2007 IEEE PPPS Conference

June 19, 2007

Albuquerque, New Mexico USA

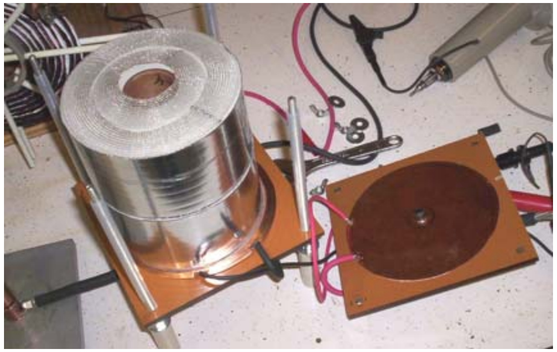
Stacked Annular Form Factor Film Capacitors for High Voltage and High Current Applications

Authors:

T.A. Hosking, SBE Inc.

M.A. Brubaker,

Consulting Engineer



Presented by:

Terry Hosking

V.P. Engineering

SBE Inc.

Power Ring Division

2005 PPPS Review

- 2005 Paper "*Annular Form Factor Film Capacitors*"
- Tests performed at 50KAmps & 130KAmps
- Low voltage testing for end connection integrity of Metallized Film capacitors
- March 2006 SBE issued patent for Pulse Film Technology, US Patent # 7,008,838

Annular Capacitor for Higher Voltage Applications

- Empirical determination that the voltage for single annular capacitor should be ~100 Volts/mm of capacitor thickness
- Higher voltage by series connection
- Simplest way is to stack them like pancakes
- Connection without terminals is simplest and most space efficient
  - Fixed or pressure connections possible

Stacking Annular Capacitors for High Voltage

- Consider the case for pressure connections
  - Interconnect accomplished with knitted wire mesh "gasket"
- Possible advantages of a "stacked" metallized film capacitor configuration
  - Higher energy density than foil designs
  - Lighter weight than conventional oil impregnated designs
  - Low cost opportunity due to terminal simplicity

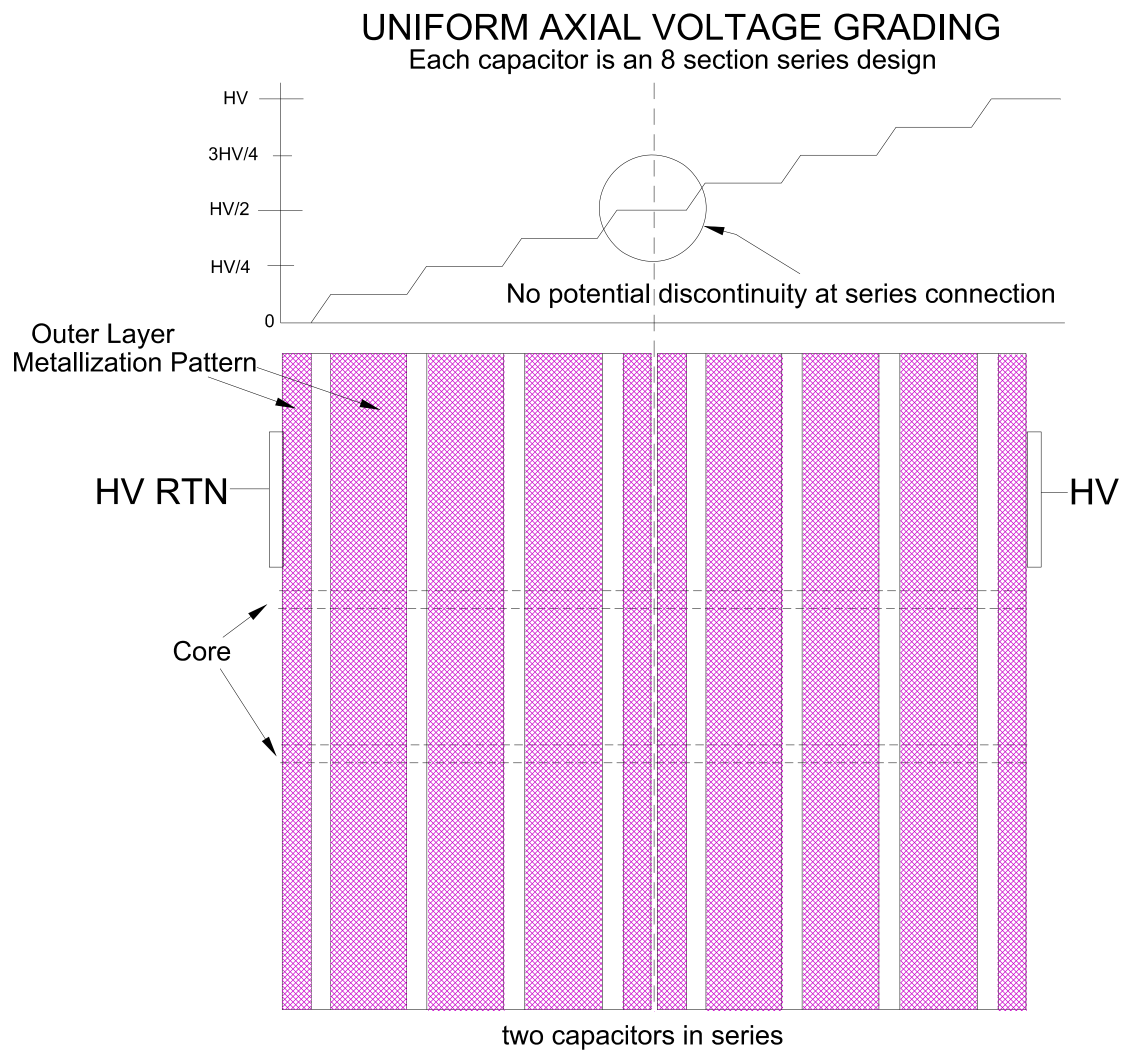
Advantages

- Modularity
- Common capacitor building block
- Capacitance/voltage tailored to application by adjusting number of blocks used
- Capacitor blocks separately replaceable

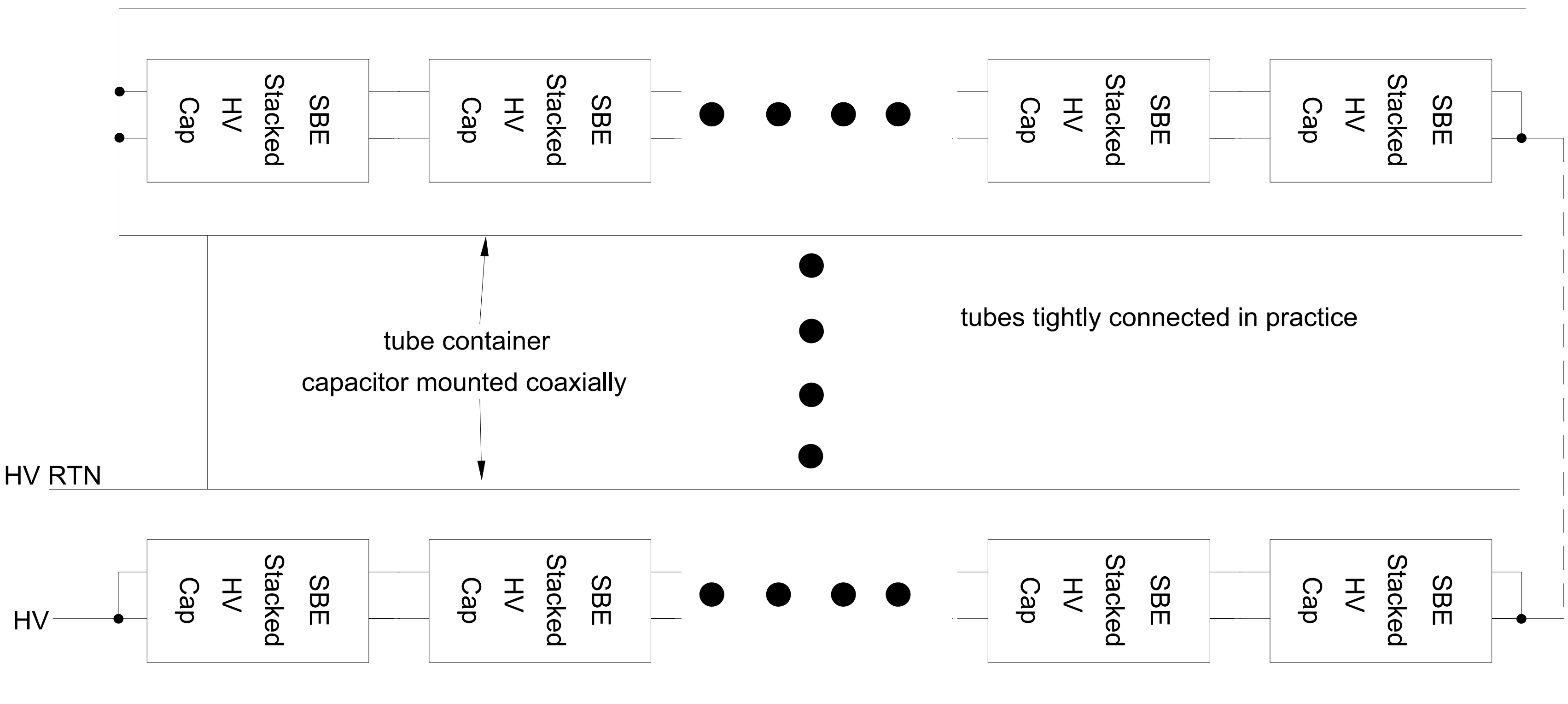
Advantages
(cont'd)

- Stacked coaxial geometry allows for low ESL
- Round capacitor reduces radial voltage gradient
- Uniform axial voltage grading
- Consider an 8 series-section capacitor

Series-Section Capacitor Design

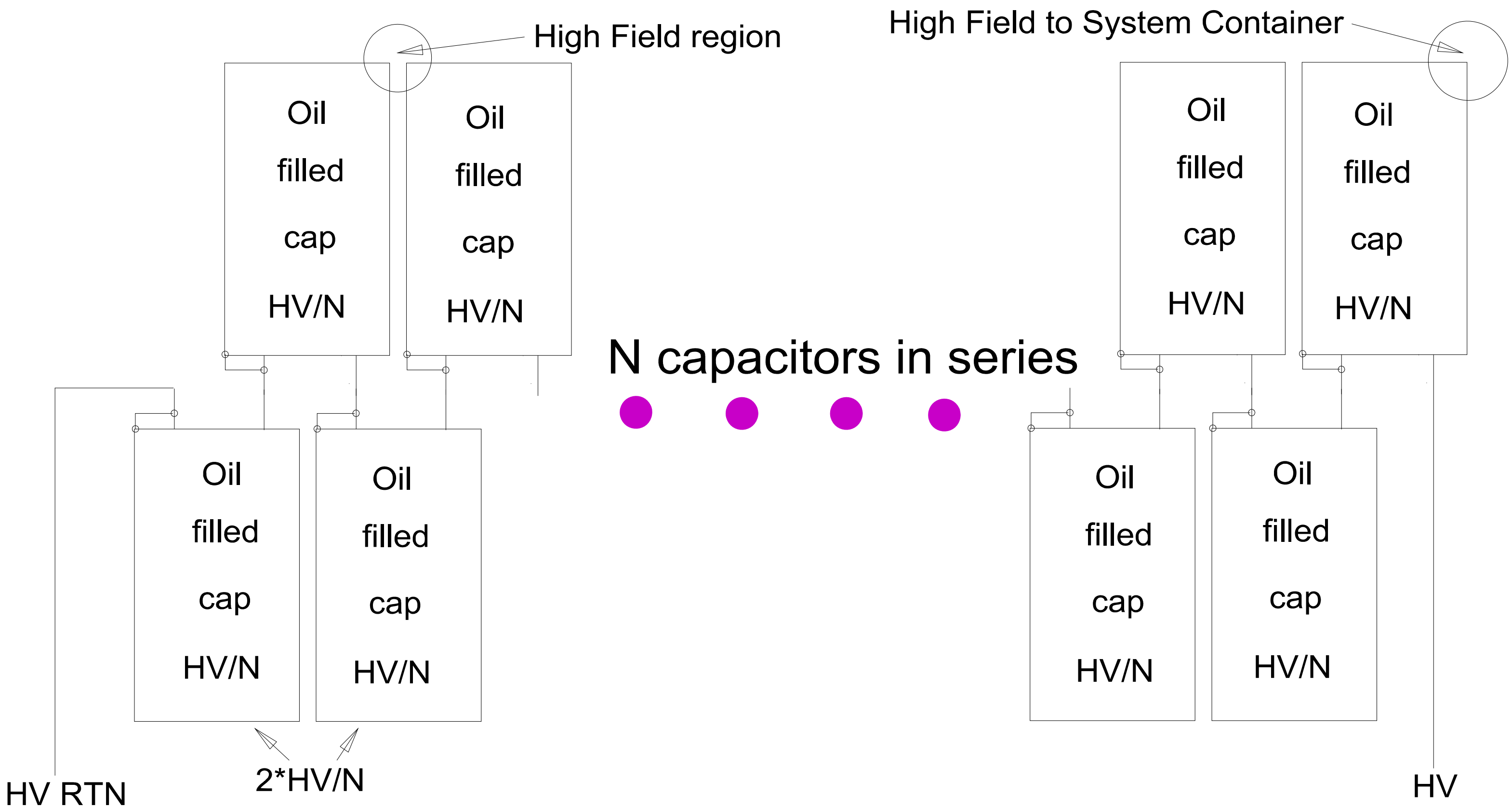


Advantages of Stacking Annular Capacitors



- Uniform axial voltage grading along the stack
- Round geometry reduces radial potential gradient
- Coaxial geometry reduces ESL

Traditional Series Connection



- Schematic showing series string of traditional “oil-filled” caps
- Arranged to minimize ESL

Testing

- Test Conditions
  - Large Voltage Swings and Peak Currents
  - Extreme, and Multiple, Reversals
- Examination of the use of knitted wire mesh for interconnection

Capacitor Design

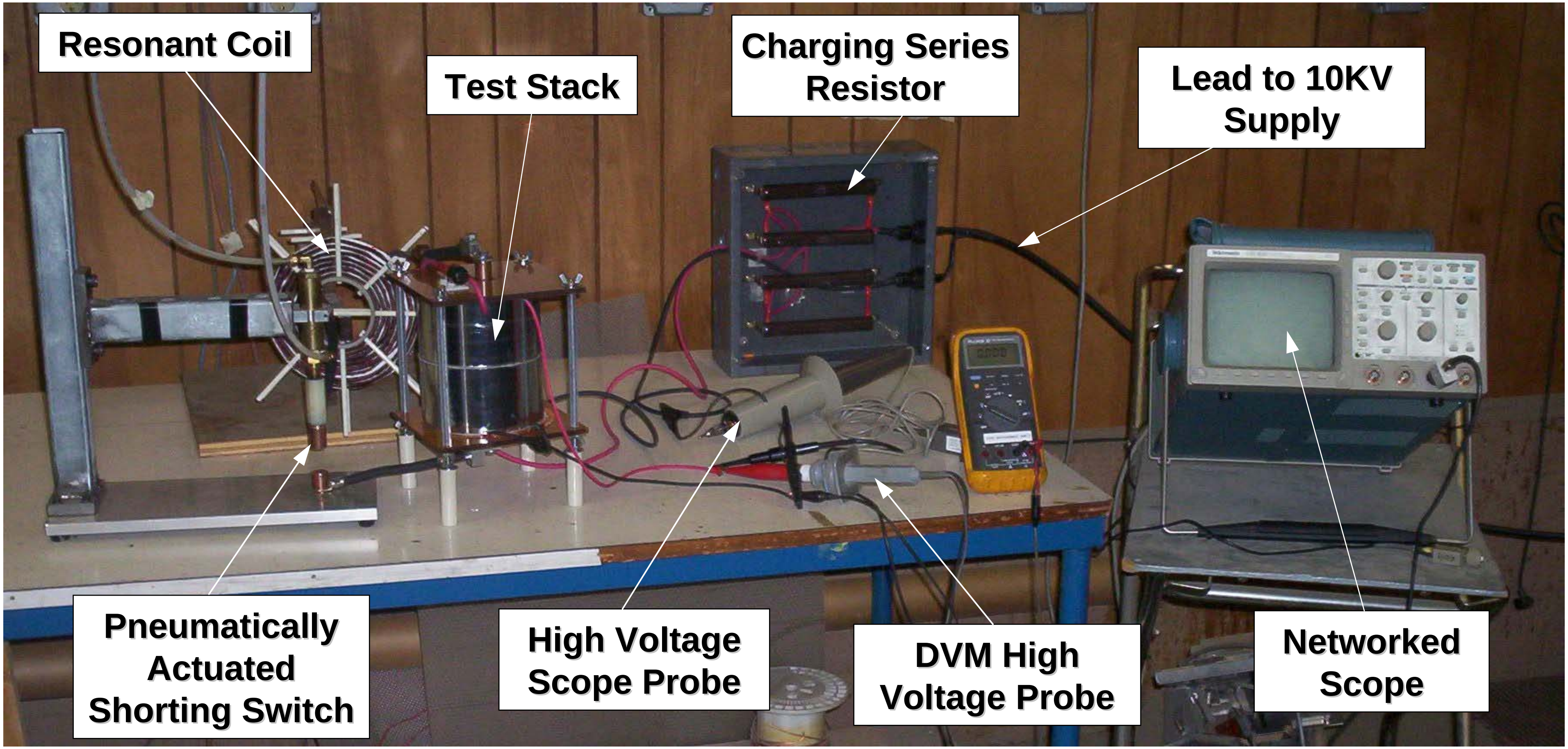
- Two of the following units were used in building the High Voltage stack
  - 8 series-section, Metallized Polypropylene film design
  - Wound on hollow phenolic core with 1.5”/38mm I.D.
  - 7.5µF, ±10%
  - 8 KVDC rating
  - 5.6”/142mm O.D
  - 3.0”/76mm Axial Length

- Resulting stack
  - 3.75µF rated at 16 KVDC

Interconnect

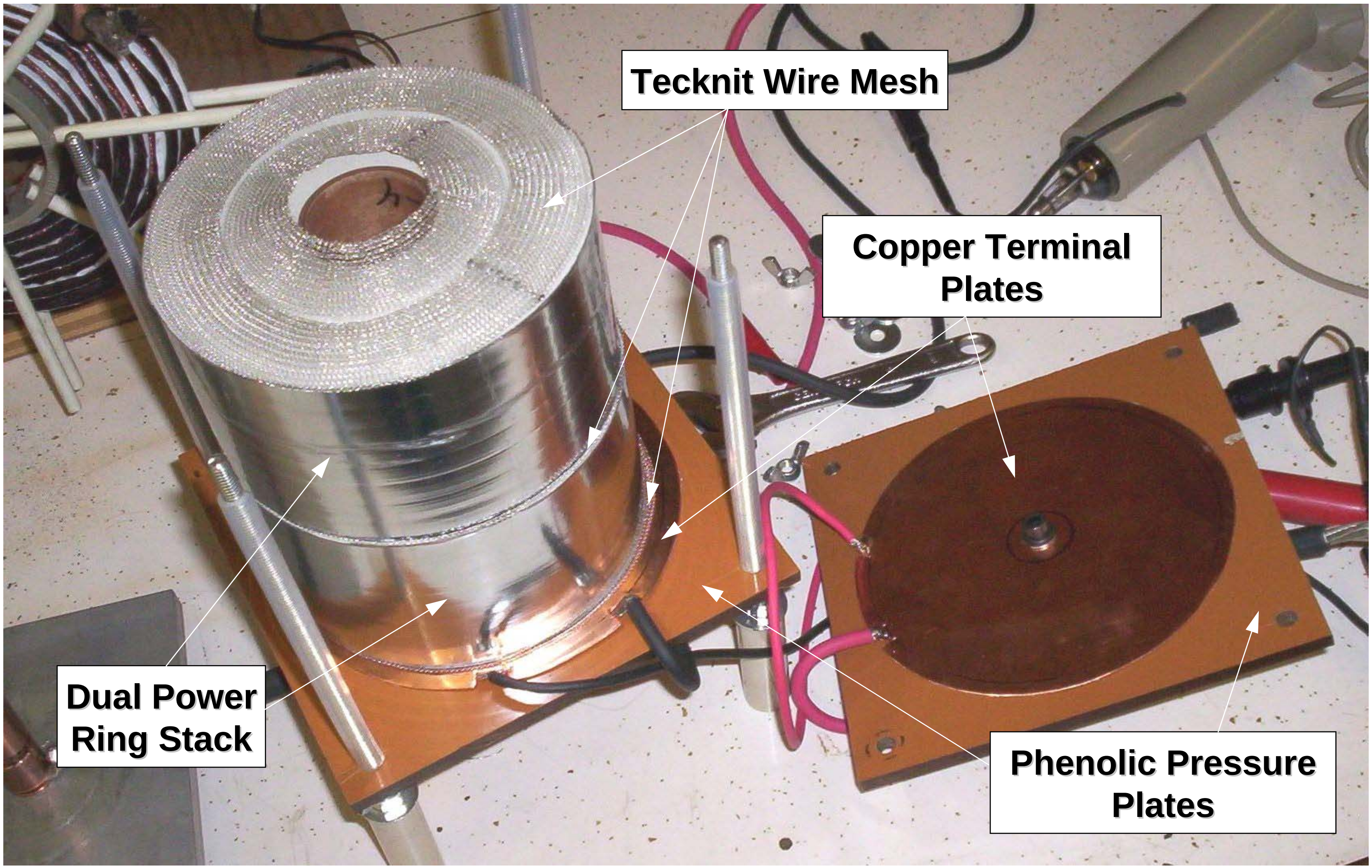
- Tecknit knitted wire mesh used between the 2 capacitor stacked sections, and on each end face of the stack to contact to copper terminal plates
  - Tecknit part # 23-502
  - Tin coated copper-clad steel (0.0045”):
    - ⇨Steel core, 57% by weight
    - ⇨Copper cladding, 40% by weight
    - ⇨Tin coating, 3% by weight

Test Setup

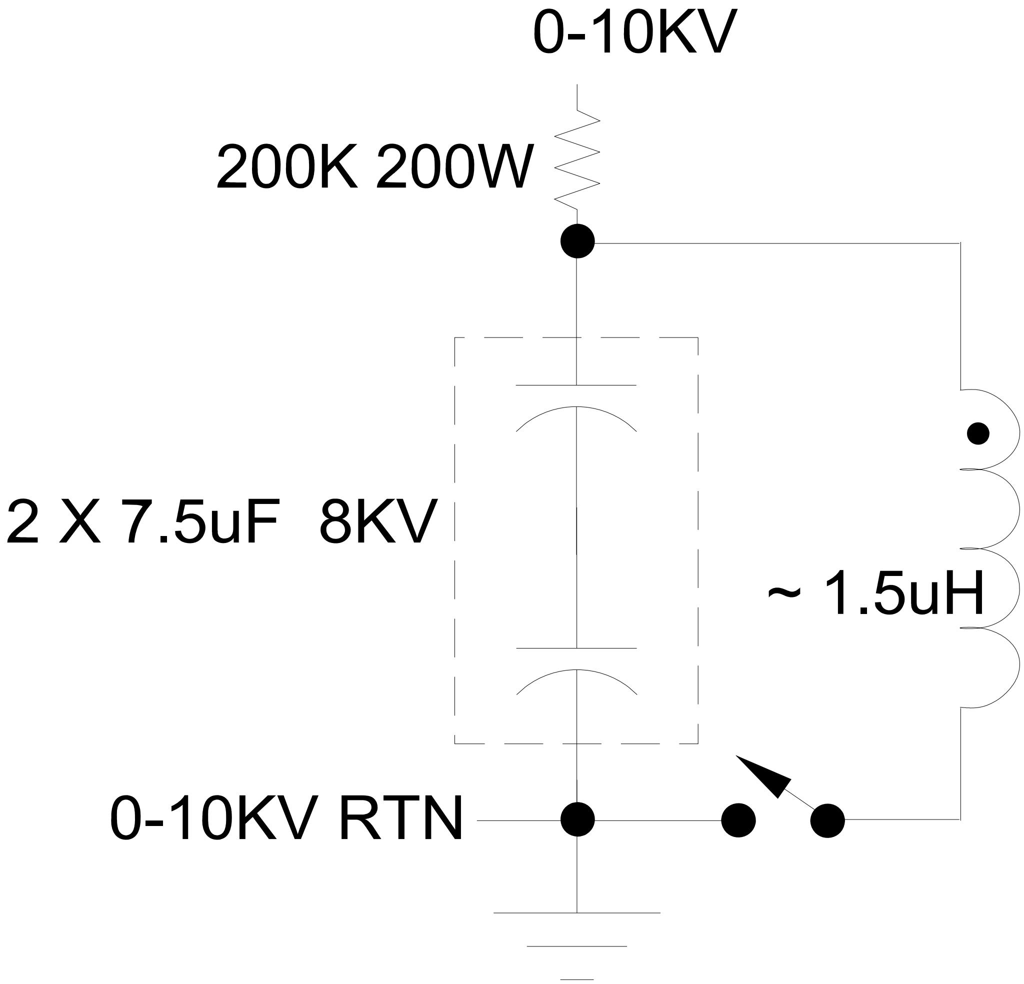

Resonant Coil
Test Stack
Charging Series Resistor
Lead to 10KV Supply
Pneumatically Actuated Shorting Switch
High Voltage Scope Probe
DVM High Voltage Probe
Networked Scope

Assembled Test Stack in Fixture

Test Stack

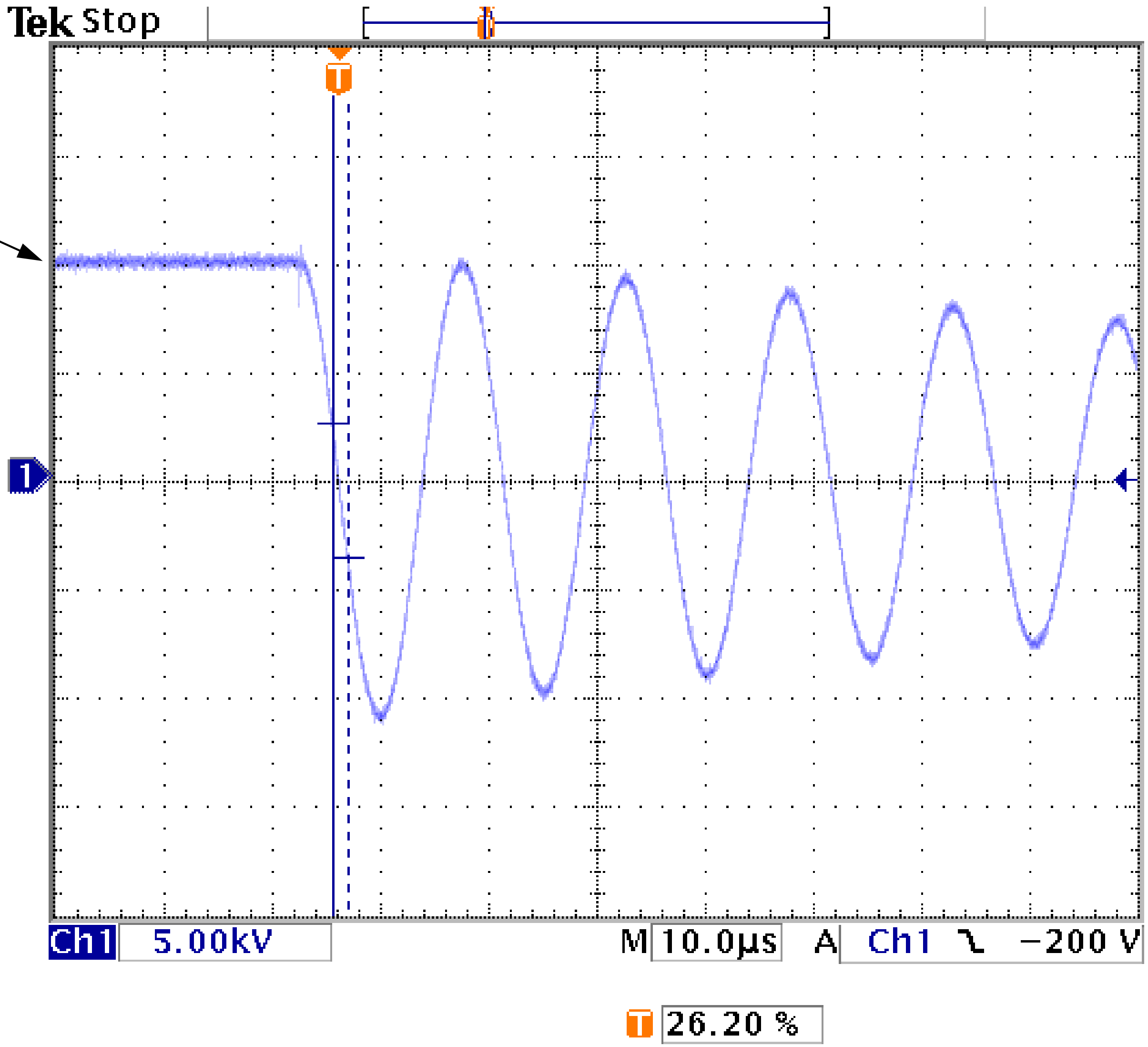

Tecknit Wire Mesh
Copper Terminal Plates
Dual Power Ring Stack
Phenolic Pressure Plates

Test Schematic



Test Waveform

10KV

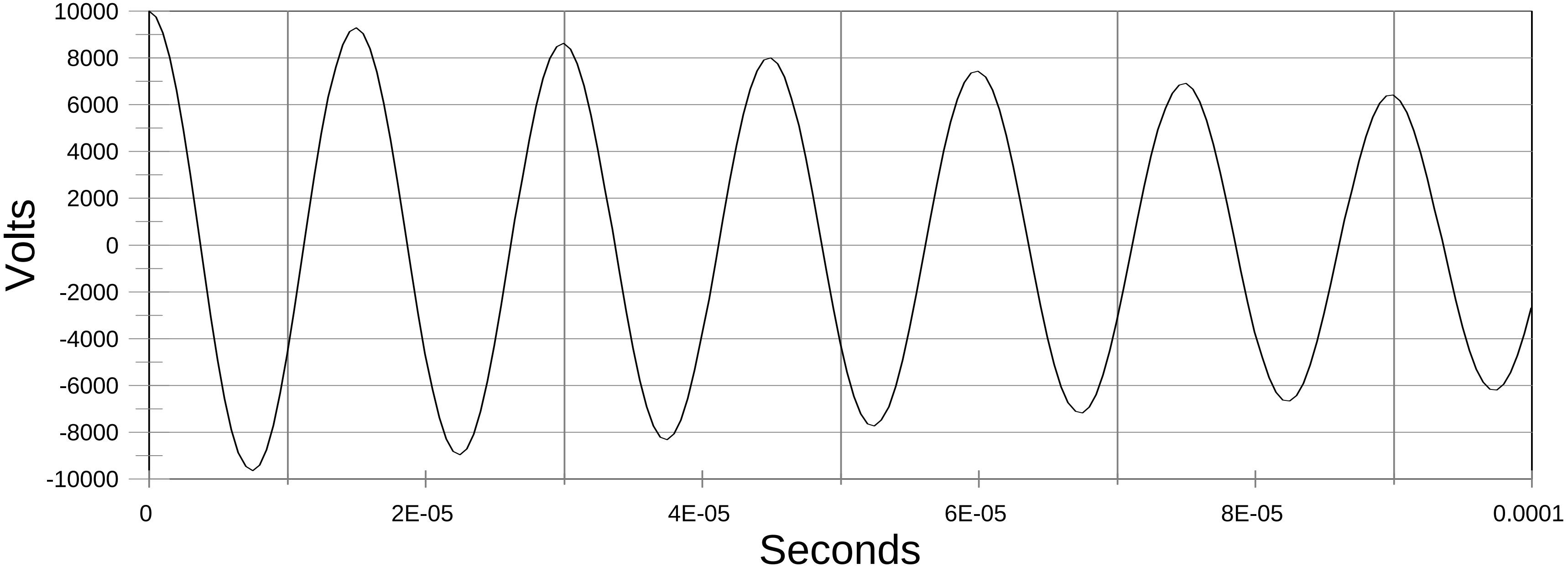


Test Waveform Description

- Every discharge results in multiple high current pulses, not just one as for typical applications
- Multiple, severe reversals
- All transitions >12 KV Peak-to-Peak result in corona damage
- Waveform indicating more than 100% reversal is an artifact of the High Voltage probe’s frequency response

Theoretical Waveform

Calculated Response
of test system when discharged



R = 15 milliohms, L = 1.53 μH, C = 3.71 μF
Calculation time step = 500 nanoseconds

Test Procedure, Results & Observations

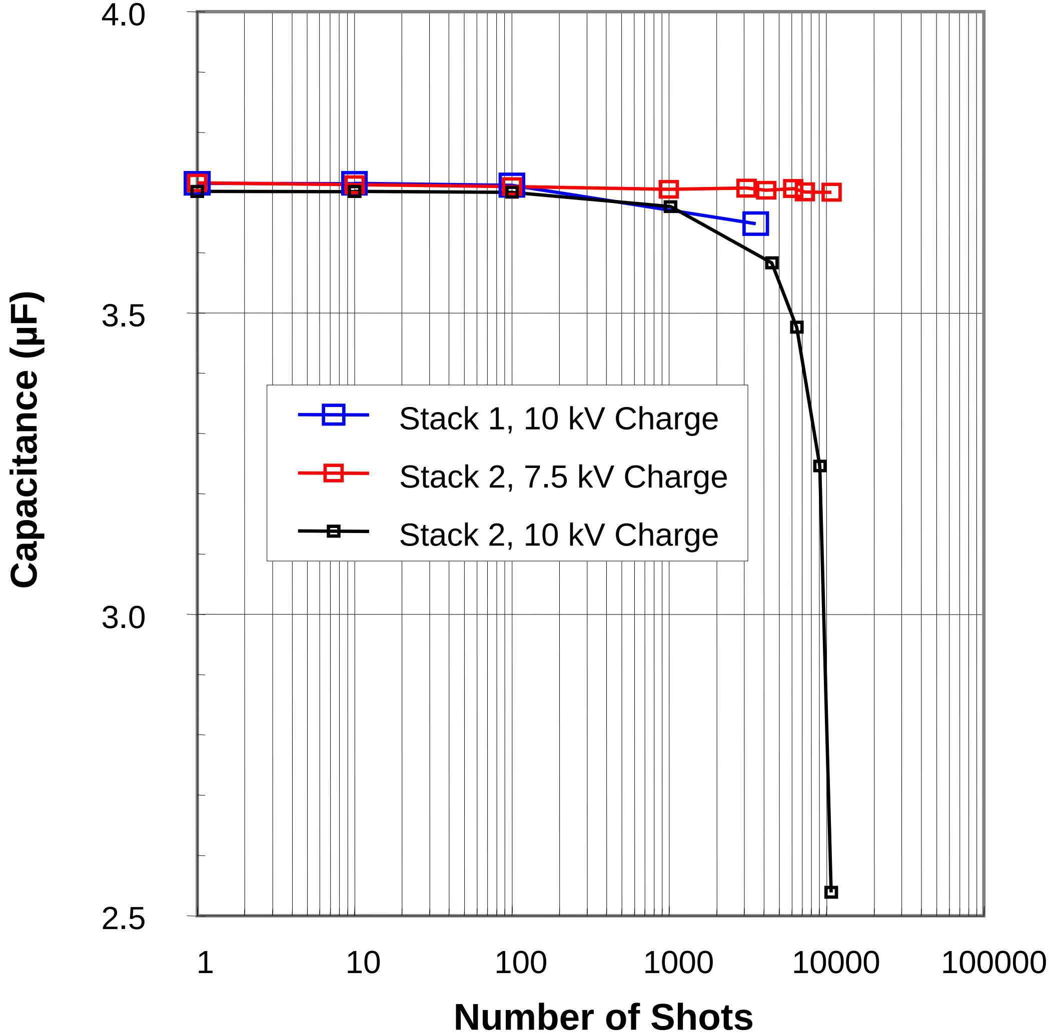
- Two capacitor stacks were assembled (Stack 1, Stack 2)
- 3 total tests were conducted

- Test 1, Stack 1
- Charge to 10KV
- After 3,000 discharges at 16.6KAmps
  - Cap loss less than 2%, initial cap 3.715µF
  - Gasket weakly welded to end spray surface in multiple locations

Test Procedure, Results & Observations

- Test 2: Stack 2 charged to 7.5KV, after 10,000 discharges at 12.2KAmps
  - Cap loss less than 1%, initial cap 3.70µF
  - No visible mechanical issues
- Test 3: Stack 2 charged to 10KV, after an additional 10,000 discharges at 16.6KAmps
  - Cap loss of 46% observed after the total of 20,000 discharges
  - Severe degradation of the end spray was apparent on the top capacitor section
  - An additional 3,000 discharges led to the failure of the top capacitor element in the stack

Capacitor Test Results

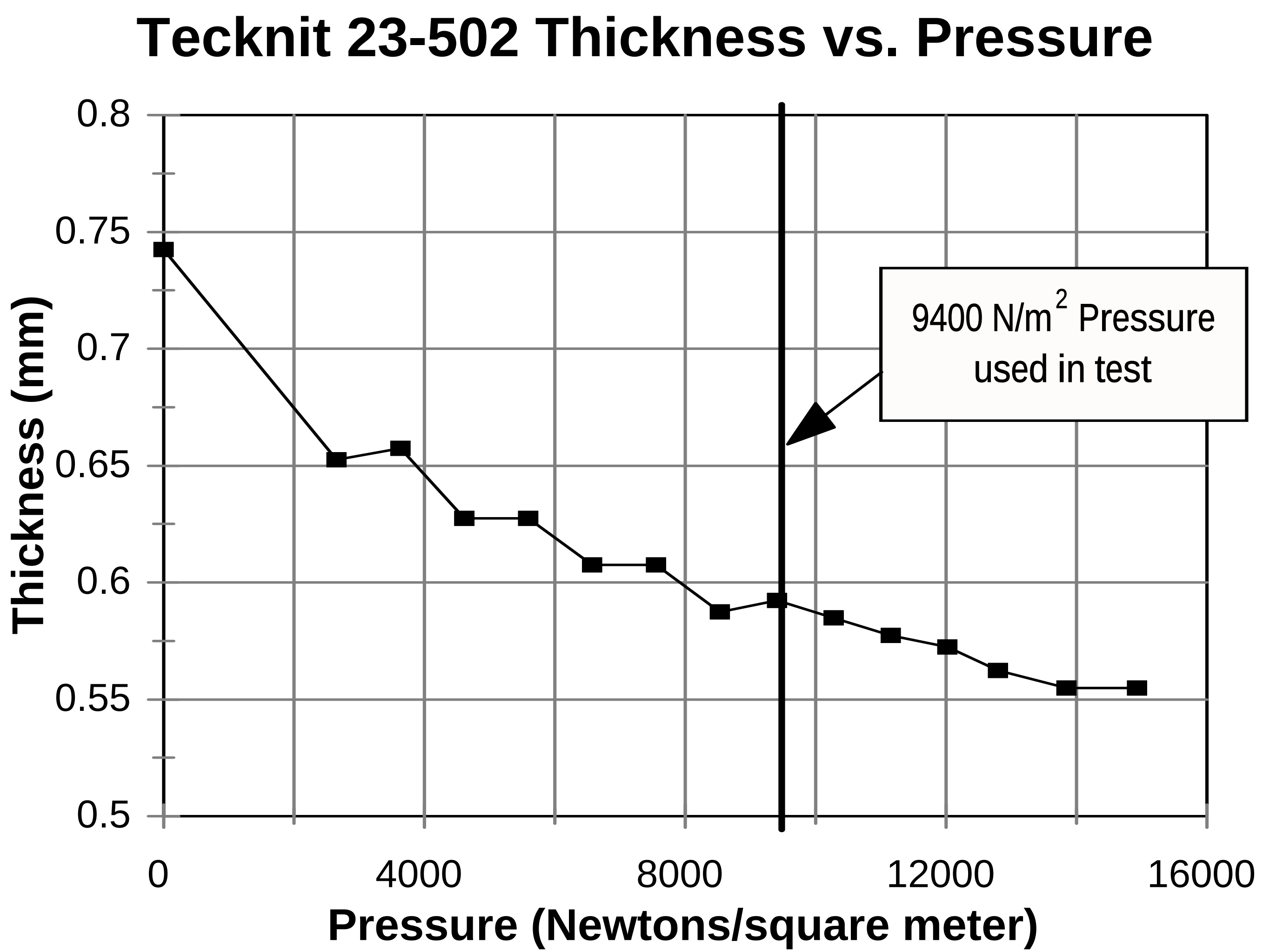


Interconnect Test

- Determine pressure on Tecknit as used in the capacitor test
  - Measure height of top plate of assembled fixture as tested
  - Release fixture pressure, add weight on top plate to duplicate same height of assembly
  - Figure the force per unit area on mesh

- Separate crush test performed to determine thickness vs. pressure behavior of a single layer of knitted wire mesh
  - 2” x 2” steel plates to sandwich Tecknit mesh
  - Plot thickness vs. pressure as force increases

Interconnect Test Results
Force vs. Crush



Interconnect Implications

- Compliance of mesh
  - Mesh made in tubular shape, then crushed flat
  - Easy to crush to about 4x the wire thickness
  - Each layer has about 0.29mm compliance
- Effect on stack
  - Non-uniform pressure results in smaller contact areas
  - Need a more rigid plate to distribute pressure
  - Capacitor end spray surface flatness is important
  - Capacitor could withstand 5x more force than was used during the test if spread uniformly across the capacitor conducting surfaces

Summary

- Brutal test, designed to determine failure modes
  - No energy transfer from cap to a “load” for this test
  - No-one would use the capacitor in this manner
- Graceful failure mode, gradual capacitance loss
- Offers perfectly symmetric voltage grading at the system level
- Ability to replace a single capacitor element, rather than an entire assembly

Conclusion

- The modular coaxial stacked concept may offer advantages for pulse power applications
- Preliminary test results are very encouraging
- Future work to be done regarding the interconnect system

Thank you!

Please see us in Booth 411

www.SBElectronics.com

SBE