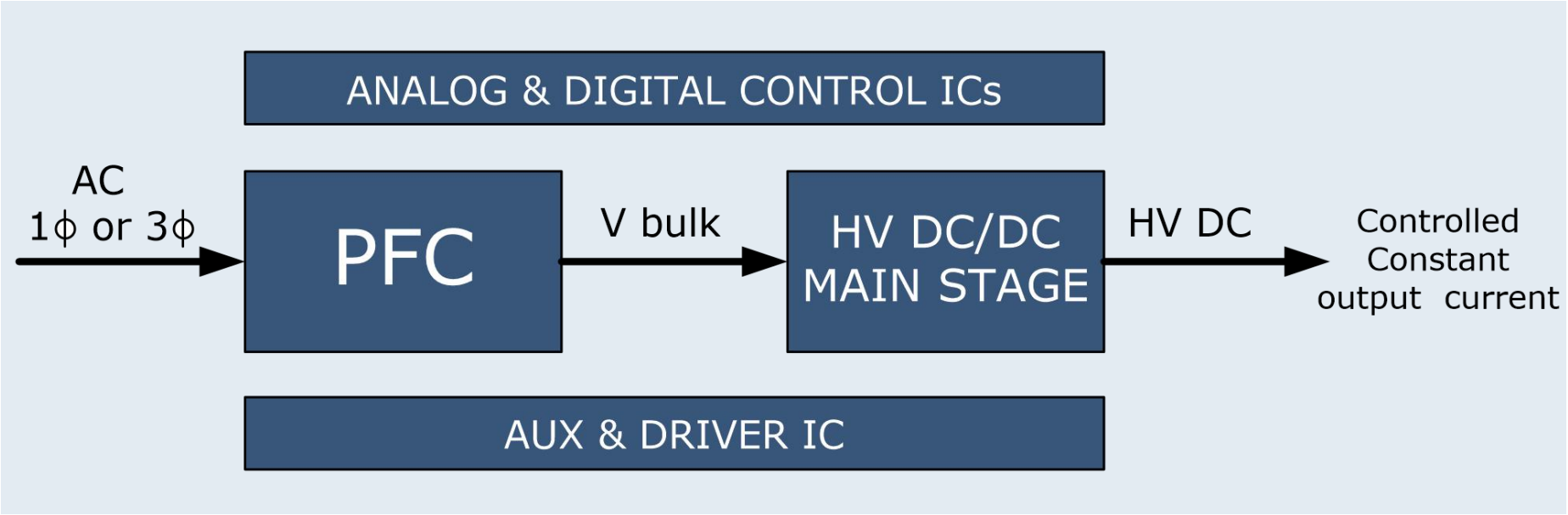
功率半导体在电动汽车充电桩中的应用

英飞凌　史威

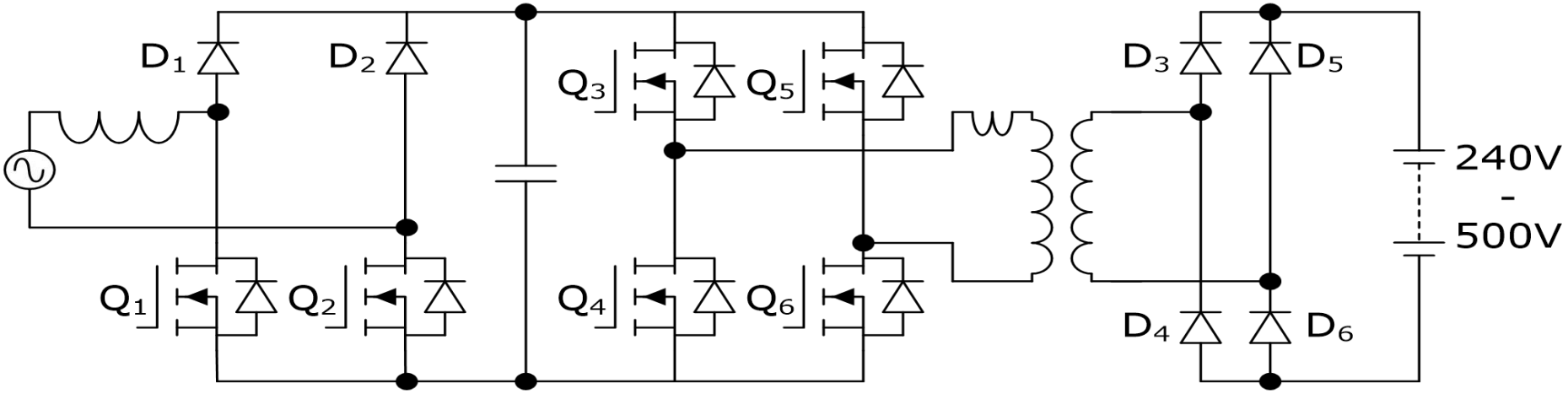
Oct. 2016

Block Diagram of Charging Station Module



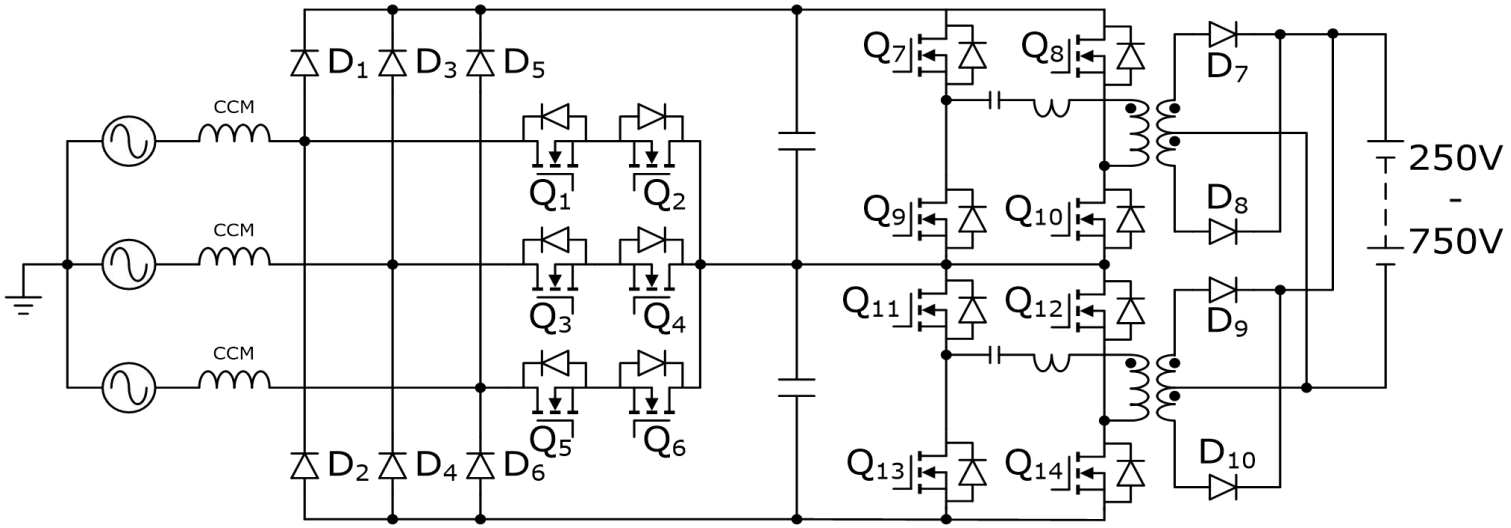
Function	Recommended Products
PFC Stage	CoolMOS™ CFD2, C7 & P6, Coolsic!™ SiC G5 650V IGBT Trenchstop5™ ; 650V Rapid 1/2 series
HV DC DC Main Stage	CoolMOS™ C7 & CFD2 1200V IGBT H3 series
Analog & Digital Control ICs	ICE3PCSXXG, XMCXXXX
AUX	CoolSET™ F2, CoolSET™ Quasi
DRIVER IC	EiceDRIVER™ 2EDN752XX/2EDN852XX, 1EDI60I12AF/1EDI60N12AF/1EDI20N12AF (Insulation)

IFX Product Proposal for DC Charging Module - Single Phase (3.3KW~6KW)



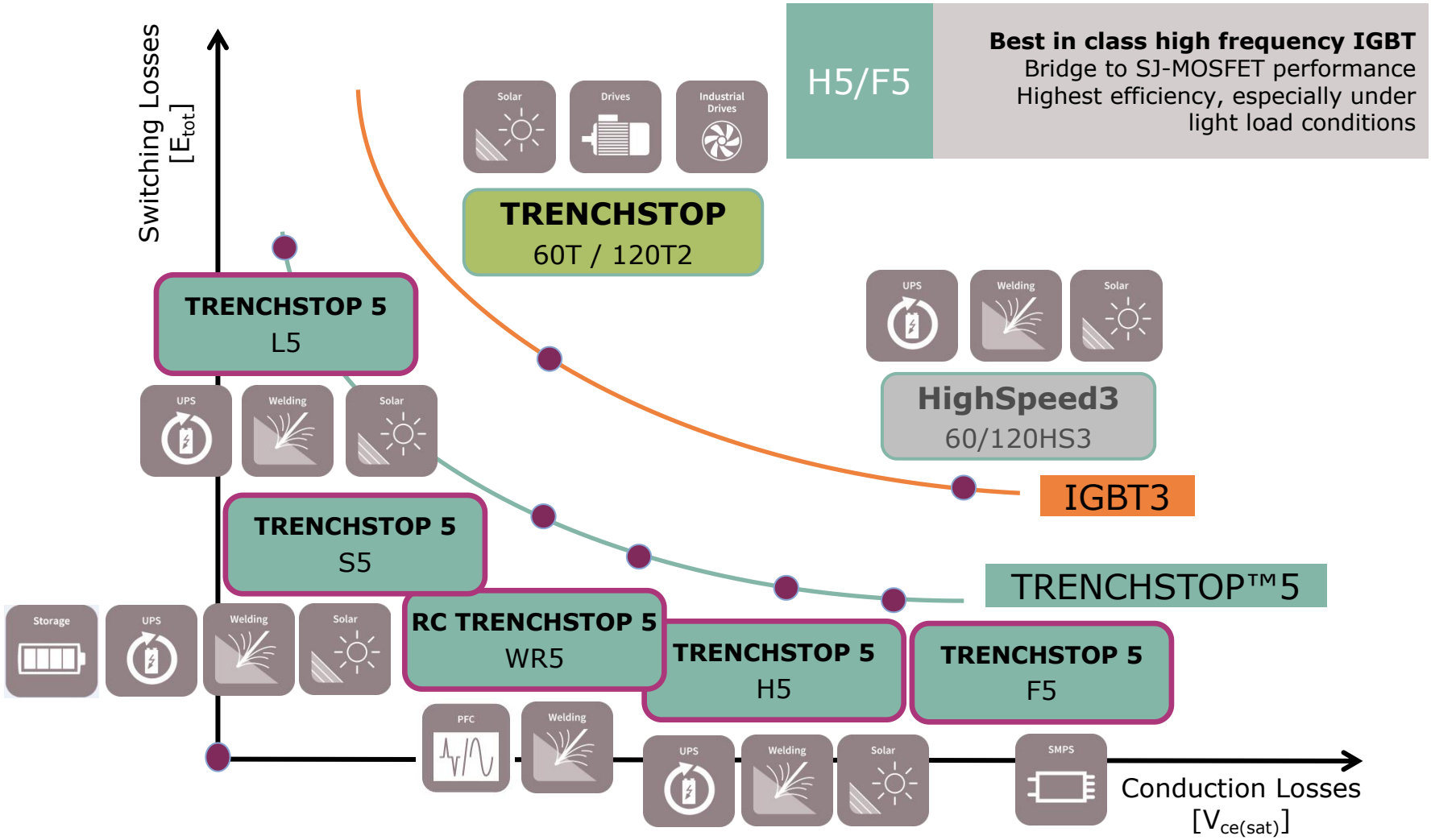
Function	Recommended Products
Single Phase Input Bridgeless PFC stage	
PFC Switch (Q_1-Q_2)	600V CoolMOS™ P6/C7 series(high efficiency & power density solution); 650V Trenchstop5™ H5/S5 series(price-performance solution);
PFC Diode (D_1-D_2)	650V CoolSiC™ G5(high efficiency & power density solution); 650V Rapid 1/2 series(price-performance solution);
PFC Controller	ICE3PCSXXG;
Soft switching type full-bridge stage	
DC/DC Switch (Q_3-Q_6)	600V CoolMOS™ CFD2(high efficiency & power density solution);
LLC Controller	ICE1HS01G-1;
Driver IC (PFC & LLC)	
Low Voltage dual driver	2EDN752XX / 2EDN852XX
High Voltage driver	1EDI60N12AF / 1EDI20N12AF(Insulation)

Three Phase Module (12KW/15KW/20kW)



Function	Recommended Products
Three-phase Input Vienna PFC stage	
PFC switch (Q_1-Q_6)	600V CoolMOS™ C7 series , P6 series CoolSiC™ SiC G5. 650V Trenchstop5™ H5/S5 series
PFC diode (D_1-D_6)	1200V CoolMOS!™ SiC G5
PFC Controller	XMC1000 series
Software switching type full-bridge stage	
dc dc switch (Q_7-Q_{14})	650V CoolMOS™ CFD2
LLC Controller	ICE1HS01G-1, XMC1000 series
Driver IC (PFC & LLC)	
Low voltage dual driver	2EDN752XX / 2EDN852XX
High voltage driver	1EDI60N12AF / 1EDI20N12AF (Insulation)

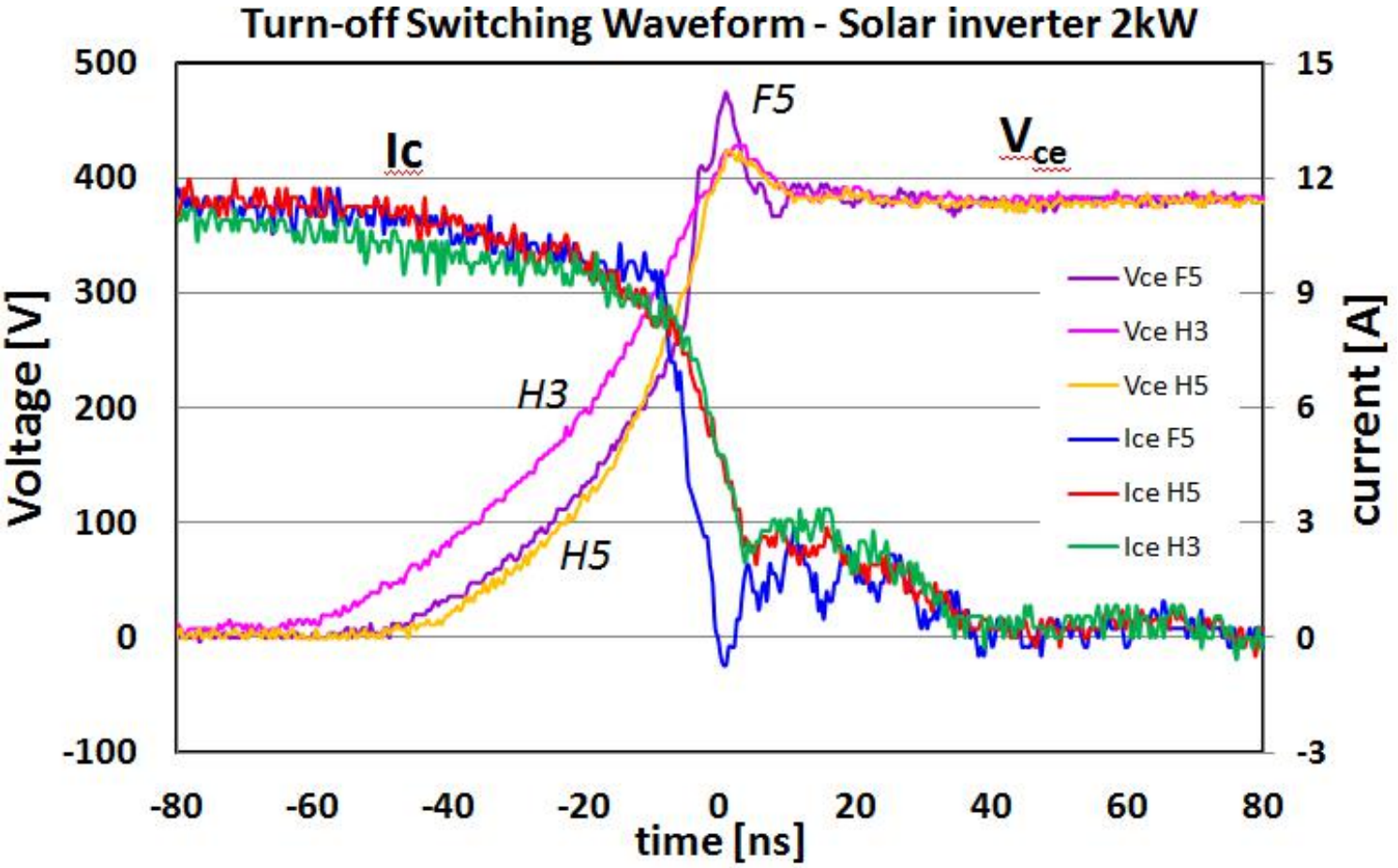
IFX Discrete IGBT Technology Evolution



<= Low switching 20kHz

Fast switching up to 70-100kHz =>

Switching Waveforms H5 and F5 vs H3



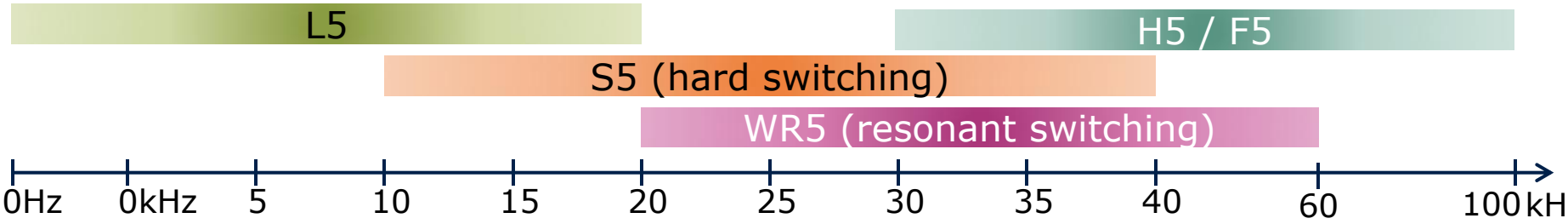
- H5, F5 shows steeper dI/dt and dV/dt, higher Vcemax, lower turn-off losses than H3 !

IFX Discrete IGBT：650V TRENCHSTOP™ 5



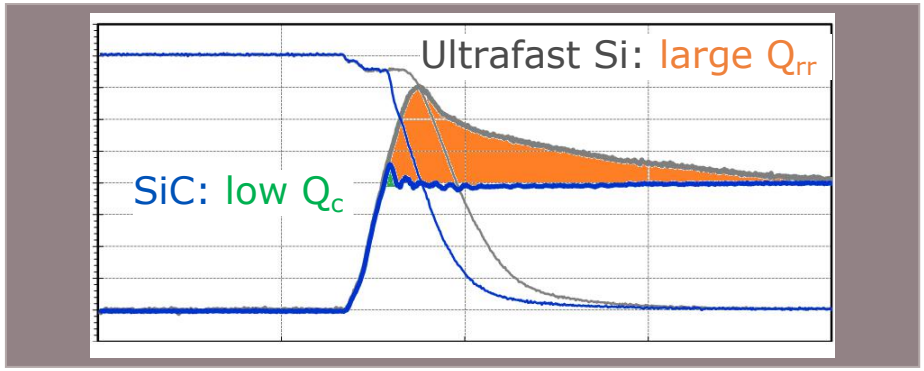

	TO-220		TO-220FP		TO-247-3							TO-247-4		
	H5	F5	H5	F5	EL5*	NL5**	ES5*	WR5	H5	EH5*	F5	EL5*	EH5*	NH5**
8	x	x	x	x										
15	x	x	x	x										
20	x	x					x	x						
30	x	x			x	x	x		x					
40	x	x					x	x	x		x			
50							x	x	x	x	x		x	x
75					x		x			x		x	x	x

WR5 | L5 | H5/F5 | S5



*Full rated Rapid 1 diode
** Full rated Rapid 2 diode
All other devices have ½ rated Rapid 1 diode

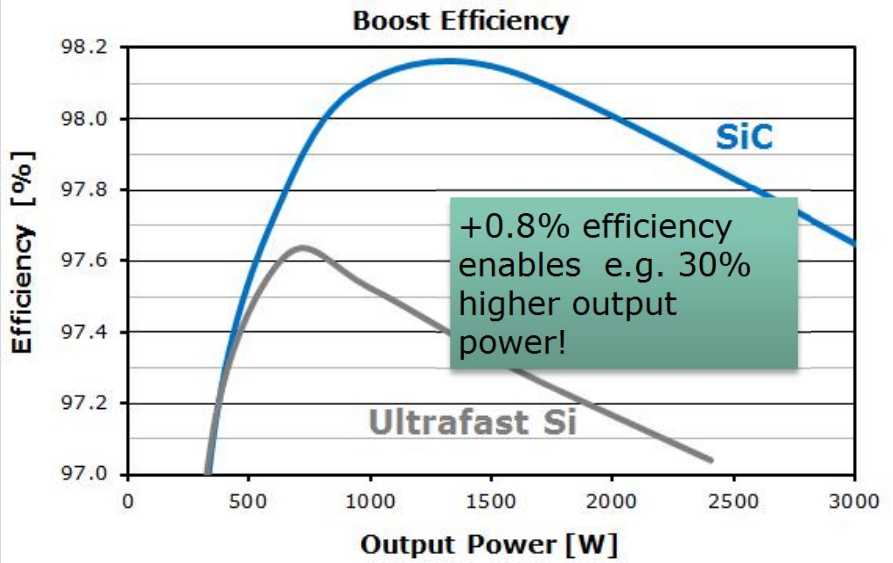
Comparison between SiC Diode and Si Diode

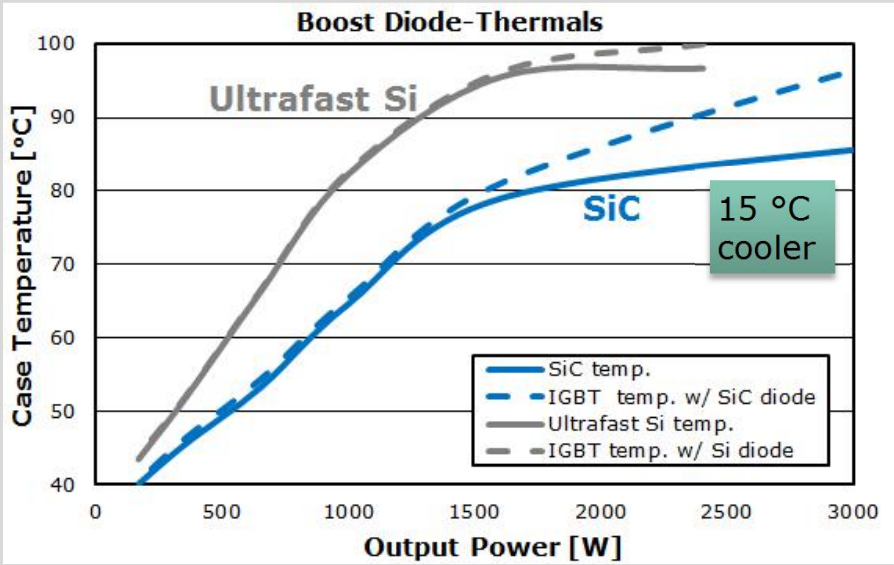


Features	Technical benefits	System benefits
› No reverse recovery charge › No forward recovery › Purely capacitive switching	› Low-loss turn-off & low IGBT turn-on loss › No voltage overshoots › Switching losses independent from load current, switching speed and temperature	› High system efficiency, output power & power density › High system reliability › Reduced cooling requirements › Reduced EMI › Reduced parts count, no need for snubber circuitry

Comparison between SiC Diode and Si Diode

Example:
Boost stage topology at f_{sw}=20 kHz, same 1200V Highspeed3™ IGBT in both tests



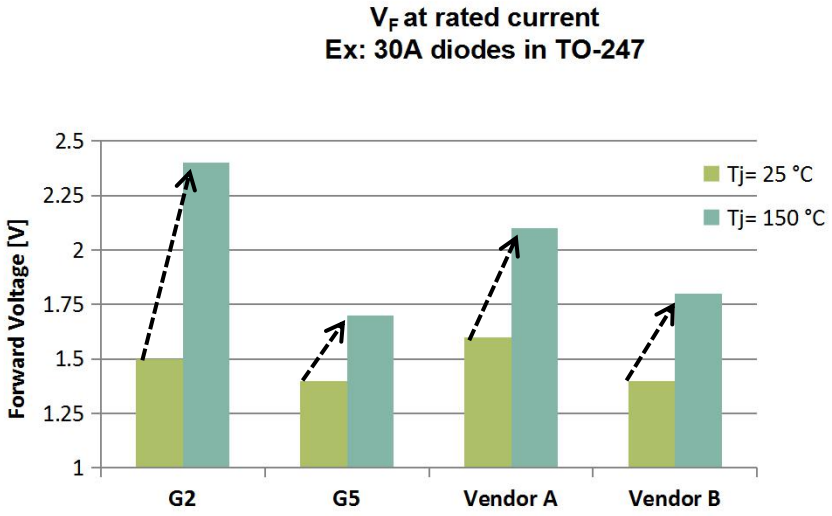


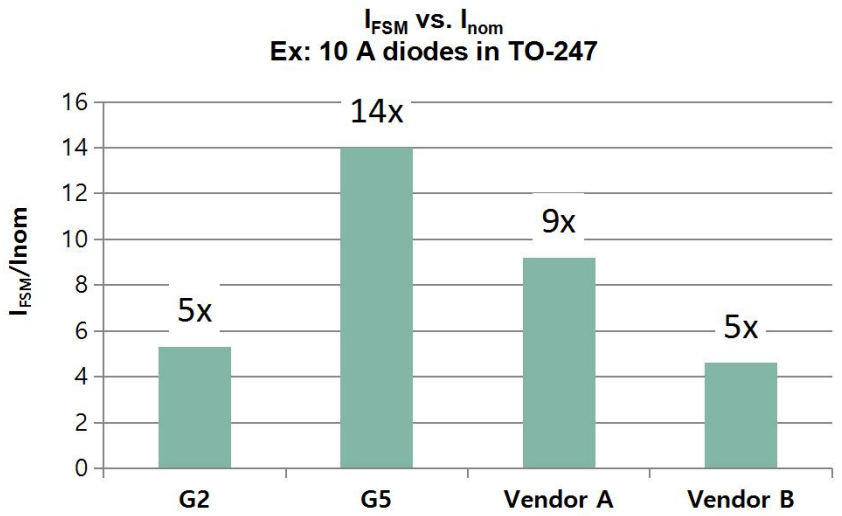
⇒ SiC diode - compared to Si diode – has ...
... higher system efficiency,
... lower device thermals, for
... increased power density and reliability!

Specific Product Information

G5 1200V CoolSiC™ Diodes:

- **Low VF with low temperature dependency** give low static losses over entire load range
- **Extended surge current capability** for improved reliability





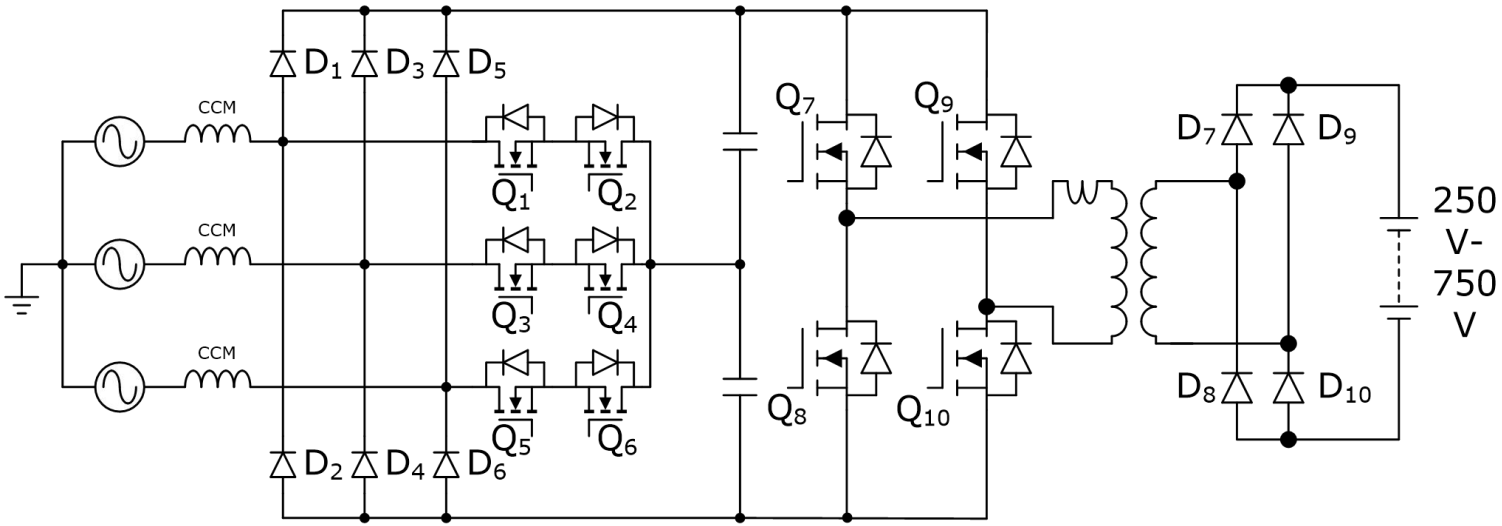
IFX SiC Diode 1200V G5 Product Portfolio





I_F	G5	G5	G2	G5	G2
2A	IDM02G120C5	IDH02G120C5	IDH02SG120		
5A	IDM05G120C5	IDH05G120C5	IDH05S120		
8A	IDM08G120C5	IDH08G120C5	IDH08S120		
10A	IDM10G120C5	IDH10G120C5	IDH10S120	IDW10G120C5B	IDW10S120
15-16A		IDH16G120C5B	IDH15S120	IDW15G120C5B	IDW15S120
20A		IDH20G120C5B		IDW20G120C5B	IDW20S120
30A				IDW30G120C5B	IDW30S120
40A				IDW40G120C5B	

Three Phase Module (12KW/15KW/20kW)



Function	Recommended Products
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PFC switch (Q_1-Q_6)	600V CoolMOS™ C7 series , P6 series 650V Trenchstop5™ H5/S5 series
PFC diode (D_1-D_6)	1200V CoolMOS!™ SiC G5
PFC Controller	XMC1000 series
Software switching type full-bridge stage	
dc dc switch (Q_7-Q_{10})	1200V IGBT HS3 (in next year, Sic-Mosfet also can be in application)
dc dc diode (D_7-D_{10})	IDB30E120
Driver IC (PFC & LLC)	
Low voltage dual driver	2EDN752XX / 2EDN852XX
High voltage driver	1EDI60I12AF / 1EDI60N12AF / 1EDI20N12AF

HighSpeed 3 & TRENCHSTOP™5 IGBT Product Spectrum

High Speed3 IGBT for hard switching topologies

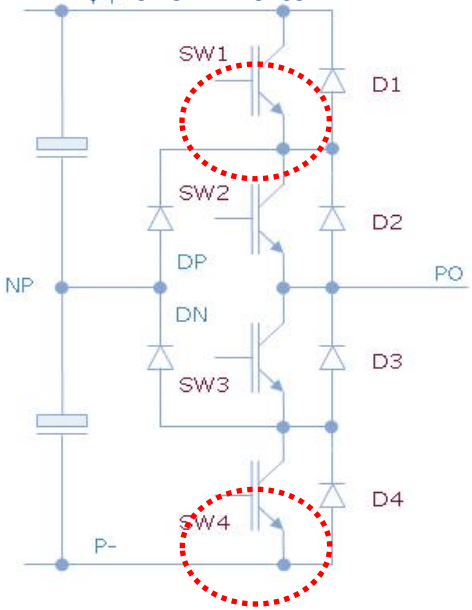
UPS, Solar, Welding:

- Frequency range 16kHz and above
- Power factor close to 1
- Low EMI, high efficiency
- Hard commutation

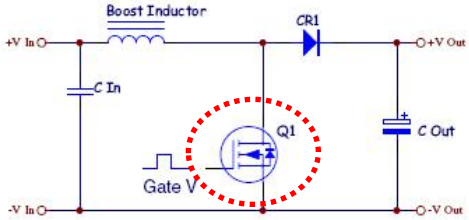
SMPS

- Frequency range < 100kHz
- High dV/dt
- Hard commutation

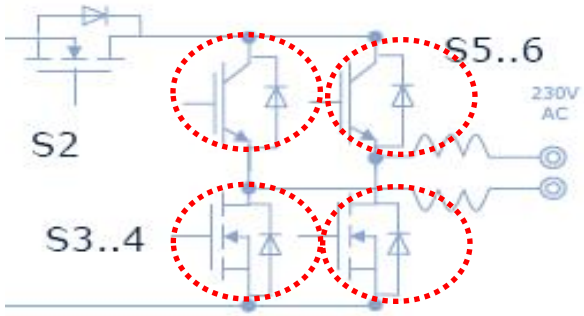
3-Level Inverter



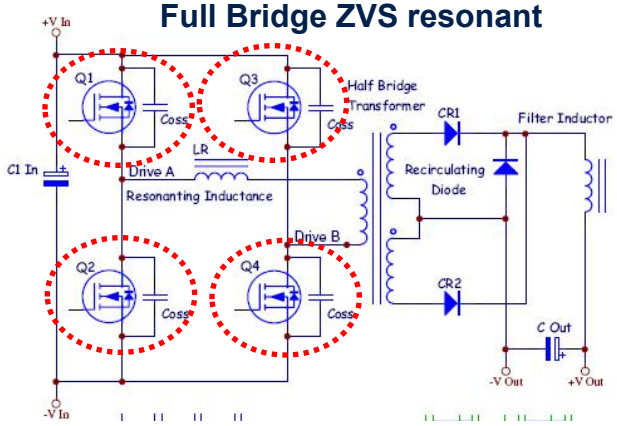
Boost PFC



H4 Inverter



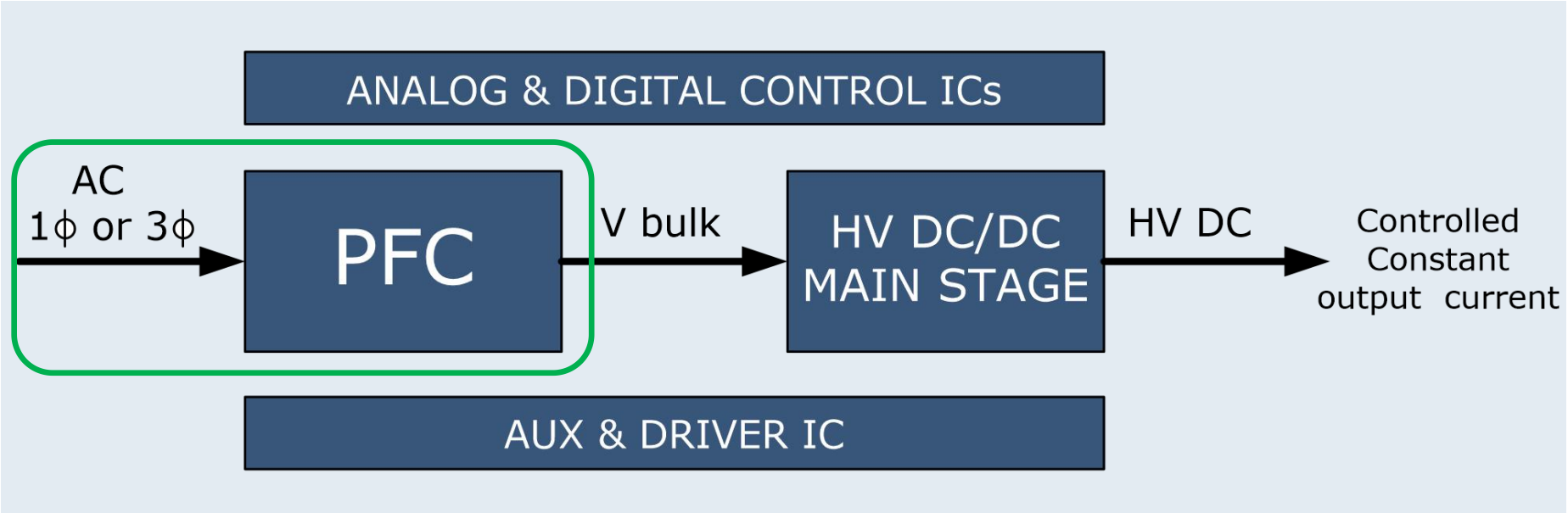
Full Bridge ZVS resonant



Development Trend:
EV Wire Charging Station Module

- Increase Output Power (shorten the charging time)
  - Single Phase 6kW->10kW pre module
  - Three Phase 15kW-> 20kW pre module
- Increase Power Density (size of the charging station is fixed)
  - Increase the switching frequency for reduce the passive components, input inductor and isolation transformer, size
- Increase Efficiency (required by operator)
  - 93% @ 15kW full load -> 95% or higher
  - Less power dissipation
    - Longer lifetime for E. Cap
    - Less heatsink for power density
    - Improve reliability of

Block Diagram of Charging Station Module



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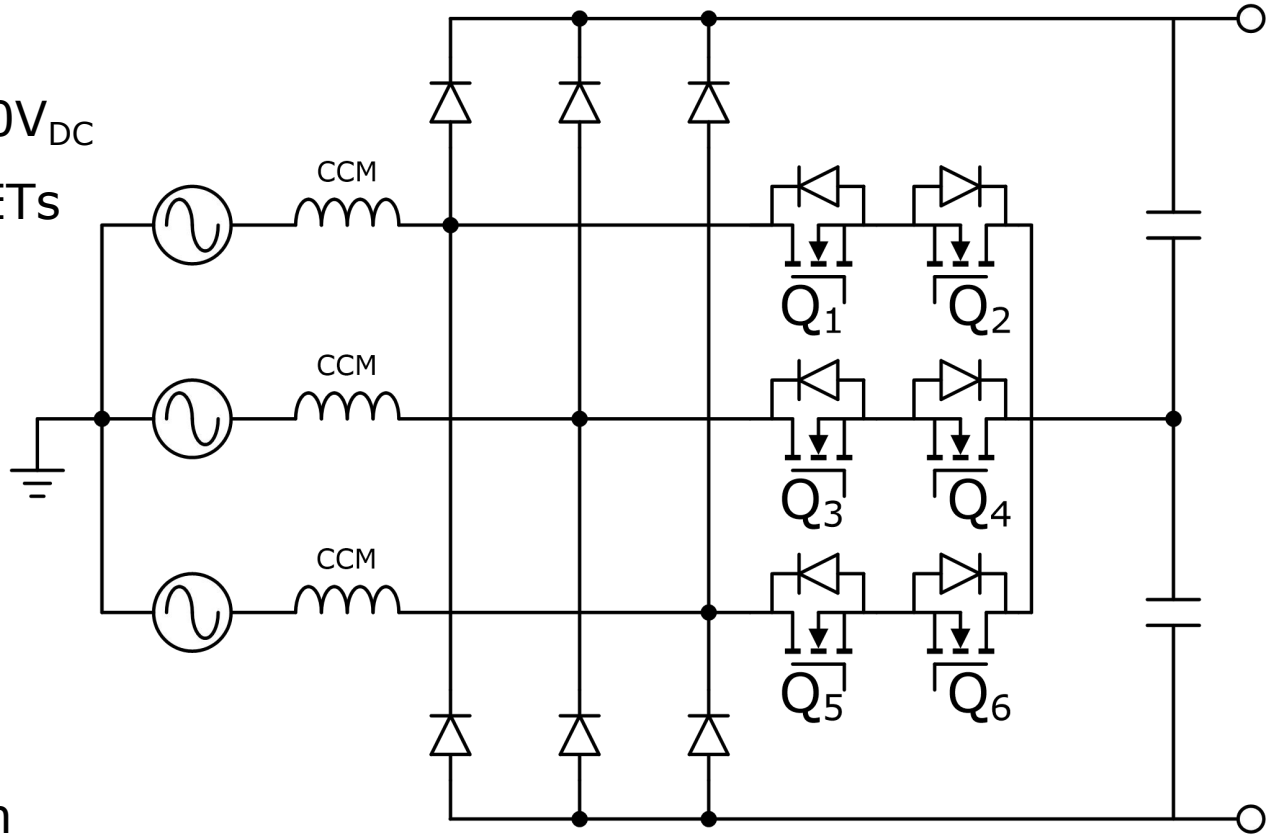
AUX	CoolSET™ F2, CoolSET™ Quasi
DRIVER IC	EiceDRIVER™ 2EDN752XX/2EDN852XX; 1EDI60N12AF/1EDI20N12AF(Insulation)

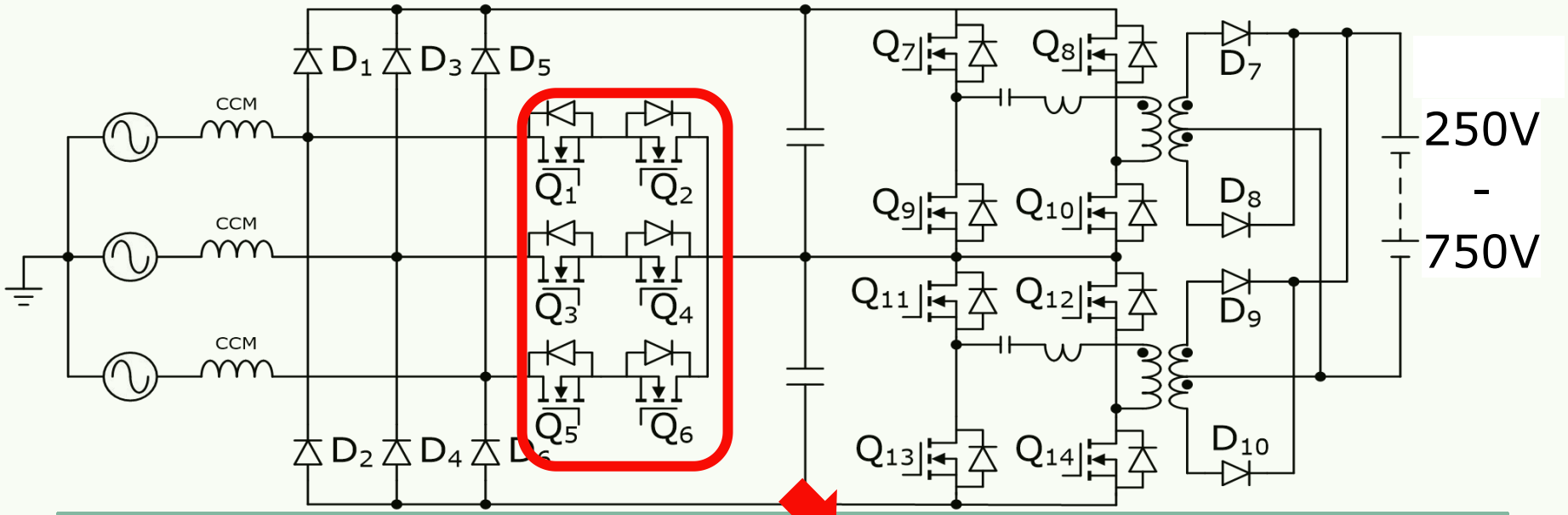
Design Example: AC->DC Stage

- Vienna (three-phase/switch/level) PWM rectifier topology
- Input Voltage: 380V_{AC} three-phase
- Output Voltage: +-400V_{DC}
- F_{sw} ≈ 60KHz of MOSFETs
- Calculated Eff. max≈98.6%
- Infineon products: IPW60R045C7, IPW60R041P6, IKW50N65H5/ES5; IKW75N65EH5/ES5; IDW40G120C5B
- Infineon possible to integrating bi-direction power switch in one package



Recommend P6 in Vienna PFC Rather CFD2

Typical Solution of 15KW Charging Module



Function	Part No.
Vienna PFC switch (Q_1-Q_6)	~~IPW65R041CFD~~ **IPW60R041P6**
LLC switch (Q_7-Q_{14})	IPW65R041CFD

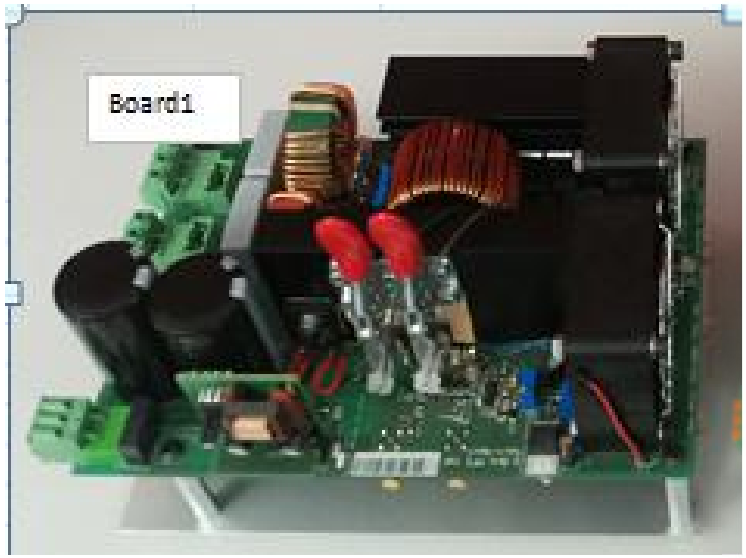
- Merits of IPW60R041P6 to replace CFD2 in Vienna PFC:
  - Similar or better performance by adjustment in R_g value
  - Better system cost and delivery

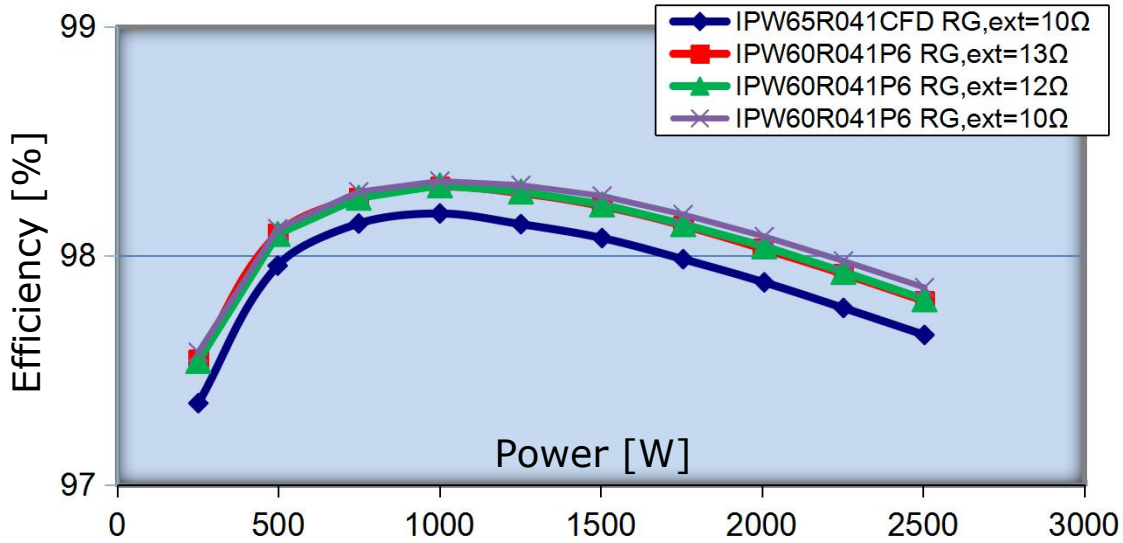
Benchmark of CFD2 and P6

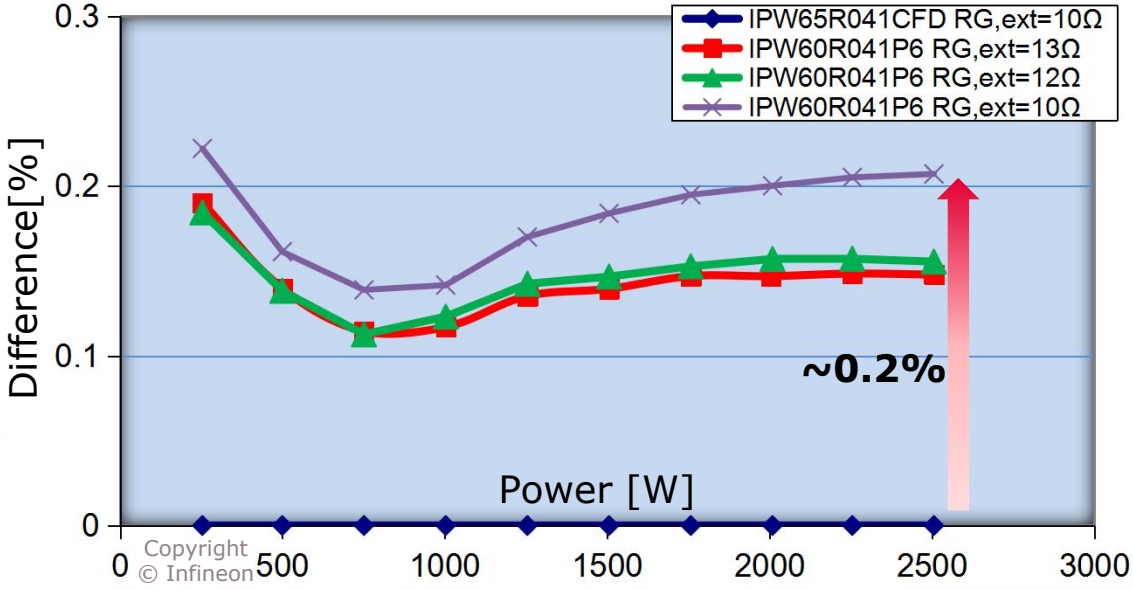
			Remark
P/N	IPW65R041CFD	IPW60R041P6	
Vds (BD)	650	600	CFD: high break down voltage
Rds(on) max. @ 25°C	0.041	0.041	Similar Rdson @ 25°C
Rds(on) @ 150°C	0.1075	0.097	P6: low Rdson @ 150°C
Rated ID @ tc =25°C (A)	68.5	77.5	P6: high current rating
Rated ID @ tc=100°C (A)	43.3	49	P6: high current rating
Qg (nC)	300	170	P6: less driving loss
Qrr(uC)	1.9	19	CFD: low Qrr value
Body diode di/dt (A/us)	900	300	CFD: high di/dt diode
Ciss (pF)	8400	8180	P6: small Ciss
Coss (pF)	400	310	P6: small Coss
Coss eq (pF) energy losses related	288	260	P6: less switching losses
Rth jc (°C/W)	0.25	0.26	Similar thermal resistance
Pacakage	TO-247	TO-247	Same package
Generation	Fast Body Diode	Cost Performance	

Efficiency Analysis CFD2 VS P6

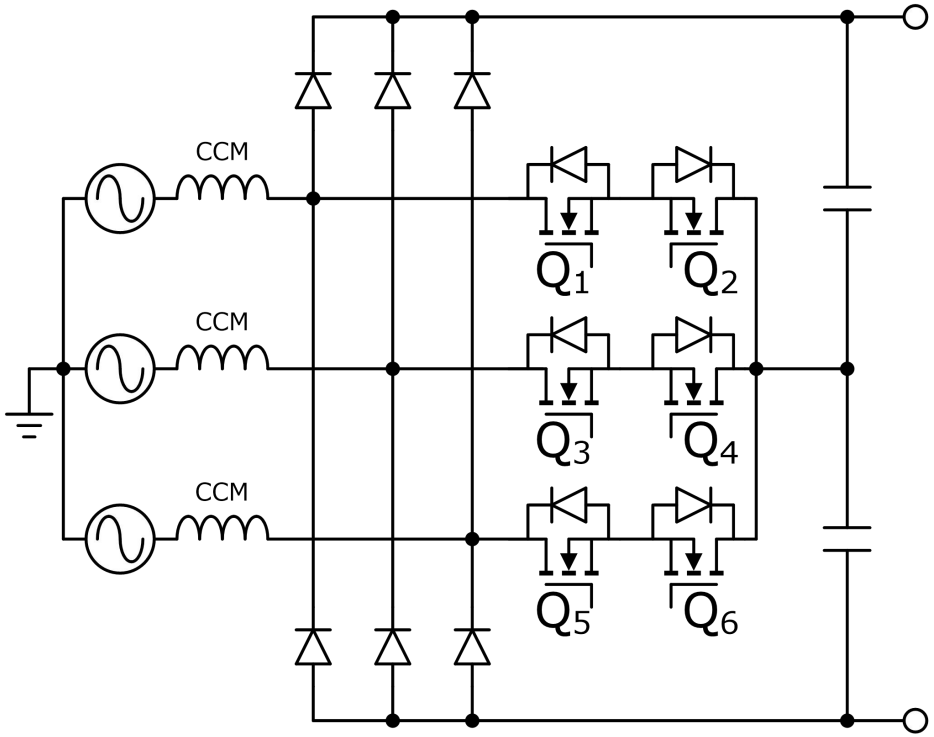
- Measurement Platform:
- PFC CCM Board
  - Output Power, Pout =2500W
  - Input Voltage, Vin=230V
  - Output Voltage, Vout=400V
  - Switching Frequency, fsw =65kHz
  - Used diode – IDH16G65C5
  - Regulated Heatsink @ T=60C







CoolMOS™ 600V P6 Fits for Vienna PFC



For three phase CCM Vienna topology
Input voltage is $230V_{ac}$ pre phase and
output voltage is $800V_{dc}$ (+/- $400V_{dc}$)

- Vienna Rectifier Characteristic*:
  - **Low blocking voltage** stress on MOSFETs could be used even for high dc-link voltage, i.e., **for output voltage 800V** values with a blocking voltage capability **V_{ds}=600V can be applied**
  - **No current flow** occurs through the **body diode of MOSFET** and/or a possible conduction of the body diode does not have to be suppressed by any other diode lying in series with the MOSFET
  - Significantly higher utilization of MOSFET (conduction of each MOSFET during positive and negative half period of the related phase current), i.e., the **lowest R_{dson} MOSFET** should be used

Remark: *Refer to Prof. Kolar^ paper entitled "A Novel Three-Phase Utility Interface Minimizing Line Current Harmonics of High-Power Telecommunication Rectifier Modules"
(^Prof. Johann W. Kolar is the founder of Vienna rectifier)

Guidelines: Replace CFD2 to P6 in Vienna PFC

- Same gate resistor condition:
  - P6 could give the efficiency gain ~0.2% at light load and ~0.1% at full load
- Guidelines for verification:
  - Check P6 V_{gs} ringing as slight fast switching behavior
  - V_{gs} ringing level will increase when I_d increases. Measure V_{gs} ringing under the designed maximum I_d within allowed V_{gs} level (+/-30V)
  - Increase gate resistor to 3-5ohm if V_{gs} level over +/-30V. Example if 10 ohm used in CFD2, 13-15 ohm is recommended for P6
  - After adjustment of Rg, the efficiency of P6 in Vienna PFC should be similar that of CFD2

Easy and fast for replacement

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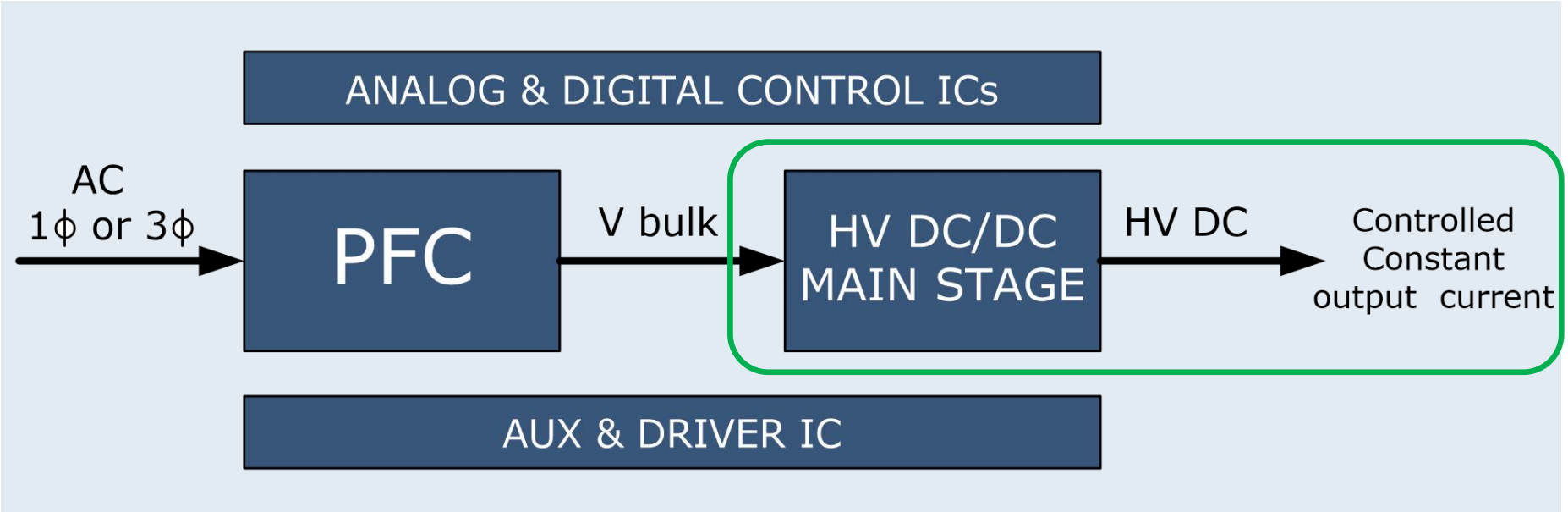

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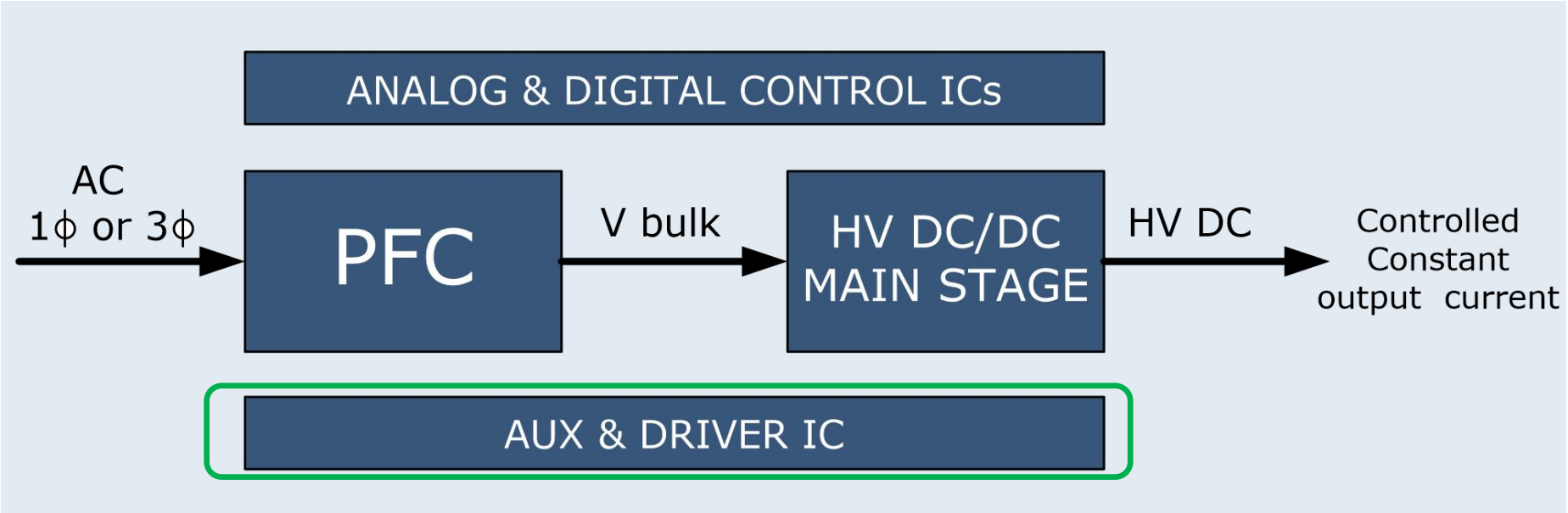

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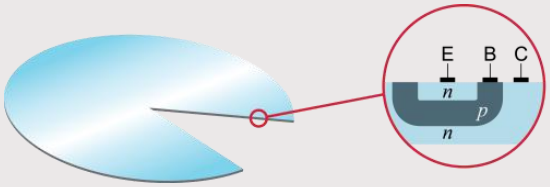
Driver Overview: Key Technology Performance Parameters

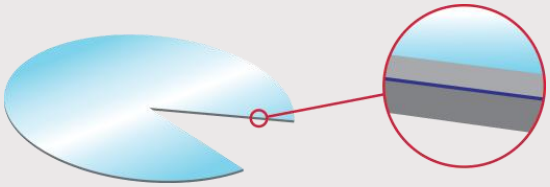
Level-Shift

Junction Isolation



- FET-based bootstrap circuit (typically 200 Ω).
- Active negative transient immunity (typically -40 V for a period of 100 ns) to prevent latch-up.
- Common mode transient immunity (CMTI) typically 50 V/ns.
- Resilient against positive voltage spikes.

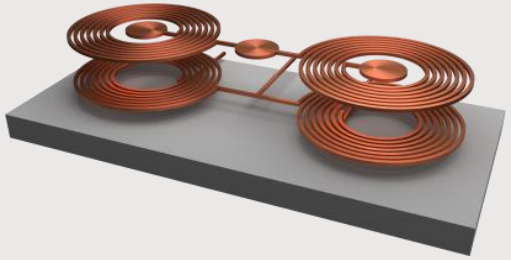
Silicon On Insulator



- PN-based bootstrap diode (typically 40 Ω).
- Negative transient immunity (-50 V for 500 ns) to prevent latch-up.
- Common mode transient immunity (CMTI) typically 50 V/ns.

Galvanic Isolation

Coreless Transformer



- Galvanic isolation.
- Continuous immunity against negative and positive transients due to floating output chip, up to ±1200 V.
- Exceptional common-mode transient immunity (CMTI) of more than 150 V/ns.
- 6 kV basic isolation capabilities.

2EDN Key Features Overview
Four Crucial Benefits

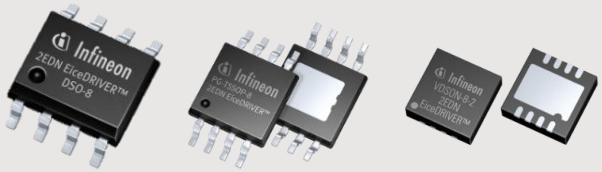
	Key Features	Technical Benefits	Customer Benefits

Power Density	› 5 A souce/sink current
	› 5 ns rise/fall times
	› <10 ns propagation delay precision
		› Fast Miller plateau transition
		› Precise timing
			› Higher power efficiency
			  › in hard-switching PFC w. SiC diode
			  › in half-bridges and SRs

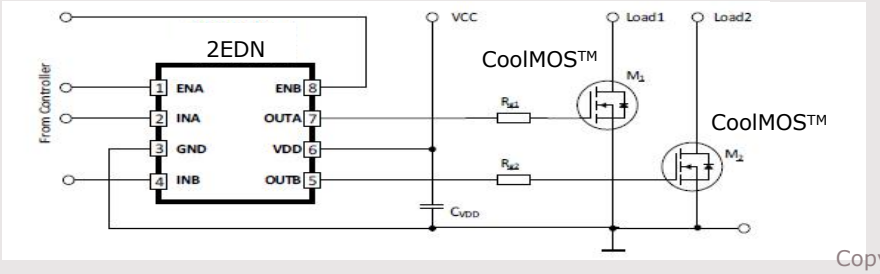
	› **True rail-to-rail low ohmic output stages**	› **Low power dissipation in Driver IC**	› **Cooler Driver IC operation** › **Higher MOSFET drive capability**
Robustness	› **4 V and 8 V UVLO options** › **19 ns propagation delay for both control and enable inputs**	› **Fast and reliable MOSFET turn-off, independent of control IC**	› **Instant MOSFET protection under abnormal operation**
	› **-10 V robustness on control and enable inputs**	› **Increased GND-bounce robustness**	› **„ Crucial safety margin to drive pulse-transformer**
	› **5 A reverse output current robustness**	› **„ Saves switching diodes**	› **Increases power density „** › **BoM savings**
Ease of design	› „ 2 independent channels „ › Excellent channel-to-channel accuracy: 1 ns	› „ Option to increase drive current by truly concurrent switching of 2 channels	› One IC covering many applications
	› Industry standard pinout and packages	› Straight-forward design up-grades	› „ Short time-to-market

2EDN MOSFET EiceDRIVER™ family
Compatible and Better

Compatible

- **Pinout & Packages:**  **DSO** **TSSOP** **WSON**
- **Power:** 2-channels, 5A strong, each
- **Pace:** 19ns propagation delay
- **Precision:** 1 ns channel-to-channel Propagation Delay Matching
- **Price:** Competitive & Shipping

Application Schematic



Better

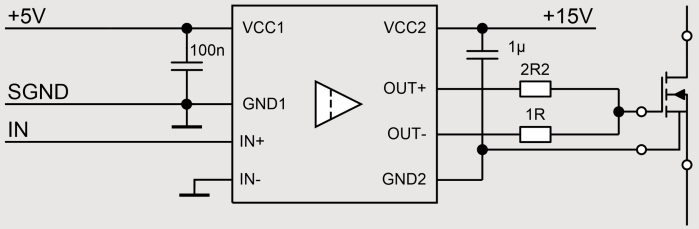
- **Truly low-ohmic output stages:**
  - **Least internal power dissipation**
  - **More thermal head-room**
- **-10V Input robustness:**
  - **Crucial noise margin to safely drive pulse transformers**
- **5A reverse current robustness**
  - **No need for Schottky clamping diodes**
  - **Higher power density, lower BoM**
- **8V UVLO Protection:**
  - **Fast and reliable SuperJunction and Standard-Level MOSFET protection**

Qualifies for Design Registration

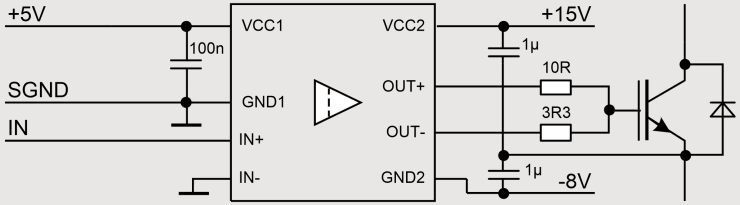
Different variants of 1EDI Compact

Variant with separate source/sink output

Circuit Diagram for CoolMOS™ C7

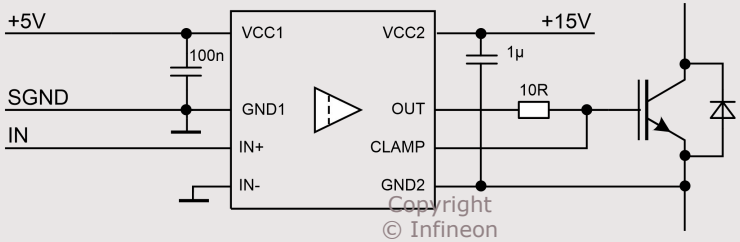


Circuit Diagram for IGBT (optional w. bipolar supply)



Variant with output and active Miller Clamp

Circuit Diagram for IGBT, unipolar (e.g. with TRENCHSTOP™ 5)



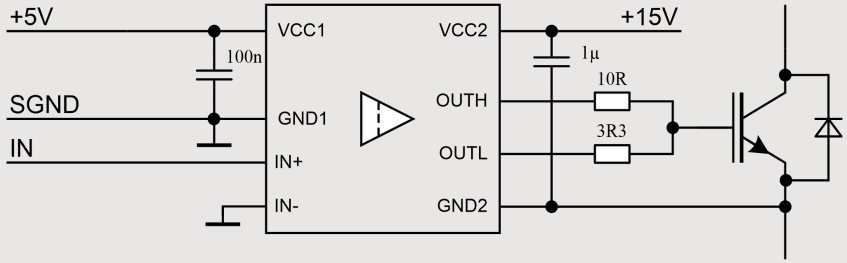
IGBT Driver: CT 1EDI Compact Family

Key Features

- Single-channel high-voltage driver in a DSO8 150mil package
- Galvanic functional isolation up to offset voltages of 1200V
- Separate source/sink output pins and up to 35V VCC2 supply voltage
- UVLO for IGBT and MOSFET

Typical Applications

Sample Schematic

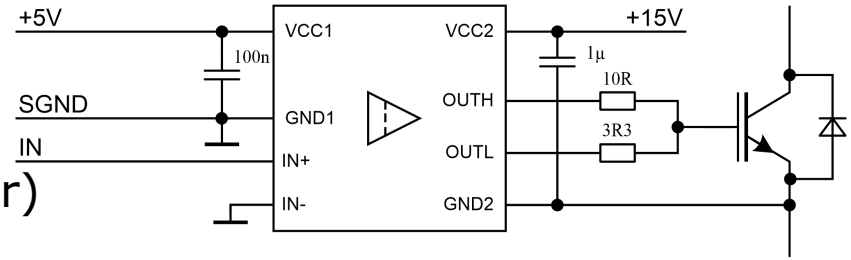


Value Proposition

- Optimized cost/performance ratio
- No need for external booster with its typical peak output current of up to 10A
- Enables short dead times due to stable propagation delay with trimmed input filter times
  MOSFET: t_{pd}<125 ns t_{flt}=40 ns
  IGBT: t_{pd}=300 ns t_{flt}=240 ns
- Exceptional CMTI robustness 100 kV/µs

1ED Compact family
Separate Output Variants

- Coreless Transformer Isolated Driver
- Target Output Current
  0,5A; 2A; 4A; 6A @ 15V
- Supply voltage up to 35V (uni- & bipolar)
- UVLO for IGBT or MOS

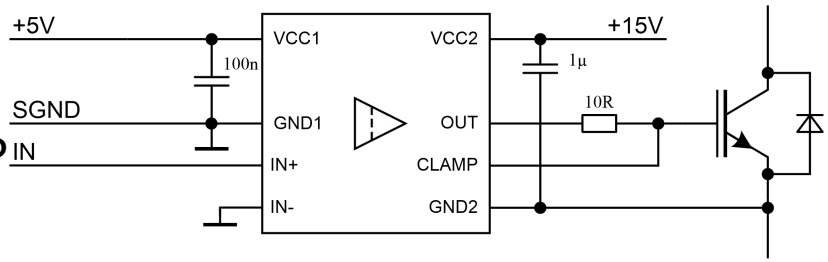


- Features:
  - 1200V functional isolation
  - Propagation delay <100ns or 300ns
  - Input Filter time 40ns or 240ns
  - Propagation delay mismatch <20ns
  - Separated sink/source Output
  - Rail-to-rail output with high current capability
  - high $T_{a,max}$ 125°C, $T_{j,max}$ 150°C
  - Small package SO8 150mil with 4mm creepage/clearance

- Benefit:
  - Tailored for 1200V IGBT
  - High Modulation
  - Robust Design, no cross coupling
  - Low Dead Time
  - Saves bypass diode
  - Direct drive w/o booster
  - High reliability
  - Low area consumption

1ED Compact family
Output with Clamp variants

- Coreless Transformer Isolated Driver
- Integrated CLAMP output
- Target Output Current for OUT & CLAMP
  1A; 2A; 3A @ 15V
- Supply voltage 20V (unipolar only)
- UVLO for IGBT



- Features:
  - 1200V functional isolation
  - Propagation delay <100ns or 300ns
  - Input Filter time 40ns or 240ns
  - Propagation delay mismatch <20ns
  - RR output with high current capability
  - high $T_{a,max}$ 125°C, $T_{j,max}$ 150°C
  - Small package SO8 150mil with 4mm creepage/clearance

- Benefit:
  - Tailored for 1200V IGBT
  - High Modulation
  - Robust Design, no cross coupling
  - Low Dead Time
  - Direct drive with out booster
  - High reliability
  - Low area consumption

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Infineon