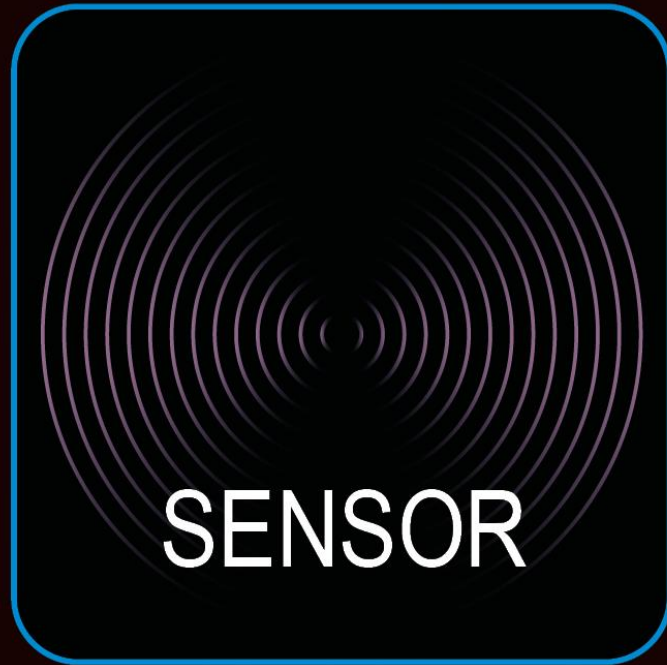


RUTRONIK TECHTALK **MEETS**



08.06. - 10.06.2021 | **ONLINE**

Off-Board Chargers for E-Mobility

Juergen Gewinner
Field Application Engineer





The DNA of tech.™

Off-Board Chargers for E-Mobility

Juergen Gewinner Field Application Engineer

Agenda

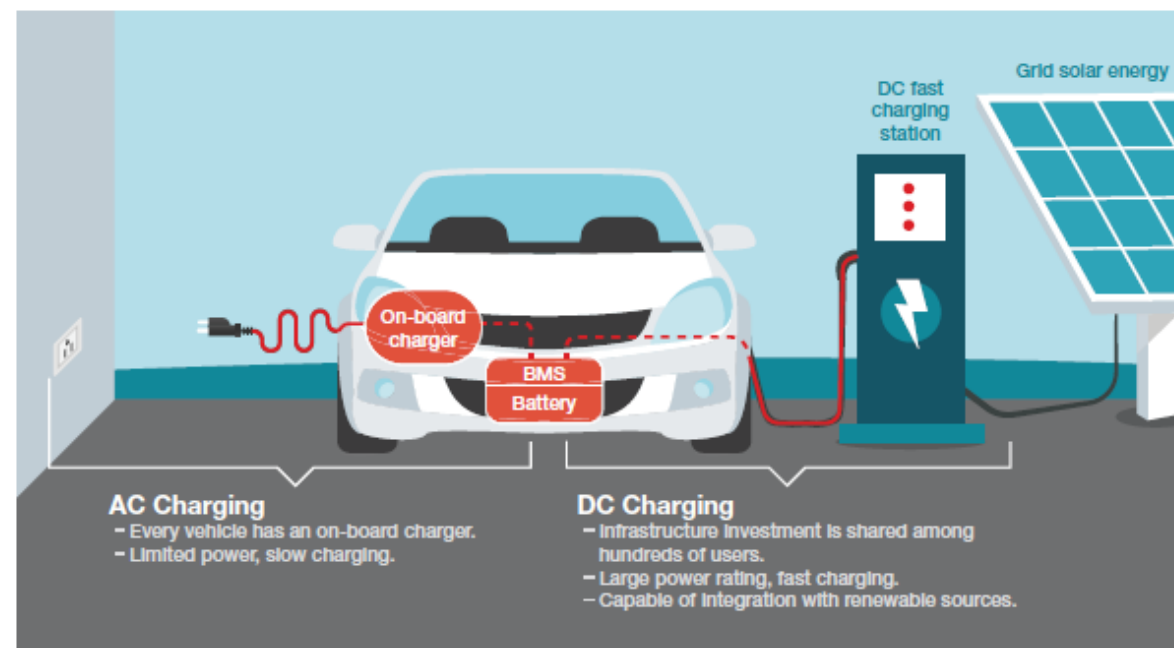
- Introduction and Motivation
 - Functionality
 - On- vs. Off-Board
 - Power Level
 - Bi- or Unidirectional
- Block Diagram
- Power Factor Correction
 - Topologies
- DC-DC Conversion
- Possible Vishay Components

Agenda

- **Introduction and Motivation**
 - **Functionality**
 - **On- vs. Off-Board**
 - **Power Level**
 - **Bi- or Unidirectional**
- Block Diagram
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Introduction and Motivation

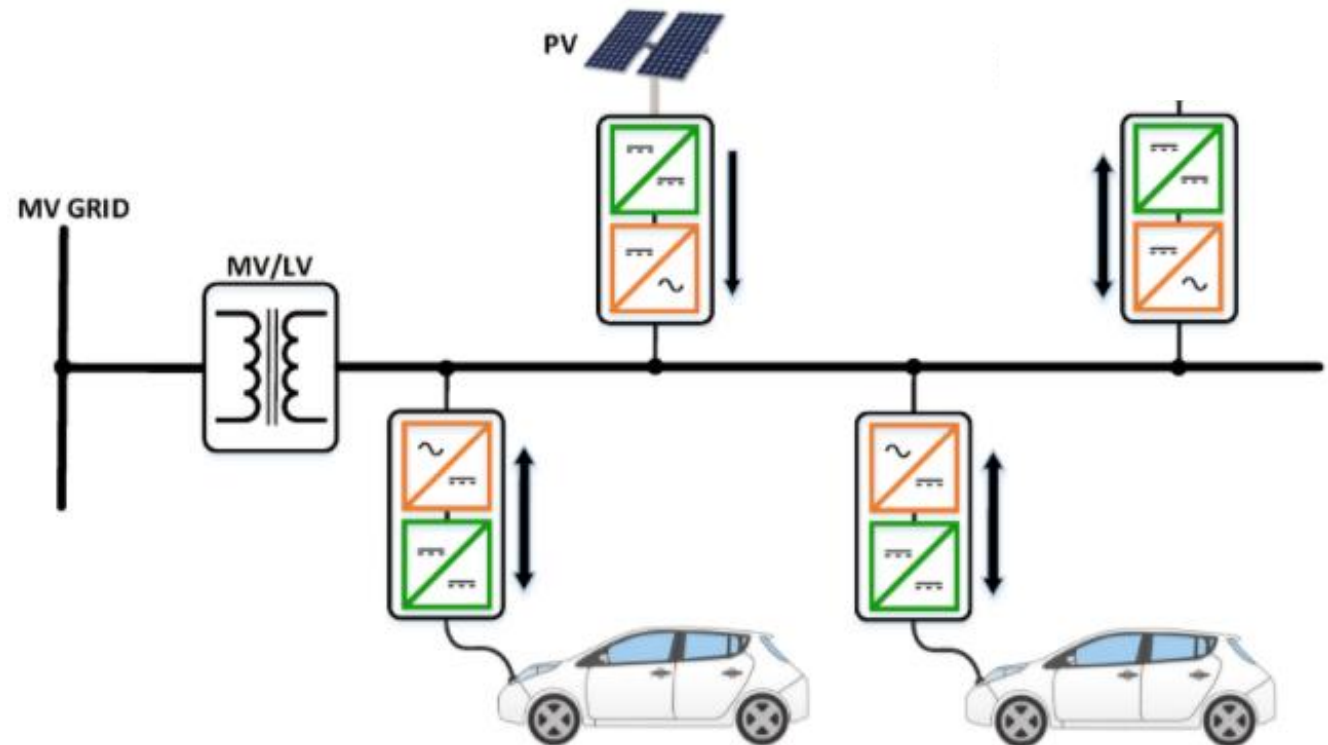
- Functionality
- On- vs. Off-Board:
 - Weight, Size and Power Level
- Power Level
 - acc. to SAE (society of automotive engineers)
- Bi- or Unidirectional



EVSE type	Power supply	Charger power	Approximate charging time for a 24 kWh battery
AC charging station: Level 1 residential	120/230 VAC and 12 A to 16 A (single phase)	~1.44 kW to ~1.92 kW	~17 hours
AC charging station: Level 2 commercial	208/~240 VAC and 15 A to ~80 A (single/split phase)	~3.1 kW to ~19.2 kW	~8 hours
DC charging station: Level 3 fast chargers	300 to 600 VDC and max 400 A (poly phase)	From 120 kW up to 240 kW	~ 30 minutes

Introduction and Motivation (2)

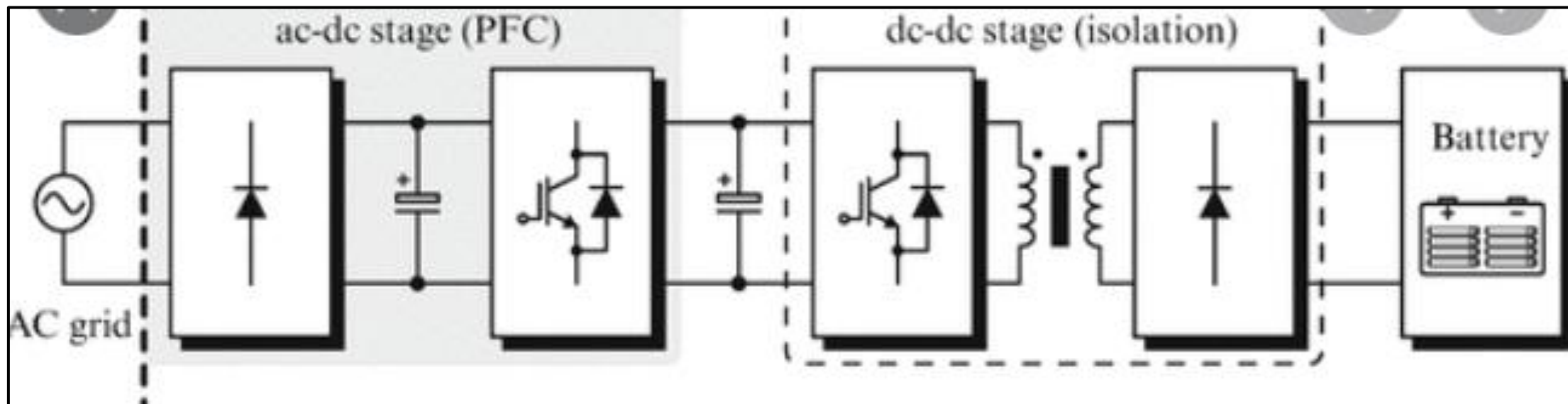
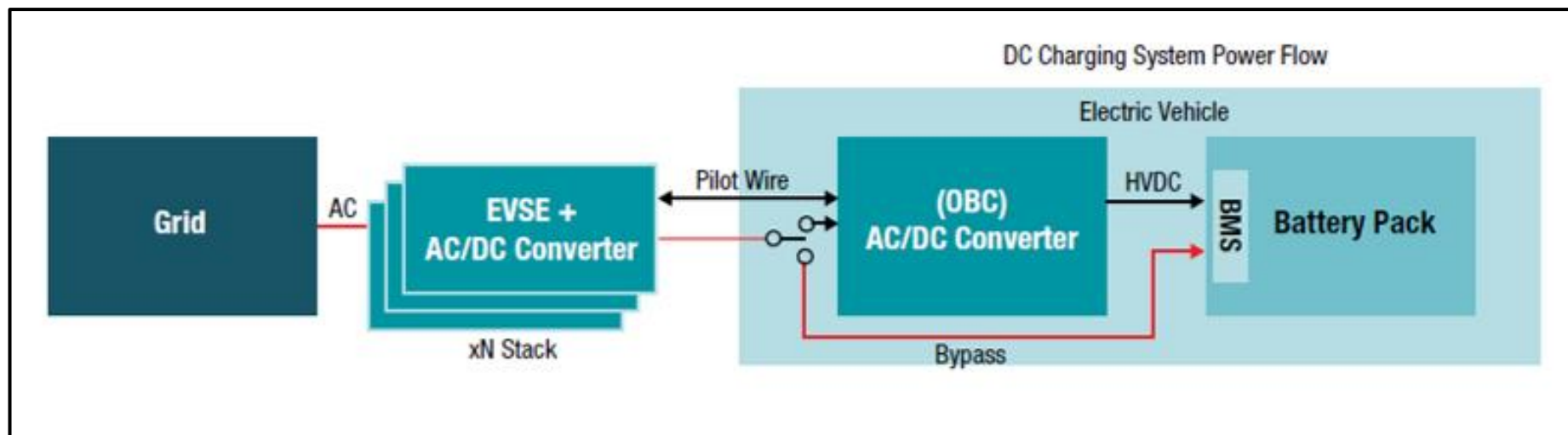
- Bi- or Unidirectional \Leftrightarrow Vehicle to Grid (V2G)
 - Grid Stabilization
 - Appropriate Topology needed



Agenda

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 - Topologies
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Block Diagram

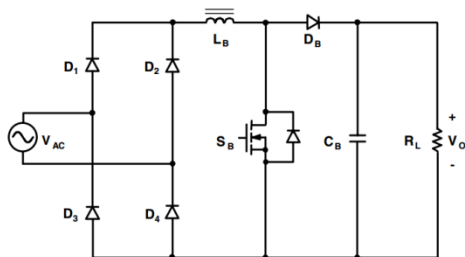


Agenda

- Introduction and Motivation
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PFC Typical Topologies

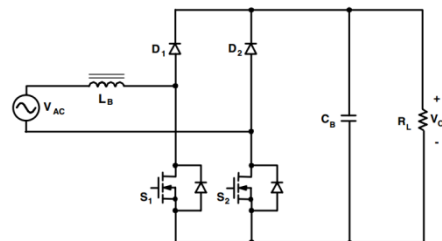
**Conventional
Boost PFC**



+ Cheap
Low EMI

- High conduction losses
due to 3 semiconductors

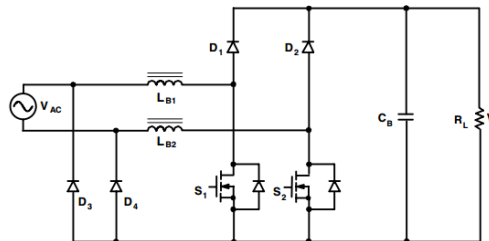
**Bridgeless
Boost PFC**



+ Reduced conduction losses

- High EMI
Decoupled GND between output
ground and AC source
Needs UF diodes (ringing)

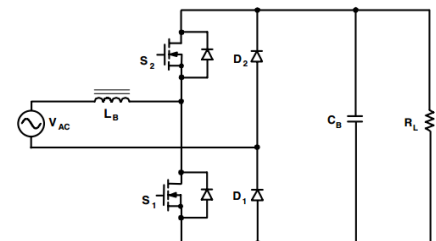
**Bridgeless Boost PFC with
two DC/DC circuits**



+ Low EMI

- High component count
Expensive

**Bridgeless
Totem Pole PFC**



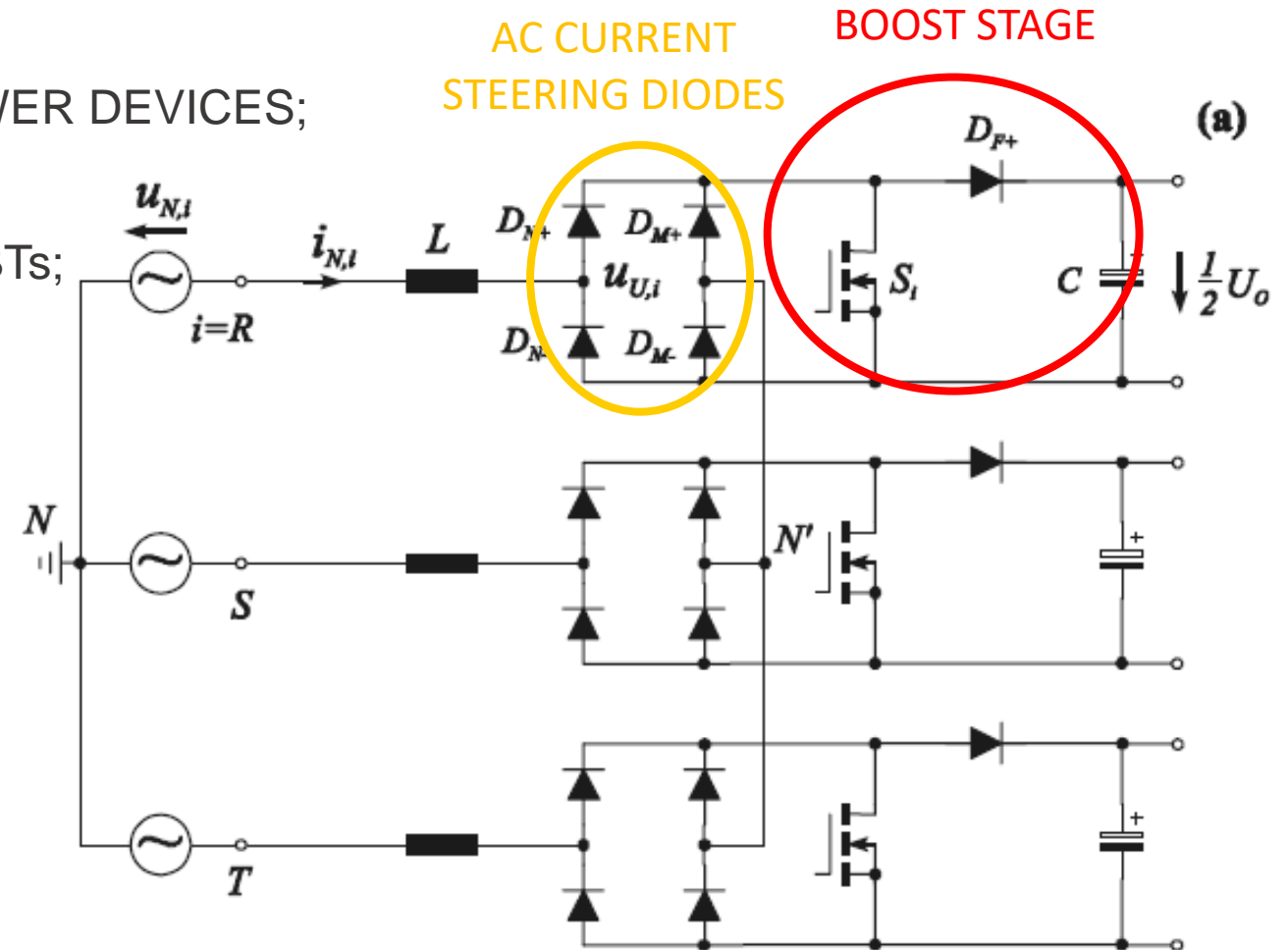
+ Low component count
Low EMI
High efficiency

- Only with GaN or SiC
possible

PFC

Topologies: Vienna Rectifier

SMALL VOLUME / HIGH POWER DENSITY;
REDUCED VOLTAGE STRESS ON THE POWER DEVICES;
HIGH EFFICIENCY AT HIGH FREQUENCY;
IT REQUIRES 600 / 650 V MOSFETS OR IGBTs;
SiC DIODES OR ULTRAFAST SI DIODES;
BUT: uni-directional only



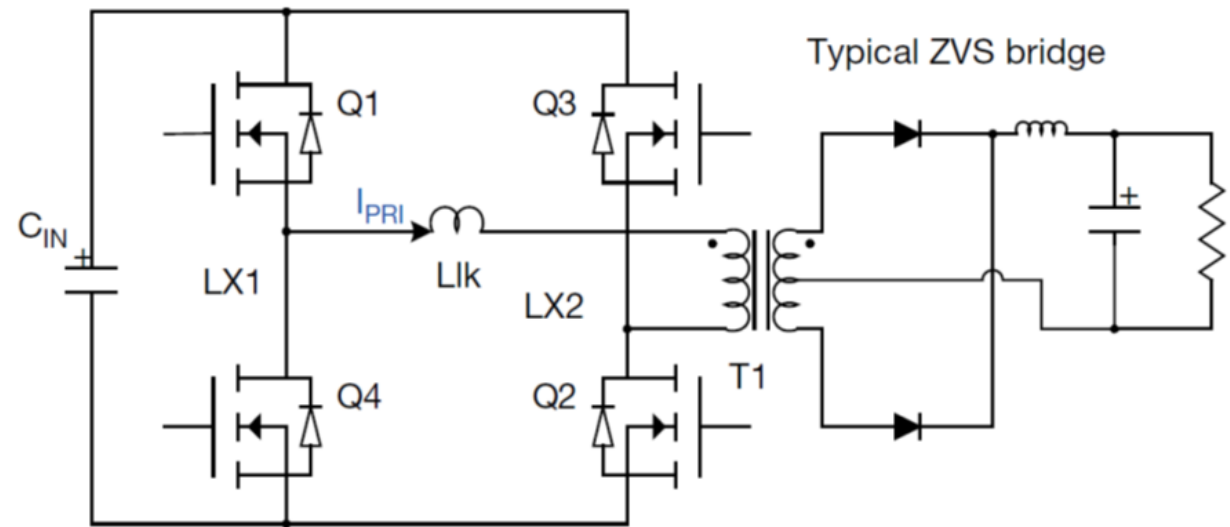
Agenda

- Introduction and Motivation
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 - Topologies
- **DC-DC Conversion**
- Possible Vishay Components

DC-DC Conversion

Full-Bridge-Phase-Shifted: Isolated and Resonant switched

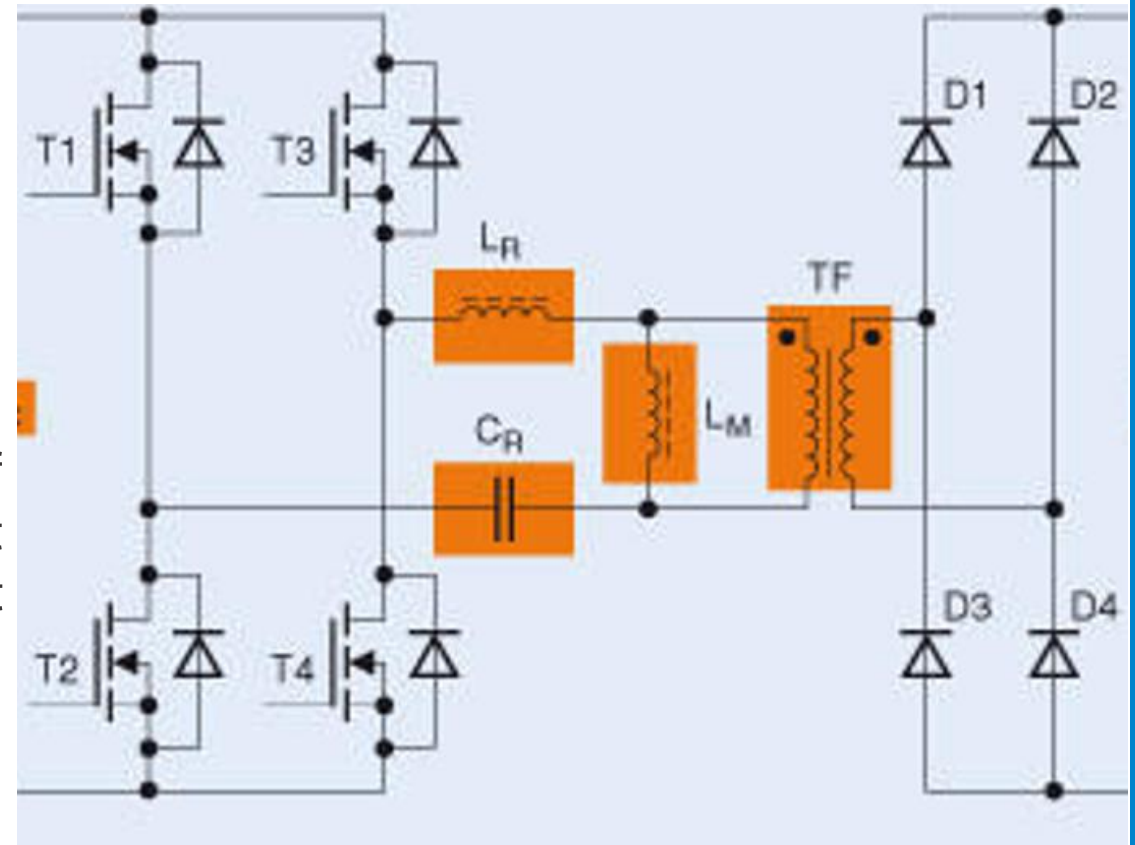
- Z.V.S. on all the switching elements
- Relatively easy design
- ZVS obtained regardless of the loading conditions at cost of larger currents for same active power even at light load
- Low (70kHz) possible frequency design allow use of IGBTs (cheaper)



DC-DC Conversion

LLC-Converter: Isolated and Resonant switched

- resonant topology features sufficient energy to be stored in the resonant tank to ensure loss-less autonomous switching
- the increased current processing (as per reactive current case) also leads to increased conduction losses
- full-bridge circuit doubles the voltage on the primary side of the transformer compared to a half bridge, so the current (also reactive) is halved, but $R_{ds(on)}$ and copper R are about doubled, net result is almost half the losses for resonant tank current
- Optimum operation at fixed voltage ratio
- Easy filtering EMI

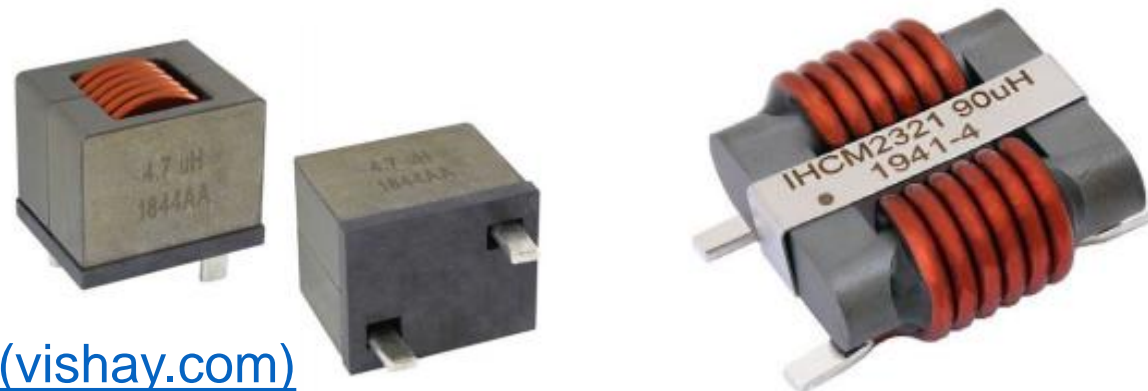


Agenda

- Introduction and Motivation
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- **Possible Vishay Components**

Components

Filter and Resonant Inductors



- Common Mode Choke: <ihcm-2321aa-10.pdf> (vishay.com)

- ✓ SMD
- ✓ Pick and Place
- ✓ Low Profile
- ✓ Reflow soldering
- ✓ 155°C

STANDARD ELECTRICAL SPECIFICATIONS						
PART NUMBER	L_0 INDUCTANCE $\pm 30\%$ AT 100 kHz, 0.25 V, 0 A (μ H)	COMMON MODE IMPEDANCE AT 10 MHz, TYP. (Ω)	DC RESISTANCE MAX. (Ω)	HEAT RATING CURRENT TYPICAL (EST.) (A_{DC}) ⁽¹⁾	SATURATION CURRENT AT 25 °C TYP. (A_{DC}) ⁽²⁾	LEAKAGE MAX. (μ H)
IHCM2321AAEG900N10	90	380	0.0015	31	35	2.5
IHCM2321AAEG121N10	120	480	0.0018	25	28	3.5
IHCM2321AAEG251N10	250	850	0.0050	14	19	7.5
IHCM2321AAEG301N10	300	900	0.0070	10	17	8.0
IHCM2321AAEG481N10	480	1200	0.0125	8	13	14.0

- Edge Wound Inductor: <ihdm-1008bc-30.pdf> (vishay.com)

- ✓ Customization possible
- ✓ Soft Saturation
- ✓ Different Terminals
- ✓ 180°C

STANDARD ELECTRICAL SPECIFICATIONS								
L_0 INDUCTANCE $\pm 20\%$ AT 100 kHz, 0.25 V, 0 A (μ H)	DCR AT 25 °C TYP. (m Ω)	DCR AT 25 °C MAX. (m Ω)	HEAT RATING CURRENT DC TYP. ⁽¹⁾ (A)	SATURATION CURRENT DC TYP. ⁽²⁾ (A)	SATURATION CURRENT DC TYP. ⁽³⁾ (A)	SRF TYP. (MHZ)	DIMENSION A ± 0.016 [0.4]	DIMENSION B ± 0.020 [0.5]
1.2	0.25	0.30	80	110	150	90	0.126 [3.2]	0.543 [13.8]
2.2	0.35	0.40	70	75	110	45	0.098 [2.5]	0.571 [14.5]
3.3	0.63	0.70	50	60	90	25	0.079 [2.0]	0.591 [15.0]
4.7	0.86	0.95	45	50	70	15	0.071 [1.8]	0.598 [15.2]
6.8	1.00	1.15	40	45	60	10	0.063 [1.6]	0.606 [15.4]
8.2	1.35	1.50	35	35	50	9	0.055 [1.4]	0.614 [15.6]
10	1.70	2.00	30	30	45	8	0.043 [1.1]	0.626 [15.9]

Components

Filter Capacitors Film Technology

High stability grade film capacitor for RFI suppression for long lasting service under severe ambient conditions of heat and humidity.

F340X2 305VAC

- Capacitance Range up to 20 μ F

F340X1 480VAC

- AEC-Q200 Qualified (under release)
- Max. Application Voltage: 530Vac

F340Y2 305VAC

- AEC-Q200 Qualified
- Maximum operation temperature: 125°C

IEC 60384-14 ed. 4 AMD1: High Robustness under High Humidity – Grade IIIB

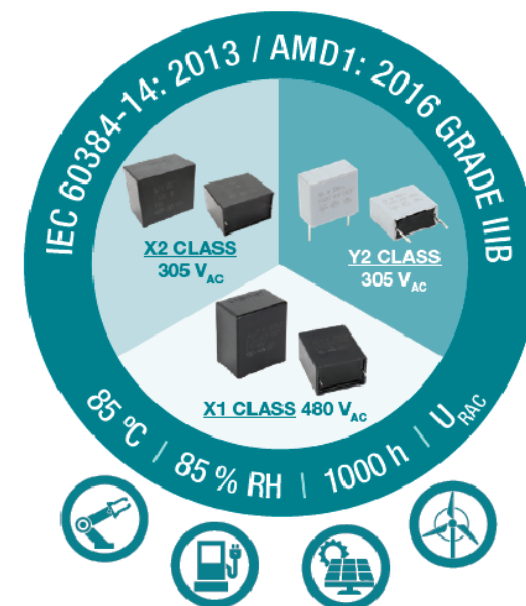
- THB: 85°C/ 85% R.H. / 1000h at VRAC

Full compliance and certified by external labs with Grade IIIB for EMI Capacitors.

[f340x1_480vac.pdf \(vishay.com\)](#)

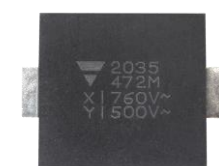
[f340y2_305vac.pdf \(vishay.com\)](#)

[f340x2_305vac.pdf \(vishay.com\)](#)



Components

Filter Capacitors Ceramic Technology



- **Leaded Single Disc:** Mainly used for Y1 applications (Line and GND):

[vy1series.pdf \(vishay.com\)](http://vy1series.pdf(vishay.com))

Features	Did You Know?	Our Advantages
<ul style="list-style-type: none"> ✓ Complying with IEC60384-14 ✓ VY1: X1/Y1 with 470pF - 4.7nF ✓ VY2: X1/Y2 with 10pF - 10nF ✓ Widest Product Portfolio 	<ul style="list-style-type: none"> ✓ The 440L series and the VY1*C series have the highest humidity robustness grade (IIIB) available at IEC60384-14 (Annex I) 	<ul style="list-style-type: none"> ✓ VY1*C: 10kV and 85/85/1000h ✓ Service and Flexibility ✓ New Product Launches

- **SMD:**

[smdy1.pdf \(vishay.com\)](http://smdy1.pdf(vishay.com))

Features	Did You Know?	Our Advantages
<ul style="list-style-type: none"> ✓ X1/Y1 with 470pF – 4700pF ✓ Reflow soldering ✓ Humidity class IIB (IEC60384-14 Annex I) ✓ Y1: 1500 V_{DC} (IEC60384-14 Annex H) 	<ul style="list-style-type: none"> ✓ Humidity robustness grade IIB is the second highest grade defined by IEC60384-14 and is tested by running the capacitor under rated voltage for 500 hours at 85 °C and 85% r.h. 	<ul style="list-style-type: none"> ✓ Industry first 500 V_{AC} and 1500 V_{DC} Y1 safety cap in SMD ✓ Highest capacitance (up to 4700 pF) ✓ Humidity class IIB ✓ MSL2a

Components

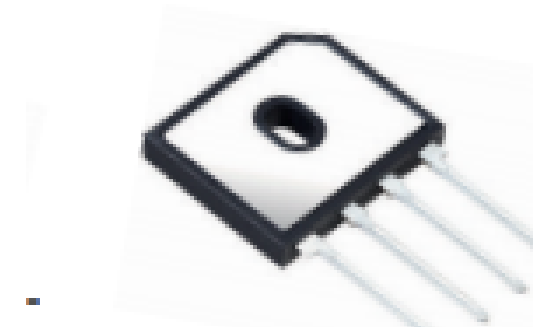
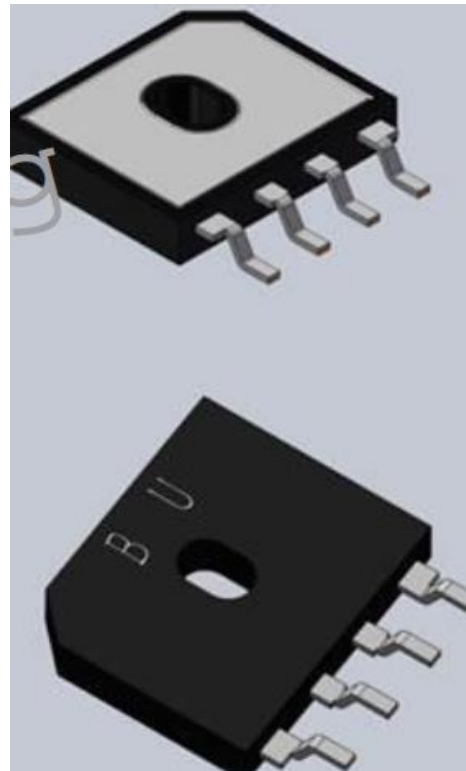
Slow Diodes for 50/60 Hz rectification

- **Single Diodes**

- [vs-60eps-m3series.pdf \(vishay.com\)](#)
- 60A
- 800 – 1200V
- 1.09V

- **Bridge Rectifier**

- 25A
- 600V or 800V
- Reverse Cooling
- Isolated Pad
- 175°C junction temperature

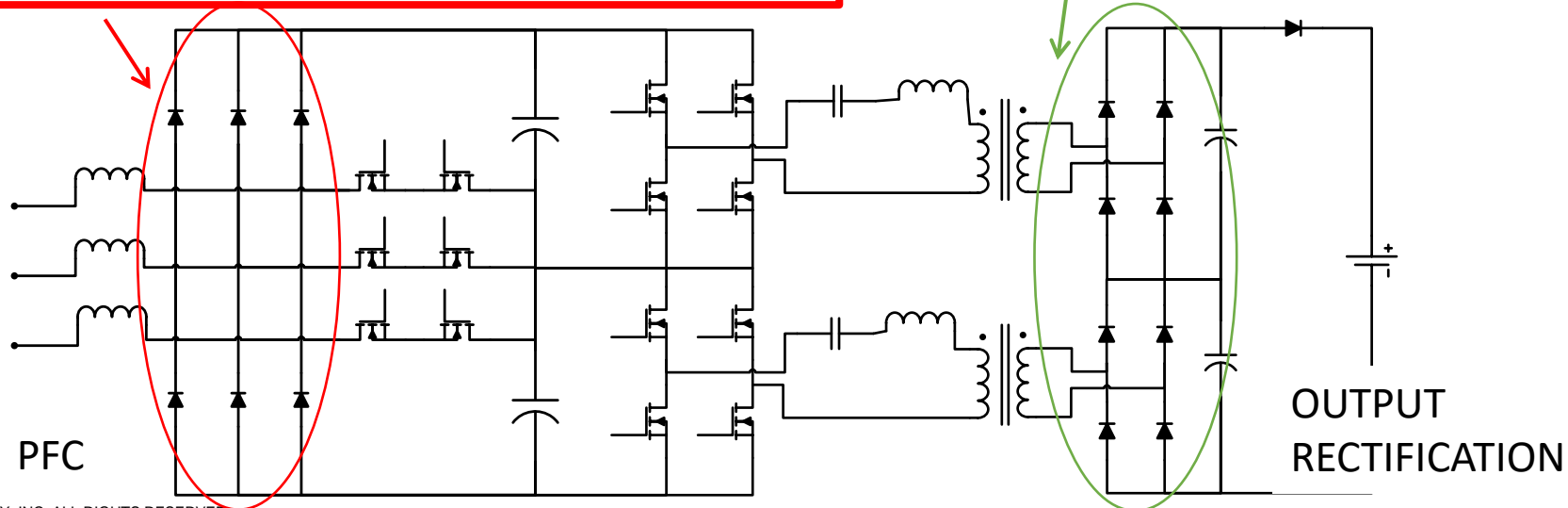


FRED 1200V G5 15-20KW BATTERY CHARGER



IF(AV)	V(BR)	Speed Class	Device	Package
30	1200	H	VS-E5TH3012T-N3	TO-220AC
30	1200	H	VS-E5PH3012L-N3	TO-247LL
30	1200	X	VS-E5TX3012T-N3	TO-220AC
30	1200	X	VS-E5PX3012L-N3	TO-247LL
60	1200	H	VS-E5PH6012L-N3	TO-247LL
60	1200	X	VS-E5PX6012L-N3	TO-247LL

$I_{F(AV)}$	$V_{(BR)}$	Device	Package
30	650	VS-ETH3007T-N3	2L TO-220
30	650	VS-ETX3007T-N3	2L TO-220
30	650	VS-EPH3007L-N3	TO-247 LL
30	650	VS-EPX3007L-N3	TO-247 LL
60	650	VS-EPH6007L-N3	TO-247 LL
60	650	VS-EPX6007L-N3	TO-247 LL



Components

PFC Diodes- Hyperfast Rectifier

- VS-E5PH6012L-N3

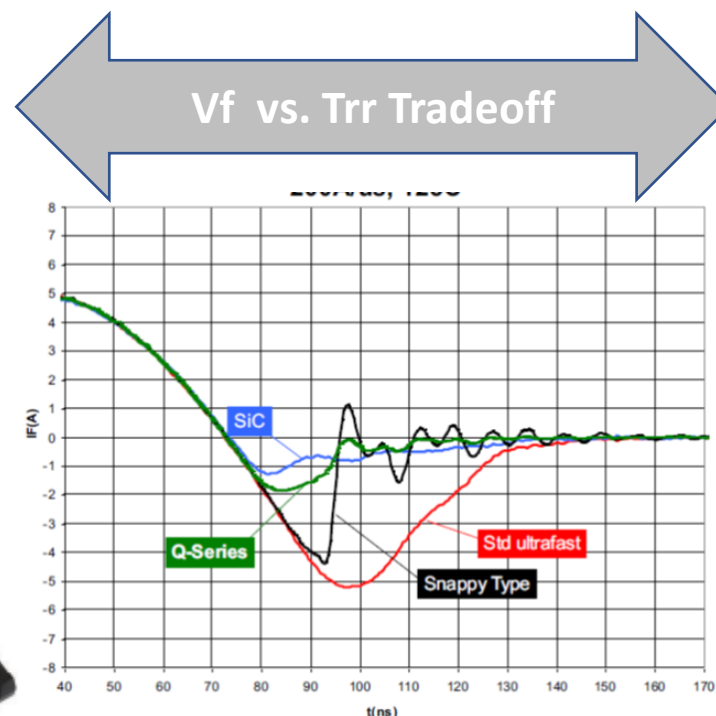
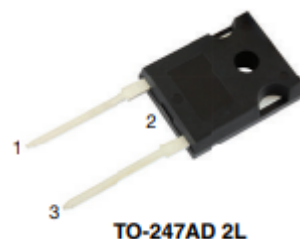
[vs-e5ph6012l-n3.pdf \(vishay.com\)](https://www.vishay.com/doc-94612/vs-e5ph6012l-n3.pdf)

- 60A
- 1.7V
- 38ns
- 2590nC
- Irr: 40A
- 1200V

- VS-E5PH7506L-N3

[vs-e5ph7506l-n3.pdf \(vishay.com\)](https://www.vishay.com/doc-94612/vs-e5ph7506l-n3.pdf)

- 75A
- 1.2V
- 32ns
- 805nC
- Irr: 28A
- 600V



- VS-E5PX6012L-N3

[vs-e5px6012l-n3.pdf \(vishay.com\)](https://www.vishay.com/doc-94612/vs-e5px6012l-n3.pdf)

- 60A
- 2.1V
- 30ns
- 1570nC
- Irr: 17A
- 1200V

- VS-E5PX7506L-N3

[vs-e5px7506l-n3.pdf \(vishay.com\)](https://www.vishay.com/doc-94612/vs-e5px7506l-n3.pdf)

- 75A
- 1.4V
- 29ns
- 484nC
- Irr: 21A
- 600V



Components

PFC Diodes- Silicon Carbide = SiC

[Silicon Carbide | Diodes and Rectifiers | Vishay](#)

- ✓ Paralleling
- ✓ Constant T_{rr} over Temperature
- ✓ Reduces switching losses

But:

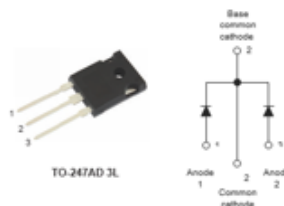
- Risk of rising losses in case of surge

Solution:

⇒ Merger PN Schottky (MPS)

Benchmarking?

⇒ On request



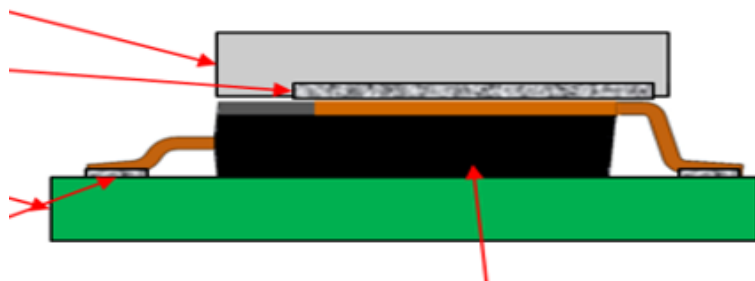
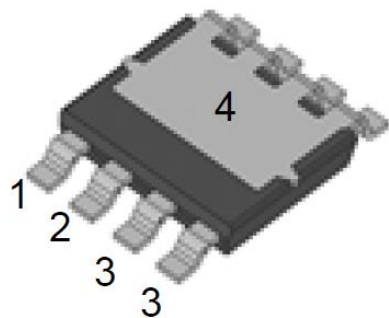
PACKAGE	PN NAME	CURRENT RATING (A)
TO220	VS-C04ET07T-M3	4
single true 2 pin	VS-C06ET07T-M3	6
	VS-C08ET07T-M3	8
	VS-C10ET07T-M3	10
	VS-C12ET07T-M3	12
	VS-C16ET07T-M3	16
	VS-C20ET07T-M3	20

TO247AC 3L dual die	VS-C16CP07L-M3	2 x 8
	VS-C20CP07L-M3	2 x 10
	VS-C40CP07L-M3	2 x 20

Components

DC-DC 600V Superjunction MOSFETs

PowerPAK® 8 x 8 LR

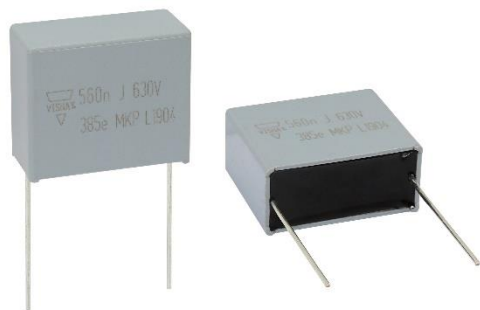


Mosfet Reverse PPAK 8x8L

R _{on} (mΩ) (max)	DPAK	TO-220	D2PAK	TO-220F	TO-247AC	PowerPAK® 8x8	PowerPAK® SO8L
690	SiHD690N60E	SiHP690N60E		SiHA690N60E			SiHJ690N60E
240	SiHD240N60E	SiHP240N60E		SiHA240N60E			SiHJ240N60E
180	SiHD180N60E	SiHP180N60E	SiHB180N60E	SiHA180N60E		SiHH180N60E	
120		SiHP120N60E	SiHB120N60E	SiHA120N60E	SiHG120N60E	SiHH120N60E	
100		SiHP100N60E	SiHB100N60E	SiHA100N60E	SiHG100N60E	SiHH100N60E	
68						SiHH068N60E	
65		SiHP065N60E	SiHB065N60E	SiHF065N60E	SiHG065N60E		
50		SiHP050N60E			SiHG050N60E		
39					SiHG039N60E		
18					SiHG018N60E		

Components

Resonant Capacitors: MKP385 and MKP385e series



AEC-Q200 Qualified

High Robustness under High Humidity $60^{\circ}\text{C} / 93\% \text{ RH} / 56\text{days at } V_{\text{NDC}}$

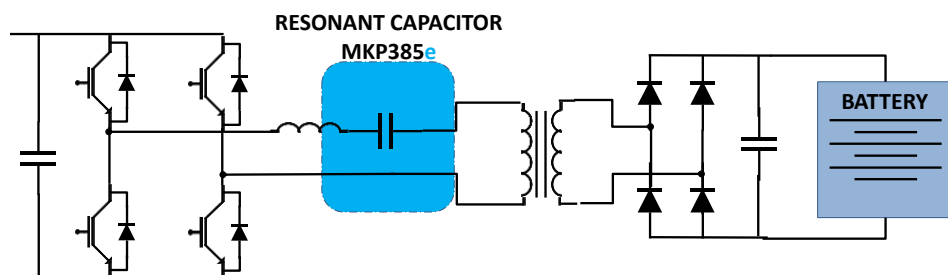
High Capacitance and Voltage range

Very Low ESR for very high Ripple current Capabilities

Very High Frequency Operation

Maximum operation temperature up to 125°C^*

For Industrial applications, MMKP383 Double Metalized also available.

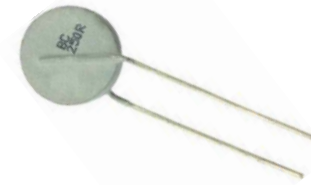


MKP385e	
U_{RDC} (V)	CAPACITANCE (μF)
400	0.047 min.
	15 max.
630	0.027 min.
	15 max.
850	0.01 min.
	4.7 max.
1000	0.018 min.
	3.3 max.
1250	0.0082 min.
	2.7 max.
1600	0.0039 min.
	1.20 max.
2000	0.001 min.
	0.68 max.
2500	0.001 min.
	0.39 max.

Components

Thermistors

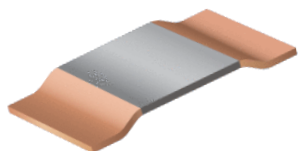
- **PTCEL**: Radial leaded ceramic PTC for inrush current limitation (ICL) and Energy Load-Dump; Can handle high direct voltage up to 1 kV and 2 kV energy-limited peak voltages; Self protecting in case of overload or circuit failure and no risk of overheating
- **NTCALUG**: NTC assembly for surface temperature measurement; Many versions and custom options available; High insulation voltage
- **NTCLE213** / **NTCLE203...SB0**: Epoxy coated NTC thermistor with tinned nickel radial leads (low heat conductivity); Highly resistant to thermal shocks
- **PTCSL03**: Mini radial leaded ceramic PTC thermistor for over-temperature protection e.g. in the charging plug



Components

Shunt resistors

WSLP3921

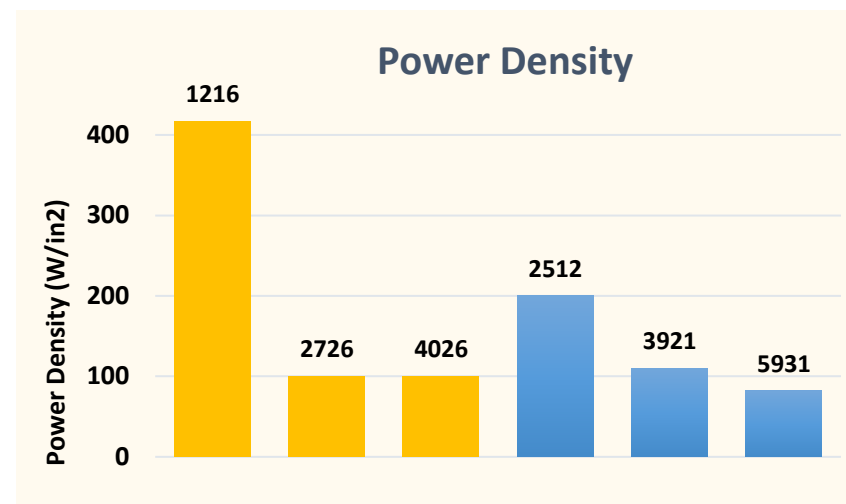


9W 0.1 mΩ to 1.5 mΩ
5W 2 mΩ to 4 mΩ

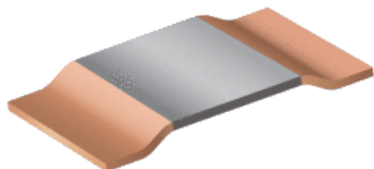
WSLF2512



6W 0.3 mΩ, 0.5 mΩ
5W 1 mΩ to 2 mΩ
4 W 3 mΩ
3W 4 mΩ

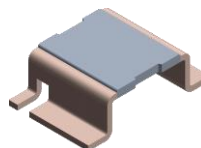


WSLP5931



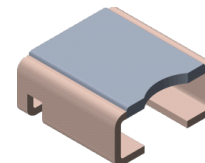
15W 0.1 mΩ
10W 0.2 mΩ to 1 mΩ
8 W 2 mΩ
7W 3 mΩ

WSLP4026



7W 0.2 mΩ to 1 mΩ
5W 1.3 mΩ to 5 mΩ

WSLP2726



7W 0.2 mΩ to 1 mΩ
5W 1.3 mΩ to 5 mΩ

WSK1216



8W 0.2 mΩ, 0.3 mΩ
5W 0.5 mΩ
3W 1 mΩ

Components

DC-Link Capacitors: MKP1848- Family



Rated capacitance range: 1 μ F to 500 μ F
 Rated DC Voltage: 450VDC to 1200VDC
 High Ripple Current Capabilities up to 54A @ 85°C / 10kHz
 Low ESR down to 1,3m Ω

- **MKP1848 (Standard)**
 - AEC-Q200 Qualified
- **MKP1848H**
 - High Robustness under High Humidity
- **MKP1848Se**
 - AEC-Q200 & Low Profile
- **MKP1848C**
 - Industrial Compact

DC VOLTAGE RATINGS						
U _{NDC} at 85 °C	450 V	700 V	800 V	900 V	1100 V	1200 V
U _{OPDC} at 70 °C	500 V	800 V	900 V	1100 V	1350 V	1500 V
U _{OPDC} at 105 °C	300 V	500 V	570 V	650 V	800 V	850 V