

Attracting Tomorrow



Technologies & Products Press Conference 2019

# **Innovative power capacitor technologies for wide band-gap semiconductors**

Advanced design features for high-frequency applications

**Dr. Lucía Cabo**

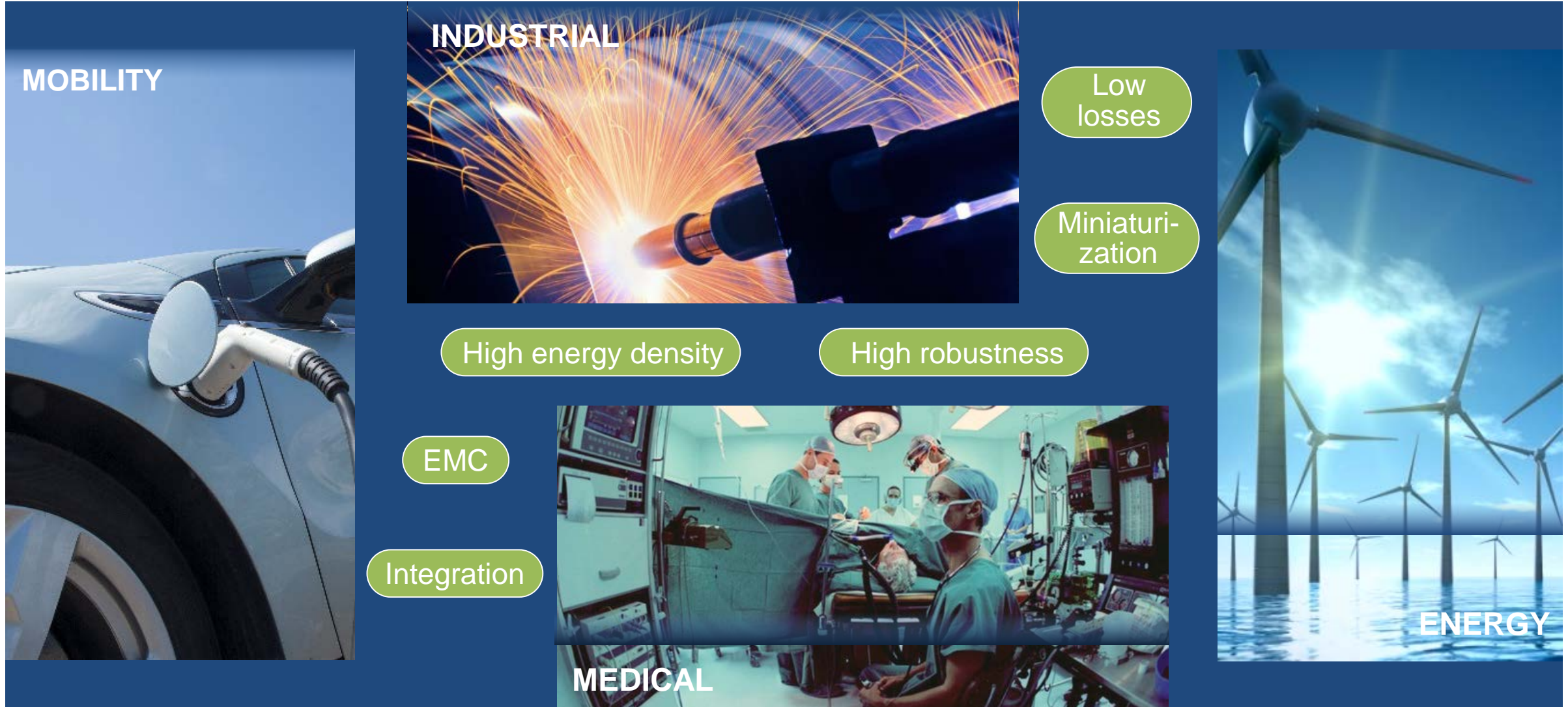
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Málaga, Spain

October 29, 2019

# Growing demands challenging power electronics



# Advanced semiconductors put high demands on the DC link



**Challenge for passive components: Not be the bottleneck in new power electronics designs**

# Design goals for high-frequency capacitors

## High operating temperature

- High temperature dielectric
- Handle heat coming from the semiconductor busbar
- High current capability

## Low ESR vs frequency

- Minimized losses
- Wider operation bandwidth up to the MHz range
- Good performance close and above the resonance frequency

## Low ESL of $<10$ nH ( $<5$ nH for special designs)

- Internal design for high  $dV/dt$  levels
- Make snubber capacitors unnecessary



# New dielectric for high temperature is needed

**Polypropylene** (PP) is a commonly used standard dielectric in film capacitors.

PP is transformed into a **biaxially oriented PP (BOPP)** film in a sequential stretching process

## Advantages of BOPP film

State-of-the-art dielectric



Excellent self-healing properties



Low losses



Low price



## Disadvantages of BOPP film



Limited performance at high temperatures



$T_{\max} = 105\text{ °C}$  for high crystalline BOPP



$T_{\max} = 125\text{ °C}$  for some special BOPP grades – with derating

## Classic high temperature alternatives to PP



Limited self-healing



Difficult to process

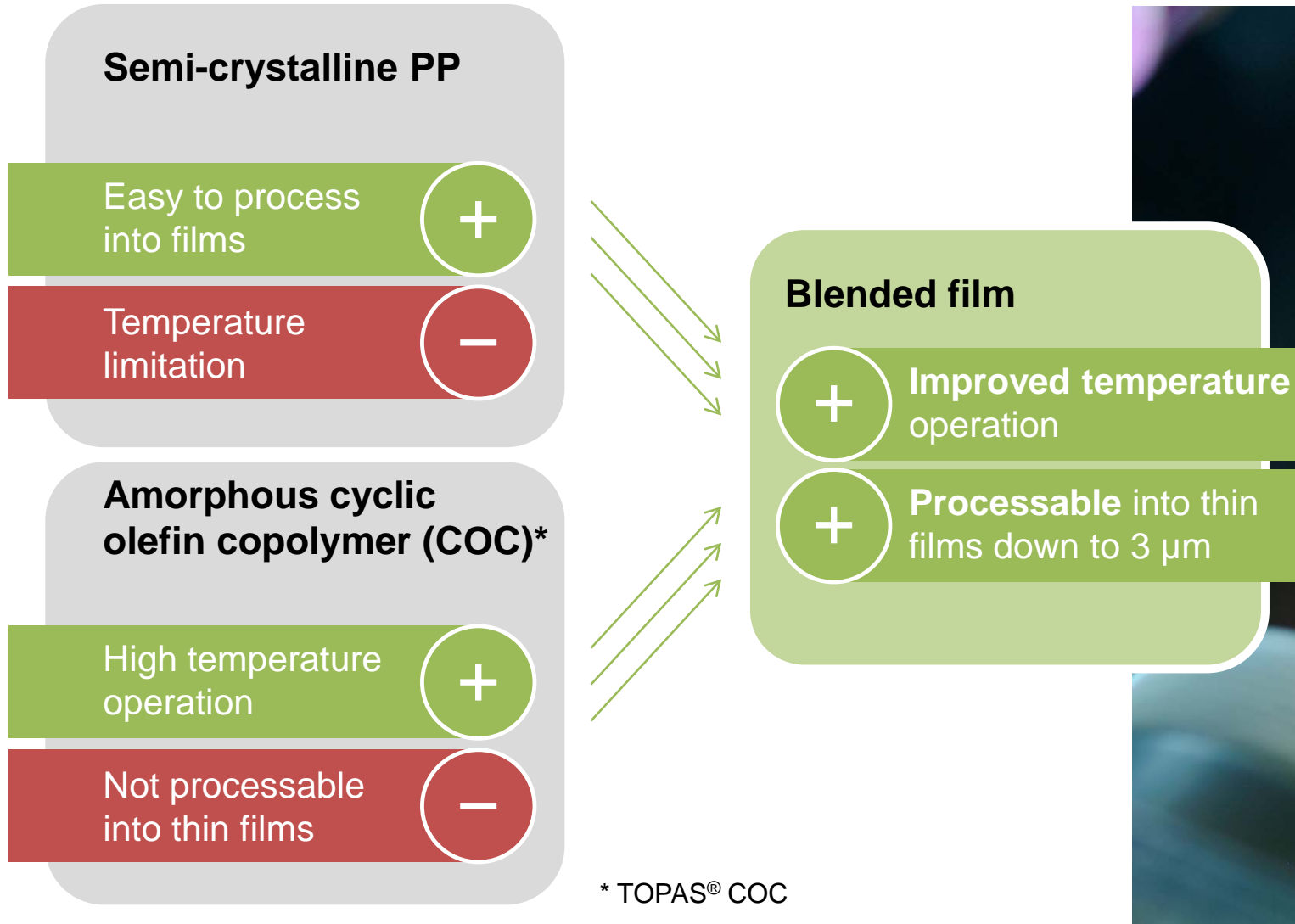


Expensive

**Polypropylene is reaching its limits due to the rising demands of new wide band-gap semiconductors, especially in high-temperature applications**

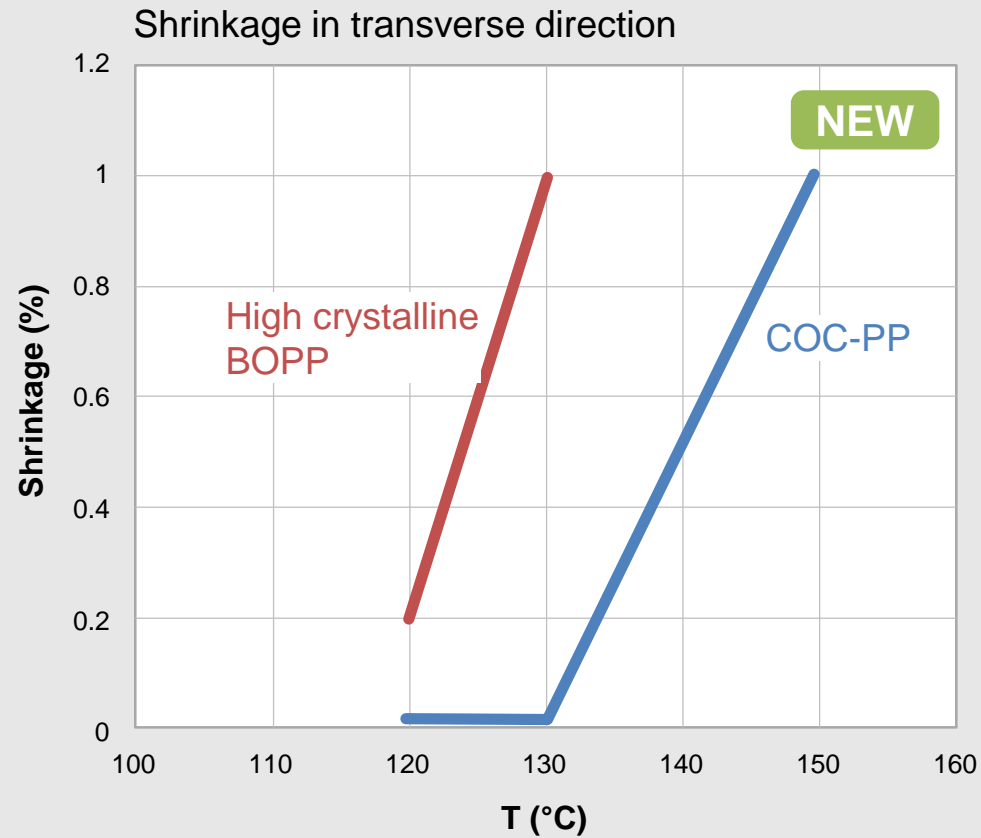


# New material blend for high temperatures

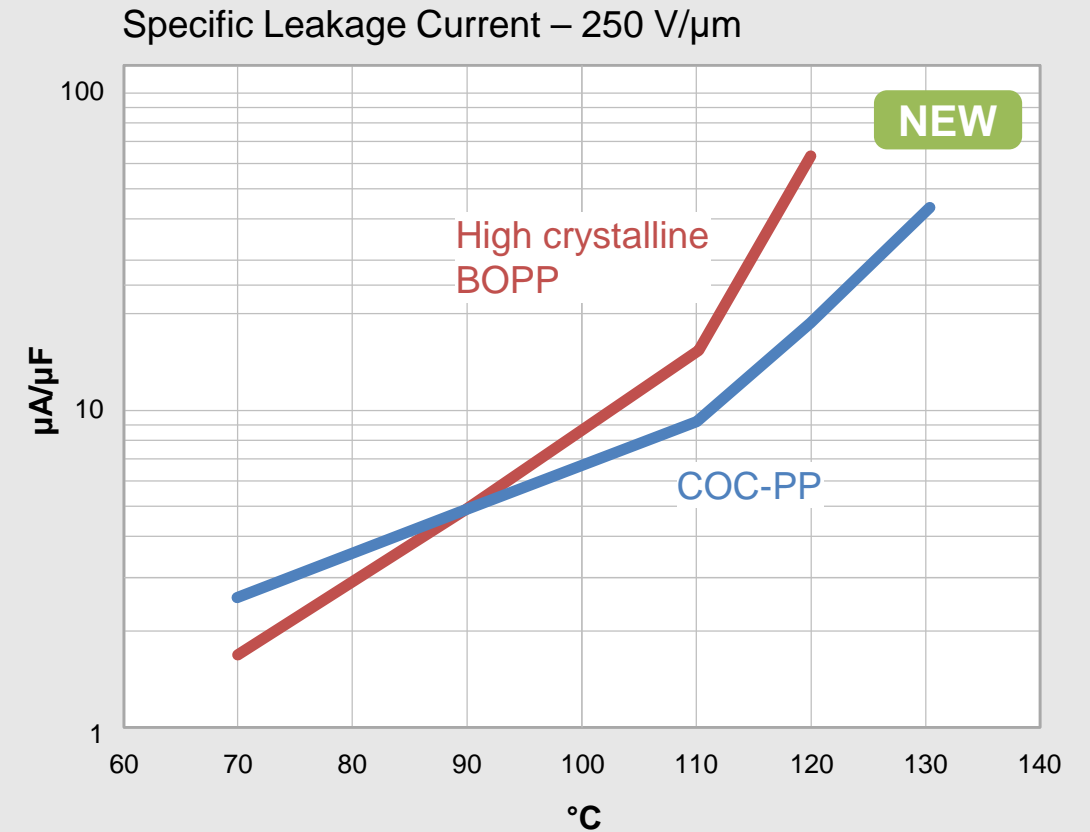


# Improved performance at high temperatures (1)

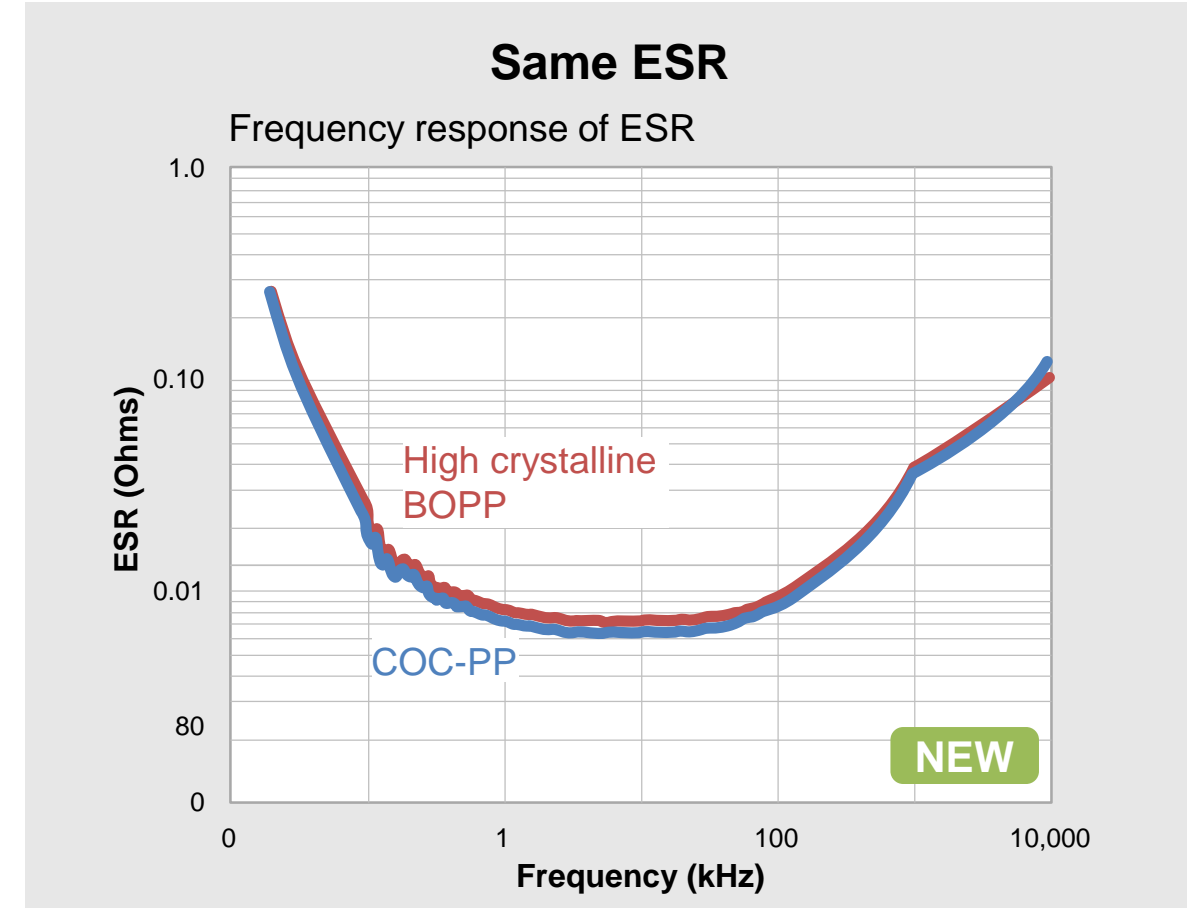
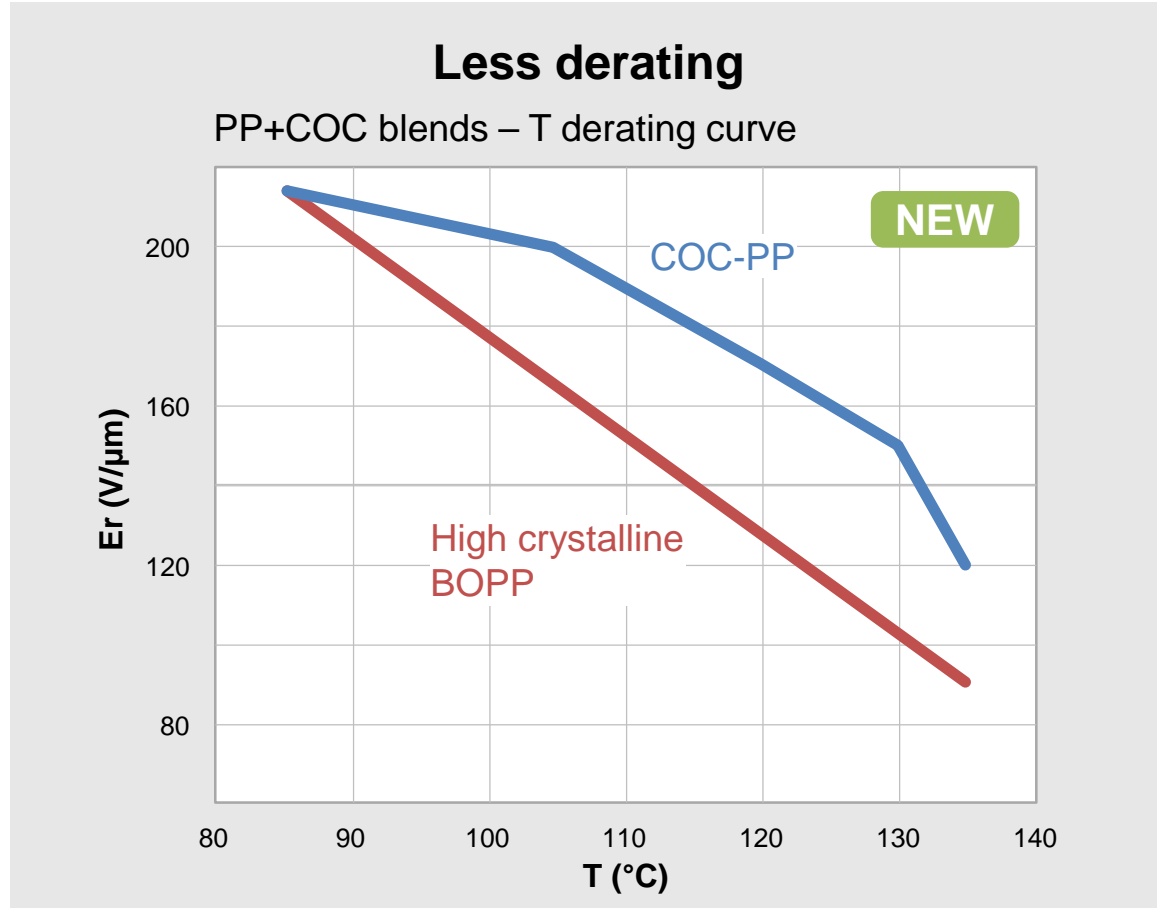
## High mechanical stability



## Low specific leakage current



## Improved performance at high temperatures (2)



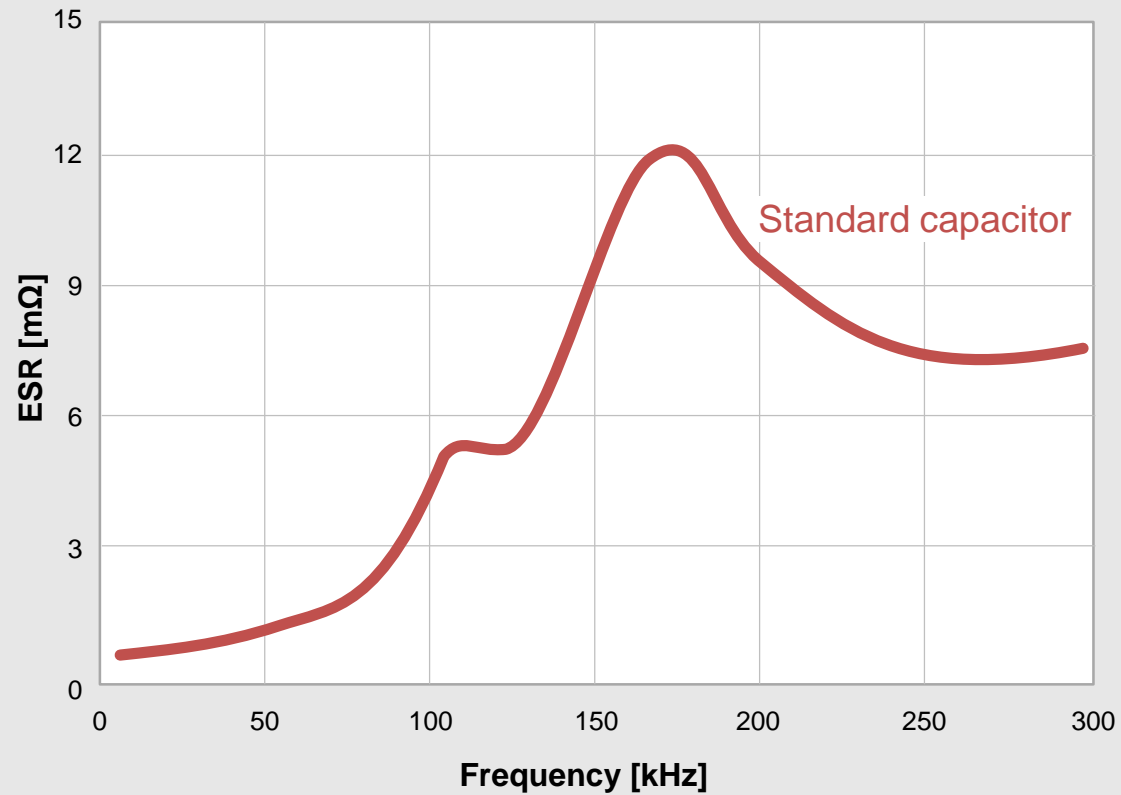
**Best of both worlds**

- Aging and failure mechanism similar to BOPP
- Similar self-healing properties
- Stable performance at up to  $125^{\circ}\text{C}$



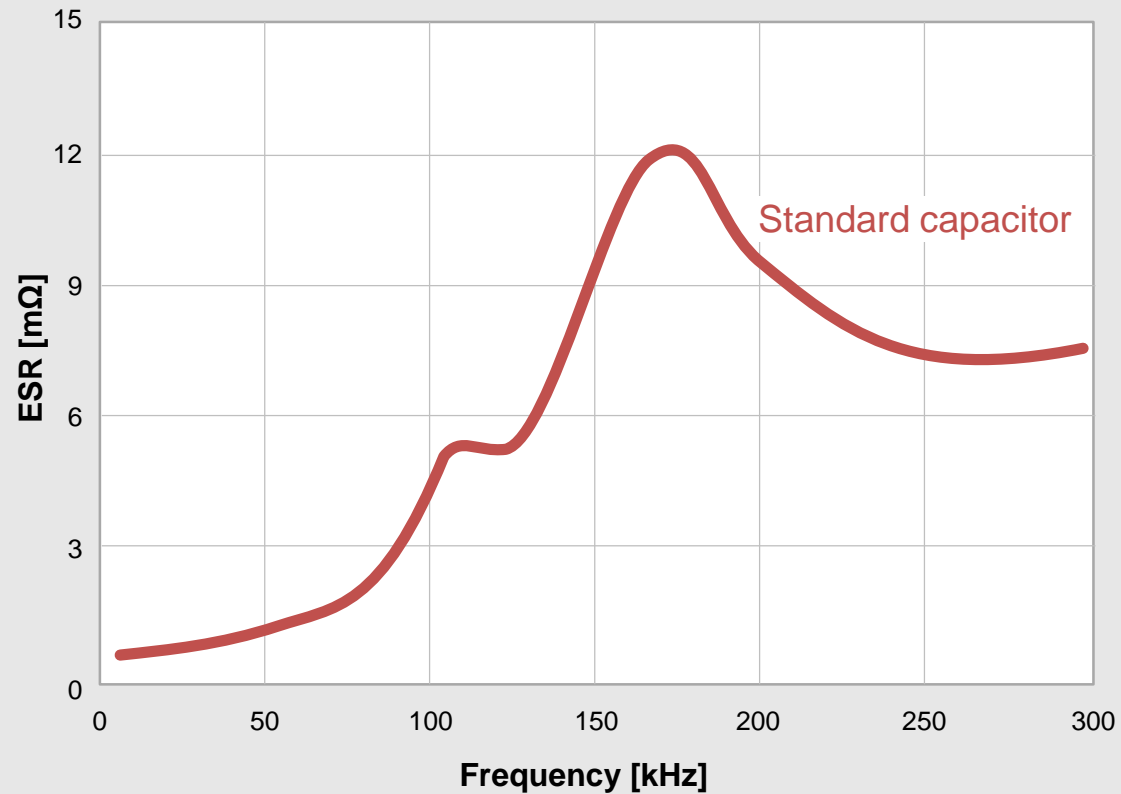
# Standard power capacitors have unfavorable ESR characteristics

ESR rises sharply with rising frequency

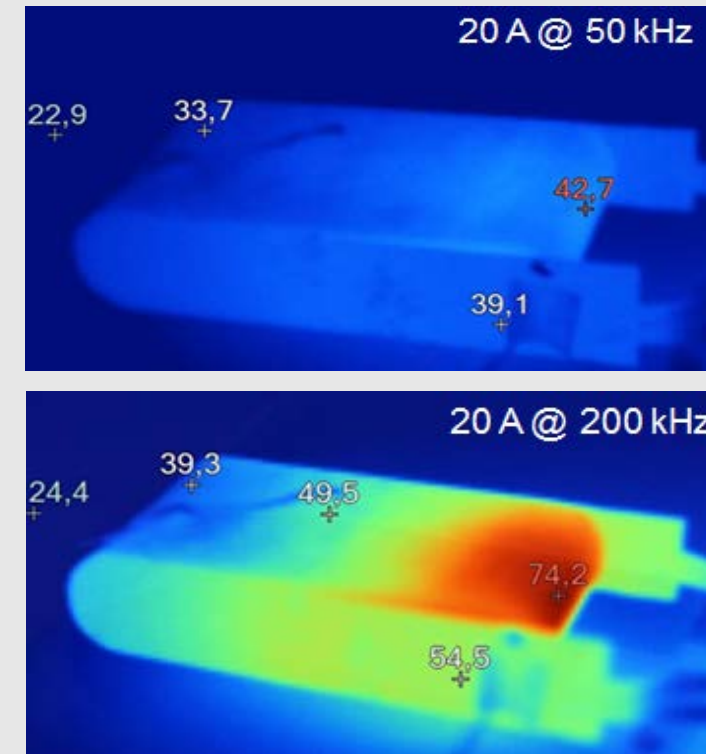


# Standard power capacitors have unfavorable ESR characteristics

ESR rises sharply with rising frequency



High ESR



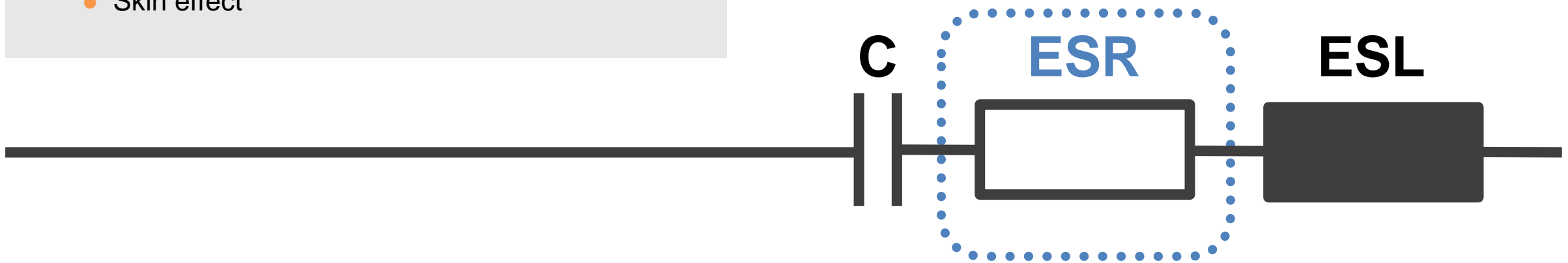
High  
power losses

1.6 W

3.6 W

# Root causes of increasing ESR

- Inhomogeneous impedance and internal resonances
- Negative electromagnetic interaction
- Winding geometry and metal profile
- Skin effect

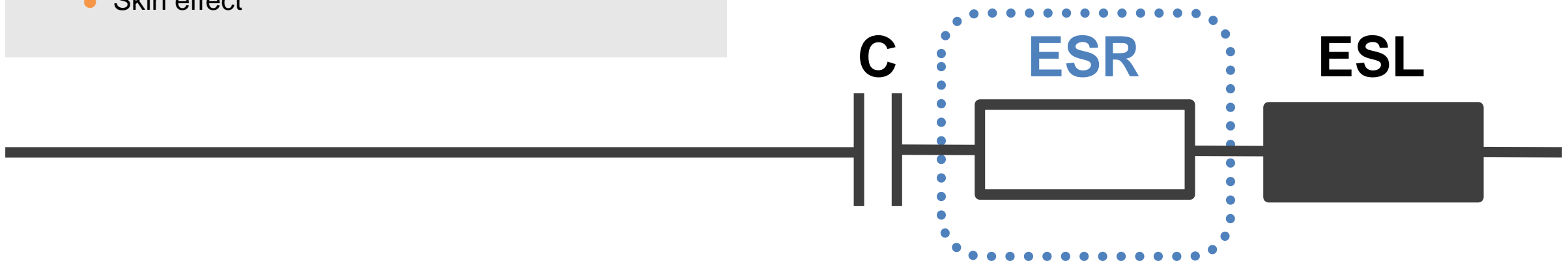


# Root causes of increasing ESR

- Inhomogeneous impedance and internal resonances
- Negative electromagnetic interaction

Factors offering most potential for improvement!

- Winding geometry and metal profile
- Skin effect



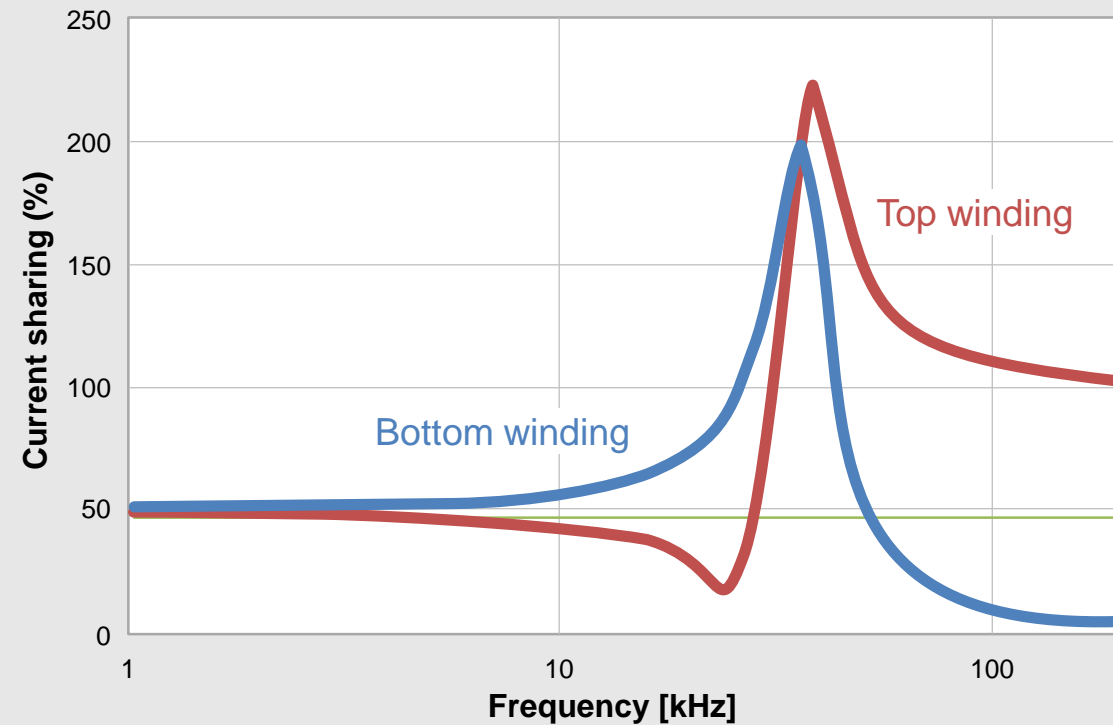
**Power capacitors must be fundamentally redesigned in order to operate reliably at higher frequencies**

# Standard capacitors are limited at high frequencies

Standard power capacitor



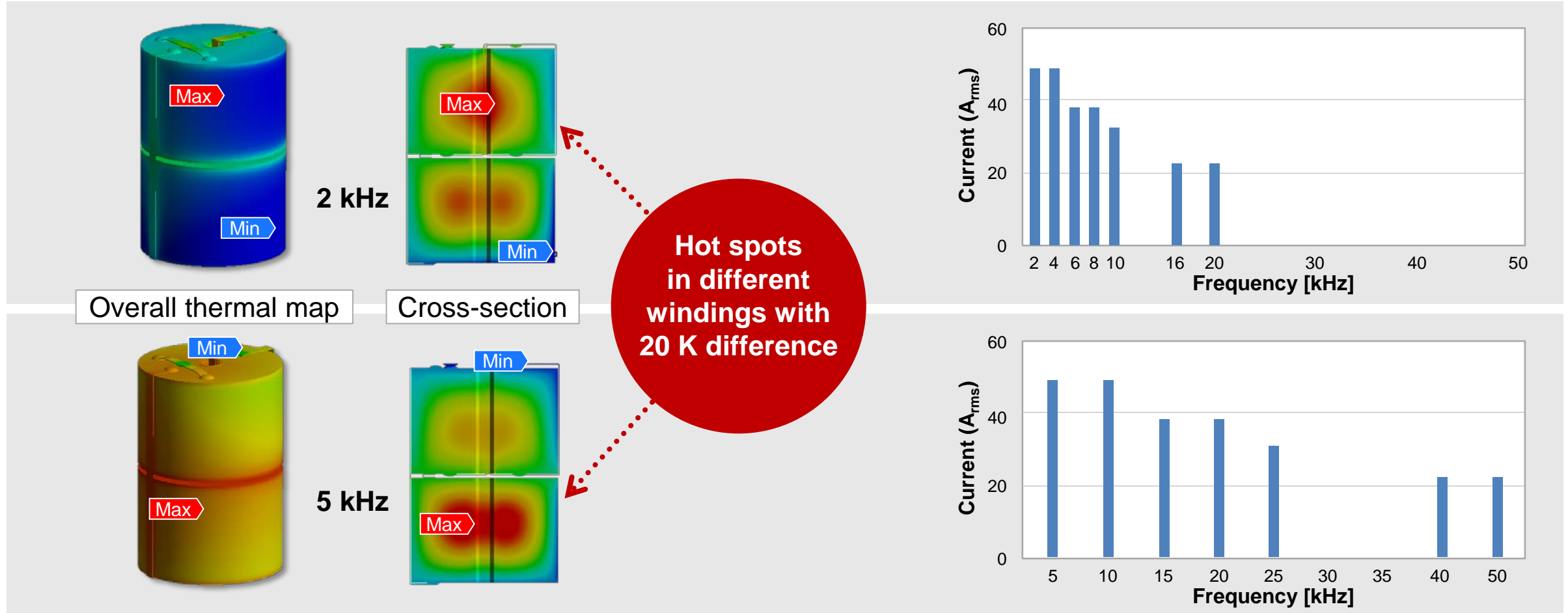
Effects of inhomogeneous impedance and internal resonances



**Standard capacitors are not ready for high frequencies**

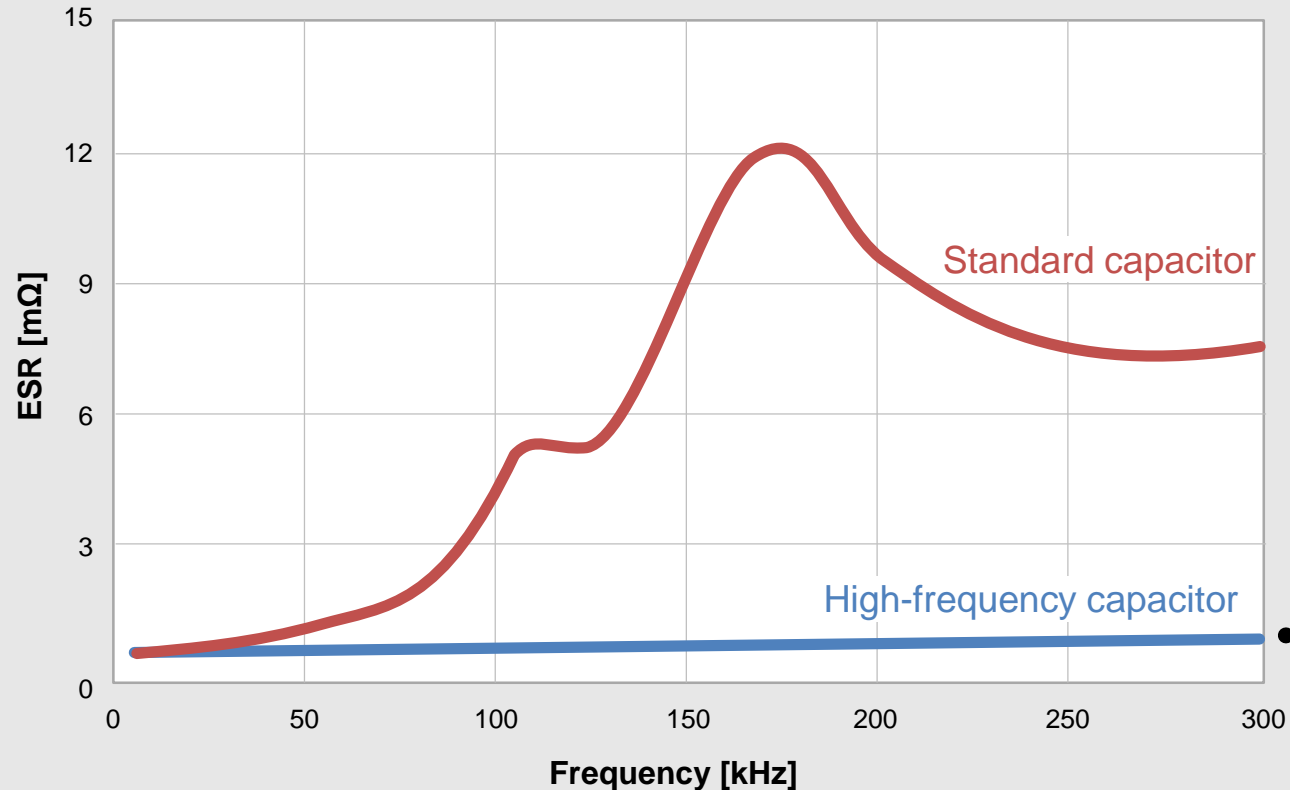


# High ESR has thermal consequences



Higher switching frequencies cause unbalanced thermal behavior

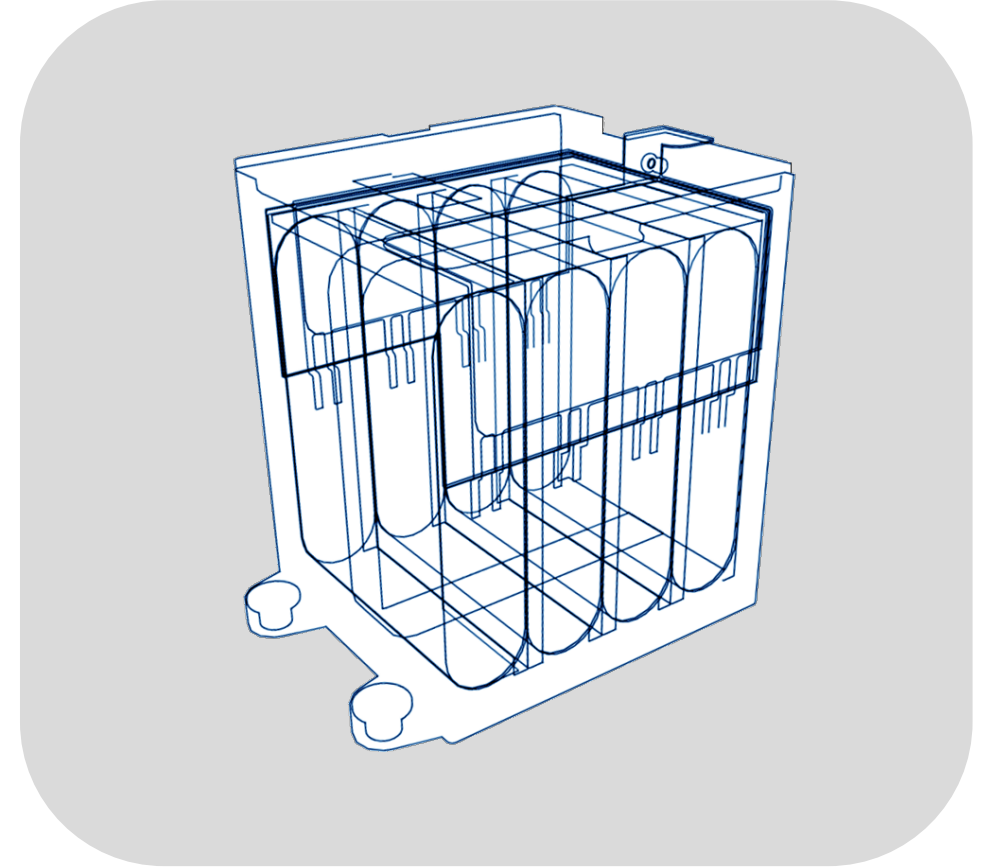
# Design of high-frequency capacitors focused on low ESR



New design must deliver  
low and stable ESR  
across the critical  
frequency range

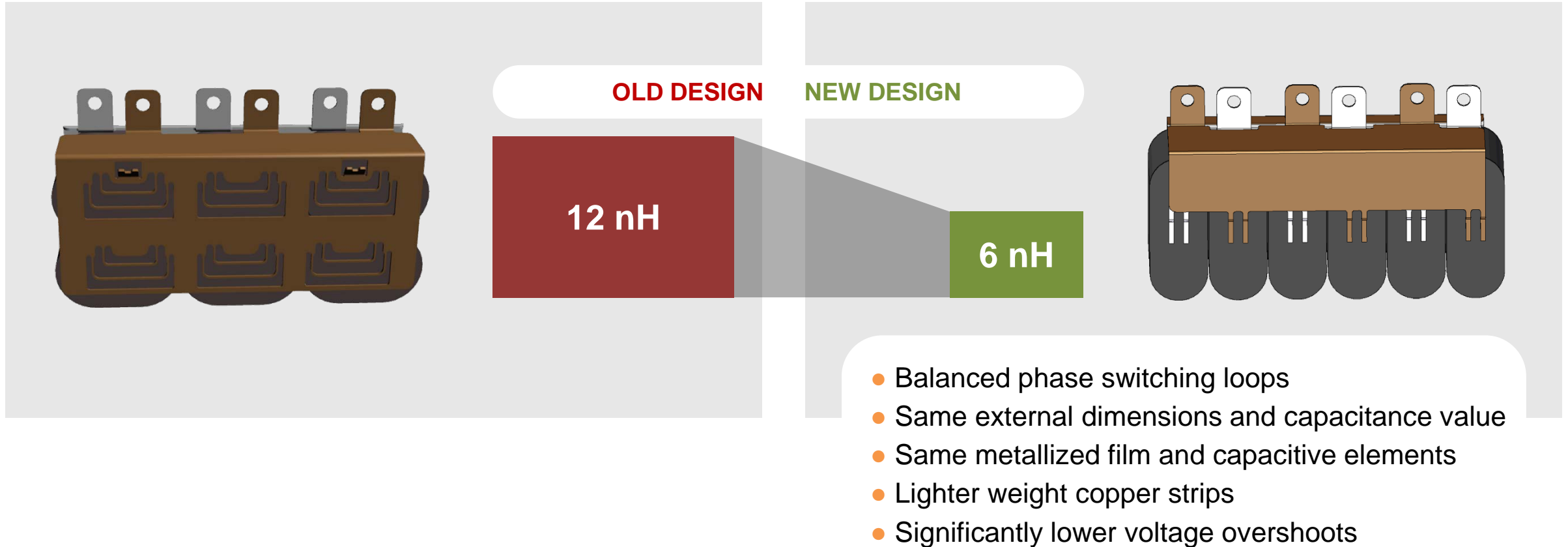
# Design rules for high-frequency capacitors

- **Same impedance** of all internal capacitive elements above, below and close to capacitor resonance frequency
- **Avoid negative electromagnetic interactions** between conductors (FEA electromagnetic software)
- **Overlapped busbar** from terminals to winding connection point is required in order to minimize the inductance



**Current must be homogeneously distributed at all frequencies**

# Optimized design enables lowest ESL



**Makes snubber capacitors unnecessary in most cases**

# Introducing the new HF film capacitor series

## Fully compatible with SiC and advanced Si semiconductors

- High power density
- Suitable for higher ambient temperatures
- Suitable for fast transients (dV/dt) and ringing effects
- Modular and suitable for parallel connection
- Snubber avoidance / low voltage overshoot
- Compact and lightweight, enables lighter cooling system

NEW



## Applications

Traction, industrial drives, renewable power

700 V / 2300  $\mu$ F to 2.2 kV / 370  $\mu$ F

Frequency operation range up to 2 MHz

ESL of 10 nH with 2 terminals

High current density of up to 150 A/mF @ 700 V and 950 A/mF @ 2200 V

Operating temperature (without voltage derating)

- Standard polypropylene: +105 °C
- Advanced COC-PP dielectric: +125 °C (in development)

Compact dimensions (4 sizes):

- 205 x 174 x 75 mm (l x h x w)
- 205 x 174 x 100 mm
- 210 x 126 x 70 mm
- 210 x 126 x 95 mm

Resin-filled plastic case

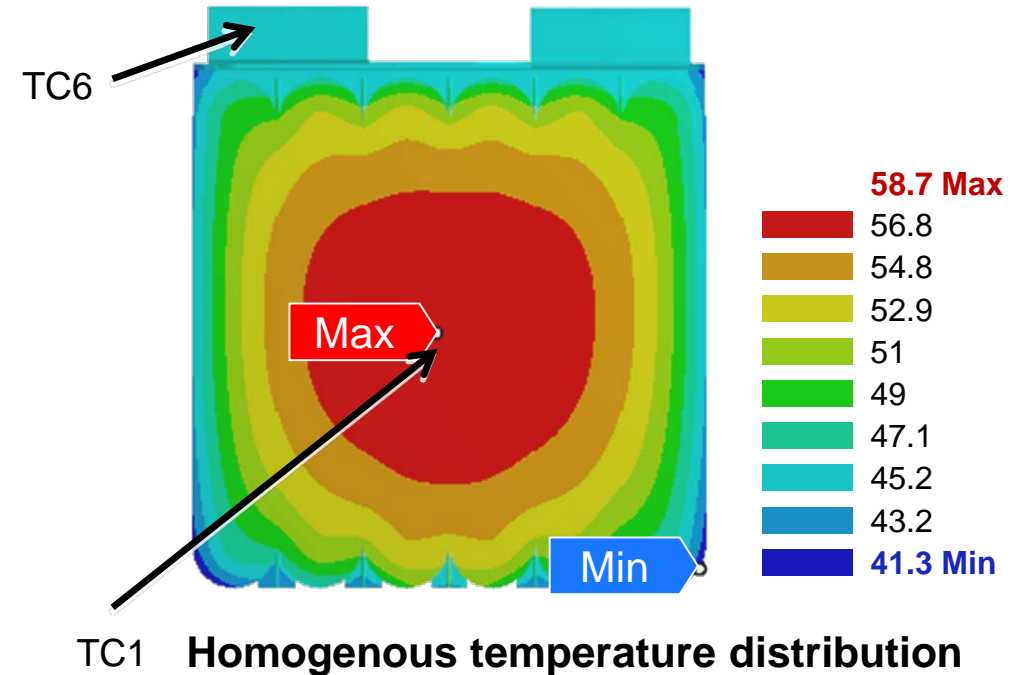
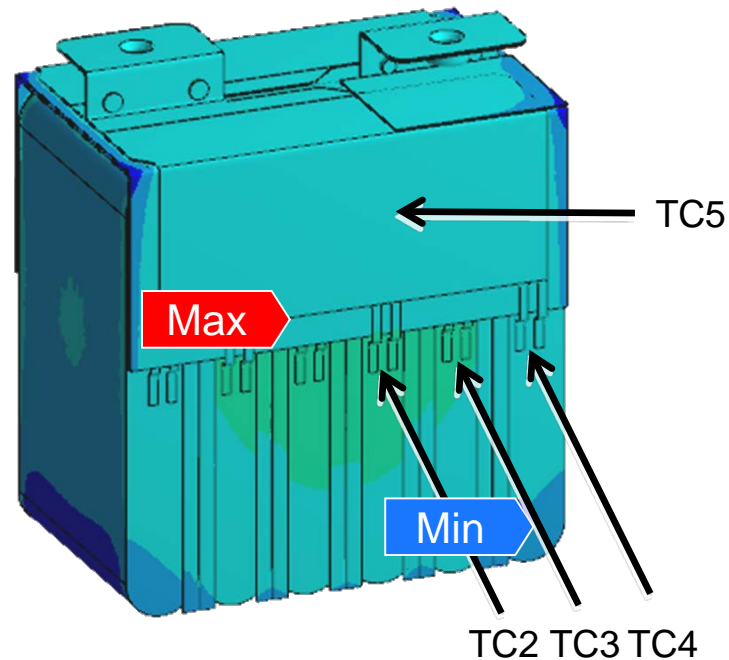
EN 45545 HL2 R23 (fire and smoke)



# Advantages of new capacitor designs with a single winding

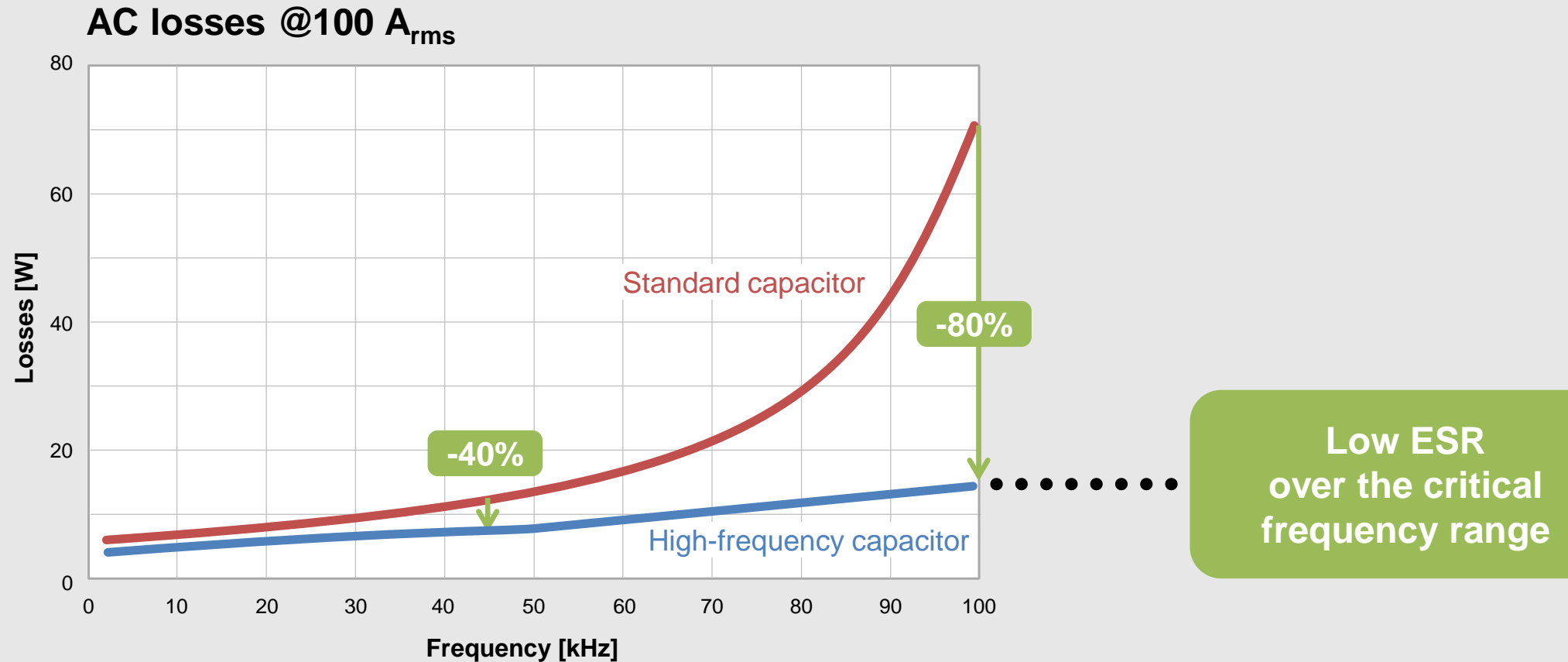
## Boundary conditions

- Current: 130 A<sub>rms</sub>
- Frequency: 30 kHz
- Ambient temperature: 30 °C
- Power losses: 13.2 W



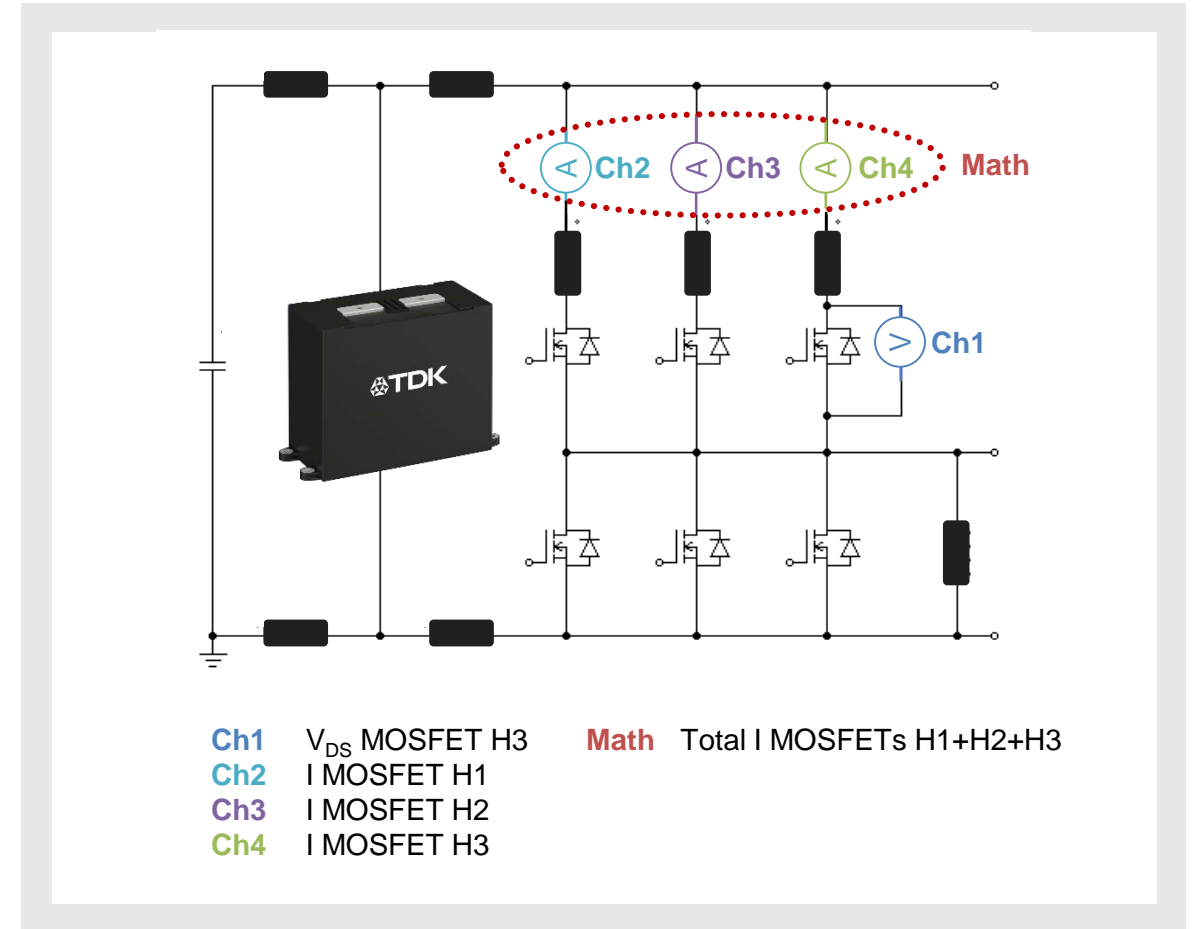
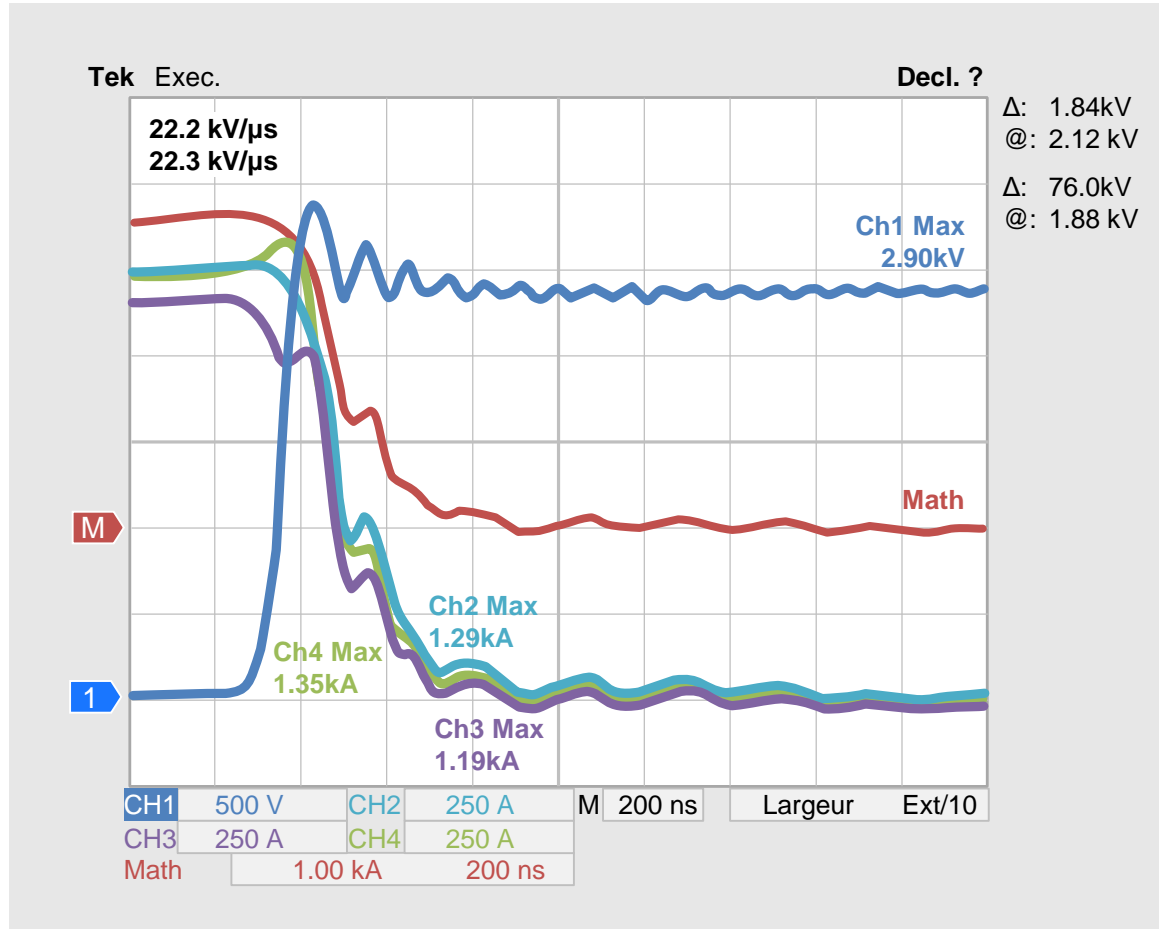
New capacitor designs enable stable thermal performance

# New capacitor design enables linear ESR characteristics



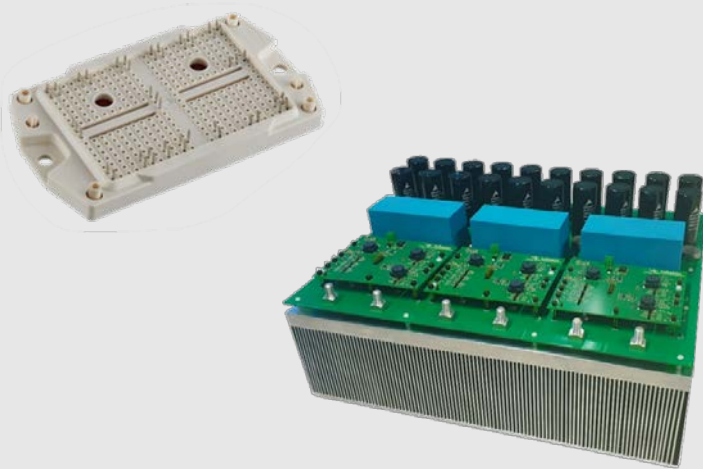
**New design features 80 percent lower AC losses at 100 kHz**

# Ready for hard switching



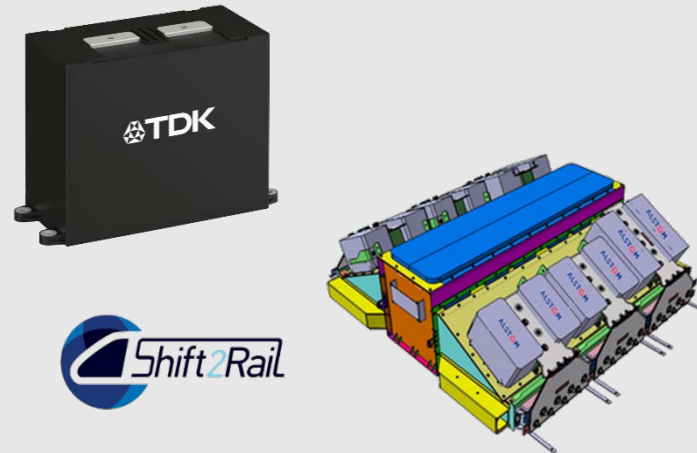
**New HF film capacitor series with extremely low voltage overshoot and ringing**

# Selected development projects with new HF film capacitors



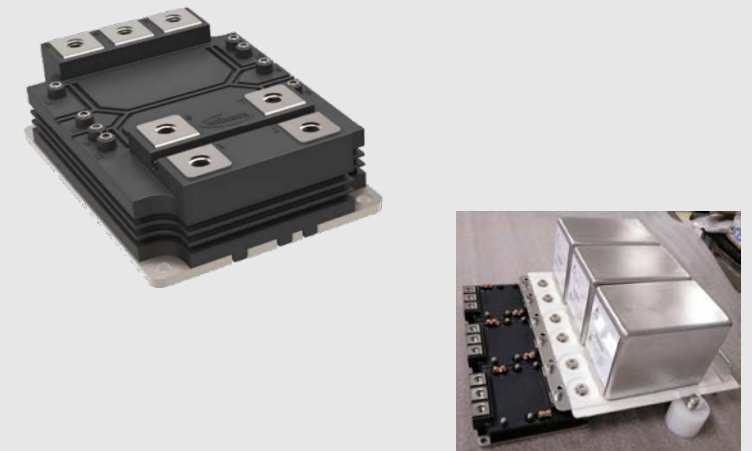
## Solar 1500 V power module (reference)

- Infineon Easy 3B: IGBT + SiC MOSFET
- TDK DC link capacitors: HF film + aluminum electrolytic



## ALSTOM traction converter

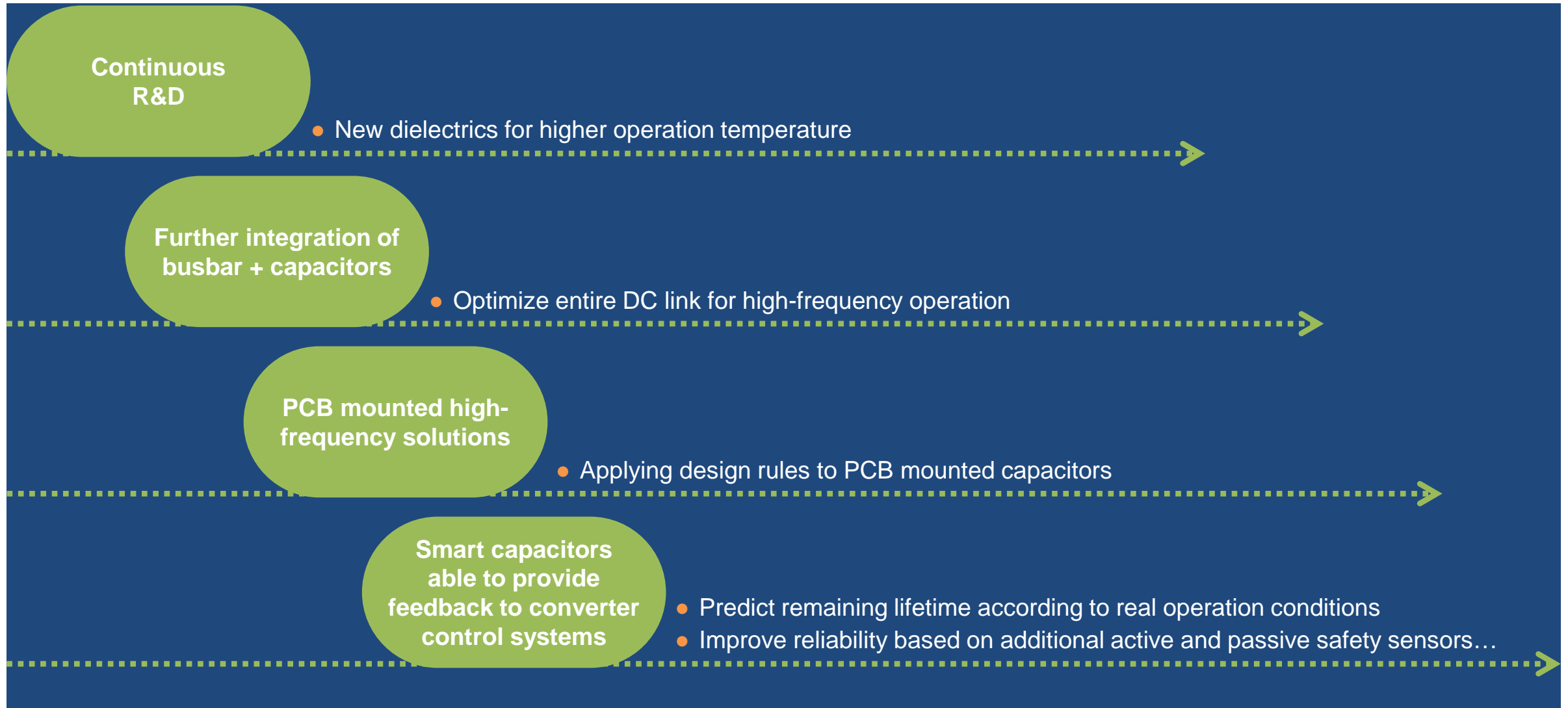
- 3.3-kV SiC MOSFET
- New TDK HF film power capacitor



## Traction power module (reference)

- Mitsubishi LV100 3.3kV SiC MOSFET
- New TDK HF film power capacitor
- Parallelization
- Extension to Infineon XHP2 (1.7 kV and 3.3 kV): Ongoing

# Future development focus







[www.tdk-electronics.tdk.com](http://www.tdk-electronics.tdk.com)