Transphrom –氮化镓FET(HEMT)

HEMT: High Electron Mobility Transistor

氮化镓**MOSFET** (600VDC, 能承受周期为1uS,100nS的连续的方波,保证750V)					
Part Number	**Package**	**Voltage (V)**	**Current (A)**	**Ron(Ohm)**	**Description**
TPH3245ED 下载	**QFN 5*6**	**750**	**6**	**0.5**	背部金属接**D**极
TPH3002LD 下载	**QFN 8*8**	**750**	**9**	**0.29**	背部金属接**D**极
TPH3002LS 下载	**QFN 8*8**	**750**	**9**	**0.29**	背部金属接**S**极
TPH3002PD 下载	**TO-220**	**750**	**9**	**0.29**	背部金属接**D**极
TPH3002PS 下载	**TO-220**	**750**	**9**	**0.29**	背部金属接**S**极
TPH3006LD 下载	**QFN 8*8**	**750**	**17**	**0.15**	背部金属接**D**极
TPH3006LS 下载	**QFN 8*8**	**750**	**17**	**0.15**	背部金属接**S**极
TPH3006PD 下载	**TO-220**	**750**	**17**	**0.15**	背部金属接**D**极
TPH3006PS 下载	**TO-220**	**750**	**17**	**0.15**	背部金属接**S**极
TPH3205WS 下载	**TO-247**	**750**	**37**	**0.063**	背部金属接**S**极

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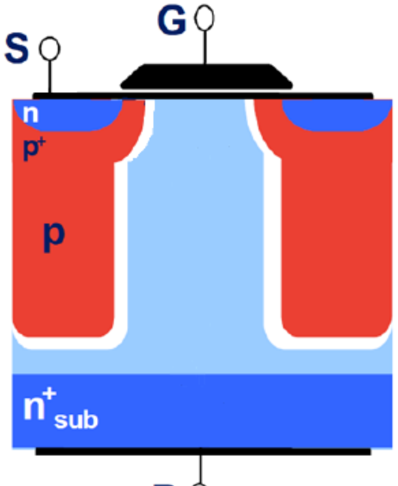
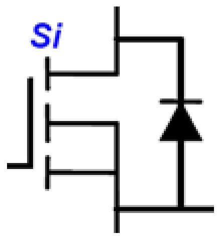
硅，氮化镓FET的结构

硅MOS

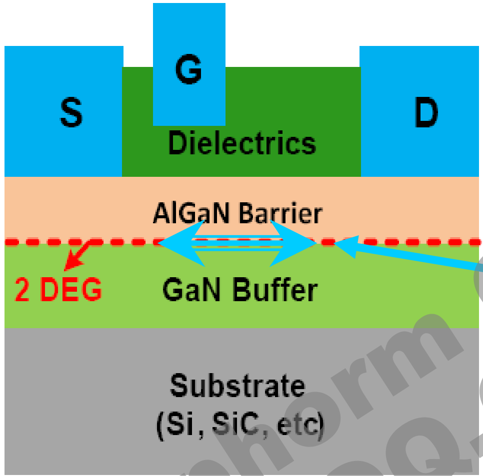


Si super junction vertical Structure

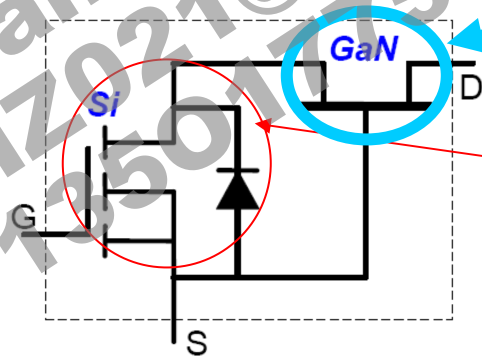


硅材料的垂直结构使得P/N结存在即必然有慢速的寄生二极管，同时D极只能在最下方

氮化镓



Normally On



氮化镓是采用水平结构,通过电子层导通没有形成P/N结，同时最下方是衬底

氮化镓FET – HEMT

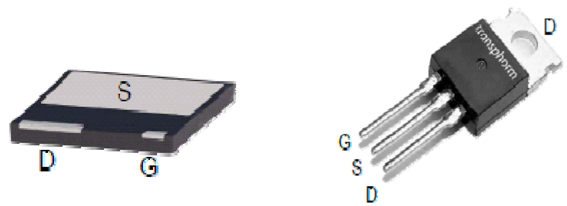
1,氮化镓与传统的硅MOS不一样，体内没有形成PN结，即没有体内二极管

2，D,S间的导体是通过中间的电子层导通，双向可导通，即常开/Normally On

3，当G极加负压时D,S间关断。实际应用不方便（需加负压）

横向结构器件
无寄生二极管
具有对称传导特性

解决的办法，就是在体内串加一个30V的低压MOSFET解决0V关断5V导通，因此成品体内实际有两个管子



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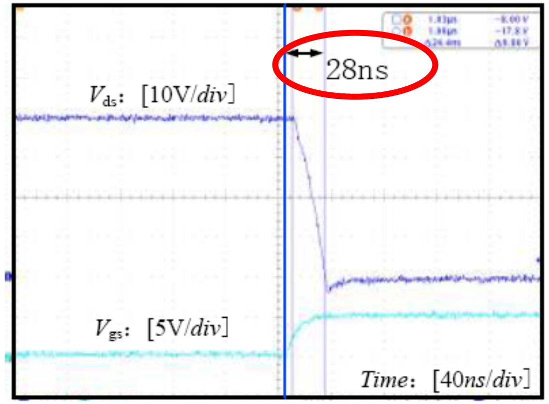
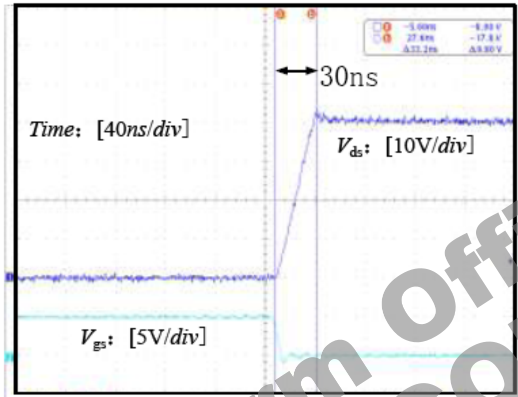
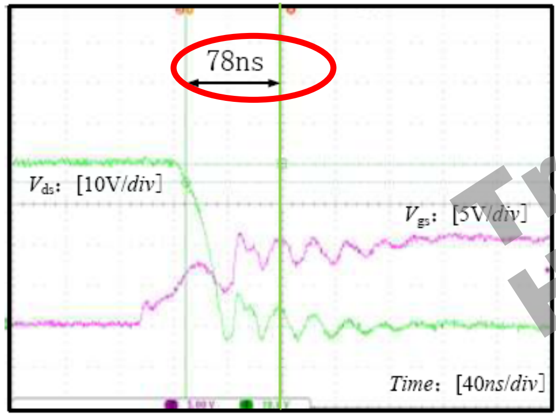
GaN,Si FET在开通，关断速度对比 (Layout上注意)



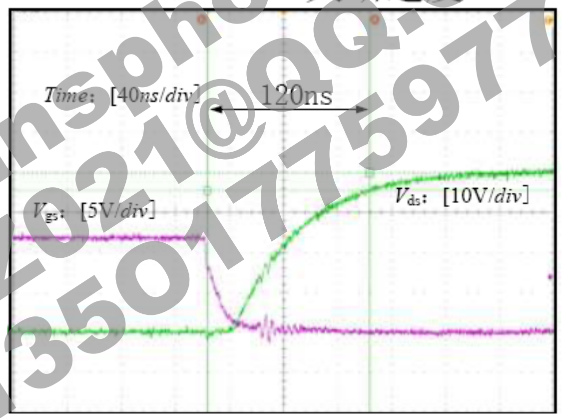
GaN HEMT开通速度



GaN HEMT关断速度



Si MOSFET开通速度



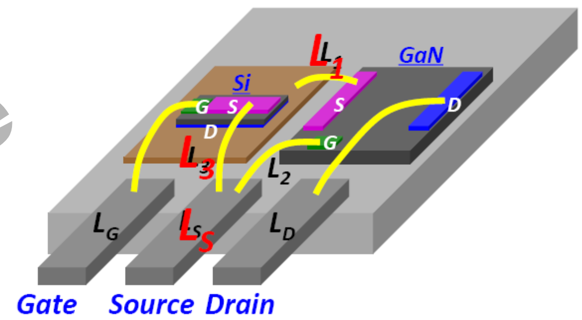
Si MOSFET关断速度

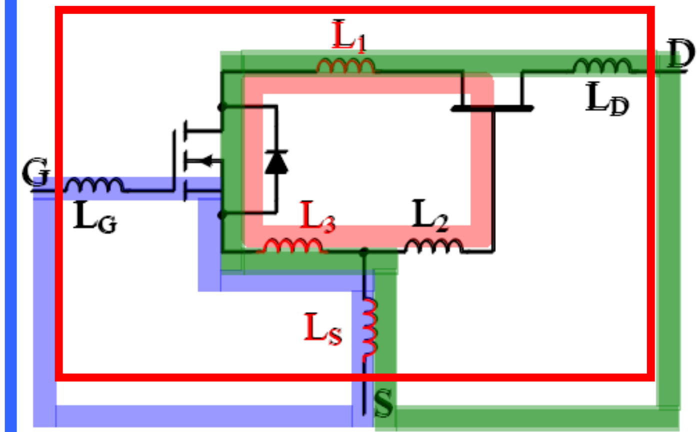
1，氮化镓的开关速度很快，dv/dt超100v/nS.

2，氮化镓体内是有SI+GaN两FET组成。相互的连线必然存在一定的寄生电感.

这些需要我们在布线的时候要尽可能地靠近以尽可能减少因走线带来的寄生参数

TO-220 Package
Simplified Bonding Diagram





L_{int1}	0.2-0.4 nH
L_{int2}	0.2-0.4 nH
L_{int3}	0.3-0.6 nH
L_S	0.6-1.0 nH
L_G	2.8-3.2 nH
L_D	1.6-1.9 nH

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氮化镓FET与Cool-Mosfet对比

	Parameters	IPA60R160C6	TPH3006PS
Static	V_{DS}	600V @ 25 ⁰C	600V (spike rating 750V)
	R_{DS} (25 ⁰C)	0.14/0.16 ohm	0.15/0.18 ohm
	Qg	75 nC	6.2 nC
	Qgd	38 nC	2.2nC
Dynamic	$C_{o(er)}$	66 pF [1]	56 pF [1]
	$C_{o(tr)}$	314 pF [1]	110 pF [1]
Reverse Operation	Qrr	8200 nC [2]	54 nC [3]
	trr	460 ns [2]	30 ns [3]

等同Rds(on)对比

更低的驱动损耗，100mA驱动电流即可

更低的米勒效应/更低的开关损耗

更小的死区时间

更小的反向恢复损耗

[1] V_{GS} = 0V, V_{DS} = 0 – 480V
[2] V_{DS} = 400V, I_{DS} = 11.3A, di/dt = 100A/μs
[3] V_{DS} = 480V, I_{DS} = 9A, di/dt = 450A/μs

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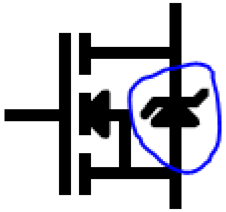
GaN 与Si在电路上的对比

硅材料MOSFET/ Cool Mos



MOSFET发热源:

1,Rds(on)损耗,

2, 开关损耗（硬开关模式CCM),

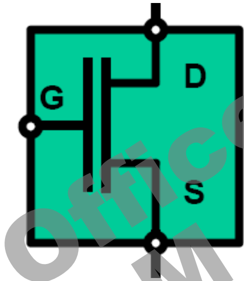
3,体内二极管反向续流损耗,

4,死区损耗(软开关模式,DCM).

氮化镓材料MOSFET -HEMT

氮化镓无体内二极管

但有二极管特性

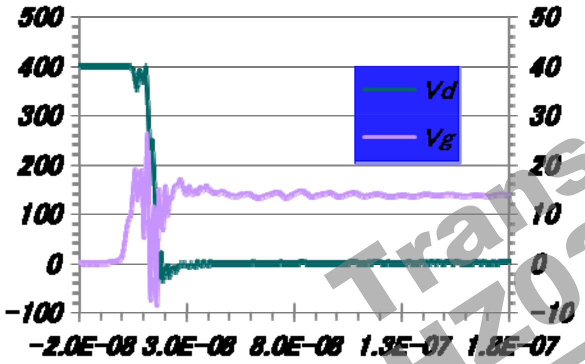


氮化镓MOS发热源:

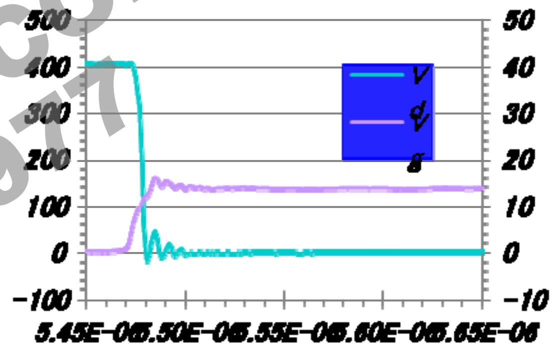
1,Rds(on)损耗

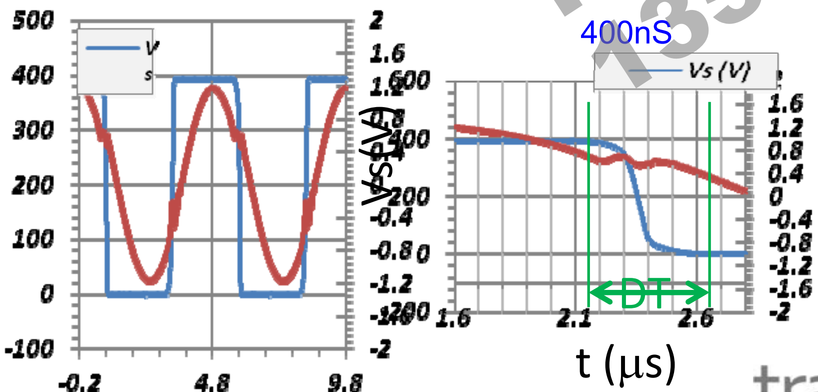
较低的开关损耗和反向续流二极管损耗. 米勒电容很小

超低的结电容保证较小的死区损耗.

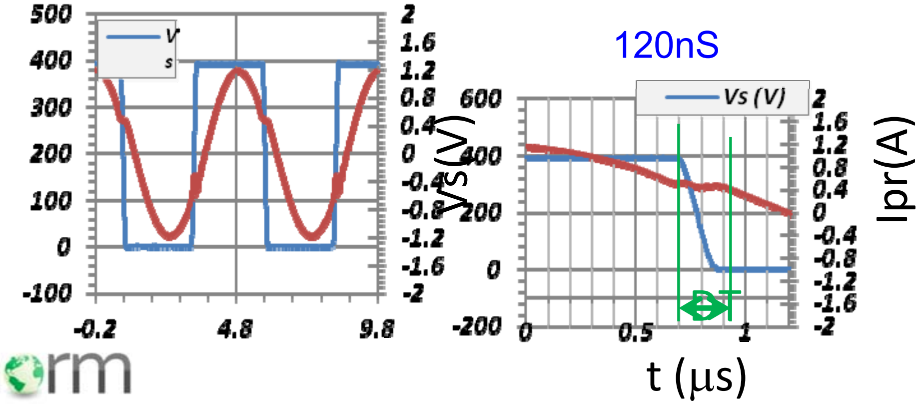


开关损耗对比





死区损耗对比



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Transphorm GaN FET允许750V的100nS连续的Spike

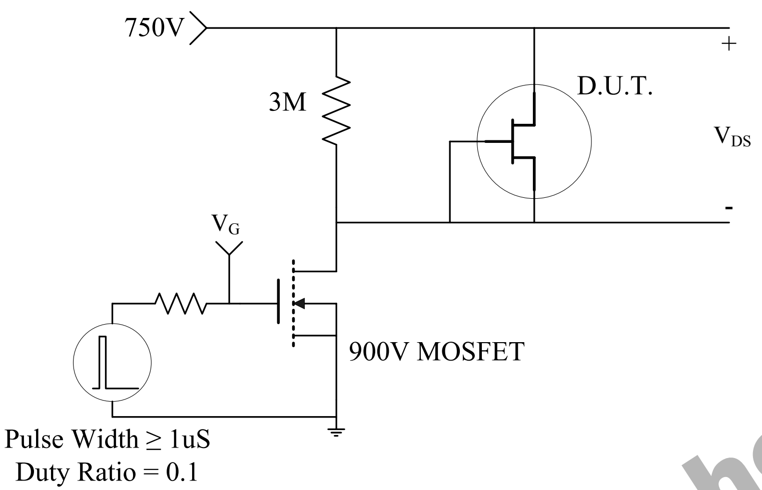

Fig. 1 Spike Voltage Test Circuit

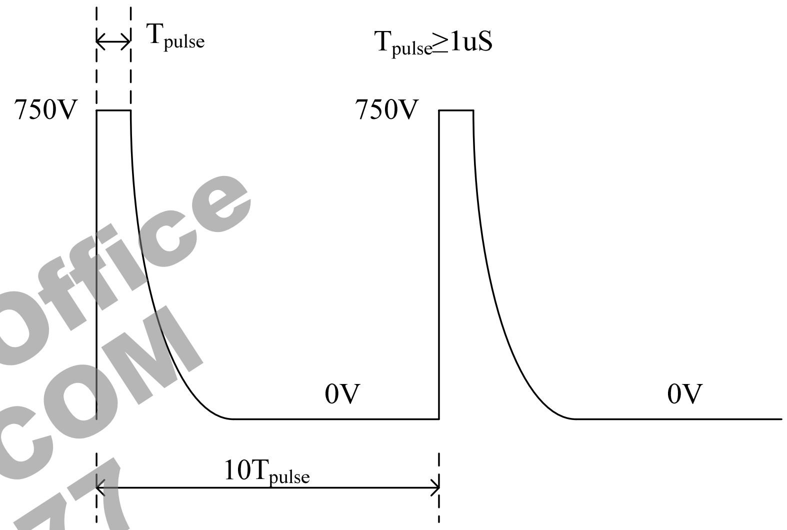

Fig.2 V_{DS} waveform

V_{DSS}	Drain to Source Voltage	600	V
V_{TDS}	Transient Drain to Source Voltage [a]	750	V

- 3 不同批次, >77 通过测试
- 通过功率器件的JEDEC标准
- 频率>10KHz, 占空比10%的750V耐压（即100nS可重复的spike电压）

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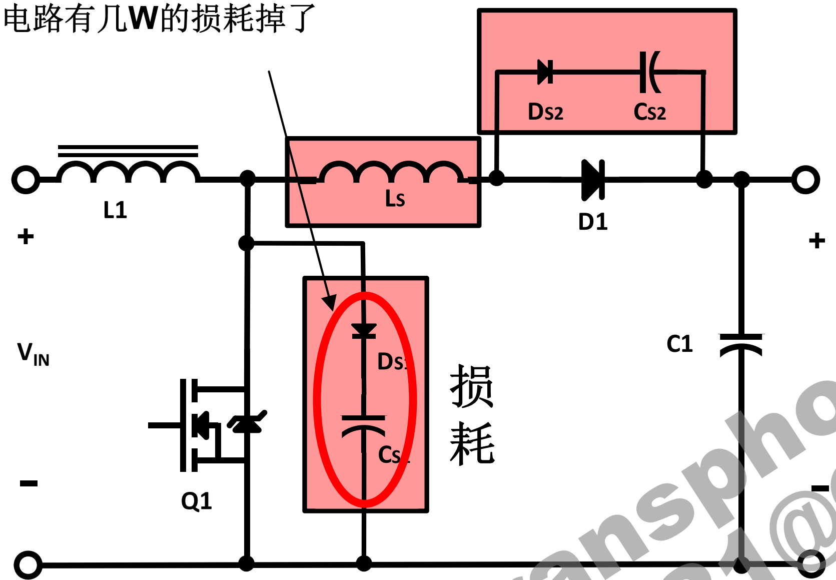
氮化镓器件能将设计最简单化

用传统**COOL-MOSFET** 或一般**MOSFET**，需加**Snubber**吸收电路。此电路有几**W**的损耗掉了

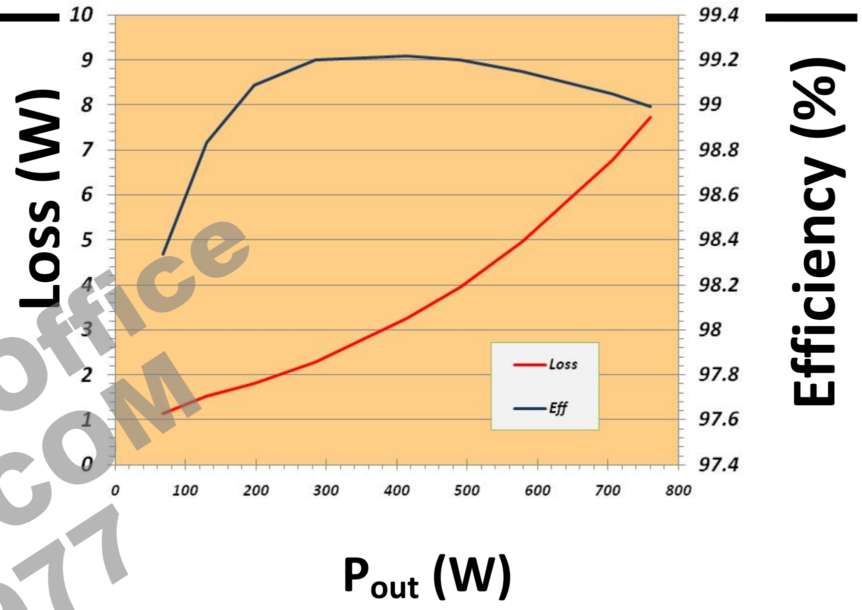


一般测试效率为**97-98%**较多

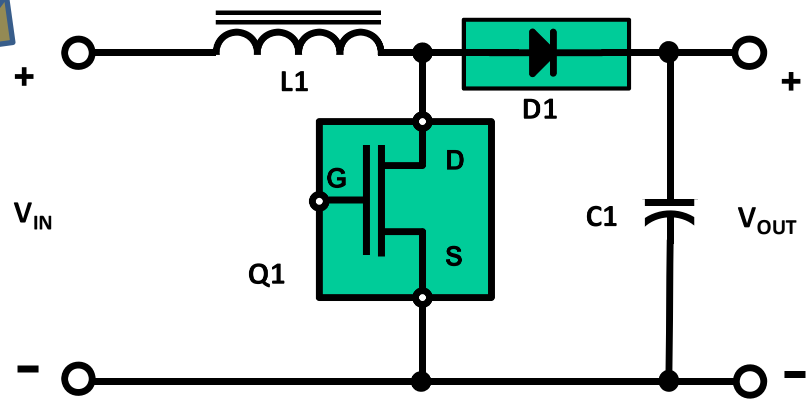
一旦换成氮化镓**MOSFET**，效率达**99.2%**

PFC Switching Conditions

- V in = 220v dc
- V out = 400v dc
- Frequency = 100kHz, 400w
- Uses TPS2012PK; lowest loss 600v/6A GaN diode
- Boost converter efficiency = 99.2%



Boost design using Transphorm's GaN MOSFET and GaN Diode producing >99% efficiency and using fewer components



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氮化镓MOS在实际电路上的应用 –CCM/硬开关

硬开关电路中，损耗主要来自于以下

1，Rds(on)导通损耗

2，开关损耗

3，体内慢速二极管的续流损耗

4，Snubber吸收电路的损耗

在保证效率一样的情况下

频率提高了10倍。其它材质保持不变。

体积变小一半以上

Coolmos换成氮化镓，唯一的一个器件成本上升，其它器件成本均下降

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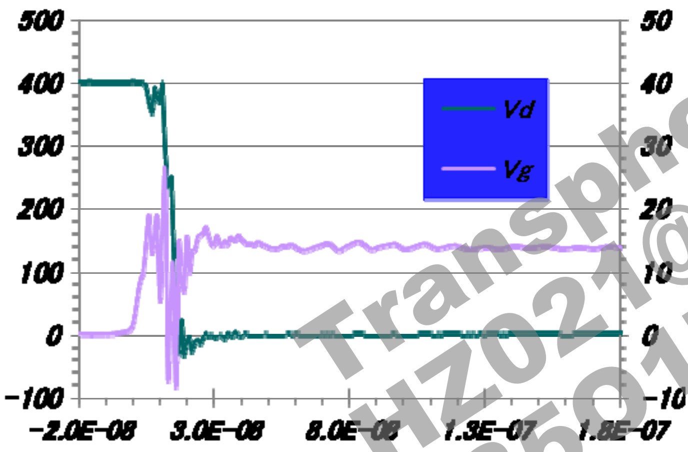
Coolmosfet 199C3+SiC二极管 –左边	等同Rds(on)的氮化镓，其余材料不变 – 右边
工作频率: 63K	工作频率: 750K
等同效率	
400W PFC板	
面积 5x5	面积 3x3

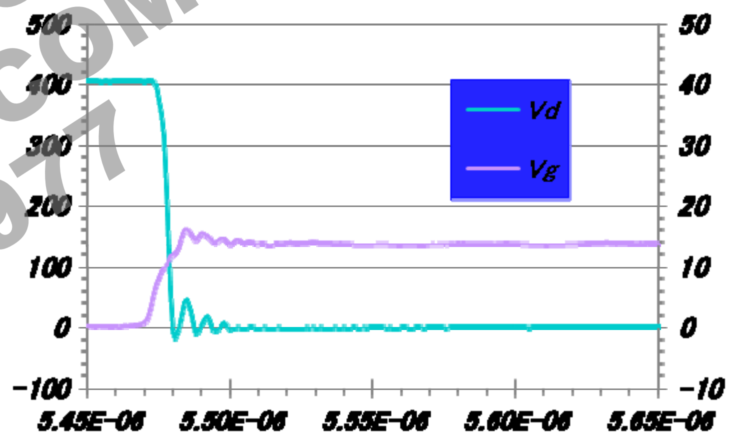
电路应用 –CCM电路/硬开关

Silicon converter: Super-junction MOSFET, 385mΩ + Ultra-fast Si diode, 10A at Tc=25°C
GaN Converter: GaN HEMT, 310mΩ + GaN DiodeTPD2012, 2A at Tc=125°C
R_G=0Ω, f=100kHz, V_{IN}=220V, V_{OUT}=400V, P_{OUT}=760W,

Cool-mos C3的开关波形



氮化镓的开关波形



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氮化镓的米勒效应比Cool-Mos的好很多。很小振荡，相应的开关损耗及EMI会好

氮化镓体内没有寄生二极管，在续流方面点在优势。

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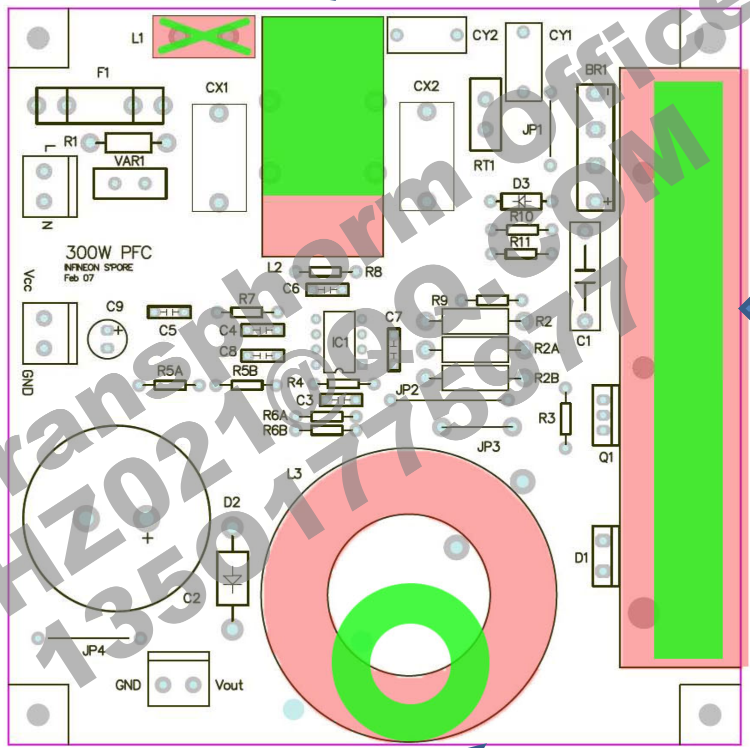
电路应用 –CCM电路/硬开关

源于好的开关波形
本案中差模去掉

共模电感变小，成本下降

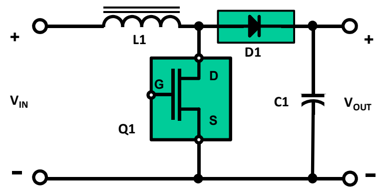
体积明显变小



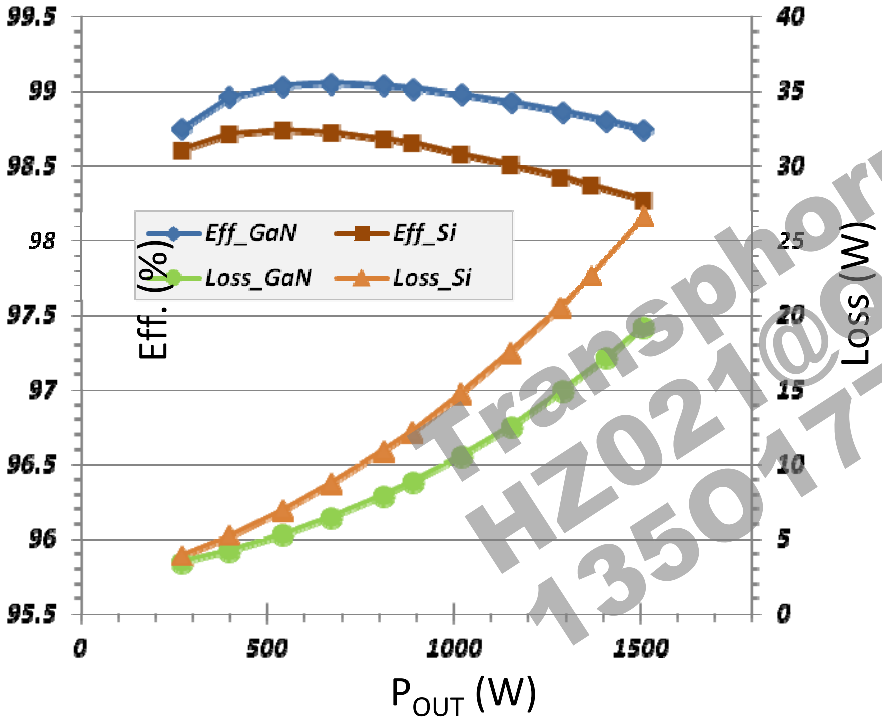
PCB变成原**1/3**
散热片去掉或变小很多 -成本下降

电感体积减小**80%**，原来**10**元
现变小后只要**2**元

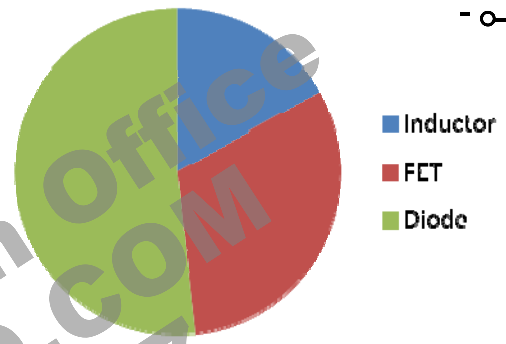
Cool-Mos与氮化镓FET BOOST电路上的损耗对比： 100 kHz



GaN devices: TPH3006PS & TPS3411PK
Si devices: CoolMOS & QSpeed diodes
V_{IN}/V_{OUT}=230V/400V, f=100kHz

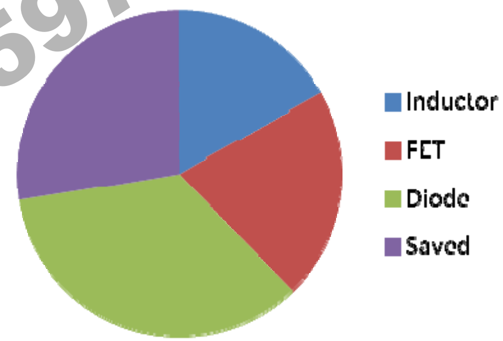


Loss breakdown



Boost电路 100K

Cool-Mos方案上的损耗图



Boost电路 100K

氮化镓方案上的损耗图

在100K时省出1/4的损耗（紫）

- **Transphorm Total GaN™ solution outperforms matured Si solution**
- **GaN cuts device loss by 33% (27.5% of total loss) at full load (1.5kW)**
- **GaN achieves 99% efficiency**

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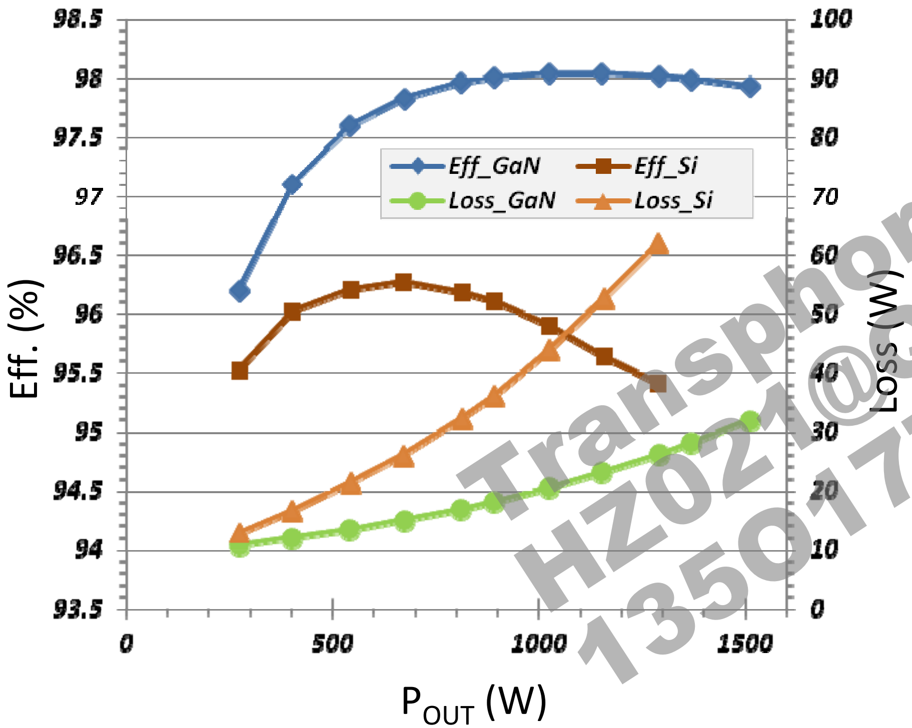
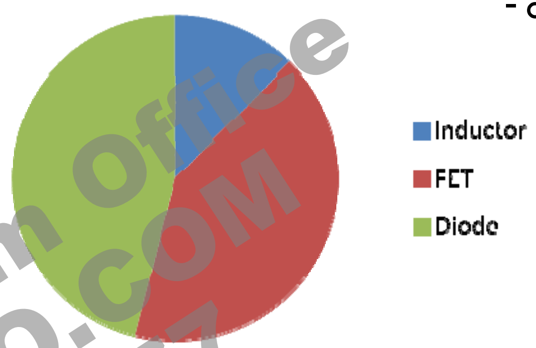
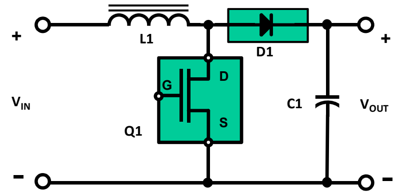
Cool-Mos与氮化镓FET BOOST电路上的损耗对比　500 kHz

GaN devices: GaN-on-Si HEMT & diode
Si devices: CoolMOS & QSpeed diode
V_{IN}/V_{OUT}=230V/400V, f=500kHz



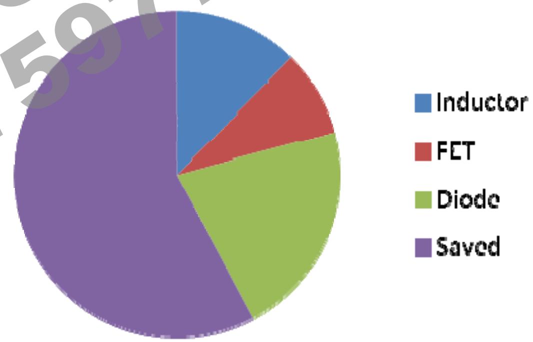
Loss breakdown





Boost电路 500K

Cool-Mos方案上的损耗图



Boost电路 500K

氮化镓方案上的损耗图

在**500K**时省出**3/5**的损耗（紫）

- GaN's advantage is amplified at high frequencies (for compact designs) due to its lower Qg and Co(er)
- GaN cuts device loss by 70% (total loss 55%) at 1.3kW
- Si converter cannot operate beyond1.3 kW safely
- GaN >98% efficiency at 500kHz

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1st Gen 600V GaN-on-Si HEMT Compared to Si Super Junction MOSFET

Devices	Parameters	On resistance (Ω)	Gate charge (nC)	Output charge (nC)	Energy related Coss (pF)	Reverse recovery charge (μC)	FOM1A	FOM1B	FOM2
	Symble	Rds, on	Qg	Qoss	Coer	Qrr	**Ron*Qg**	**Ron*Qoss**	**Ron*Qrr**
GaN HEMT TPH3006	GaN Gen1	0.15	6.2	52.8	56	0.054	**0.93**	**7.9**	**8**
Si CoolMOS 60R199CP	SJ Si Gen5	0.18	32	86.4	69	5.5	**5.76**	**15.6**	**990**
Si CoolMOS 60R190C6	SJ Si Gen6	0.17	63	127.68	56	6.9	**10.71**	**21.7**	**1173**
Si CoolMOS 65R2250C7	SJ Si Gen7	0.199	20	126.32	29	6	**3.98**	**25.1**	**1194**
Si CoolMOS 20N60CFD	SJ Si for Low Qrr	0.19	95	76.8	83	1	**18.05**	**14.6**	**190**

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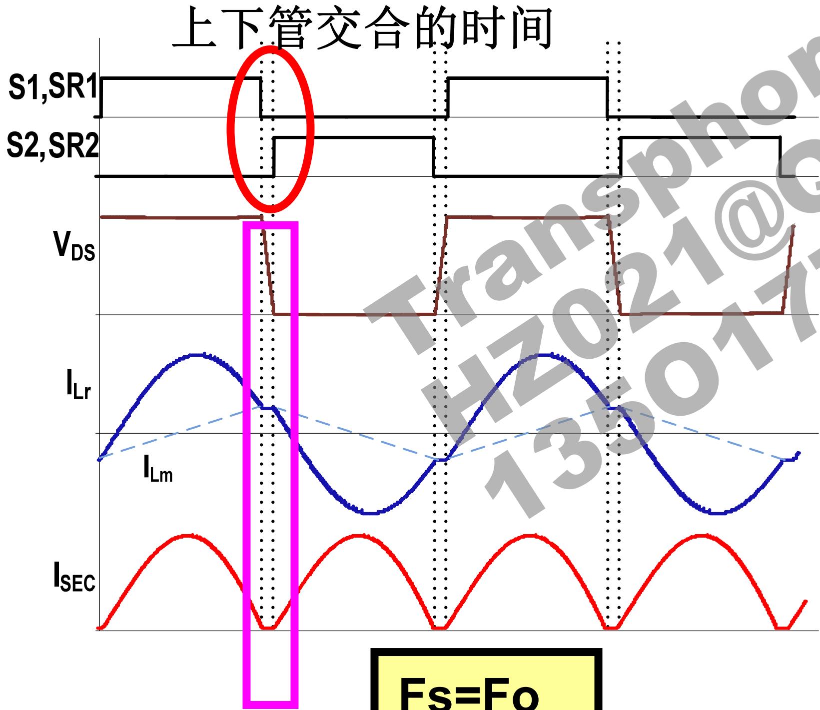
- 1st generation GaN is already superior to Si
- GaN still has ample potential to improved

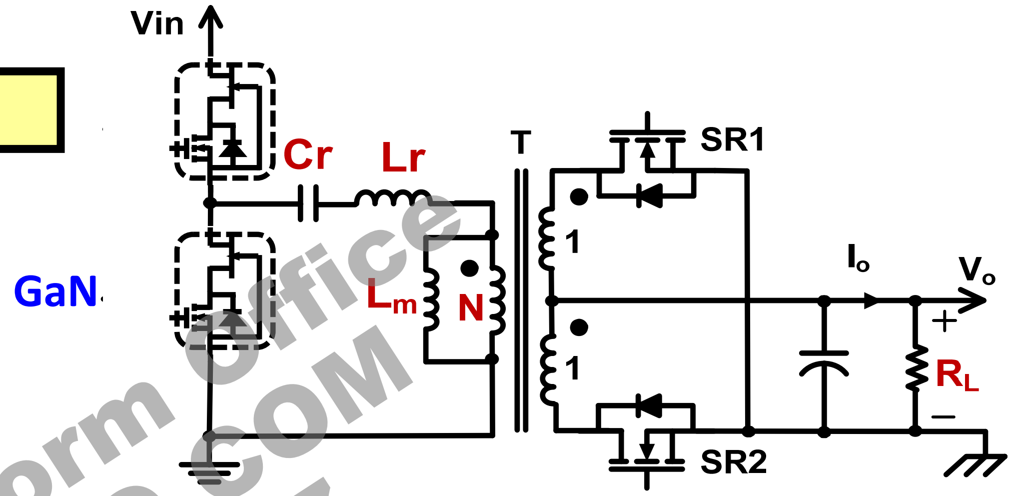
氮化镓的LLC电路应用

High step down LLC Converter

- Input: 380~420V_{DC}
- Output:12V/25A
- Fs: 500kHz



Fs=Fo



LLC Resonant Converter

LLC-DCX , Fs=Fo

- Gain equals one
- Simple SR driving scheme
- Lowest Conduction loss

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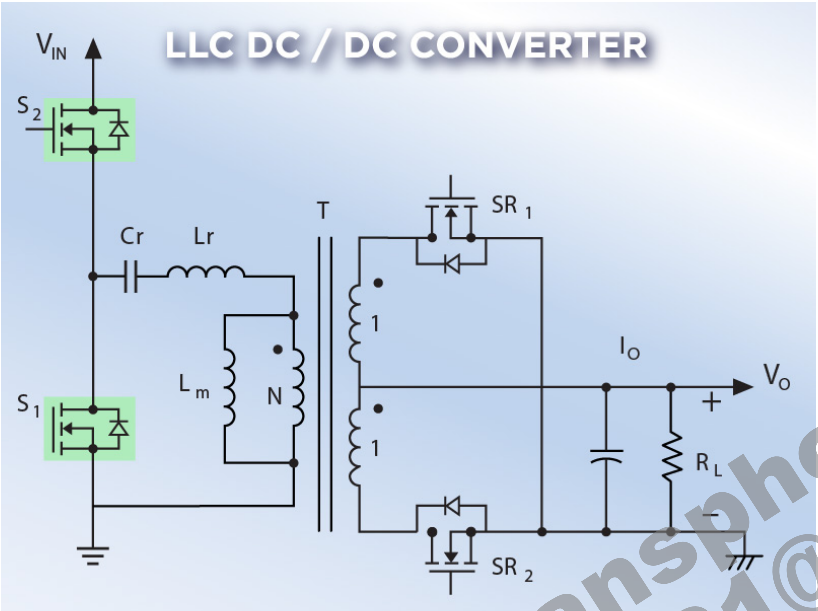
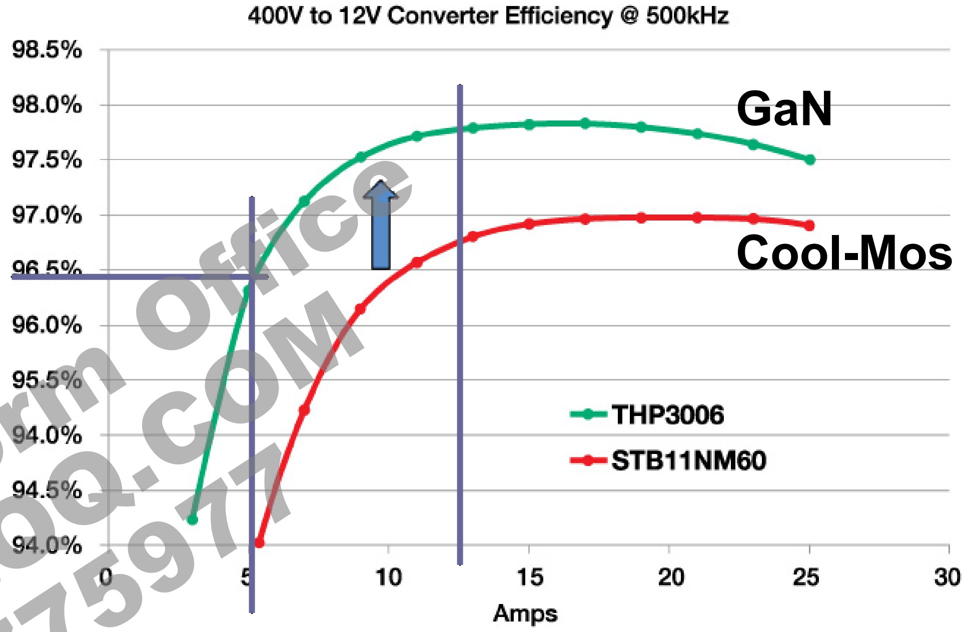
基于氮化镓的LLC电路 （效率1%-3%提高等同频率，等同Rds(on)





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Parameters	Value	Parameter	Value
Vin(V)	400	$Vo(V)/Io_{max}(A)$	12/25
Lm(uH)	100	Lr(uH)	5.05
Cr(nF)	15	Fr(kHz)	530
Td(ns)	120	Fs(kHz)	470

Reduced losses by > 30%

Low residue charge for GaN allows for a fast reset time & a much reduced recirculation energy

GaN vs CoolMosfet效率差别			
500K LLC	10%负载	50%负载	100%负载
	3.50%	1.80%	1.0%

Courtesy: Work done by Virginia Tech.

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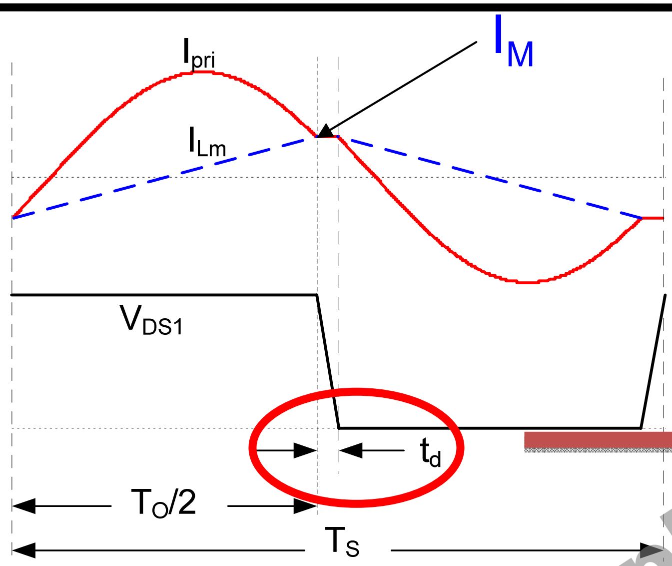
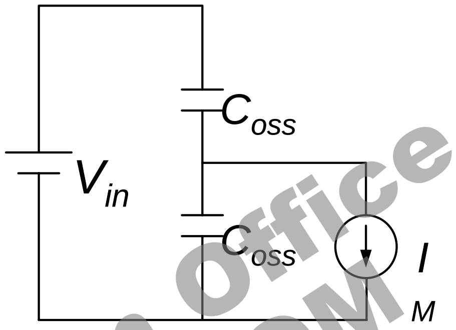
用氮化镓来优化死区时间Td和Lm





$$I_M \approx \frac{NV_o}{L_m}\frac{T_o}{4}$$

Larger L_m,
Less circuilating energy

$$t_d \approx \frac{2C_{OSS}V_{in}}{I_M}$$

Smaller t_d,
Less duty cycle lose

$$C_{OSS} \approx \frac{T_O t_d}{16L_m}$$

从公式上看

死区时间**Td**与**Coss**有关系。

Coss是与器件有明显关系

选择不同的器件会带来不同的损耗

	$C_{OSS(tr)}$(pF)
硅MOSFET /Cool-Mosfet	*100*
Cascode GaN氮化镓FET	*25*

With much smaller Coss,
GaN can achieve both

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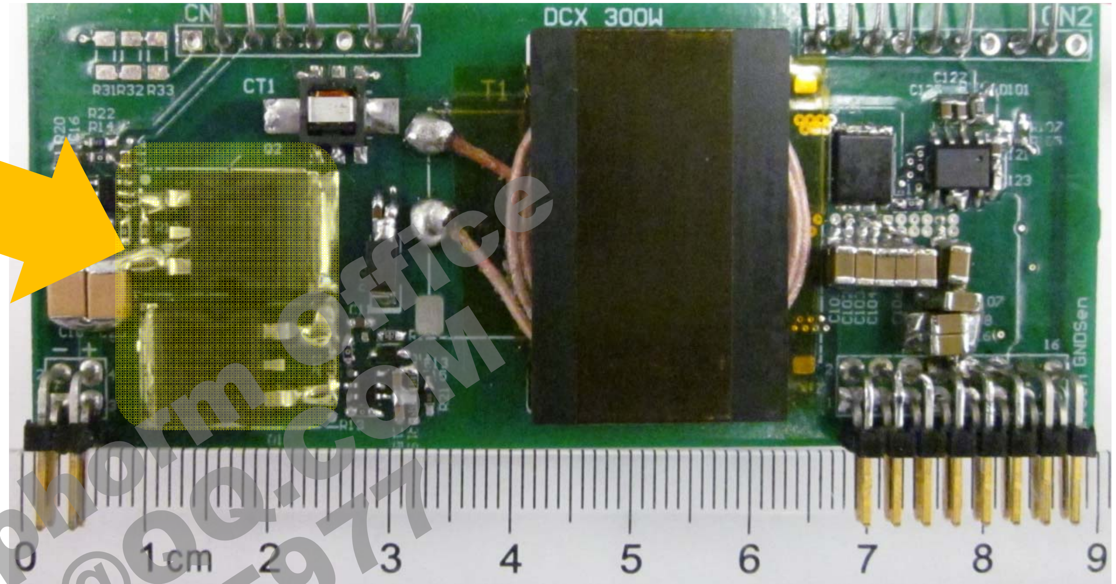
Experiment Platform



Cascode GaN:TPH2002
内阻：**290**毫欧
体积**30*90**
DC400V – 12V/25A
无散热片

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Parameters	Value	Parameters	Value
Vin(V)	400	$V_o(V)/I_O(A)$	12/25
Transformer Turn Ratio	16:1	Fs(kHz)	500
Core Material	N49	Primary switch	TPH2002
Core Shape	ER32/5/21	SR	BSC017N04NS

产品的应用：Adapter

90W: PFC+LLC

65W: FLYBACK

48W: FLYBACK

36W: FLYBACK

5W AC Adapter (80%)
1” x 1” x 1”

10W AC Adapter
2” x 2” x 1”

充电器电源，在等同频率下，体积大小一直受控于整个板子热损耗，即效率。效率高体积就小。

氮化镓**MOSFET**有助于实现高效率，从而降低热损实现小体积。

同时氮化镓适合高频。提高工作频率有效减少电感，变压器体积。

采用**GaN**技术，**15W**产品有望达到**94%**效率，**24W**产品有望达到**96%**效率

40W的小充电器，改用**TPH3002LD**氮化镓后，效率提高**0.5%/100KHZ.**温度有所有下降。 **200K**时提高**1%**效率

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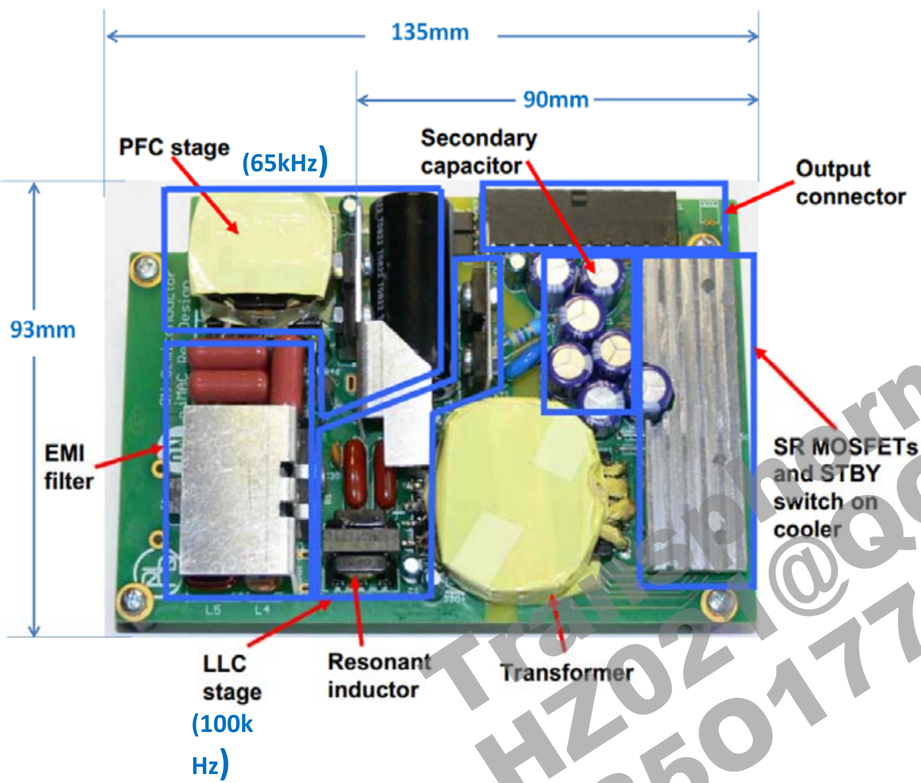
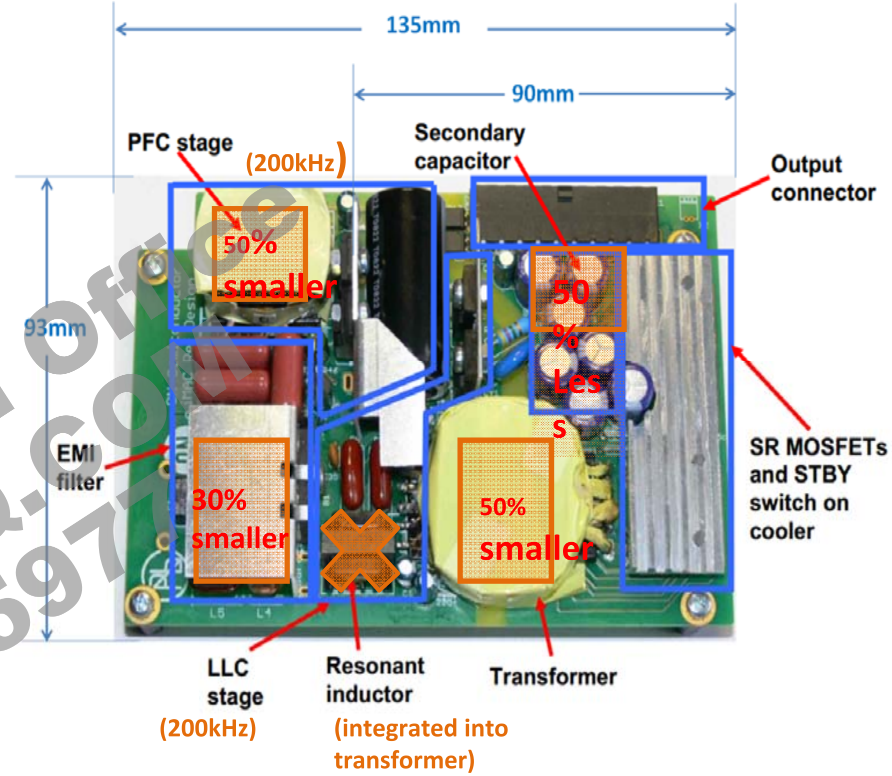
产品的应用：LLC应用，216W PFC+LLC Cool-Mos VS 氮化镓 3%效率提高





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Cool-Mos C6 +碳化硅二极管
PFC: 65KHZ
LLC: 100KHZ
90-260Vac输入，12Vout,效率93%

氮化镓MOS + 碳化硅二极管
PFC: 200KHZ
LLC: 200KHZ
90-260Vac输入，12Vout,效率95.4%

提高工作频率将大大减少板子的体积，同时效率也提高2.5%

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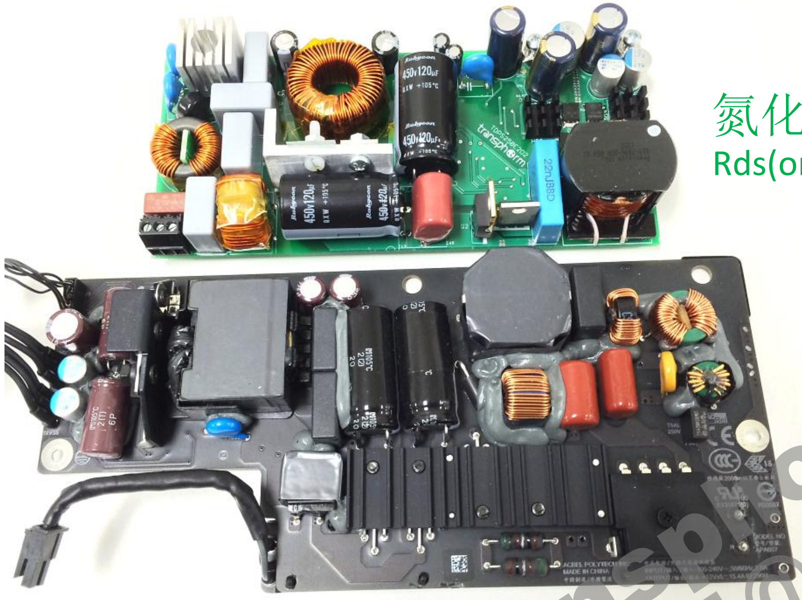
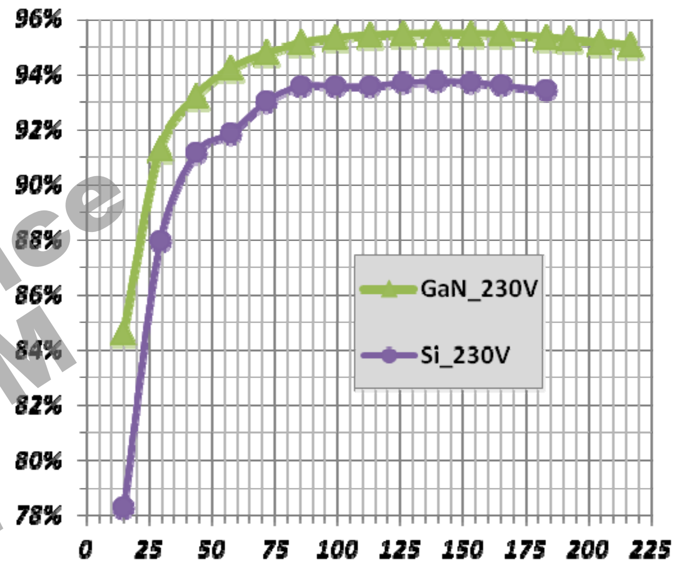
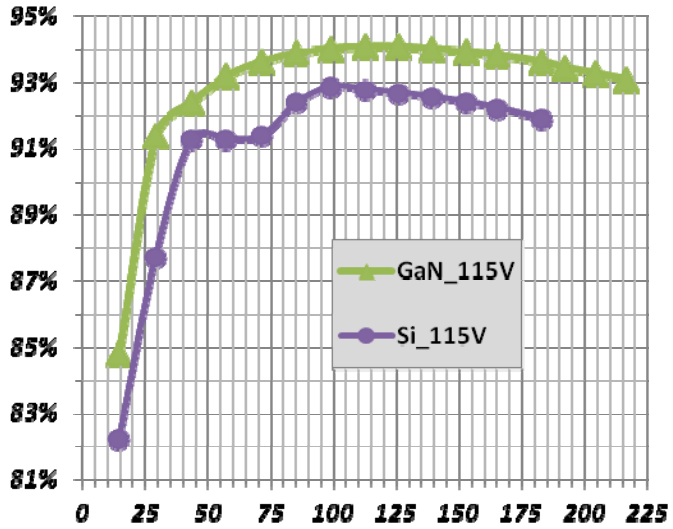
产品的应用：250W PFC+LLC 苹果一体机电源对比 C6方案与氮化镓方案



氮化镓方案
Rds(on):300mOHM

原Cool-mos
199C6方案
Rds(on):190mOHM





- 黑色为苹果原方案，工作频率PFC 65K，LLC，100K
- 小板为采用氮化镓方案，均200K，96%效率，无散热片。
- PWM: 200kHz for GaN
  50-80kHz for Si
- Size: 45% reduction
- Efficiency:+1.7% at full load +3% at 10% load

原效率93%， 新方案近96%，体积缩小近50%

相对原方案COOLMOS，氮化镓方案成本稍低一点

CoolMos, 190毫欧， 氮化镓300毫欧

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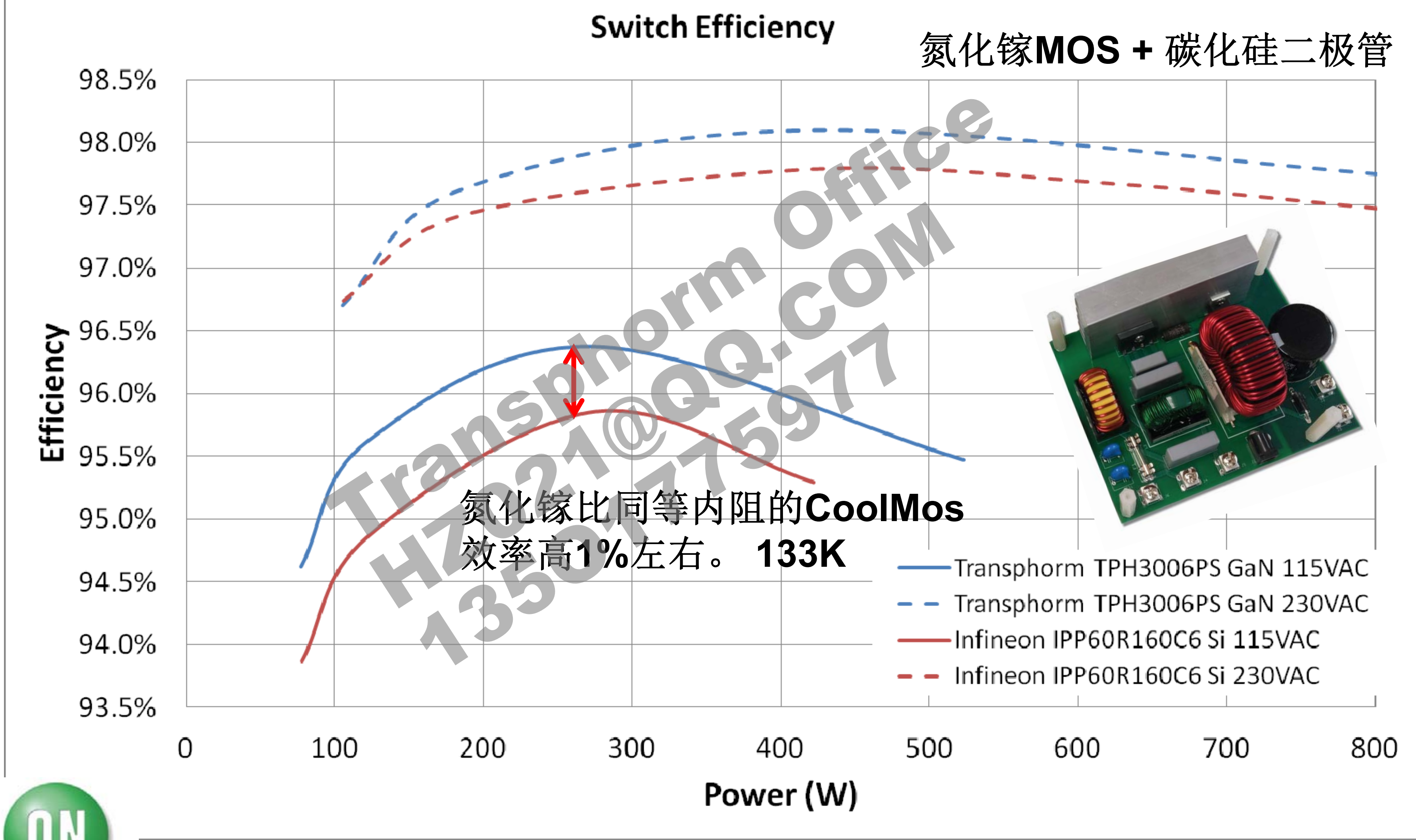
产品的应用：单极PFC，1000W 98.6% 133K (C6与氮化镓比较）

PFC芯片：NCP1654-133

氮化镓MOS + 碳化硅二极管



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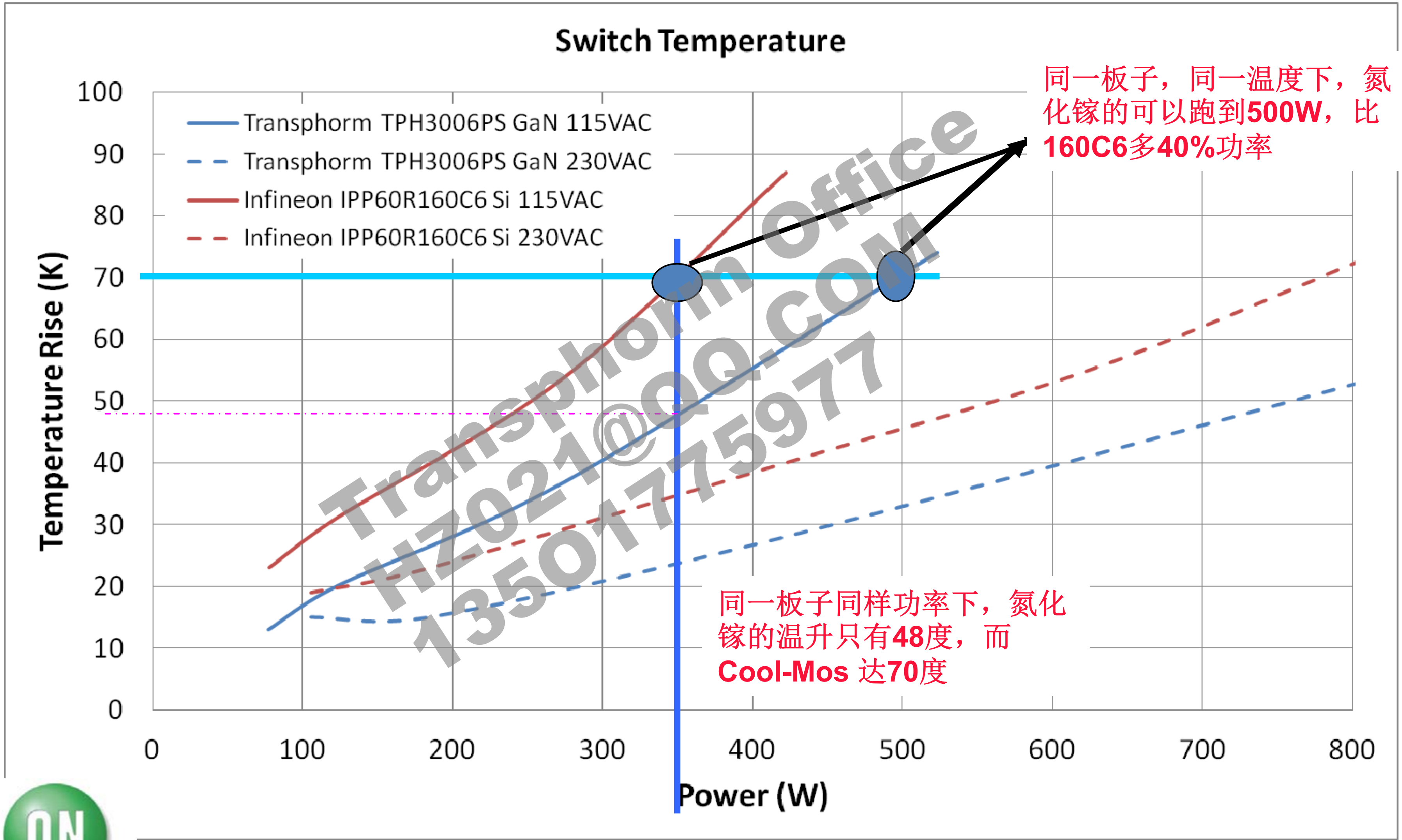
产品的应用：单极PFC 133kHz PFC Switch Temperature



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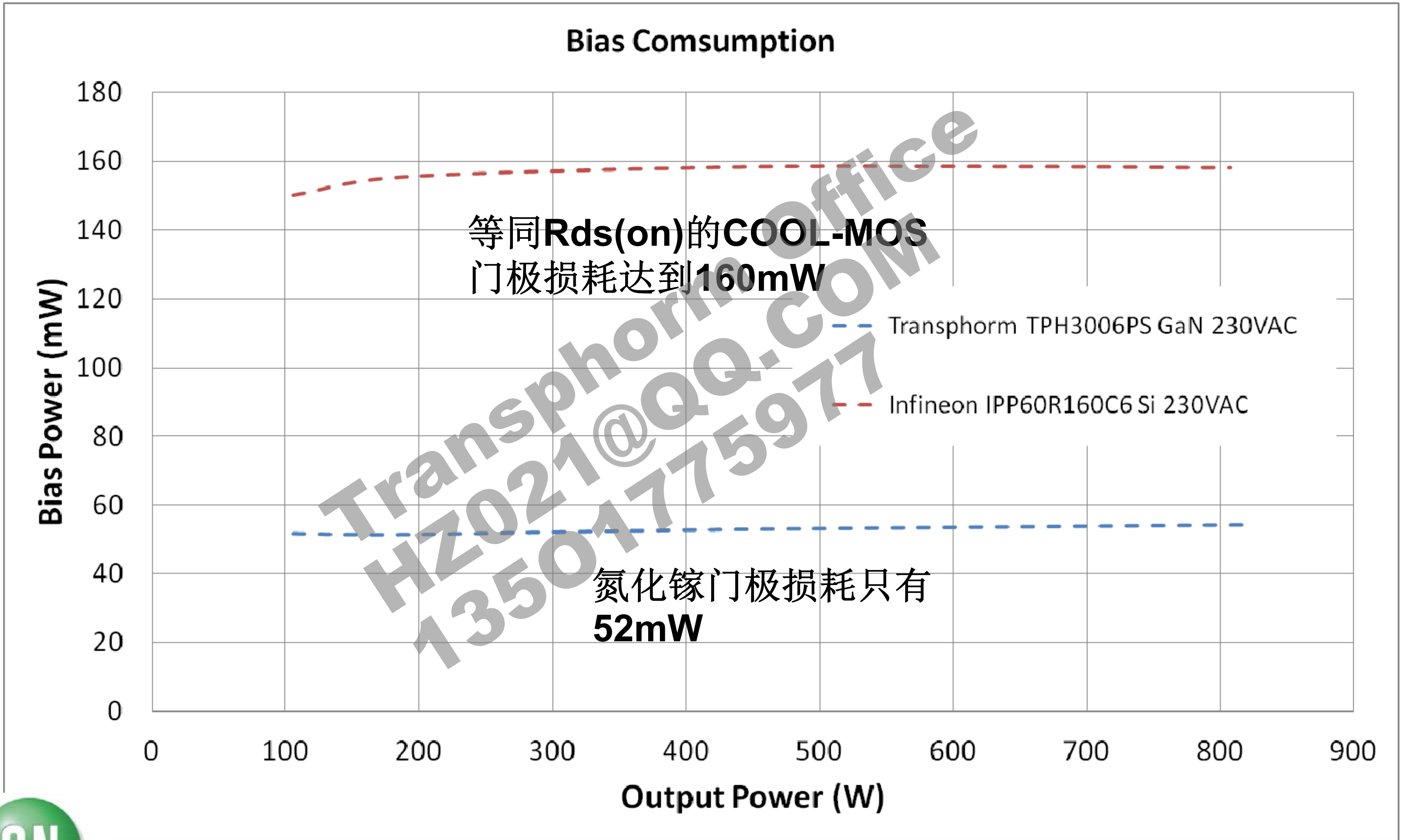
产品的应用：单极PFC PFC板上的门极损耗对比 Bias Power



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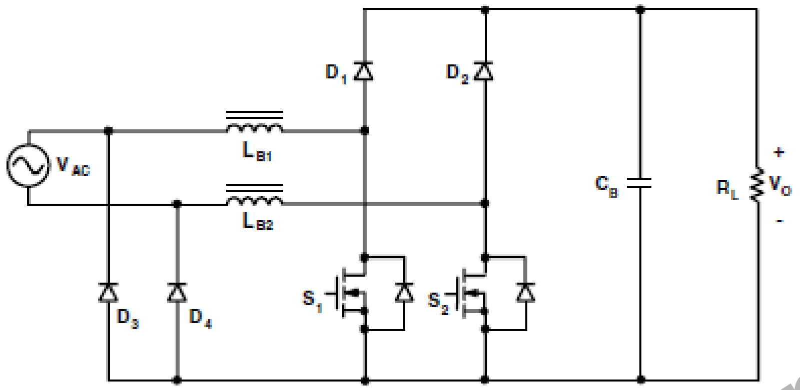
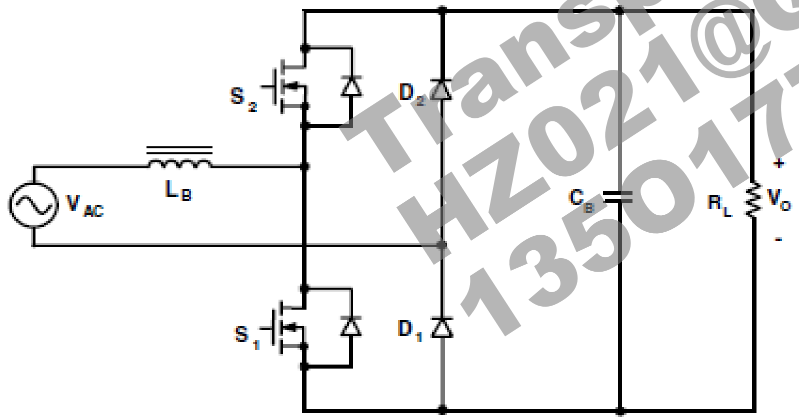
产品的应用：氮化镓的无桥PFC /Totem Pole PFC

用FET代替整流桥同时实现高效PFC功能



传统Dual-boost无桥PFCPFC



氮化镓的图腾无桥 PFC

- 传统用的无桥需要2MOSFET，2电感，2碳化硅二极管（D1,D2)才能实现高效率
- 采用氮化镓的图腾无桥PFC只要一个电感，2个氮化镓MOS,另D1,D2可以用二极管也可以从等同内阻的硅MOSFET以实现更高效率
- 就现阶段氮化镓无桥的方案已比传统的低了（传统的会用上两个高碳货硅二极管及多用一个电感）
- 同时因氮化镓适合高频。采用氮化镓高频化的无桥PFC后，体积大大变小，综合成本更有优势/效率依然很高

此设计是利用氮化镓体内二极管超低的反向恢复特性来实现高效低成本。

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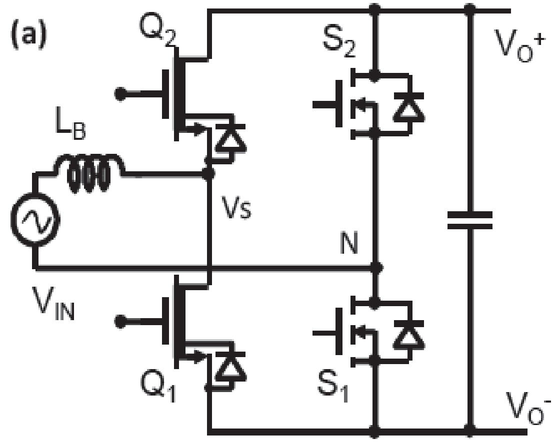
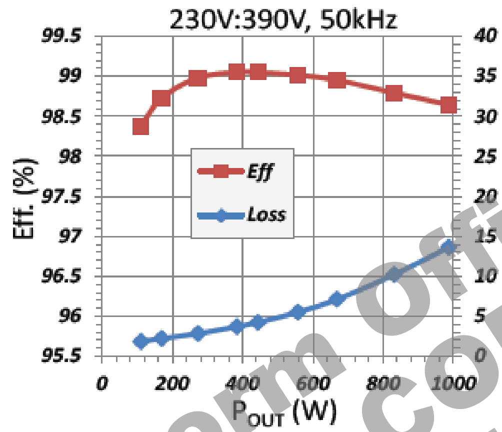
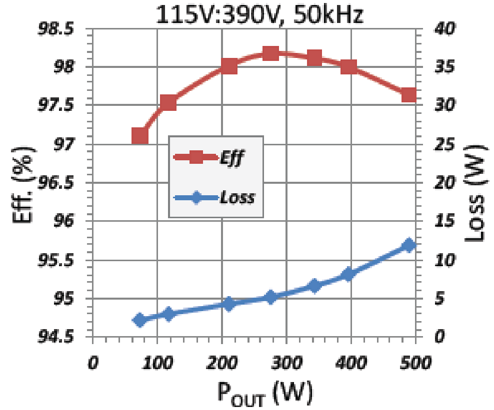
产品的应用：氮化镓的无桥PFC

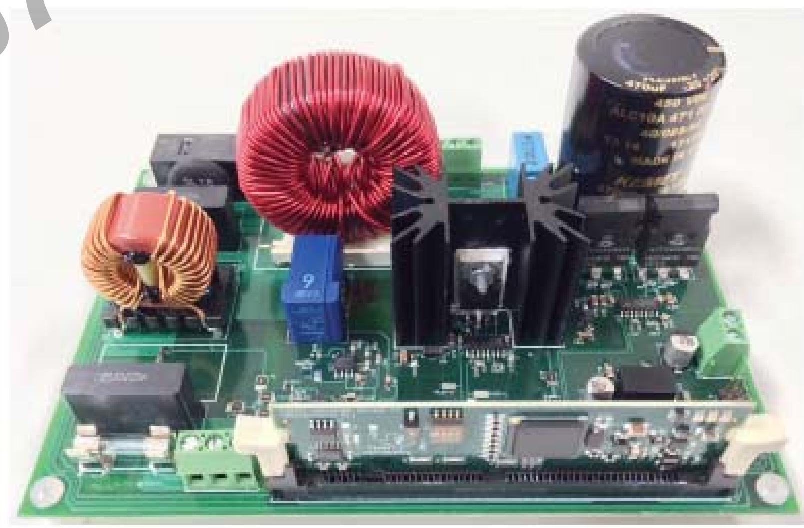






- 图腾PFC是一种最高效的无桥PFC，周边器件少。
- 将高频开关的Q1,Q2换成氮化镓FET以实现高效的CCM操作
- 1000W的氮化镓无桥PFC 效率达99.2%以 上

	230V:400V boost	Totem pole	Totem pole with EMI filter and current sense
50kHz	99.16%	99.1%	98.9%
100kHz	99.03%	98.97%	98.77%
150kHz		98.84%	98.64%
200kHz		98.7%	98.5%
250kHz		98.57%	98.37%



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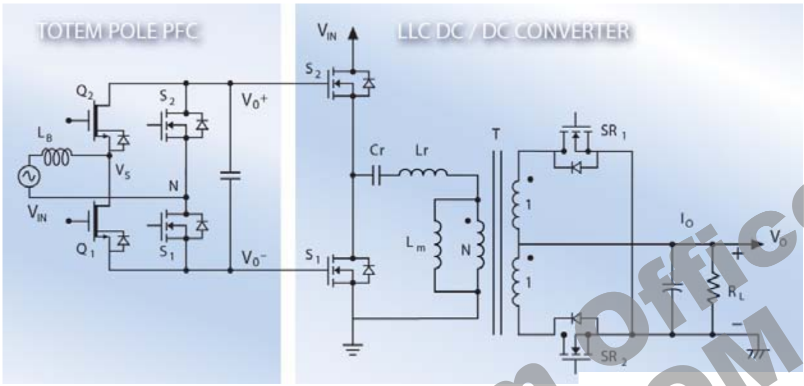
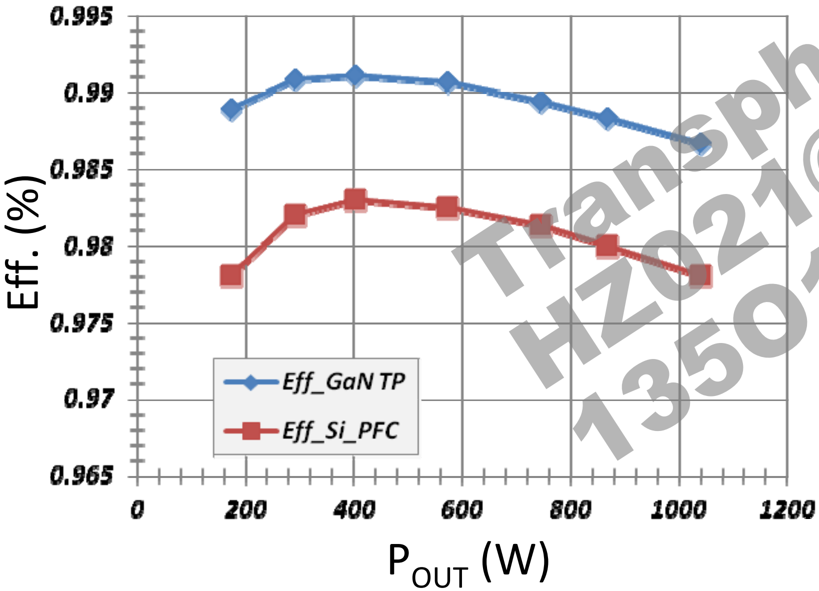
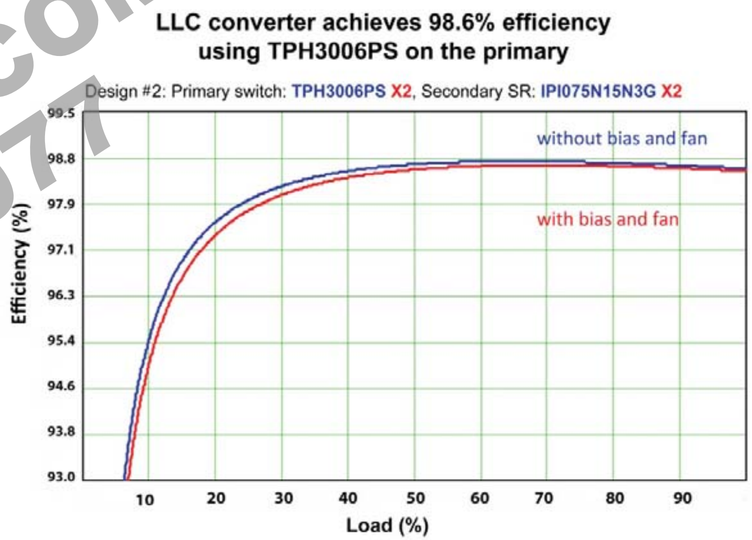
采用氮化镓实现全电源97.5%效率（AC-DC 1000W)



将**Transphorm**公司的无桥**PFC**板及**LLC**的演示板整合起来就得到**97.5%**以上效率的电源



采用氮公镓方案的**1000W** 无桥**PFC**电源的效率 **99.2%**



1 kW LLC, 400 V dc to 48 V dc, 200 kHz

采用氮化镓的**LLC**电源效率 **1000W 98.8%**

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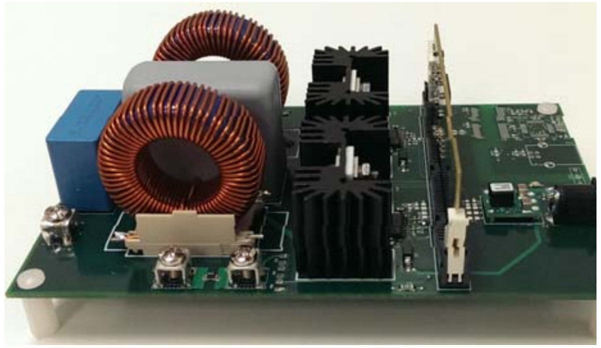
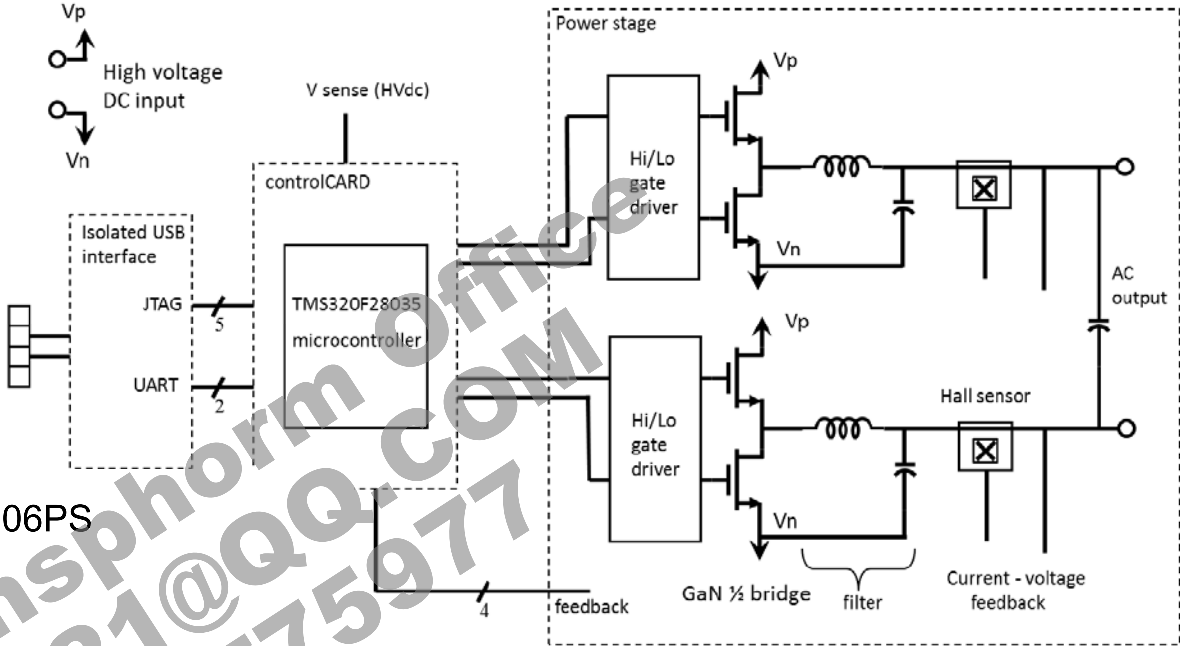
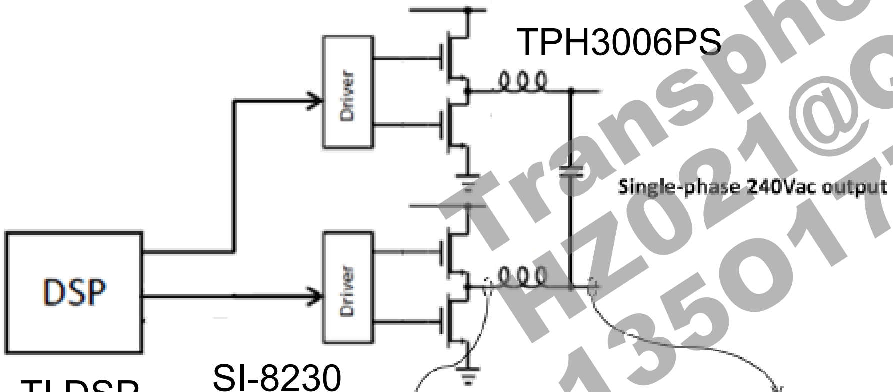
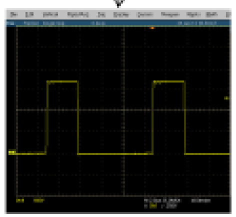
产品的应用：逆变器 INVERTER

采用GaN的逆变器应用—1500W， DEMO 板DC400Vin, 240Vacout, 98.7%, 成本明显下降

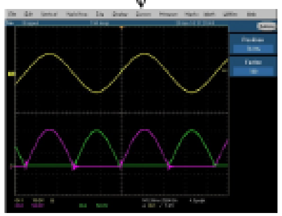








100kHz switching waveform



60Hz output voltages & current (yellow)

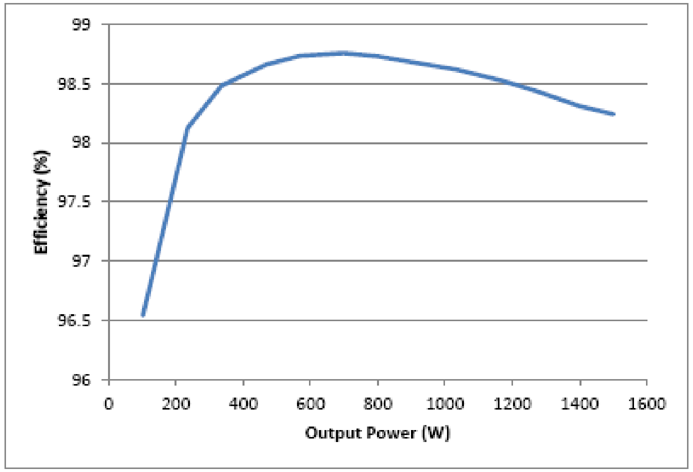


Figure 7. Typical Efficiency 240Vac output

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YASKAWA

PV converter GaN prototype

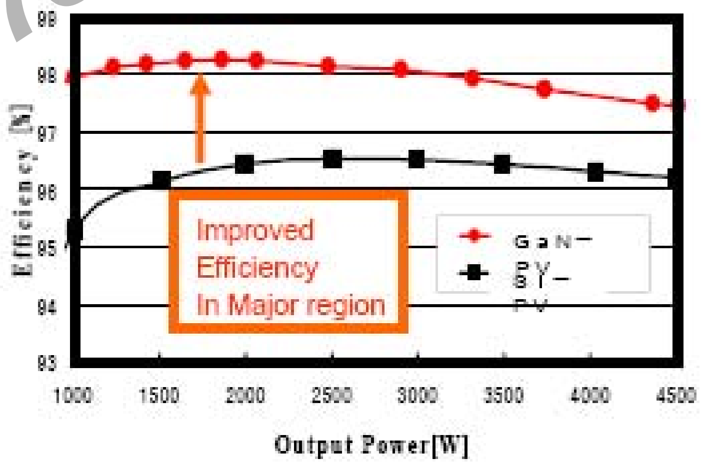
- Output power 4.5kw (Single Phase 200V)
- Input voltage 60-400V
- Maximum Power Efficiency > 98% (vs. >96.5% with Silicon)
- Volume about 10L <18L (existing Silicon based)

同样大的逆变器产品,氮化镓的体积减小了一半左右,同时整体成本下降**100USD**,售价反提高了**100USD.** 效率反提高了**1.5**个点. **4500W**, 频率从**16K**提到到**50K**

散热器,风散,驱动电路,电感,**EMC**电路可大大减小体积,还有填充物

40% volume reduction

Significant loss reduction



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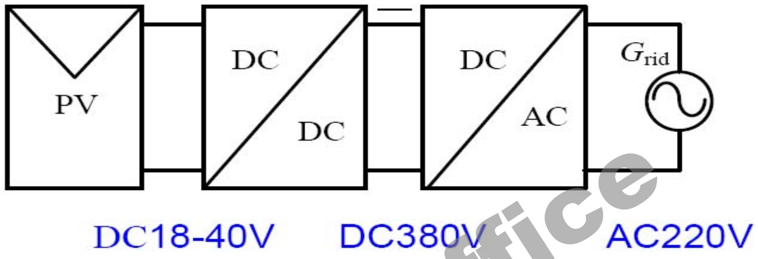
GaN modules allowed for kW class PV power conditioner with 40% smaller size and loss

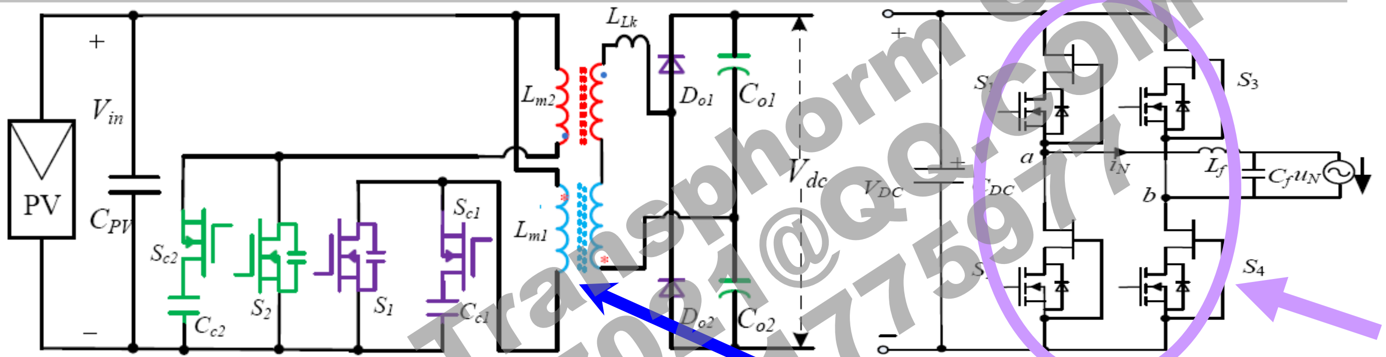
- Output power 4.5kw (Single Phase 200V)
- Input voltage 60-400V
- Maximum Power Efficiency > 98% (vs. >96.5% with Silicon)
- Volume about 10L <18L (existing Silicon based)

Courtesy: Testing done and published by Yaskawa Electric.

40% volume reduction | **>40% loss reduction**

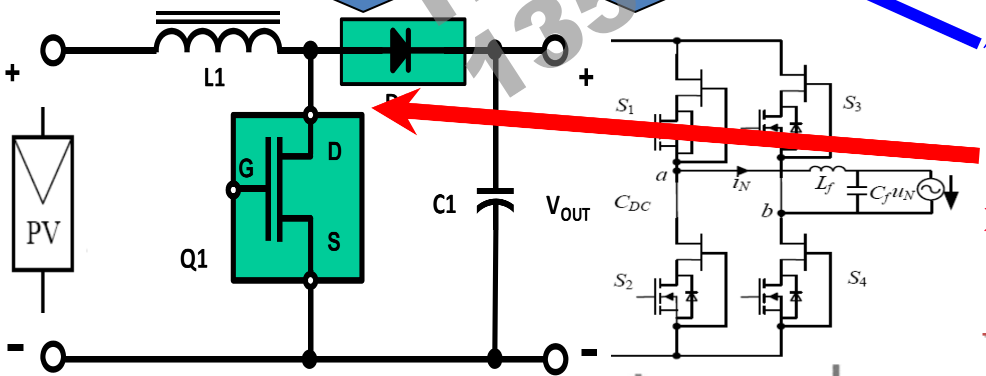
微型逆变器应用





传统线路
输出采用**600V**的低频工作**MOSFET**
无‘无功补偿’

新的设计需要输出逆变高频化以尽可能提高无功补偿
氮化镓适合高频，高效



传统的采用变压器升压**400V**

因氮化镓支持大比例升压且高效率达**98**以上。
不同于传统的硅**MOSFET,**可直接**boost**升压

** 降低成本，空间节省*

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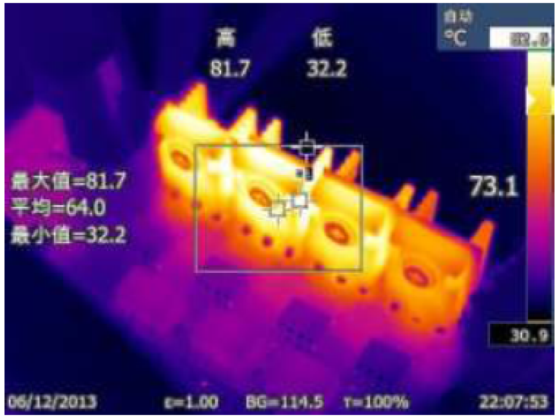
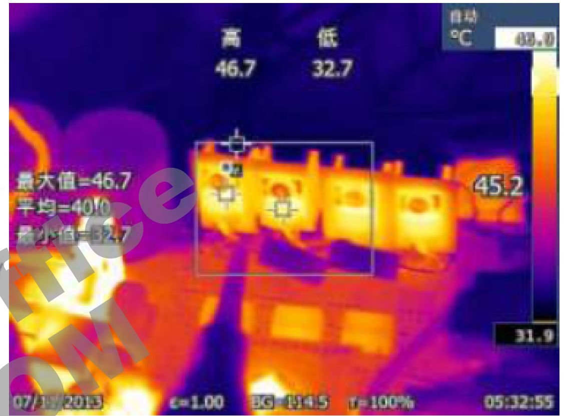
微型逆变器应用



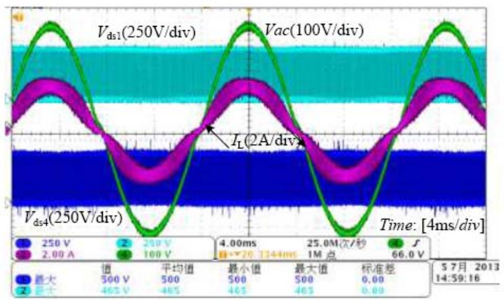
IPB60R190C6 500w温度测试



TPH3006 500W温度测试

Si MOSFET 500W满载效率为95.91%

GaN HEMT500W满载效率为98.29%



基于Cascode GaN HEMT单相逆变器实验结果

基于 GaN HEMT逆变器实物

采用氮化镓**THP3006**的温度明显低于**COOL-MOSFET C6**产品。 **81.7’C VS 46.7’C**

效率直接提高**2.5%**

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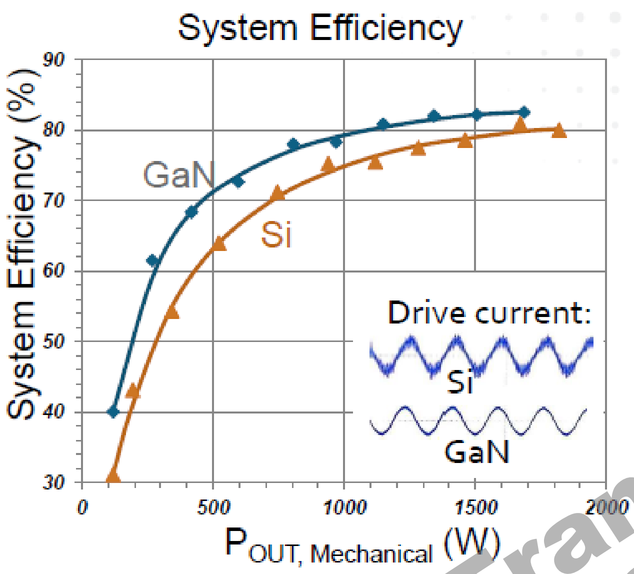
产品的应用：马达驱动



三相马达驱动,超高效率. **IGBT**频率
16Khz, 氮化镓频率**100Khz**

Pure sine-wave motor drive (2-8% points
efficiency gain for the system)

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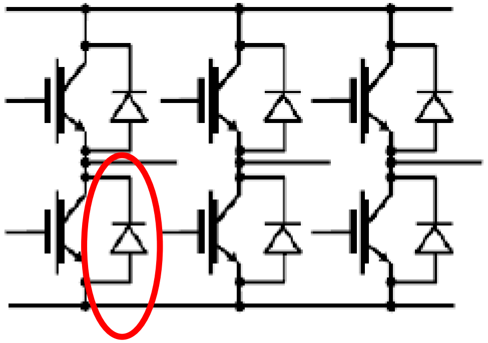
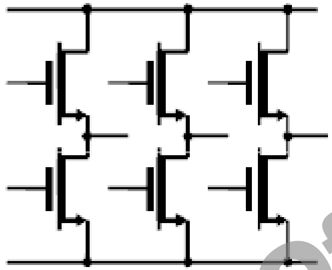
IGBT 3-phase Bridge

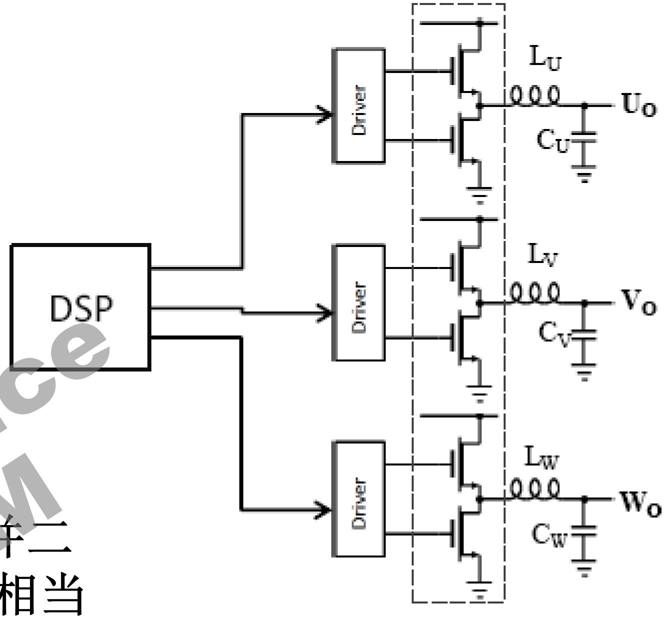


有时**IGBT**为了提高效率
还要并一个快速的二极管.

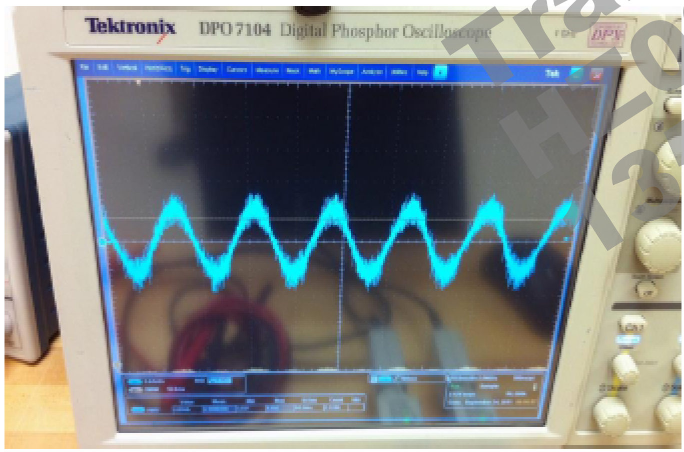
GaN HEMT 3-phase Bridge



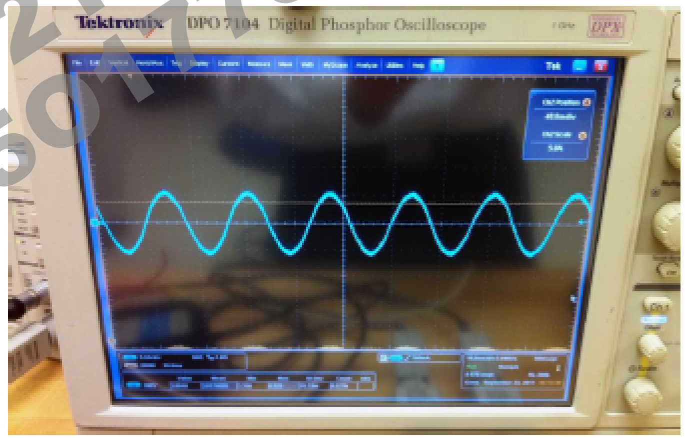
采用氮化镓,无需并二
极管.可直接使用.相当
于**0**恢复（极小）



IGBT Inverter: PWM Power



GaN Inverter: Sine-wave Power



采用GaN的好处:

1,提高了逆变效率
2,输出波形**TH**明显改进很多.
3,TH的改进对输出负载的应用要求降低
4,有助于对逆变的负载/或应用部分的效率提高

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