英飞凌发布业界首款支持5~48V PD3.1 PFC+HFB二合一控制器XDPS2222

钱家法 | 总监 技术支持
英飞凌大中华区电源与传感系统事业部

Infineon is a global leader in power systems and IoT

Global leader

in automotive, power management,
energy efficient technologies and IoT

~56,200

employees[1]

Market position

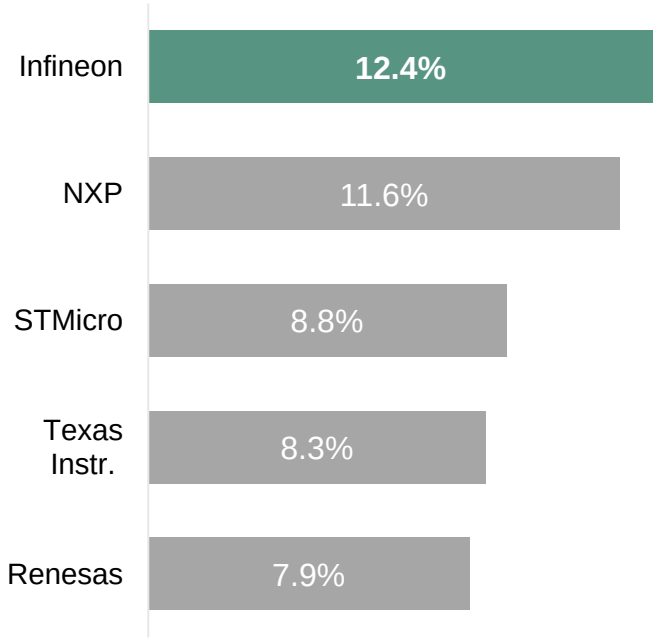
Automotive	Power	Microcontroller
#1	#1	#5
TechInsights, March 2023	Omdia, October 2022	Omdia, May 2023

[1] As of 30 September 2022

Infineon is a top player in all target markets

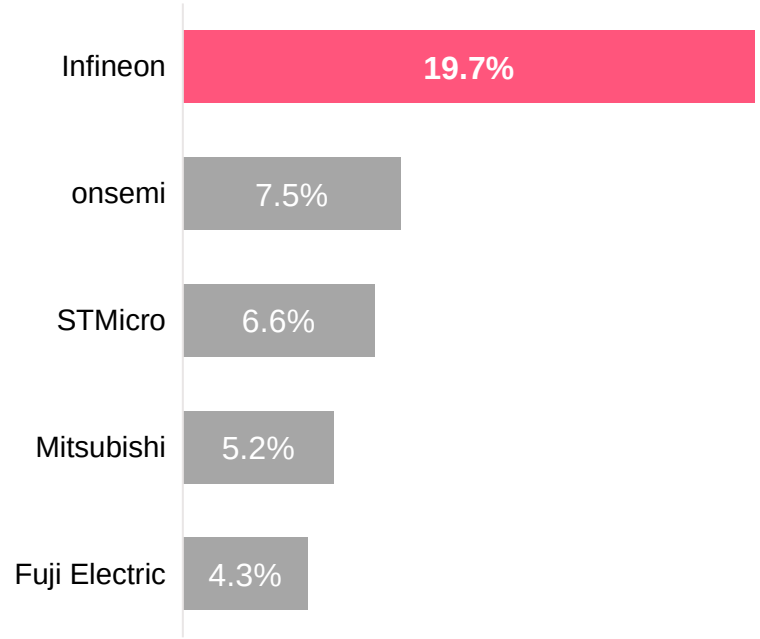
Automotive semiconductors[1]

Total market in 2022: USD 59.4bn



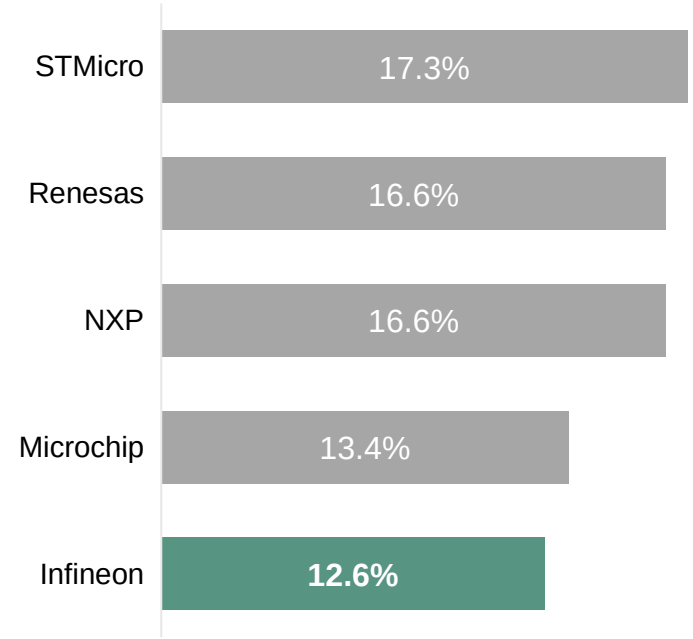
Power discretes and modules[2]

Total market in 2021: USD 27.5bn



Microcontroller[3]

Total market in 2022: USD 26.9bn



[1] TechInsights: Automotive Semiconductor Vendor Market Shares. March 2023. | [2] Based on or includes research from Omdia: Power Semiconductor Market Share Database – 2021 – Final V2. October 2022. | [3] Based on or includes research from Omdia: Annual 2001-2022 Semiconductor Market Share Competitive Landscaping Tool – 1Q23. May 2023. Results are not an endorsement of Infineon Technologies AG. Any reliance on these results is at the third party's own risk.

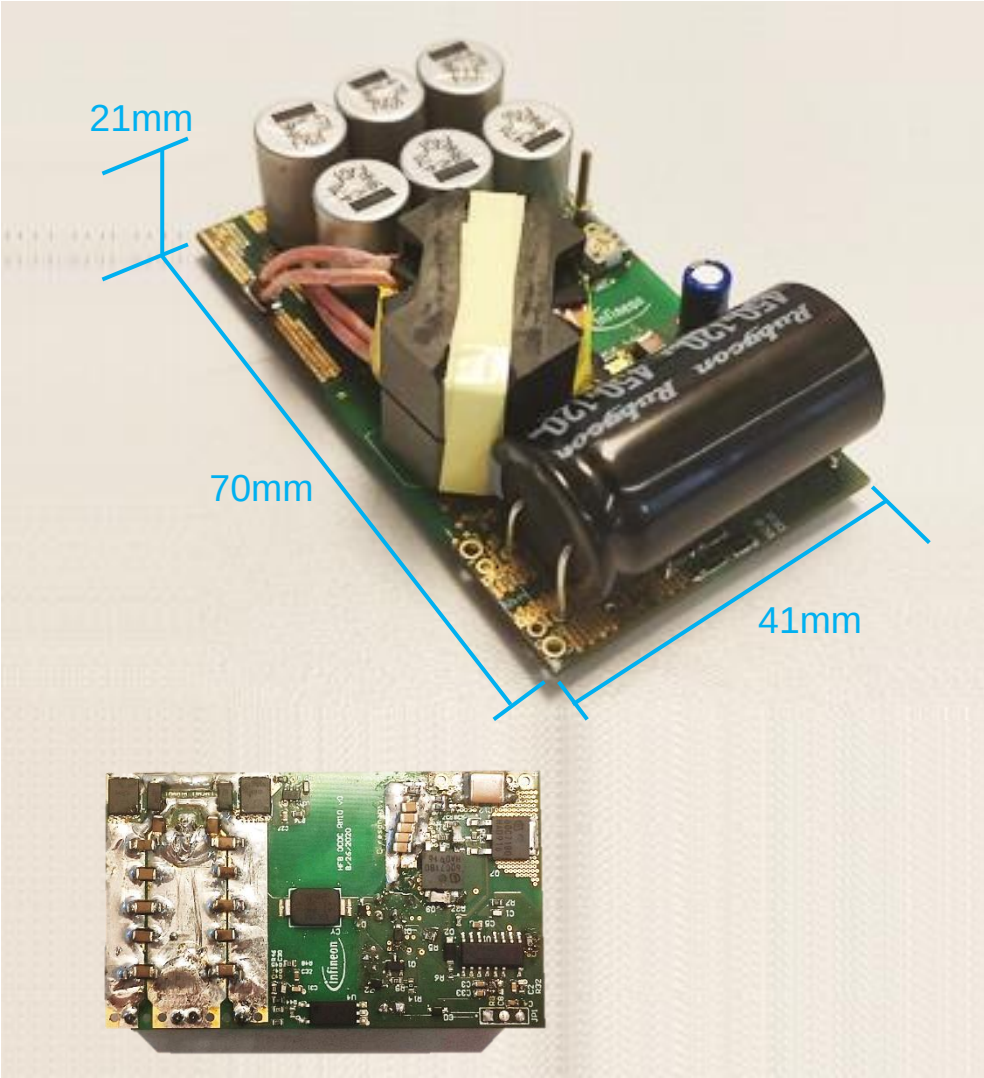
XDPS2221/XDPS2222 应用

	XDPS2221		XDPS2222	
USB-PD	Charger 	SPR EPR up to 28V	Adapter 	SPR EPR up to 48V
Non USB-PD	Battery charger 	TV 	Docking 	Gaming 

高功率密度PD3.1 ERP 的挑战

- PFC级效率是进一步提升效率的瓶颈
- PD适配器的平均效率问题
- 5~48V超宽输出范围与效率存在矛盾
- PWM控制器驱动GaN的电路较复杂
- 主控制器与SR控制器的适配问题

240W HFB 控制器 XDPS2201 宽输出、峰值功率 DC/DC演示版



240W 5 ~ 24V

240W@5~24V/10A

300W@24V/12.5A, 10s
350W@24V/14.58A, 1s

峰值

4 W/cc

65 W/in³
70 x 41 x 21 mm³

97.6%

96.7% @12V/10A

97.6% @24V/10A

输入：320-400V$_{DC}$

- **HFB IC** XDPS2201
- **HFB GaN** 2 x IPD60R180C7 (CoolMOS™)
- **SR MOSFET** BSC037N08NS5 (OptiMOSTM 5 power MOSFET)

- 变压器磁芯 RM10
- 母线电解电容 450V/120uF
- 输出电解电容 35V / 470μF

140W PFC+HFB 二合一控制器XDPS2221 PD3.1演示版

140W **5~28V**

5 V / 3 A, 9 V / 3 A,
15 V / 5 A, 20 V / 5 A,
28 V / 5 A

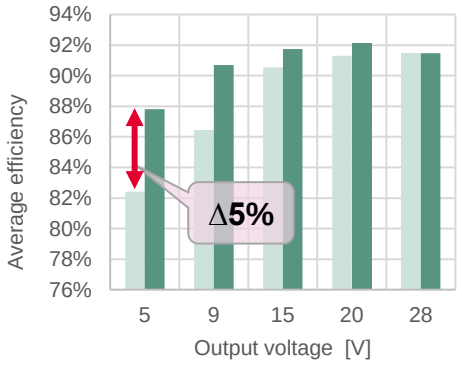
1.38 W/cc

22.7 W/in³
109.5 x 38.5 x 24.0 mm³

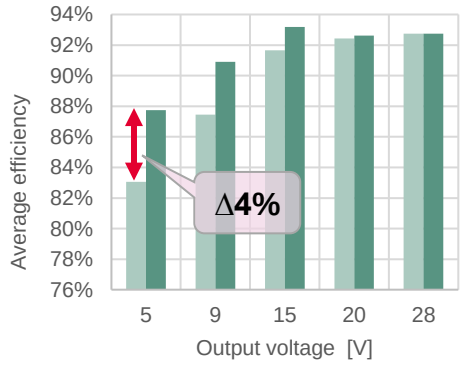
95% 峰值效率，230Vac

4~5%↑ 平均效率提升
5Vo/230Vac~115Vac

平均效率 @115Vac



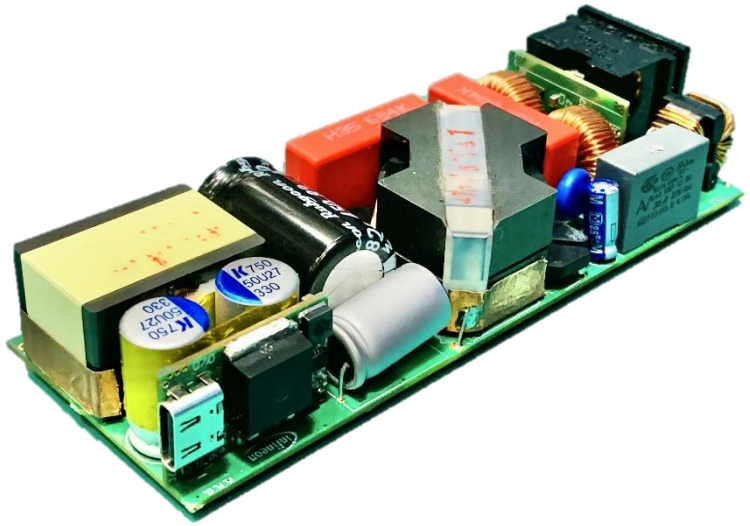
平均效率 @230Vac



- **PFC+HFB IC** XDPS2221
- **PFC GaN** IGLD60R190D1 (CoolGaN™)
- **HFB GaN** 2 x IGLD60R190D1 (CoolGaN™)

- **SR MOSFET** BSC040N10NS5 (OptiMOS™ 5 power MOSFET)
- **PD IC** CYPD3175 (EZ-PD™ CCG3PA)
- **Output MOSFET** IRF7240

240W PFC+HFB 新一代二合一控制器 XDPS2222 PD3.1演示版



240W 5 ~ 48V

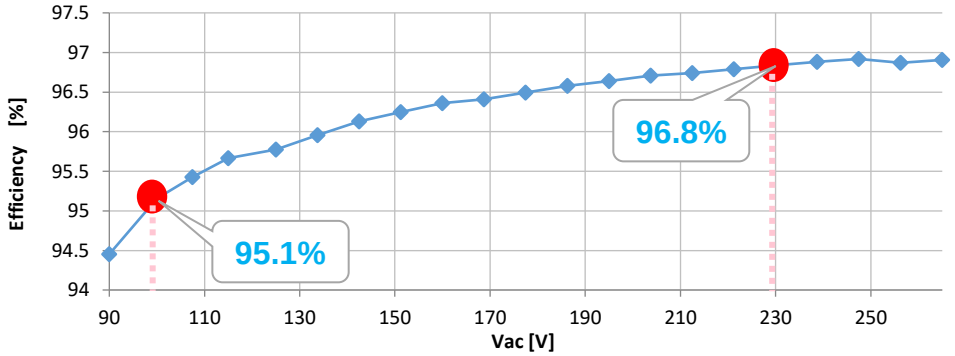
5 V / 3 A, 9 V / 3 A,
15 V / 5 A, 20 V / 5 A,
28 V / 5 A, 36 V / 5 A, 48V V / 5 A

2.7 W/cc

44 W/in³
110 x 40 x 20 mm³

95.1 ~ 96.8%

100Vac：前级~ 97 % (有源桥)，HFB: ~ 98 %
230Vac：前级~ 98.8 %，HFB: ~ 98 %

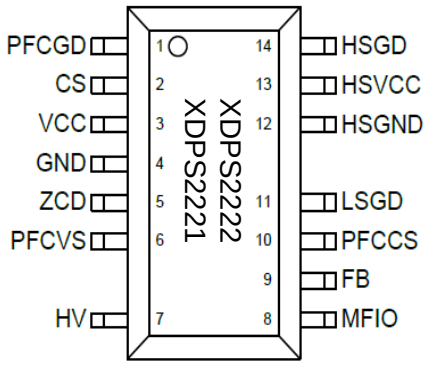


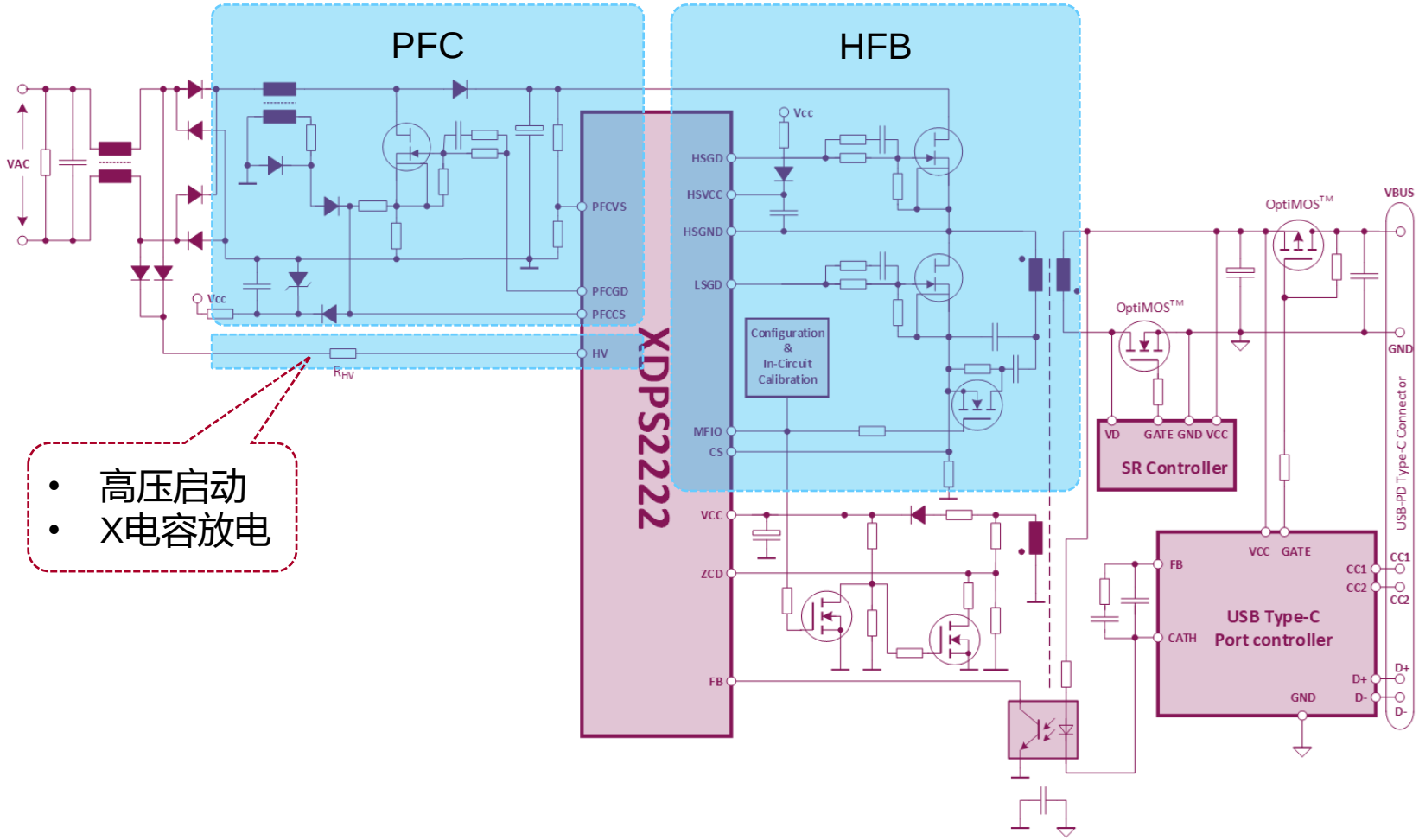
- **PFC+HFB IC** XDPS2222
- **Active Bridge** 4xIPL60R065P7 (CoolMOS™ 600 V)
- **PFC MOSFET** IPL60R104C7 (CoolMOS™ 600 V)
- **HFB GaN** 2 x IGLD60R190D1 (CoolGaN™)

- **SR MOSFET** BSC074N15NS5 (OptiMOSTM 5 power MOSFET)
- **PD IC** CYPD3175 (EZ-PD™ CCG3PA)
- **Output Switch** IPB110P06LM (p-channel power MOSFET)

XDP™ 数字电源 XDPS2222: PFC + HFB（Hybrid FlyBack） 二合一控制器

- **集成自适应PFC和软开关HFB**
- 支持MOSFET/GaN应用
- 参数可配置，优化系统
- DSO-14 封装，与XDPS2221脚兼容
- 高压和低压单元宽安全爬电距离





- 高压启动
- X电容放电

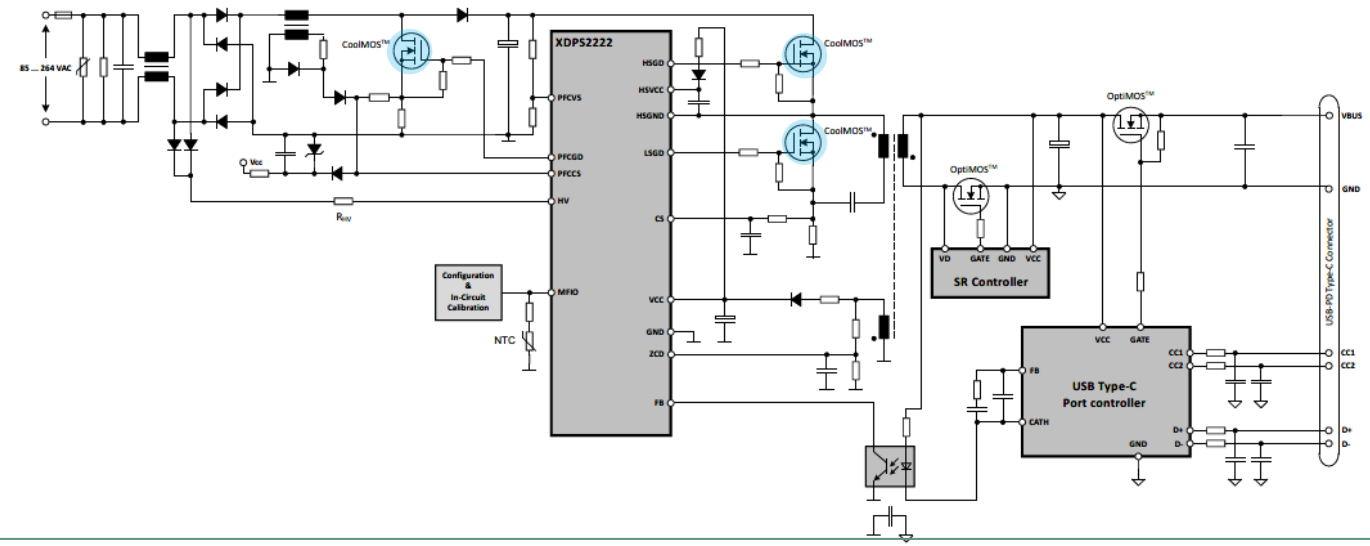
Hybrid FlyBack（HFB） = AHB Flyback

XDPS2222的几种应用形式 ——搭配 MOSFET 或Infineon的GaN

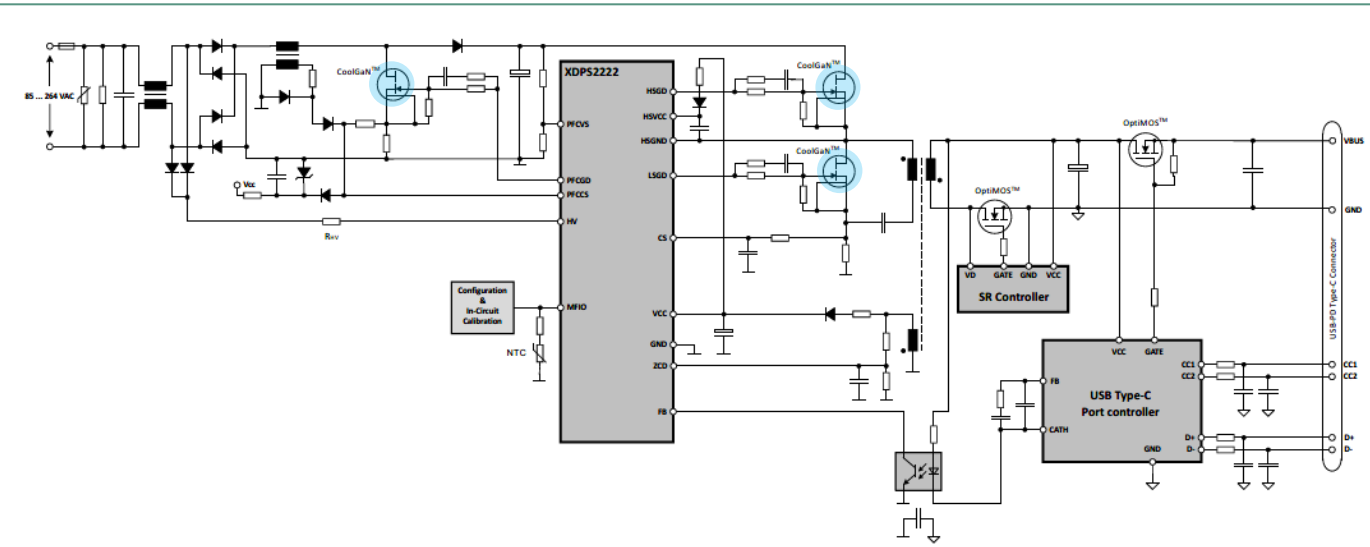
- 搭配MOSFET
  - 无需外部驱动器
  - 可搭配CoolMOS™（C7,P7,P7S…）

- 搭配英飞凌电流型驱动的GaN
  - 可搭配单管或半桥GaN
  - 直接驱动，无需外部驱动器和限压电路

搭配MOSFET



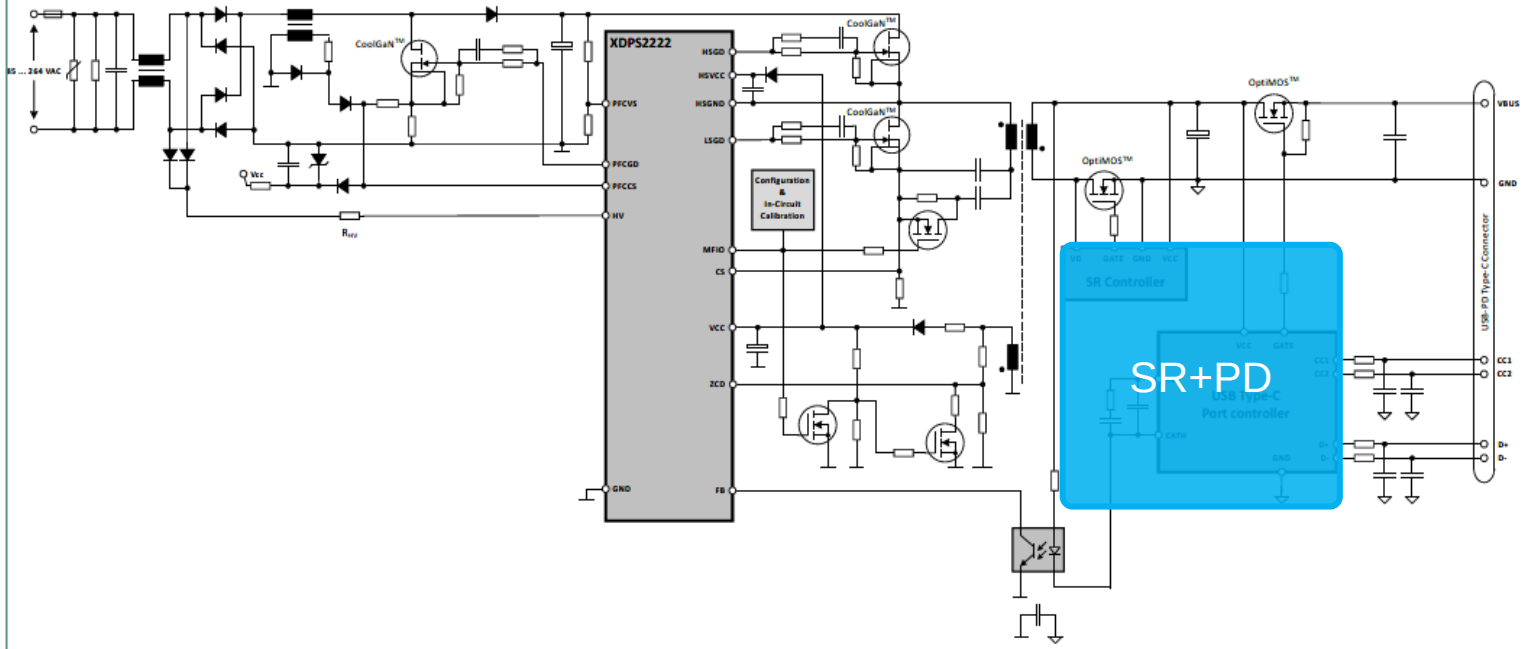
搭配英飞凌GaN



XDPS2222的几种应用形式 —— 搭配Infineon的 SR+PD二合一控制器

- 简化次级电路
  - SR+PD 二合一（CYPAG2xx）
  - 负载开关控制
  - CYPAG2xx支持MV GaN
- 与初级协同工作提高可靠性
  - 与XDPS2221/2222 可灵活协同
  - 减少SR与初级开关的误动作

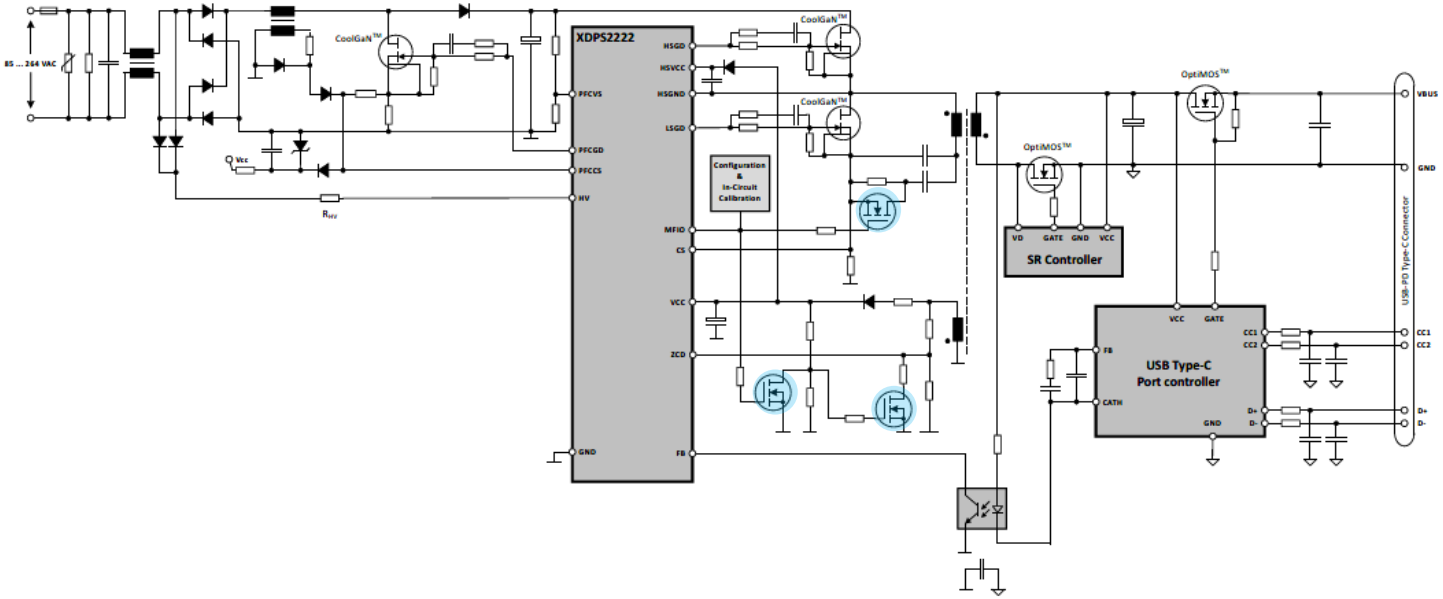
与Infineon的 SR+PD二合一控制器（CYPAG2xx）搭配



XDPS2222的几种应用形式 —— 半桥谐振电容切换

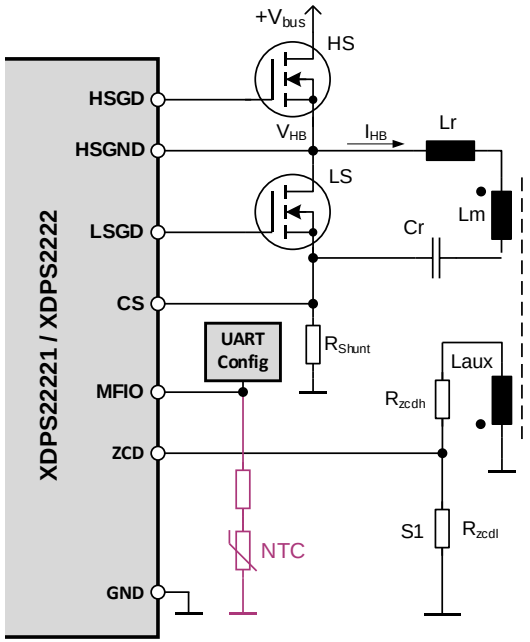
- 半桥谐振电容切换
  - 为高低不同的输出电压采用不同的谐振容容值，从而改变谐振槽路
  - 减小低输出电压时的RMS电流，提高效率
- 切换ZCD分压比例
  - 根据输出电压高低切换ZCD分压比例
  - 提高ZCD电压分辨率

谐振电容切换



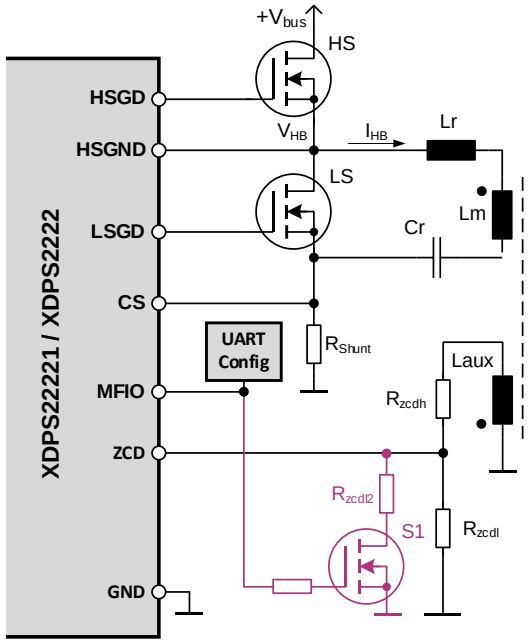
XDPS2221与XDPS2222的区别

过温保护(XDPS2221 / XDPS2222)



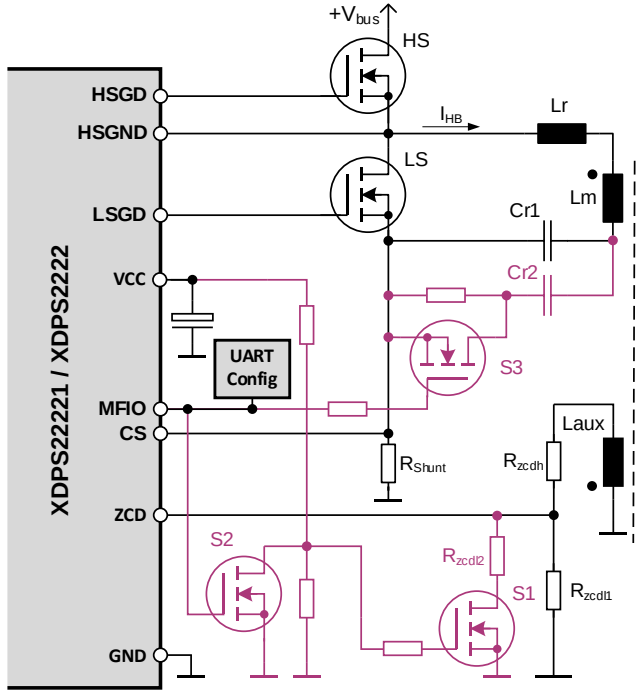
- MFIO脚 使用NTC做外部过温保护

切换ZCD分压比(XDPS2222)



- MFIO脚 根据输出电压高低切换ZCD分压比例
  提高ZCD电压分辨率

谐振电容切换(XDPS2222)

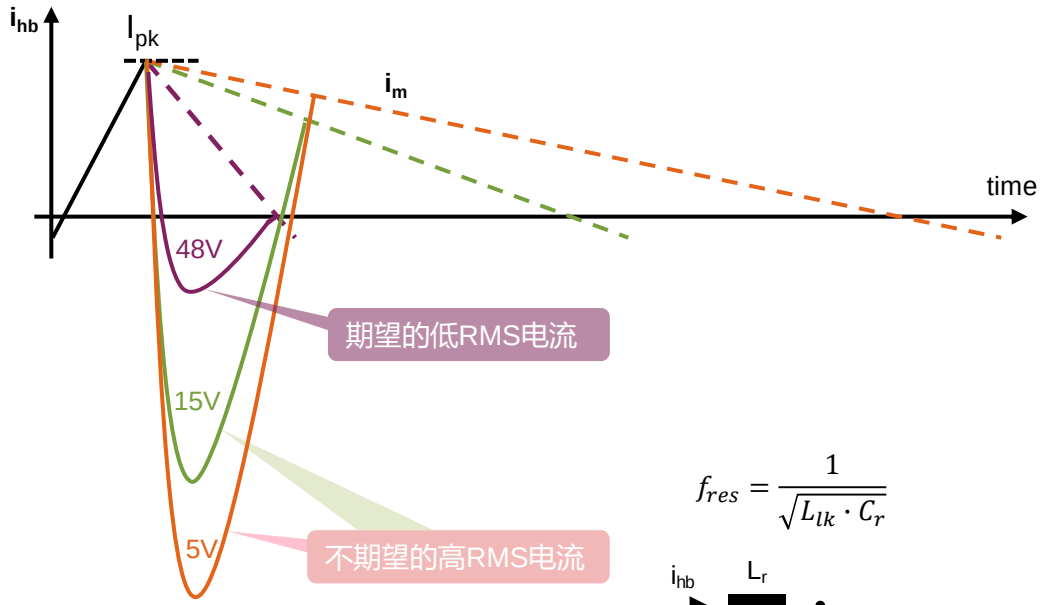


- MFIO脚进一步根据输出电压切换谐振电容

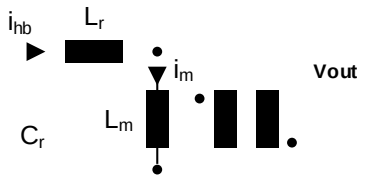
不同输出电压下的混合反激电流波形

谐振槽路不变的电流波形

$$t_{demag} = \frac{I_{pk}}{V_{cr}} L_{mag} = \frac{I_{pk}}{NV_{out}} L_{mag}$$



$$f_{res} = \frac{1}{\sqrt{L_{lk} \cdot C_r}}$$

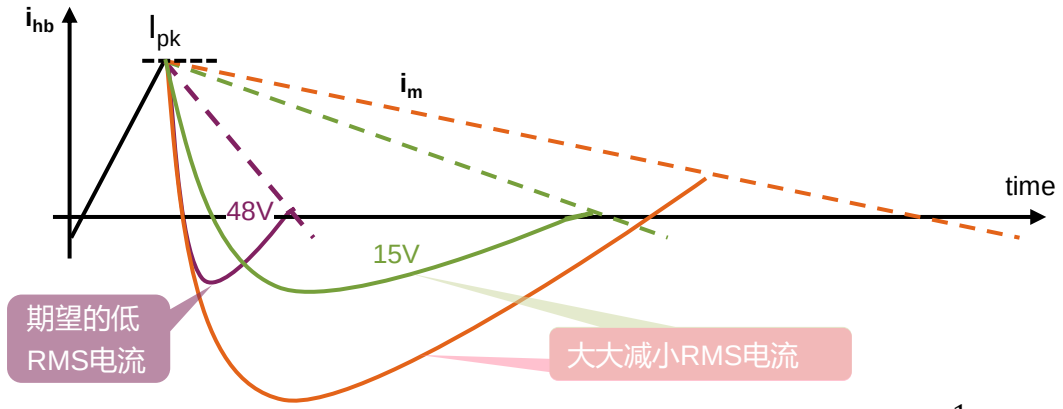


5V/15V/48V: 谐振电容 = C_r

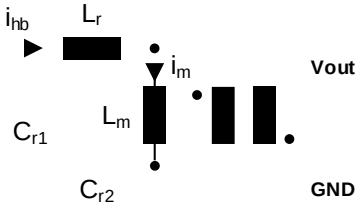
→ 低输出电压下，变压器退磁时间长
低输出电压下，峰值谐振电流大，RMS电流大，低效率

谐振电容切换情形下的电流波形 (*XDPS2222*)

$$t_{demag} = \frac{I_{pk}}{V_{cr}} L_{mag} = \frac{I_{pk}}{NV_{out}} L_{mag}$$



$$f_{res} = \frac{1}{\sqrt{L_{lk} \cdot (C_{r1} + C_{r2})}}$$



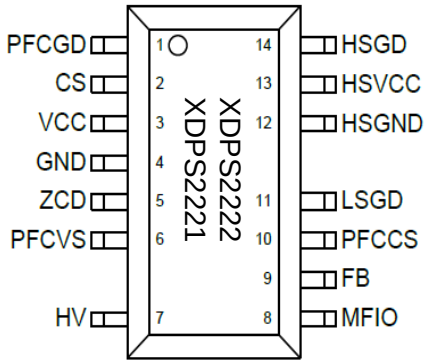
48V: 谐振电容 = C_{r1}

5V/15V: 谐振电容 = C_{r1} +C_{r2}

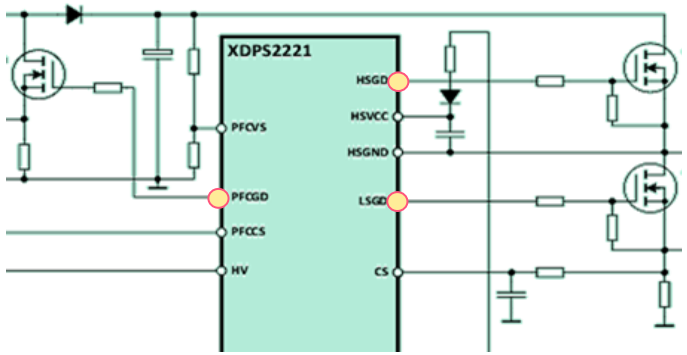
→ 为高低不同的输出电压采用不同的谐振容容值
减小RMS电流，提高效率

PFC+HFB 二合一控制器 XDPS2221/2222 —— 高集成，易设计

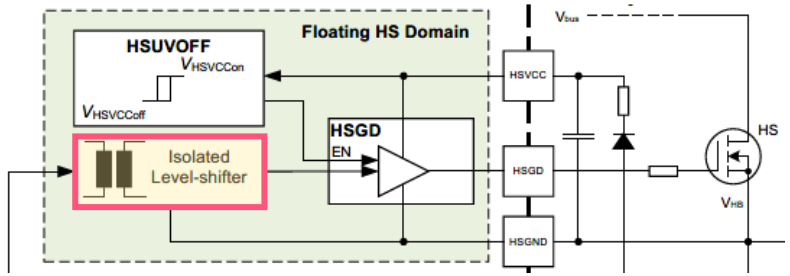
- 能效提高单元
  - 600 V 高压启动单元
  - 有源 X电容放电功能
- 集成 3 个开关驱动器
  - PFC驱动+半桥驱动（低侧+高侧）
  - 无磁芯变压器 高侧驱动
    - 高耐压，抗干扰能力强，高可靠性
  - 驱动电流可调
    - 电流大小可调
    - 电流斜率可调，优化EMI



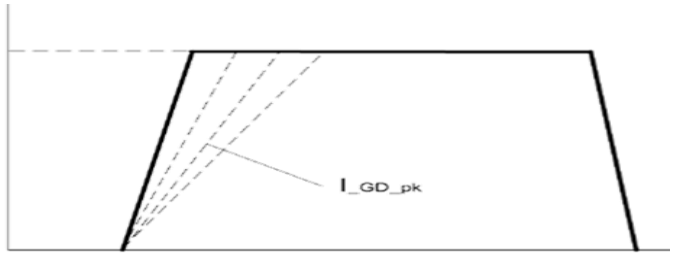
集成3个驱动



无磁芯变压器驱动



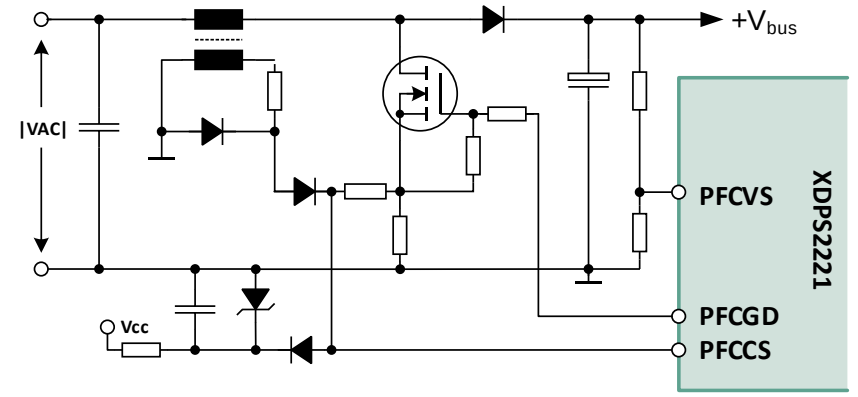
驱动电流可调



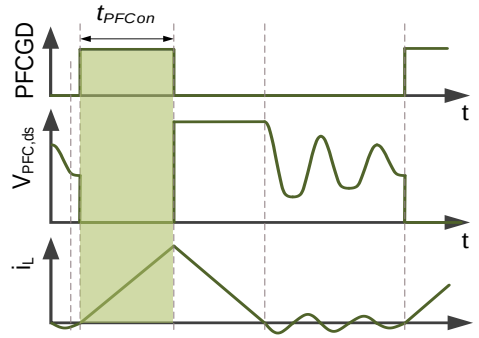
XDP™ 数字电源 XDPS2221/XDPS2222 —— PFC控制

- PFC多模式工作
  - 准谐振QR模式，谷底开通
  - 最高频率限制，跳频工作
  - 轻载间歇工作
- 固定开通时间控制
- 高PF值，低谐波畸变
- 与后级HFB协同工作，同步间歇工作
  - 更好的待机效率
  - 较小轻载或待机纹波电压
  - 减小负载切换电压过冲

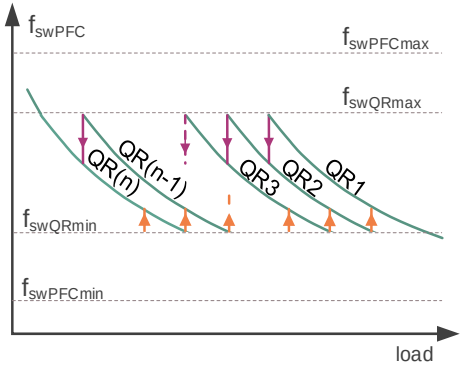
PFC电路



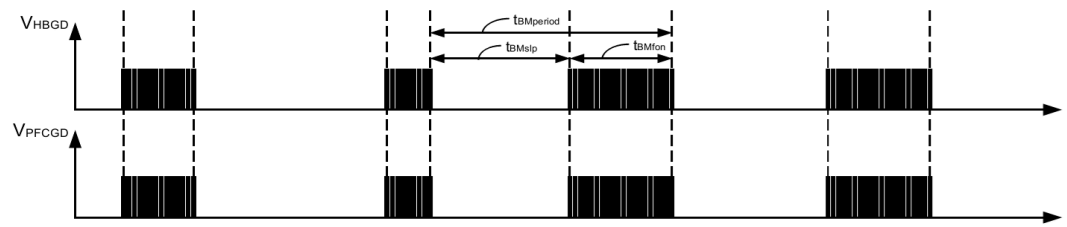
工作波形



跳频工作

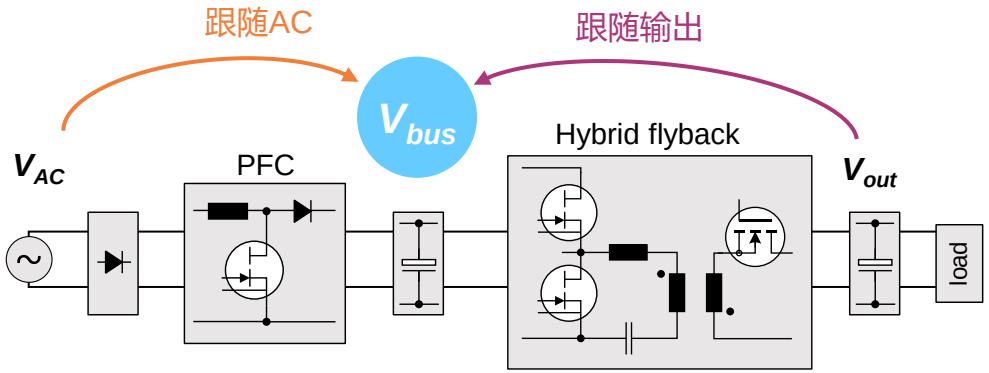


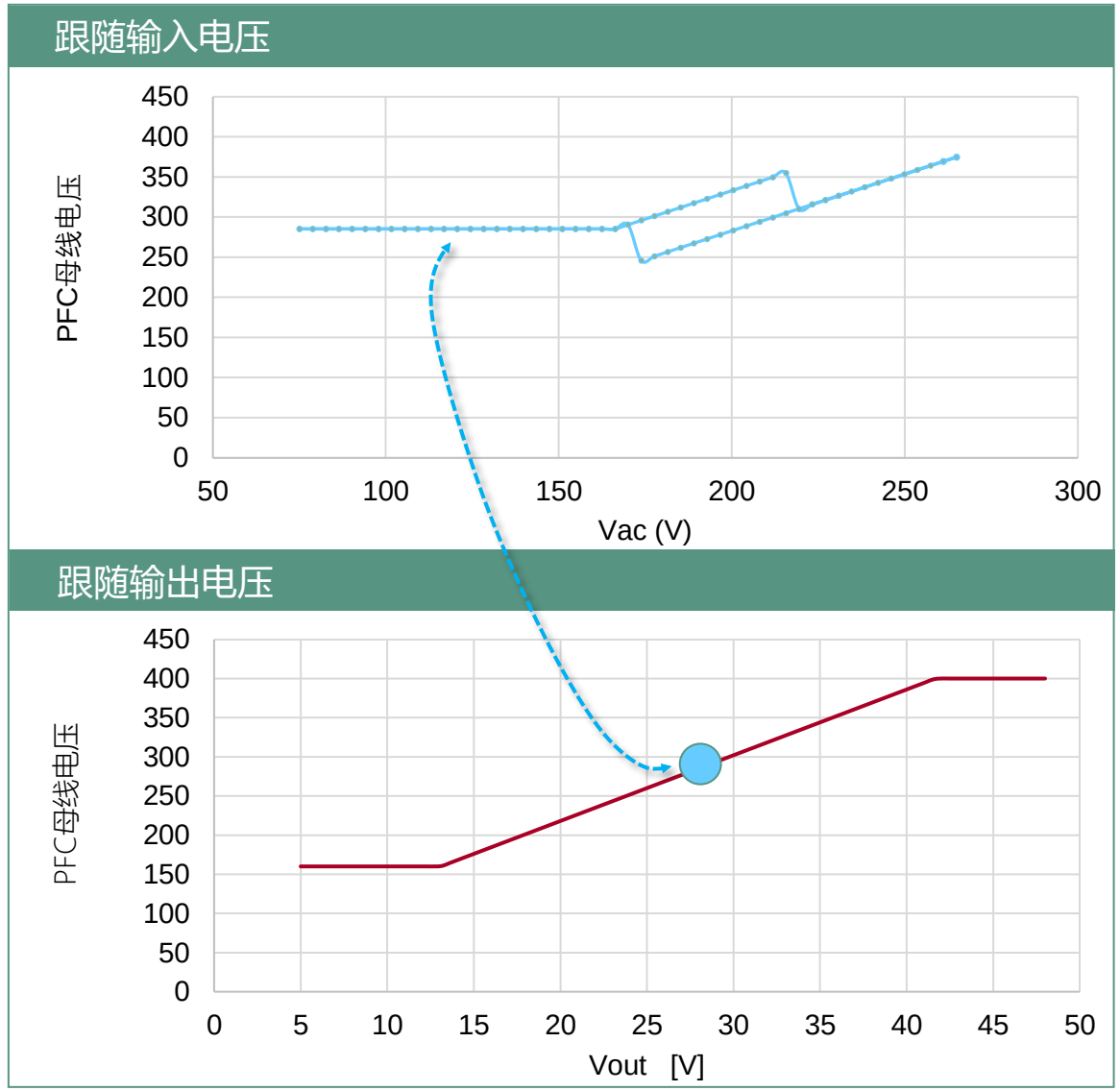
同步工作



PFC母线电压自适应—— 提高平均效率

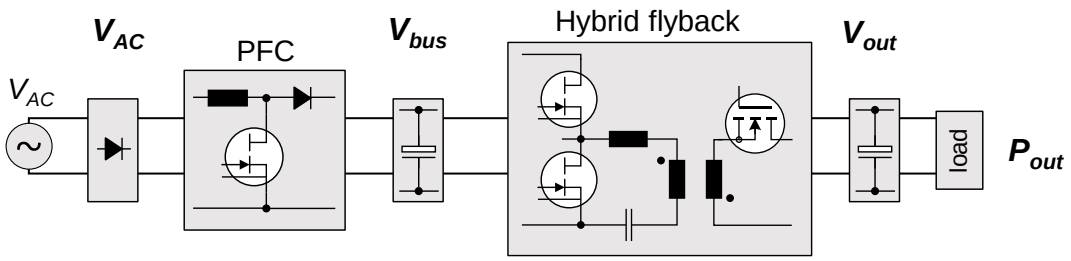
- PFC母线电压根据不同条件改变
  - 跟随输入电压，提高PFC级效率
  - 跟随输出电压，维持HFB级增益和效率
  - 切换条件可在配置文件中自定义

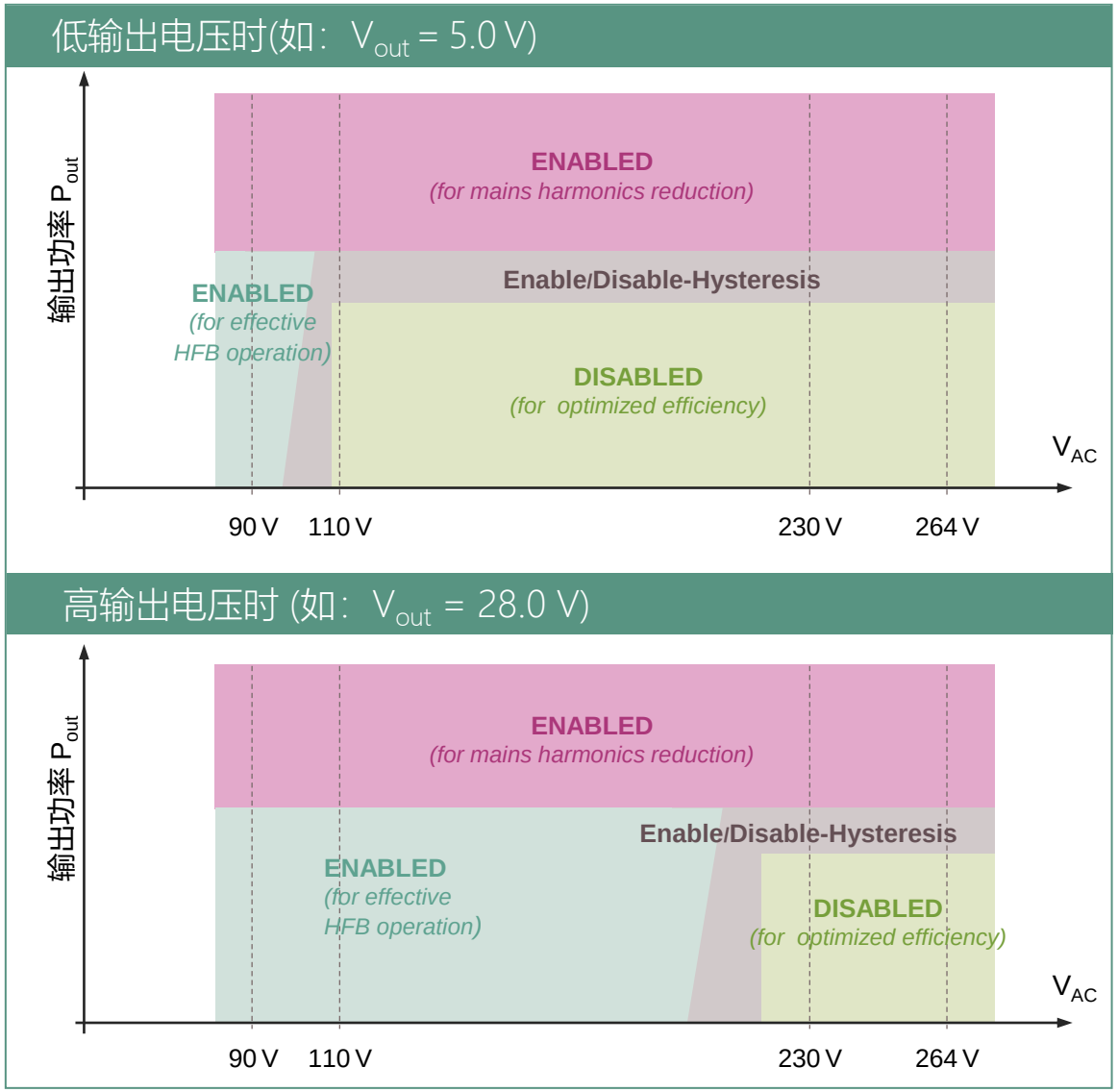




PFC自动启停 —— 提高轻载和待机性能

- PFC根据不同的条件启停，提高轻载和待机性能
  - HFB轻载间歇工作时睡眠/唤醒的状态
  - 根据输出功率大小启停
  - 根据输入AC电压和输出电压的不同组合启停
  - 切换条件可在配置文件中自定义

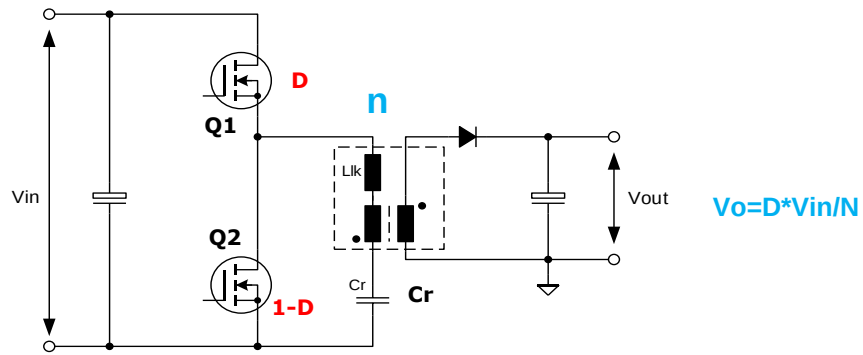




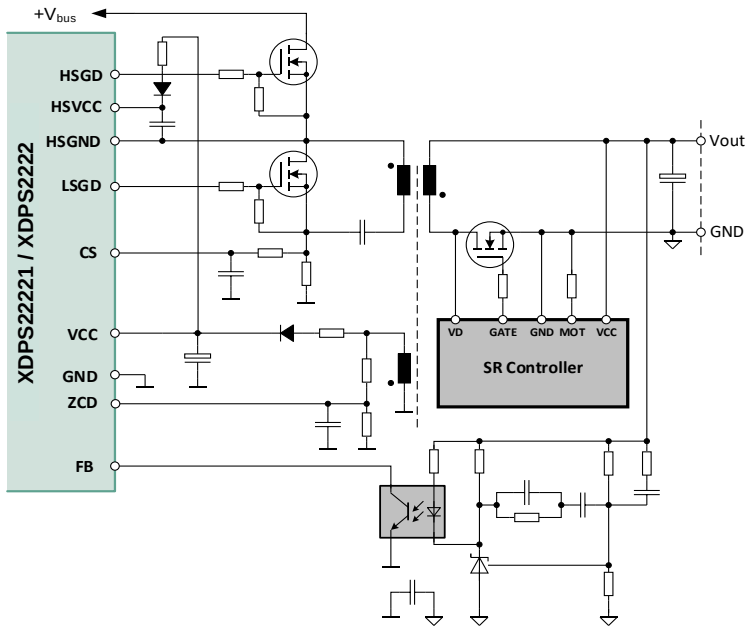
XDPS2221/XDPS2222的HFB混合反激控制

- 拓扑优点
  - 相比于传统反激，变压器更小（小一半或以上）
  - 初级和次级的开关应力更低
- HFB混合反激控制
  - 峰值电流模式控制
  - 传递延时补偿
  - 频率抖动改善EMI
  - 全工况软开关工作
  - 独有ZVS脉冲插入技术实现轻载软开关

HFB拓扑



HFB混合反激电路



HFB混合反激拓扑减小变压器 （相比于 QR或ACF）

- ACF 变压器转移的功率

  $P_{m\_ACF}=P_o$

- HFB 变压器转移的功率

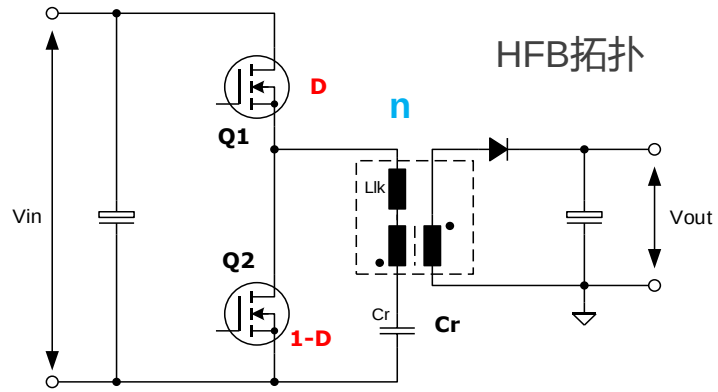
  $P_{m\_HFB}=P_o*（1-D）$

- HFB 谐振电容转移的功率

  $P_{c\_HFB}=P_o*D$

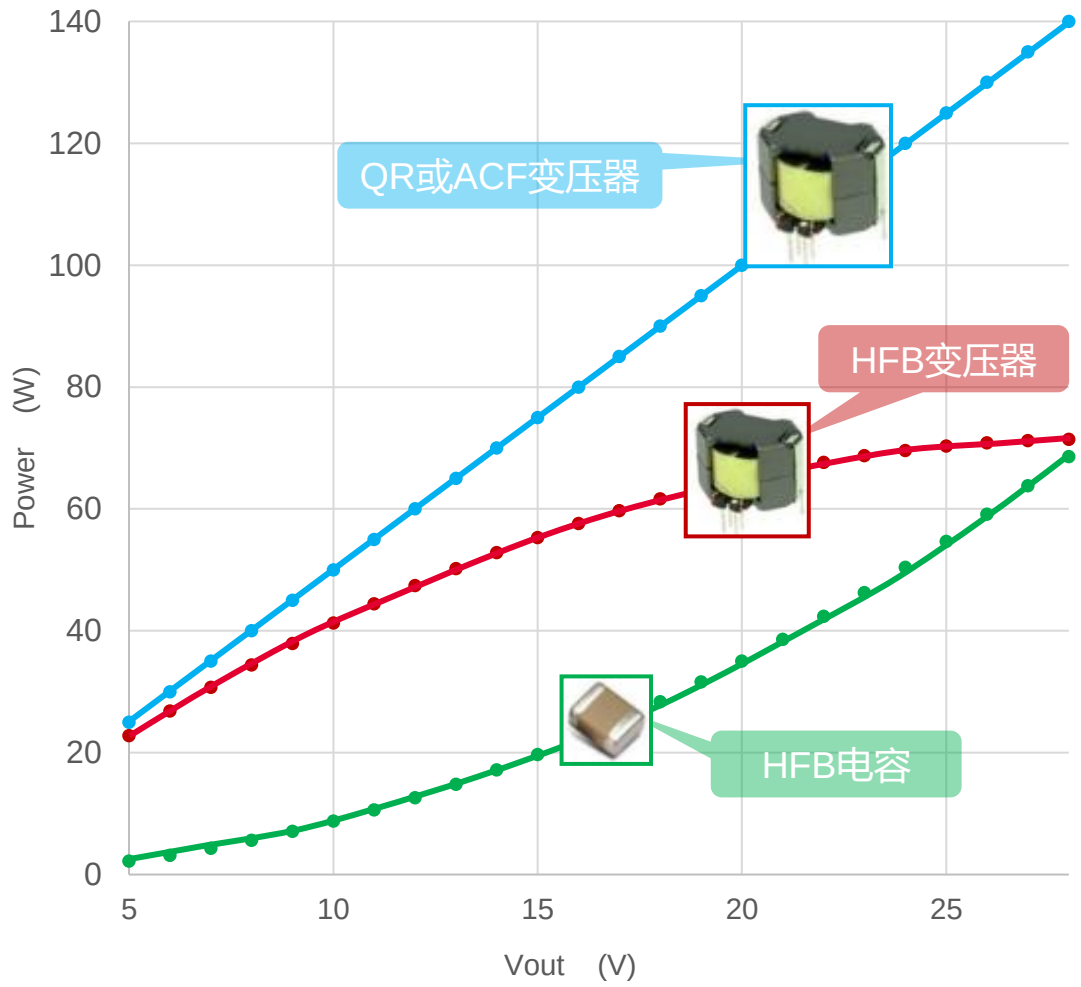
$$P_{m\_HFB}+P_{c\_HFB}=P_o$$

- HFB 在相同频率下，相同的变压器能传输更大的功率



*理想情况对比

固定母线电压下变压器储能对比（临界工作模式）



HFB 的开关管具有更小的电压应力 （相比于QR反激/ACF）

- ACF (注：近似计算)
  - 主开关管的电压应力较大，是输入电压加上反射电压:

$$V_{ds\_Q} = V_{in} + n \cdot V_o$$

  - 整流管的电压应力:

$$V_{ds\_SR} = \frac{V_{ds\_Q}}{n} = \frac{V_{in}}{n} + V_o$$

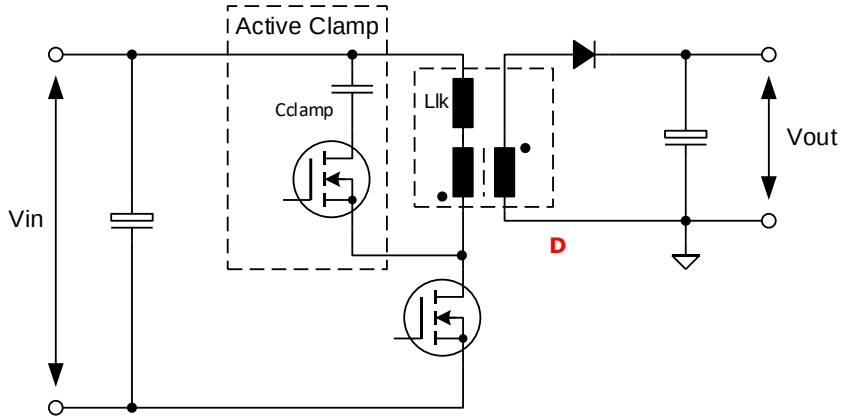
- HFB
  - 主开关管的 电压应力较小， 钳位到输入电压:

$$V_{ds\_Q} = V_{in}$$

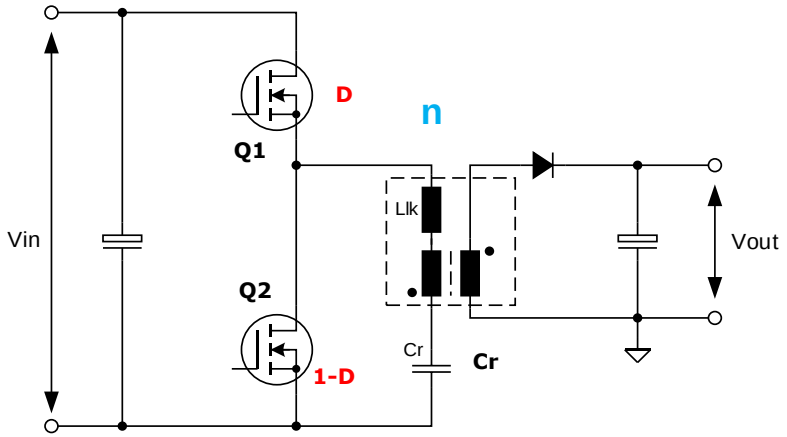
  - 整流管的电压应力:

$$V_{ds\_SR} = \frac{V_{ds\_Q}}{n} = \frac{V_{in}}{n}$$

ACF有源钳位反激

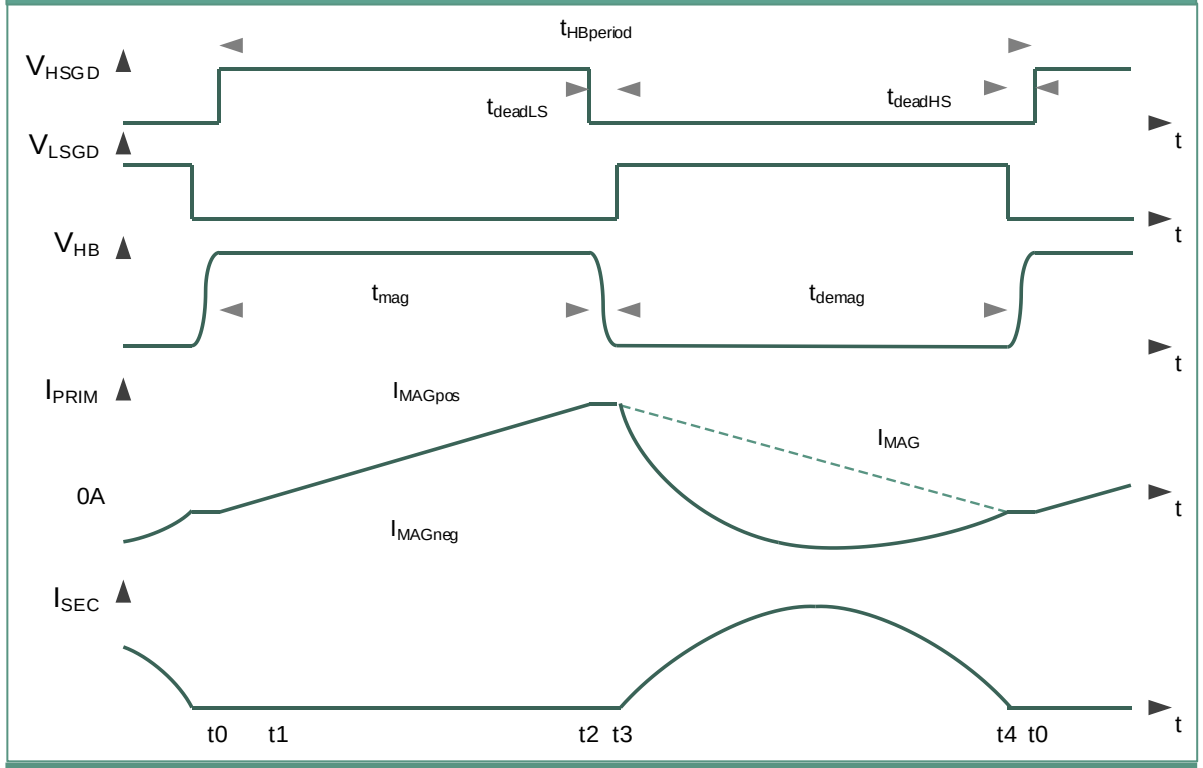


HFB混合反激



HFB不同模式的波形

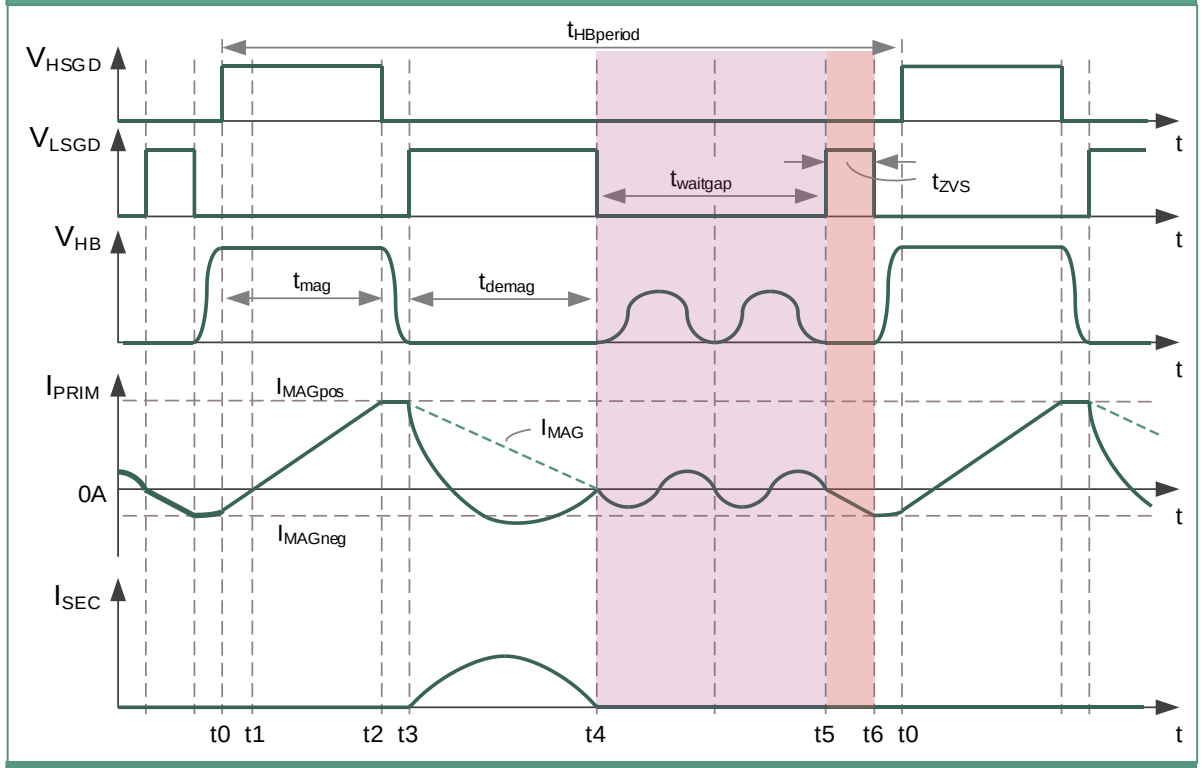
CRM 模式：重载条件下工作



$$I_{out} = \frac{N\left(I_{MAGpos} + I_{MAGneg}\right)}{2}$$

$$F_{sw} = \frac{V_{cr}(V_{in} - V_{cr})}{I_p L_p V_{in}}$$

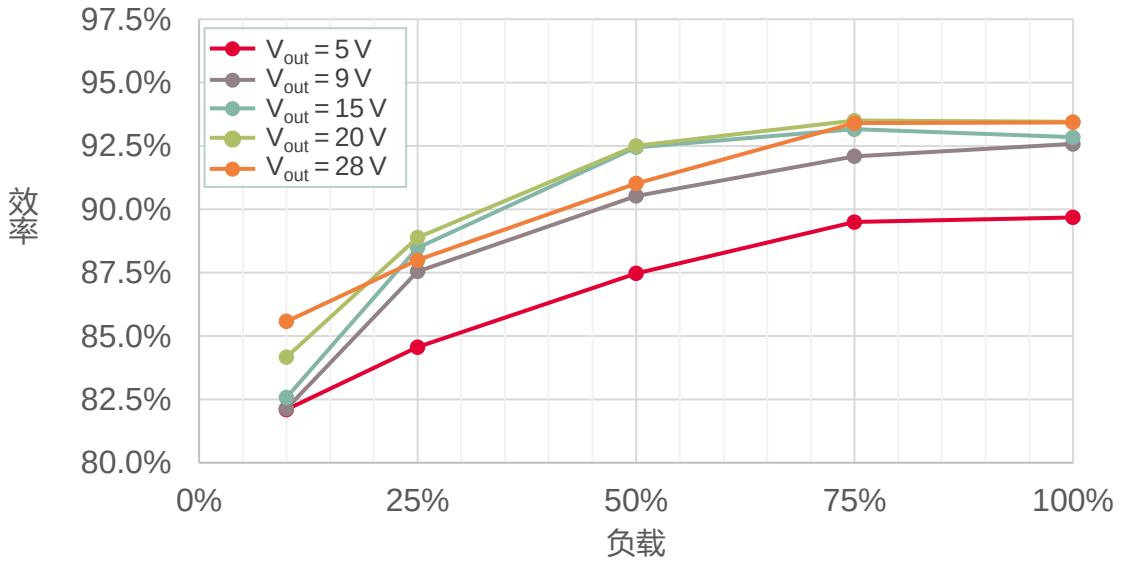
ZV-RVS模式：轻载条件，脉冲插入



$$I_{out} = \frac{t_{HBperiod} - t_{waitgap}}{t_{HBperiod}} \frac{N\left(I_{MAGpos} + I_{MAGneg}\right)}{2}$$

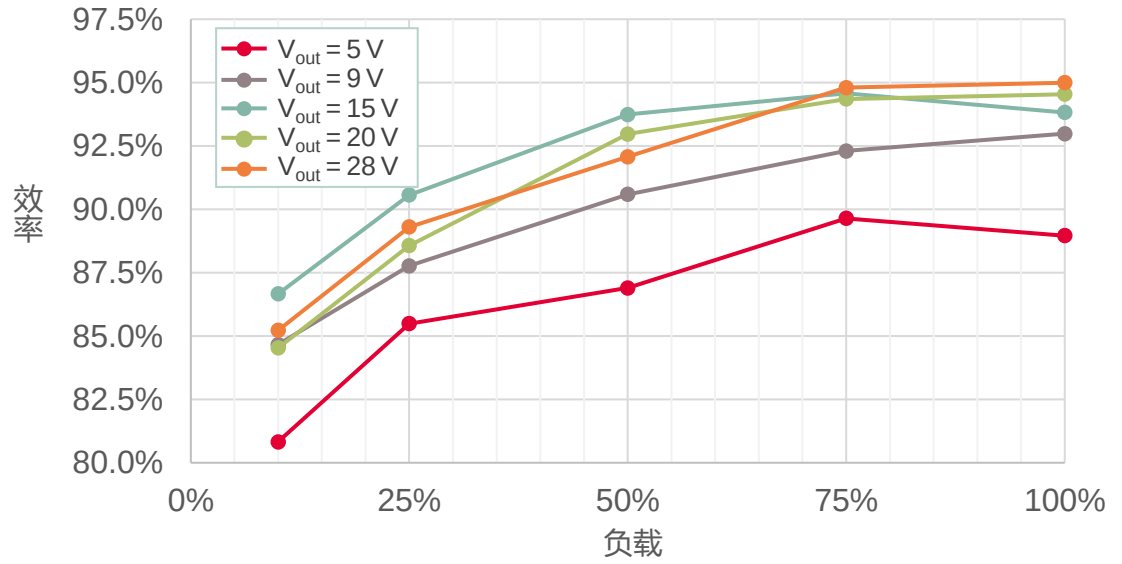
140W 演示版效率数据

V_{AC} = 115V / 60 Hz



V_{out}	平均效率 (25%, 50%, 75%, 100%)	DoE level 6	CoC Tier 2	结果
5.0 V	87.75 %	81.39 %	81.84 %	PASS
9.0 V	90.91 %	87.73 %	88.85 %	PASS
15.0 V	93.18 %	88.0 %	89.0 %	PASS
20.0 V	92.91 %	88.0 %	89.0 %	PASS
28.0 V	92.80 %	88.0 %	89.0 %	PASS

V_{AC} = 230V / 50 Hz

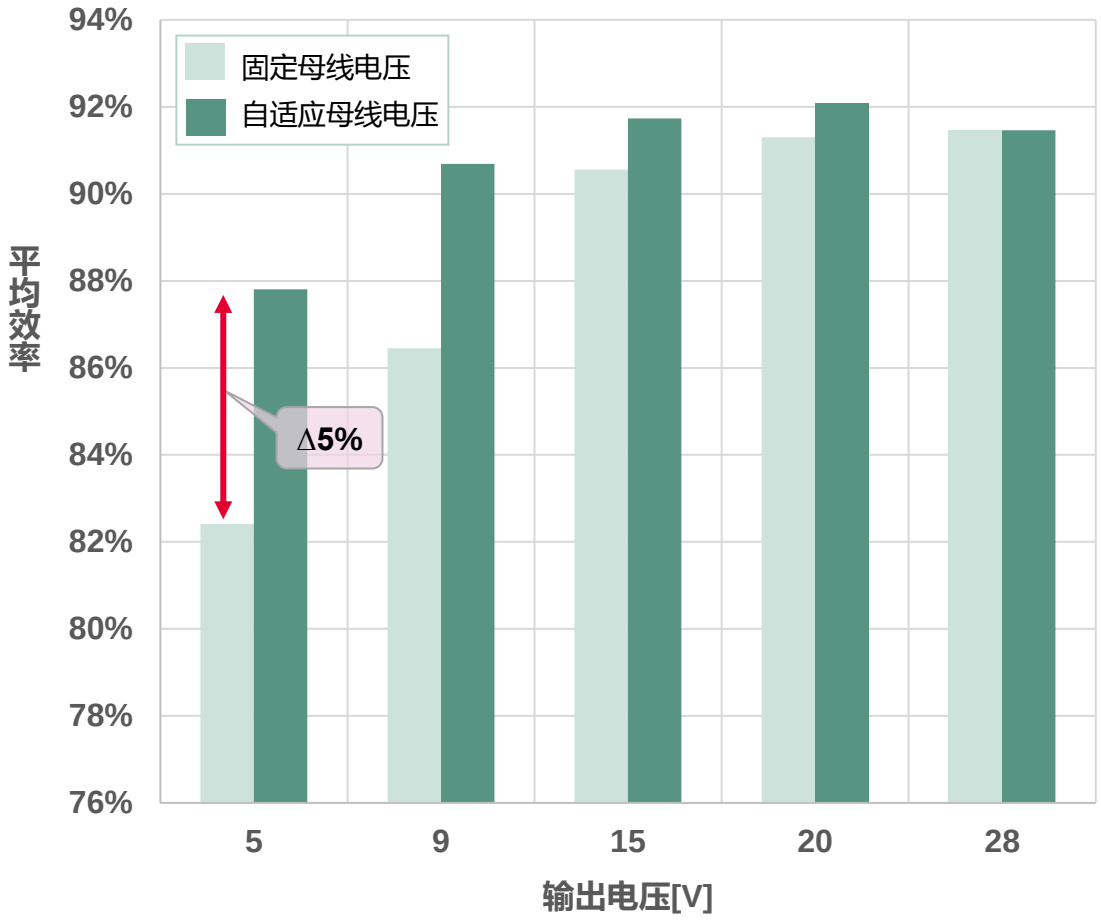


V_{out}	平均效率 (25%, 50%, 75%, 100%)	DoE level 6	CoC Tier 2	结果
5.0 V	87.63 %	81.39 %	81.84 %	PASS
9.0 V	90.85 %	87.73 %	88.85 %	PASS
15.0 V	93.09 %	88.0 %	89.0 %	PASS
20.0 V	92.33 %	88.0 %	89.0 %	PASS
28.0 V	92.51 %	88.0 %	89.0 %	PASS

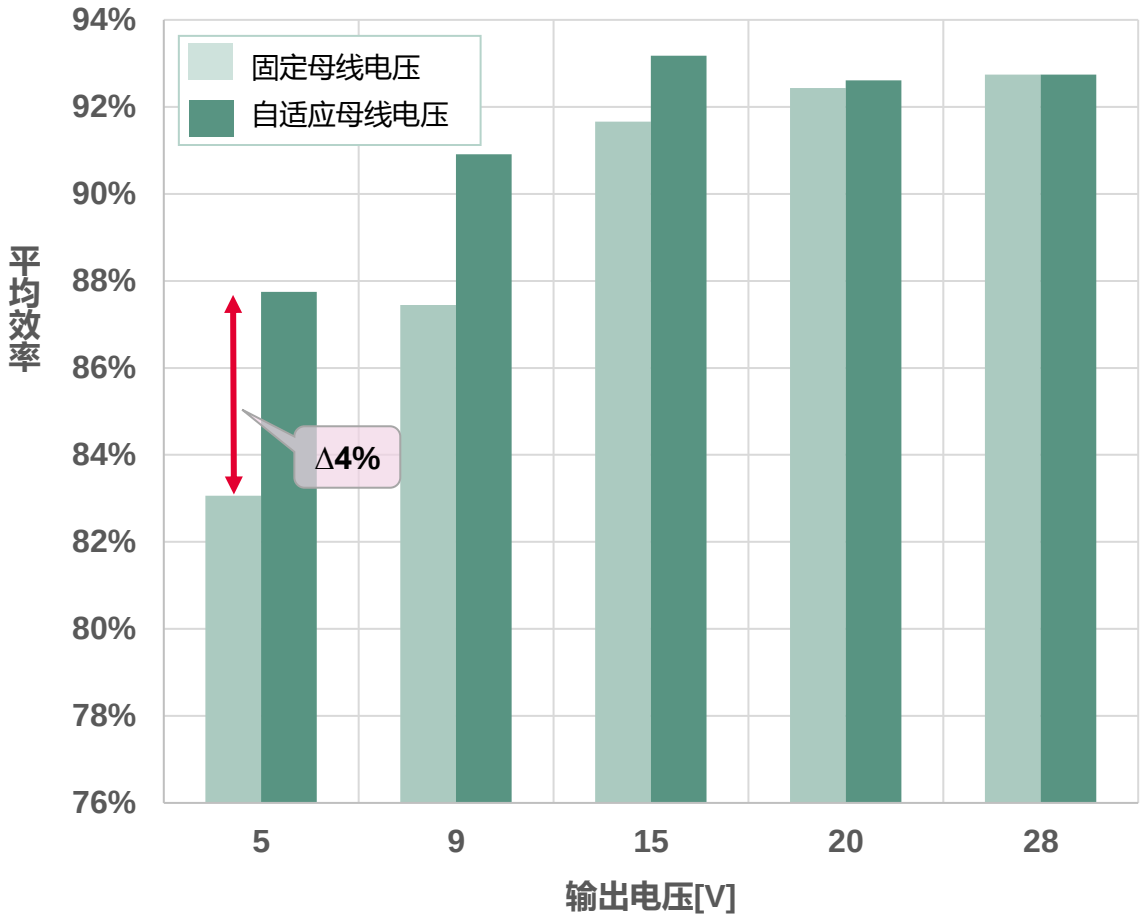
注：数据来自于140W XDPS2221 演示板

明显提升平均效率 —— 可达 4~5%

V_{AC} = 115 V / 60 Hz



V_{AC} = 230 V / 50 Hz



注：数据来自于140W XDPS2221 演示板

总结

- XDPS2221与XDPS2222引脚兼容
- 自适应PFC母线电压提升平均效率
- PFC自动启停提高待机及轻载性能
- HFB谐振电容切换功能轻松实现5~48V超宽输出范围
- 可以直接驱动英飞凌电流型GaN
- SR+PD二合一控制器（CYPAG2xx）可协同提高可靠性

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