (1)$$ **[1]**

Where $\varphi_{filler}$ represents volume fraction of the filler in the composite, while $\varepsilon'_{filler}$ and $\varepsilon'_{matrix}$ are the dielectric constants of the filler and the polymer matrix respectively.

For energy storage applications using high voltage ultra-capacitors it is necessary to optimize the working energy density of the dielectric. This means that a method had to be developed that increases both the dielectric constant and working voltage of a ceramic-polymer or polymer-polymer blends.

The capacitance of a parallel plate capacitor is given by the formula

$$C = \varepsilon_r \varepsilon_0 A/d \quad (3)$$ **[2]**

Where

C is the capacitance, in farads;
A is the area of overlap of the two plates, in square meters;
$\varepsilon_r$ is the relative static permittivity (sometimes called the dielectric constant) of the material between the plates (for a vacuum, $\varepsilon_r = 1$);
$\varepsilon_0$ is the electric constant ($\varepsilon_0 \approx 8.85... \times 10^{-12}$ F·m$^{-1}$); and
d is the separation between the plates, in meters.

Capacitance is proportional to the area of overlap and inversely proportional to the separation between conducting sheets.

The energy stored in a capacitor is given by the equation

$$W_{stored} = (1/2)CV^2 = (1/2)\varepsilon_r \varepsilon_0 (A/d) V^2 \quad (3)$$ **[2]**

Where

V is the voltage applied in volts across the capacitor plates,
$W_{stored}$ is the energy stored in joules.

To summarize the energy density of a capacitor is directly proportional to the dielectric constant $\varepsilon_r$ and applied voltage squared.

## LTL's Solution

1st Lighten the Load Inc. (LTL) applied the principals of electrorheological fluids **[3]** for which there is available an extensive amount of research results and published papers. In the LTL process a capacitor is fabricated with the composition of the dielectric constructed such that an electric field can be applied across the electrodes before the polymer is set or cured. During the application of an AC electric field the parts of the dielectric with similar dielectric properties align between the electrodes. This creates bands of dielectric material with similar electrical properties aligned perpendicular to the electrodes.

What has taken place is that the ceramic-polymer or polymer-polymer blend has been organized into regions of material with similar electric properties perpendicular to the electrodes. There is no longer the problem of electric field concentration around particles or molecules of highest dielectric constant because they no longer exist. Furthermore the highest k portion of the dielectric of the matrix is concentrated in bands between the electrodes, greatly increasing the dielectric constant. The result of applying the electric field while the dielectric was still fluid is a significant increase in both the working voltage and dielectric constant over that of the unordered state.

## Example

A dielectric material was constructed using Barium Titanate (BT) with a particle size of 200nm, made by Inframat Advanced materials Part# 5622-ON2. The BT was combined 35% by volume to 65% silicones. The silicone portion was composed of DMS-V05 20%, HMS-301 58%, DMS-V21 17% and VDT-731 0.5% all made by Gelest. The catalyst used to cure the silicone was platinum based with 48-hour room temperature cure or 15 minutes at 100 Celsius. The dielectric constant of a silicone is typically 4 with a working voltage of 450 to 600 Volts per mil (25 microns). The BT & silicone mixture was combined using a proprietary LTL process and benzene added to adjust the mixture to the viscosity to the value required by the coating process.

Test capacitors were constructed by coating the dielectric mixture of BT and silicone on a metalized propylene film to make one electrode of the capacitor, the excess benzene was allowed to evaporate, then a second propylene metalized film was laid on top for the opposite electrode. External electrical terminations were made using a conductive polymer. The capacitors were put under pressure and 7kHz, 300Vp-p ac applied across the film. After a few minutes the uncured dielectric was slowly heated to 100 Celsius to accelerate the cure of the silicone-ceramic dielectric. The capacitor generated a large amount of audible noise at the same frequency as the applied ac voltage.

## Results

Sample 1: A company called Professional Testing, located in Round Rock Texas, made all measurements and tests conducted on this capacitor and a certified copy of their test report is available. The capacitor electrode area was measured to be 1024 square mm, average dielectric thickness was 0.1mm (100 micron) giving a total volume of 100 cubic mm. The capacitance was measured as 47nf with a breakdown voltage greater than 500Vdc. The sample capacitor had a total volume of approximately 1/10 that of an equivalent commercial 47nF 500 Vdc metalized film capacitor.

The dielectric constant is unknown so it will be necessary to use equation 3 to calculate it.

$$C = \varepsilon_r \varepsilon_0 \, A/d \quad (3)$$

Where

$C = 4.7 \text{ x } 10^{-8}$ F
$A = 0.001 \text{ m}^2$
$\varepsilon_0 \approx 8.85 \times 10^{-12} \text{ F m}^{-1}$
$d = 0.0001\text{m}$
$\varepsilon_r = ?$

The dielectric constant $\varepsilon_r$ for the tested capacitor was calculated to be **531**.

What would have been the dielectric constant if there were no enhancement? From equation 1 the unenhanced value would be

$$\log \varepsilon'_{composite} = \log \varepsilon'_{matrix} + \varphi_{filler} \log(\varepsilon'_{filler} / \varepsilon'_{matrix}) \quad (1)$$

Where:

$\varphi_{filler}$ is 0.35, $\varepsilon'_{filler}$ *is 1500* and $\varepsilon'_{matrix}$ is 4

gives $\log \varepsilon'_{composite} = ? = \log 4 + 0.35 \log(1500 / 4) = 1.5$
where $\varepsilon'_{composite} = 32$

The calculated dielectric constant of 32 is much higher than would normally be expected for a ceramic polymer blend comprising 200nm BT. Typical experimental results produce dielectric constants of 12 to 20 when using a low k polymer such as silicone and BT.

How much was the dielectric constant increased through electrical enhancement?

Enhancement = (k of Measured lab sample 1) /(theoretical unenhanced k)

= 531/32 = 16.6 times

The amount of increase in the dielectric constant is very significant and should provide similar results with other dielectrics, especially those that are a ceramic-polymer or polymer-polymer blend.

## Conclusion

The example clearly demonstrated the potential for the LTL electrical enhancement process to significantly increase the energy density of many different dielectric materials. The enhancement process is expected to produce similar results for other ceramic-polymers and polymer-polymer combinations. The result will be the increase in the energy density of a number of dielectric materials from their current state of 5 - 50 J/cc to 50 - 300J/cc; the energy density similar to that of a number of battery technologies.

## References

[ 1 ] **Polymer Composites with High Dielectric Constant by:** C. K. CHIANG and R. POPIELARZ *Polymers Division, National Institute of Standards and Technology, Gaithersburg, MD 20899-8541, USA (Received May 19, 2001; In final form December 24, 2001).*

[ 2 ] From www.Wikipedia.org topic capacitance.

[ 3 ] **JOURNAL OF CHEMICAL PHYSICS VOLUME 112, NUMBER 8 22 FEBRUARY 2000**
**Structure of electrorheological fluids**;
U. Dassanayake and S. Fraden *Complex Fluids Group, Martin Fisher School of Physics, Brandeis University, Waltham, Massachusetts 02454;*
A. van Blaaderen; Van 't Hoff Laboratory, Debye Institute, Utrecht University, The Netherlands and FOM Institute for Atomic and Molecular Physics, Amsterdam, The Netherlands

# 1st Lighten The Load Inc

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## Independent Test Report & Amendments

The following pages contain an Independent Test Report on a capacitor sample made using the 1st Lighten The Load Inc's enhancement process, by Mr. Bradford E. Rehm, Ph.D., Senior Regulatory Engineer from the company called Professional Testing, 1601 N. A.W. Grimes, Suite B, Round Rock, TX 78665, Tel 512-244-3371, http://www.ptitest.com.

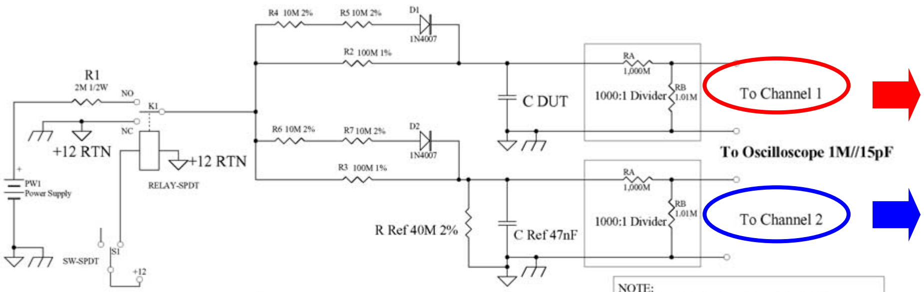
## AMENDMENTS TO

Report on Film Capacitor Evaluation
For
1st LTL
Professional Testing
Project: 10765-90
February 5, 2010

## LIST OF CORRECTIONS

1. In Figure 1, page 4 "Channel 1" should be labeled "1st LTL Sample" and "Channel 2" should be labeled "Reference Device".
   This corrects any confusion that may arise because the test measurements were made with the test leads reversed compared to how they are shown in Figure 1, page 4. The person making the test did not follow Figure 1, page 4 exactly and he interchanged Channel 1 and Channel 2 going to the oscilloscope.
   All graphs are labeled the way he had connected the oscilloscope to the test circuit and devices.

**BELOW IS A PROPERLY RELABELED FIGURE 1, FROM PAGE 4**



This should be labeled ***Channel 2*** or ***1st LTL Sample***

This should be labeled ***Channel 1*** or ***Reference Device***

NOTES:
1. All grounds must be connected together for high voltage testing.
2. The common point of the common ground must be tied to Earth.
3. K1 may be eliminated with a short circuit if the power supply is able to continuously operate into a 10 to 30 Mega-ohm load.
4. The capacitor under test has a slow dielectric response time with a charge - discharge time constant of 2 to 10 seconds. Use longer

NOTE:
The 1 Mega ohm input resistor of the Oscilloscope changes the divider ratio to 1,000: 0.502 or1,990:1. The actual voltage on the capacitors is 2,000 times the displayed value.

**1st Lighten The Load Inc.**
**Capacitor Lab Sample Comparison Circuit**
**DC Charge/Discharge Test Circuit 03 Feb. 2010**

www.1-LTL.com Revision 1.0
25 May 2010

# Report on Film Capacitor Evaluation
# For
# 1st LTL

**Professional Testing**
**Project: 10765-90**

**February 5, 2010**

## Overview

The tests described in this report were designed to explore three characteristics of film capacitors submitted by 1st LTL. The characteristics of interest were:

1. The capacitance developed by the samples.
2. The relative charge and discharge rates of the sample as compared with a standard capacitor.
3. The effects of the leakage resistance of the samples.

A fixture was prepared to simultaneously charge a conventional film capacitor and a film capacitor prepared by 1st LTL. In its “inactive” state, the fixture ensured that both capacitors were brought to a neutral state by discharging them through a 2 megohm resistor. When a relay in the fixture was activated, a charging voltage was applied to both capacitors through identical resistors and diodes.

The charge and discharge rates of the capacitors were observed and stored on a two-channel oscilloscope. Although high voltages were not used in these tests, identical high voltage probes were used to monitor the behavior of the capacitors. These probes were selected because they have 1 gigohm internal resistances and thus would have little effect on the charge and discharge rates of the capacitors when they are connected to the circuit.

The tests of the capacitors prepared by 1st LTL demonstrated the following:

1. Capacitance is approximately 47nF for test Capacitor 1,
2. Although the charge rates are comparable to those of conventional film capacitors, their discharge rates are substantially slower.
3. The leakage resistance of the samples began to limit their ability to accept charge at approximately 300 Volts and above.

This information is significant for the following reasons:

1. These capacitors are compact—occupying less than 1024 square mm (1.6 square inches) by a thickness of roughly 100 micrometers. For reference,

the standard tubular capacitors with which these were compared, occupied 9800 cubic millimeters (0.6 cubic inches). These data suggest that the energy storage capability of the 1st LTL capacitors is substantially higher than that of conventional film capacitors.

2. The relatively slow discharge rate of the 1st LTL capacitors indicates they may be most suitable for applications requiring high energy density and controlled discharge rates and times. Their ability to accept charge as rapidly as standard capacitors is also an asset. Energy storage for automotive use is an example application.

3. At voltages under 300 Volts, the leakage resistance of the 1st LTL capacitors was found to be comparable to that of conventional film capacitors.

## The Test Apparatus

The discharge/charge relay and discharge and charge resistors were mounted on a polyethylene platform. Banana jacks provided convenient connection points for the internal components and the capacitors. The test fixture and associated wiring are shown in Photo 1. The entire test stand is shown in Photo 2.

Figure 1 is a schematic of the fixture, with notes about how it is to be used. The capacitors are charged through the R4/R5 and R6/R7 pairs and D1 and D2. The diodes ensure that the lower-value resistors are in the circuit only during charging. The 100-megohm resistors, R2 and R3, determine the discharge rates and currents. R1 is present to limit current in the event of a short circuit in the relay or elsewhere in the circuit.

## The Findings

Connecting the BK high-voltage probes directly to the inputs of the oscilloscope captured the following plots. Although the charge voltages used in these tests was 100 Volts through 500 Volts, the peak voltages of the waveforms are relatively low because of the high resistance of the probes—on the order of 1 gigohm. The absolute values of the measurements are less important, however, than the behavior of each of the capacitors.

In the following tests, the reference capacitor, a CDE 47nF 3000 Volt part (CDE 940C30S47K-F) was shunted with a 40 megohm resistor to make its leakage resistance similar to that of the 1st LTL sample. This ensured that the charge and discharge curves would appear at the same points on the oscilloscope display.

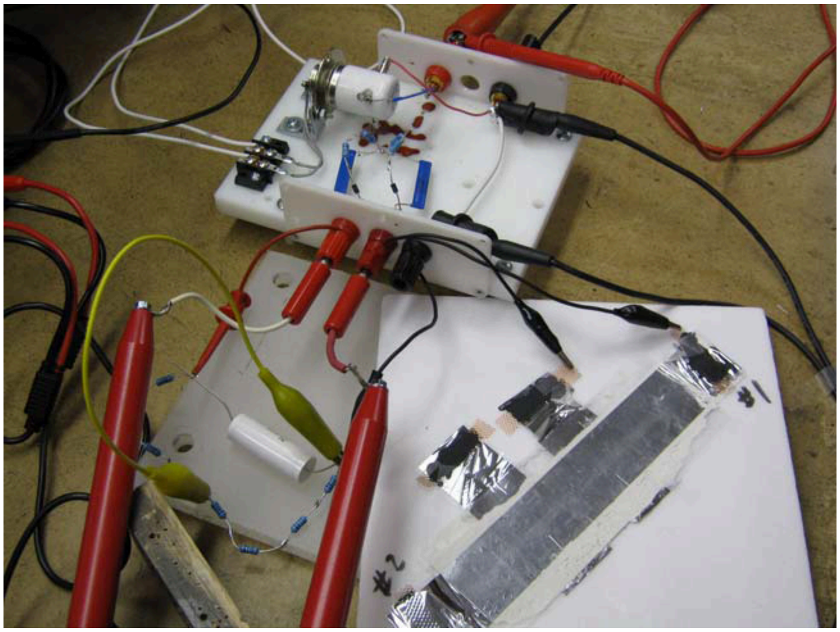


Photo 1. The polyethylene platform is shown in the upper part of the photograph. The reference and test capacitors are connected to the banana jacks facing the camera. The high impedance, high voltage probes used to monitor capacitor charge state are in the foreground.

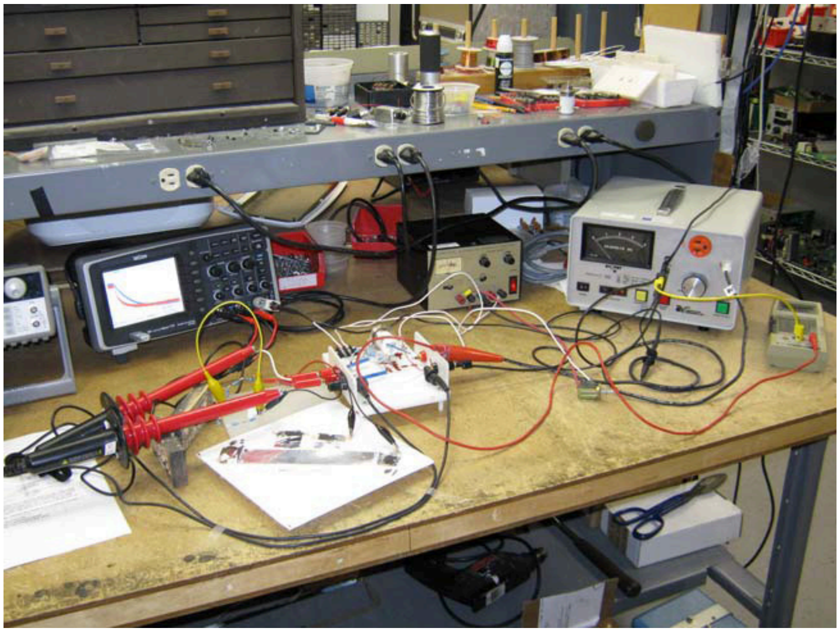
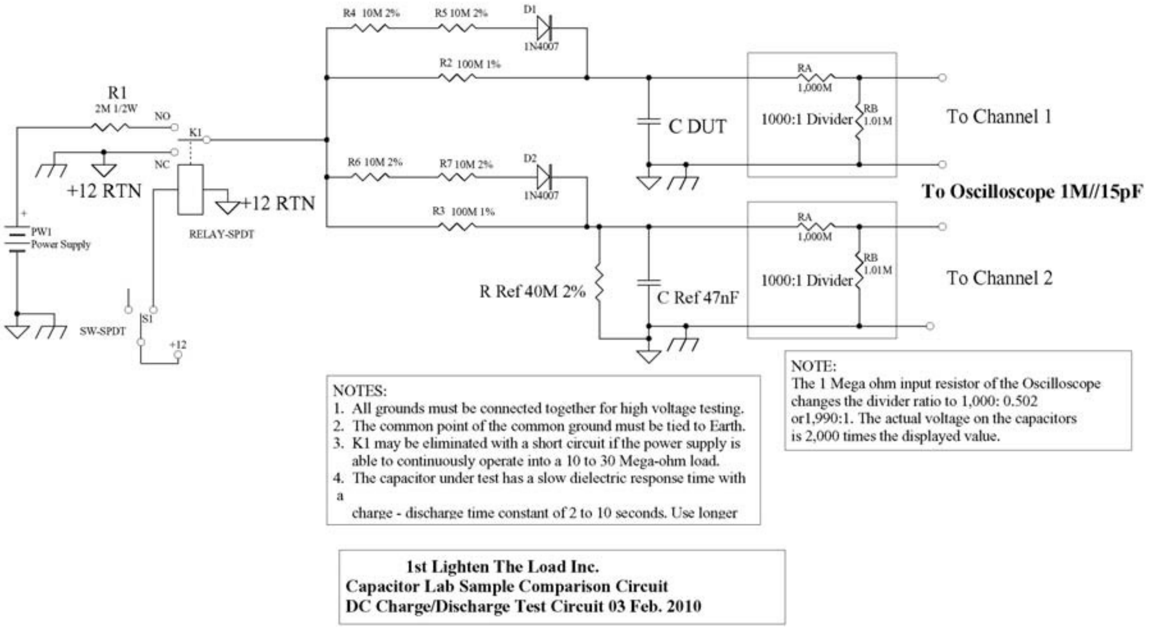


Photo 2: The entire test stand, with oscilloscope and HiPot high voltage source. The small power supply in the middle of the picture powers the discharge/charge relay.



NOTES:
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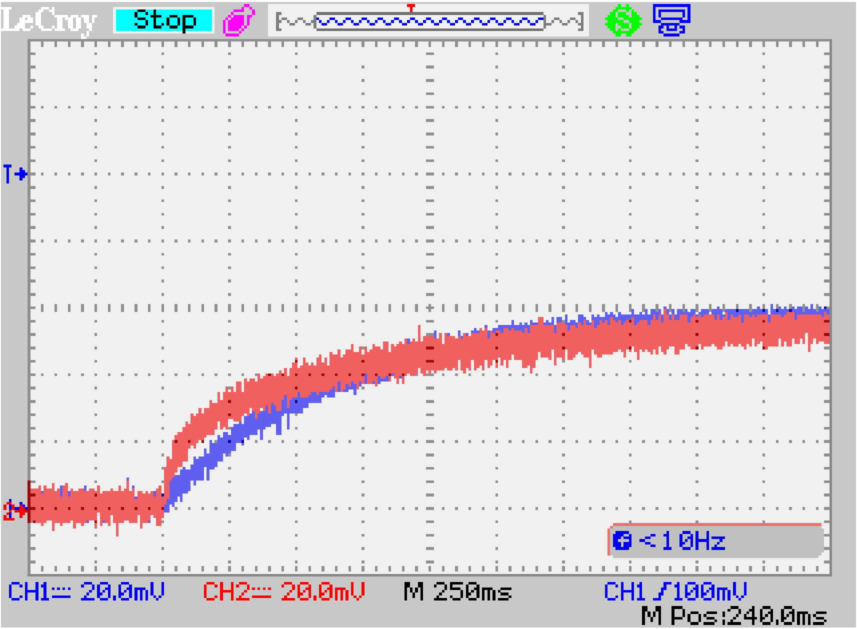
**Capacitor Lab Sample Comparison Circuit**
**DC Charge/Discharge Test Circuit 03 Feb. 2010**

Figure 1. A schematic of the test fixture.

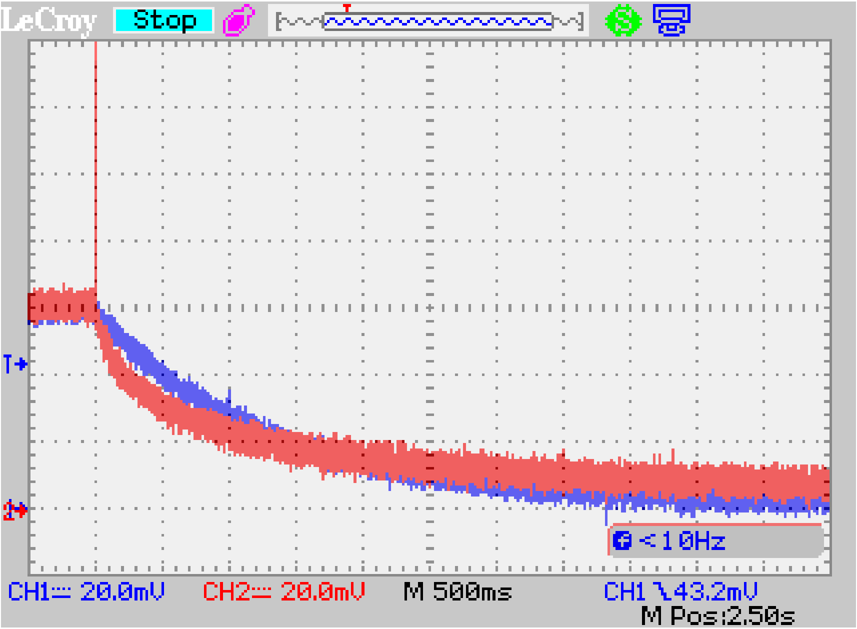
Plots 1 and 2 show the charge and discharge curves for the two capacitors at 150 Volt charge level. The separation of the two traces during the rising, charge portion of the waveform indicates that the 1st LTL sample accepts a charge more quickly than the standard part. During the discharge portion of the cycle, the standard part depletes its charge more rapidly than the 1st LTL sample does.

Plots 3 and 4, and 5 and 6 show the charge and discharge waveforms at 300 Volts and 400 Volts, respectively. The discharge waveforms clearly differentiate the standard and 1st LTL components. The latter delivers a substantial portion of its stored energy more quickly than the standard part does, but it slows the release of its entire charge, taking longer to deplete than the standard part does.

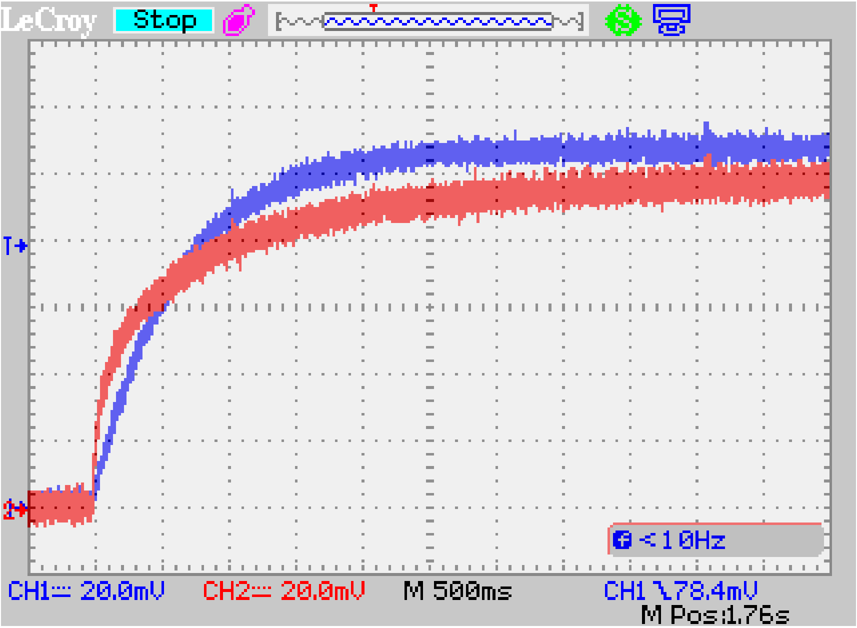
Plot 7 demonstrates more clearly than the others that leakage resistance limits the ability of the 1st LTL sample to accept a high voltage (500 Volt) charge. As the charge voltage at the capacitor rises, it reaches the point at which most of its energy is dissipated in the internal resistance of the sample, instead of being stored in the capacitor.



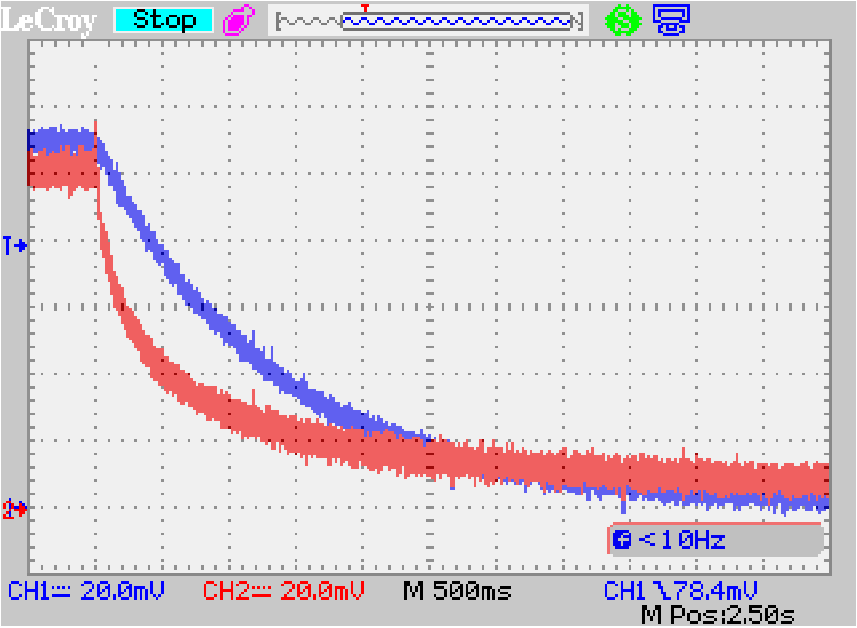
Plot 1. The charge waveform at 150 Volts. The blue trace is the reference capacitor, and the red trace is the 1st LTL sample.



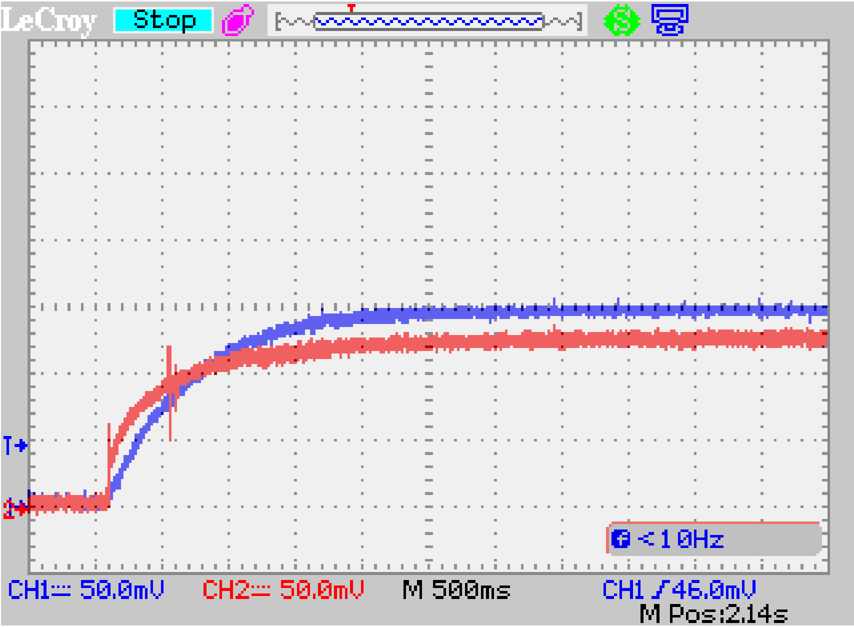
Plot 2. The discharge charge waveform at 150 Volts. The blue trace is the reference capacitor, and the red trace is the 1st LTL sample.



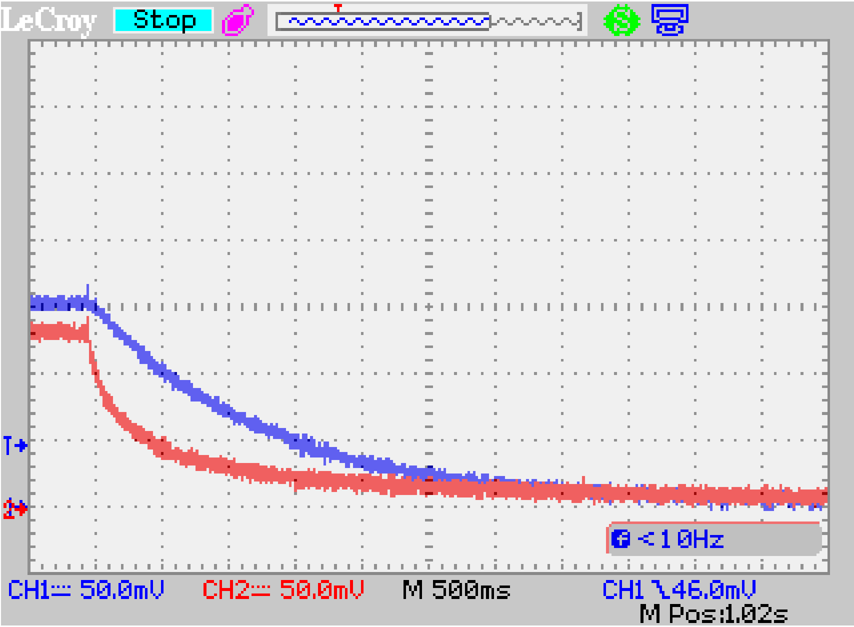
Plot 3. The charge waveform at 300 Volts. The blue trace is the reference capacitor, and the red trace is the 1st LTL sample.



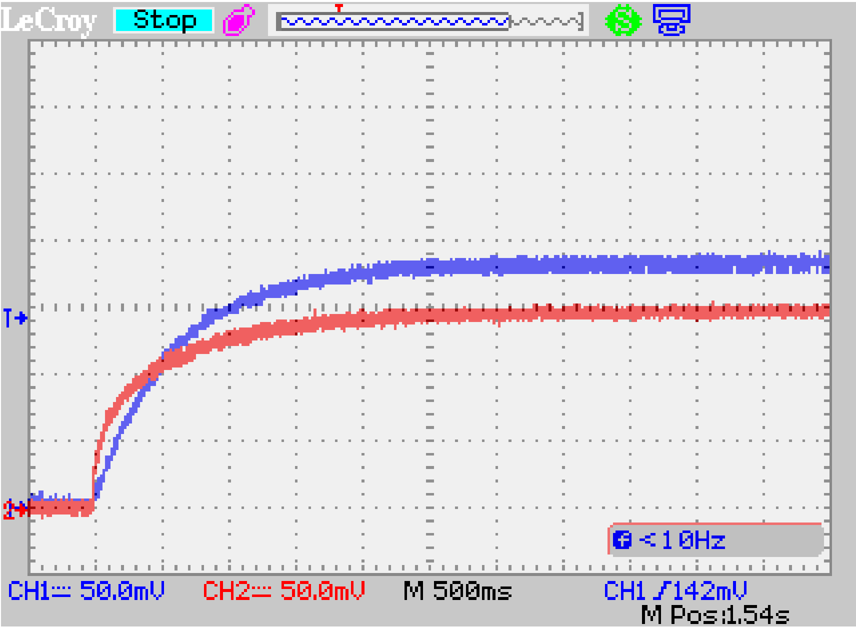
Plot 4. The discharge charge waveform at 300 Volts. The blue trace is the reference capacitor, and the red trace is the 1st LTL sample.



Plot 5.  The charge waveform at 400 Volts.  The blue trace is the reference capacitor, and the red trace is the 1st LTL sample.



Plot 6.  The discharge charge waveform at 400 Volts.  The blue trace is the reference capacitor, and the red trace is the 1st LTL sample.



Plot 7. The charge waveform at 500 Volts. Although the influence of leakage resistance in the 1st LTL sample is visible in all of the waveforms taken at 300 Volts and above, the effect is most visible at 500 Volts.

## Physical Measurements

Following the electrical tests, the 1st LTL sample was disassembled so that the dimensions of the materials could be measured. Although 1st LTL brought several pairs of samples, data from only one pair were taken. It was necessary to set several samples aside because they had been damaged by handling and by exposure to humidity in their environment.

The capacitors were constructed in pairs for these tests. Two strips aluminum foil and dielectric are positioned 19 mm apart on polyethylene substrate. A third length of aluminum foil with substrate is placed perpendicular to the first two pieces of material. Figure 2 is a sketch of the sample capacitor pair.

The width and spacing of the metalized layers are large when compared with the thickness of the materials. At the same time, the thickness of the film on which the capacitors are built varies measurably in comparison with its absolute value. Photos 3 and 4 show the sample capacitor being disassembled and measured.

Table 1 shows the data taken in the measurements. The legends in the table reflect the following measurements:

Dimension A – Thickness of the foil and backing layer common to both capacitors.
Dimension B – Thickness of the foil and backing layer in each of the capacitors.
Dimension C – Thickness of the common and capacitor-specific layers, plus the dielectric layer between them.

The thickness of the dielectric layer can be found by subtracting the thickness of the individual capacitor layers ("A" or "B") from the thickness of the entire sandwich ("C" at Cap. 1 or "C" at Cap. 2). The equation is:

Dielectric Thickness = C – [A+B]

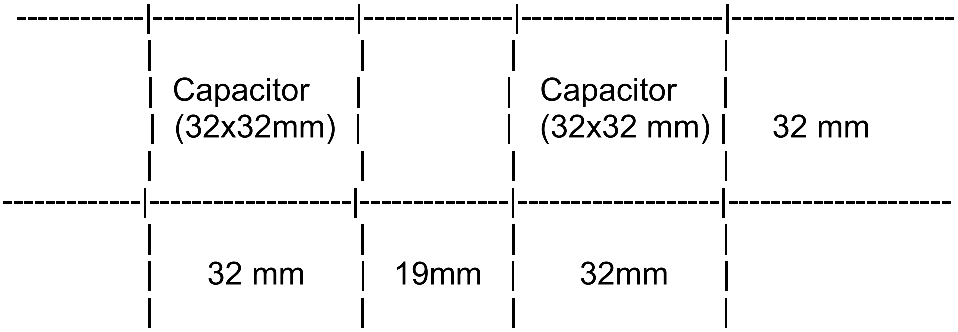


Figure 2. Layout of the capacitors on the foil strips.

| | A (Cap. 1) | B (Cap. 2) | C Total (Cap. 1) | C Total (Cap. 2) |
|---|---|---|---|---|
| | 7μm | 10μm | 153μm | 63μm |
| | 8μm | 9μm | 151μm | 74μm |
| | 8μm | 10μm | 180μm | 89μm |
| | 9μm | | 152μm | 75μm |
| | 10μm | | 128μm | 66μm |
| | 9μm | | 136μm | 88μm |
| | | | 151μm | 59μm |
| | | | 119μm | 83μm |
| | | | 123μm | 90μm |
| | | | 108μm | 88μm |
| | | | 98μm | 81μm |
| | | | 81μm | 64μm |
| | | | 80μm | 46μm |
| | | | 84μm | 77μm |
| | | | 84μm | |
| | | | 80μm | |
| | | | 110μm | |
| | | | 111μm | |
| | | | 110μm | |
| | | | 116μm | |
| Mean Thickness: | 8.5μm | 9.7μm | 118μm | 70μm |

Table 1. Measurements of foil and backing layer materials. The mean thickness of each layer pair is given on the bottom row of the table.

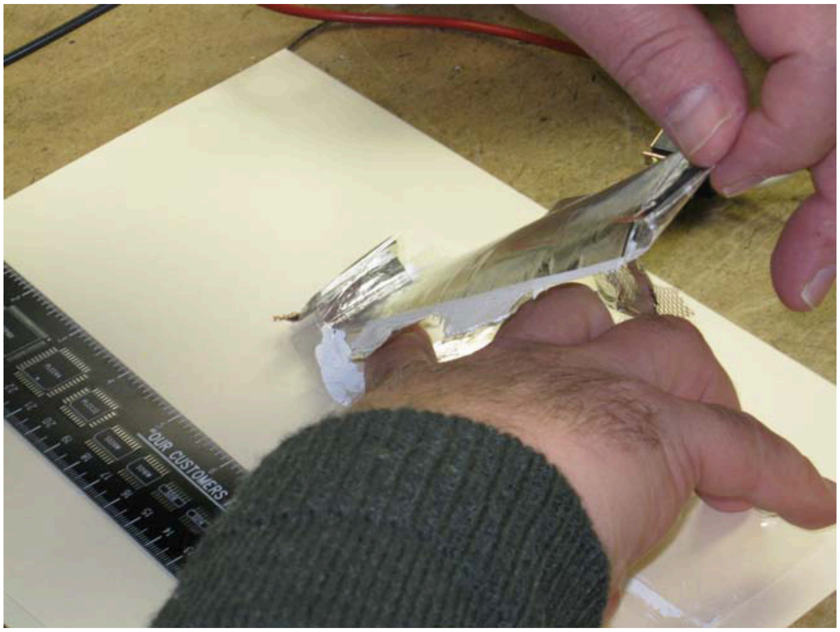


Photo 3. Disassembling the 1st LTL sample capacitors.

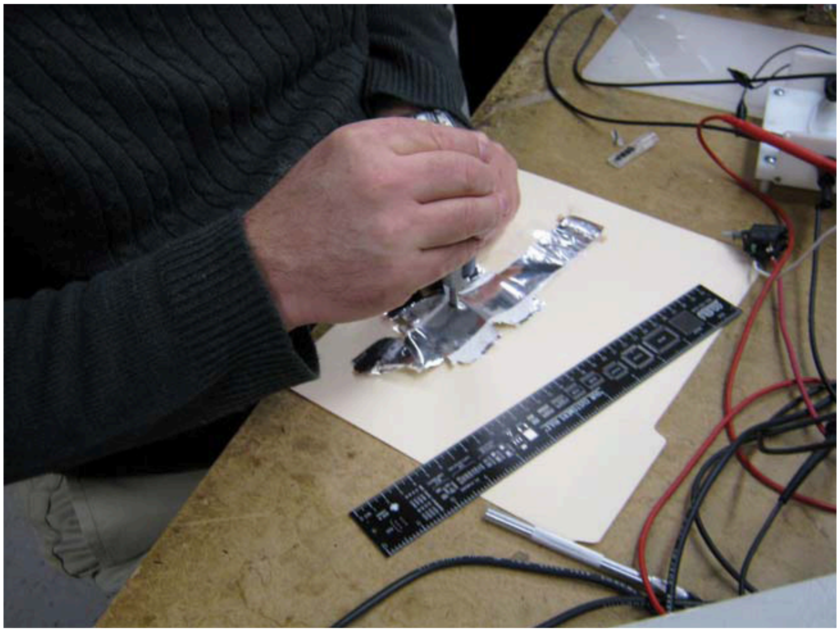


Photo 4.  Measuring the thickness of the foil and substrate materials.

* * *

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February 5, 2010