Advanced Conversion Capacitor Technology and Solutions

PCIM 2025

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Capabilities and Offerings

- Advanced Conversion
  - Metallized Dry Film Capacitors and Integrated Capacitor/Bus Solutions
  - Unique annular “ring shaped” capacitors for high performance applications (Power Ring)
  - Specialized high-performance integrated capacitor designs for power conversion applications
  - High temperature applications using multiple industry available films including W.L. Gore
  - Custom bus design and fabrication
  - Full simulation and design capability

Advanced Conversion Technology

Unique proprietary winding technology

+

High performance capacitor design, simulation, and testing

+

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

+

Advanced packaging

=

New Product Space: Integrated Capacitor/Bus DC Link Solutions

=

High Performance Pulse Capacitor Solutions

=

High Temperature Solutions for Demanding Applications

The Power Ring Advantage

- Film is film to all capacitor vendors – what can you do with it?
- APCS has targeted the annular form factor to provide the best possible performance
  - Significant investment in proprietary winding technology
  - Patent coverage for key technology aspects
    - Integration of polymer winding with copper terminals
  - Advanced design and simulation capabilities
  - Understanding performance at the system integration level

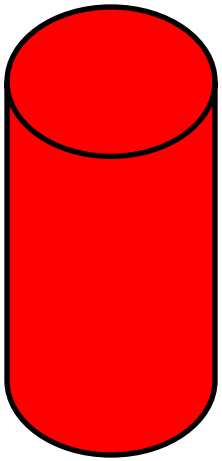
The Power Ring Advantage

- 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
  - Highest possible current rating for given capacitance
  - Best performance for ANY film

Key Technology Factors

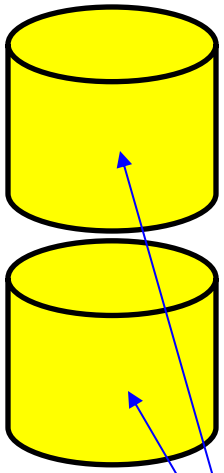
- Maximize A/mF so mF/kW is defined by control limit not capacitor current rating

Typical “Can”



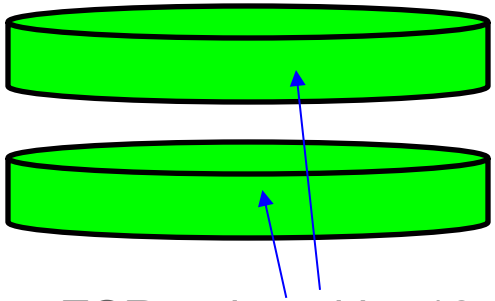
$\Delta T = I^2 \times ESR \times R_T$

Cut in Half



ESR reduced by 2x
R_T reduced by 2x

Narrow film wound into into a “Platter”



ESR reduced by 10x
R_T reduced by 10x

APCS Next Generation Film Capacitor Solutions

Power Ring Film Capacitor™ is a Building Block for Enabling Technology at the SYSTEM Level

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

Integrated Solutions

- APCS winding technology is a key building block, but optimized system level integration is required to harvest full advantage
- We are expert in the design and fabrication of advanced capacitor solutions
  - Bus structures
  - Advanced packaging
  - Ready-to-install product rather than a component

DC Link

- Traditional inverter design takes the approach of adding mF 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

DC Link

- 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/mF rating such that capacitance is defined by control limit rather than capacitor life (minimize mF/kW)
  - Integrated cap/bus to provide the lowest possible inductance at switch module inputs

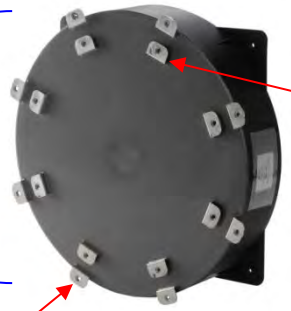
DC Link

- Packaging and integration of the capacitors is critical for best performance
  - Optimize terminal configuration for capacitor to improve magnetic flux cancellation
  - Integrate capacitor(s) directly onto the bus structure as “surface mount” devices
    - Eliminate redundant conductor layers
  - Improve connection geometry from cap/bus to switch module(s) = optimal TOPOLOGY

DC Link Topology

Example: Test Kit (3000uF at 1100V)

Start with 700D590 discrete capacitor



Keep top “crown” terminal for low ESL

Remove bottom terminal from “discrete” capacitor and let bus conductor be the terminal (reduce copper and path length)

Coaxial “through-hole” connections to half-bridge

Integrated cap/bus solution

Locate DC input tabs to optimize current distribution

Enabling Ecosystem

- Next generation inverters must improve power density and efficiency
  - This requires an enabling “ecosystem” to support the semiconductor switches
    - Gate driver
    - Bus bar
    - DC link capacitor
    - Cooling

APCS integrated cap/bus topology forms the foundation

Enabling Ecosystem

- Advanced Silicon
  - Higher operating voltage
  - Faster switching
  - Massive paralleling of switch modules to achieve very high current
- Silicon Carbide
  - Higher operating voltage
  - Higher operating temperature
  - Very fast switching
  - Parallel modules needed to get to medium current

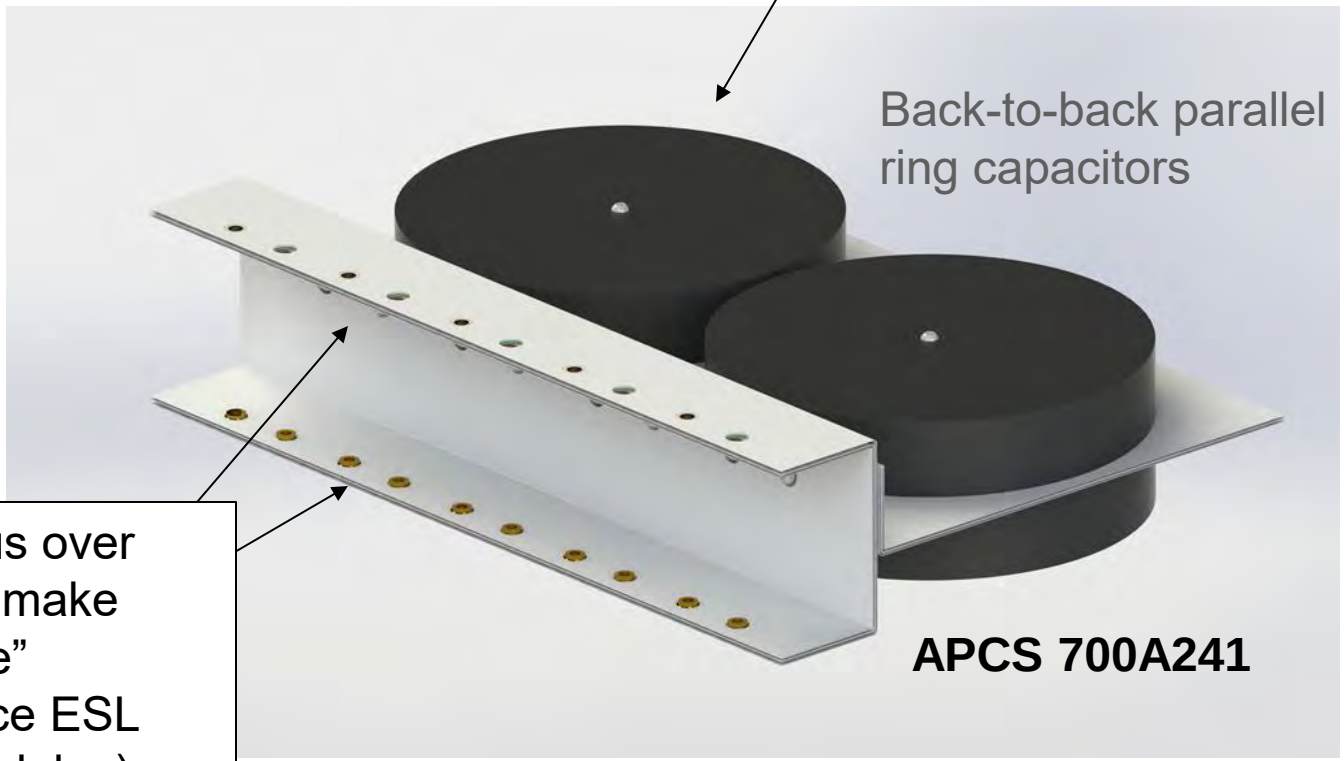
Enabling Ecosystem

- The enabling DC link requires the following ingredients
  - Optimized topology and bus structure
    - Very low commutation inductance
    - Paralleling of switch modules (balancing)
  - Very low capacitor losses
  - Higher capacitor working voltages
  - Increasing capacitor temperatures

Paralleling Modules

DC Link for Paralleling Infineon XHP™ Modules

Add additional rows of 4x windings as needed for system mF value (e.g. weak grid)



Extend laminated bus over switch modules and make coaxial “through hole” connections to reduce ESL (< 10nH seen by modules)

Paralleling Modules

Paralleling Modules

- Infineon double pulse testing demonstrates current balancing is better than 5% with 10x modules in parallel
- The use of two-sided cooling plate for modules complicates topology => multiple bus components needed
  - "C" bus connected to main cap/bus with multiple parallel coaxial contacts

Higher Working Voltage

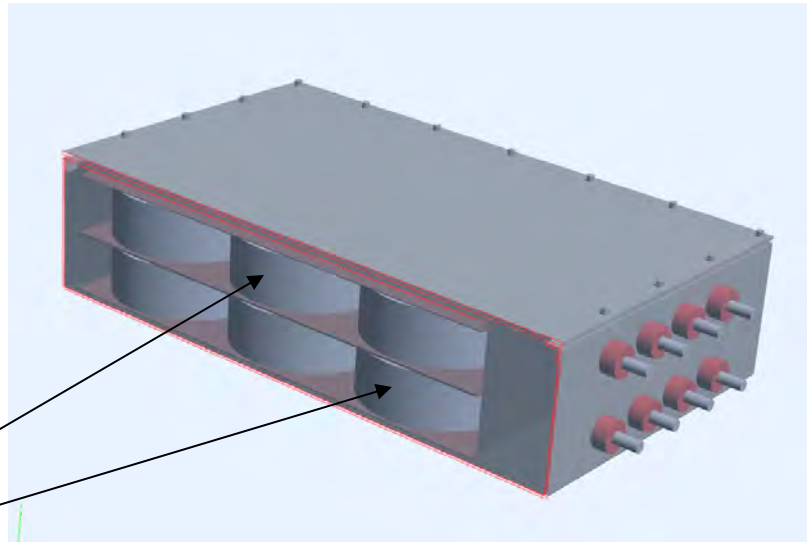
- Example: HVDC and SVC applications
  - 2.8kV and up
  - Customers are now looking to reduce all component losses
- Power density = capacitance density
  - Thinner film to manage capacitor volume
  - Lighter metallization to support higher operating stresses
    - APCS form factor can actually reduce ESR while taking this approach

Higher Working Voltage

The traditional “box cap”

Improved “box cap” with lower losses using Advanced Conversion rings

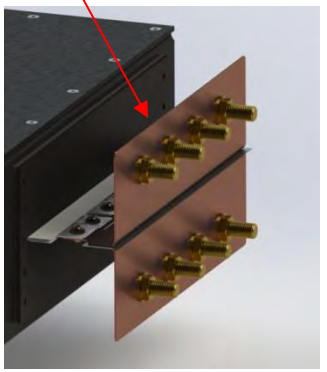
- Dissipation losses are the same
- Electrode losses are reduced by up to 3x



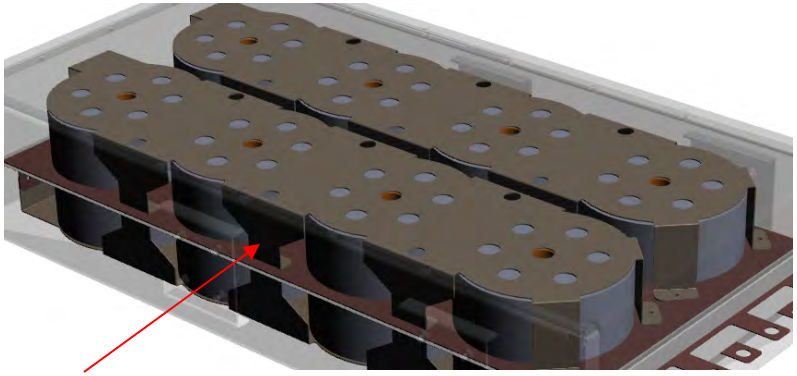
Array of ring capacitors connected to bus plates with patented technology

Topology

Universal bus with adapters allows immediate use with existing hardware with later upgrade



Support ESL migration roadmap



Low ESL “crown terminal”

Optimized: Mount capacitors “back-to-back” on low-inductance bus and transition bus out to of case to the switch modules

Higher Temperatures

- W.L. Gore has partnered with APCS to supply their high temperature capacitor film
- Capacitors that operate to 200 C and beyond
  - The film self-heals and offers very low dielectric losses – no catastrophic fails
  - Available as standard wrap-and-fill (in stock)
  - Designs to utilize low ESR and efficient bulk capacitance (rings) already being sampled

Higher Temperatures

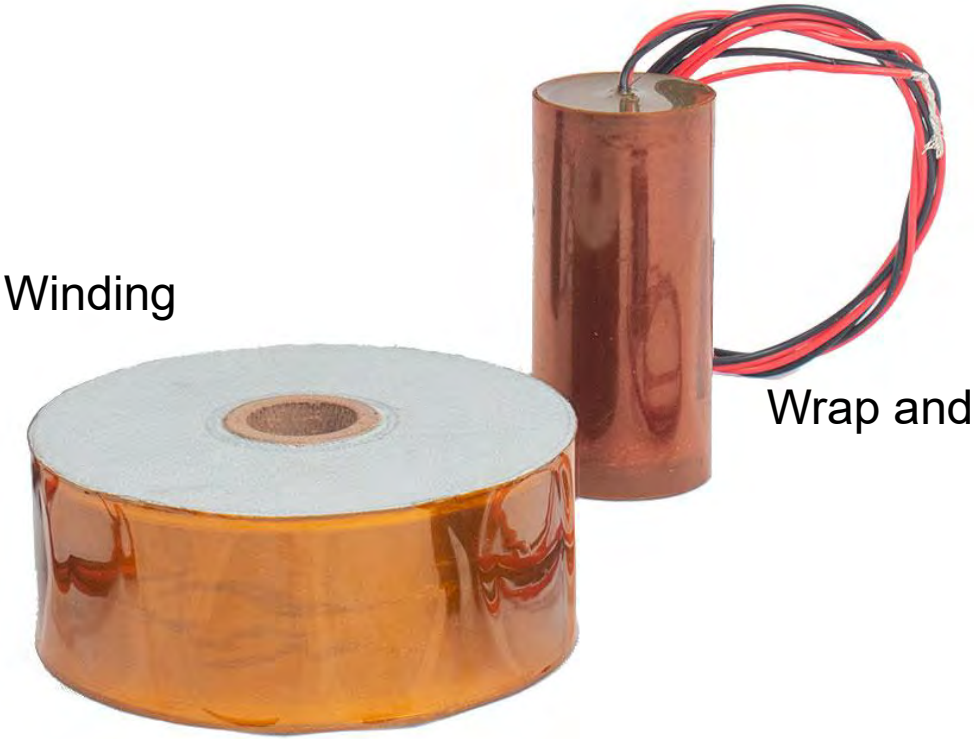
- W.L. Gore has tested Advanced Conversion capacitors to validate performance in extreme environments
  - Insulation Resistance (DWV) MIL-STD-202G, Method 301, Condition A (600 V), Pass
  - Thermal Cycling MIL-STD-883J, Modified Condition D (-30°C to +170°C), Pass
  - Lead Pull MIL-STD-202G, Method 211A, Test Condition A (5 lbs), Pass
- Customers have also performed in-situ shock and vibration testing

Higher Temperatures

- APCS winding technology enables full utilization for higher temperature films in development or commercially available
- Very low ESR and R_T exploits higher hotspot limit
  - Higher temperature rise due to ripple current
  - Higher ambient temperature
- Numerous lead attachment and packaging methods in development

High Temperature Capacitors

Power Ring Winding



Wrap and Fill

Test Kits

- We offer fully integrated capacitor/bus test kits for many industry standard switch modules
  - Infineon HybridPACK™ Drive (and equivalent)
  - Hitachi RoadPak™ (and equivalent)
  - Cissoid
- Drop in connection with low ESL and optimized DC input location

Test Kits

- Stock parts give you an easy way to try out a particular module with an optimized DC link

700A186 for Infineon HybridPACK™ Drive

700A386 for Hitachi RoadPak™

Box Cap Replacements

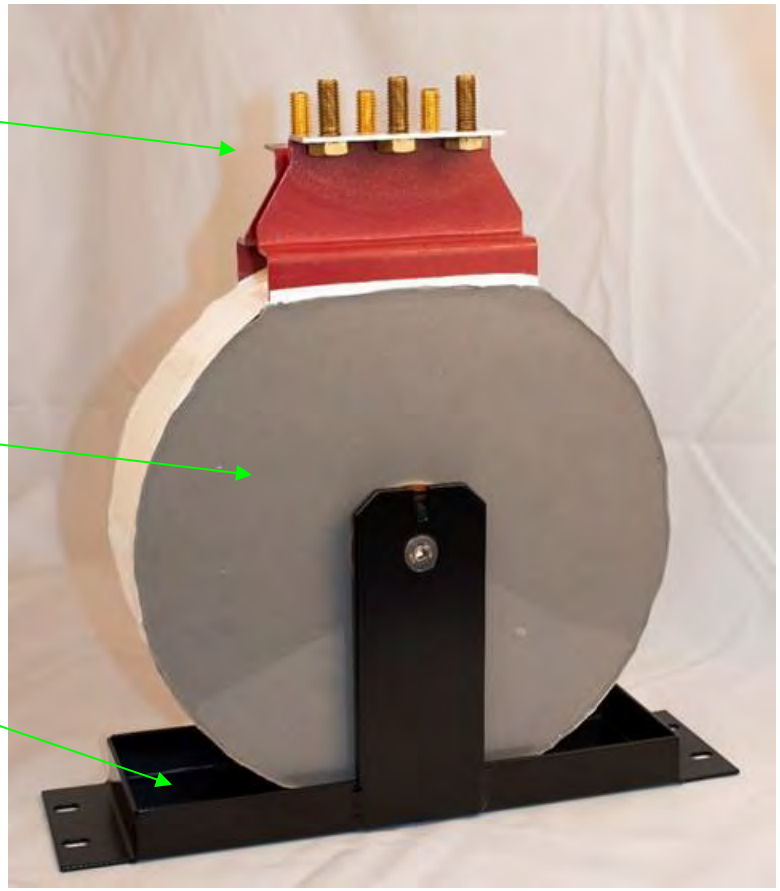
- Many conventional vendors are pushing out lead times, and in some cases exiting from the large box cap business
- The Power Ring can be implemented as a lower cost replacement with a simplified mechanical structure
  - Form factor provides improved thermal performance

Box Cap Replacements

Terminal Structure to Match Existing Configuration

Single “Wrap and Fill” Winding

Simplified Support Structure



Prototype Capabilities

- Our Colorado facility provides fast custom prototyping
  - Discrete capacitors
  - Capacitors with integrated bus
    - Powder coat
    - Laminated
    - Specialty insulation
  - Lead times from 10 weeks after design lock

Please Visit Our Booth 9-542

- We are happy to discuss your unique system requirements and goals
- Hardware examples on hand for discussion

THANK YOU FOR YOUR ATTENTION