Metallised Film Comparison

	PP	PET	PEN	PPS
Dielectric Strength	650V/µm	550V/µm	500V/µm	450V/µm
Temperature Stability	+	-	-	- -
Dielectric Losses	++	- -	- -	+
Maximum Temperature	105° C	125° C	150° C	150° C
Self Healing Behaviour	++	O	-	-
Cost	++	+	- -	- -

PP = Polypropylene
PET = Polyethylene Terephthalate
PEN = Polyethylene Naphthalate
PPS = Polyphenylene Sulfide

Metallized Film Comparison

Metallized Polypropylene (MKP) Capacitors have become the preferred solution for High Power Capacitors, due to the wide **voltage range** available, **very low losses** and **excellent cost.**

	PP	PET	PEN	PPS
Dielectric Strength	650V/µm	550V/µm	500V/µm	450V/µm
Temperature Stability	+	–	–	++
Dielectric Losses	++	– –	– –	+
Maximum Temperature	105° C	125° C	150° C	150° C
Self Healing Behaviour	++	o	–	–
Cost	++	+	– –	– –

However, their relatively low **max operating temperature** limits their use in applications with high ambient temperatures and their maximum effective current.

Power Film Capacitor Design Criteria

Factors considered by manufacturers when designing a power film capacitor

A “Complete” Data Sheet

- Lifetime (Hrs)
- Failure Rate (FIT or Survival Rate)
- Operating Temperature associated with Voltage and Current Ratings
- Lifetime Curves showing relationship between Operating Temperature and Operating Voltage / Rated Voltage Ratio
- Rms Current vs. Temperature Graph

Many data sheets are missing critical information which makes it difficult to truly understand performance characteristics – Ducati fully characterizes its products

ICT POWER USA

Lifetime / Failure Mode

To correctly define the expected Life-Time and thus dimension the MKP Capacitor for a certain application, it is necessary to define/estimate:

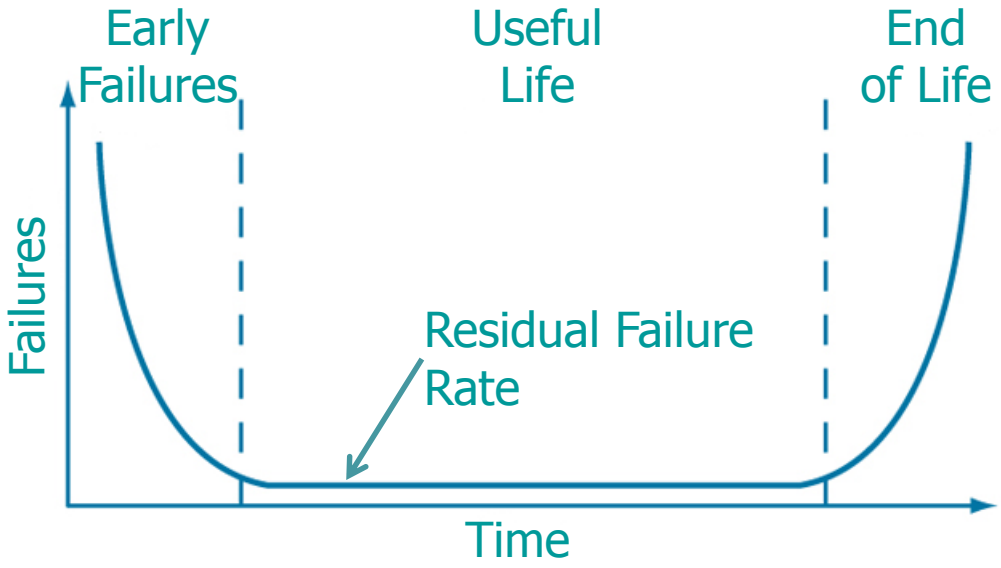
- **The Electrical Stress**
- **The Thermal Stress**
- **The Residual Failure Rate (FIT Rate)**

Lifetime / Failure Mode

The main parameters driving the ageing of PP Film are

- **Electrical Stress – expressed as**
  - Gradient of Electrical field applied to PP Film [V/µm]
  - Operating Voltage / Rated Voltage [U/U_N]
- **Thermal Stress**

Data indicates MKP Capacitors age according to a two-parameter Weibull distribution, which results in a life-cycle described by the typical **«Bathtub Curve»**



DIMENSIONING CRITERIA

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Electrical Stress Determination

U_{APP} → $U_{N\text{-}CAP}$

For example, a dielectric film capable of withstanding 1500V, can be used in a 900V or 1200V *RATED* capacitor.
The 900V RATED part using this film would have a higher reliability than a 1200V RATED part using the same film

$U_{N\text{-}CAP}$ ⟷ **V/µm**

Assigned by each manufacturer based on its **Metallisation and Winding Technology** as well as its chosen **Safety/Reliability Level**

↓

Capacitor Dimension – Form Factor

↓

Thermal Resistance R_{TH}

Thermal Stress Determination – HotSpot Calculation

$$\theta_{HS} = \theta_C + R_{TH} \times (P_J + P_D)$$

θ_C = Temperature of the Case

P_J = Resistive Losses = R_s x I_{RMS}^2

P_D = Dielectric Losses (practically negligible for MKP Capacitors)

DIMENSIONING CRITERIA

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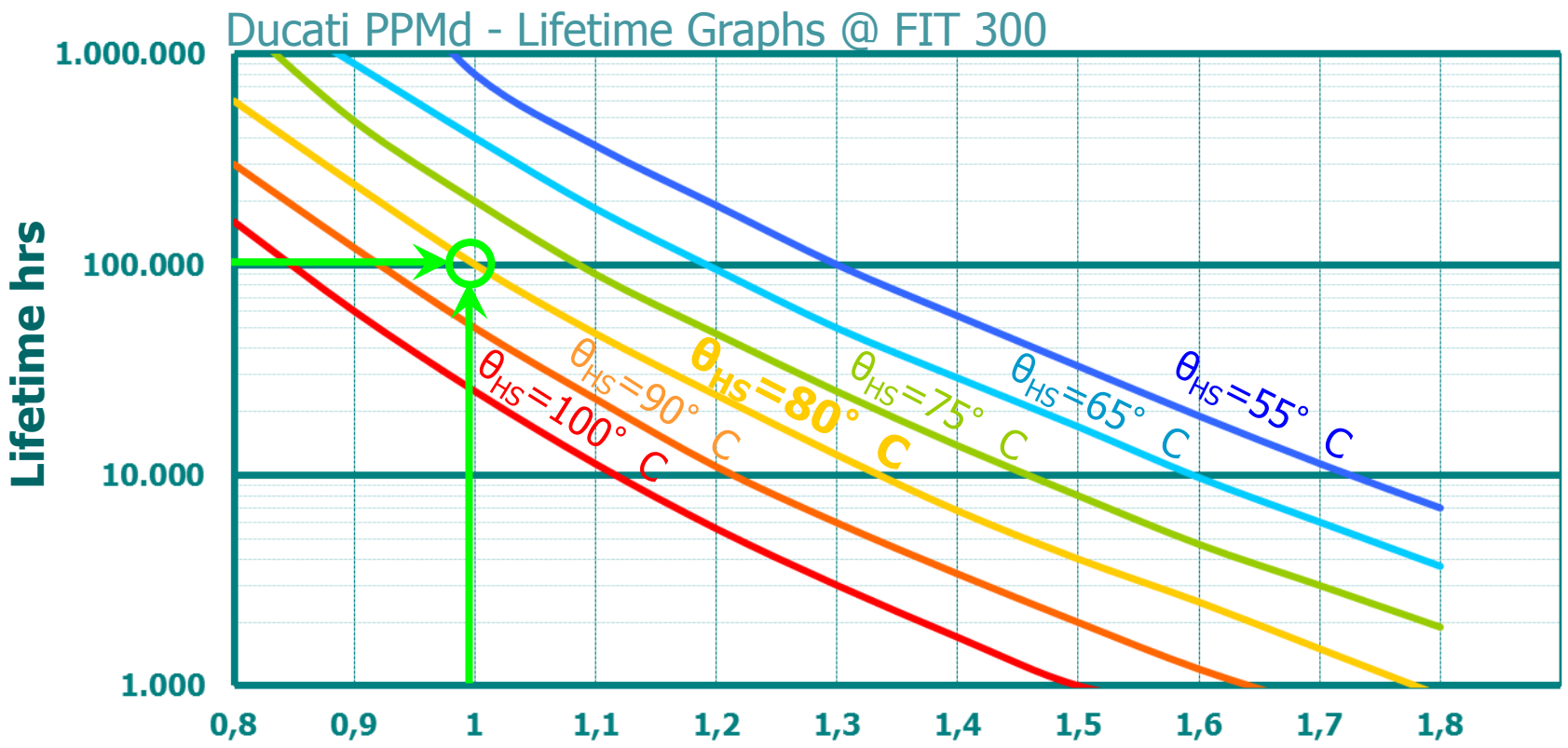
Calculation of Useful Life



Working Voltage / Rated Voltage U/Un

Market Drivers for Next Generation Polypropylene Film Capacitor Product Development

New Generation Converters' demand to DC-Link Caps

Higher Power Density

- Higher Capacity per Volume (µF/cm3) = Higher V/µm
- Higher RMS Currents

Higher Ambient/Case Temperatures in Operation

$V/\mu m \Longleftrightarrow U/U_N$

$\theta_{HS} = \theta_C + R_{TH} \times (P_D + P_J)$

Longer Lifetime / Lower FIT Rates

$\frac{V_{applied}}{\mu m}$

$\frac{\theta_{HS}}{\theta_{MAX}}$

Technical Requirements for Product Development of Next Generation Polypropylene Film Capacitor (based on market drivers)

OUTLOOK

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To meet the aforementioned goals, it is necessary to:

1. Increase the max. operating temperature of the metallised film
2. Increase the V/µm of the metallized film

	PP	PEN	PPS
Dielectric Strength	650V/µm	500V/µm	450V/µm
Temperature Stability	+	–	– –
Dielectric Losses	++	– –	+
Maximum Temperature	105° C	150° C	150° C
Self Healing Behaviour	++	–	–
Cost	++	– –	– –

PEN and **PPS** Films can be a solution if the main goal is to achieve a very high **maximum operating temperature**.

However, they miss the target of high power density due to **significantly lower max V/µm**; furthermore they may be affected by strong limitations for the max capacity (**high dielectric losses**) and available form factors (**constructive constaints**).

The very **high cost** due to raw material and complex working also limit their capability of substituting PP.

Ducati Energia - New High-Crystallinity metallized PP Film

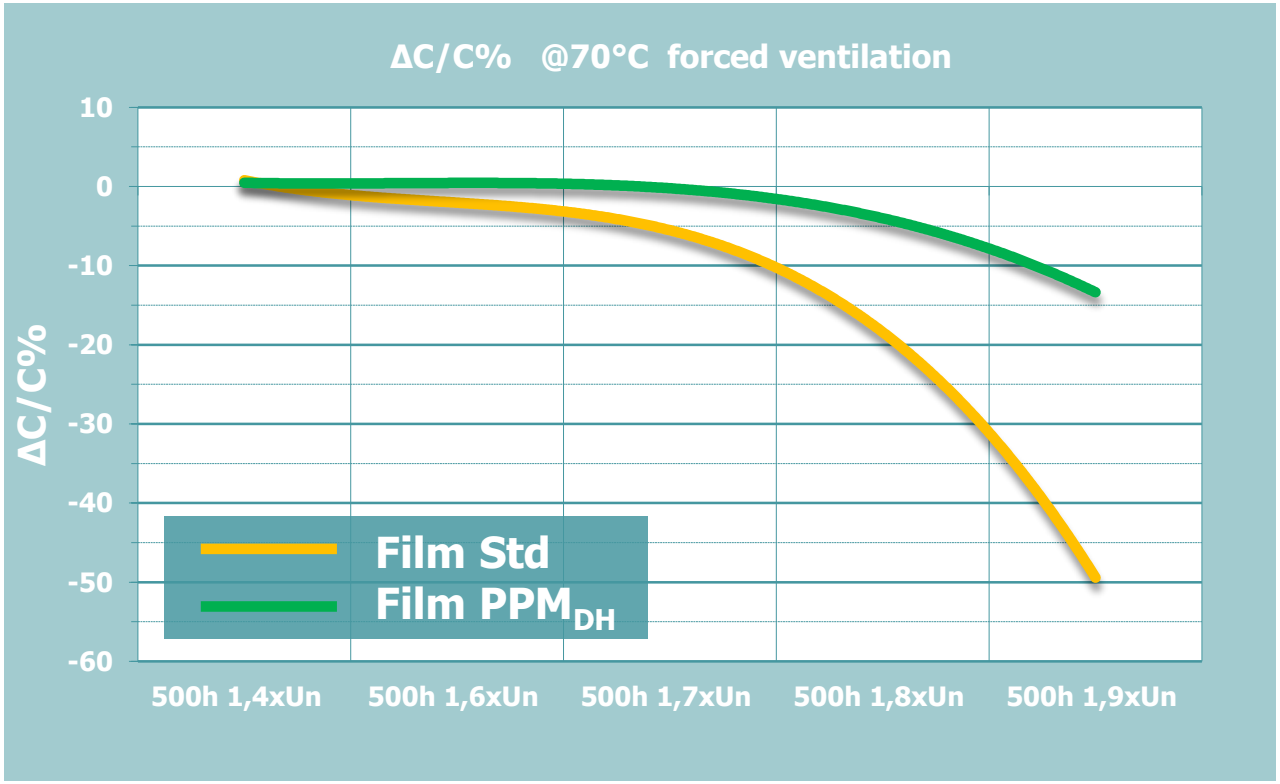
- Developed in cooperation with Raw Material Manufacturer and Research Institutions;
- Increased Max. Operating Temperature to 125° C;
- Increased Operating Electric Stress V/µm (20-25% enhancement);
- Competitive Cost (comparable to standard Metallized PP technology);
- No constructive limitation; 1-to-1 compatible with existing form factors.

Accelerated Life Testing Data For New High Crystallinity Polypropylene Film Capacitors

NEW DEVELOPMENTS

DUCATI energia

Progressive Voltage Stress Test

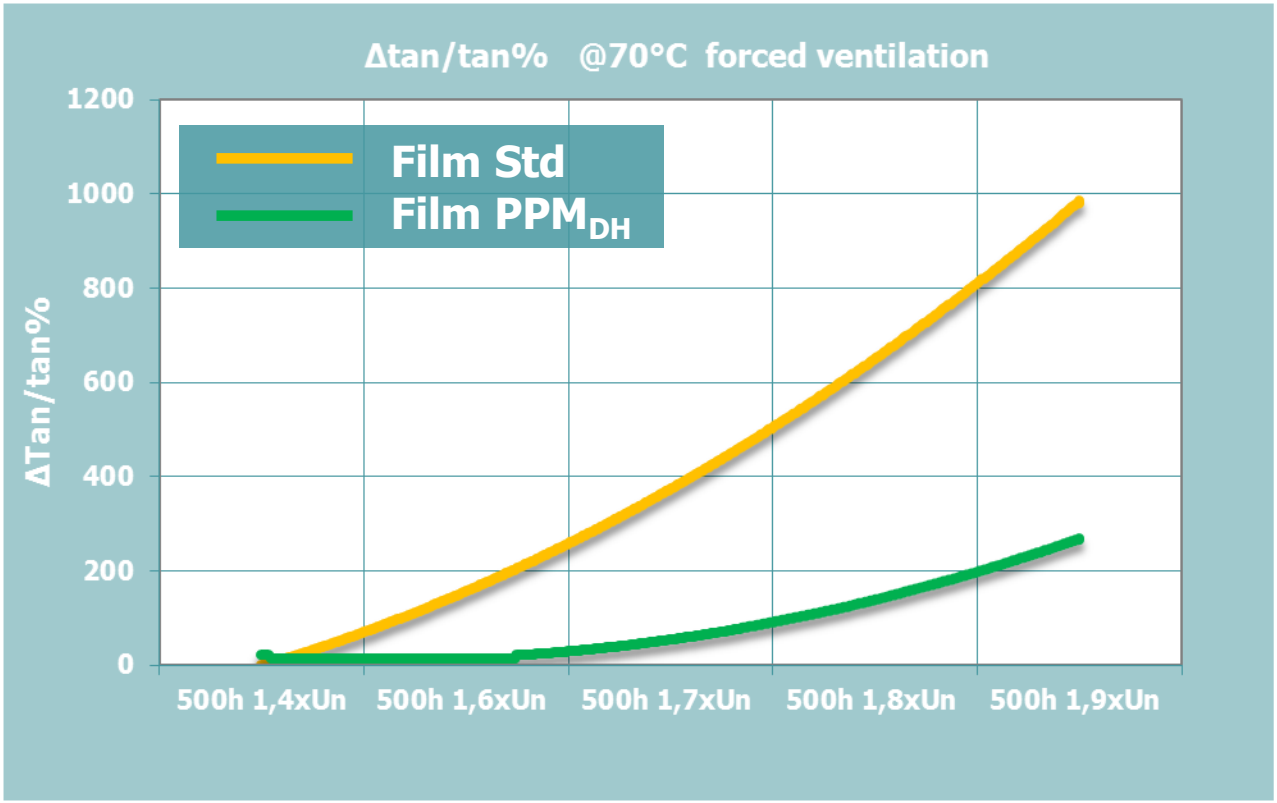


Capacitance Variation

NEW DEVELOPMENTS

DUCATI energia

Progressive Voltage Stress Test

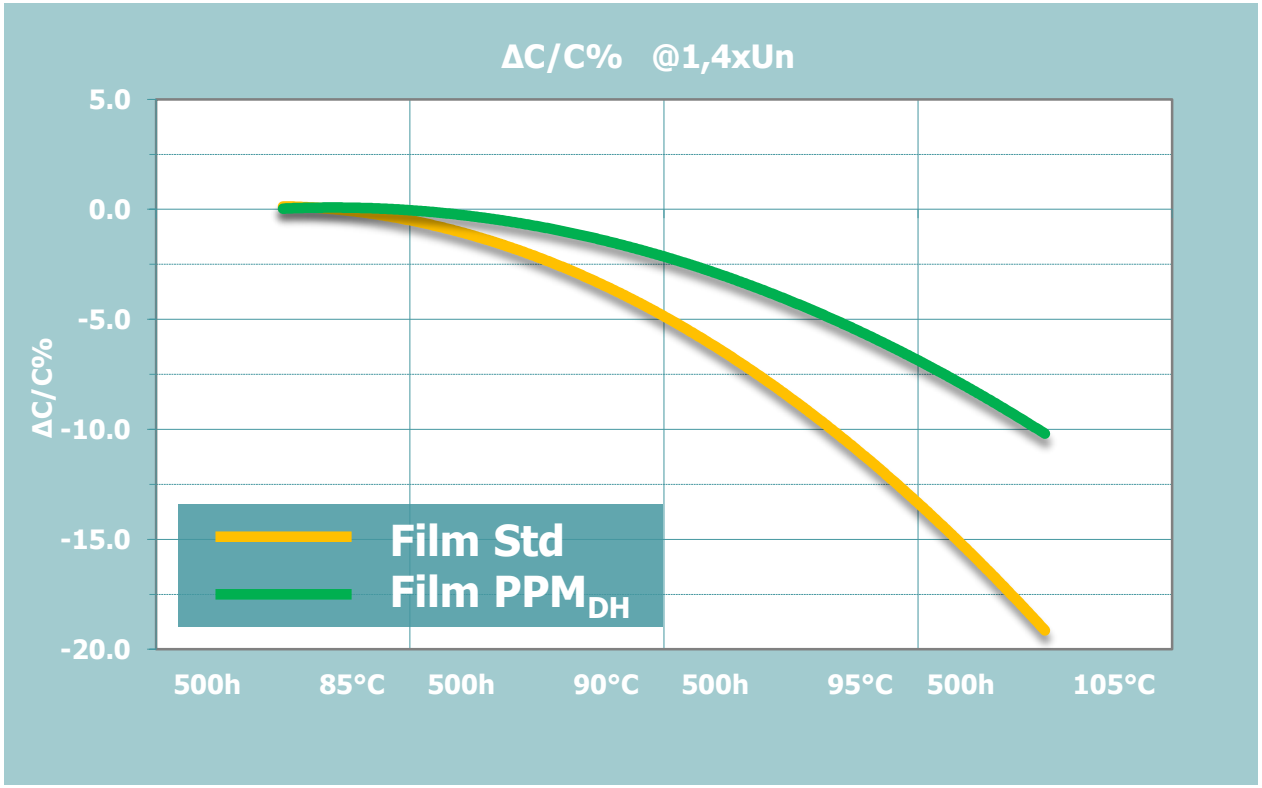


Tand Variation

NEW DEVELOPMENTS

DUCATI energia

Progressive Temperature Stress Test

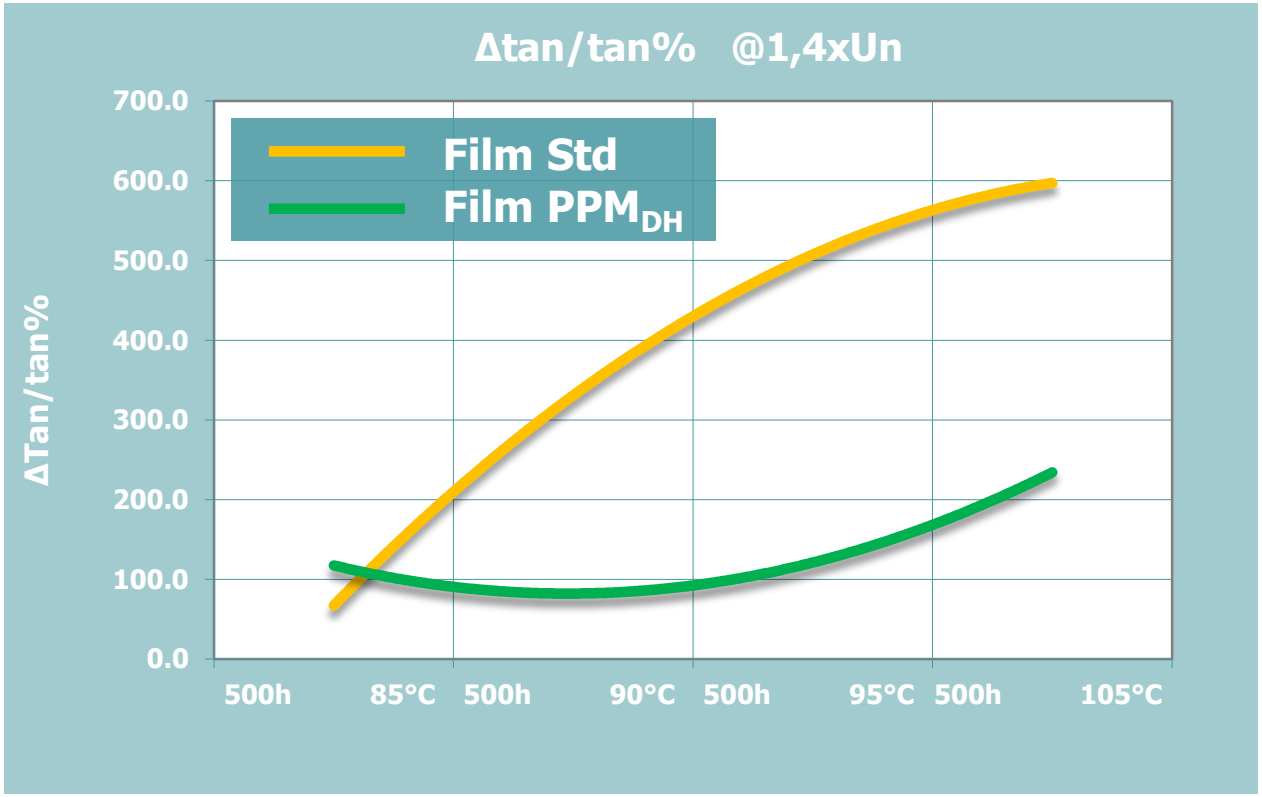


Capacitance Variation

NEW DEVELOPMENTS

DUCATI energia

Progressive Temperature Stress Test



Tand Variation

Ducati PPM_{DH} Film – Updated Caparison Table

	PP	PPM_{DH}	PET	PEN	PPS
Dielectric Strength	650V/µm	**+650V/µm**	550V/µm	500V/µm	450V/µm
Temperature Stability	+	+	–	–	– –
Dielectric Losses	++	++	– –	– –	+
Maximum Temperature	105° C	**125° C**	125° C	150° C	150° C
Self Healing Behaviour	++	++	O	–	–
Cost	++	++	+	– –	– –

Ducati's new **PPM_{DH} Metallised, High-Crystallinity Film** increases the Maximum Temperature of the film to **125° C**.

PPM_D: 100.000hrs at U/Un=1 and θ_{HS}=80° C
PPM_{DH}: 100.000hrs at U/Un=1 and **θ_{HS}=100° C**

Advantages of Ducati PPM_{DH} Film

For the same 100.000hrs Lifetime @ 300FIT reference

- +20° C θ_{HS} – respective to Ducati PPM_D film

$$\theta_{HS} = \theta_C + R_{TH} \times (P_D + P_J)$$

Higher Case/Amb. Temp.

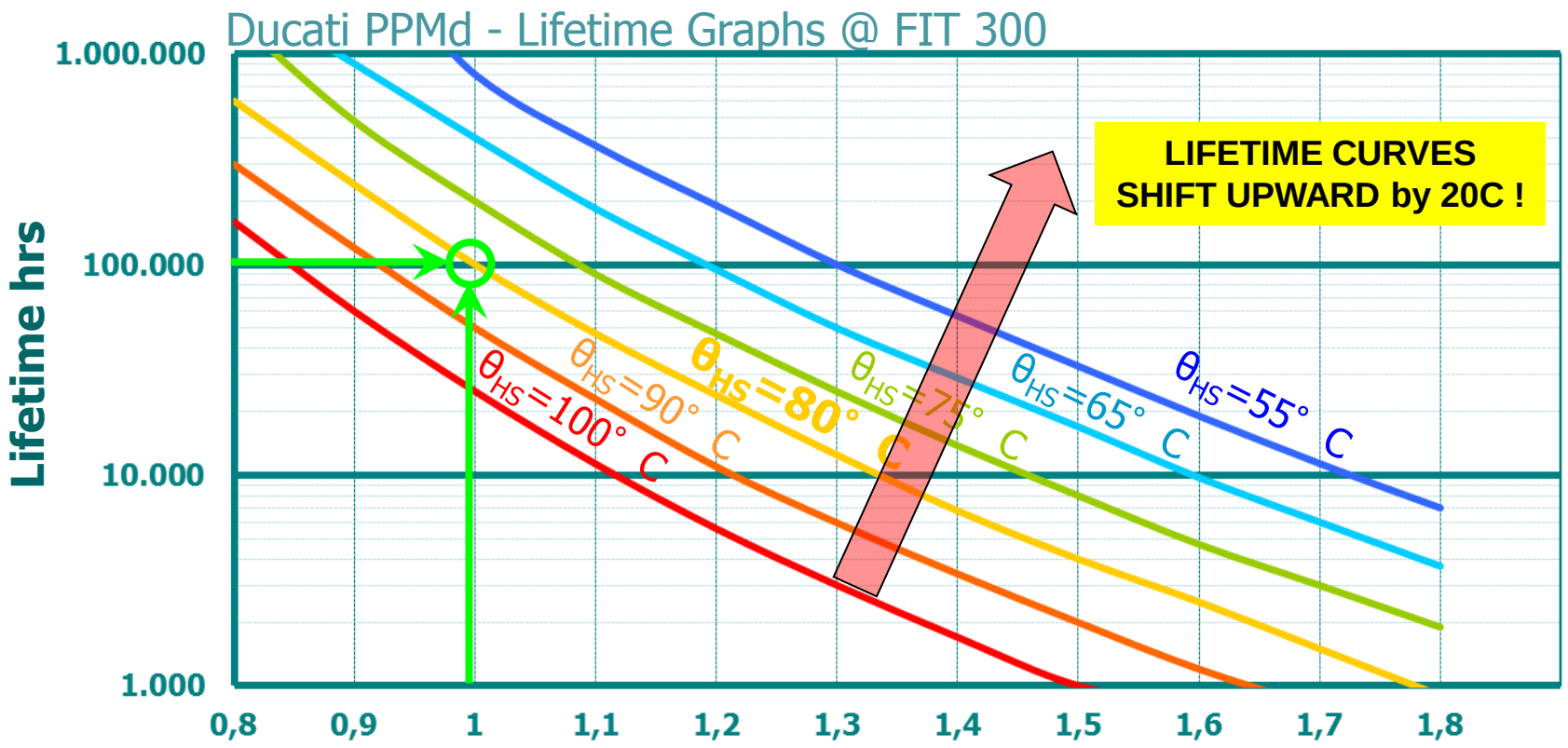
Higher RMS Current

- +25% V/µm Voltage Stress Capability

DIMENSIONING CRITERIA

DUCATI energia

Calculation of Useful Life



Working Voltage / Rated Voltage U/Un

High Crystallinity PP Capacitors – A New Engineering Tool

How will you leverage this new technology in your application?

- Use in higher ambient temperature applications
- Drive more ripple current through each capacitor
  - Increased power density
  - Reduce # caps in DC Link bank to achieve same lifetime / reliability
- Significantly improve lifetime / reliability
  - Direct replacement of existing PP caps with same voltage and capacitance ratings
- Reduce physical size and weight of DC Link capacitor bank
- A combination of any of the above advantages

Work with the Ducati technical sales team to leverage this technology to meet the requirements specific to ***your application***

Advantages of Ducati PPM_{DH} Film

No Reduction of typical PP Film Advantages

- Low Losses → High Capacities / Powers
- Excellent Self-Healing → Excellent Safety / Reliability
- No working process limitation → no size or form-factors limitations; immediately appliable to existing designs
- Excellent Cost → Comparable to standard PPM_D Film