

中国家电电控方案创新直播周

PFC控制在变频家电中的应用价值和发展趋势

Bryan Tian (IPC TM)
Oct, 2021



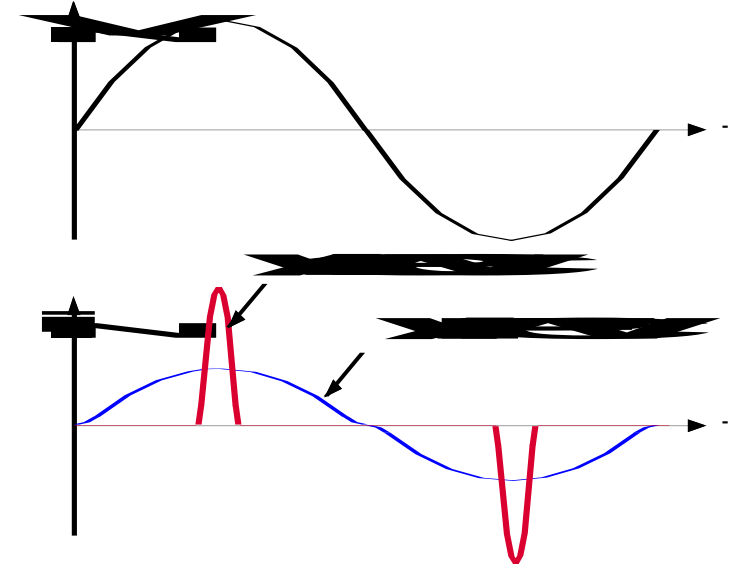
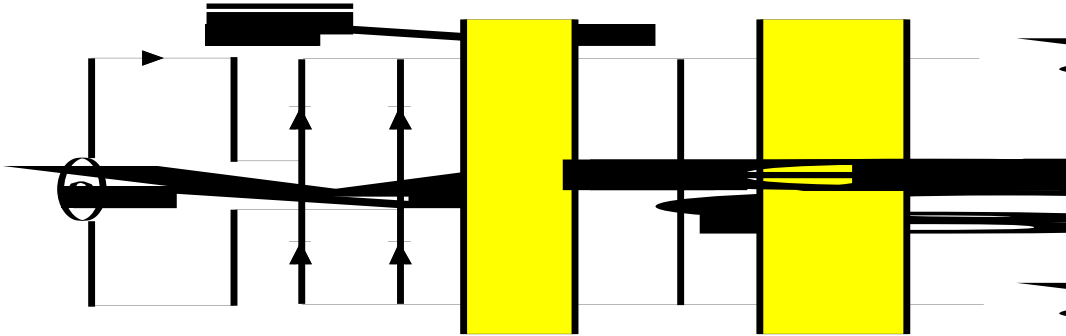
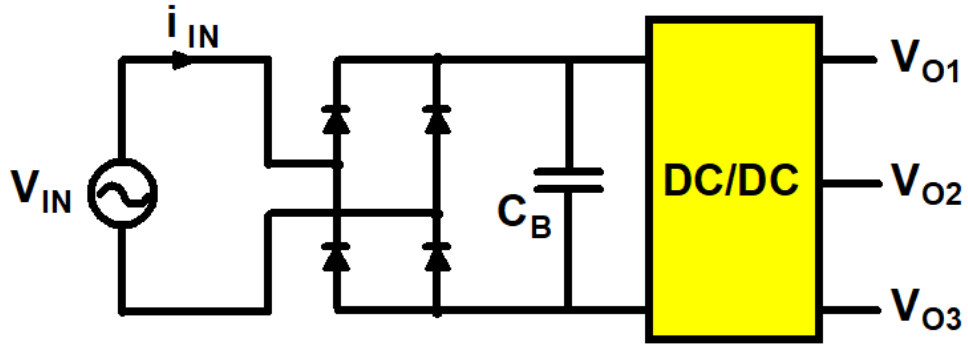
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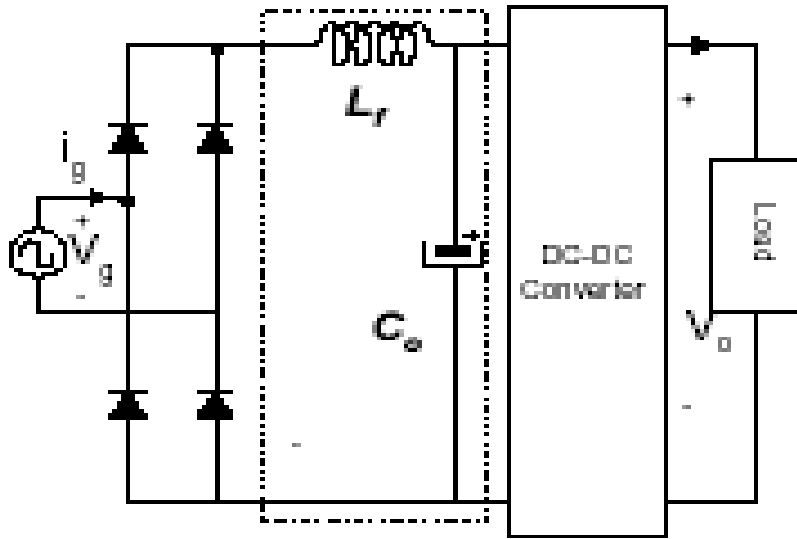
为何需要PFC (Power-factor-correction)?



必须使用PFC电路来满足电流谐波 (THD) 要求

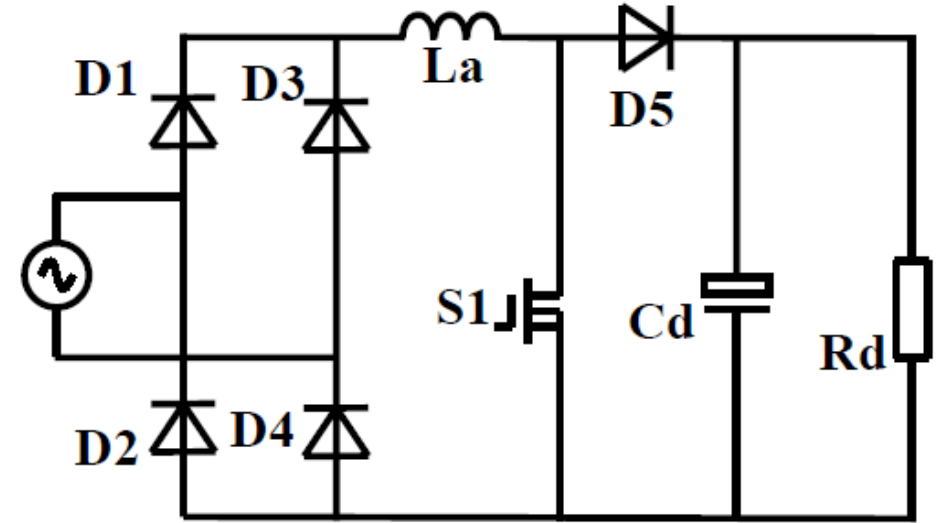
如何实现PFC?

Passive PFC



- › 结构简单，低成本，无EMI
- › 功率因数和THD较差
- › 仅适用于小功率应用

Active PFC



- › 使用功率开关器件和控制器
- › 优异的功率因数和THD
- › 适用功率范围广泛

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PFC在冰箱应用中的价值

Classification	IEC 61000-3-2: 2009	IEC 61000-3-2: <u>2014</u>
Class A	<ul style="list-style-type: none"> - Balanced three-phase equipment; - Household appliances, excluding equipment identified as Class D; - Tools excluding portable tools; - Dimmers for incandescent lamps; - Audio equipment; - Equipment not specified in one of the three other classes shall be considered as Class A equipment. 	<ul style="list-style-type: none"> - Balanced three-phase equipment; - Household appliances, excluding equipment identified as Class D; - Tools, excluding portable tools; - Dimmers for incandescent lamps; - Audio equipment; - Equipment not specified in one of the three other classes shall be considered as Class A equipment.
Class D	Equipment having a specified power $75W \leq P \leq 600 W$; <ul style="list-style-type: none"> - Personal computers and personal computer monitors; - Television receivers; 	Equipment having a specified power $75W \leq P \leq 600 W$; <ul style="list-style-type: none"> - Personal computers and personal computer monitors; - Television receivers; - <u>Refrigerators and freezers having one or more variable-speed drives to control compressor motor(s).</u>



- › IEC 61000-3-2: Limits for harmonic current emissions (equipment input current ≤ 16 A per phase and nominal voltages $\geq 220V$, line-to-neutral)
- › The IEC 61000-3-2:2014 New Standard reclassify refrigerators and freezers with variable-speed drives into Class D.
- › The IEC 61000-3-2:2014 publication date: 2014-05-26 → Stability date: 2017

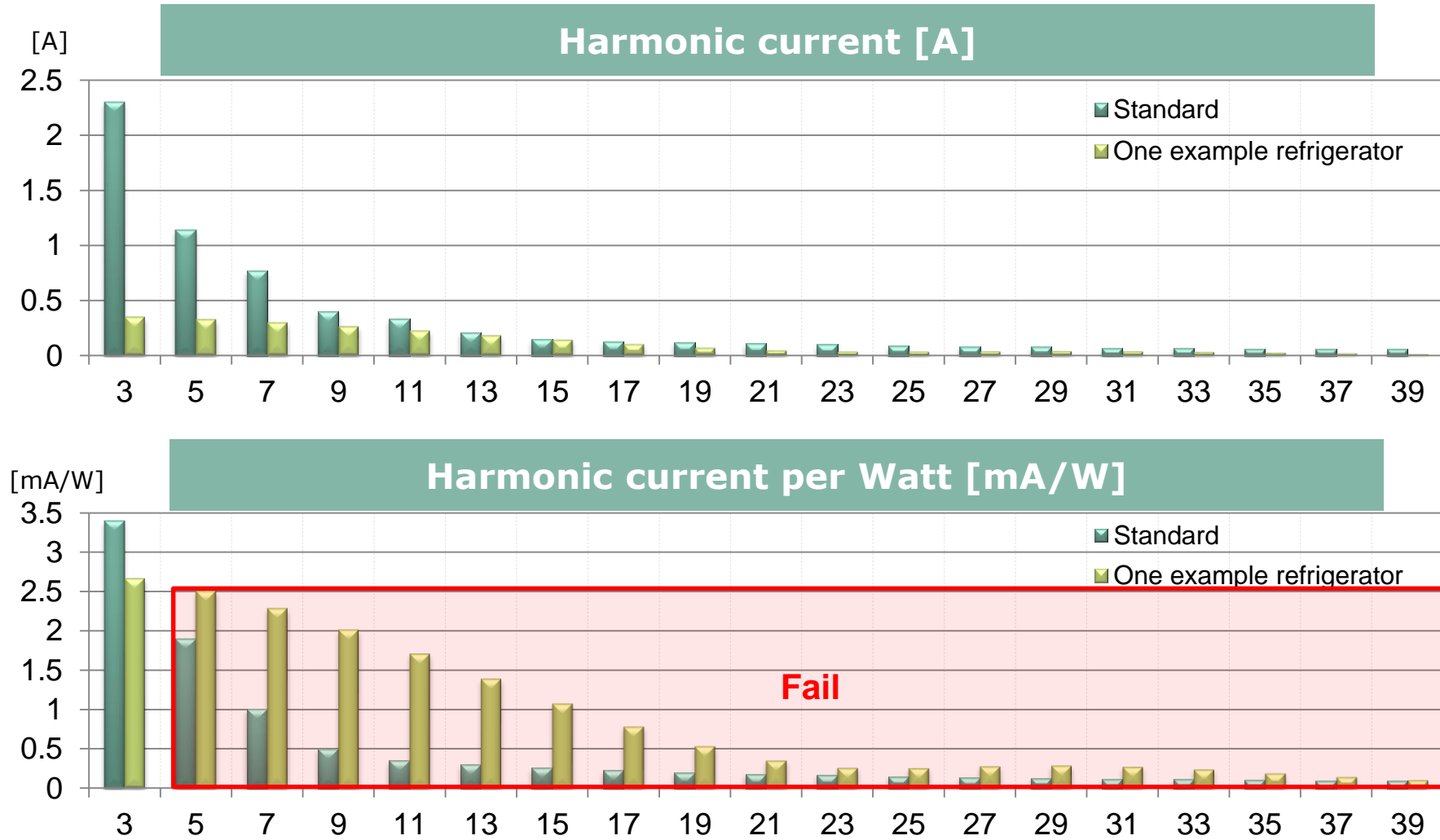
Class A vs. Class D

Limit Lines	Class A	Class D	
Odd Harmonics order [n]	Maximum permissible harmonic current [A]	Maximum permissible harmonic current [A]	Maximum permissible harmonic current per watt [mA/W]
3	2.30	2.30	3.4
5	1.14	1.14	1.9
7	0.77	0.77	1.0
9	0.40	0.40	0.5
11	0.33	0.33	0.35
13	0.21	0.21	3.85/n (13 ≤ n ≤ 39)
15 ≤ n ≤ 39	0.15X15 /n	0.15X15 /n	



- › Same maximum permissible harmonic current
- › Maximum permissible harmonic current per watt in only Class D

实测结果证明必须使用PFC



Standards for limits for harmonic current emissions

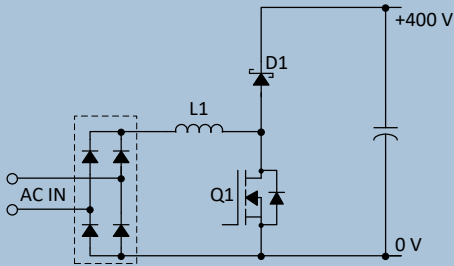
- › Regulation requirements:
 - IEC 61000-3-2 / GB17625.1
 - Must be used at $P_{out} > 75W$
 - Ensures a sinusoidal power
 - Minimizes harmonics to the grid and noise to other appliances

- › Application trend:
 - Best efficiency
 - Minimize additional cost & space
 - Easy to use: Isolation from heat sink



家用空调中几种单相PFC方案

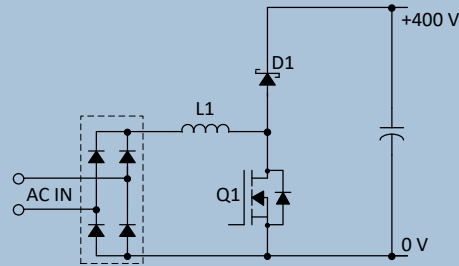
Classic PFC



- Less System Cost
- Less Efficiency

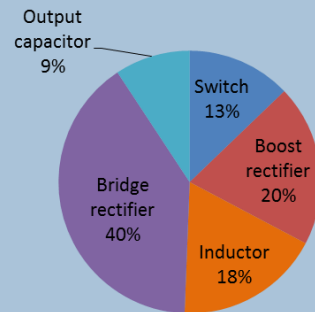
- IGBT (Q1)
- Si Diode (D1)

Classic PFC(SiC)



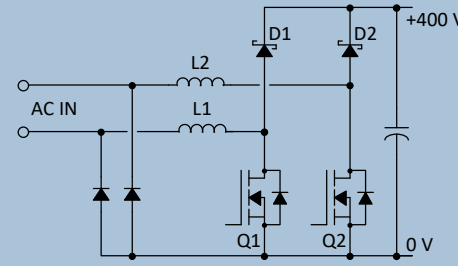
- Less System Cost
- Less Efficiency
- High Power Density

Classic PFC 3kW 65kHz 230Vac 75% load
Total Ploss = 43.9W



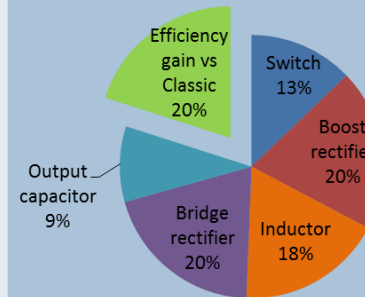
- CoolMOS™ / IGBT (Q1)
- SiC (D1)

Dual Boost PFC



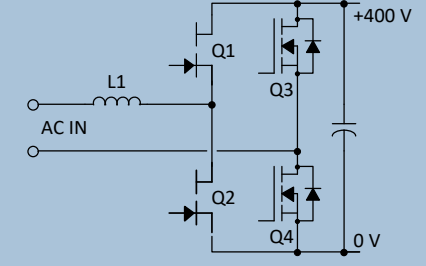
- High System Cost
- High Efficiency
- Less Power Density

DualBoost PFC 3kW 65kHz 230Vac 75% load
Total Ploss = 35.1W



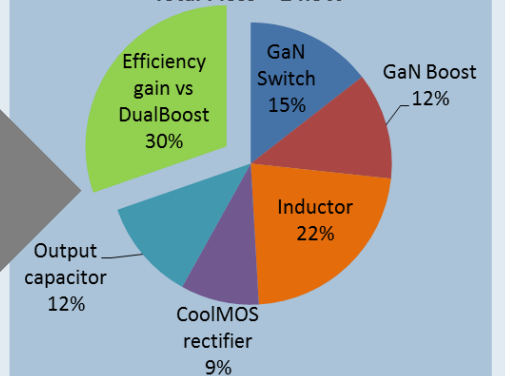
- CoolMOS™ / IGBT (Q1, Q2)
- SiC (D1, D2)

Totem Pole PFC



- Less System Cost
- Highest Efficiency
- Best Cost of Ownership

Totem Pole PFC 3kW 65kHz 230Vac 75% load
Total Ploss = 24.5W

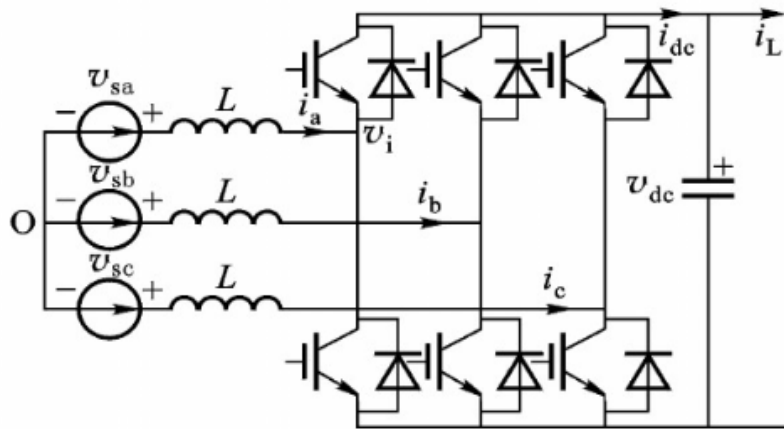


- GaN (Q1, Q2)
- CoolMOS™ (Q3, Q4)

GaN enables hard commutation on internal "diode"

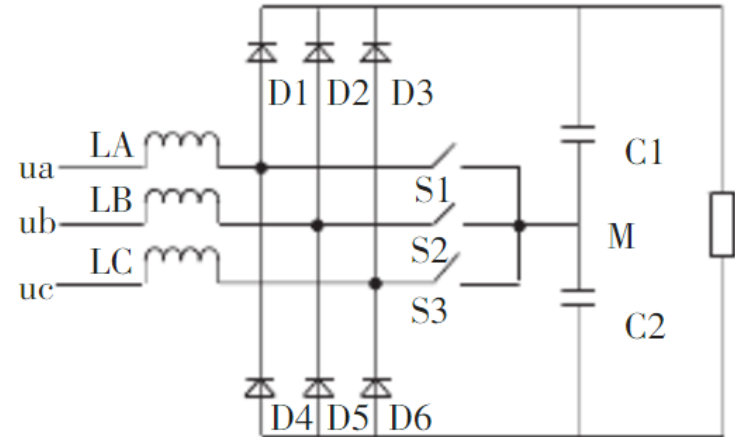
用于商用空调的三相PFC的方案

3 Phase Full bridge PFC



- › 结构简单
- › 低THD, 高功率因数
- › 需要1200V的快速开关器件

3 Phase 3 level Vienna PFC



- › 三电平拓扑
- › 结构相对复杂, 器件较多
- › 工业上成熟拓扑

3相PFC不同方案的对比

	Existing 3ph Diode Bridge Solution	1 IGBT IPM Solution	2 IGBT Module Solution	3 SiC IPM Solution
Power Device	1700V/75A	1200V 35A IPM	1200V 40A	IFX: IM828-XCC SiC IPM
Inductor	4.5mH/25A	3.5mH/25A	1.1mH/10A	1.1mH/10A or 0.6mH/13A
DC-Bus Cap	1500uF	1500uF	1500uF	1500uF
Current Sense Filter	-	330ohm/0.1uF	330ohm/0.1uF	470ohm/0.1uF
Control Method	Na	1x PWM Interruption	1x PWM Interruption	2x PWM Interruption
Switching Frequency	Na	16kHz	16kHz	36kHz
Input range	310~415Vac	310~415Vac	310~415Vac	310~415Vac
Output Voltage/Power	400-500Vdc/8kW	650Vdc/8kW	650Vdc/8kW	660~675Vdc/8kW
Output Current	12Arms	12Arms	12Arms	12Arms
Inductor Image				

3相PFC不同方案的效率比较

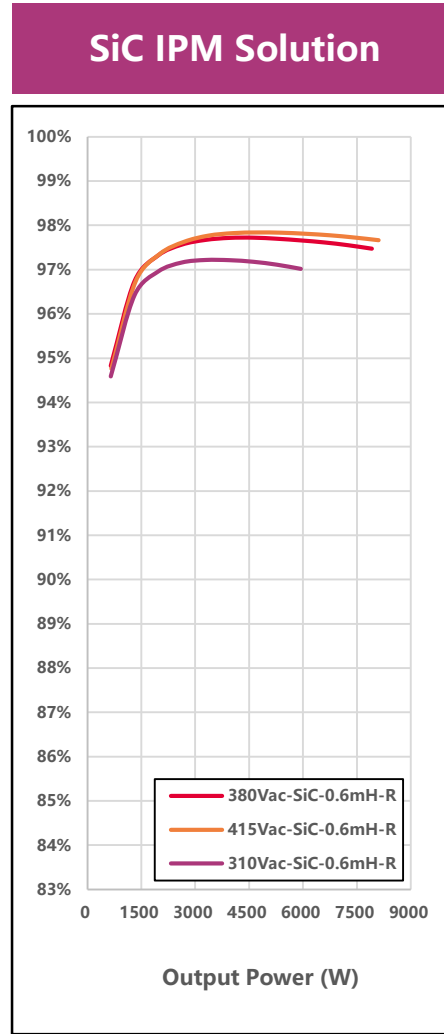
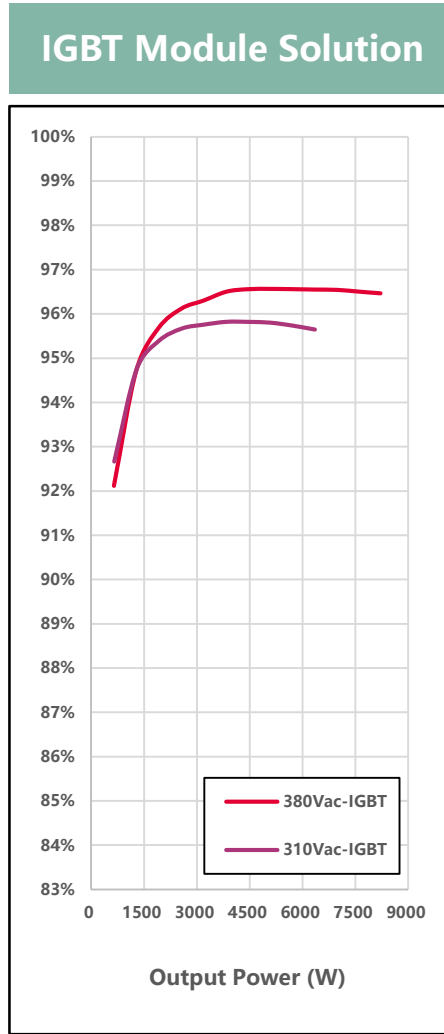
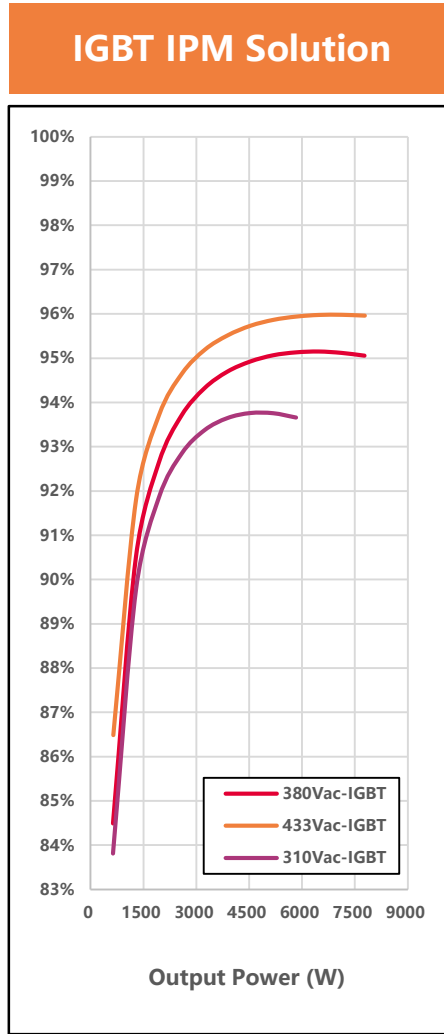
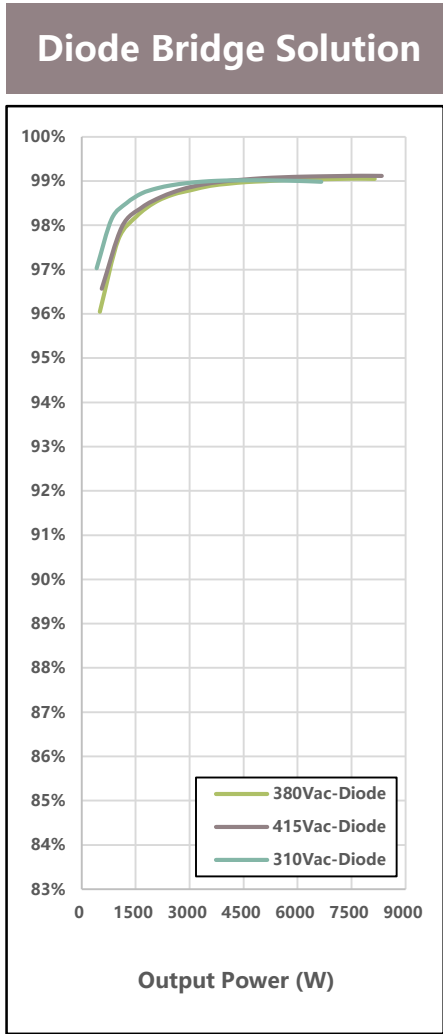
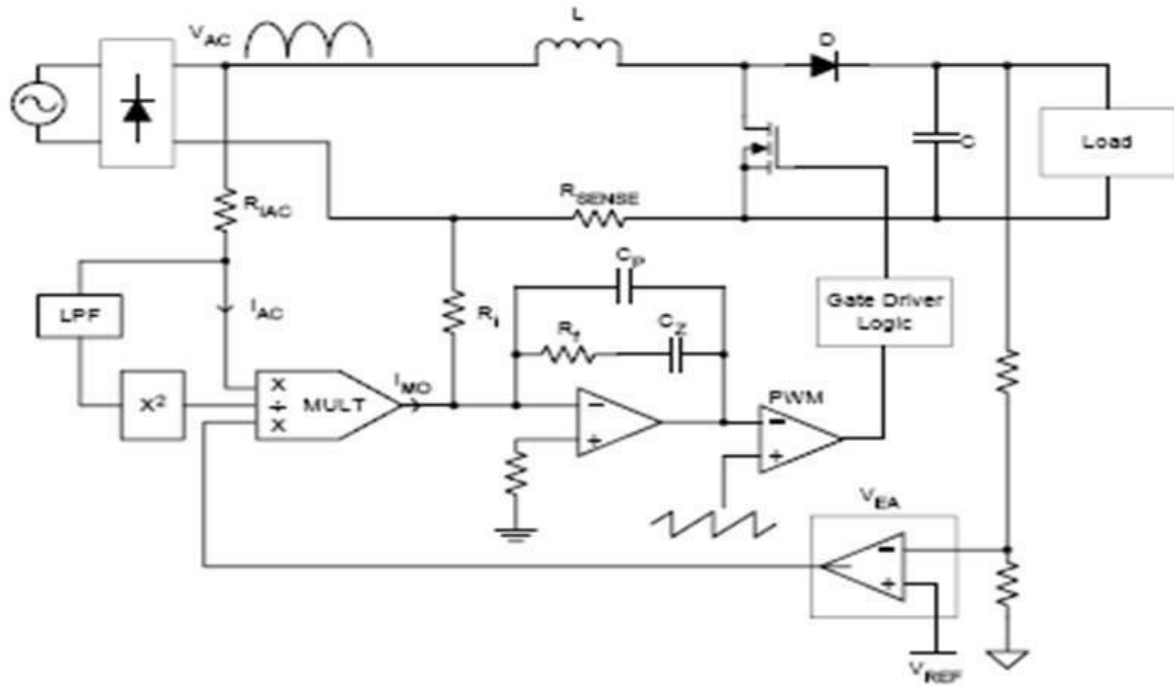


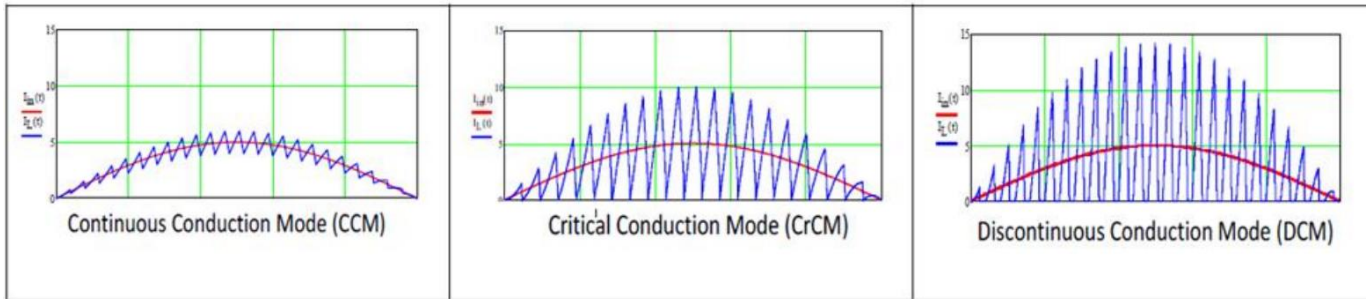
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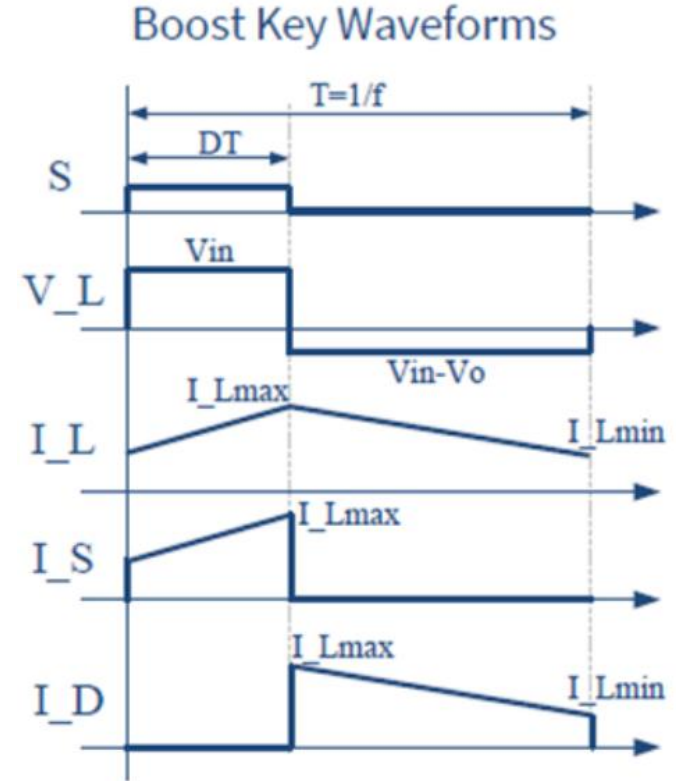
Boost PFC 简介



Simplified block diagram concept



Three operation modes

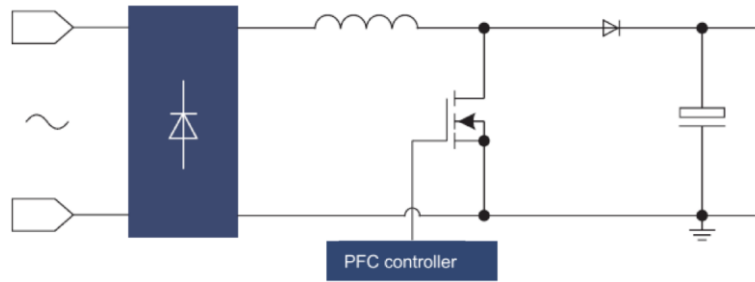


$$\frac{V_o}{V_{in}} = \frac{1}{1 - D} \quad (\text{CCM operation})$$

2.5KW WR5 IGBT CCM single boost PFC (70kHz)



EVAL_2K5W_CCM_4P_V3



Schematic of the topology



Q1

IKW30N65WR5

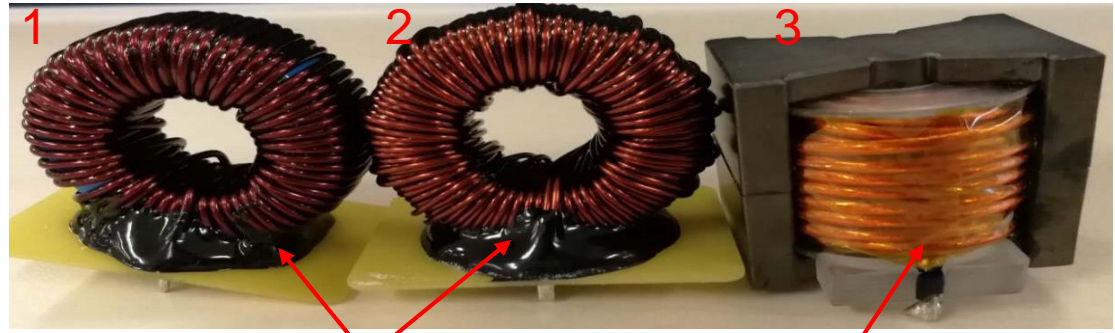


D1

SiC Schottky Diode

1
2

IDH16S65C5



铁硅粉芯电感

铁氧体电感

IGBT和二极管的温升-采用不同的电感

› 测试条件:

1. $T_a=25^{\circ}\text{C}$, 强制风冷;
2. $V_{in}=176\text{Vacrms}$, $V_{out}=364\text{Vdcrms}$, $P_{out}=1604\text{Watts}$



With NO.1 choke



With NO.2 choke

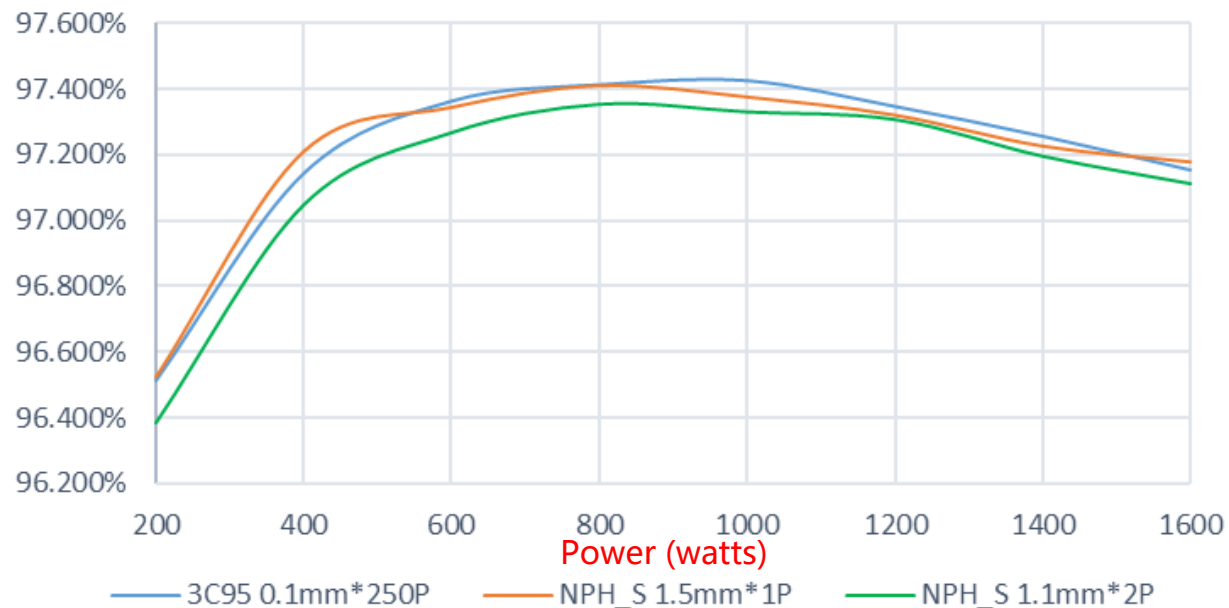


With NO.3 choke

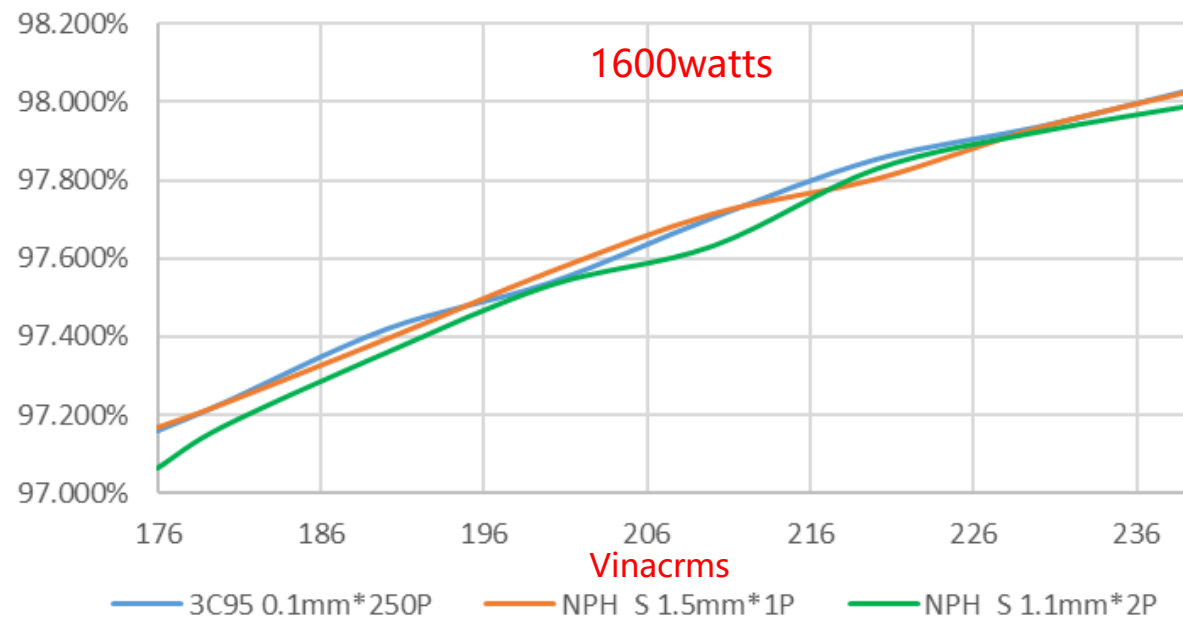
- › IKW30N65WR5 IGBT用于70kHz PFC, 损耗小, 温升高, 性价比高;
- › SiC二极管用作PFC整流管, 温升非常低, 适用于高频PFC场合;

实测效率和THD性能对比

176Vac→364Vdc efficiency



Vin→364Vdc efficiency

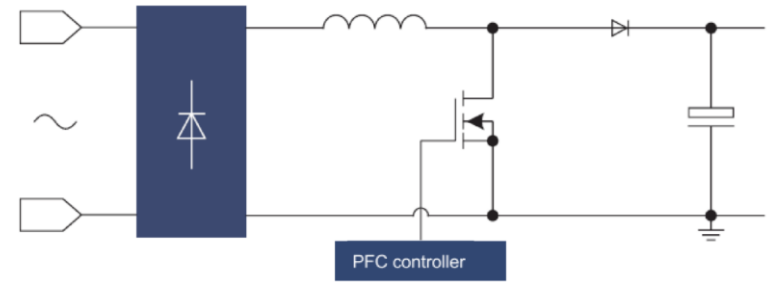


› 铁氧体电感有助于提升PFC功率级的效率

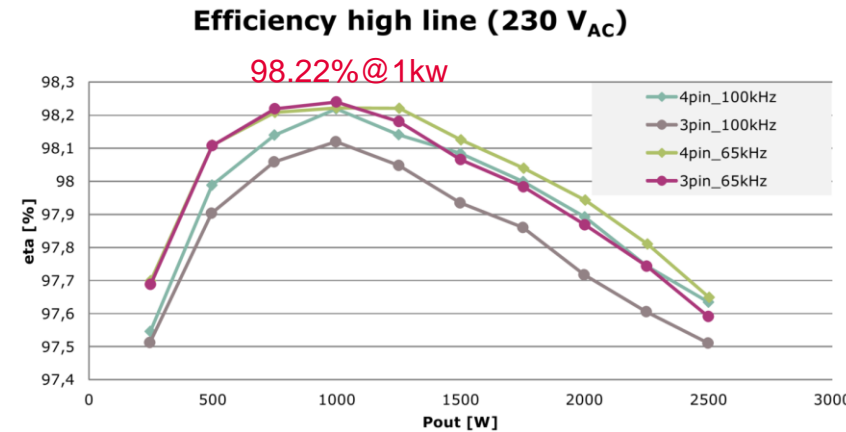
2.5KW Coolmos CCM single boost PFC



EVAL_2K5W_CCM_4P_V3



Schematic of the topology



Target applications:
 › high power SMPS

Specifications:

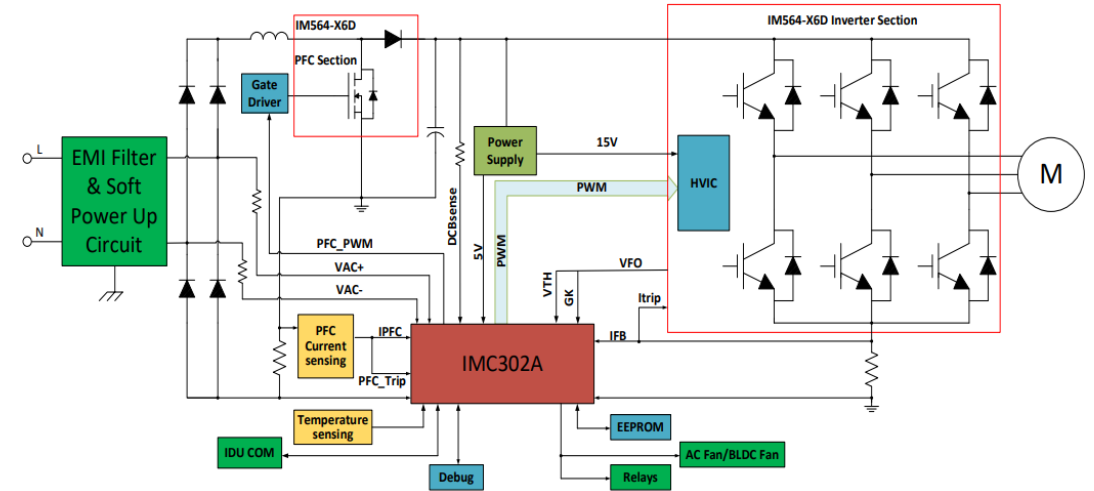
Input voltage	85 V _{AC} ~265 V _{AC}
Input current	14 A _{eff}
Input frequency	47~63 Hz
Output voltage and current	400 V _{DC} , 6.25 A
Output power	~ 2.5 kW (at V _{in} =230 V _{AC})
Average efficiency	>95% at 115 V _{AC}
Switching frequency	Possible range: 40 kHz~250 kHz; Board frequency is set to 65 kHz; Changeable by R20
Power switch	4pin and 3pin MOSFET

- › [IPZ60R040C7](#), 600V CoolMOS MOSFET
- › [IDH16G65C5](#), Generation 5 SiC Schottky diode
- › [1EDI060N12AF](#), gate driver
- › [ICE3PCS01G](#), CCM PFC controller
- › [ICE3RBR4765JZ](#), CoolSET Flyback controller
- › [IFX91041](#), Buck controller

1.4KW air conditioner board with IMC302A and IM564-X6D

Target applications:

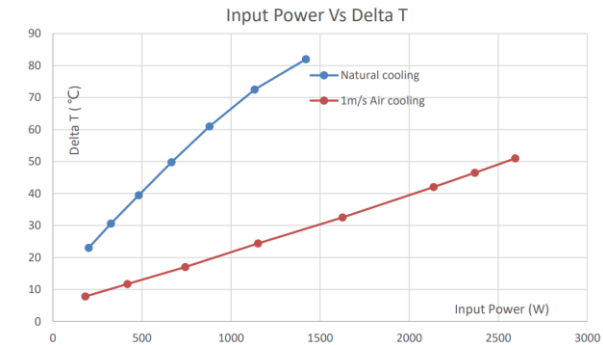
- > Air conditioner
- > Fan
- > Pump



Block diagram

Specifications:

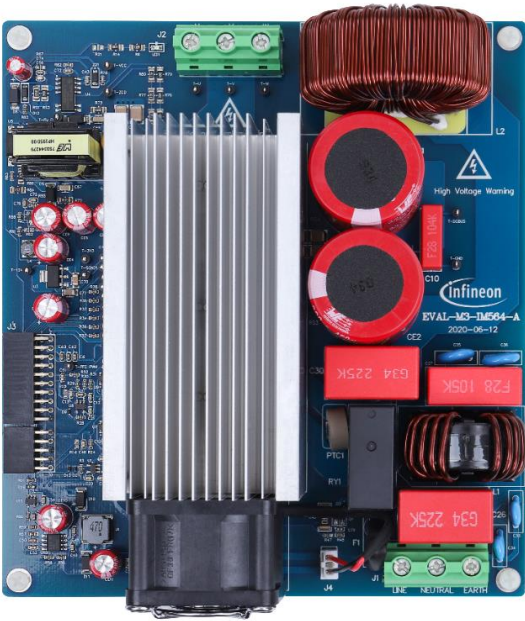
Parameter	Symbol	Conditions / comments	Value	Unit
Input voltage	V_{ac}	Optimized design for 220 V _{AC} applications	85 ~ 265	V _{rms}
Maximum input current	$I_{ac(max1)}$	Input 220 V _{AC} , T _a =25°C, natural cooling mode	6	A _{rms}
	$I_{ac(max2)}$	Input 220 V _{AC} , T _a =25°C, with 1 m/s wind cooling	12	A _{rms}
Maximum output power	$P_{in(max1)}$	Input 220 V _{AC} , Motor f _{PWM} = 6 kHz, PFC f _{PWM} =40 kHz, T _a =25°C, IPM T _C = 105 °C, Natural cooling mode	1400	W
	$P_{in(max2)}$	Input 220 V _{AC} , Motor f _{PWM} = 6 kHz, PFC f _{PWM} =40 kHz, T _a =25°C, IPM T _C = 105 °C, 1 m/s force cooling mode	2500	W
Maximum motor current	$I_{mtr(max1)}$	Input 220 V _{AC} , Motor f _{PWM} = 6 kHz, PFC f _{PWM} =40 kHz, T _a =25°C, IPM T _C = 105 °C, Natural cooling mode	6	A _{rms}
	$I_{mtr(max2)}$	Input 220 V _{AC} , Motor f _{PWM} = 6 kHz, PFC f _{PWM} =40 kHz, T _a =25°C, IPM T _C = 105 °C, 1 m/s force cooling mode	10	A _{rms}
DC bus voltage				
Maximum DC bus voltage	$V_{dc(max)}$	DC bus capacitors are 450 V, 470 μF x 2	450	V
Minimum DC bus voltage	$V_{dc(min)}$	Aux power supply brown-in voltage	80	V



Thermal characterization of IM564-X6D, Vin=220Vac

- > [IMC302A](#), dual-core M0 MCU
- > [IM564-X6D](#), 600V CIPOS IPM integrates MOSFET for PFC
- > [1ED44175](#), low-side gate driver
- > [1CE5AR4770BZS](#), CoolSET

2.8KW CCM PFC with IM564 – MOSFET for PFC in IPM

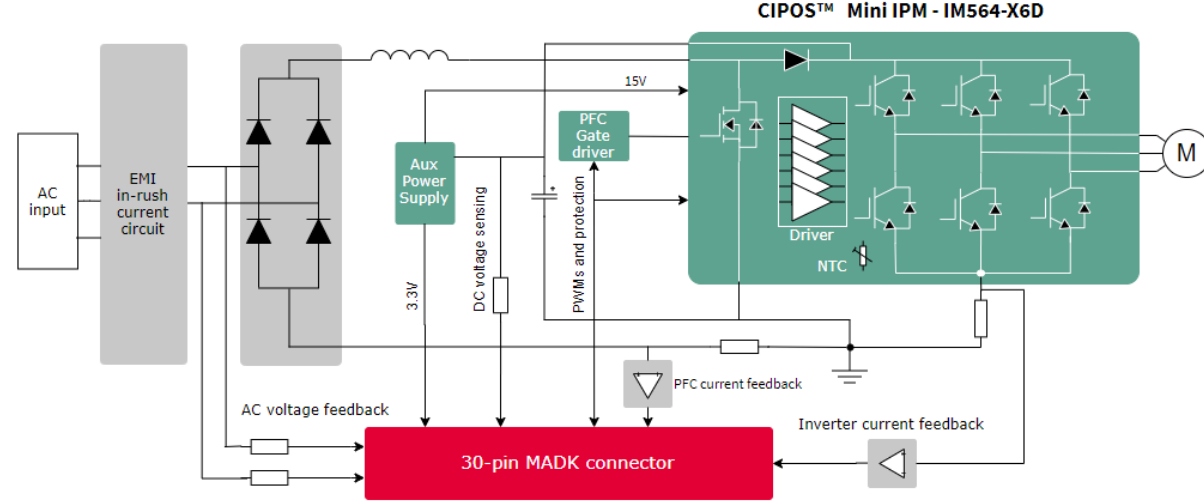


EVAL-M3-IM564

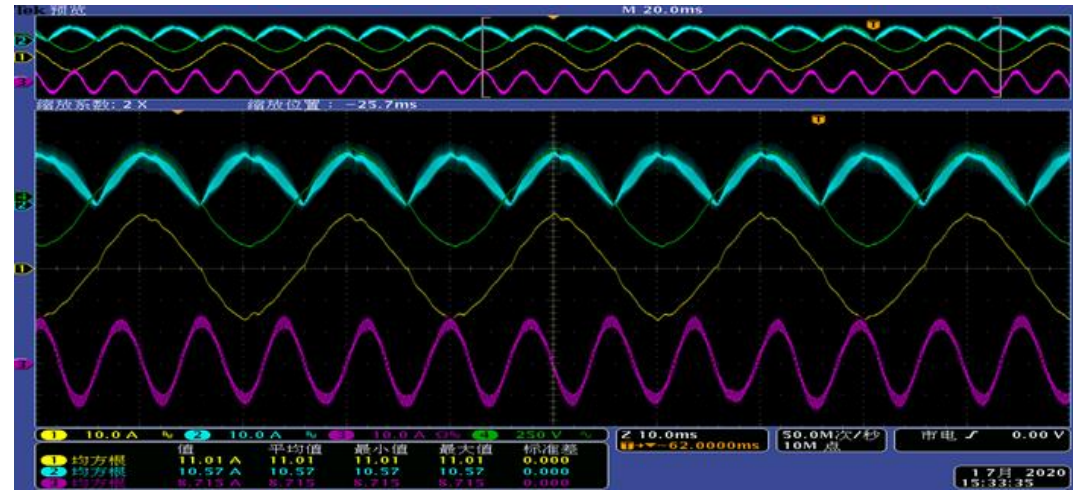
- Target applications:
- > Air conditioner
 - > Other motor control applications

- Specifications:
- > Input Voltage: 165Vac-265Vac
 - > Output Voltage: 340Vdc-380Vdc
 - > Output Power: MAX 2.8kW
 - > Switching frequency: 50kHz (PFC), 6kHz (inverter)

- > [IM564-X6D](#), 600V CIPOS IPM integrates MOSFET for PFC
- > [IRS44273L](#), low side gate driver



Block diagram



CH1: input current CH2: PFC inductor current
CH3: motor current CH4: input voltage

5KW two-channel interleaved PFC

Target applications:

- › Floor-standing air conditioner
- › High-power SMPS

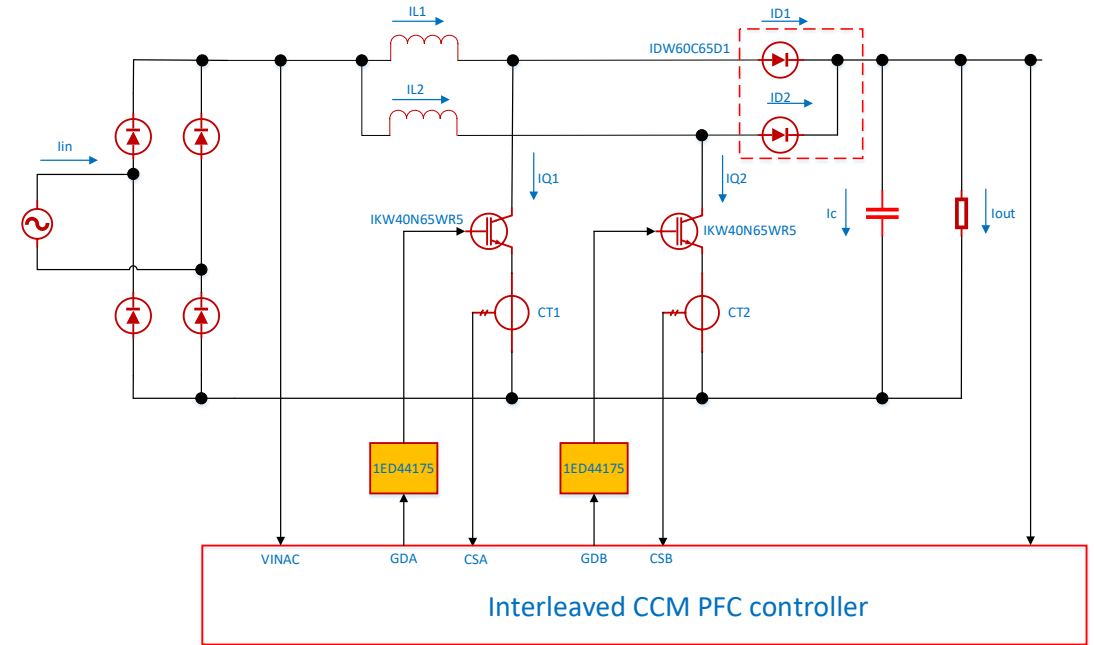


EVAL-PFC5KIKWWR5SYS

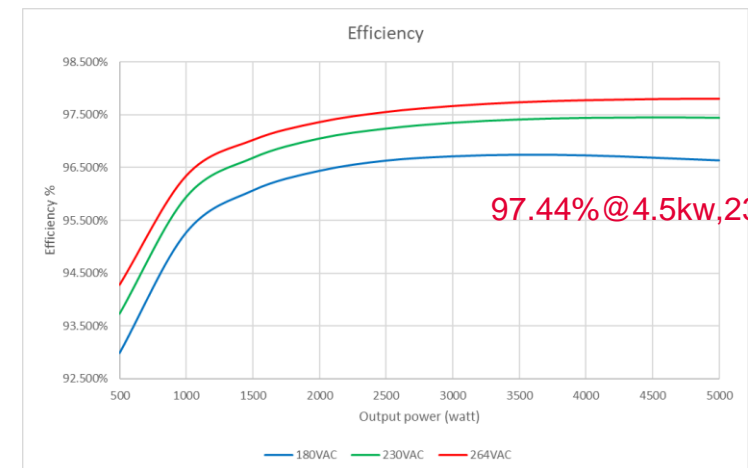
Specifications:

NO.	Parameters	Symbol	Value
1	Output power	P_{out}	5000 watt
2	Input voltage range (rms)	V_{in}	180 V _{ac} to 264 V _{ac}
3	Input frequency range	f	50 Hz or 60 Hz
4	Output voltage	V_{dc}	400 V
5	Output ripple voltage	V_{ripple}	20 V
6	Inductance	L1, L2	53 μ H
7	Switching frequency	F_s	60 kHz

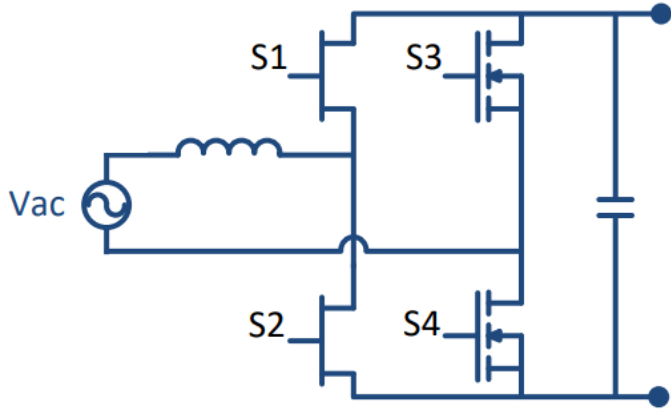
- › [IKW40N65WR5](#), 650V TRENCHSTOP™ 5 WR5 IGBT
- › [IDW60C65D1](#), 650 V/ 60 A rapid1 diode
- › [1ED44175](#), low-side gate driver
- › [ICE5QSAG](#), CoolSET QR Flyback controller
- › [IPP90R340C3](#), 900V CoolMOS MOSFET
- › [IFX1963TEV](#), LDO



Block diagram of two-channel interleaved PFC



Totem pole PFC简介



Schematic of the topology

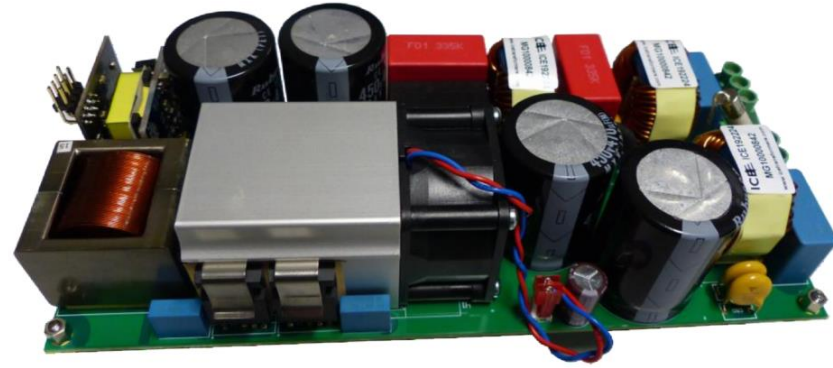
> Operation mode: CCM, CRM

Positive AC voltage half-line	Negative AC voltage half-line
<p>S1: Switching as synchronous switch S2: Switching as control switch S3: Off S4: On</p>	<p>S1: Switching as control switch S2: Switching as synchronous switch S3: On S4: Off</p>

3.3KW totem pole PFC with SiC MOSFET

Target applications:

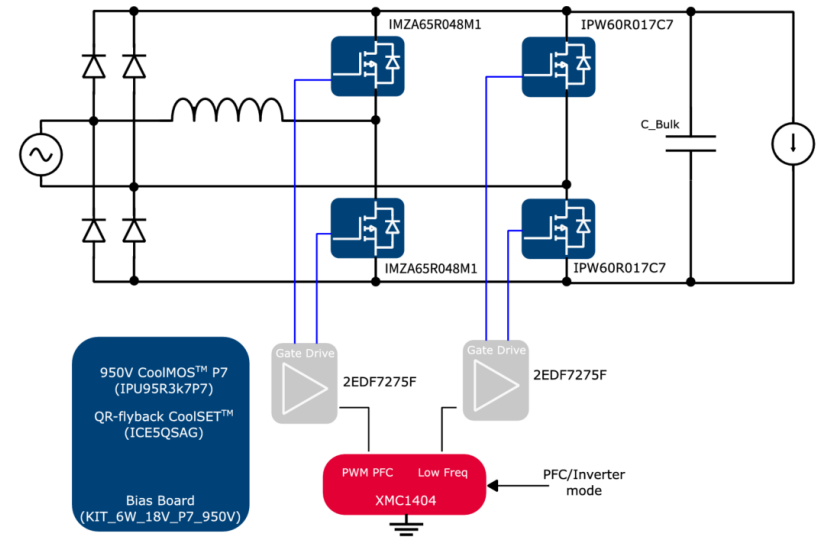
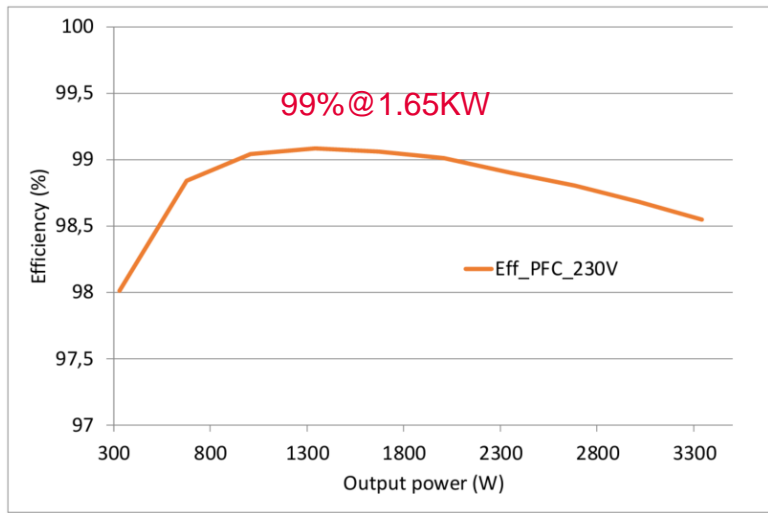
- > High-end server and telecoms
- > Battery charger



EVAL_3K3W_TP_PFC_SIC

Specifications:

- > Input Voltage: 176Vac-265Vac
- > Output Voltage: 400Vdc
- > Output Power: 3.3kW
- > Switching frequency: 65kHz



- > [IMZA65R048M1](#), 650V CoolSiC MOSFET
- > [IPW60R017C7](#), 600V CoolMOS MOSFET
- > [2EDF7275F](#), isolated gate driver
- > [XMC1404](#), microcontroller
- > [ICE5QSAG](#), CoolSET QR Flyback controller
- > [IPU95R3K7P7](#), 950V CoolMOS P7 SJ MOSFET

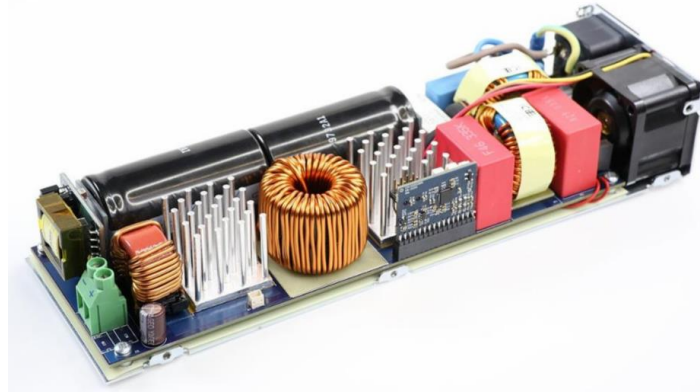
3.3KW totem pole PFC with CoolMOS

Target applications:

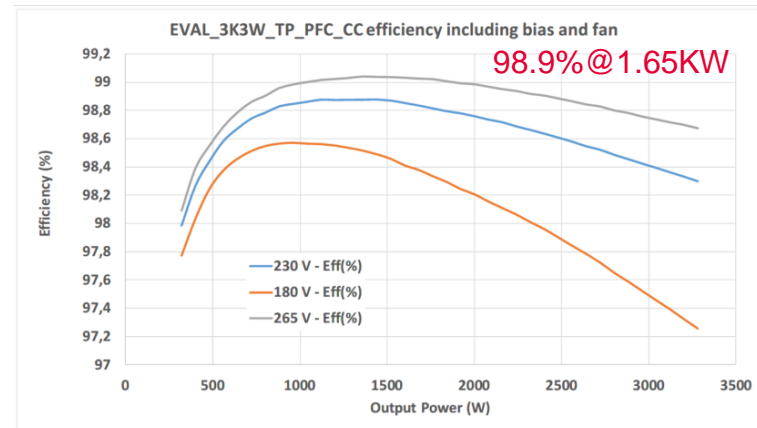
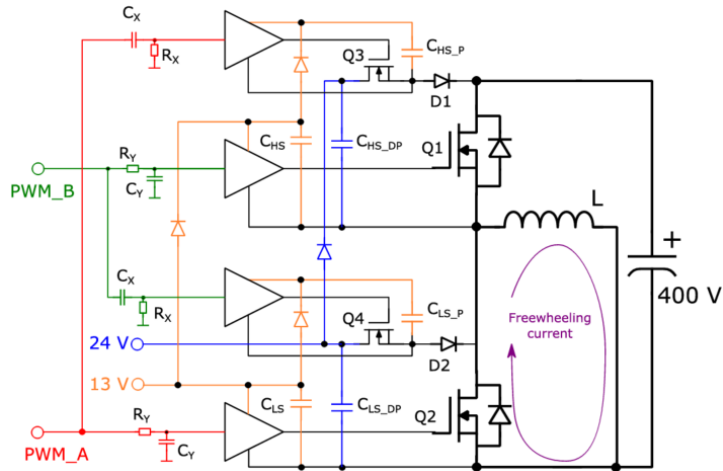
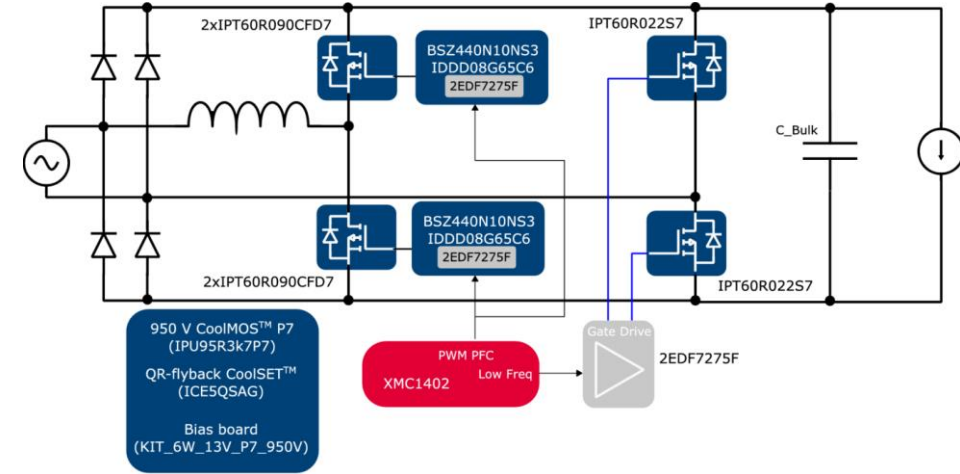
- › High-end server and telecom

Specifications:

- › Input Voltage: 176Vac-265Vac
- › Output Voltage: 400Vdc
- › Output Power: 3.3kW
- › Switching frequency: 65kHz



EVAL_3K3W_TP_PFC_CC

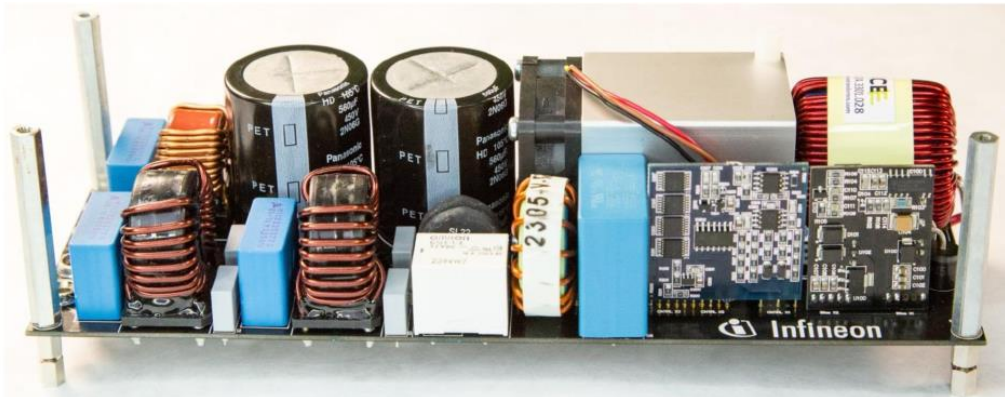


- › [IMZA65R048M1](#), 650V CoolSiC MOSFET
- › [IPW60R017C7](#), 600V CoolMOS MOSFET
- › [2EDF7275F](#), isolated gate driver
- › [XMC1402](#), microcontroller
- › [ICE5QSAG](#), CoolSET QR Flyback controller
- › [IPU95R3K7P7](#), 950V CoolMOS P7 SJ MOSFET

Pre-charger circuit is the key point for CoolMOS be used in CCM totem pole PFC

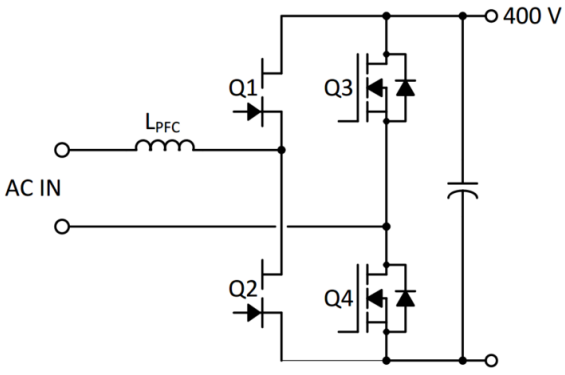
2.5KW totem pole PFC with GaN

- Target applications:
- > efficiency-critical server or telecom rectifier

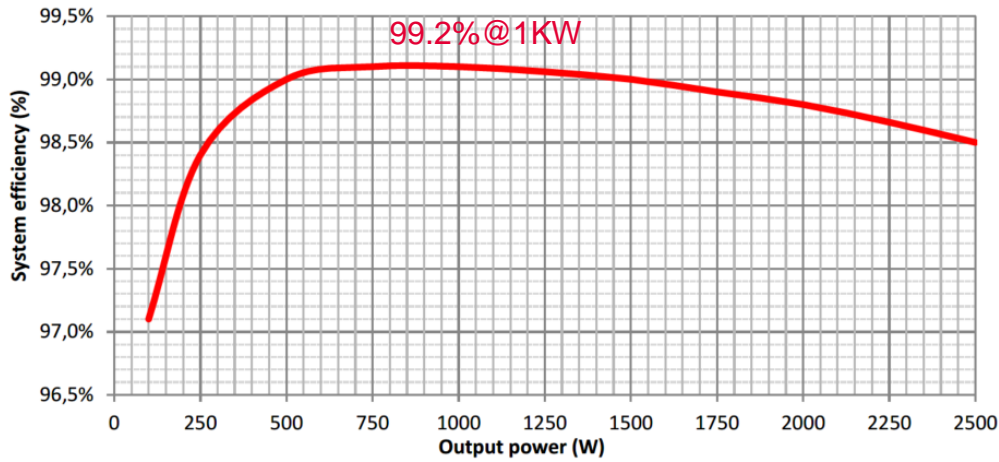


EVAL_2500W_PFC_GAN_A

- Specifications:
- > Input Voltage: 85Vac-265Vac
 - > Output Voltage: 400Vdc
 - > Output Power: 2.5kW
 - > Switching frequency: 65kHz



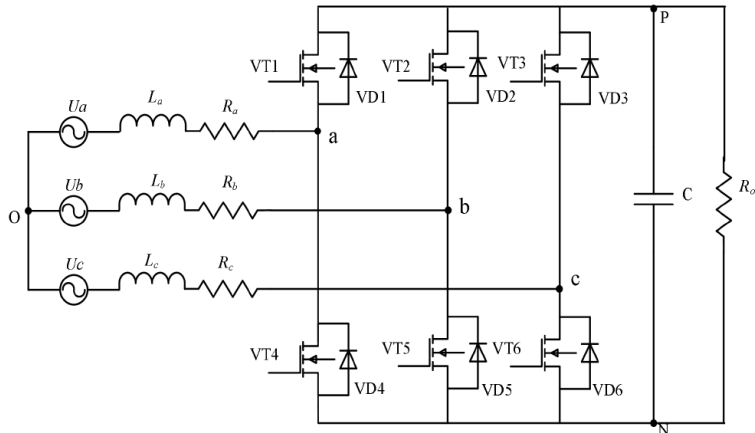
Schematic of the topology



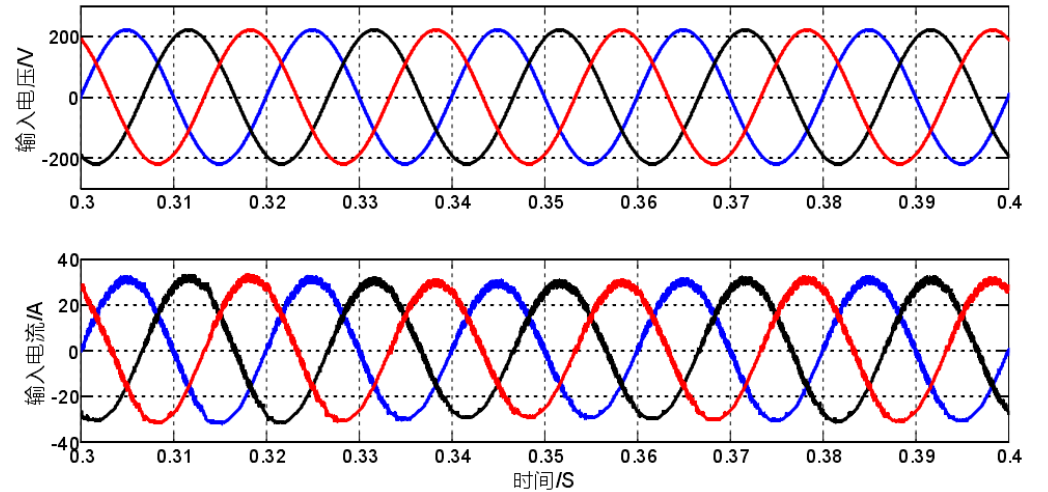
Vin = 230Vac

- > [IGO60R070D1](#), 600V CoolGaN e-mode HEMTs
- > [IPT65R033G7](#), 650V CoolMOS C7 Gold SJMOSFET
- > [1EDI020N12AF](#), gate driver
- > [1EDI60N12AF](#), gate driver
- > [2ED7523G](#), gate driver
- > [ICE3PCS01G](#), CCM PFC controller
- > [ICE2QR2280G](#), CoolSET QR Flyback controller

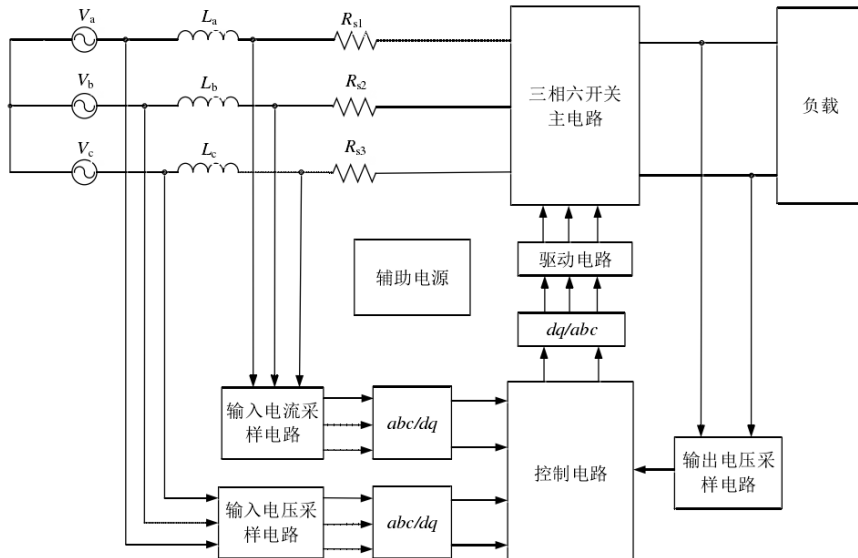
三相全桥B6 PFC 简介



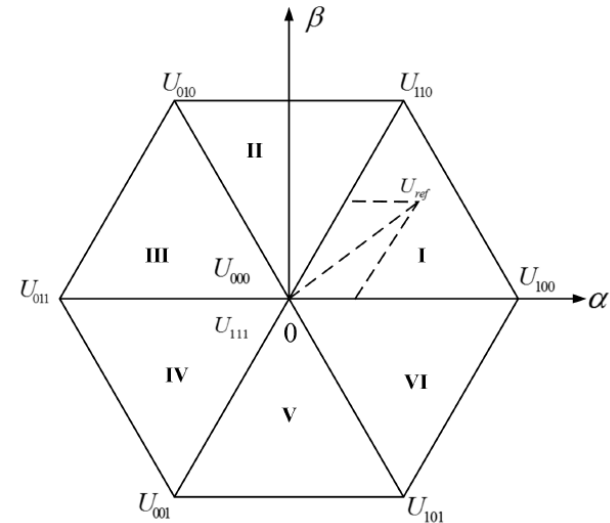
Schematic of the topology



Simulation of three phases input voltage and current



Block diagram of B6 PFC

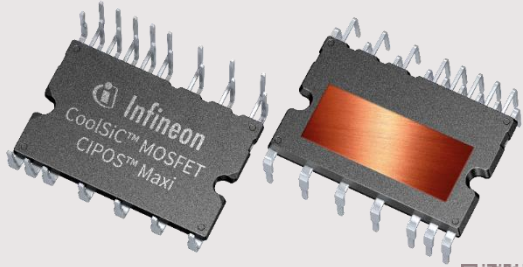


SVPWM control

8KW 3ph PWM rectifier with IM828 IPM

Products

DIP 36x23D package



Dimension [mm]	36 x 22.7 x 3.1 mm ³ with 24 pins
Configuration	3-phase inverter with open emitters
Voltage rating	1200 V
Rds(on)	55 mΩ (I _D =20 A, V _{in} =5 V, T _J < 25°C)
I _D DC drain current	20 A (T _C = 80°C, T _J < 150°C)

Rectifier specifications

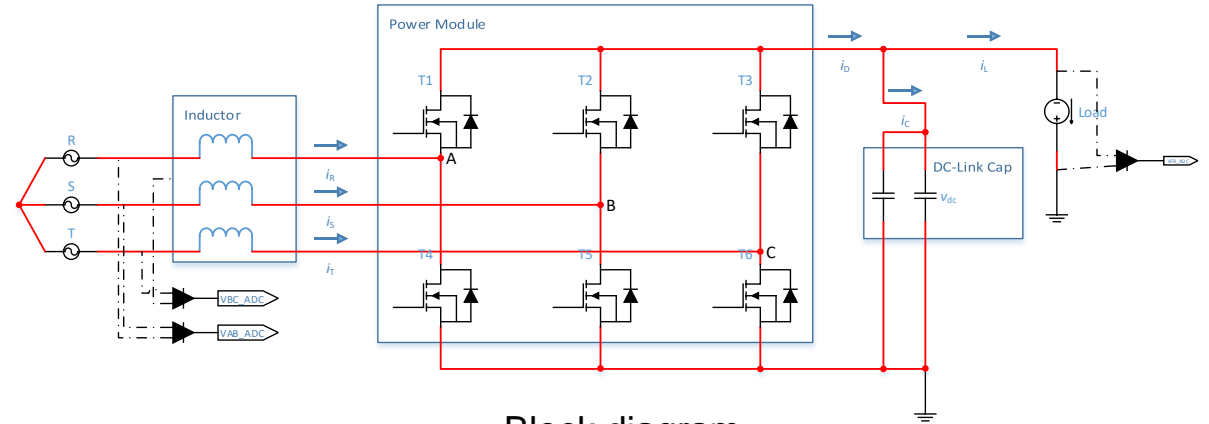
- Input voltage: 310Vac – 415Vac
- Output voltage: 660Vdc- 675Vdc
- Output power: 8KW
- Switching frequency: 36kHz

Value proposition

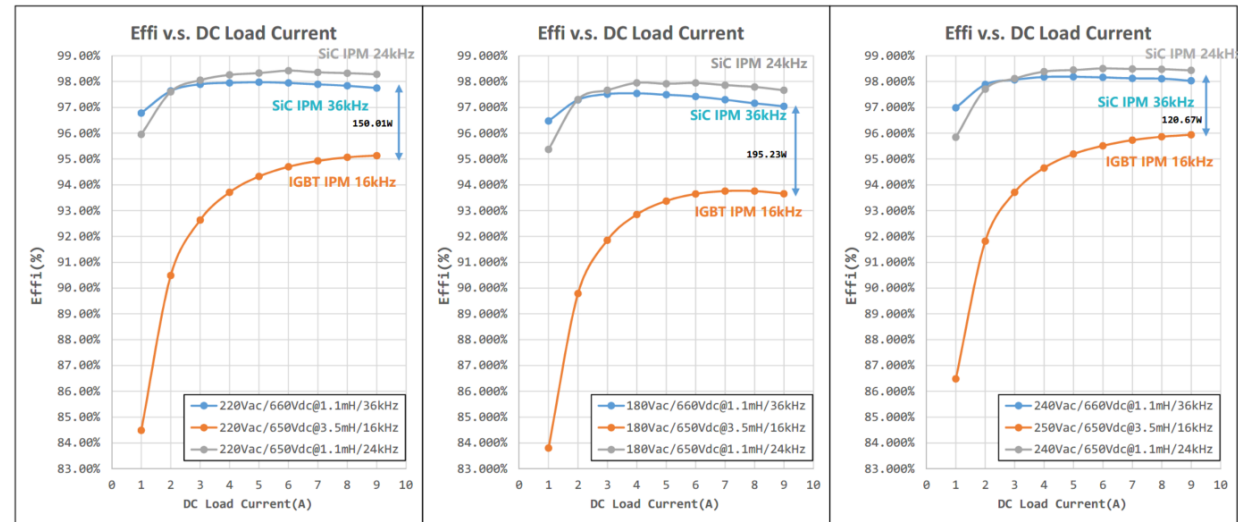
- Offer very low loss by using the advanced CoolSiC™ MOSFET technology
- High power density and high efficiency
- High output power in one small package
- Provide wide switching speed range
- Minimize system size and reduce system costs
- Fast time to market

Application

- > Commercial air conditioners
 - Active filter (PFC)/compressor
- > Industrial motor drives
- > Pumps

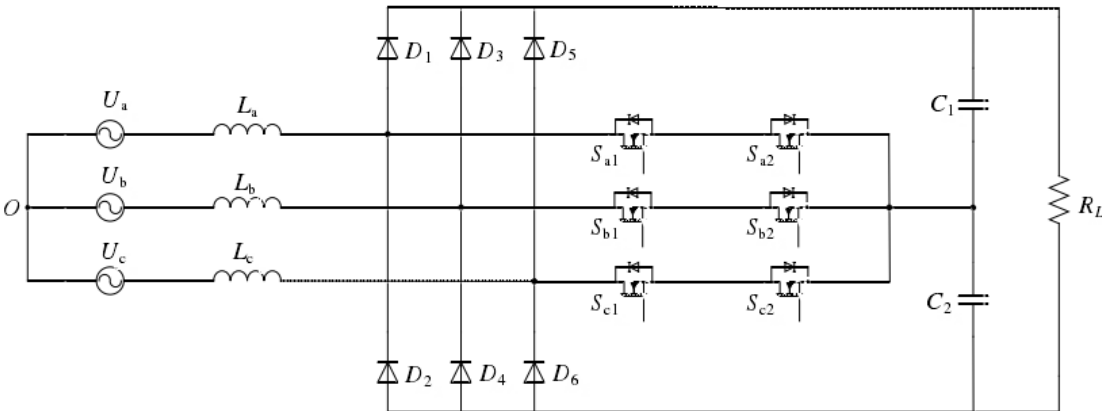


Block diagram

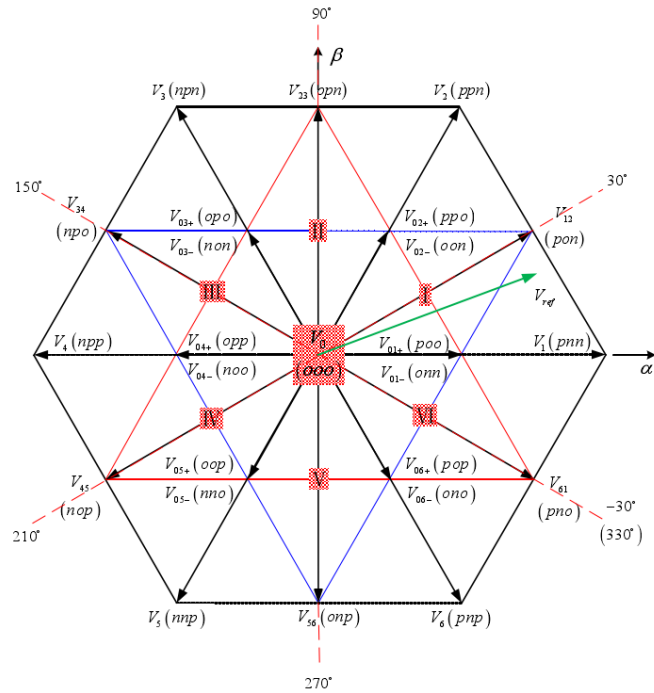


Efficiency comparisons

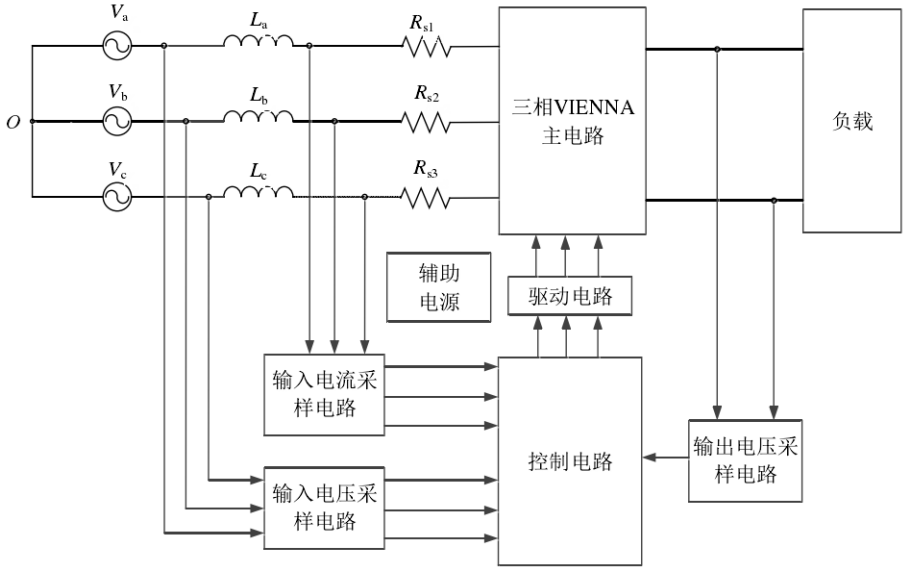
Vienna rectifier introduction



Schematic of the topology

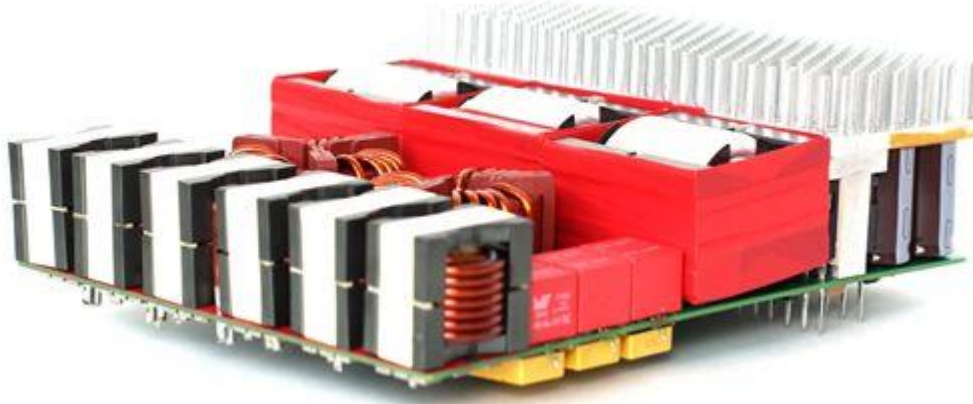


SVPWM control

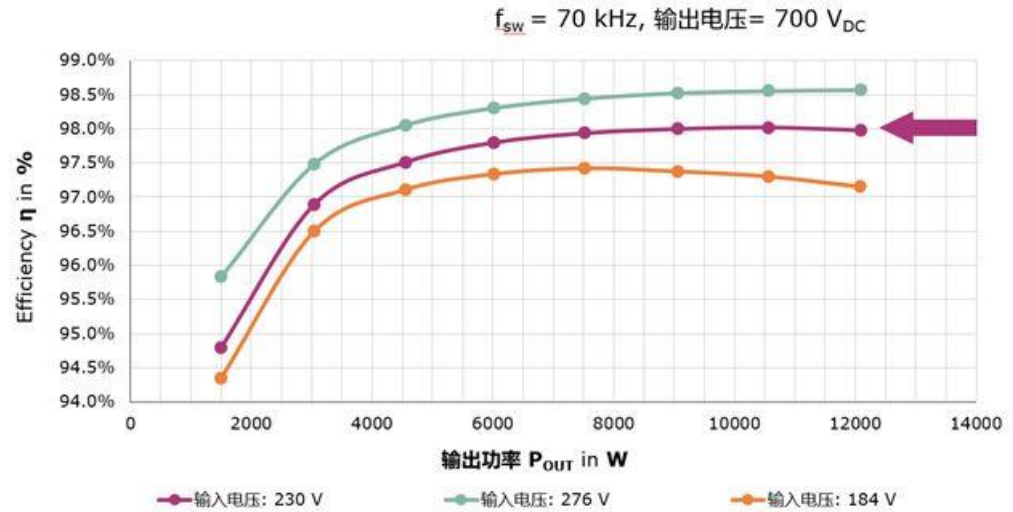
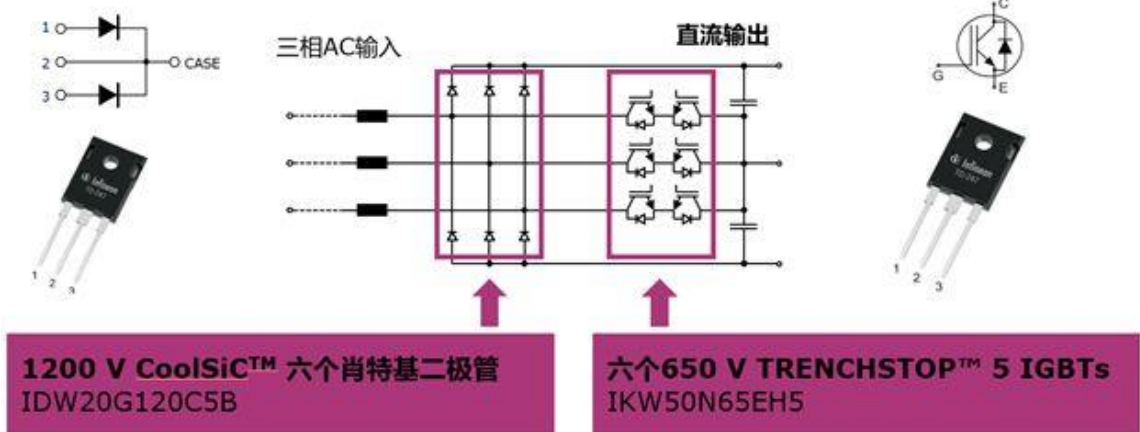


Block diagram of Vienna rectifier

12KW Vienna rectifier



Prototype



Target applications:

- > OBC and EV-chargers
- > CAC applications

Specifications:

- > Input Voltage: 184Vac-276Vac
- > Output Voltage: 700Vdc-800Vdc
- > Output Power: 12kW
- > Switching frequency: 70kHz
- > Power Density: 8.5 kW/dm³

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PFC广泛应用于家电应用

- › 全球各地越来越严格的谐波规范

PFC设计发展趋势

- › 高效、高频、小体积、低成本以及简单易用

系统级别应用设计

- › 英飞凌提供的PFC整体方案能够满足所有家电应用需求



Part of your life. Part of tomorrow.