Just How *Good* is SB Electronics' Patented Pulse Capacitor?

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It is often said: "The proof of the pudding is in the eating"! How true it is in this case.

The SB Electronics' Patented Pulse Film Capacitor technology (U.S. Patent #7,008,838) has allowed for a fascinating improvement in the pulse performance of metallized capacitors.

For years the gold standard for pulse film capacitor design has been film/foil construction. However, film/foil capacitors have two significant drawbacks. The first is size, and the second is the lack of self-healing capabilities. Metallized capacitors hold the answer to solving these two problems.

The use of metallized capacitors in pulse applications has been a delicate balance of dielectric thickness, body length and resulting edge current capability. Voltage stress often dictates the dielectric thickness, but beyond that the capacitor designer must balance edge current density against packaging requirements. When this occurs, size and lead spacing requirements may not meet the designer's needs. In conventional metallized capacitor designs the user has imposed peak current limits such that a catastrophic disconnection can occur if the limits are exceeded. Sometimes this disconnect is called "unzipping", and can actually be seen visually at the capacitor ends in a darkened room. When this occurs the capacitor virtually goes open circuit with very little capacitance left, and quite high internal ESR or losses. The only solution is a costly field replacement. Sometimes this type of failure does not occur right away. The capacitor might function for a short time but fails dramatically once the "unzipping" has been initiated.

How do you evaluate and compare pulse capacitor design, construction and performance of various vendors? Specifications list dV/dt and/or peak current ratings that give some feeling of adequacy but do little to tell you how "hard the capacitor can be pushed" and still continue working.

Enter the Step-Stress Discharge Test

An extremely rugged test to differentiate one capacitor type from another is the step-stress discharge test. In this test the capacitor is charged to an initial voltage and discharged to a dead short. As an example, this can be accomplished by placing a solid copper bar across the terminals in the shortest lead configuration to ensure the lowest resistance and inductance possible. Such a discharge results in extremely high peak currents (many thousands of amps for each discharge), and provides a jarring test of the termination scheme. The voltage is then incremented and the process repeated. The capacitance and loss factor are measured initially, and after each pulse. The change in capacitance value is examined to look for a start toward open circuit. When the capacitance change crosses some limit, the voltage per pulse is held constant and the capacitor is pulsed repeatedly at that value until a total loss of capacitance occurs or some other criteria limit is reached.

Keep in mind that the energy content (in Joules) of the charged capacitor is equal to ½ the capacitance value times the voltage squared. Thus, the energy being discharged for each increment rises rapidly and the peak current in amps with it!

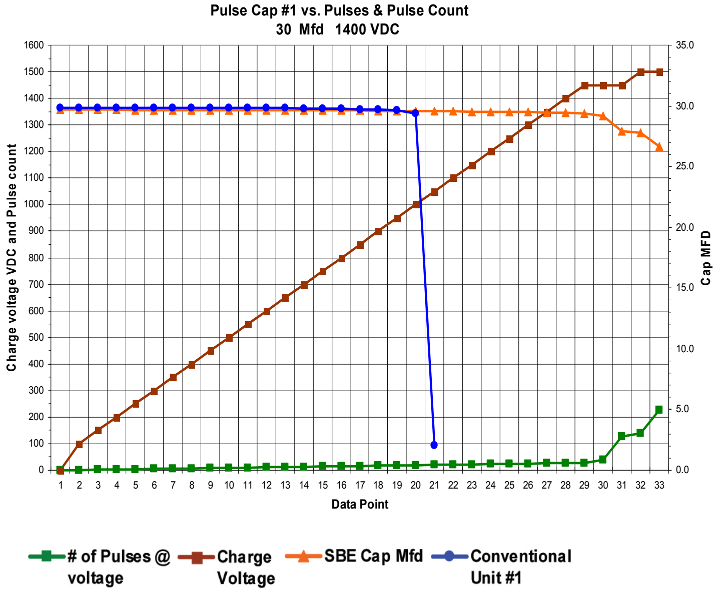
In the test program described here two sets of two different capacitor values of a very high quality, conventionally constructed pulse capacitor using metallized polypropylene from one of the leading suppliers of pulse film capacitors, and two corresponding units using the SB Electronics' Patented Pulse Technology metallized polypropylene construction were compared. Two ratings, 40 µF at 1000

VDC and 30 µF at 1400 VDC were compared. For this test data was recorded at 1000 Hz for capacitance and dissipation factor initially, and after each pulse, while the voltage was incremented.

Charge voltages began at 100 VDC and incremented 50 VDC per step. When the capacitors reached a 1% capacitance loss or the D.F. exceeded 1%, the voltage was then held and the pulsing continued for another 10 cycles, and the capacitance and D.F. measurements were repeated. If the capacitance value drop was less than 10% and the D.F. was less than 10%, then the pulsing was continued for an additional 90 pulses and the capacitance and D.F. measurements were repeated. If the capacitance value drop was still less than 10% and the D.F. was still less than 10%, then the voltage was incremented 50 VDC and the 10 & 90 pulse sequence repeated. This continued until the capacitance loss limit or D.F. limit was exceeded. At that point the test was terminated.

Actual Part Performance of Group 1, 30 µF at 1400 VDC

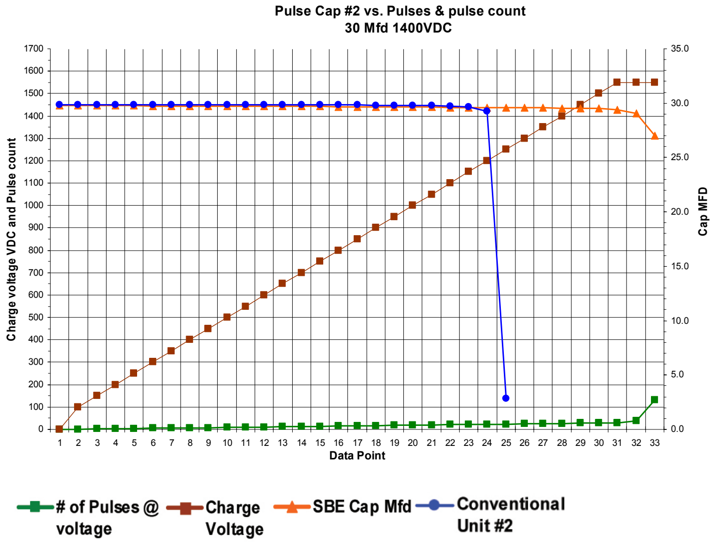
Two sets of units were tested. The first set of 30 µF/1400 VDC capacitors behaved as shown in the following chart:



Analysis of data

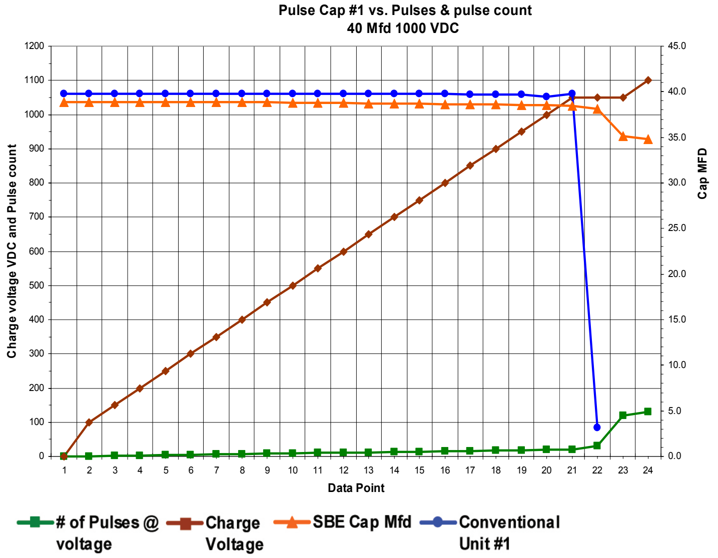
The conventional unit and the SBE patented pulse unit behaved roughly the same for first 20 data points. At that point the conventional unit's capacitance change exceeded 1%, so it was pulsed 10 times at that voltage. At data point 22 the conventional part fell to about 2 µF and was considered a failure. Meanwhile, the SBE patented unit continued on to data point 29 when it finally dropped 1%. After 10 more pulses, and 90 more pulses, it was still viable. The voltage was incremented 50 VDC and the process repeated. After another cycle of 10 and 90 pulses, the cap loss finally exceeded 10% but the bulk of the capacitance was still available for duty. This demonstrates the rugged response of the SBE pulse capacitor to such vicious discharge duty!

The second set of 30 µF/1400 VDC units were tested and the following chart shows the performance of these units. Note the behavior was much the same.



Actual Part Performance of Group 2, 40 µF at 1000 VDC

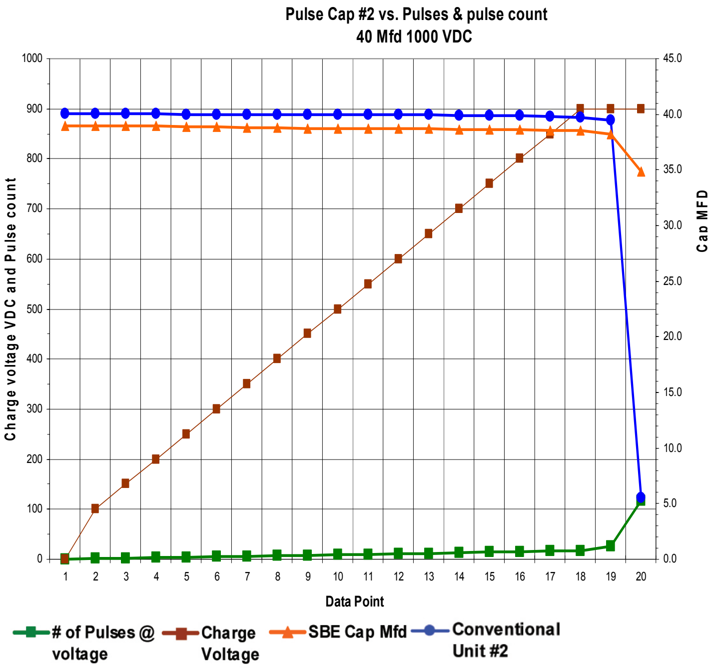
The second group of capacitors was rated at 40 µF/1000 VDC. Again 2 sets of samples were tested and compared. The resulting data for the first set of 40 µF/1000 VDC units is shown in the chart below:



Analysis of data

The behavior of the parts in this second group was similar to the first. At data point 20 the conventional capacitor sample exceeded the 1% capacitance loss limit, was pulsed an additional 10 pulses and fell to a very low value. Meanwhile, the SBE pulse cap also changed more than 1% at data point 20 but went on for the additional 10 & 90 pulses before finally exceeding the 10% capacitance drop limit. However, once again the final cap value was still high and the capacitor remained useful.

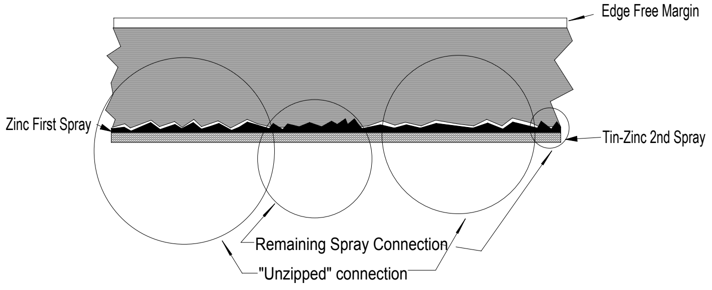
The second set of 40 µF/1000 VDC units were tested and the following chart shows the performance of these units. Note the behavior was much the same.



The value of the conventional cap changed greater than 1% at data point 18 and was pulsed 10 more pulses and fell to a very low value at that point. The SBE pulse capacitor changed 1% at data point 17, was pulsed 10 times and 90 times at that voltage before dropping below 10% change but still had most of its capacitance left.

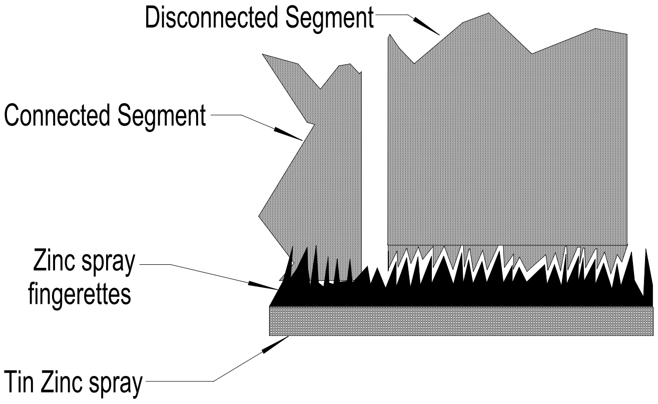
What Caused the Failures?

Examining the failed conventional parts revealed that the electrode-to-spray interface along the connecting edge became disconnected in large areas. This is often called “unzipping” and is best shown by the following diagram:



Under conditions of high impulse current, the concentrations of current at the Zinc “Fingers” that impinge on the metallized layer exceed the ability of the connection to pass current. Consequently, the weaker area, the metallization, vaporizes much the same as if a fault and “self healing” had occurred. Subsequently for the next pulse, the current concentration is higher because of the reduced interconnection. Thus another connection fails and the connection proceeds toward an open circuit with each pulse. The resulting capacitor electrode has limited connectivity and the current flowing must flow in the machine direction until an outward connection point is found. This results in increasing loss, and the capacitor’s DF and ESR rises as the part proceeds toward open circuit. Finally, most all of the energy stored is dissipated along the electrode. The actual capacitance value still exists, but most measurement bridges cannot resolve readings with such high loss factors and the capacitor measures a very low value. This is strictly an academic point as the capacitor is useless for its intended purpose.

The SBE patented segmented electrode construction behaves differently. The following diagram shows what happens to this construction:



Here we see that since each electrode is independent the capacitor electrically looks like a very large number of smaller capacitors in parallel. If a fault should occur in just one segment, then that segment alone is disconnected. The current from the rest of the capacitor **does not** flow along the electrode seeking a connection path. Consequently, the capacitance for that segment is lost and thus a slight decrease in capacitance value is noticed, but the balance is still available and functions normally. Since the segments are quite small the loss of one does not impact total value much. This phenomenon has been verified many times.

Conclusion

This test series showed the value of the SBE pulse capacitor design. It largely survived this brutal test with most of its usable capacitance left while the conventional part essentially failed open circuit dropping to a very low unusable value. This test data should give the designer confidence that the SBE part can be "pushed" beyond its ratings with only the possibility of a "soft failure" (i.e. moderate capacitance loss). This rating extension can be intentional or unforeseen system surges that really "hammer" the capacitor. On the other hand, such "pushing" may result in a catastrophic failure of a conventionally-constructed part.

Indeed, the proof is in the pudding and it is pretty good!

Ted Von Kampen, Senior Application Design Engineer with SBE Inc., graduated with a BSEE in 1964 from the University of Nebraska. He has been employed in the capacitor industry since 1966 and has worked for several capacitor companies including, TRW capacitors, American Shizuki capacitors, Industrial Midwec Capacitors, Arcotronics and SBE. He has written several papers and application notes over the years and presented papers at several industry conferences.

Additional Technical Papers of Interest:

"Improvements in Pulse Capacitor Technology"
by Ted Von Kampen

"Thermal Considerations Regarding the Use of the Power Ring in High Ripple Current Applications"
by Terry Hosking

"Power Ring Optimized for Short Pulse Power"
by Terry Hosking and Michael Brubaker

"Power Ring for Embedded E-Drive Applications"
by Terry Hosking

"An Extremely Low ESR and ESL Annular Film Capacitor" by Terry Hosking and Michael Brubaker

"Annular Form Factor Capacitors"
by Terry Hosking

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