Capacitor Solutions for Resonant Converter Applications

Eduardo Drehmer + Michael Cannon – TDK

Eduardo Drehmer

Director of Marketing

FILM Capacitors

Eduardo.drehmer@tdk-electronics.tdk.com

Background:

- Over 20 years experience with knowledge on Manufacturing, Quality and Application of Electronic Components.
- Responsible for Technical Marketing for Film Capacitors

Michael Cannon

Product Manager

Ceramic Capacitors

Michael.cannon@us.tdk.com

Background:

- Product manager at TDK Corporation of America (Lincolnshire, IL) with over 25 years' experience with passive component applications.
- Contributing member of the Automotive Electronics Council (AEC) and chair of the EIA Ceramic Capacitor subcommittee.
- B.S. in Ceramic Engineering from the University of Illinois.

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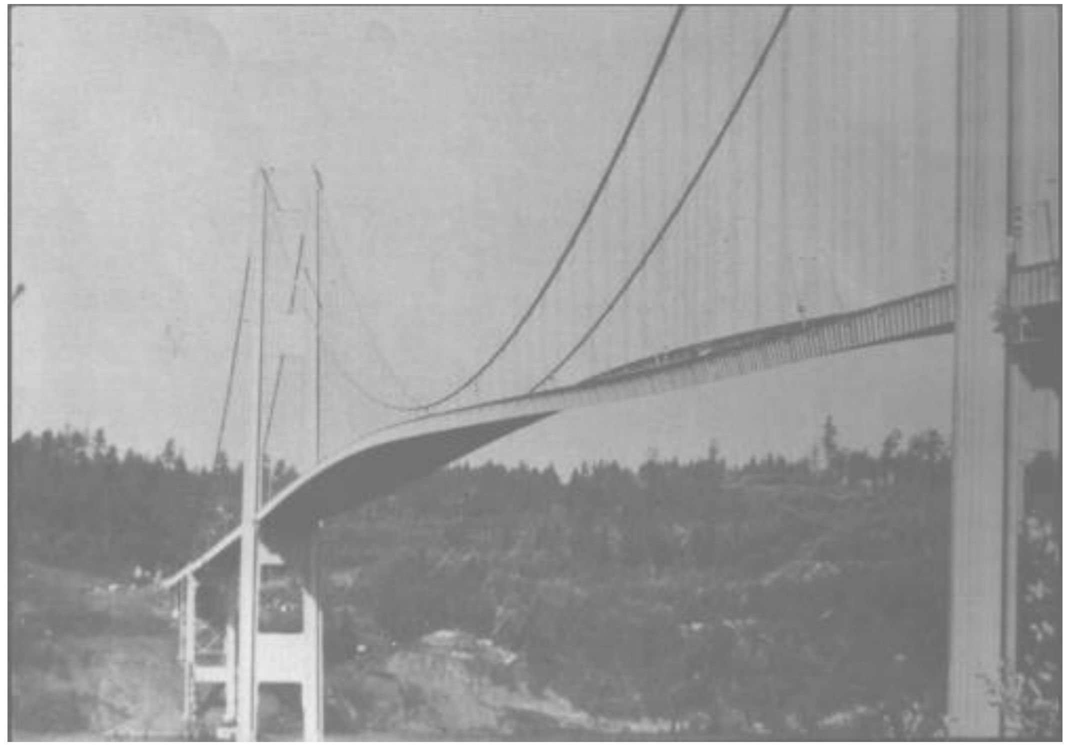
What's resonance?

When an oscillating force is applied at a resonant frequency of a dynamical system, the system will oscillate at a higher amplitude than when the same force is applied at other, non-resonant frequencies.

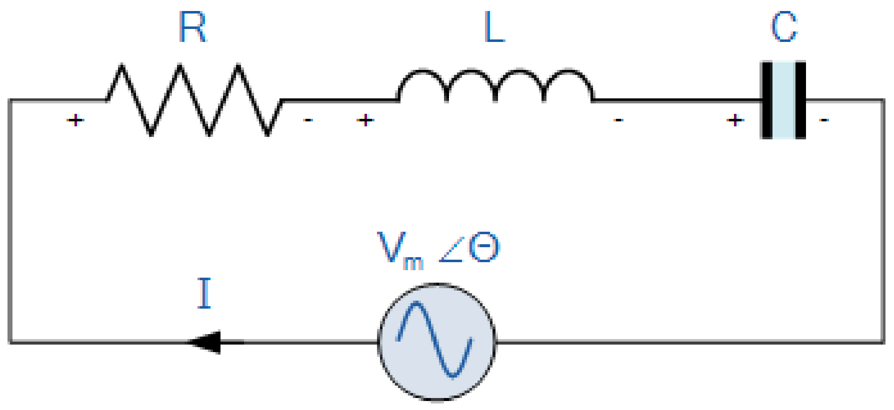
[Halliday, Resnick & Walker 2005]

Good or bad?



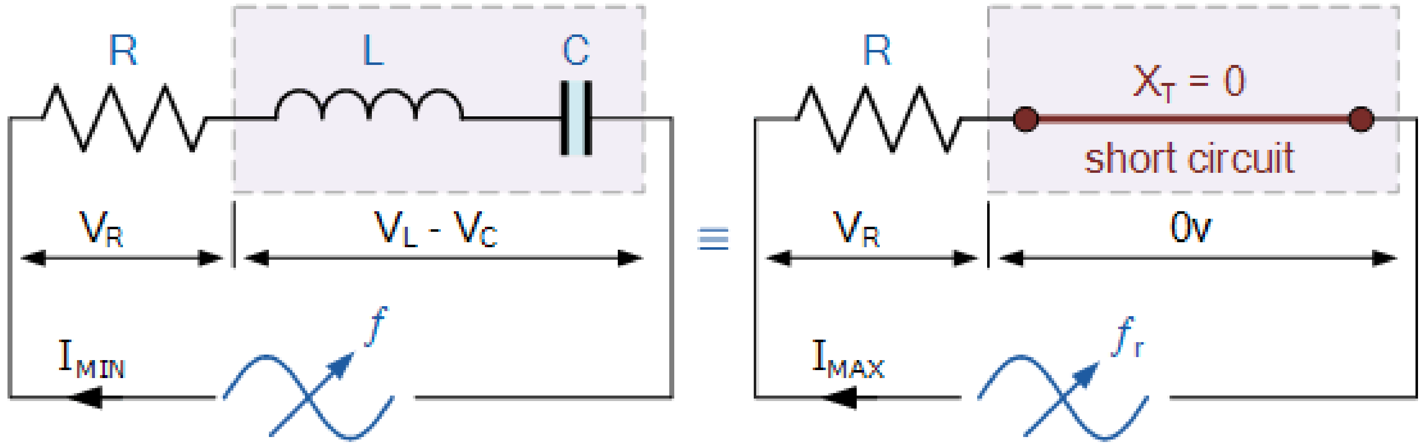
Principles

Series RLC Circuit

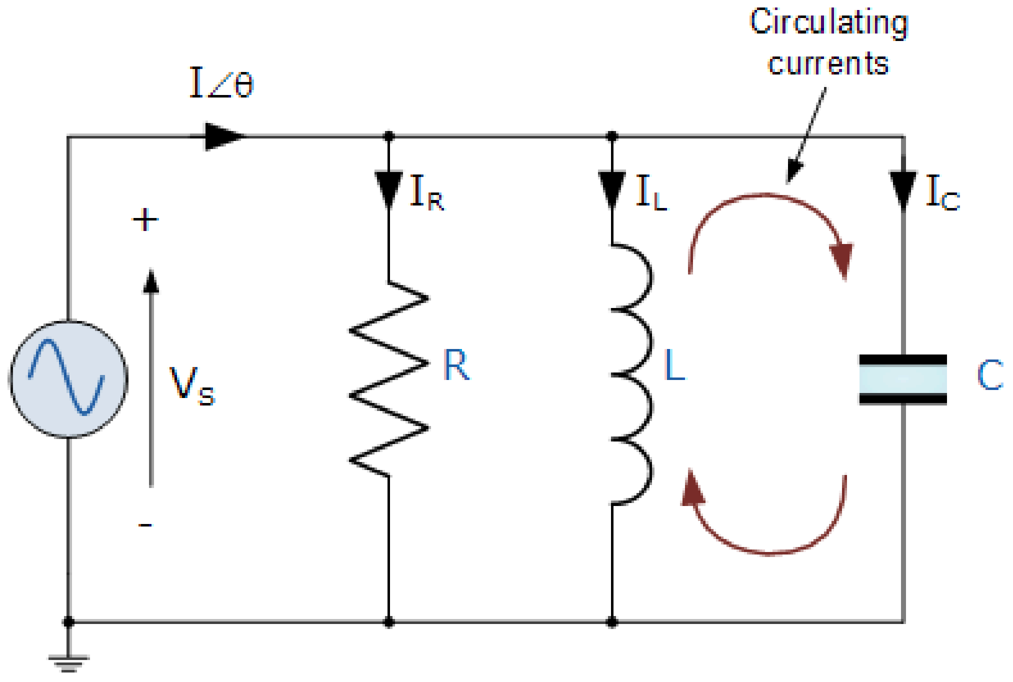


Either side of resonance the voltage drop = $V_L - V_C$

At resonance the voltage drop equals zero

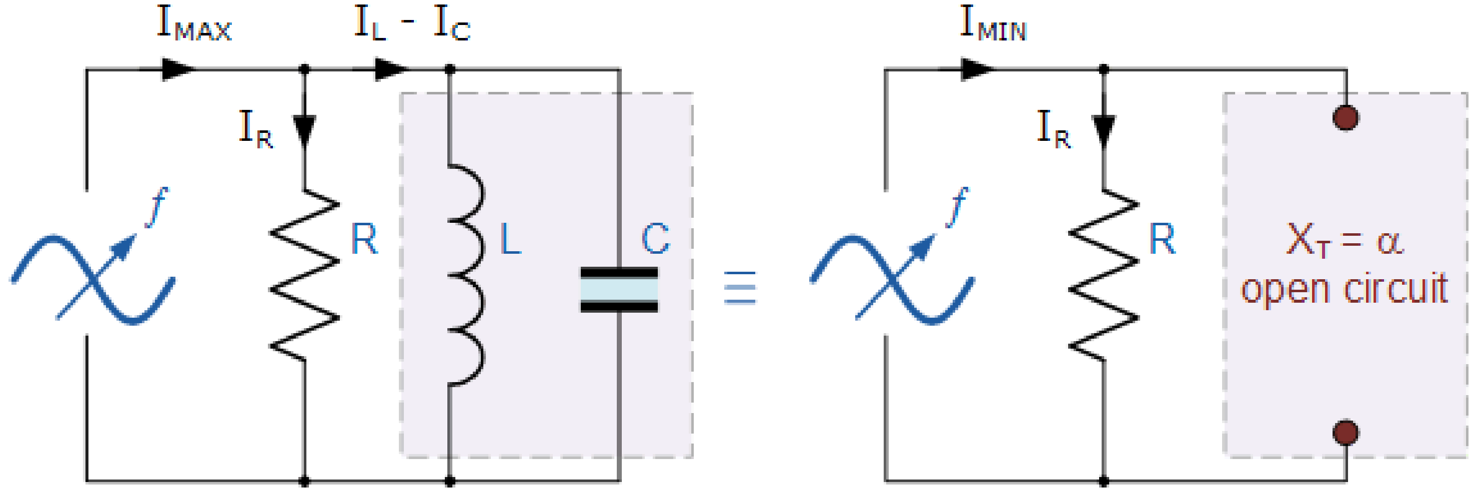


Parallel RLC Circuit



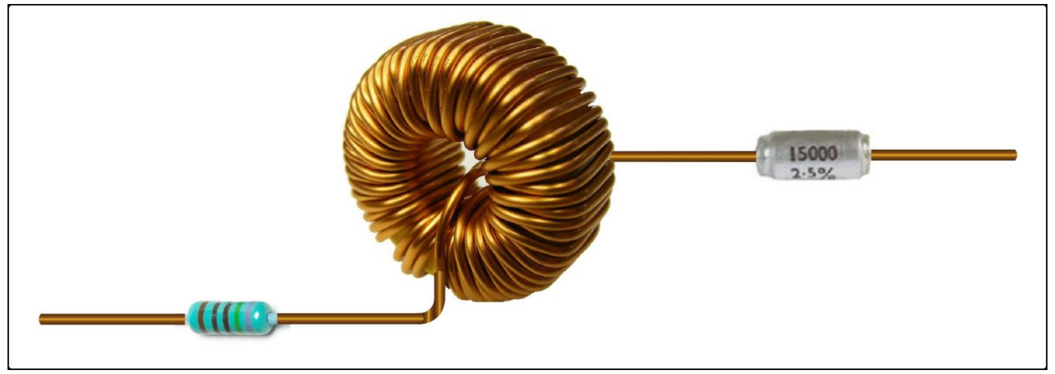
Either side of resonance the current = $I_L - I_C$

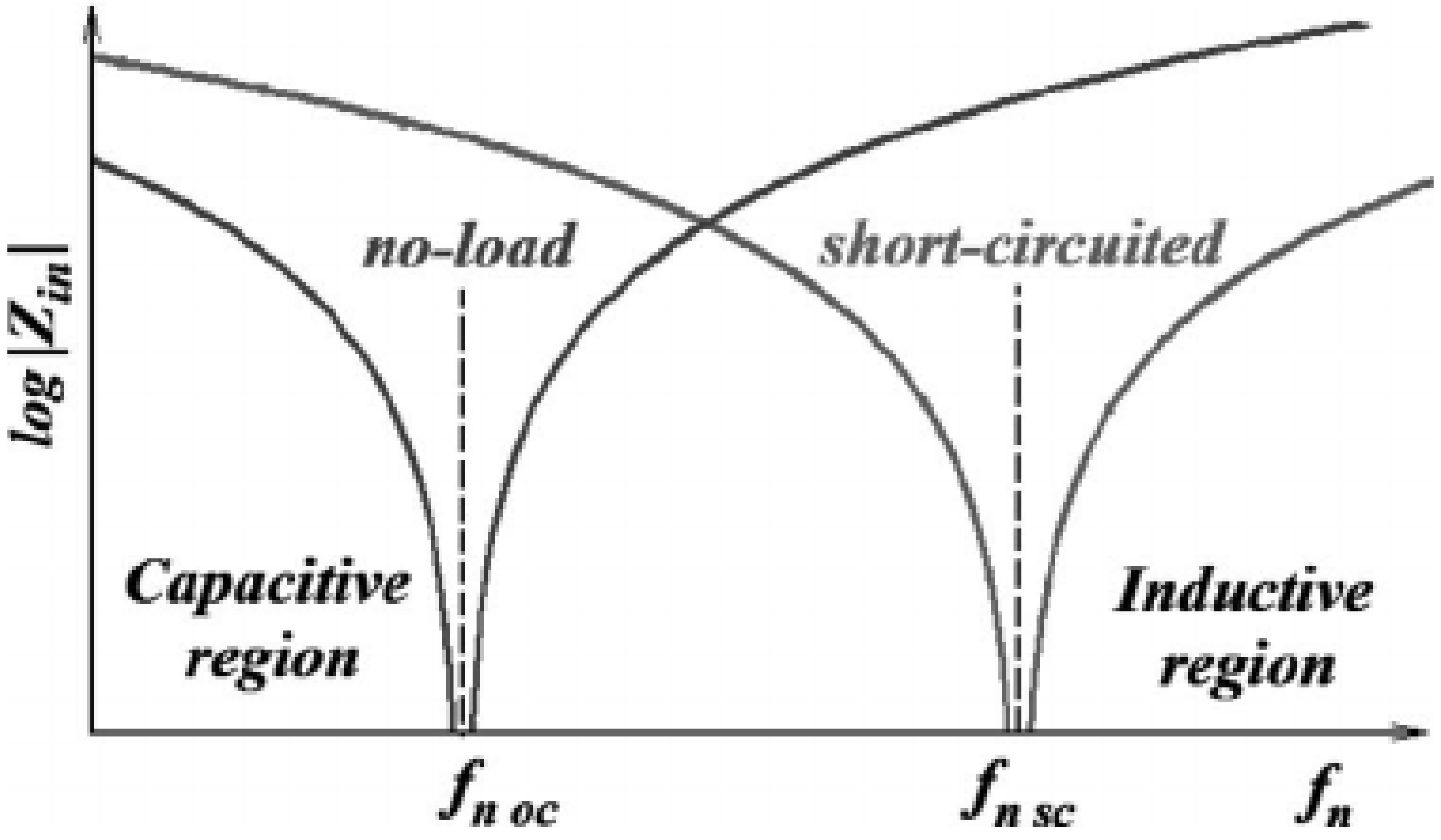
At resonance the reactive current is zero



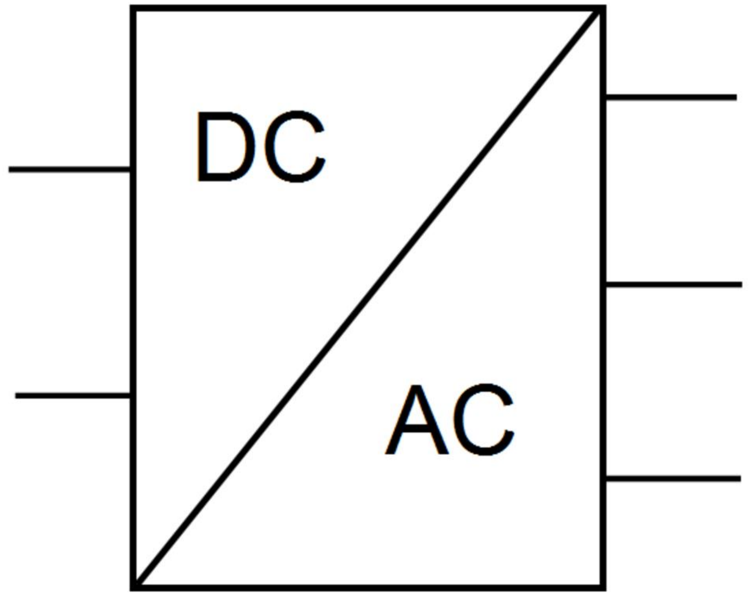
Resonant converters characteristics

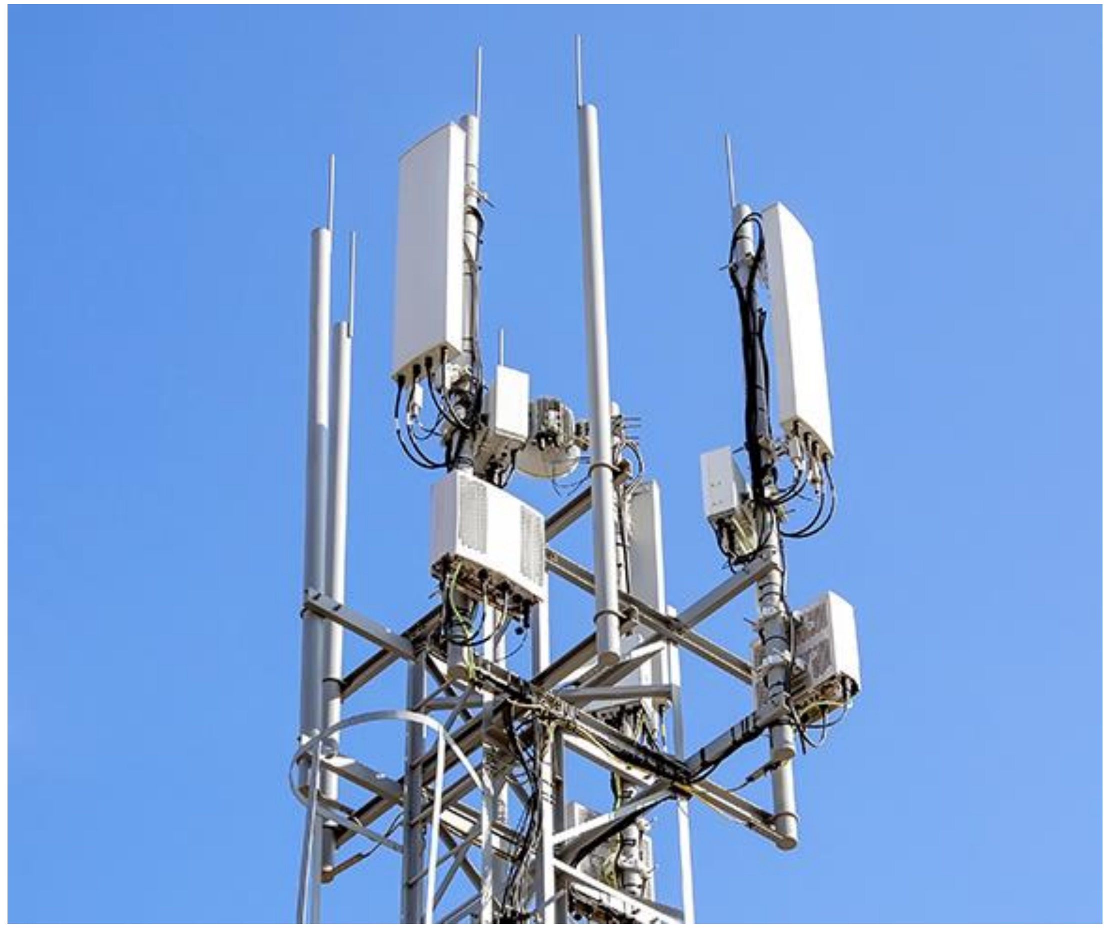
Resonant circuits are very sensitive to variations in impedances of their components and of the load they supply.





Applications



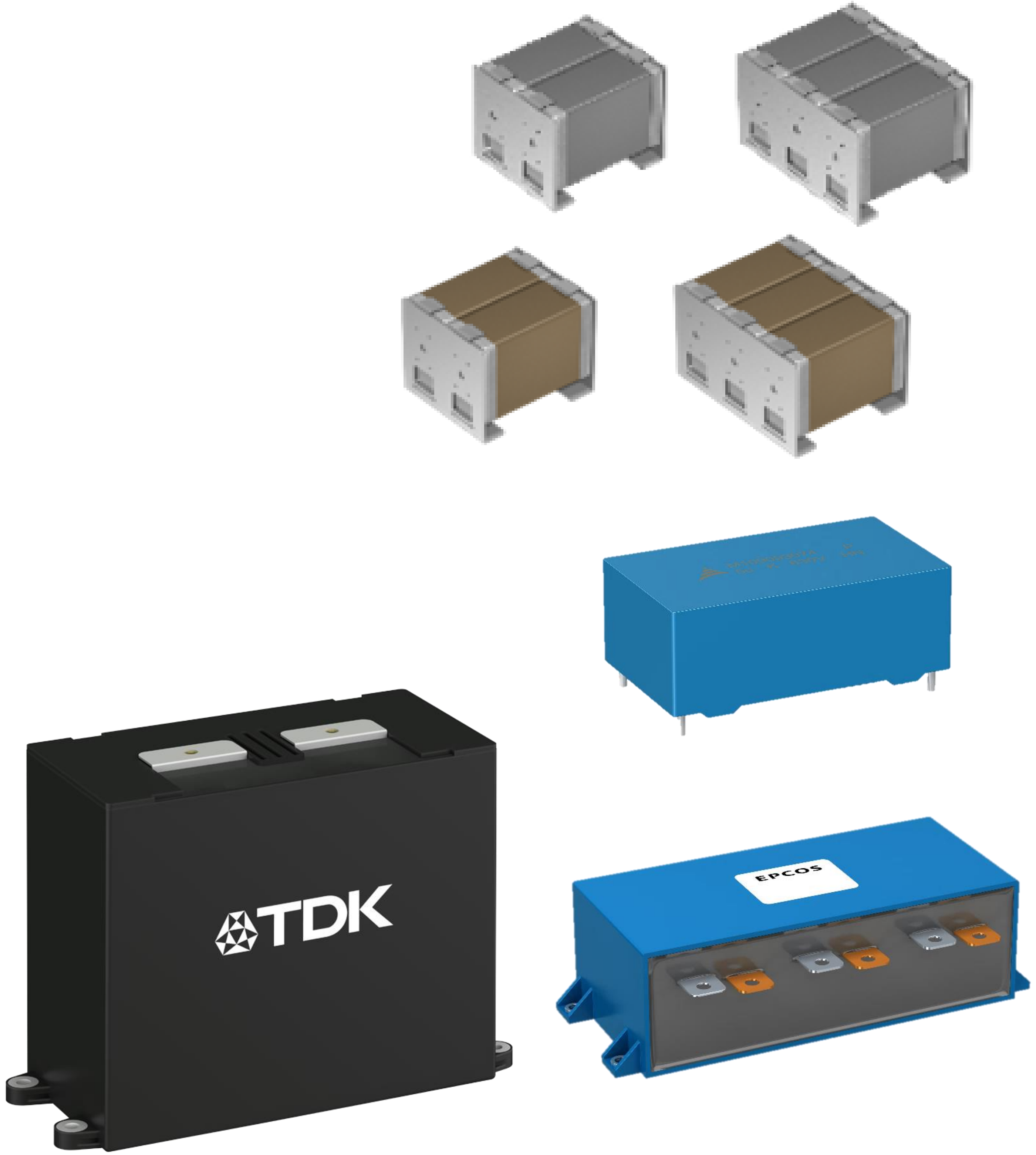


AC/DC

Wireless Power Transmission

WPT is a good example of opportunities for resonant coupled converters.

Capacitor Design considerations



Charging profile challenges
- Variable voltage
- Variable current
- Variable frequency
- Variable temperature

Physical challenges
- PCB/volume constraints
- Creepage and clearance requirements

Processing challenges
- SMD vs. PTH technology
- Soldering temperature

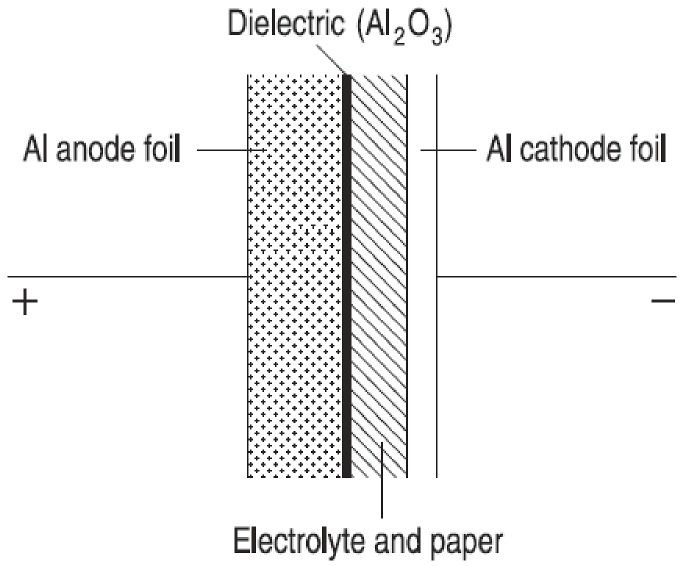
Capacitor Technologies

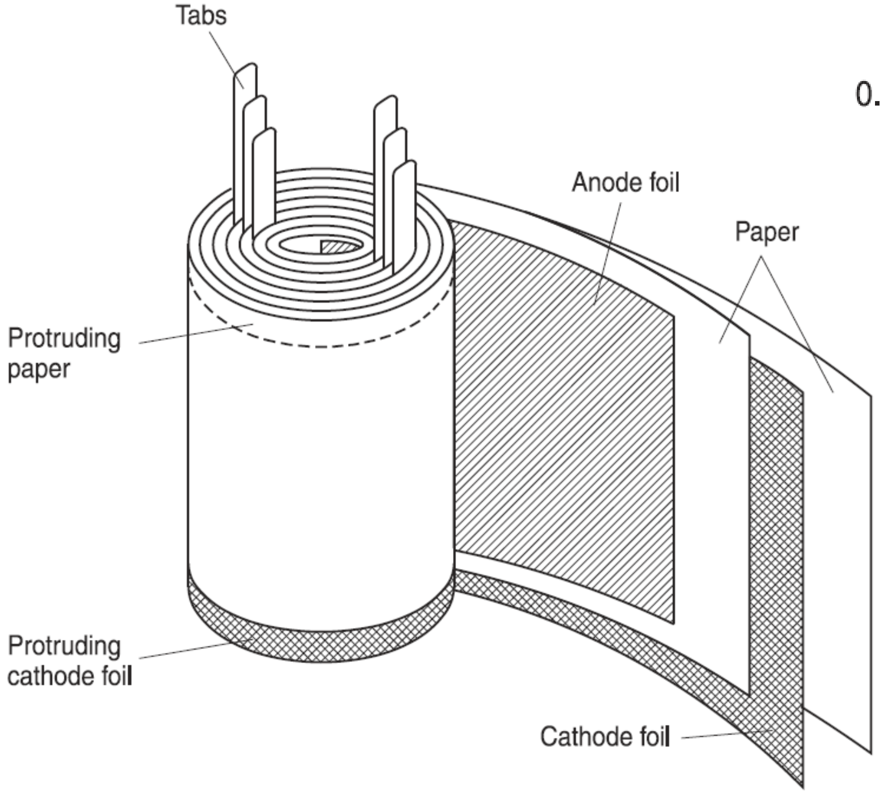
Aluminum Electrolytic Capacitors

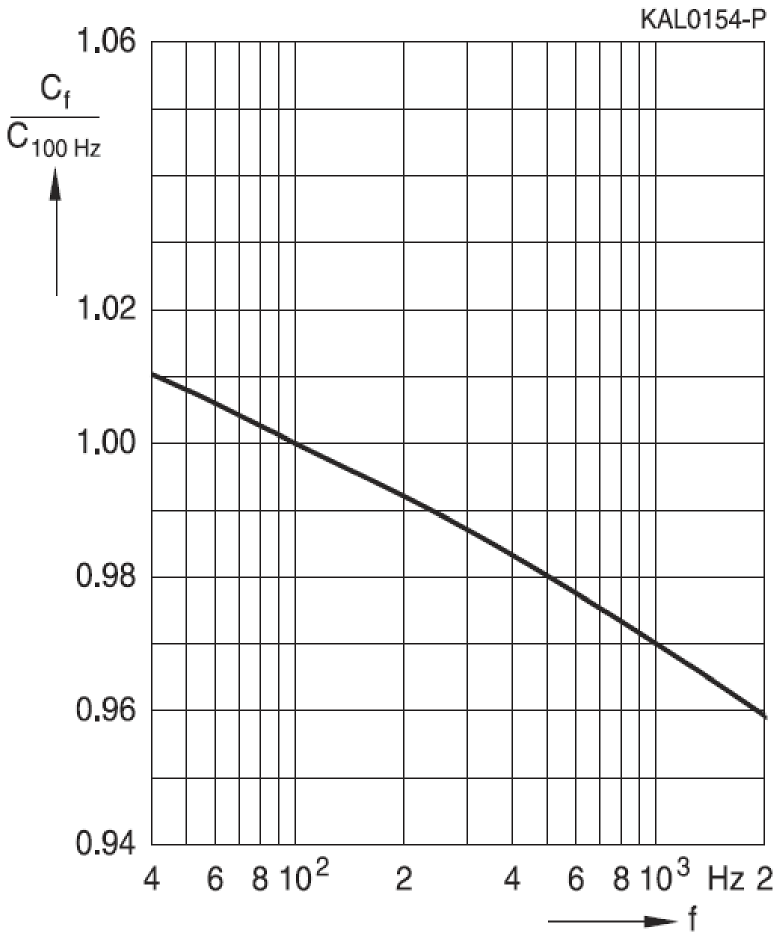
Ceramic Capacitors

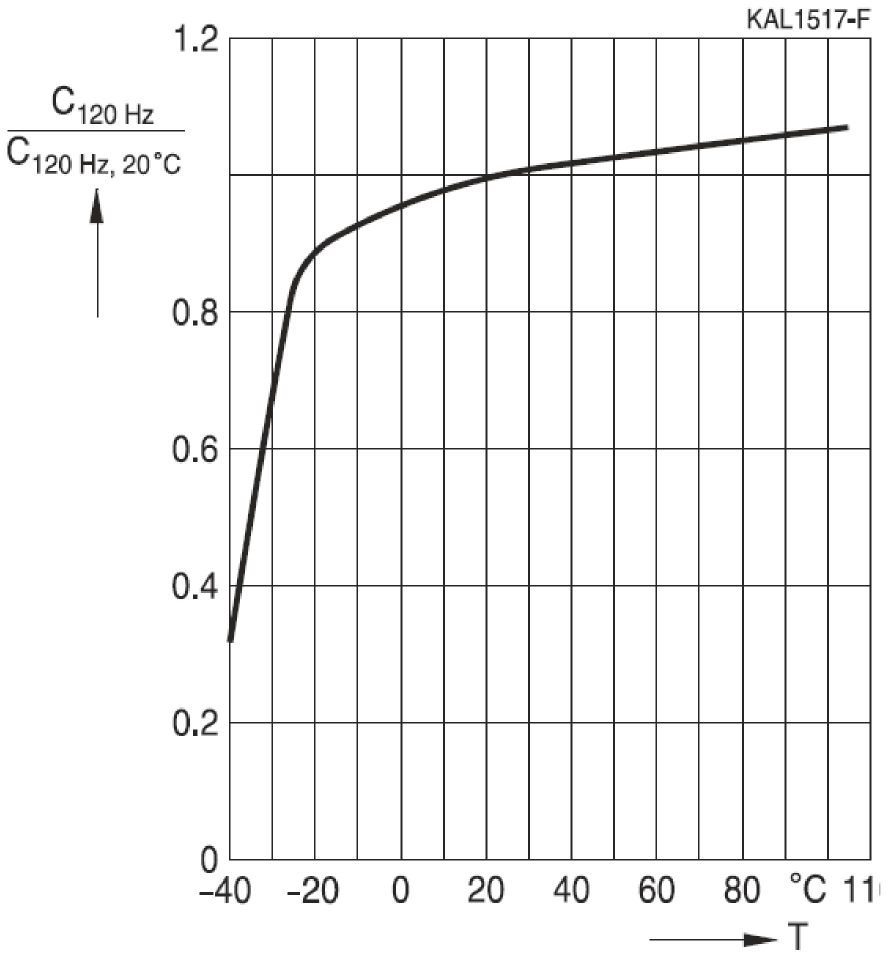
Film Capacitors

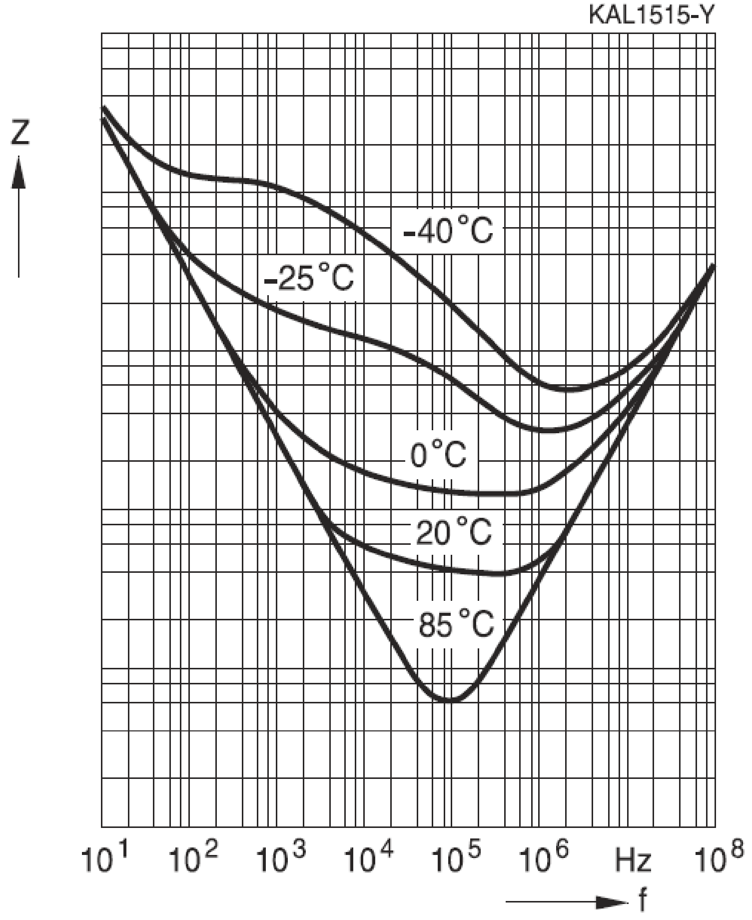
Aluminum Electrolytic Capacitor Characteristics



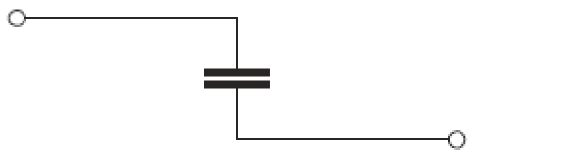
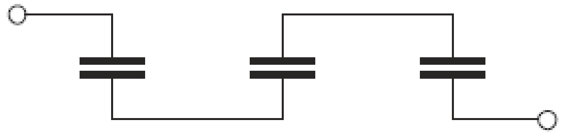
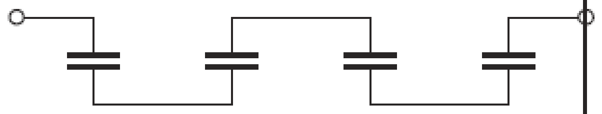


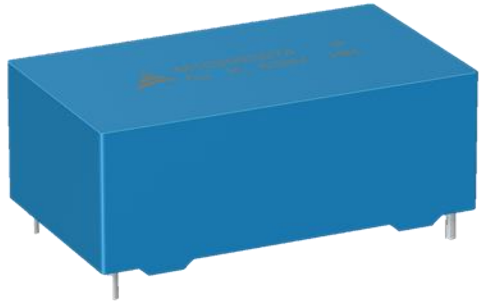


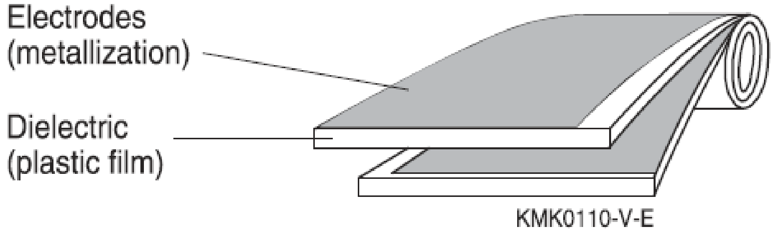


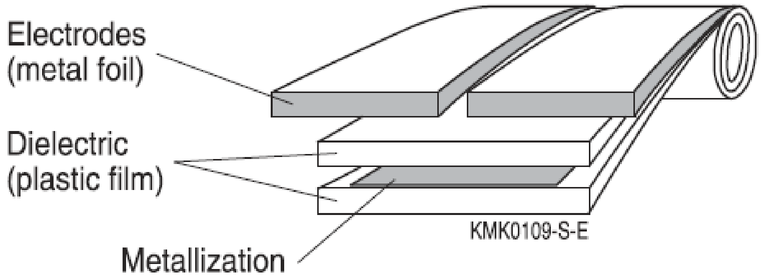


Film Capacitor Characteristics

Simple connection	Film and foil arrangements	Types
 KMK0986-5	 KMK0987-D	MKP MKT MKN EMI suppression capacitors
 KMK0411-M	 KMK0988-L	
 KMK0431-2	 KMK0415-K	
 KMK0429-Q	 KMK0416-T	
 KMK0411-M	 KMK0413-4	MFP
Metal foil  KMK0989-U	Metallized plastic film  KMK0990-X	Plastic film without metallization  KMK0991-6

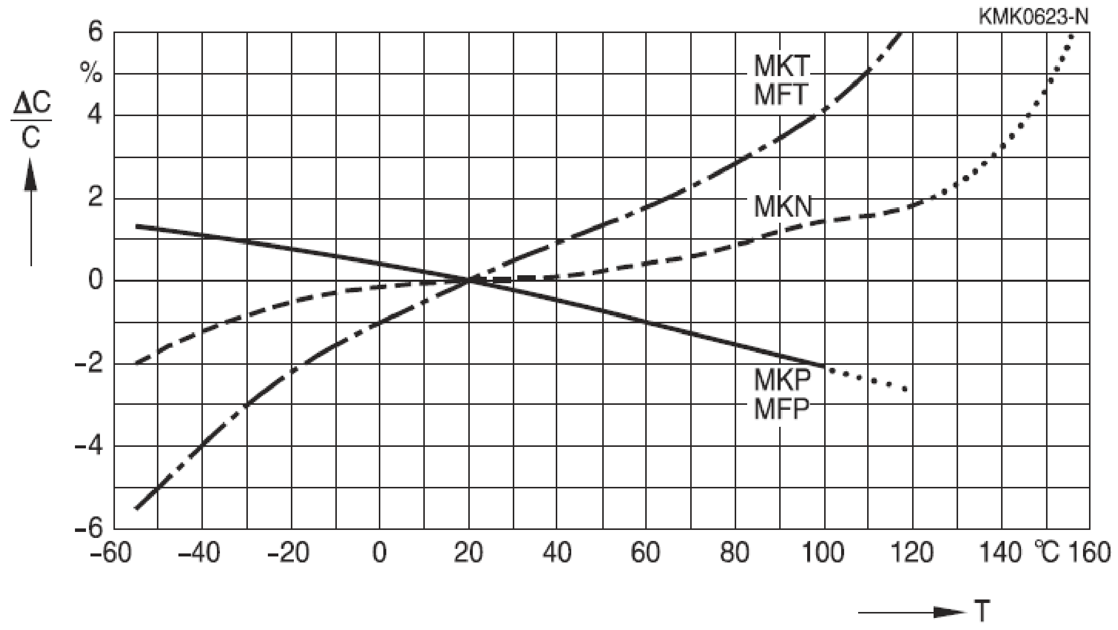


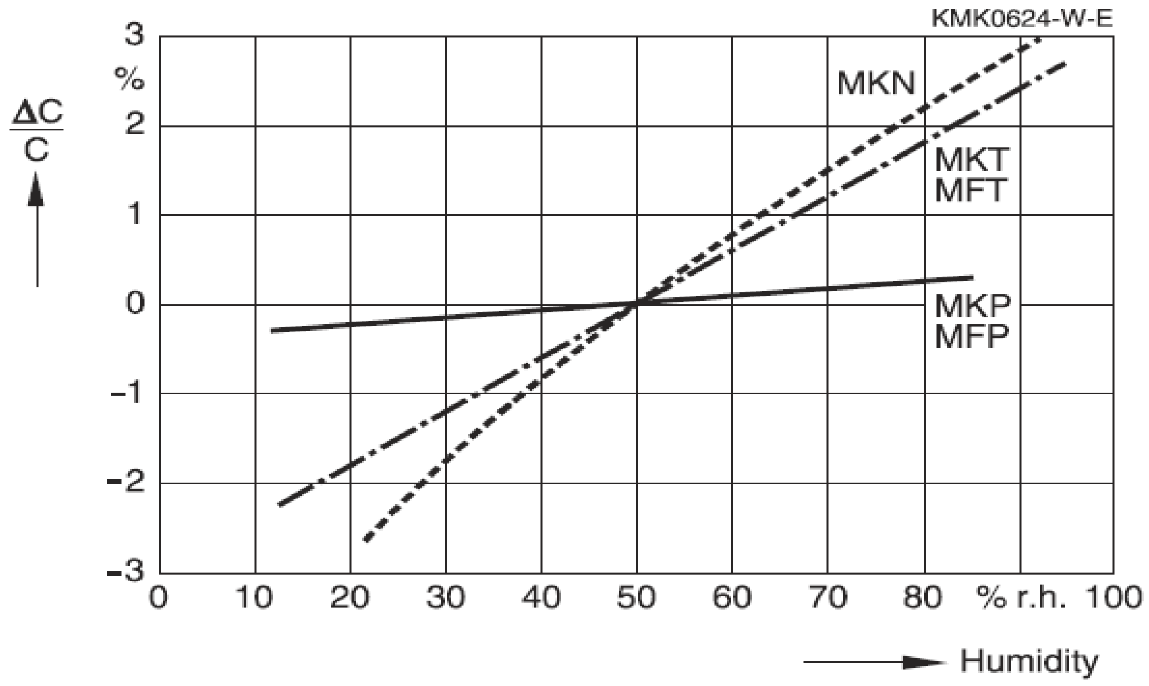


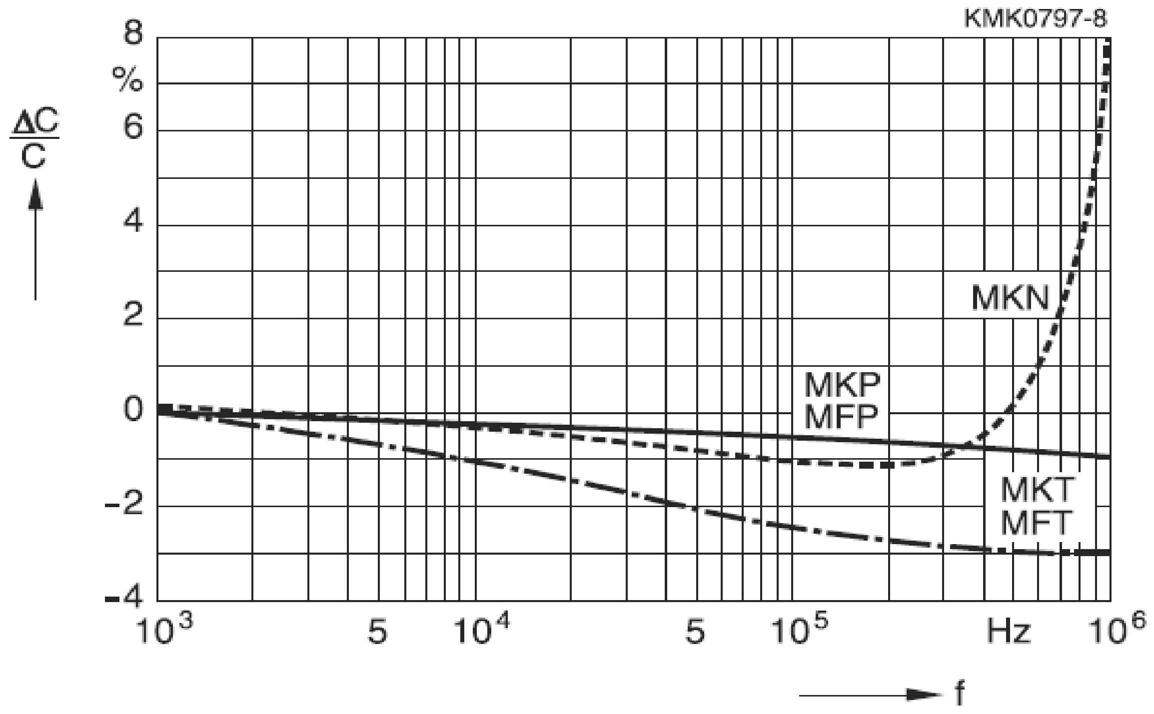


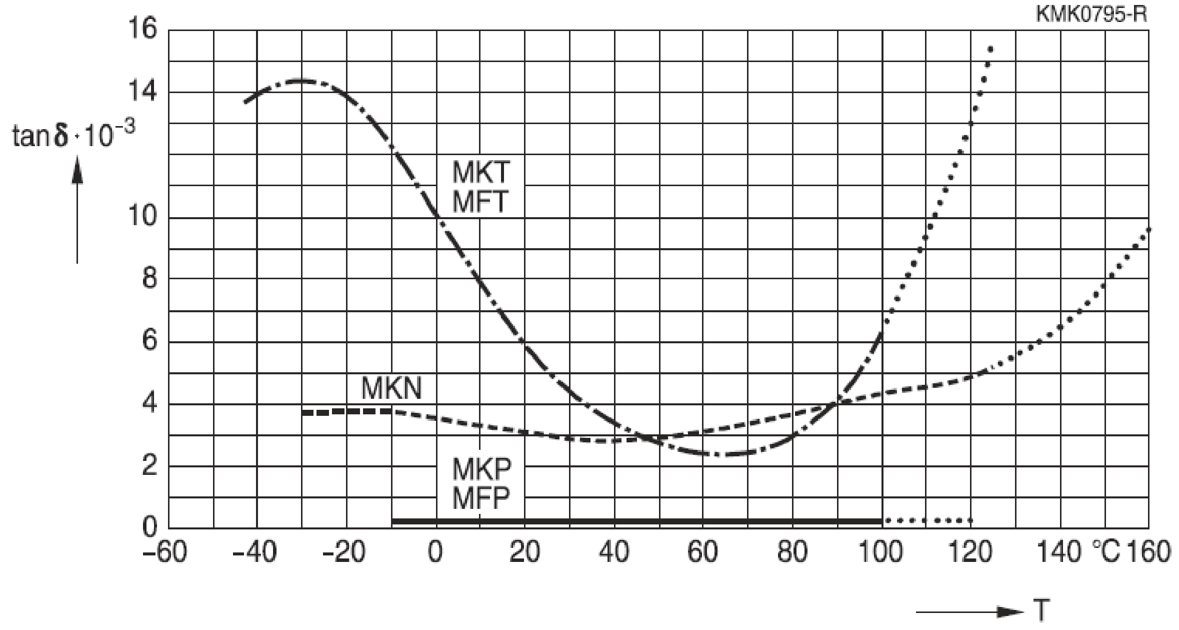
Dielectric		PP	PET	PEN
Dielectric constant (ε_r)		2.2	3.2	3.0
C drift with time ($i_z = \Delta C/C$)	%	3	3	2
C temperature coefficient α_c	10^{-6}/K	−250	+600	+200
C humidity coefficient β_c (50 ... 95%)	10^{-6}/% r.h.	40 … 100	500 … 700	700 … 900
Dissipation factor (1 kHz)		0.0005	0.0050	0.0040
Time constant	s	100 000	25 000	25 000
Dielectric absorption	%	0.05	0.2	1.2

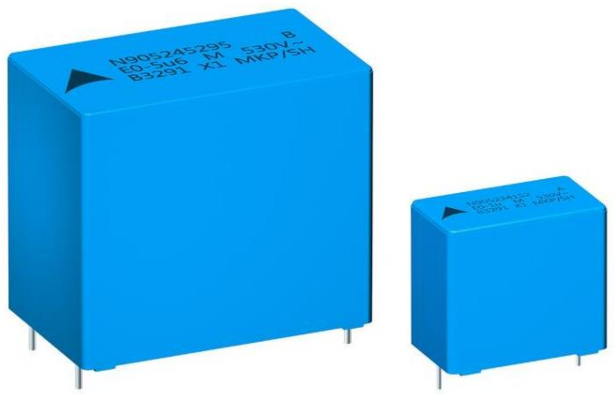
Film Capacitor Performance











New Film Materials for improved thermal performance

Semi-crystalline BOPP

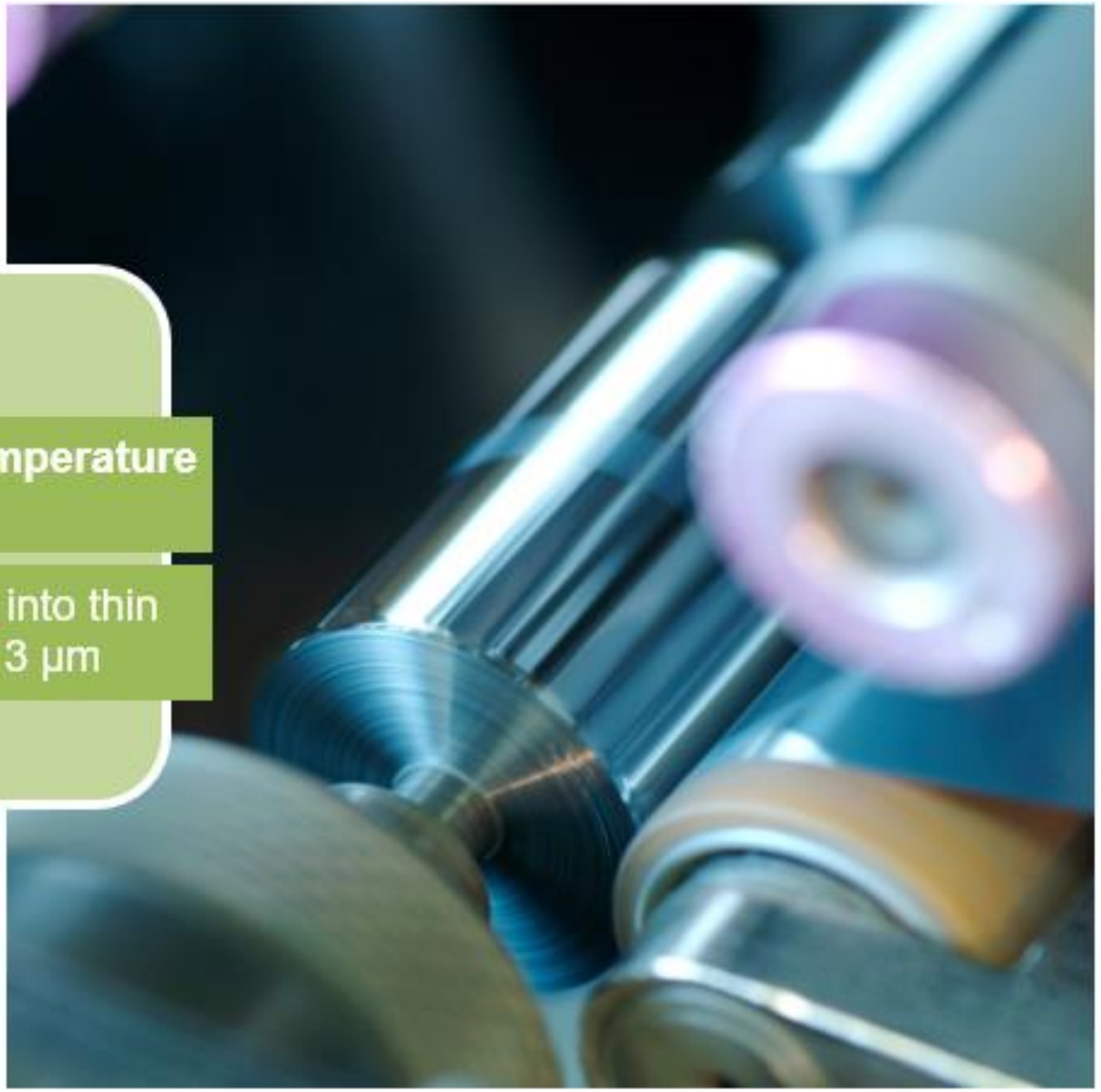
- \+ Easy to process into films
- − Temperature limitation

Amorphous cyclic olefin copolymer (COC)

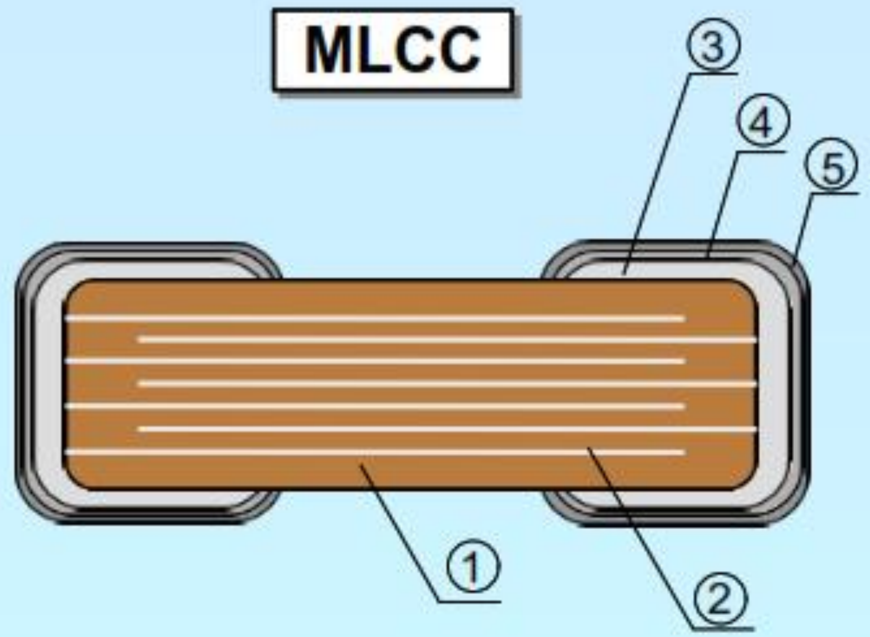
- \+ High temperature operation
- − Not processable into thin films

Blended film

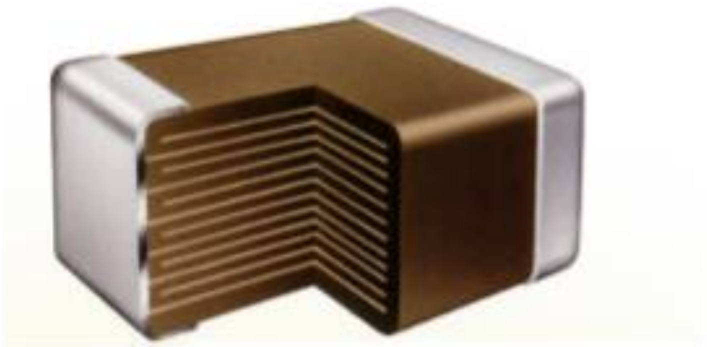
- \+ Improved temperature operation
- \+ Processable into thin films down to 3 µm



Ceramic capacitor construction/material

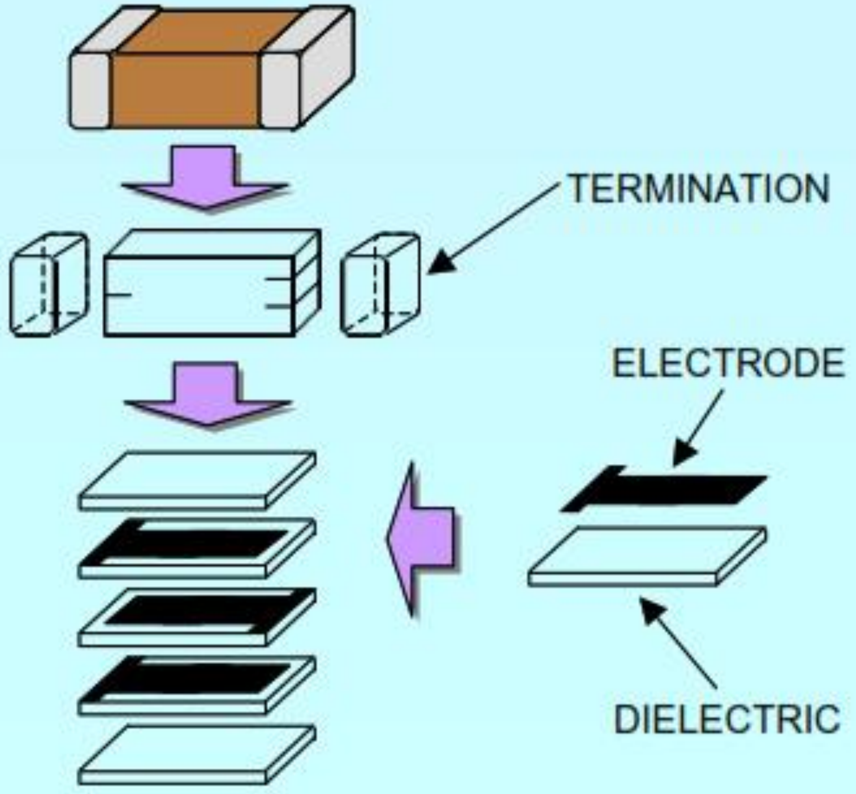


$$C = K \cdot \frac{N \cdot S}{d}$$

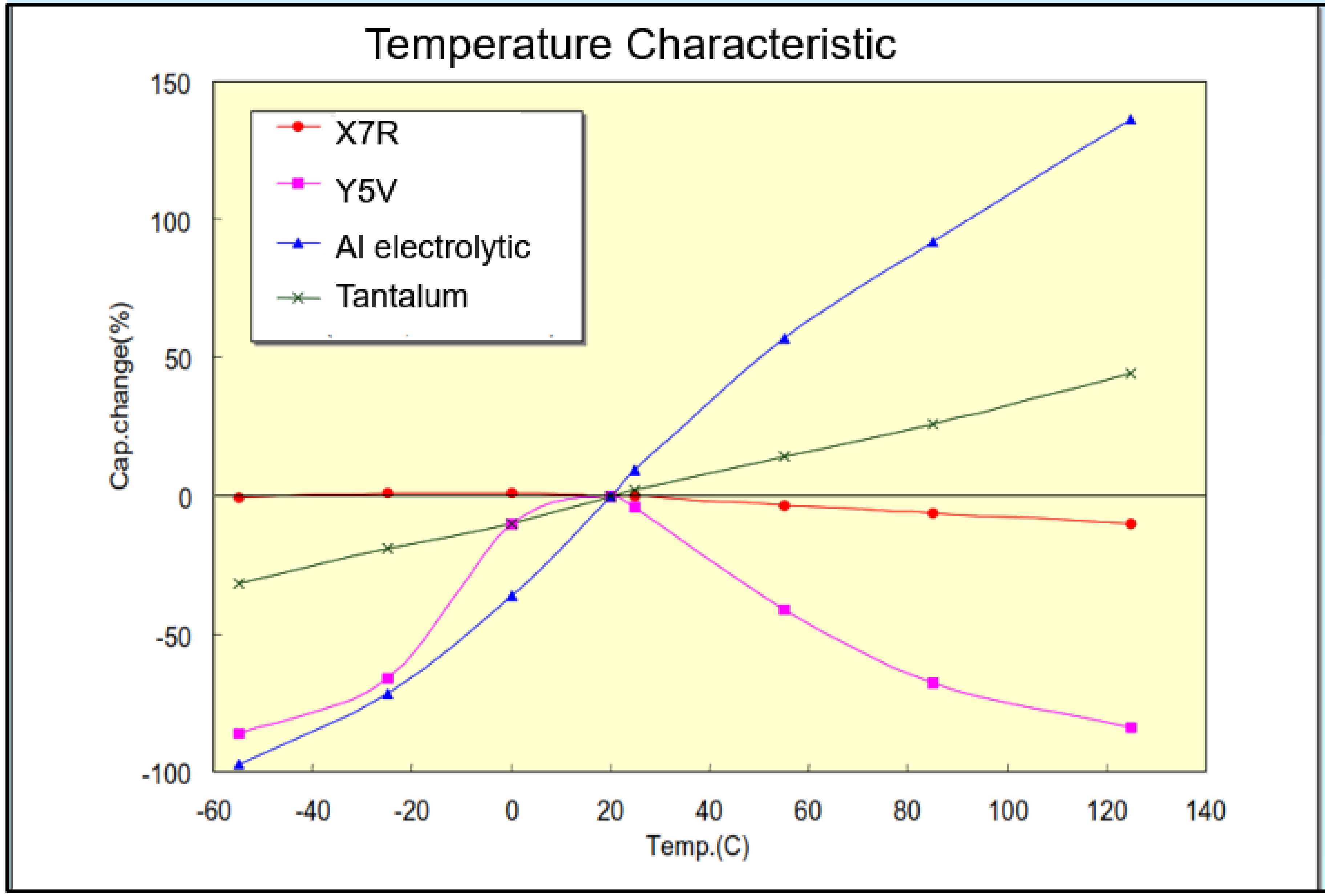


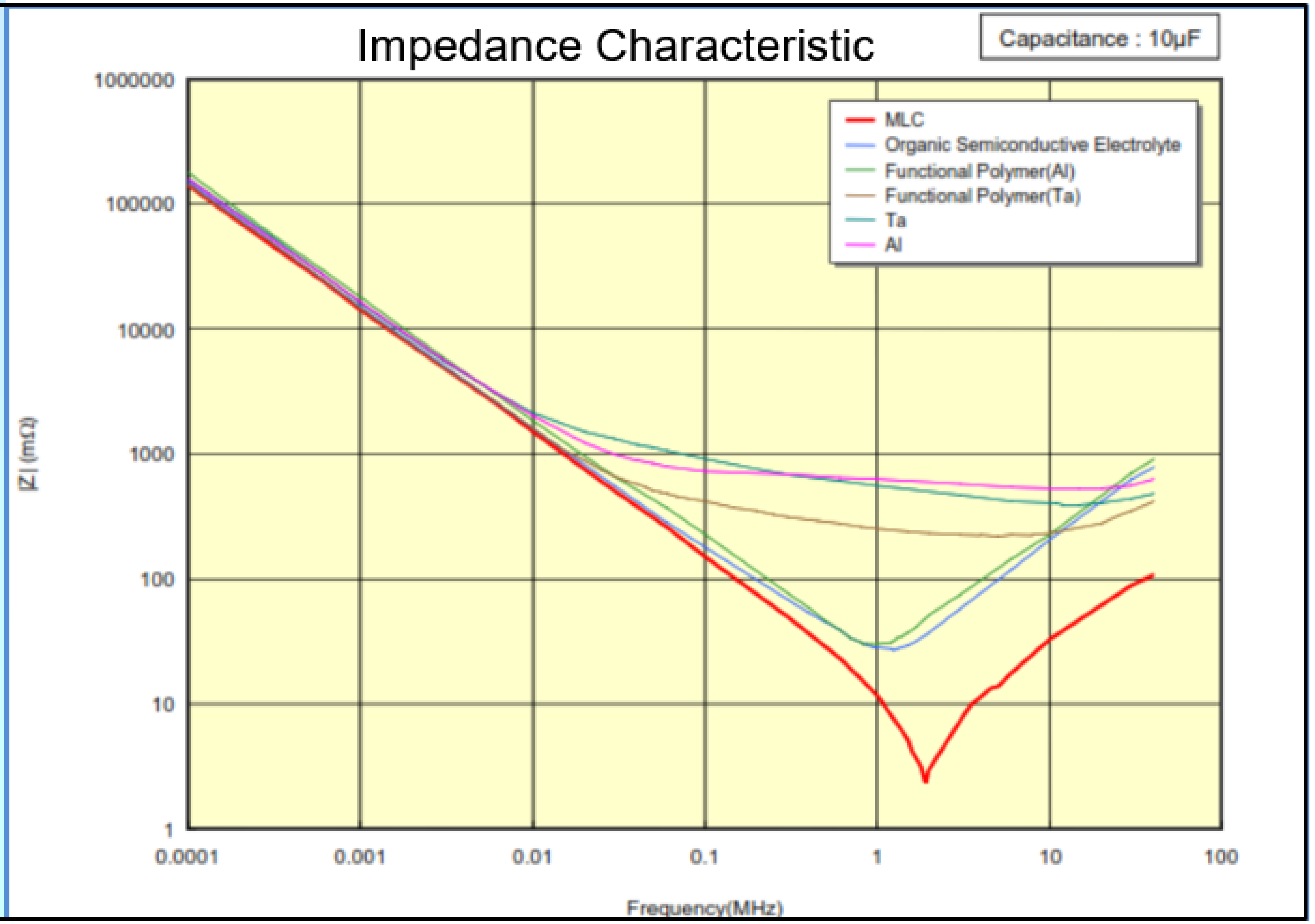
C : Capacitance
K : Dielectric Constant
n : Number of layer
S : Overlapping surface area
d : Layer thickness

No.	ELEMENTS	MATERIAL		
		CONVENTIONAL	BME	
		Class I	Class I	Class II
①	DIELECTRIC	TiO_2	$CaZrO_3$	$BaTiO_3$
②	ELECTRODE	Pd	Ni	
③	TERMINATION	Ag or Ag/Pd	Cu	
④		Ni		
⑤		Sn		

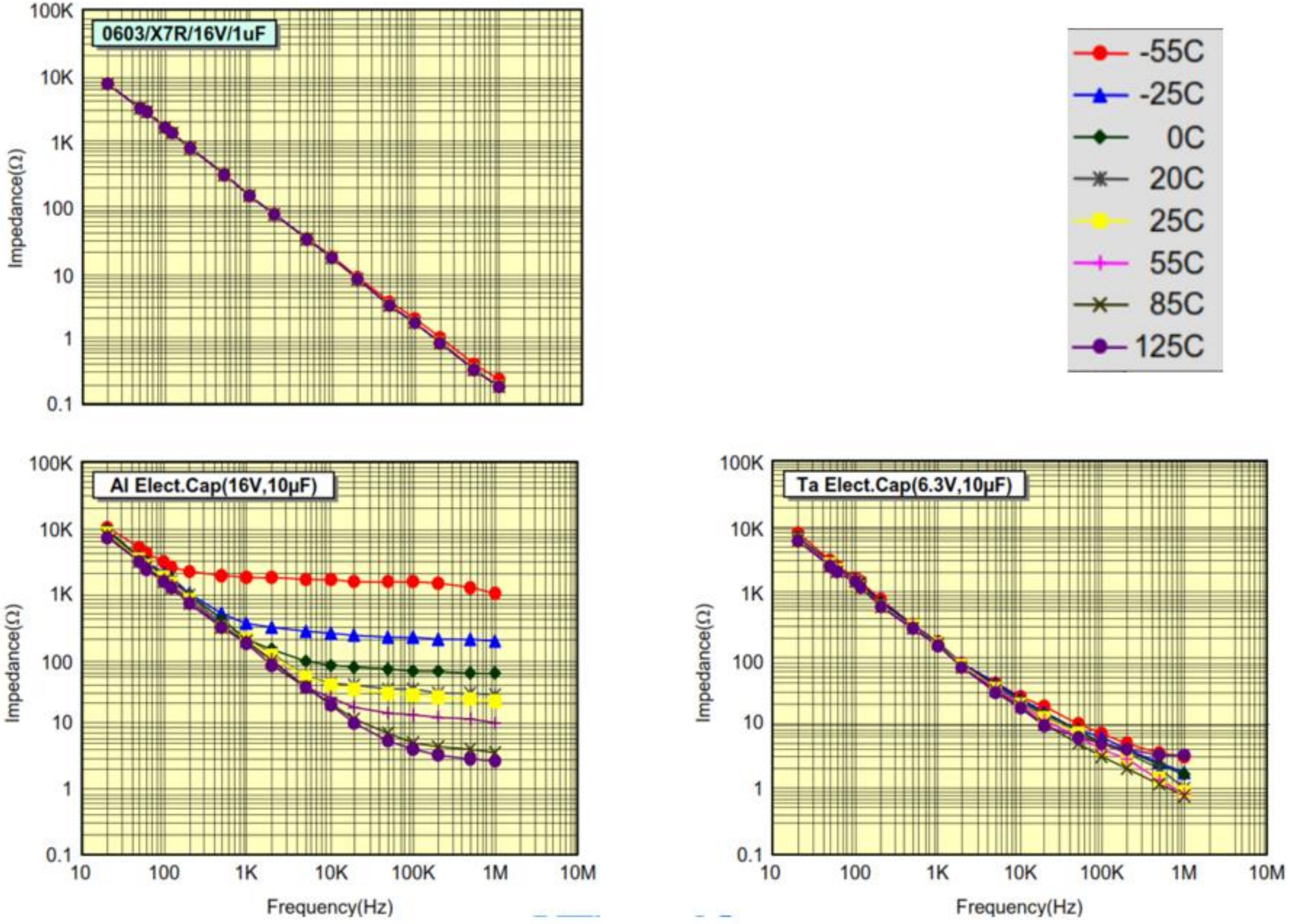


Technology comparison: HiCV types

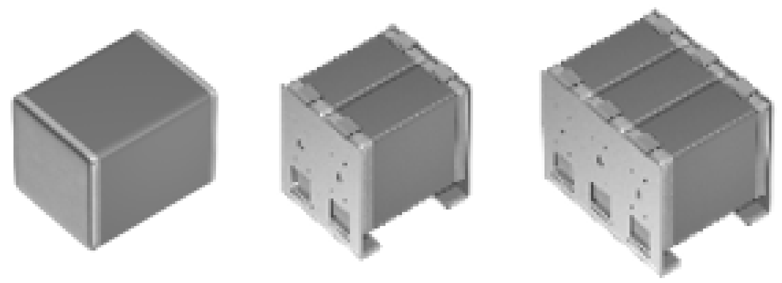




Technology comparison: HiCV capacitors

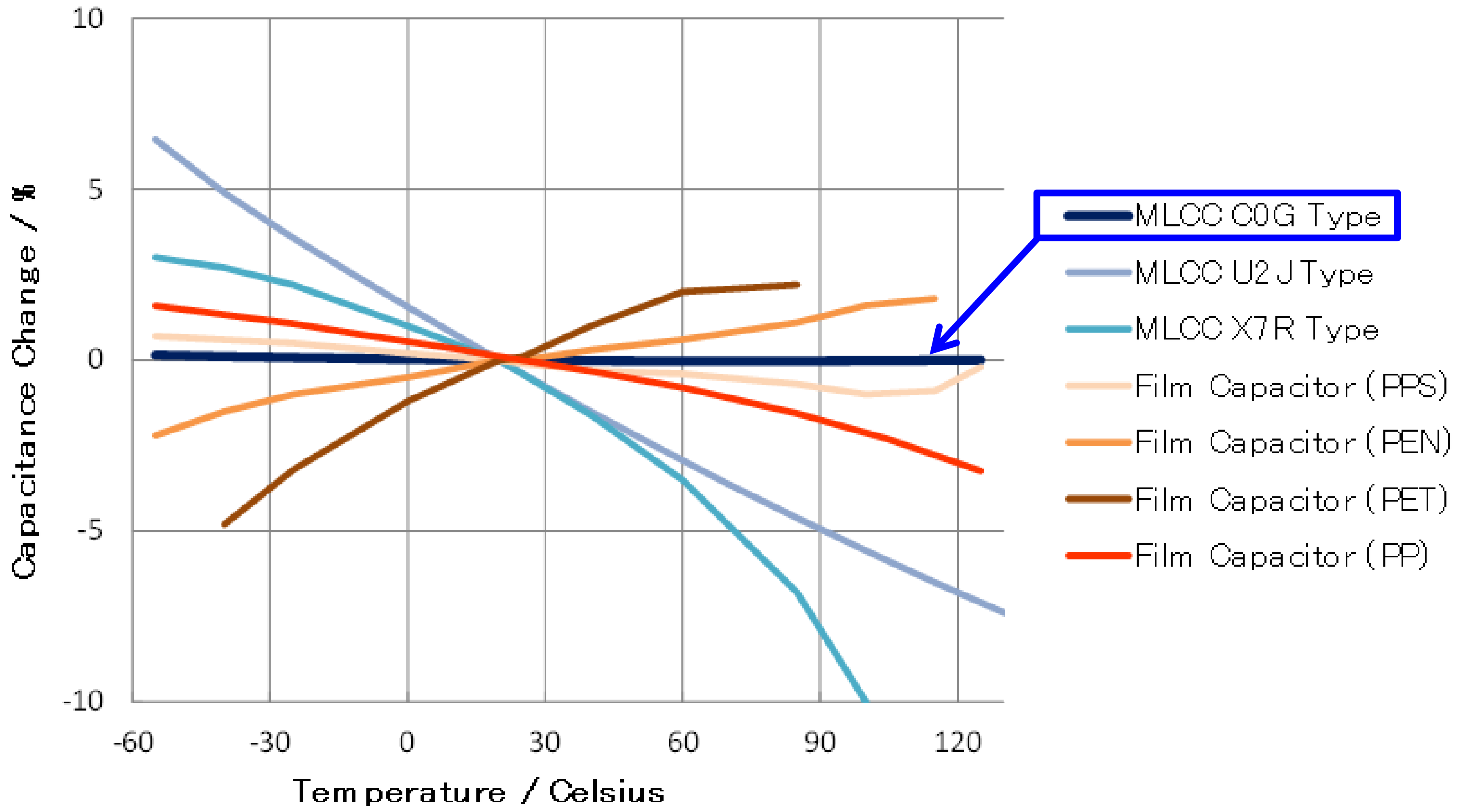


MLCC for Resonant / C0G

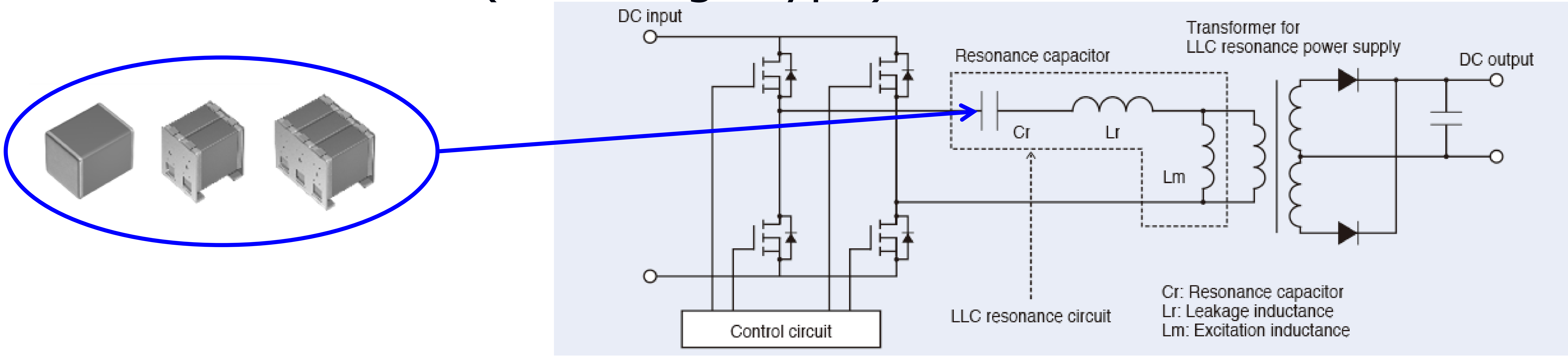


- Small size, High Capacitance
- High Rated Voltage (630Vdc, 1kVdc)
- High Operating Temperature: 125degC (and higher)
- High stability(C, ESR) over temp, frequency, voltage
- AEC-Q200 Compliance

C0G MLCC has better capacitance stability than any other type of capacitors !



MLCC for Resonant / C0G
ex. LLC converter (full bridge type)



LLC converter uses the PFM (pulse frequency modulation) method, which controls the switching frequency while maintaining a fixed pulse width. Therefore, the resonance capacitor requires superior characteristics.

Little variation in capacitance and tanδ ; optimal as a resonance capacitor

Since LLC converters have a PFM power supply which uses LC resonance, transformers and resonance capacitors are both extremely important components. The following types of characteristics are required in resonance capacitors which are used in the LLC capacitors of onboard chargers.

《Characteristics required in resonance capacitors of LLC converters》

•**Superior temperature characteristics**

Since the resonance capacitors are used in resonance circuits, it is extremely important that the capacitance change caused by temperature fluctuations is small.

•**Superior withstand voltage characteristics**

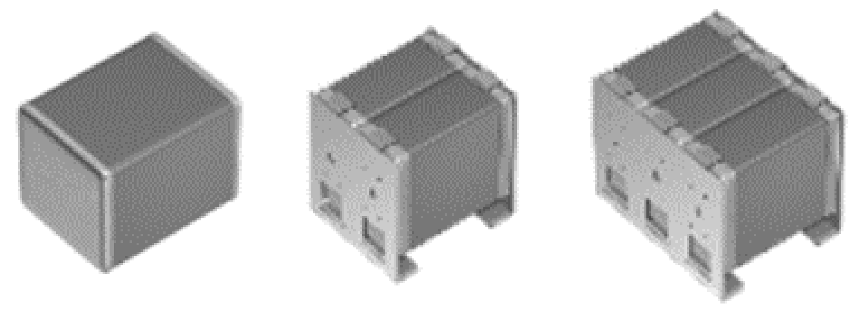
LLC converters are power supplies appropriate for use with relatively high power. However, since larger voltage rectangular waves than those in general electronic devices are applied, high withstand voltage (rated voltage) is required.

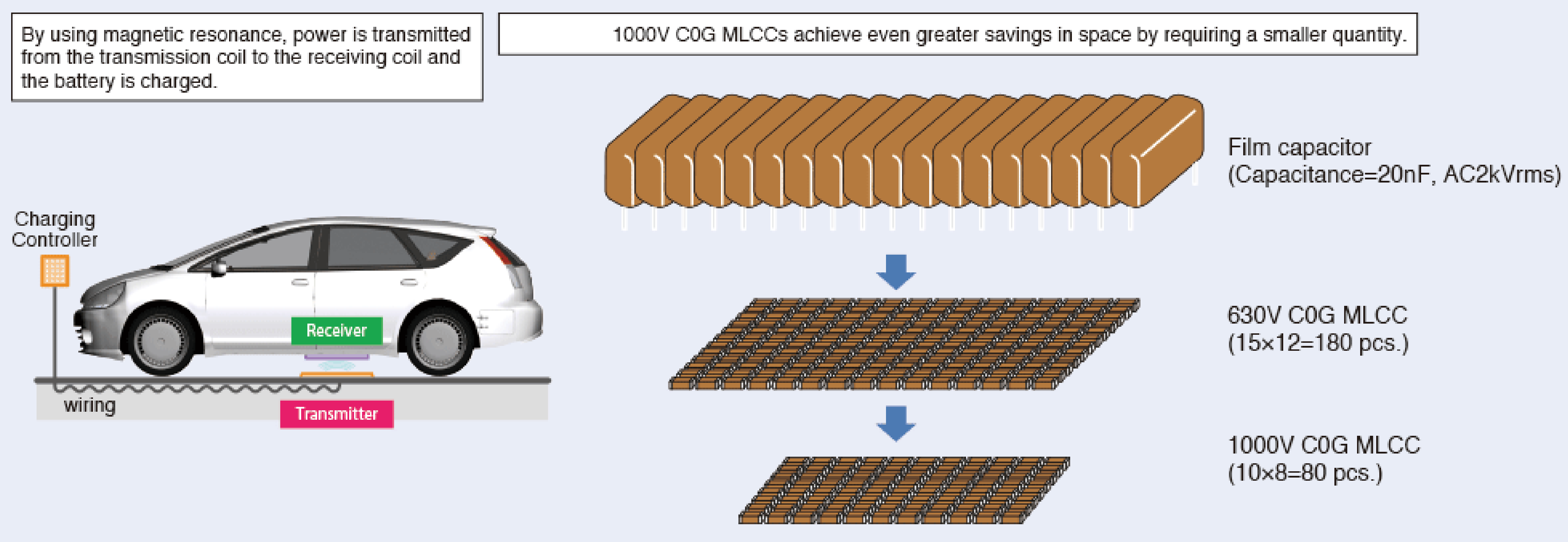
•**Superior ESR characteristics**

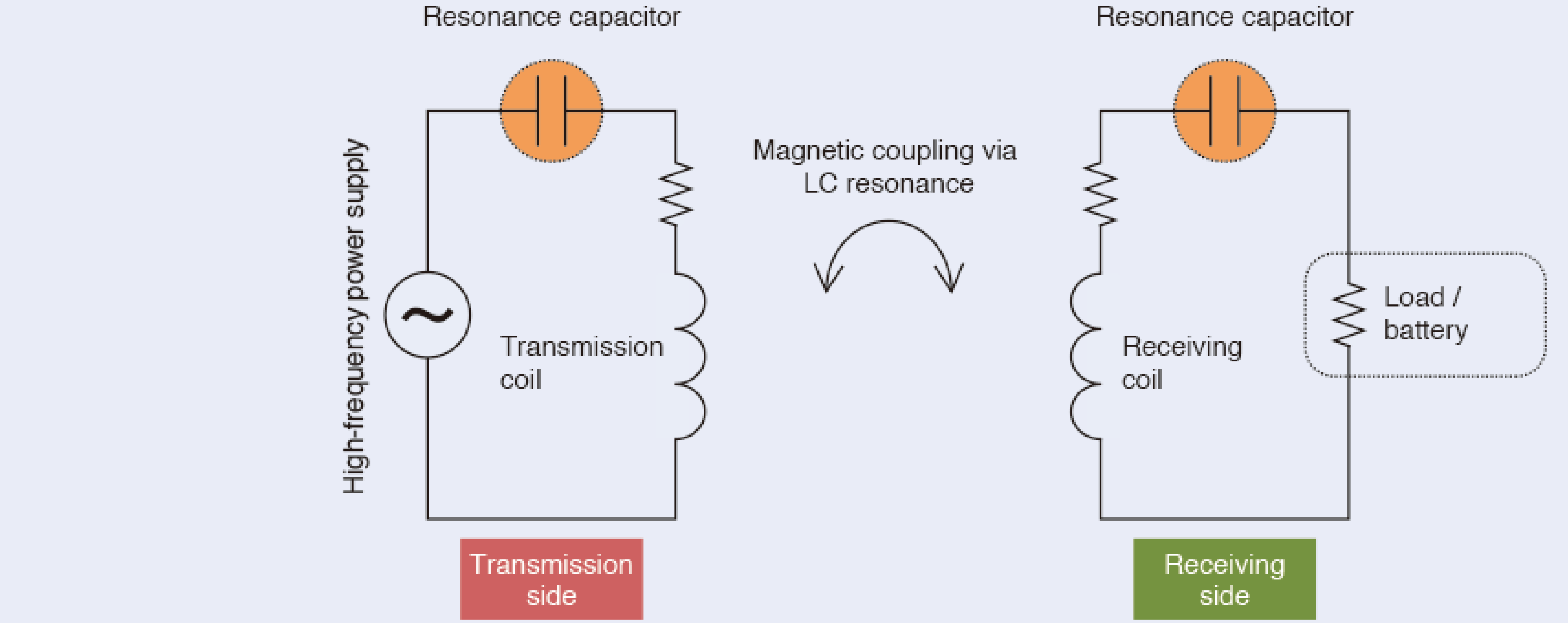
Since a large current flows in resonance circuits, superior ESR is required.

In the past, film capacitors were normally used as resonance capacitors in the LLC converters of onboard chargers. This was because film capacitors have a good balance of withstand voltage and relatively high capacitance. However, in recent years, MLCCs have been developed with characteristics that approach the region of film capacitors, and there is an increasing need for a replacement for film capacitors in automotive electronics.

MLCC for Resonant / C0G
ex. Wireless power transfer

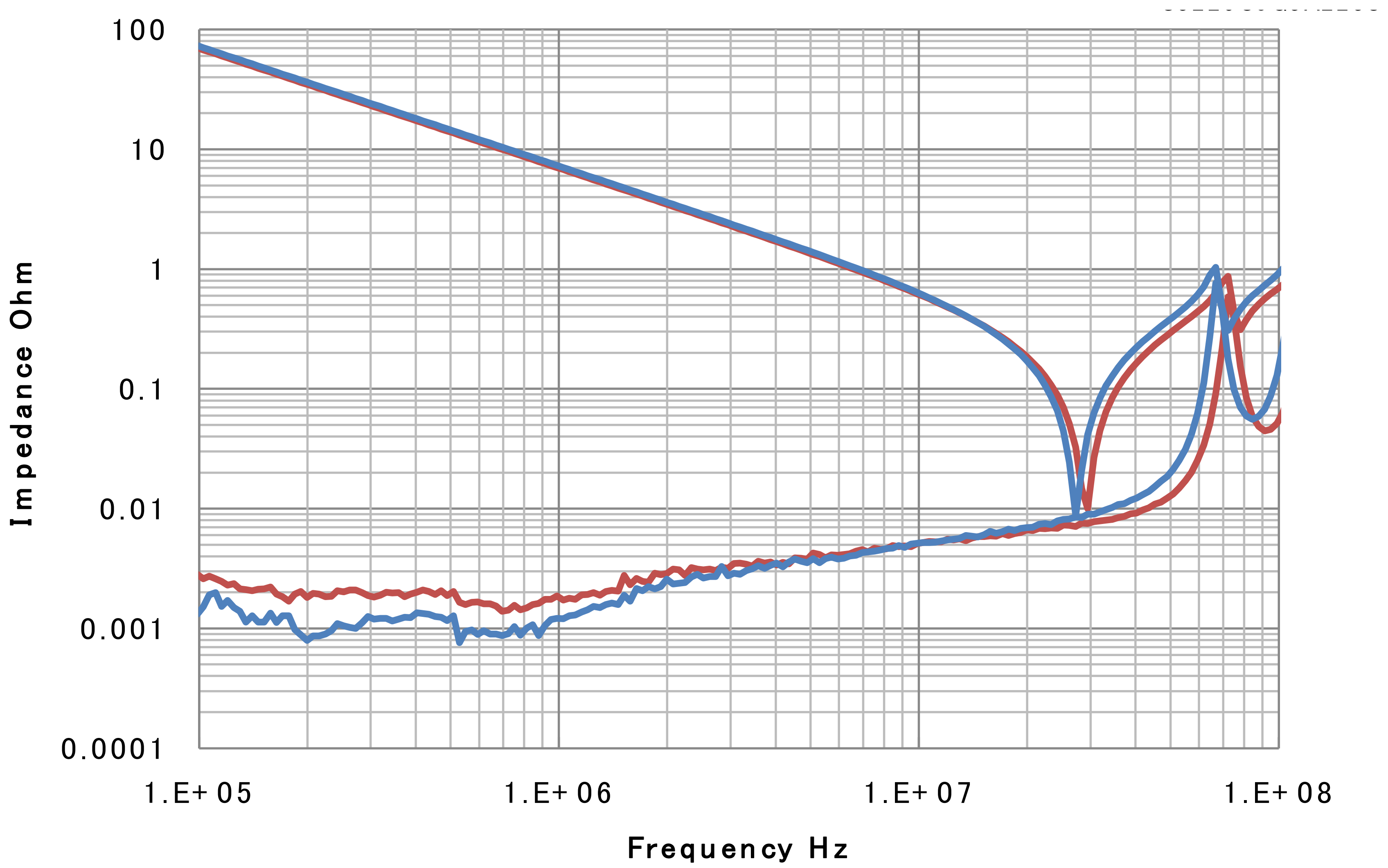






High-power resonance capacitors are an important component in magnetic resonance using wireless power transfer EV charging systems. This is because a high-accuracy resonance circuit with high withstand voltage is required for quick, efficient wireless transfer of a large amount of power.

MLCC for Resonant / C0G



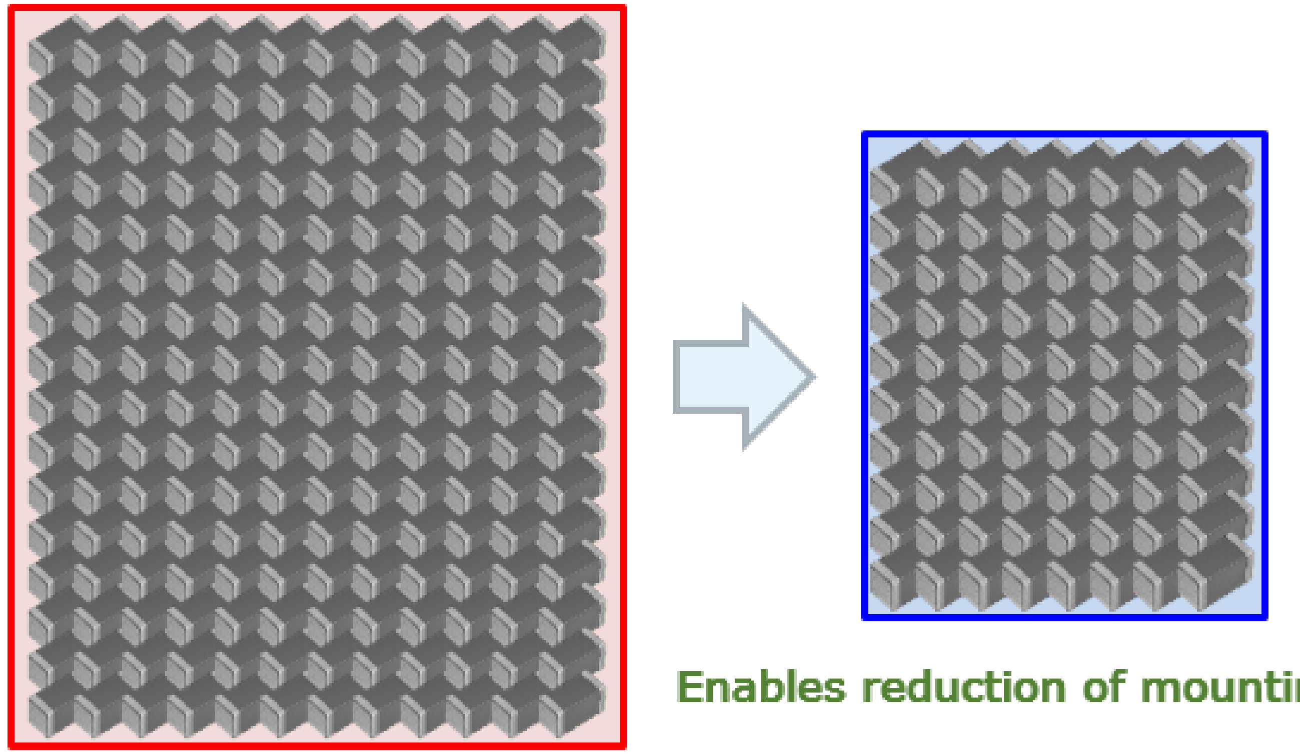
The 1000V MLCC has a 50% lower ESR than the 630V MLCC. This enables a significant reduction in the number of resonance capacitors necessary.

Example MLCC combination

C=17.6nF V=1.65kVrms I=17Arms

1206/C0G/630V Series

1210/C0G/1kV Series



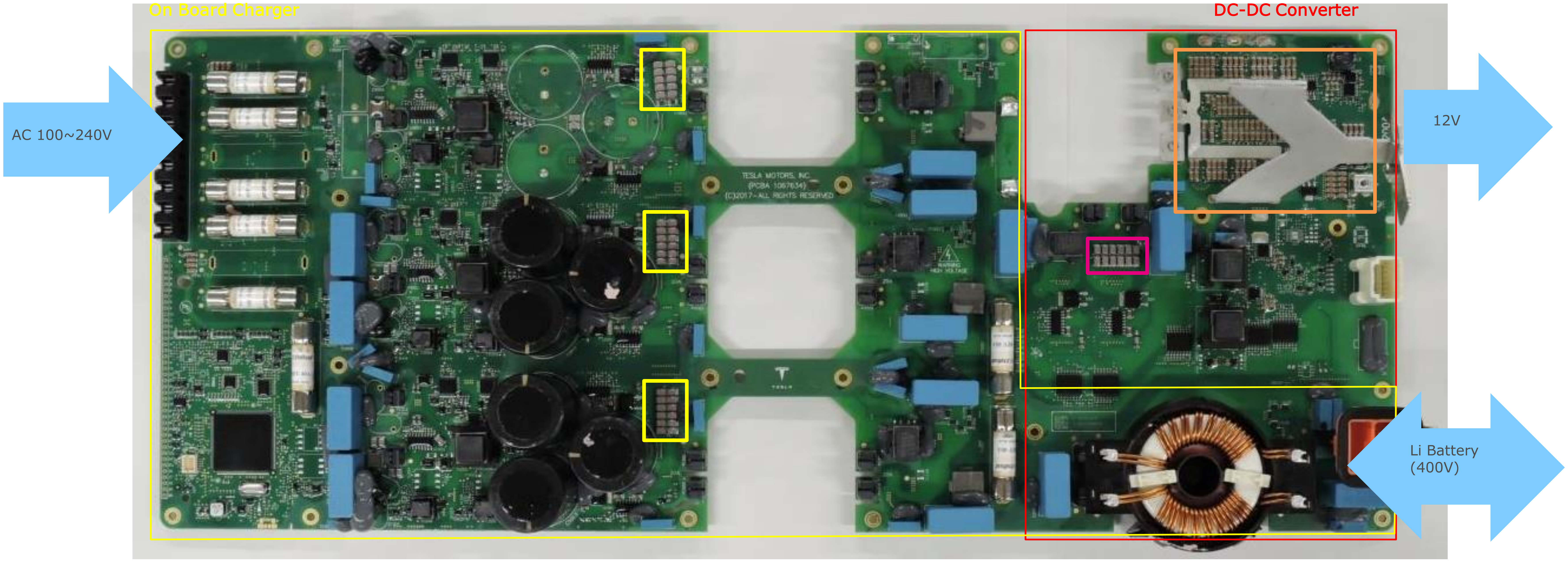
Enables reduction of mounting area!

Series	Parallel	Irms / pcs
15	12	1.42Arms
10	8	2.13Arms

Irms x 1.5

On Board Charger + DC-DC Converter

TDK Item	Borad Qty	Function	TDK Item	Borad Qty	Function
CGA6N1C0G3A822J	36	LLC Resonant	CGA5L1X7R1E106K	120	Output Filter
CGA6P1C0G3A153J	12	Output Filter	CGA6L4C0G2J153J	20	TBD



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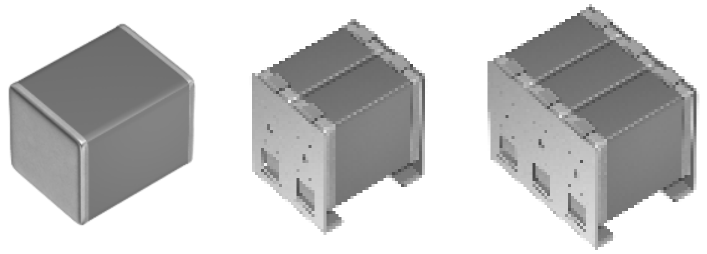
Resonant Capacitor : C0G Mid Voltage Series

Appearance



- Automotive grade
- Based upon AEC-Q200

Line UP

LW Size mm (inch)	T.C.	Capacitance Range (F)								
		3.9n	4.7n	5.6n	6.8n	8.2n	10n	15n	22n	33n
3216 (1206)	C0G	630V	630V	630V	630V	630V	630V			
3225 (1210)	C0G	630V	630V	630V	630V	630V	630V	630V	630V	630V
3225 (1210)	C0G		1kV		1kV		1kV	1kV	1kV	

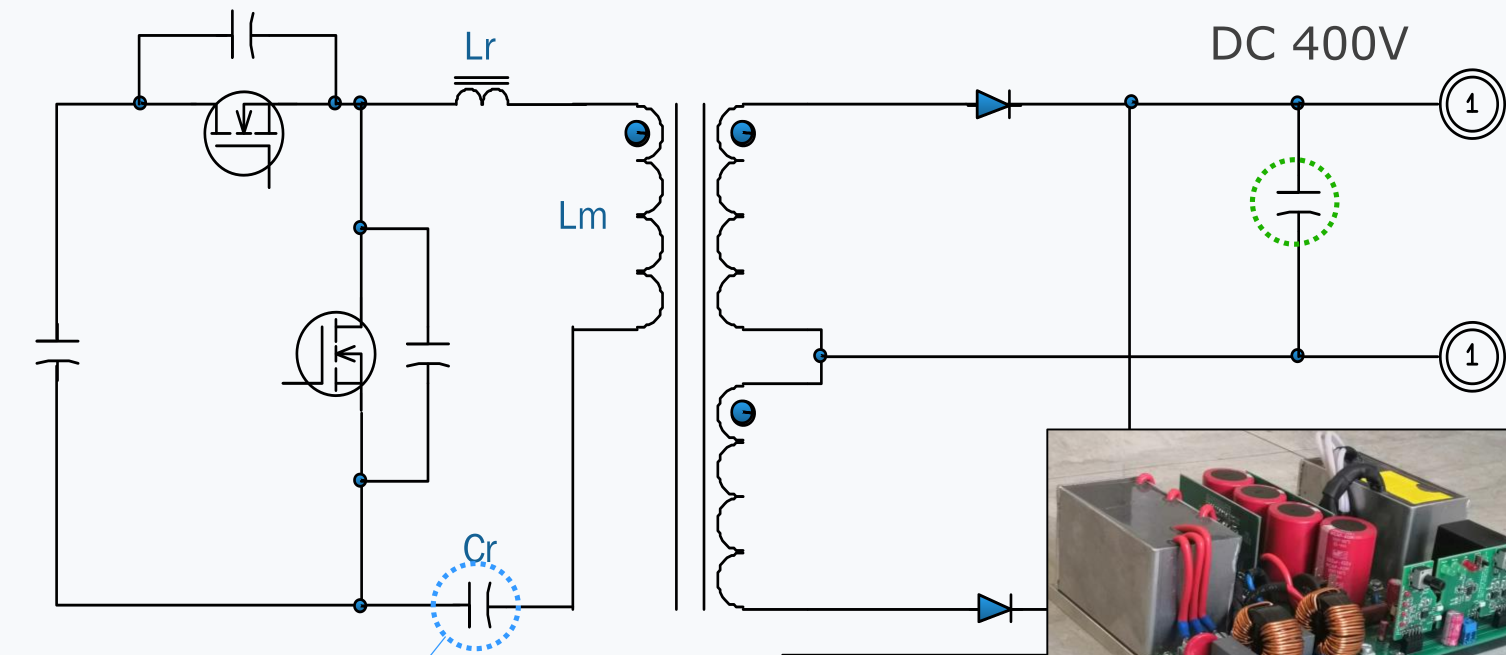
LW Size mm (inch)	Visual	T.C.	Capacitance Range (F)						
			20n	30n	44n	66n	99n	200n	300n
CAA572		C0G	1kV	1kV	1kV	1kV		630V	
CAA573		C0G					1kV		630V

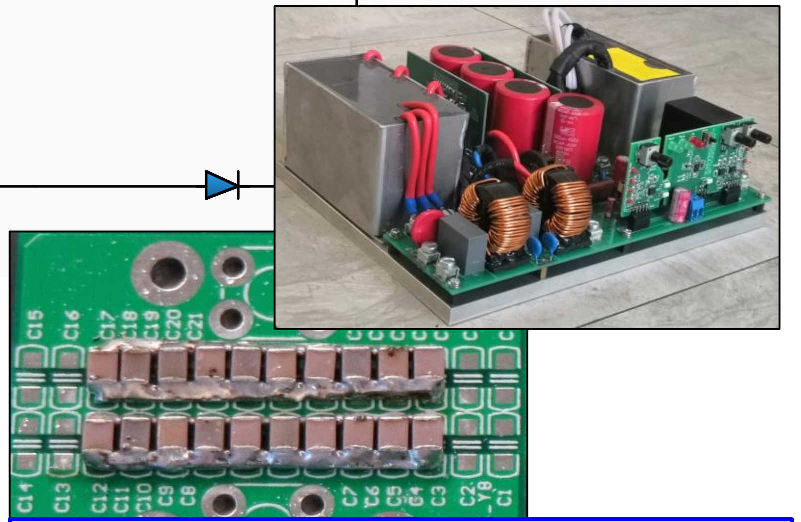
In production

U.D. Sample Ready, MP 2021

Example of use

■Application : OBC、WPT、DC-DC Converter LLC circuit





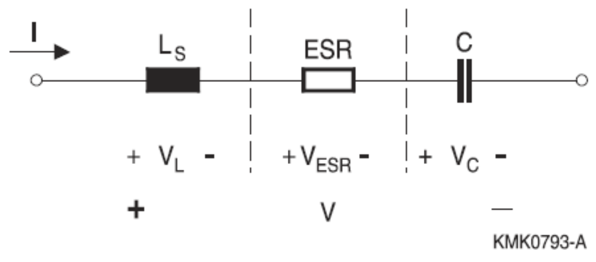
Resonant Capacitor

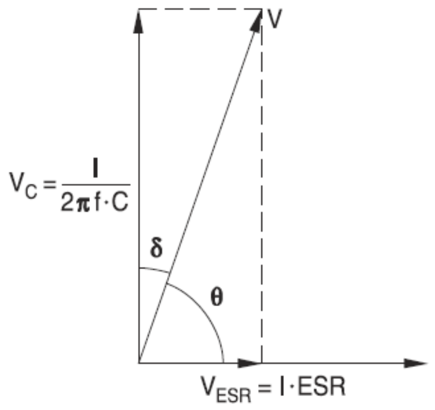
- 3216mm 10nF 630V C0G
- 3225mm 22nF 1kV C0G

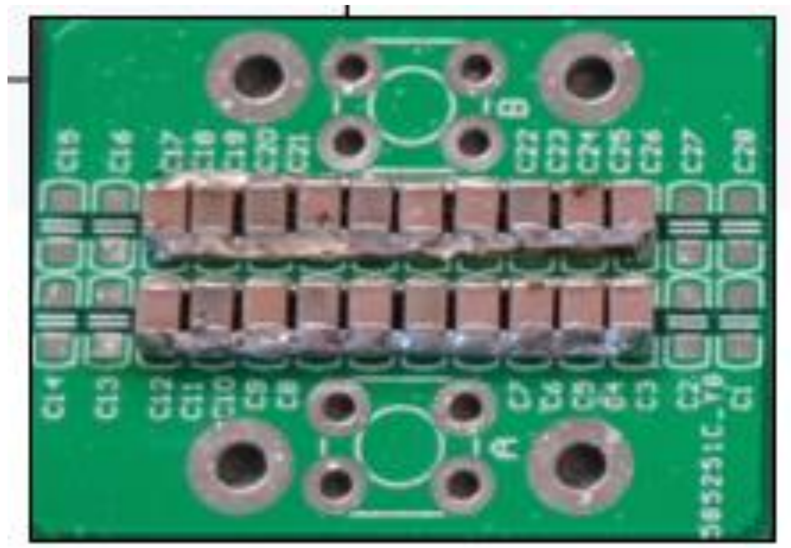
MLCC 1210-1,000V-22nF 2s10p
TDK CGA6P1C0G3A223J

PSMA

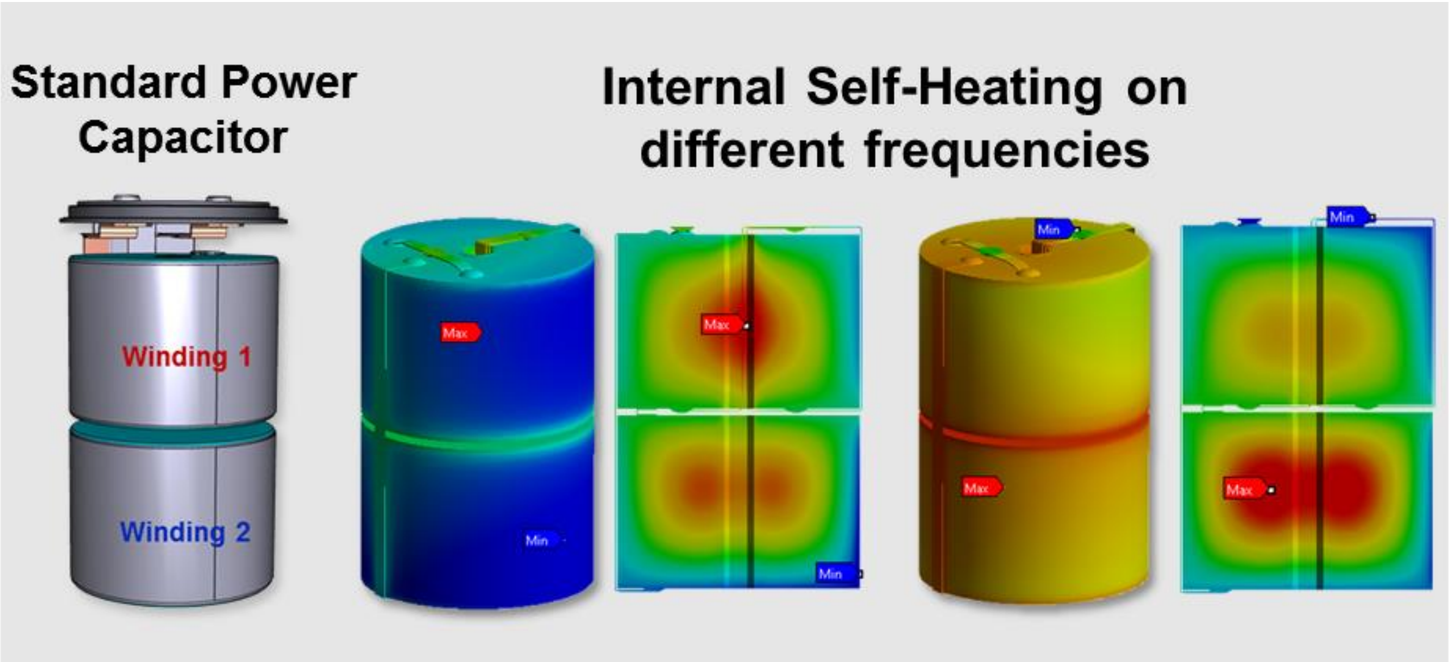
Design Considerations

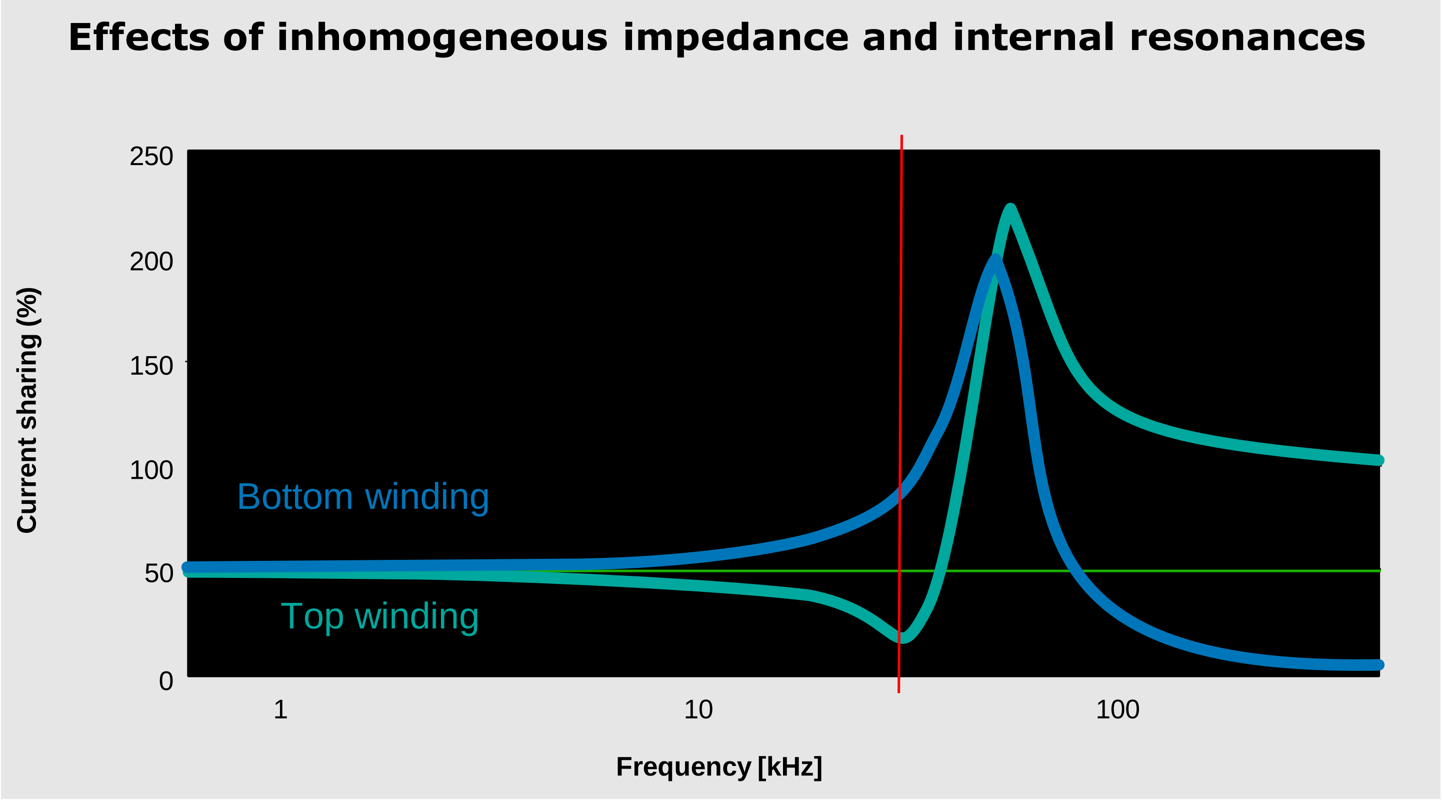




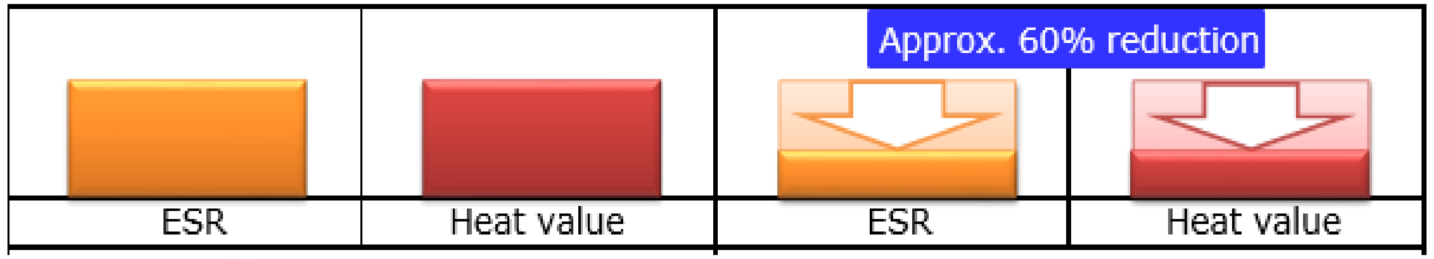


MLCC 1210-1,000V-22nF 2s10p



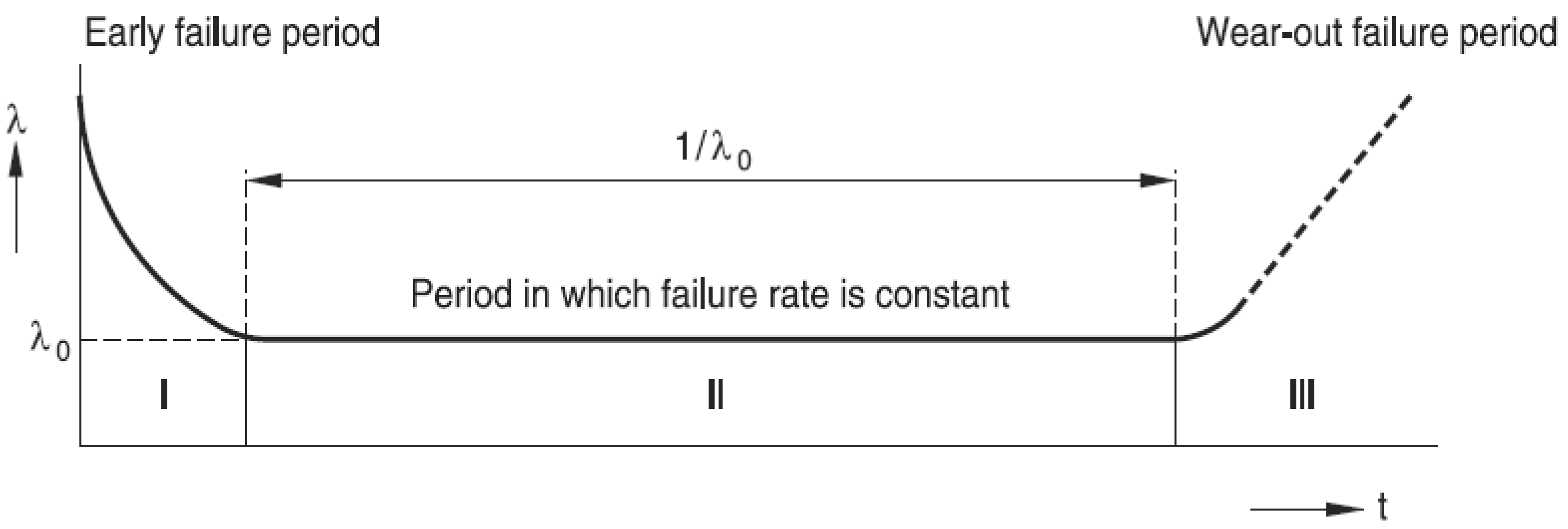


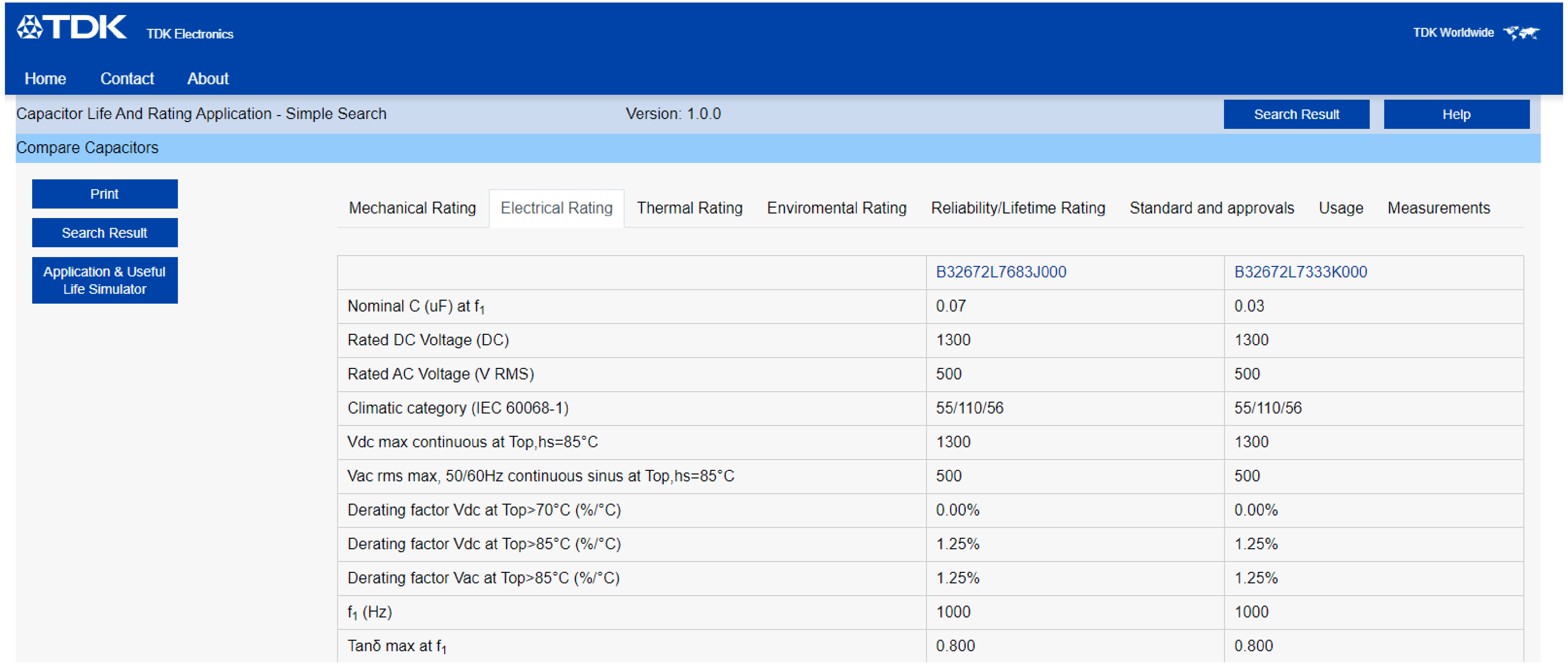
ESR / Heat value



Design Considerations

Lifetime characteristic variations





Simulation Tools

Design Considerations

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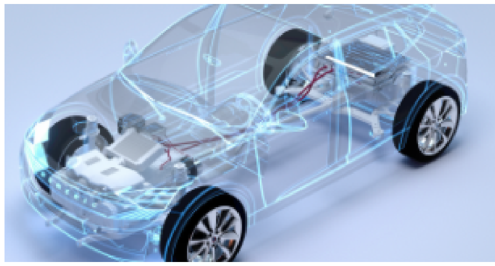
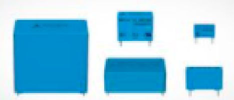
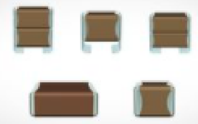
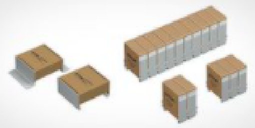
Capacitors for DC-Link circuits

TDK is one of the world's leading manufacturer of DC-Link capacitors.
Explore our comprehensive portfolio by clicking on the application icons below.



12 / 48 V 500 W | 12 / 48 V 1 kW | 48 V Inverter | OBC | HV DCDC | HV Heater | HV 1 kW range | HV Traction Inverter

On Board Charger for PHEV and BEV

Key Characteristics ⓘ 400 V / 800 V	 Aluminum Capacitors	 Film Capacitors	 MLCC	 CeraLink
Remark			all values apply for a single element	for all 500 V types (not SP)
Max. Operational Temperature (ambient + self heating)	105 °C	105 °C 125 °C 105 °C 105 °C	125 °C	150 °C
Max. Ripple Current Capability 100 kHz, 85 °C	4.91 A (120 Hz, 85 °C) 3.93 A (120 Hz, 85 °C)	3.5 … 108 A (85 °C, 20 kHz)	2.0 … 2.5 A	11 … 47 A

Design Considerations

Regulatory Approvals and
EMI requirements

PSMA

PSMA

Thank you