



High Performance Integrated DC Link Capacitor/Bus Structures and AC Filter Capacitors



PCIM Vendor Seminar

SBE, Inc.

May 12, 2016

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Vice President and Chief Technology Officer





Agenda



- Corporate Overview
 - Licensing agreement with Rogers Corporation
- SBE Power Ring Film Capacitor™
- Next generation DC link
- New AC filter products
- Summary

SBE Corporate Overview



Established:	1945 as Sprague Electric ; SBE formed in 1985 with film cap lines purchased from Sprague
Locations:	Headquarters, Manufacturing and R&D Center: Barre, Vermont Application Engineering and Sales: Colorado and China
Facilities:	53,000 square feet new facility with capacity for over 100,000 Vehicles China: engineering and assembly – 5,000 square feet
Distributors:	Future Electronics – worldwide Richwood – China and Hong-Kong Flux Interconnect - Korea
Ownership:	Privately Held Corporation
Markets:	Transportation, Alternative Energy, Medical/Laser, Military, UPS
Key Customers:	TM4 - PEPS, UQM, Solectria Renewables, Candela Laser, Emerson Electric, Caterpillar, GE, Siemens, Dynapower Danfoss, Hofer



Vermont Facility



SBE Roadmap



DOE SBIR and Recover Act Funding plus investment



Next generation polypropylene film capacitors for 105C coolant automotive applications



Power Ring Capacitor with optimized form factor = best performance for ANY film



State of the Art 53,000 square foot factory in Barre, Vermont

High performance capacitor design, simulation, and testing

Proprietary winding technology

Advanced packaging



New Product: Integrated capacitor/bus



The Power Ring Advantage



- Film is film to all capacitor vendors - everyone has access to the same film suppliers
- SBE has targeted the annular form factor to provide the best possible performance
 - Significant investment in proprietary winding technology
 - Patent coverage for key technology aspects
 - High value of knowledge through R&D
 - Performance at the system integration level

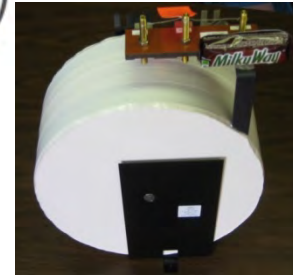
Key Technology Factors



- Large monolithic winding for lower cost
 - Better performance than a bank of smaller parts
- Short current path provides very low ESR
 - Low losses
- Large thermal cross section area provides efficient heat removal
 - Minimal hot spot temperature rise
 - Best possible current rating for given capacitance
- Optimized terminal structure provides very low ESL

SBE Next Generation Film Capacitor Solutions

Ring Form
Factor:
Building
Block
Enabling
Technology



Pulse caps with
excellent
reliability and
peak current
rating



AC Filter – Oil free patented
segmentation eliminates
catastrophic failures



DC Link – Integrated cap/bus for high
performance traction drive



DC Link – integrated cap/bus for increased
power density in alternative energy and
network power



Licensing Agreement with Rogers Corporation



- Rogers to supply SBE integrated cap/bus technology solutions to industry in 2H2016
 - Second source!
- Facilitates a three geo manufacturing plan by the end of 2017
 - US
 - Europe
 - China

DC Link Overview



- Introduction
- SBE DC link technology
- DC link examples
- Test kits
- Summary



Introduction



- Traditional inverter design takes the approach of adding μF until the capacitor bank can handle current to achieve the required life
 - This is not effective in terms of power density, cost, or volume
- Working voltage and switching speed (efficiency) limited by the ESL of the DC link
 - Interconnection between DC link capacitor and switch module is limiting factor

SBE DC Link Technology



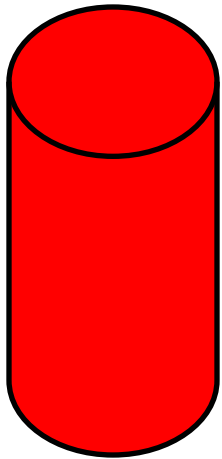
- Objective: Provide an optimized DC link such that customer can extract maximum value from investment in switch modules
- This is achieved as follows:
 - Provide highest possible Ampere/ μ F rating such that capacitance is defined by control limit rather than capacitor life (minimize μ F/kW)
 - Integrated cap/bus to provide the lowest possible inductance at switch module inputs

SBE DC Link Technology (cont.)



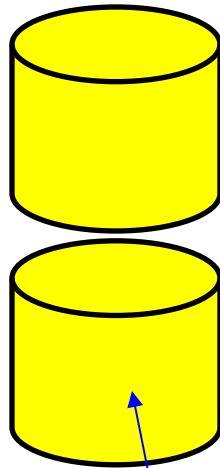
- Large $A/\mu\text{F}$ and small $\mu\text{F}/\text{kW}$ is achieved with Power Ring form factor

Typical "Can"



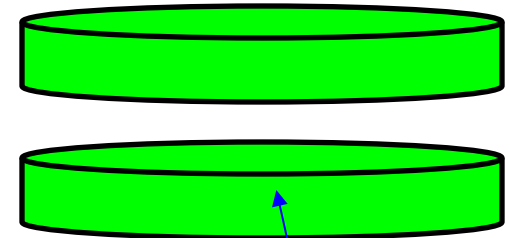
$$\Delta T = I^2 \times \text{ESR} \times R_T$$

Cut in Half



ESR reduced by 2x
 R_T reduced by 2x

Compress into a "Platter"



ESR reduced by 10x
 R_T reduced by 10x

SBE DC Link Technology (cont.)



- Example: Danfoss 1MW power stack fits in a 500kW rack using only 2.4mF of DC link capacitance



Power Rings are
“back-to-back” on
the bus

SBE DC Link Technology (cont.)



- Configurations – NPC or 2 level
- Demonstrated overshoot less than 12% at full power



Demonstrated 4nH ESL at IGBT connections – no snubbers needed

SBE DC Link Technology (cont.)

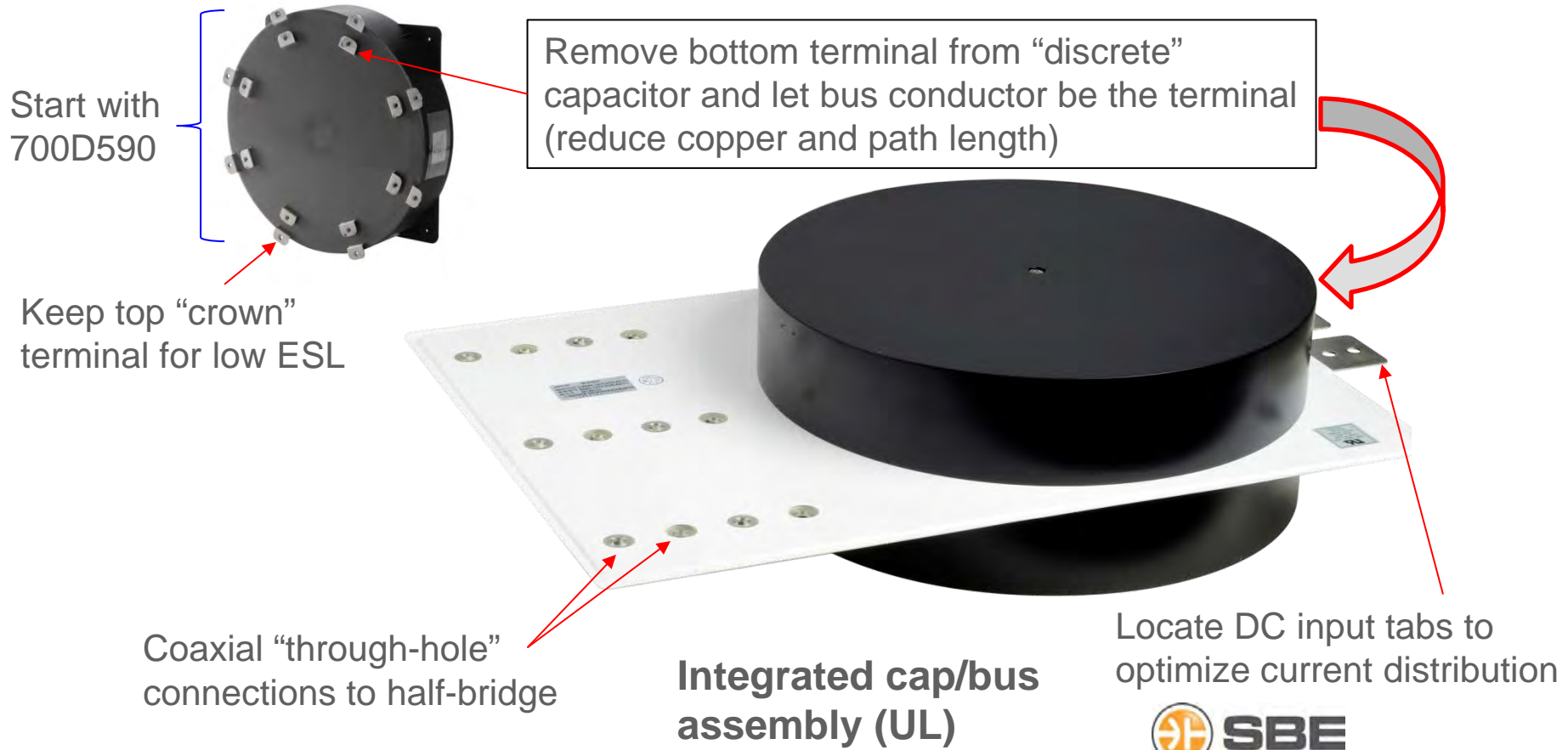


- The DC link inductance can be reduced as follows:
 - Optimize terminal configuration for capacitor to improve magnetic flux cancellation
 - Integrate capacitor(s) directly onto the bus structure as “surface mount” devices
 - Improve connection geometry from bus to switch module(s)

SBE DC Link Technology (cont.)



Example: 777A104 Test Kit (3000uF at 1100V)





Test Kits



- Provide an integrated cap/bus assembly that can be easily evaluated with industry standard modules
 - Validate DC link performance with minimal investment
 - Customize to specific customer requirements for production

Test Kits (cont.)



- Optimized test kits are now available for the Infineon HybridPACK™ Drive!
 - Match reduced footprint of power module
 - Integrated cap/bus for low inductance
 - Horizontal and vertical configurations are available
 - 500 μ F and 500V support full HP Drive capability for 10,000 hour life in realistic drive cycle
 - Low ESL is mandatory for high working voltage and fast switching for best efficiency

Test Kits (cont.)



- Horizontal configuration 700A186

Optimized cap/bus gives 8nH at module inputs



DC tabs located to balance capacitor charge and discharge to avoid current hogging

Combined with cooling plate and Infineon HybridPACK™ Drive for testing at ORNL



Test Kits (cont.)



- Vertical configuration 700A205

Optimized cap/bus 12nH at power module inputs



Cooling plate extracts heat from power module and bus = higher rating

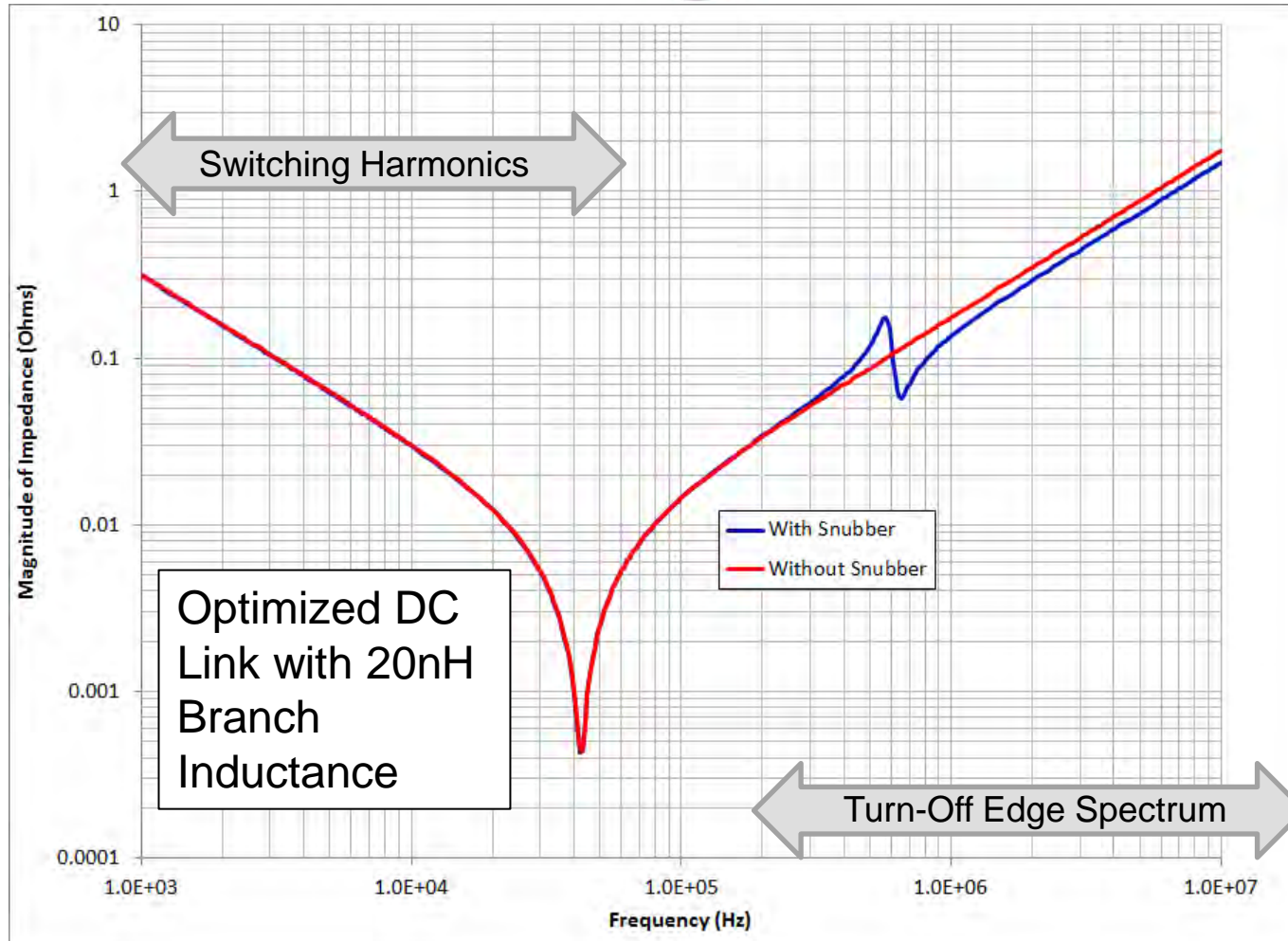
DC tabs located to balance capacitor charge and discharge to avoid current hogging

Are Snubbers Really Needed?



- Integrated cap/bus provides a very low inductance DC link
- Is there really any reason to use snubber capacitors, particularly a higher switching frequencies for WBG?
 - Snubbers are weak link for reliability and have minimal effect on voltage overshoot
 - See SBE application note:
<http://www.sbeelectronics.com/wp-content/uploads/2009/11/Snubber-App-Note-Final-web.pdf>

Are Snubbers Really Needed?



DC Link Summary



- Lowest $\mu\text{F}/\text{kW}$ rating
 - *Smallest size and lowest cost*
- Integrated cap/bus for low ESL
 - *Allows for much greater switch utilization*
- Best return on investment in power modules
- Cap/bus test kits available to support Infineon HybridPACK™ Drive module
 - Use “as is” or customize to your specific space and housing needs.

AC Filter Overview



- Introduction
- Conventional AC filter caps
- SBE AC filter caps
 - Combine Power Ring with patented segmentation technology
- New AC filter topology
- Summary



Introduction



- AC filter capacitors are a weak link for reliability of network power systems (e.g. UPS)
- Catastrophic failure of capacitors can take down the entire system
- Industry is now starting to demand better capacitor technology

Conventional AC Filter Caps



- End of life is defined as follows:
 - Catastrophic failure if pressure interrupter does not actuate during initial stages of fault
 - Field replacement of caps where pressure interrupter has operated as intended and disconnected
 - Field replacement based on DF increasing past a defined limit

Conventional AC Filter Caps (cont.)



- Data sheets typically define a life number (e.g. 40,000 to 60,000 hours)
- What does this really mean with regard to field experience?
 - How many capacitor banks actually achieve the life claimed with the originally installed cans?
 - Can we really claim data sheet life if some cans are replaced during regular maintenance?

SBE AC Filter Caps



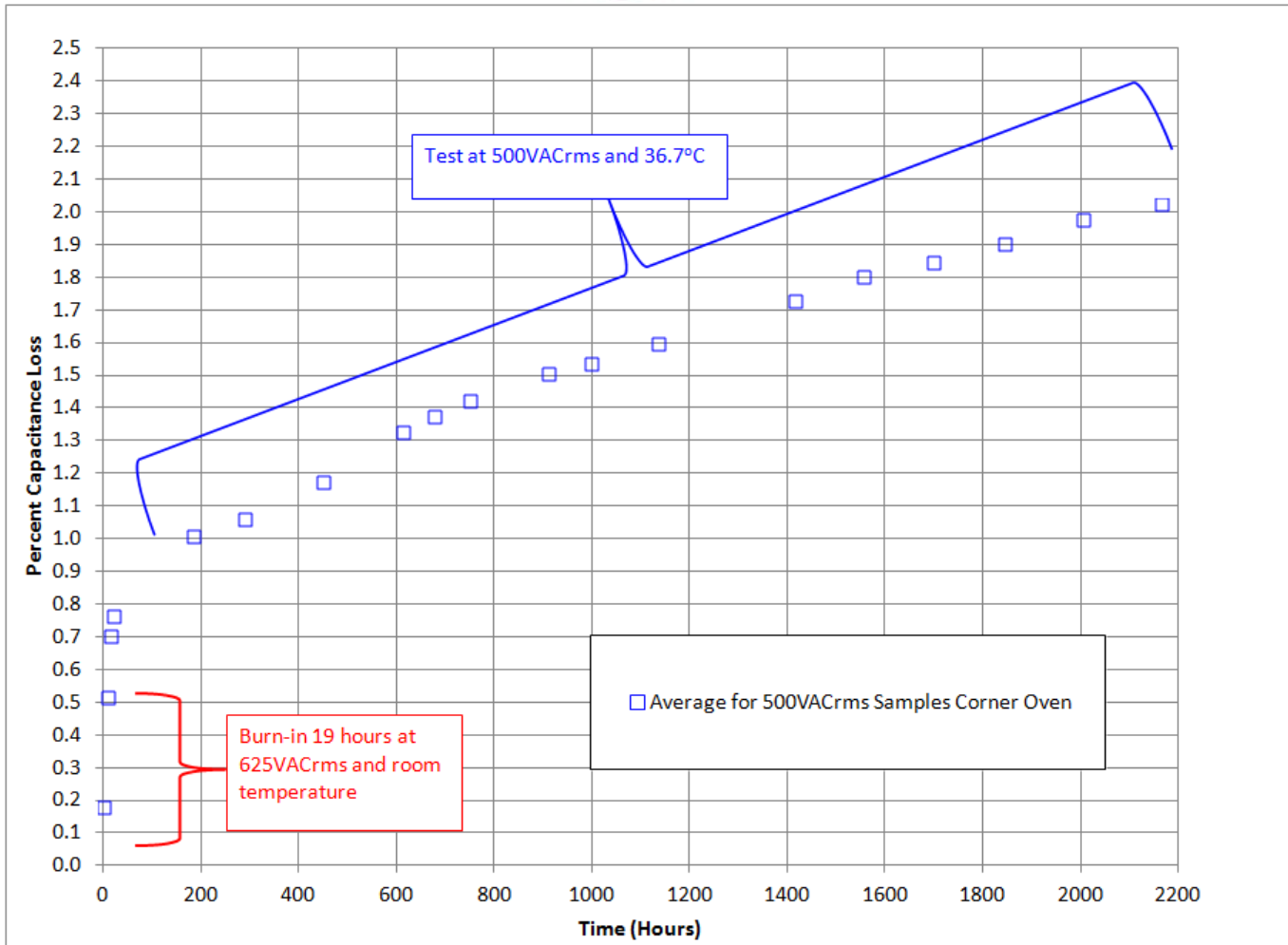
- ***First priority: solve catastrophic failure problem***
 - Combine SBE Power Ring form factor with patented segmentation technology developed for pulse applications
 - Eliminate “unzipping” failure mode
 - Clearing and segment disconnection prevents hard fault

SBE AC Filter Caps (cont.)

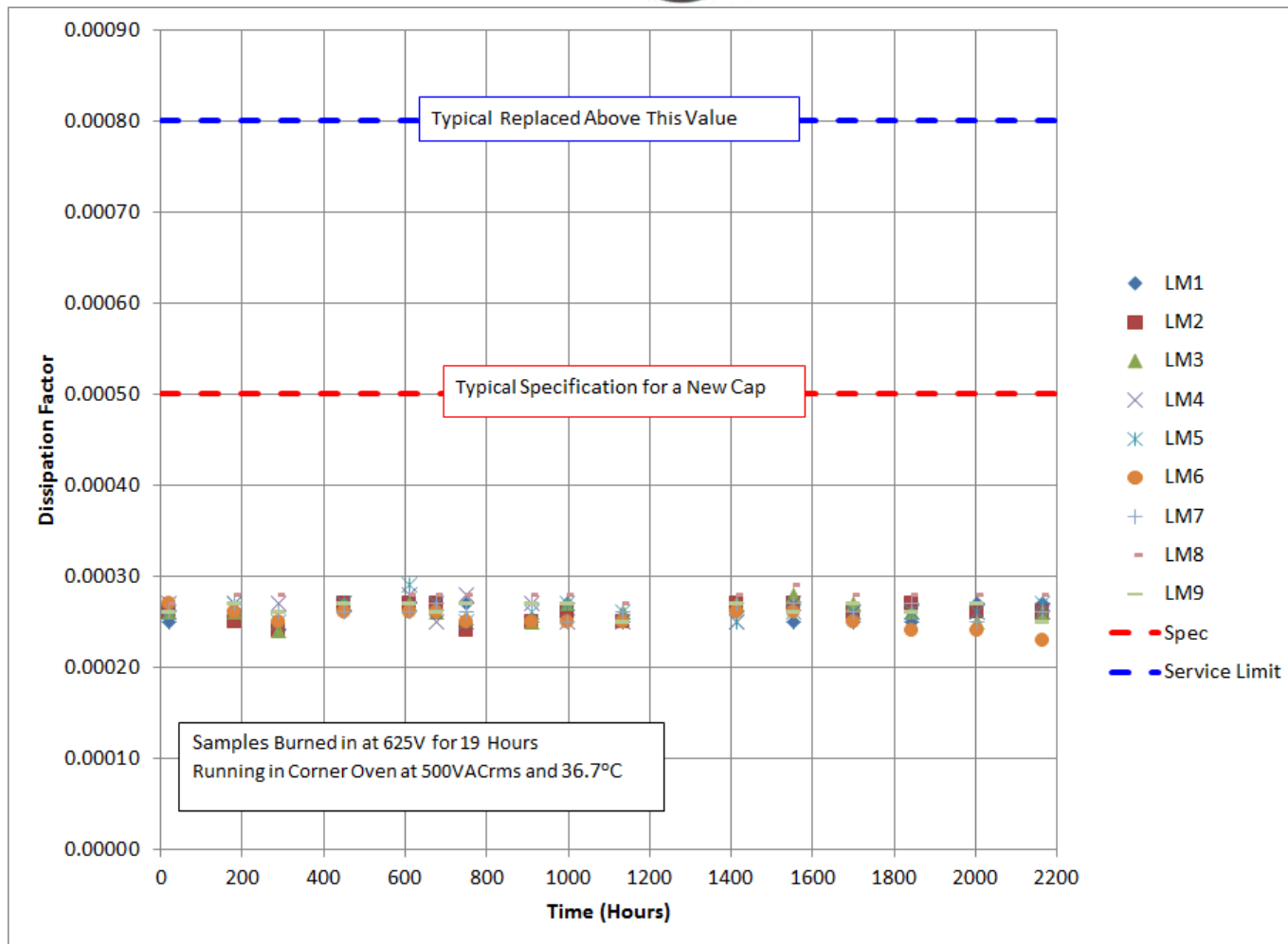


- The metric for AC filter capacitor life is now different
 - Catastrophic failure is eliminated
 - Capacitor DF is significantly lower and does not change
 - Life is now defined by a steady rate of capacitance loss to a lower limit defined by total harmonic distortion (THD) requirements for the filter
 - Testing results indicate > 80,000 hour life for 30% capacitance drop

SBE AC Filter Caps (cont.)



SBE AC Filter Caps (cont.)



SBE AC Filter Caps (cont.)



- Additional advantages
 - Form factor provides for easy removal of heat given large surface area to height ratio
 - Rings run up to 20°C cooler than conventional cans
 - Fewer discrete capacitors to make the same bank value = easier monitoring
 - Rings can be supported from the core for mounting in a variety of configurations...

New AC Filter Topology

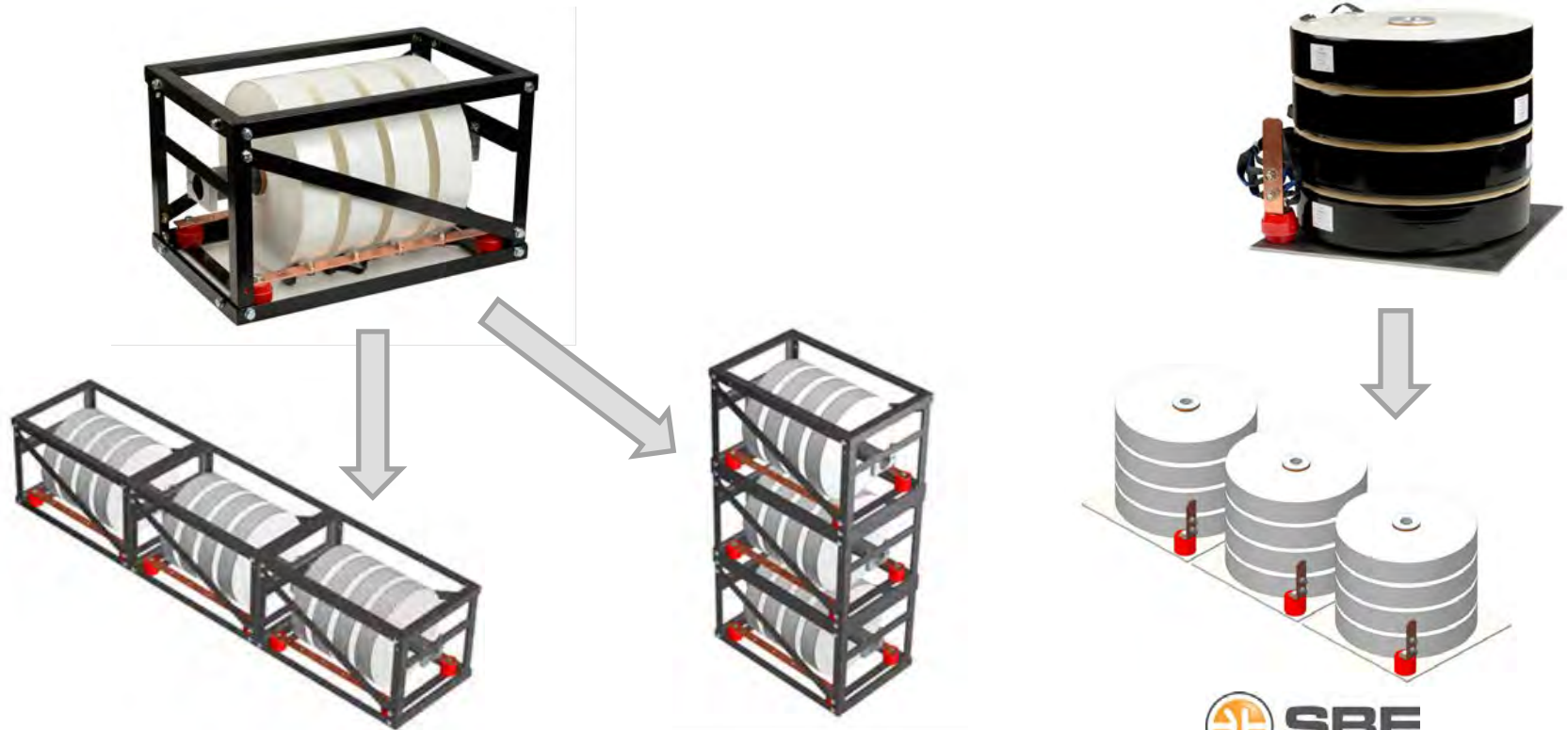


The 705A1285480-100 is a 480VAC, 1250 μ F Single Phase, AC Filter Bank utilizing Power Ring Film CapacitorTM technology.

New AC Filter Topology (cont.)



- Many different configurations are possible...



AC Filter Summary



- Capacitors are the weak link for existing network power applications
- Combine the SBE power ring with patented pulse technology
- Eliminate catastrophic failure mechanism
- Life is now defined by capacitance loss and THD limits – not by a failure or increasing DF
- New topologies are enabled



Summary



- SBE annular form factor offers highest performance film capacitor
- Integrated cap/bus for next generation DC link
- New AC filter technology
- Rogers Corporation has licensed SBE cap/bus technology for second source
- Come see us at booth 9-131 to discuss your application!