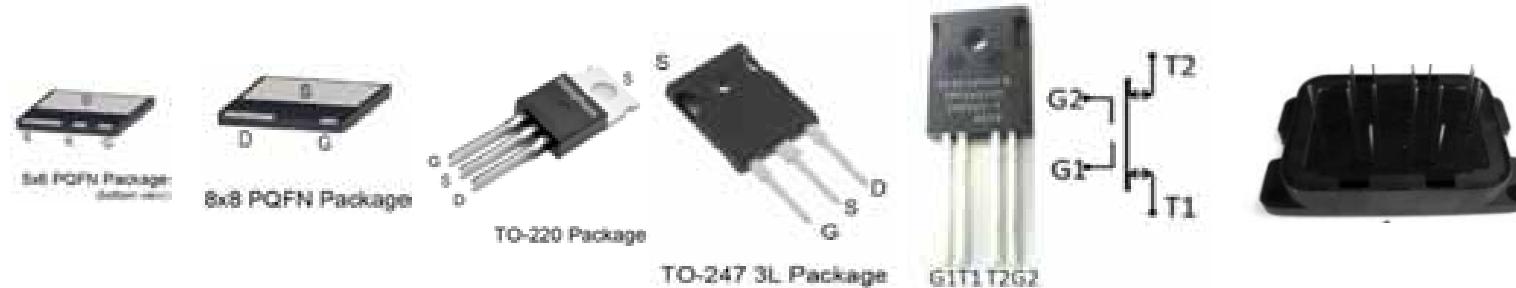


# 氮化镓MOS(HEMT)

HEMT: High Electron Mobility Transistor

更多资料云下载: <http://pan.baidu.com/s/1sj39UW1>



氮化镓MOSFET (650VDC, 能承受周期为1uS, 100nS的连续的方波, 保证750V)

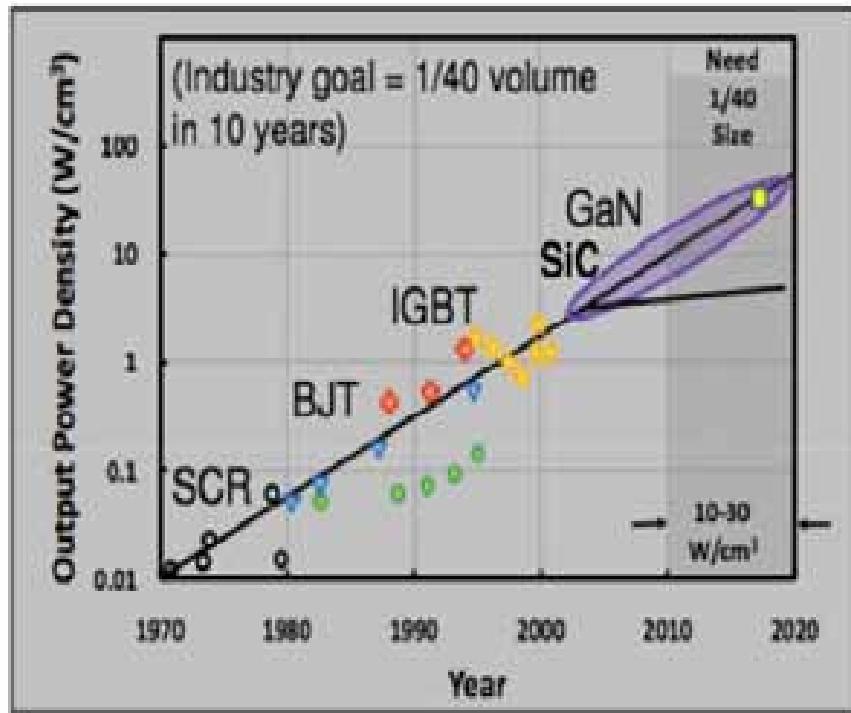
Part Number	Package	Voltage (V)	Current (A)	Ron (Ohm)	Power range
TPH3245ED 点击	QFN 5*6	750	6	0.5	<150W
TPH3002LD TPH3202LD 点击	QFN 8*8	750	9	0.29	100W – 500W
TPH3202PS TPH3002PS 点击	TO-220	750	9	0.29	100W – 500W
TPH3006LD TPH3206LD点击	QFN 8*8	750	17	0.15	300W – 1600W
TPH3206PS TPH3006PS 点击	TO-220	750	17	0.11	300W – 1600W
TPH3205WS 点击	TO-247	750	37	0.052	1500W-6000W
TPH3207WS 点击	TO-247	750	37	0.052	1500W-6000W
TPFX4010Y	TO-247-4	750	20	0.15	双向开关, 4象位
TPT3016M	模块	750	30	0.08	6管桥模块
TPT3044M	模块	750	16	0.15	6管桥模块

更多资料 点击  
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Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

# 电源功率密度趋势-Transphorm氮化镓FET



电源的发展必然需要**小体积高效率**产品，**提高工作频率**是必然趋势

功率密度上看**GaN, SiC**占优势

- 传统硅材料在电源转换上应用发展几十年了，现已到达它的物理极限，发展空间有限。
- 氮化镓材料最早是从LED及RF方面进行人们的视线，现在发展进入功率器件应用领域。适合高频高压。
- 氮化镓GaN将提供高性能，低成本的方案。因氮化镓基于硅衬底，将来8, 12英寸的晶元将大大降低使用成本。

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Tel:13501775977  
Mail: hz021@qq.com

# Si,SiC,GaN三种不同材料半导体比较

材料	Si	SiC	GaN
禁带宽度 $E_g$ (eV)	1.1	3.2	3.4
电子迁移率 $\mu$ (cm/Vs)	1500	900	2000
临界击穿电场 $E_c$ (MV/cm)	0.3	2.0	3.3
电子饱和速度 $V_s$ ( $10^7$ cm/s)	1.0	2.0	2.5

- 禁带宽度大、热导率大、介电常数小、饱和电子漂移速度高、击穿电场强度高、高抗辐射能力等特点。
- 禁带宽度3.4eV，存在很强的原子键，是极稳定的化合物。
- 三种属于不同晶系的结构：六方纤锌矿结构、立方闪锌矿结构以及立方盐矿结构。

- GaN and SiC offer:
  - 适合更高的工作电压
- GaN offers:
  - 高速电子迁移
  - 更适合高频工作
- SiC offers:
  - 更适合高温应用场合

# Transphorm公司介绍 [www.transphormusa.com](http://www.transphormusa.com), [Hong.zheng@transphormusa.com](mailto:Hong.zheng@transphormusa.com) 13501775977

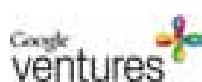
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- 2007年成立
- 位于美国加州**Goleta**
- 超过130百员工
- 超过250多专利
- 目前唯一过JEDEC认证GaN企业
- 超过2.5亿美金投资
- 日本，香港，上海，法国，办事处

## Japan office

投资商:



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Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

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## World-Class Financial Backing

KKR



FUJITSU



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## Transphorm Executive Leadership Team



**Mario Rivas**  
**Chief Executive Officer**  
30+ years experience in technology, manufacturing, and P&L management



**Primit Parikh**  
**COO and Co-founder**  
15+ years experience in Semiconductors, GaN and Business leadership



**Yifeng Wu**  
**SVP Engineering**  
PhD, 15+ years experience in GaN technology and devices



**Umesh Mishra**  
**CTO and Co-founder**  
Professor at UCSB and first to develop GaN RF / Power devices.

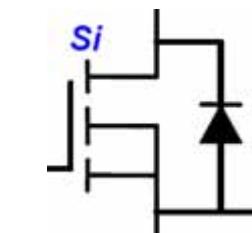
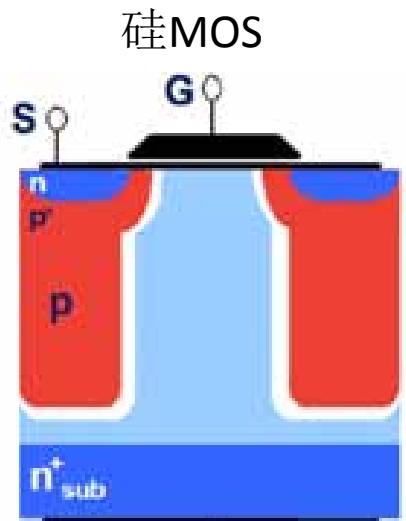


**Michael White**  
**SVP Sales & Marketing**  
25+ years P&L mgt., strategy, sales & marketing leadership

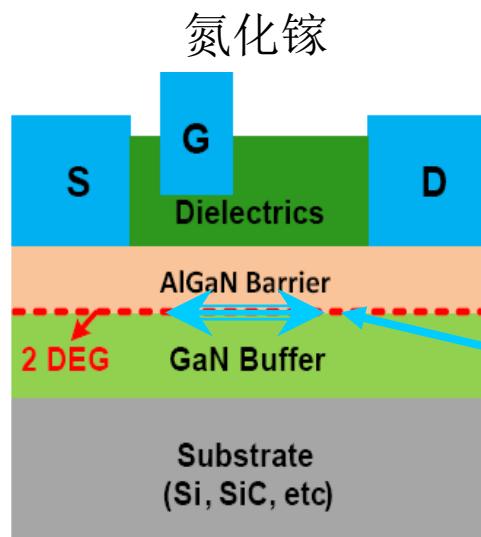


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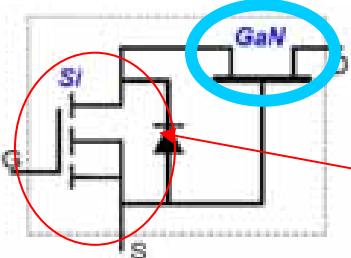
# 硅，氮化镓FET的结构



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，下方直接接金属散热片。



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

横向结构器件  
无寄生二极管  
具有对称传导特性

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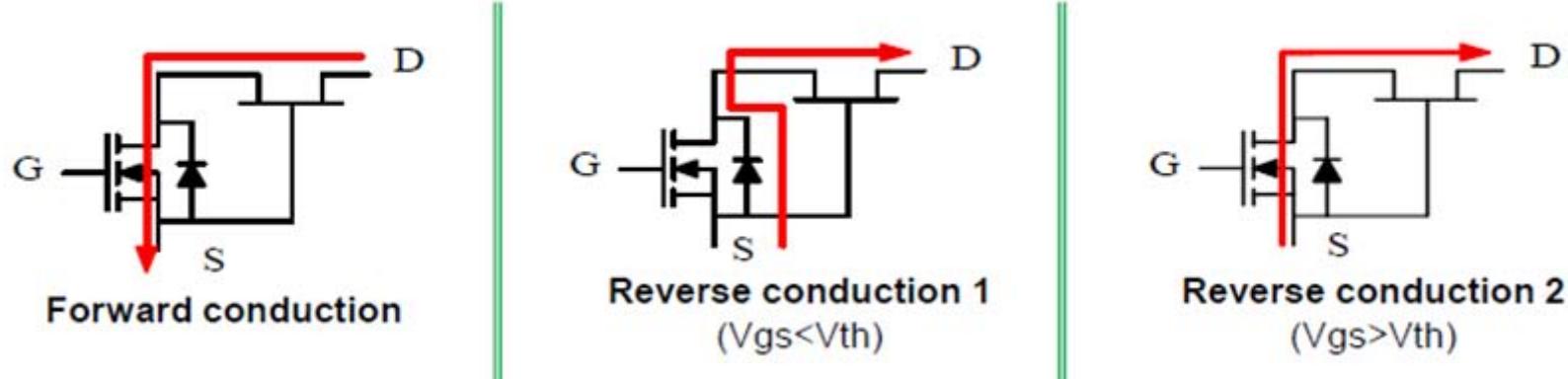
## 氮化镓FET – HEMT

- 1, 氮化镓与传统的硅MOS不一样，电流在流动的时候体内没有形成PN结，即没有体内二极管，故没有反向恢复的问题。
- 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）



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，因此成晶体内实际有两个管子，资料上的反向恢复时间均与此小MOSFET上的二极管有关。

# Transphorm GaN 驱动线路很简单



- 无需外加驱动芯片
  - 2V门阀电压 (5V 全开通, 0V 关断)
  - +/- 18V max. GATE电压
  - 采用通用驱动即可，如ON,Silicon-labs,Fairchild,IR....
  - 正常开通只需要不到100mA电流。所有IC均满足此要求
- 30V低压(LV) Si FET 速度是非常快，不会影响到氮化镓
  - Low Qg. & Low Qrr
  - 30V的Si Mosfet与氮化镓FET串接

# Cool-Mosfet 与 氮化镓Mos对比

	Parameters	IPA60R160C6 Cool-Mosfet	TPH3006PS 氮化镓
Static	$V_{DS}$	600V @ 25 °C	650V (spike rating 750V)
	$R_{DS}$ (25 °C)	0.14/0.16 ohm	0.15/0.18 ohm
	$Q_g$	75 nC	6.2 nC
	$Q_{gd}$	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	$Q_{rr}$	8200 nC [2]	54 nC [3]
	$t_{rr}$	460 ns [2]	30 ns [3]

等同 $R_{ds(on)}$ 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

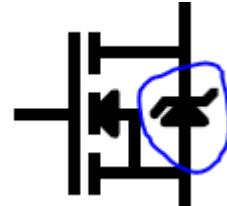
[1]  $V_{GS} = 0V, V_{DS} = 0 - 480V$

[2]  $V_{DS} = 400V, I_{DS} = 11.3A, di/dt = 100A/\mu s$

[3]  $V_{DS} = 480V, I_{DS} = 9A, di/dt = 450A/\mu s$

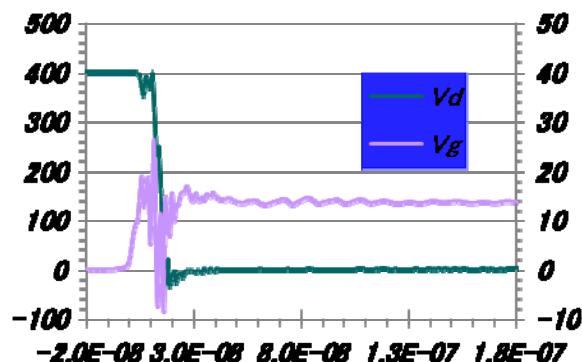
# GaN 与 Si 在电路上的对比

## 硅材料MOSFET/ Cool Mos



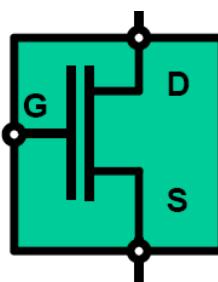
MOSFET发热源:

- 1,  $R_{ds(on)}$ 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).



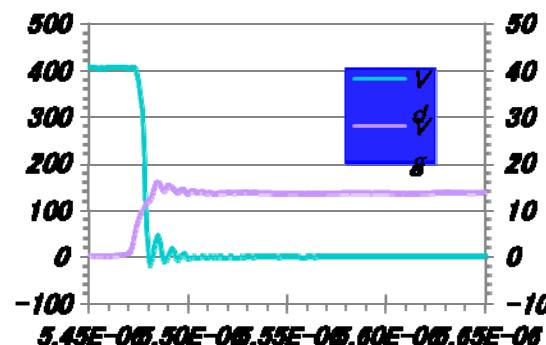
但氮化镓无体内二极管  
仅有二极管特性

## 氮化镓材料MOSFET -HEMT



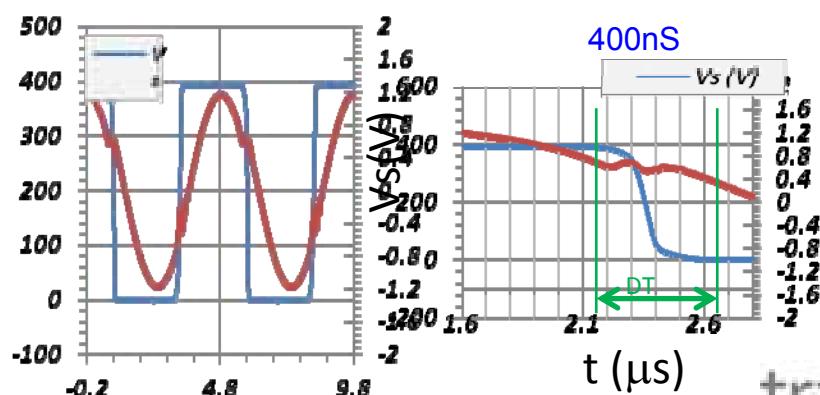
氮化镓MOS发热源:

- 1,  $R_{ds(on)}$ 损耗
- 2, 极其小开关损耗, 不足Si管 1/10
- 3, 只有54nC反向恢复损耗, 不足Si管的 1/100 损耗
- 4, 超低的结电容保证较小的死区损耗.

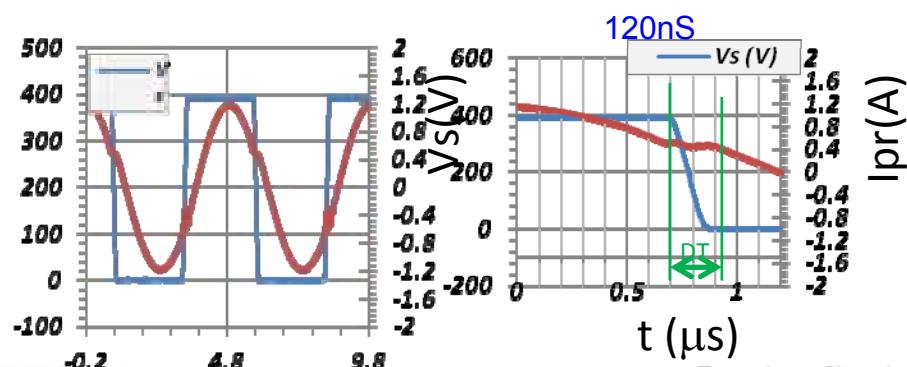


开关损  
耗对比

明显小于  
左边



死区损  
耗对比



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

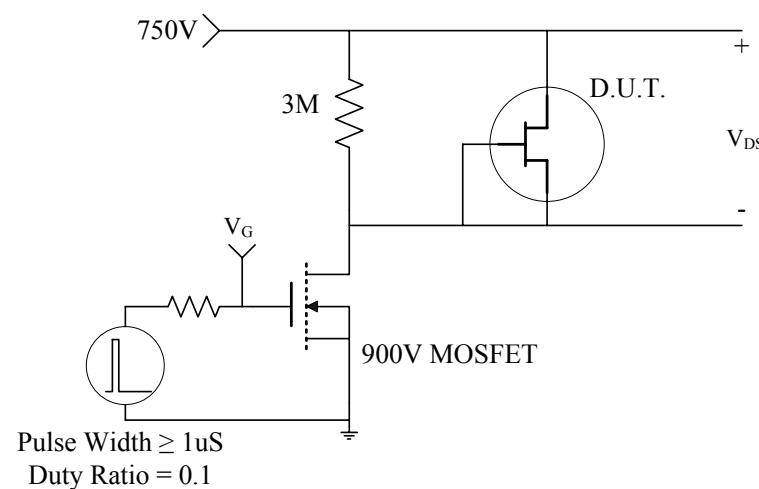


Fig. 1 Spike Voltage Test Circuit

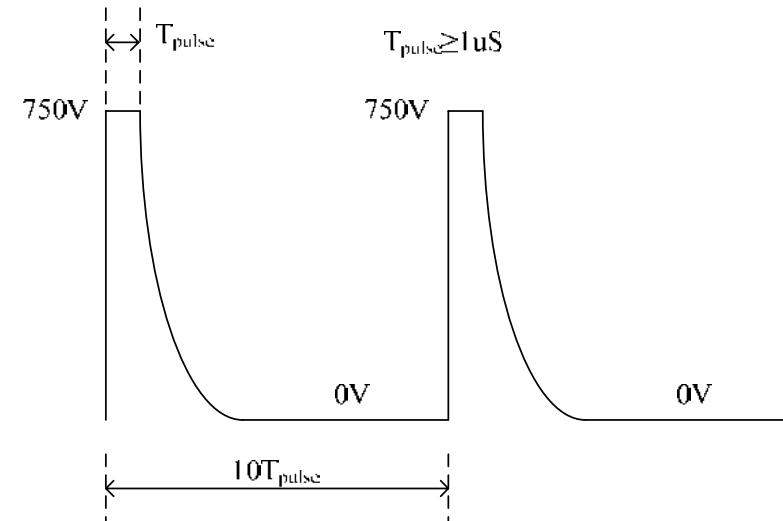
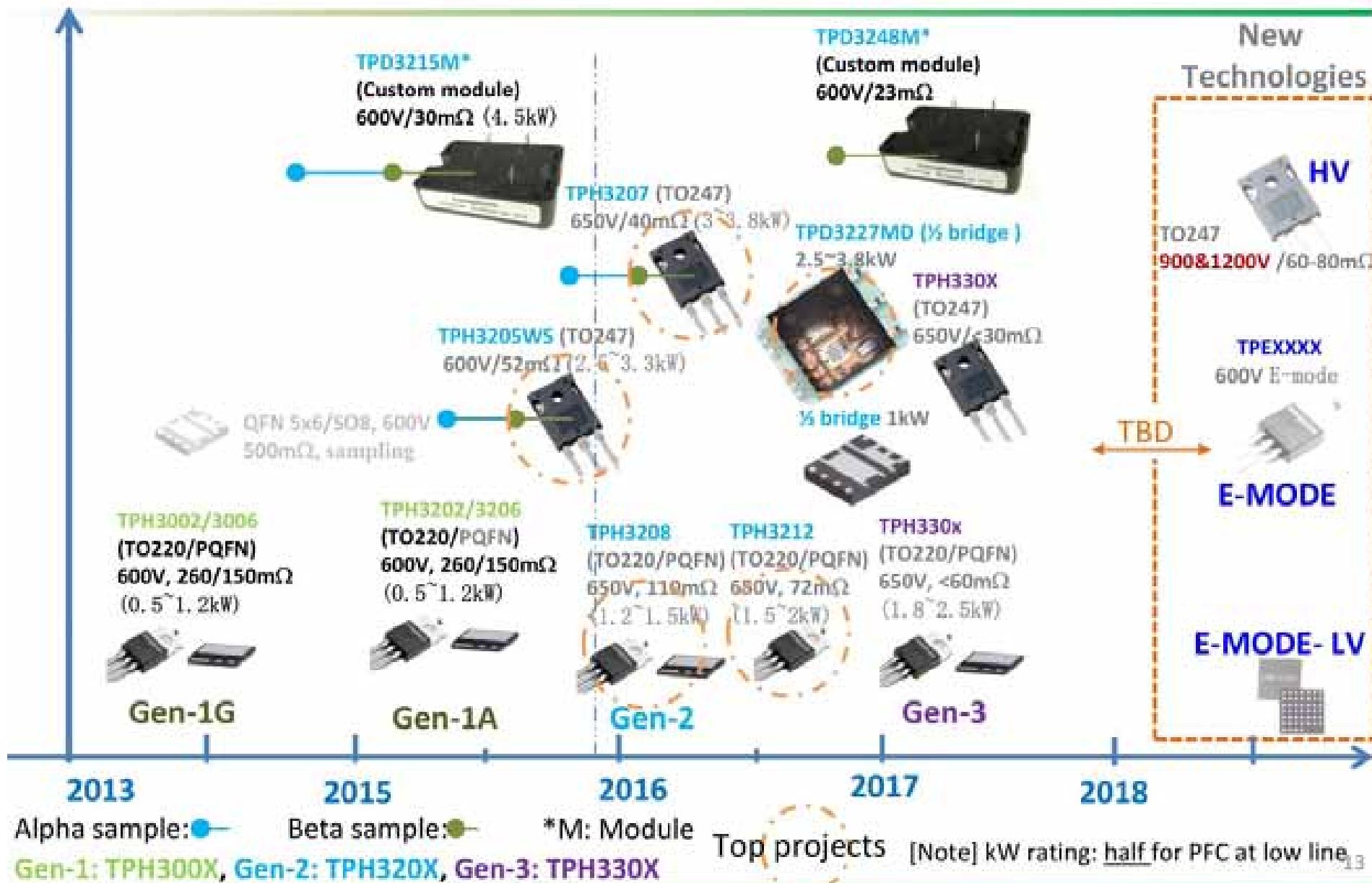


Fig.2  $V_{DS}$  waveform

$V_{DSS}$	Drain to Source Voltage	600	V
$V_{TDS}$	Transient Drain to Source Voltage *	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）

# Transphorm Product Roadmap Summary



R(on) Typ

## Product Roadmap

600-650V  
D-Mode

Gen 1 Gen 2

Gen 3 Development

Gen 3

Surface Mount

500W-  
3KW HL

T0220

500W-  
2.5KW HL

T0247

2.5KW-3.0+ HL

E-Mode

150, 290mΩ  
8x8 PQFN

100mΩ  
8x8 PQN

80mΩ  
8x8 PQFN

Family Half-Bridge  
(50, 80, 100, 150, 300mΩ)

Development

150, 290mΩ  
T0220

100mΩ  
T0220

80mΩ  
T0220

60mΩ  
T0220

Development

52mΩ  
T0247

42mΩ  
T0247

30mΩ  
T0247

Development

EMODE- 650V

LV &  
HV

2015

2016

2017

2018

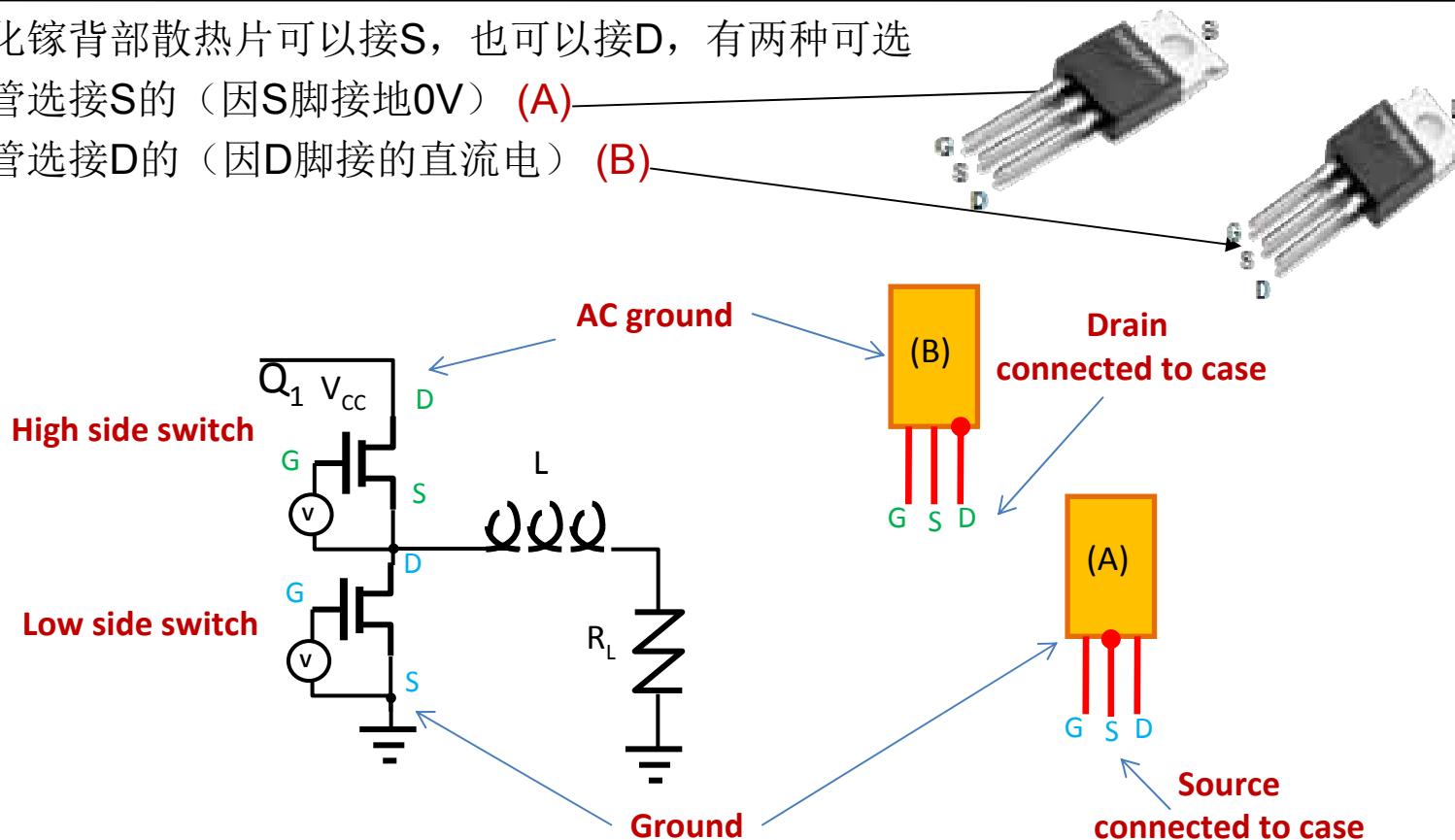
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# Qualified GaN on Silicon products from Transphorm: TO220 & PQFN (Production), TO247 (Eng Samples)

Specification	Production				Eng Samples
	TPH3006PS/PD	TPH3002PS/PD	TPH3006LS/LD	TPH3002LS/LD	
					
	Source Tab (PS) Drain Tab (PD)		Source Dap (LS) Drain Dap (LD)		Source Tab Only
Part No.	TPH3006PS/PD	TPH3002PS/PD	TPH3006LS/LD	TPH3002LS/LD	TPH3205WS
Package	TO220	TO220	PQFN88	PQFN88	TO247
RDS(ON)Typ. (OHM)	0.15	0.29	0.15	0.29	0.063
ID25°C (A)	17	9	17	9	34
Co(er) (pF)	56	36	56	36	170
Co(tr) (pF)	110	63	110	63	283
Og (ns)	6.2	6.2	6.2	6.2	10
Trr (ns)	30	30	30	30	30
Qrr (nC)	54	29	54	29	138
Vgs(V) (Gate Voltage)	+/- 18	+/- 18	+/- 18	+/- 18	+/- 18

# Quiet Tab™ package made possible by lateral GaN devices

- 氮化镓背部散热片可以接S，也可以接D，有两种可选
- 下管选接S的（因S脚接地0V）(A)
- 上管选接D的（因D脚接的直流电）(B)



TPH3002PS --背部金属接S极 (TO-220 600V/9A)

TPH3002PD –背部金属接D极

TPH3002LD --背部金属接D极 (QFN 8x8)

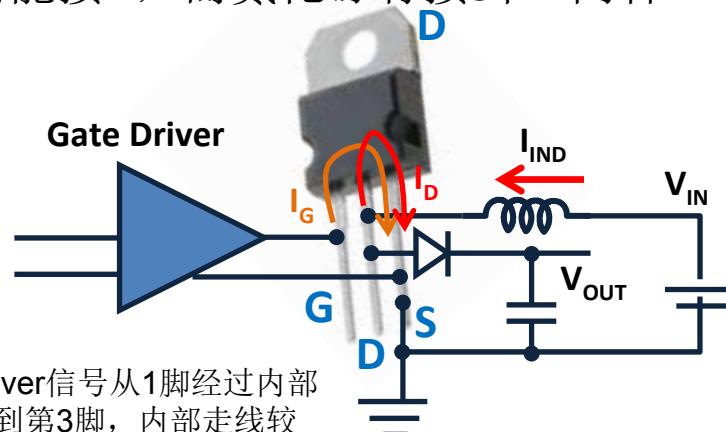
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Mail: hz021@qq.com

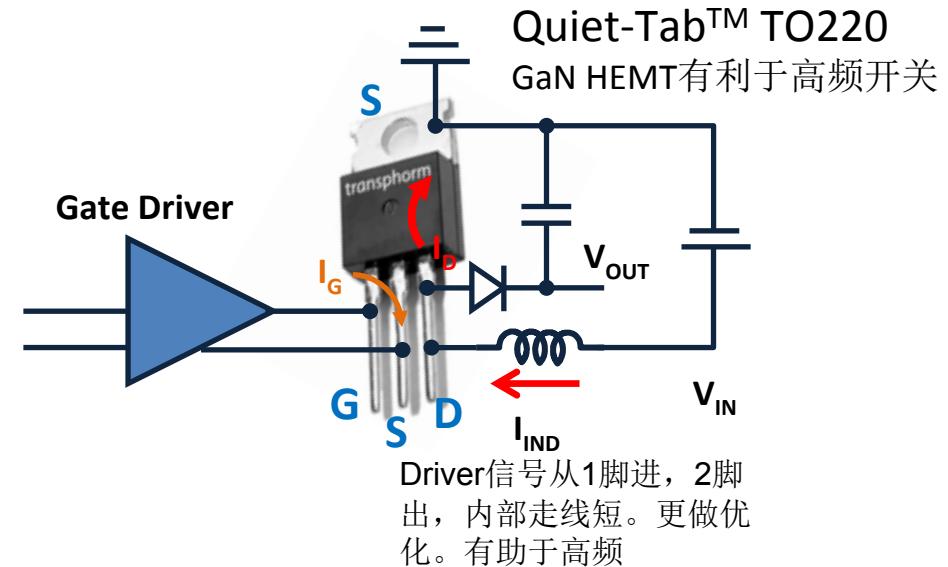
# The Quiet-Tab™ TO-220 Package Matches GaN's High Switching Speed

传统的TO-220硅MOSFET

背部只能接D，而氮化镓有接S和D两种

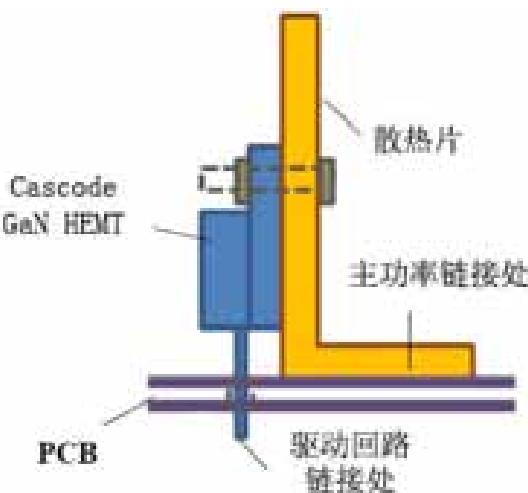


Driver信号从1脚经过内部  
绕到第3脚，内部走线较长，  
会带来较大的寄生电感



Quiet-Tab™ TO220  
GaN HEMT有利于高频开关

- 传统的结构，D极的瞬间电流可能给Vgs带来大的干扰
- Kelvin引脚（背部接S），分开的S极，一个作为GATE脚用，另一个作为D极大电流用，分开有助于减少Vgs振铃
- 硅材料的结构决定不能提供Kelvin脚.
- G,S,D更有助于安规及布线。

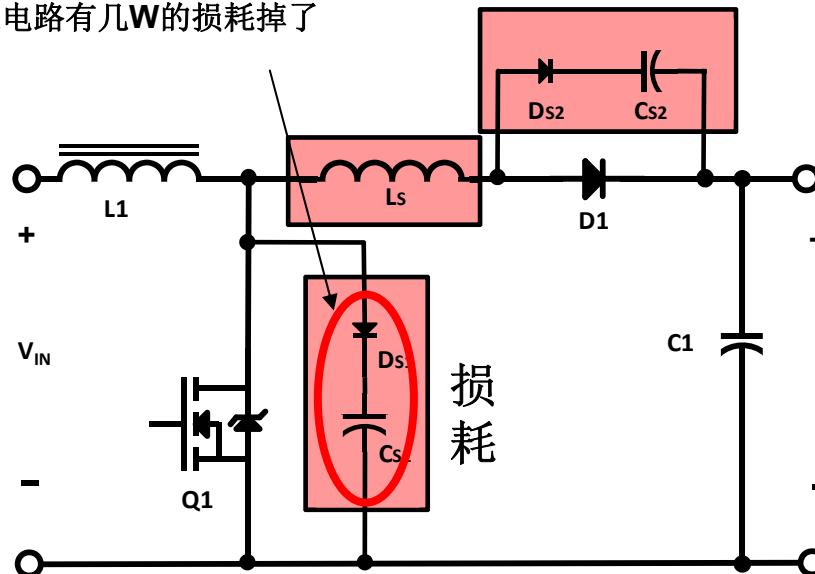


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Tel:13501775977  
Mail: hz021@qq.com

## 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

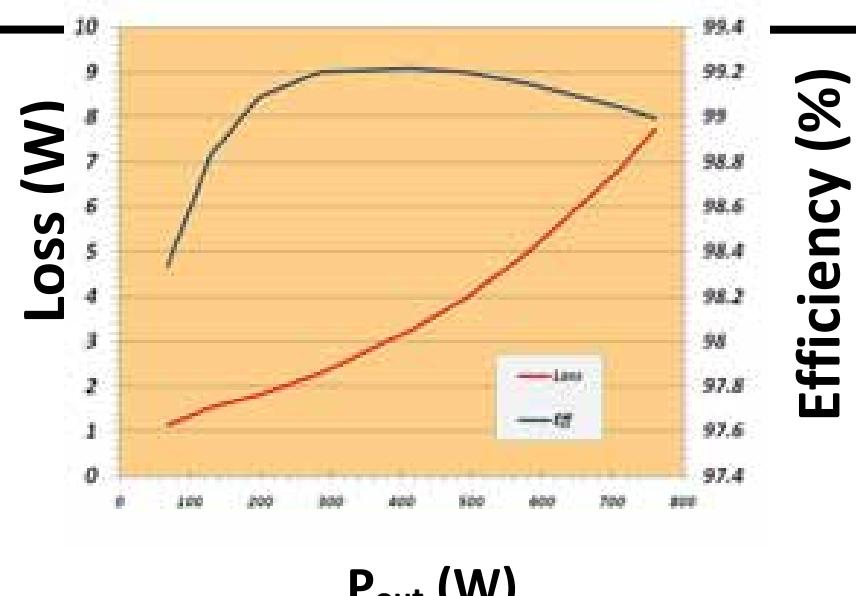


一般测试效率为97-98%较多

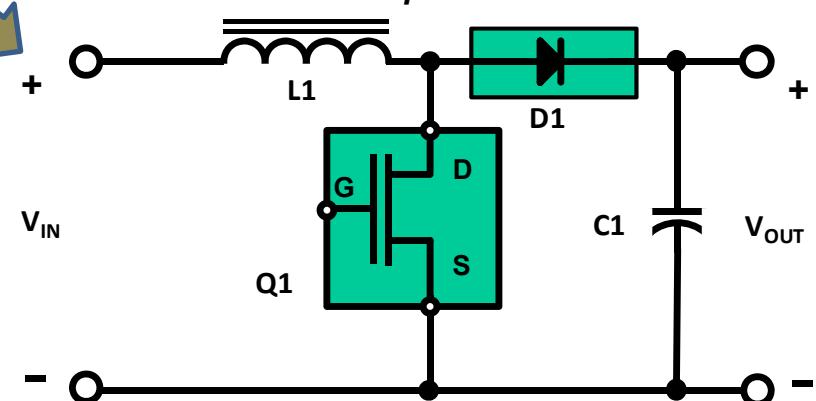
一旦换成氮化镓MOSFET，效率达99.2%

### PFC Switching Conditions

- $V_{in} = 220\text{v dc}$
- $V_{out} = 400\text{v dc}$
- 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*



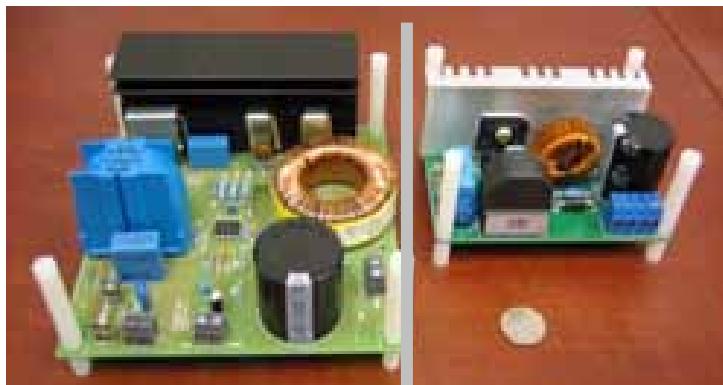
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Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

# 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, **R<sub>ds(on)</sub>**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

Coolmosfet 199C3+SiC二极管 - 左边	等同R <sub>ds(on)</sub> 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

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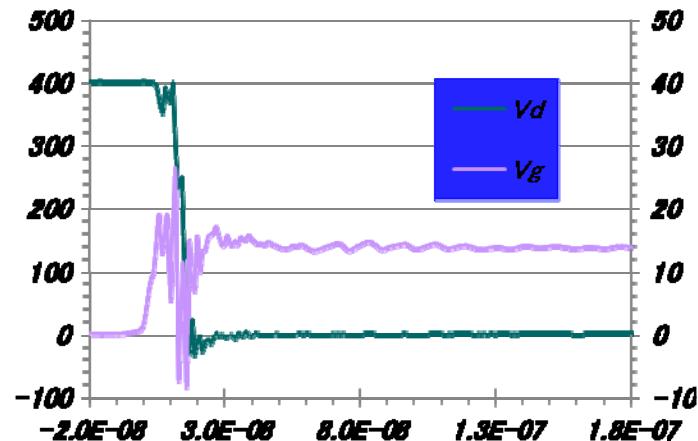
# 电路应用 –CCM 电路/硬开关

Silicon converter: Super-junction MOSFET,  $385\text{m}\Omega$  + Ultra-fast Si diode, 10A at  $T_c=25^\circ\text{C}$

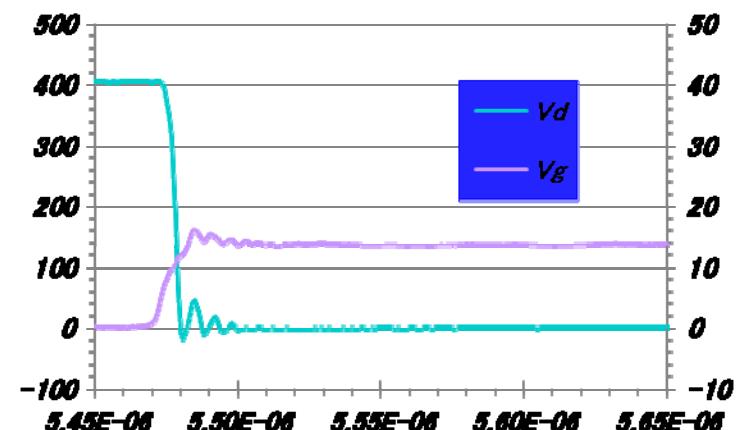
GaN Converter: GaN HEMT,  $310\text{m}\Omega$  + GaN Diode TPD2012, 2A at  $T_c=125^\circ\text{C}$

$R_G=0\Omega$ ,  $f=100\text{kHz}$ ,  $V_{IN}=220\text{V}$ ,  $V_{OUT}=400\text{V}$ ,  $P_{OUT}=760\text{W}$ .

Cool-mos C3的开关波形



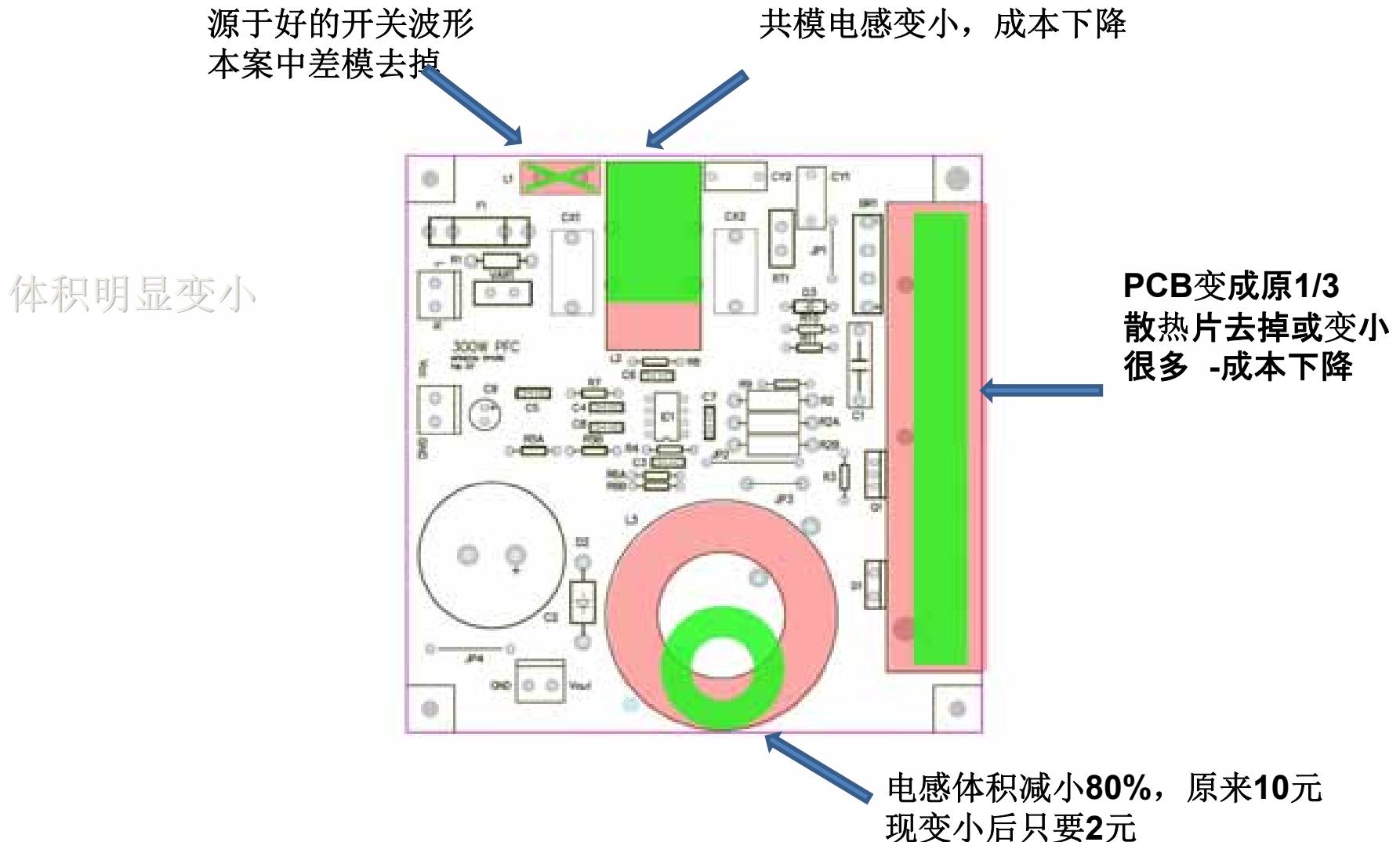
氮化镓的开关波形



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即非常小的 $\text{T}_{rr}$ ，在续流方面有很大优势。

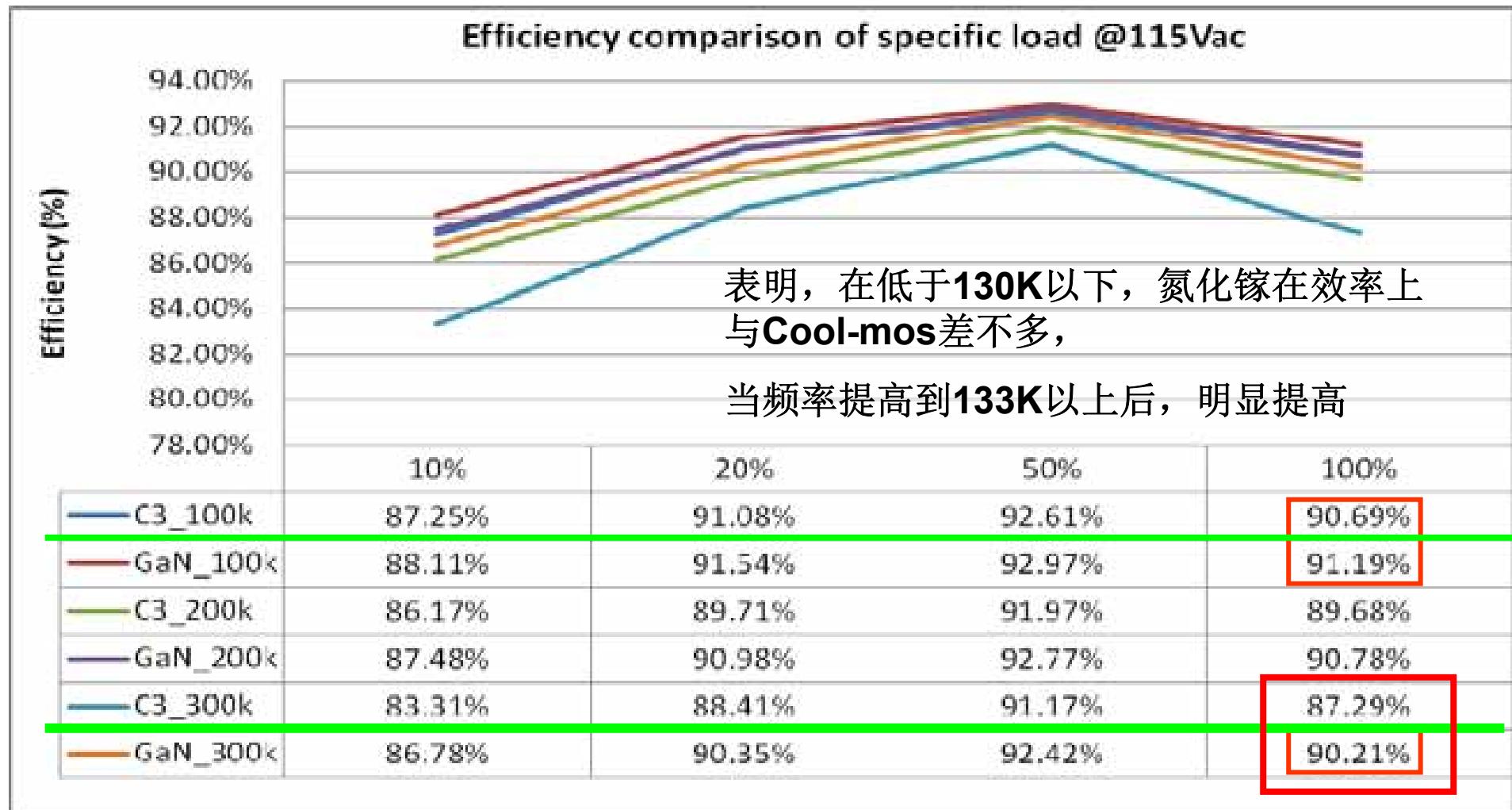
# 电路应用 –CCM 电路/硬开关



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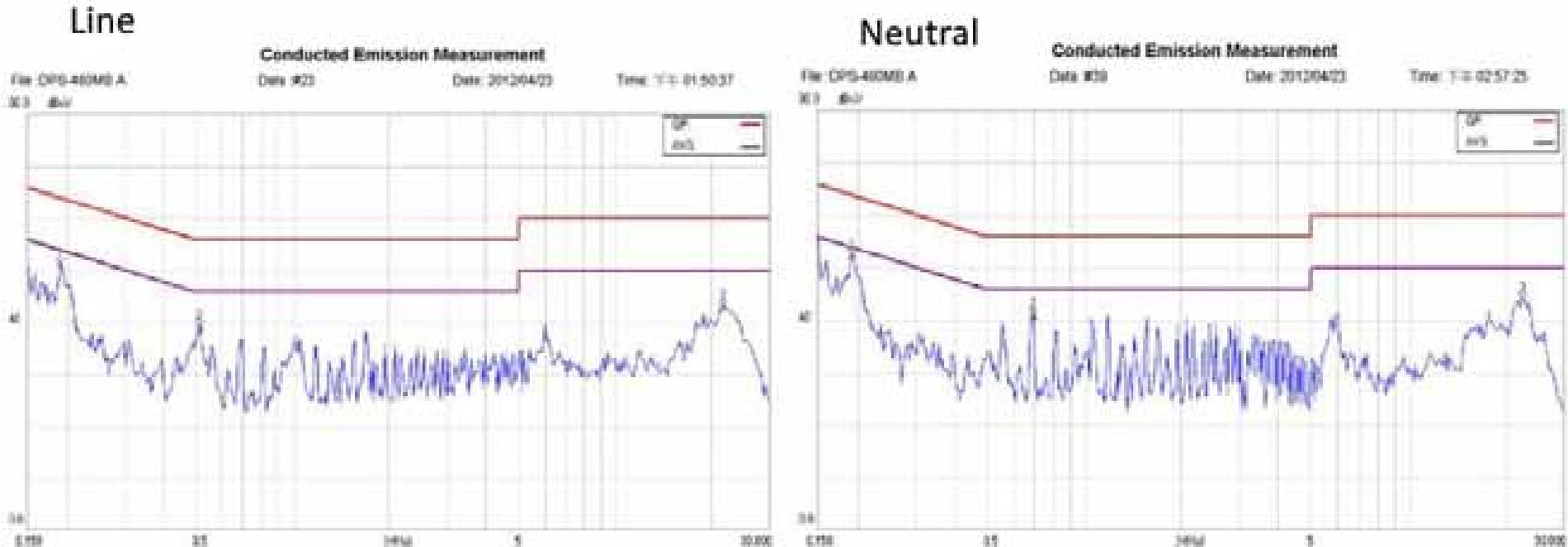
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Tel:13501775977  
Mail: hz021@qq.com

# Customer A 460W带PFC电源测试对比



# 客户实测EMI

460W PFC电源  
Cool-mos 100K HZ



Input: 110V, 60Hz

Mode: Original Source Cool MOS, fs:100khz

Limit: CISPR22 Class B Conduction (QP)

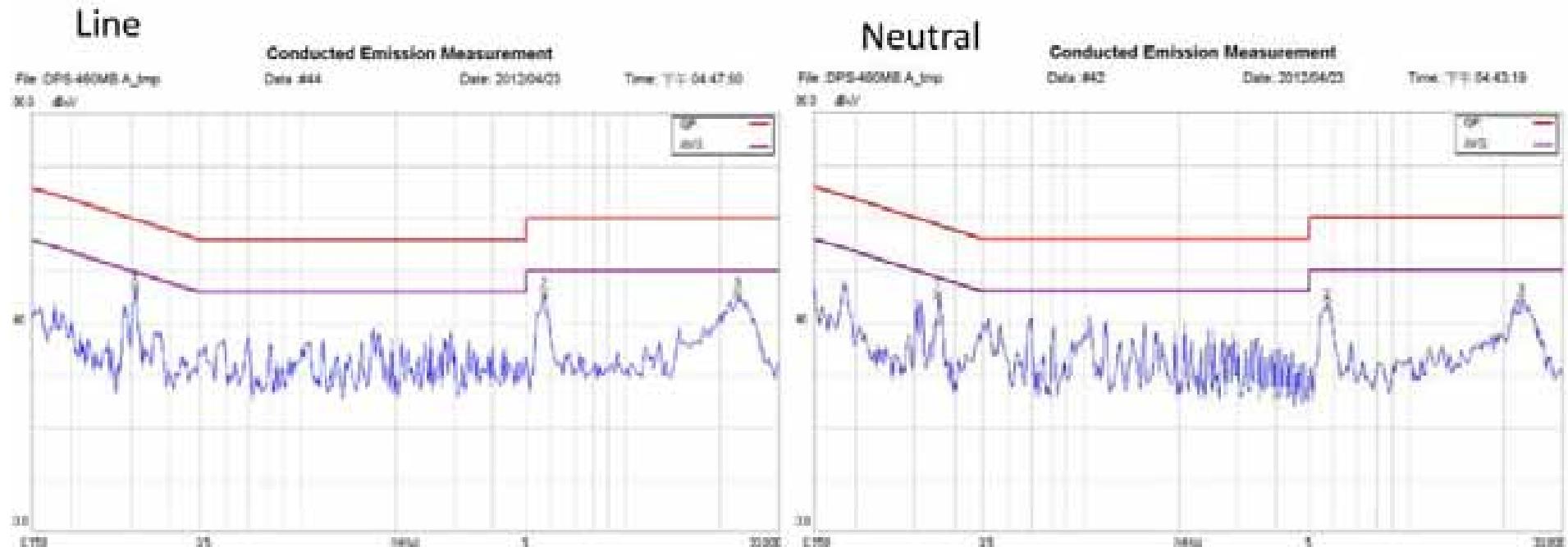
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Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

## 客户实测EMI

## 采用**GaN**提高工作频率并没有提高**EMI**

460W PFC电源  
GaN 300K HZ



Input: 110V, 60Hz

Mode: New Source **GaN**, fs:300khz

Limit: CISPR22 Class B Conduction (QP)

与上张图**Cool-mos**在**100K**的时候对比。  
并没有存大较大的变化。但频率提高达  
到了**300KHZ**

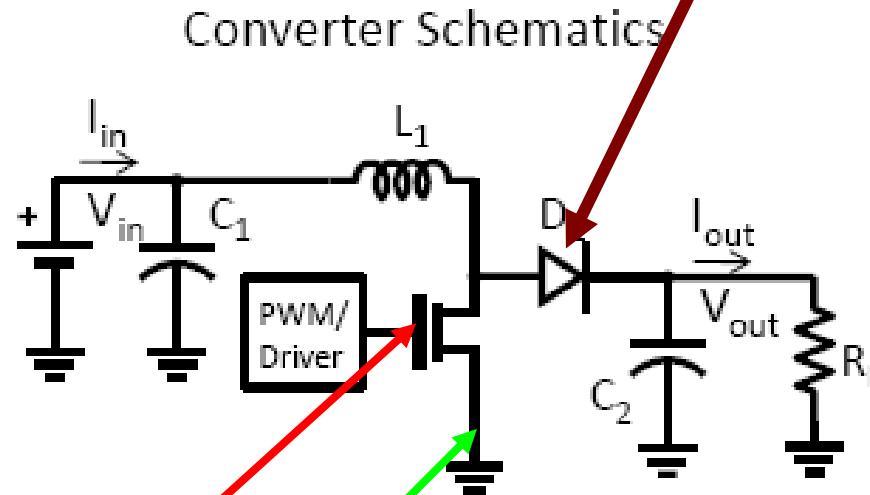
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Tel:13501775977  
Mail: hz021@qq.com

# 硬开关式PFC电路/BOOST升压电路 – 采用氮化镓FET及二极管

无需吸收电路

二极管尽可能靠近FET以减少走线上的寄生电感!!



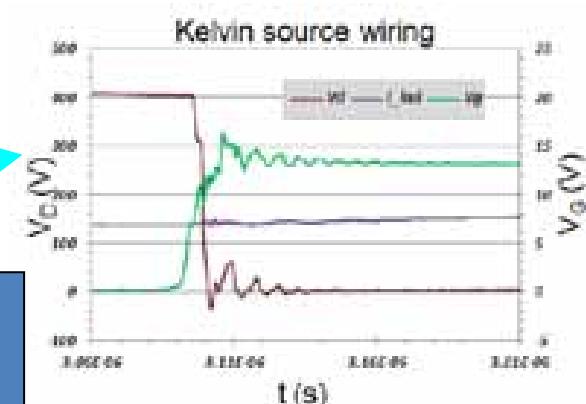
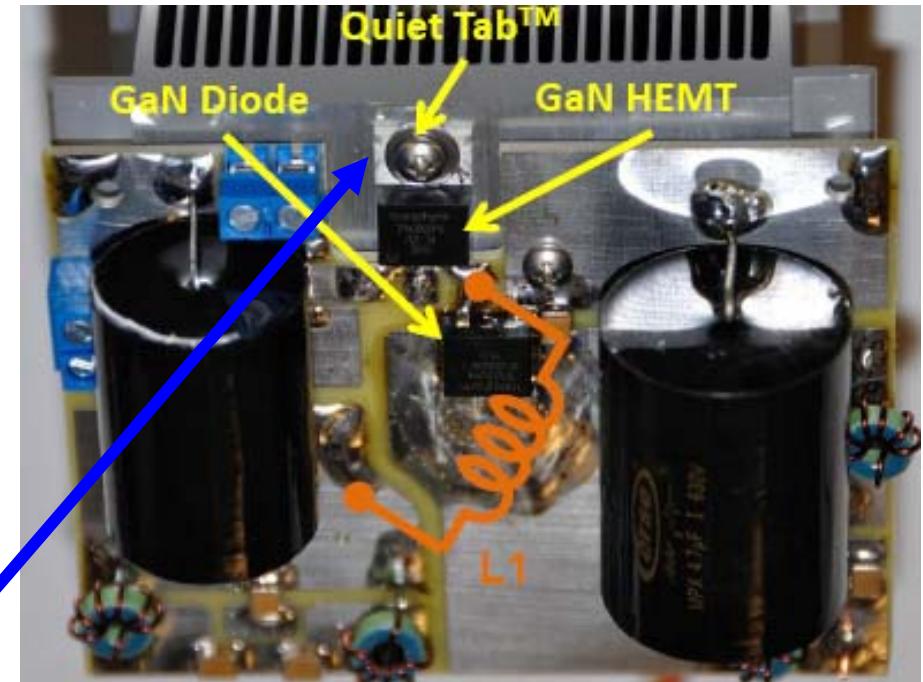
按书本原理即可实现DC升压电路

Gate驱动无需补偿电路,可直接驱动。

氮化镓FET无需snubber吸收电路

可选TO-220金属背面接S极的管子,因而散热片间无需隔离垫片,因S接地了.安全.

快而超低的振荡波形保证更低的损耗

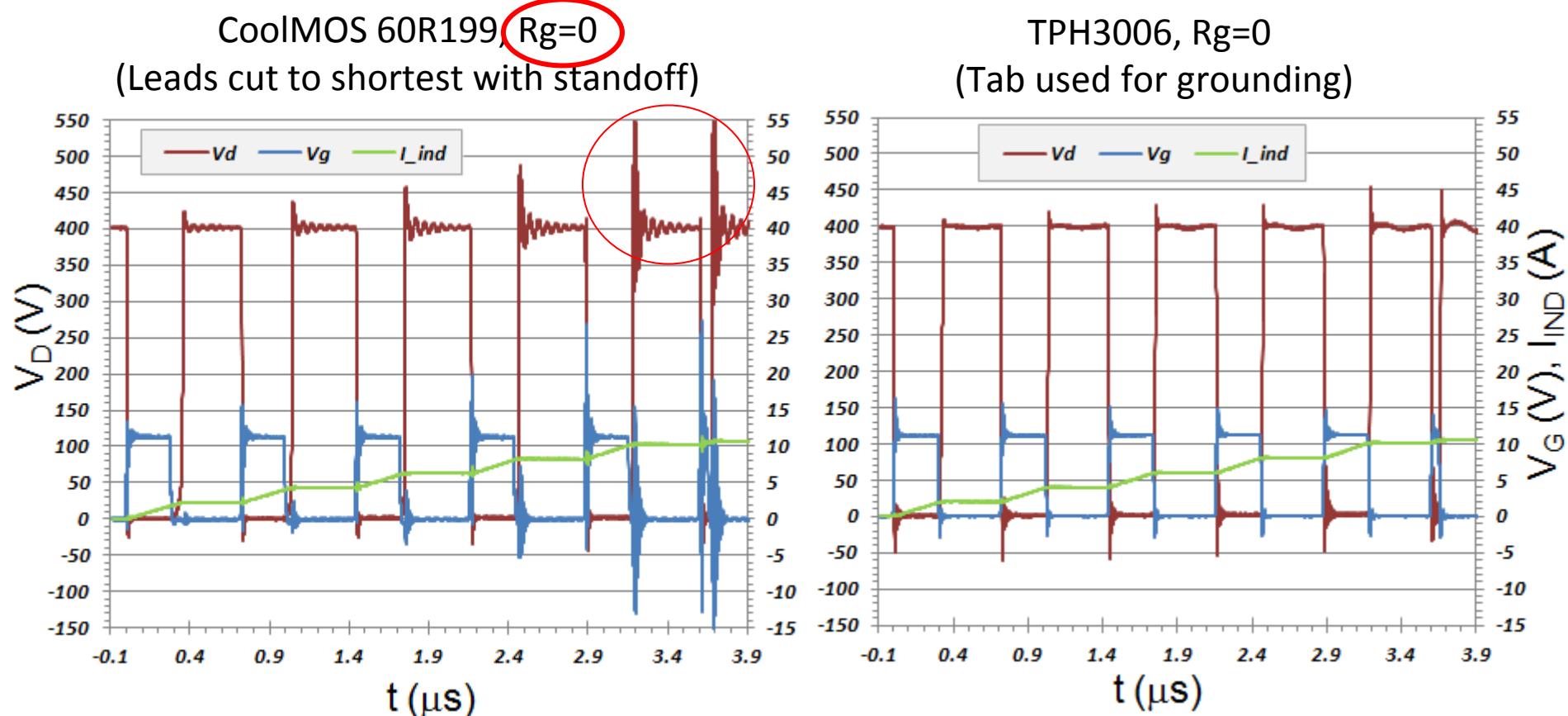


PFC电路,二极管尽可能靠近GaN管.功率越大,  
越要靠近!!!

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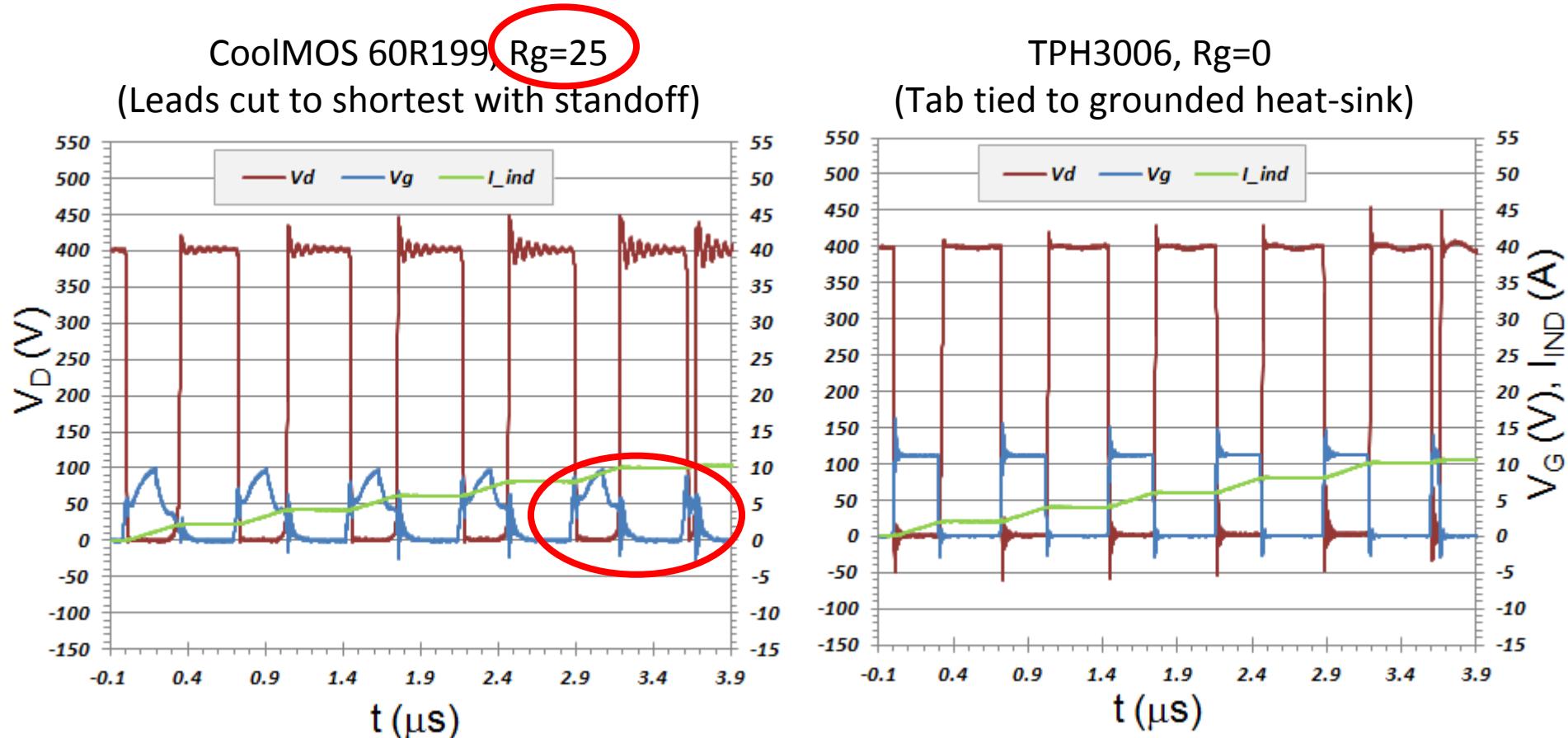
# 高速开关:

## CoolMOS TO-220 Vs. GaN HEMT in Quiet-TabTM TO-220



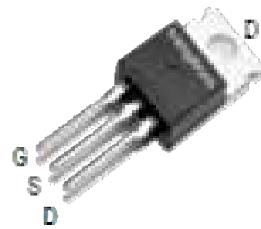
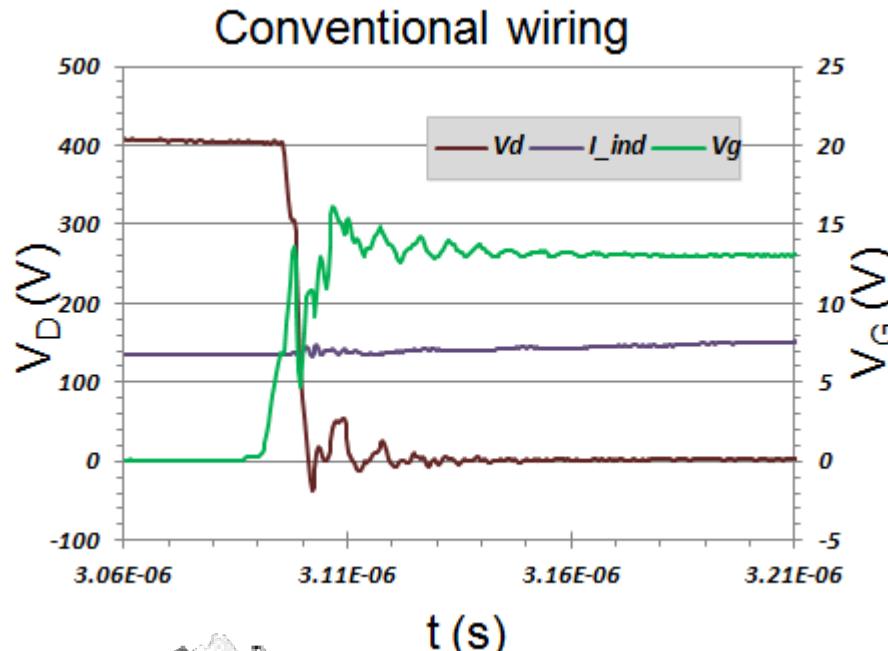
- Cool-Mos Gate脚不加电阻， $V_{ds}$ 过冲电压很高，要选600V以上器件。同时带来EMI问题。
- 氮化镓GATE脚没有加电阻。波形整齐，很小的过冲电压。

# Operation Waveforms: Slowed-down CoolMOS Vs. Fast GaN

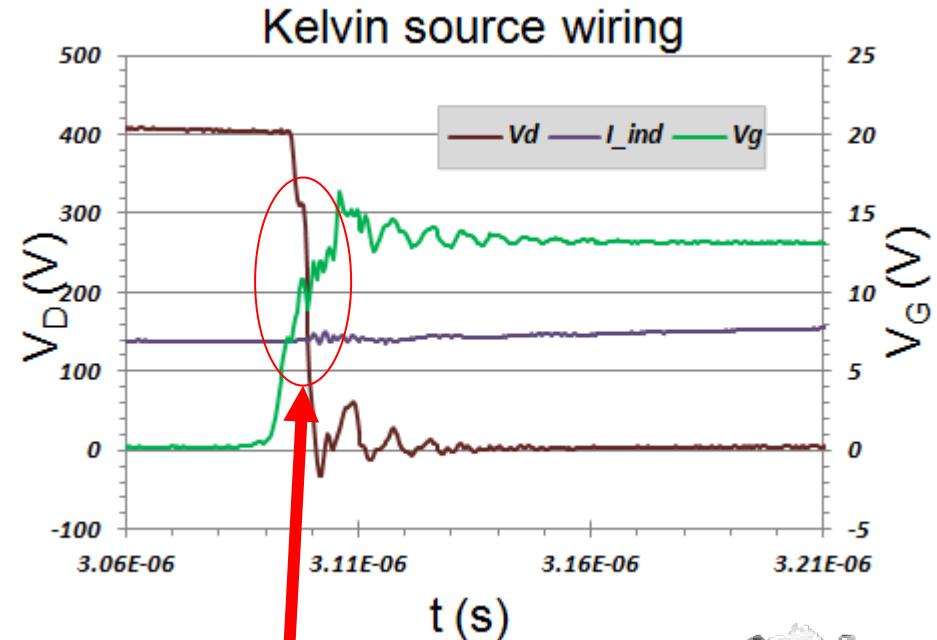


- 所以COOL-MOS要在前门极加一个电阻，25欧会将VDS电压降下来，但门极驱动波形变形。。。所以会选一个择中值如10欧，此时VDS依然会较高.同时也会带来损耗。
- 氮化镓器件不需要外加电阻。低EMI。

# GaN高速开关时的开通波形(Boost电路)



采用标准封装脚波形



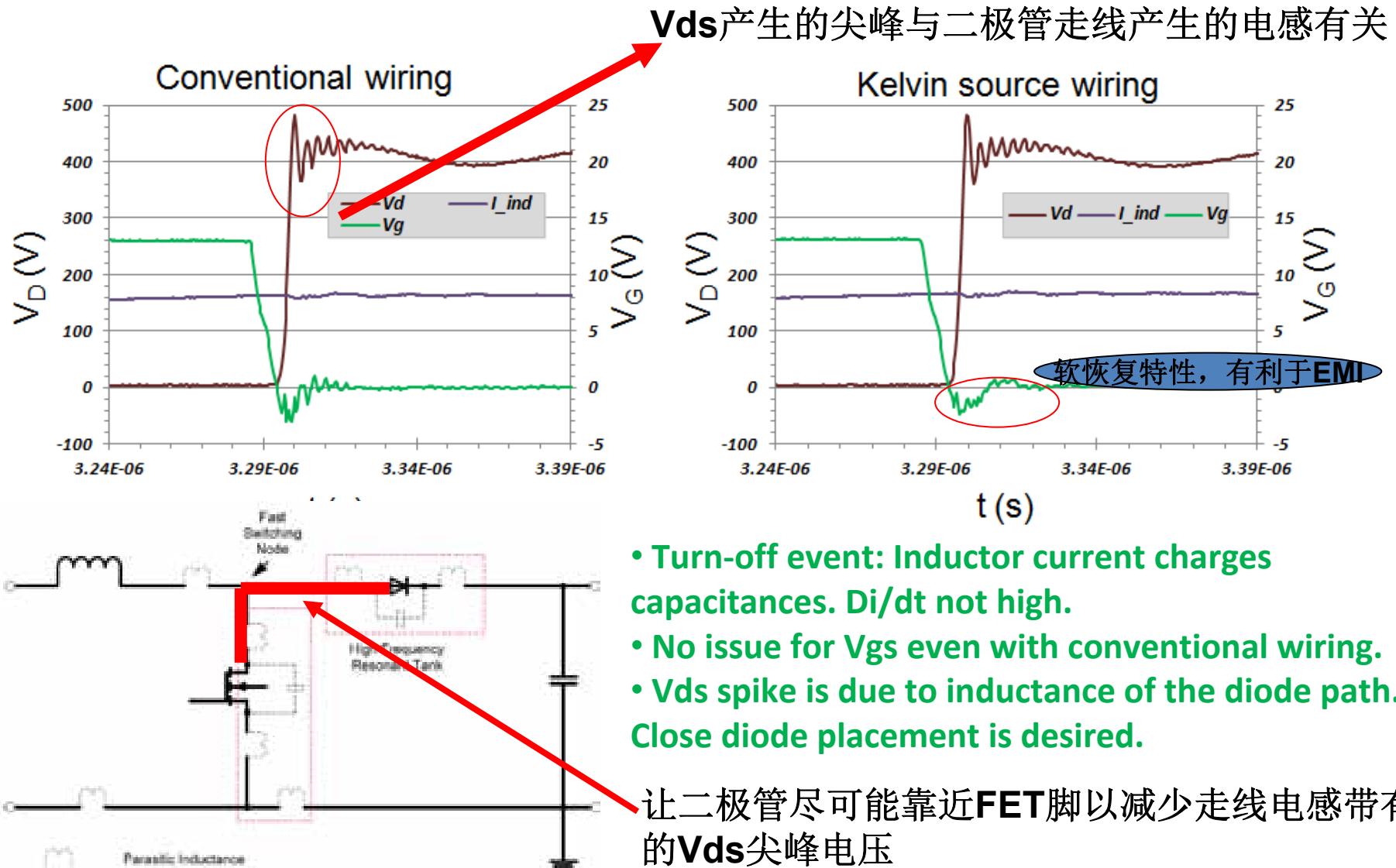
采用Kelvin脚时波形

因氮化镓的速度太快，从波形上看采用Kelvin封装更有利  
于电路上的EMI

- GaN HEMTs is capable of  $dV/dt$  of  $>100V/ns$ .
- Resultant high  $di/dt$  causes apparent  $V_{gs}$  dips in conventional wiring.
- Kelvin source wiring eliminates the large  $V_{gs}$  dip.

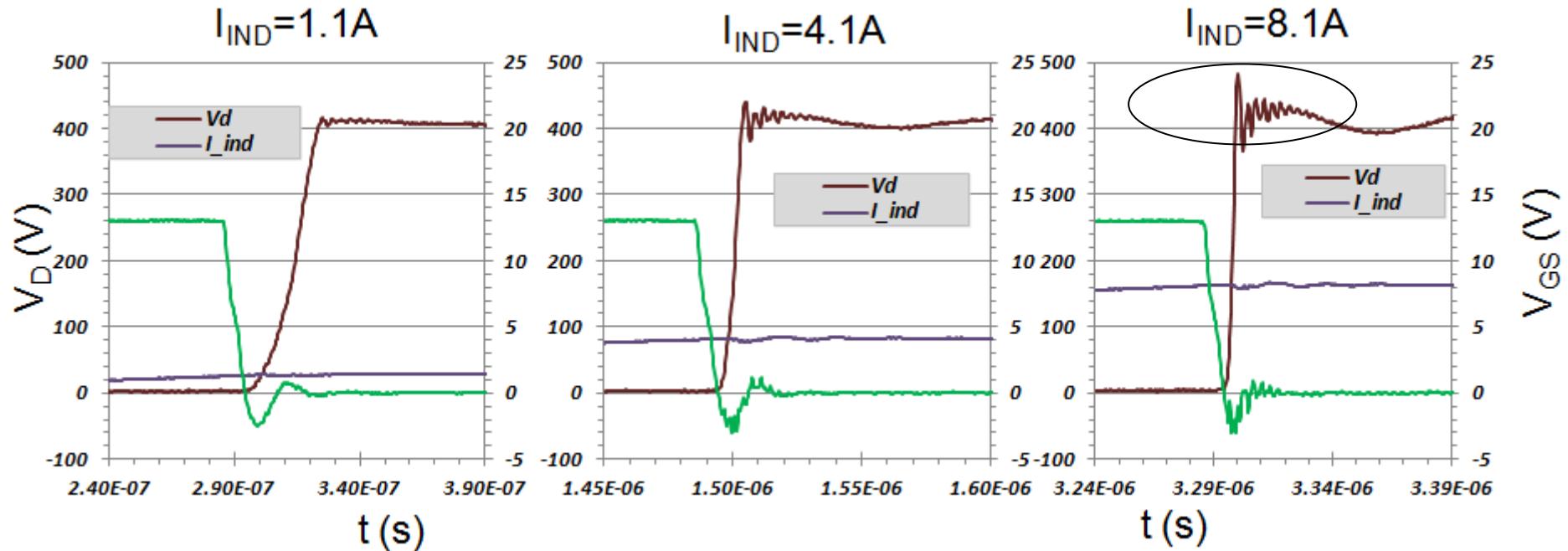
# 高速BOOST电路: Turn-off Waveforms

## 关断时波形

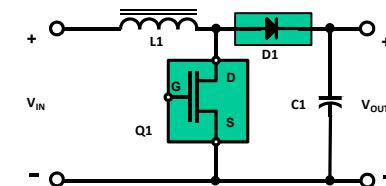


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# 关断时的尖峰电压- 电感电流的作用

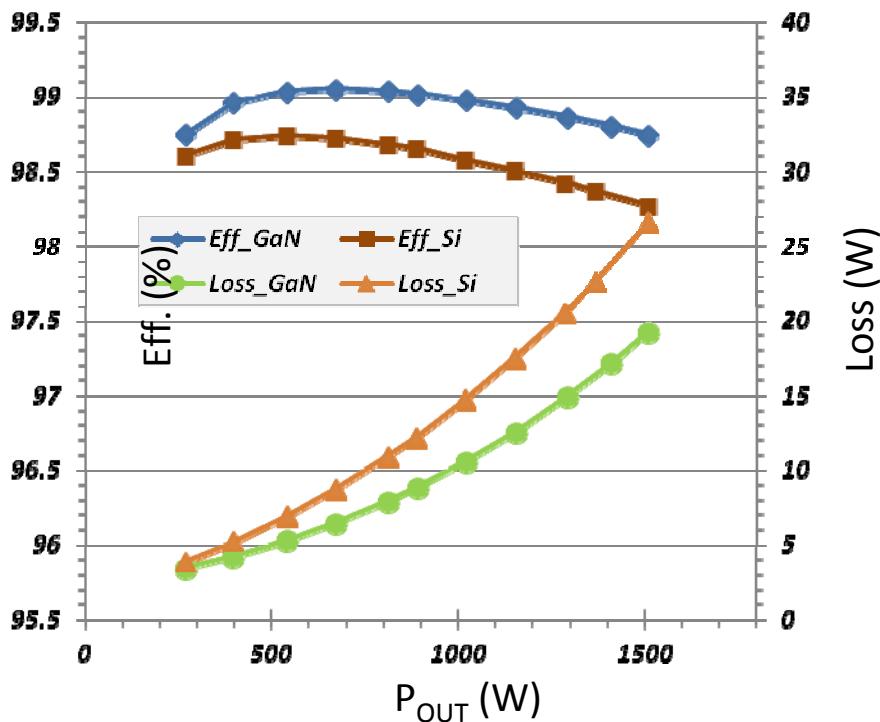


- 试验测试是以传统的封装器件（非KELVIN脚式）
- 尖峰电压很低，且与电感电流大小成正比
- 可以看出功率越大，在电路上就必须将二极管尽可能靠近FET脚。以减少走线带来的寄生电感。

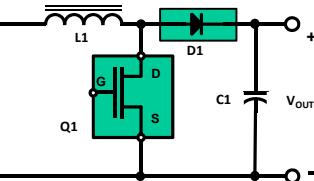
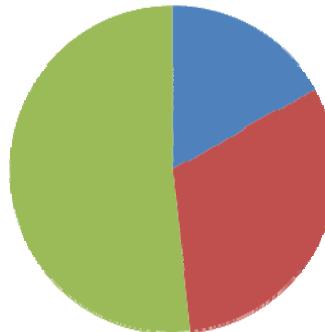


# Cool-Mos与氮化镓FET BOOST电路上的损耗对比: 100 kHz

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

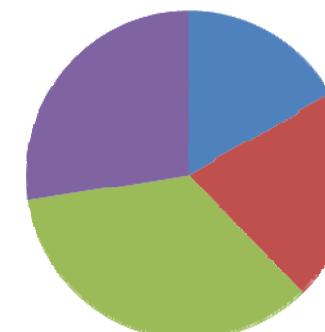


Loss breakdown



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）

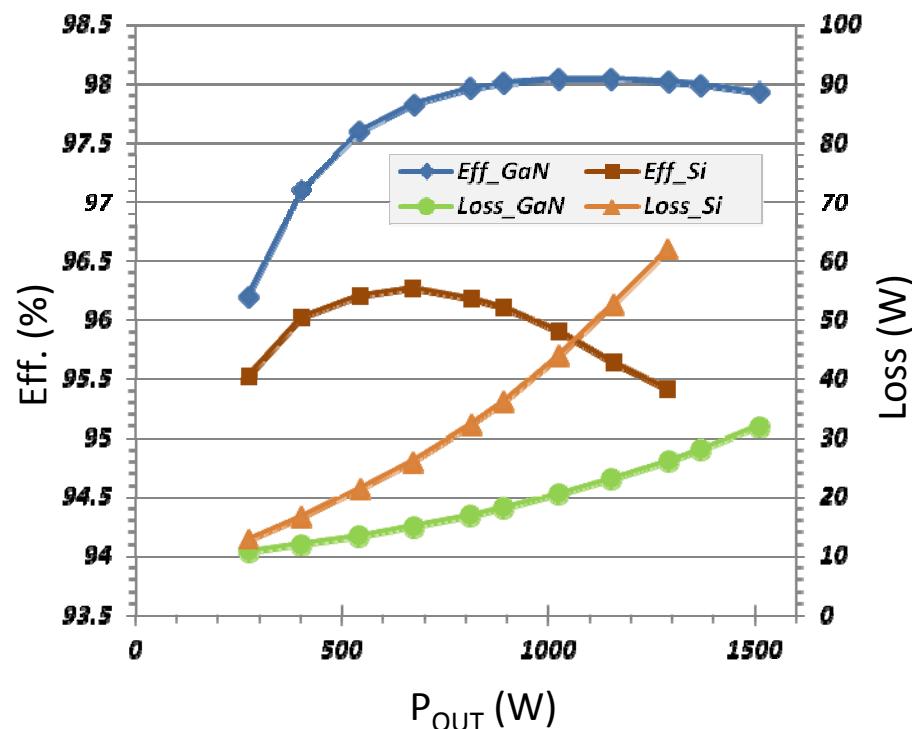
- Transphorm Total GaN™ solution outperforms matured Si solution
- GaN cuts device loss by 33% (27.5% of total loss) at full load (1.5kW)
- GaN achieves 99% efficiency

transphorm

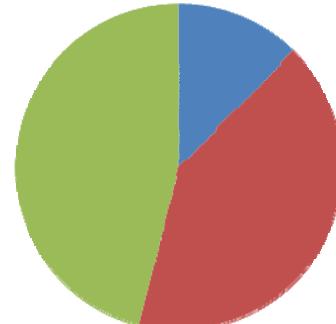
Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

# 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

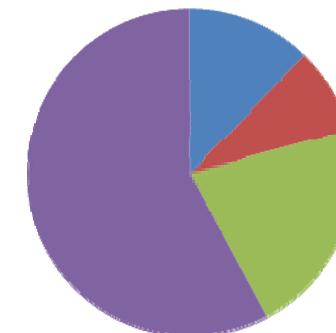


Loss breakdown



Inductor  
FET  
Diode

Boost电路 500K  
Cool-Mos方案上的  
损耗图



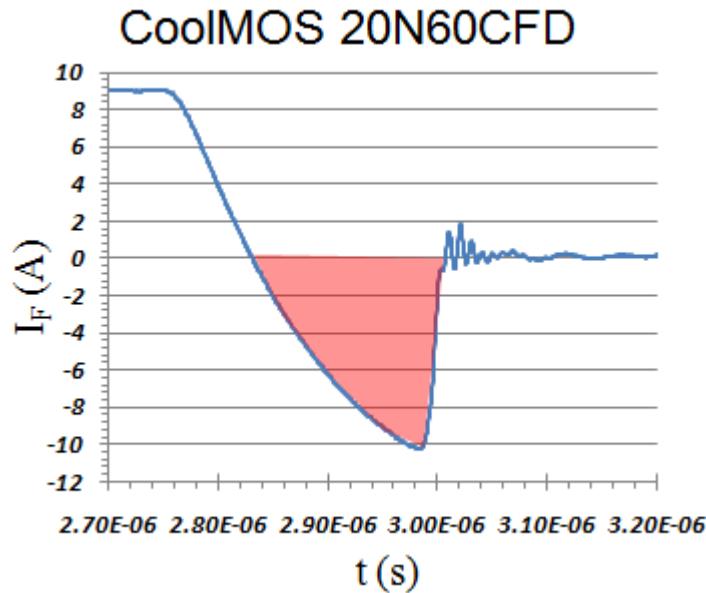
Inductor  
FET  
Diode  
Saved

Boost电路 500K  
氮化镓方案上的  
损耗图

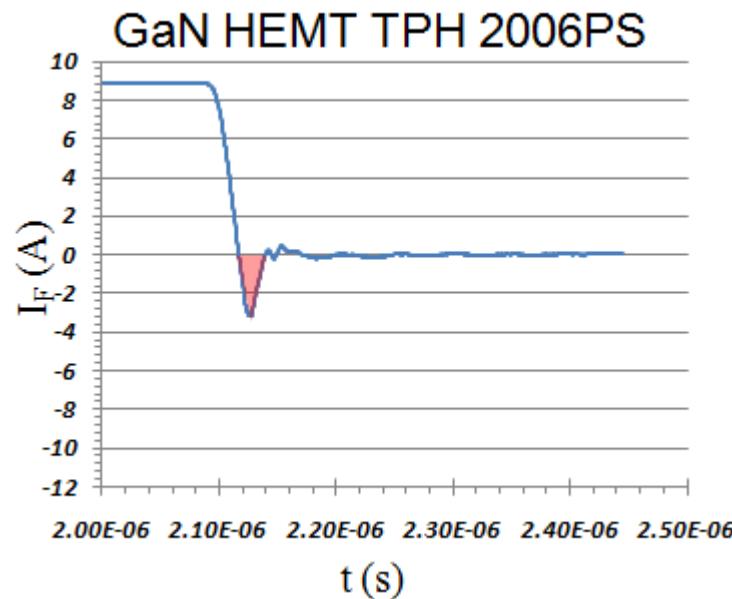
在500K时省出3/5  
的损耗（紫）

- GaN's advantage is amplified at high frequencies (for compact designs) due to its lower  $Q_g$  and  $C_{o(er)}$
- GaN cuts device loss by 70% (total loss 55%) at 1.3kW
- Si converter cannot operate beyond 1.3 kW safely
- GaN >98% efficiency at 500kHz

# 氮化镓与Cool-Mos CFD系列对比Qrr/Trr (CFD是体内寄生二极管速度最快的一系列)



$Q_{rr}=1000\text{nC}$  at 9A, 400V



$Q_{rr}=54\text{nC}$  at 9A, 400V

- Both measured in the same test board
- Transphorm GaN HEMT was tested at  $450\text{A}/\mu\text{s}$  with little ringing
- CoolMOS was not stable at  $450\text{A}/\mu\text{s}$ .  $dI/dt$  reduced to  $100\text{A}/\mu\text{s}$  for stability.
- GaN HEMT has Qrr of  $\sim 20$ x less than CFD-type CoolMOS (Low Qrr design).

# 1<sup>st</sup> Gen 600V GaN-on-Si HEMT Compared to Si Super Junction MOSFET

---

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

- 1<sup>st</sup> generation GaN is already superior to Si
- GaN still has ample potential to improved

## 氮化镓MOS在软开关电路上的应用：

---

针对软开关， 电路上的**MOS**开关损耗都差不多， 此时电路的损耗主要来于以下：

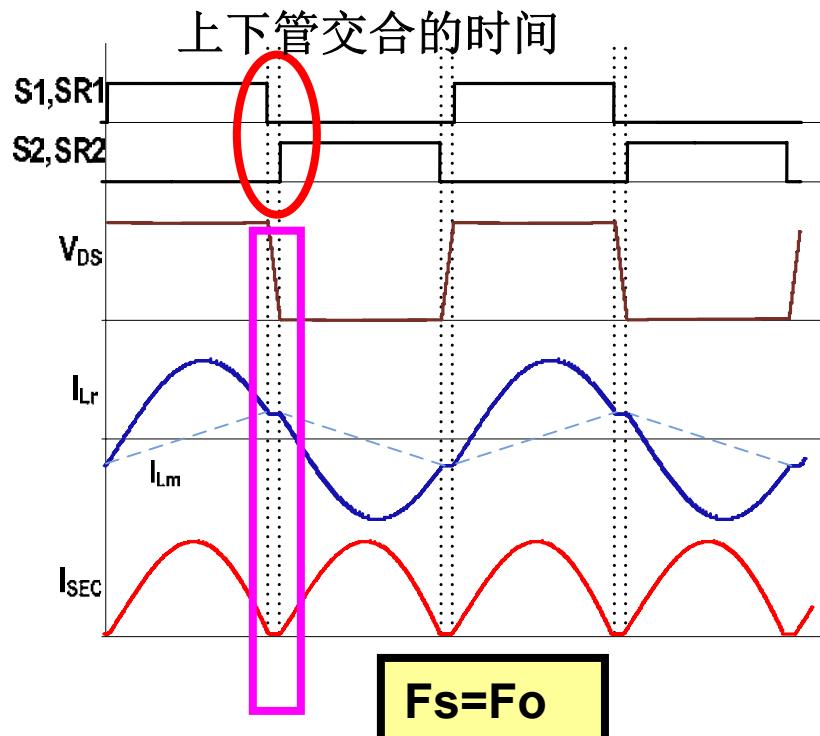
- 1,R<sub>d</sub>s(on)** 导通损耗
- 2,**工作过程中的开关死区损耗（死区时间越小越好）
- 3,**上升下降沿快慢
- 4,**二极管多少存在续流损耗

氮化镓主要是在死区上的损耗大大降低

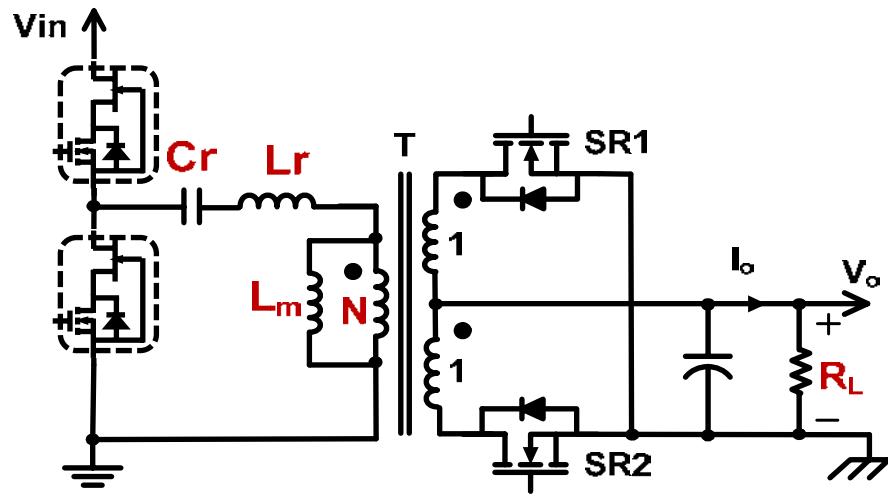
# 氮化镓的LLC电路应用

## High step down LLC Converter

- Input: 380~420V<sub>DC</sub>
- Output: 12V/25A
- F<sub>s</sub>: 500kHz



GaN

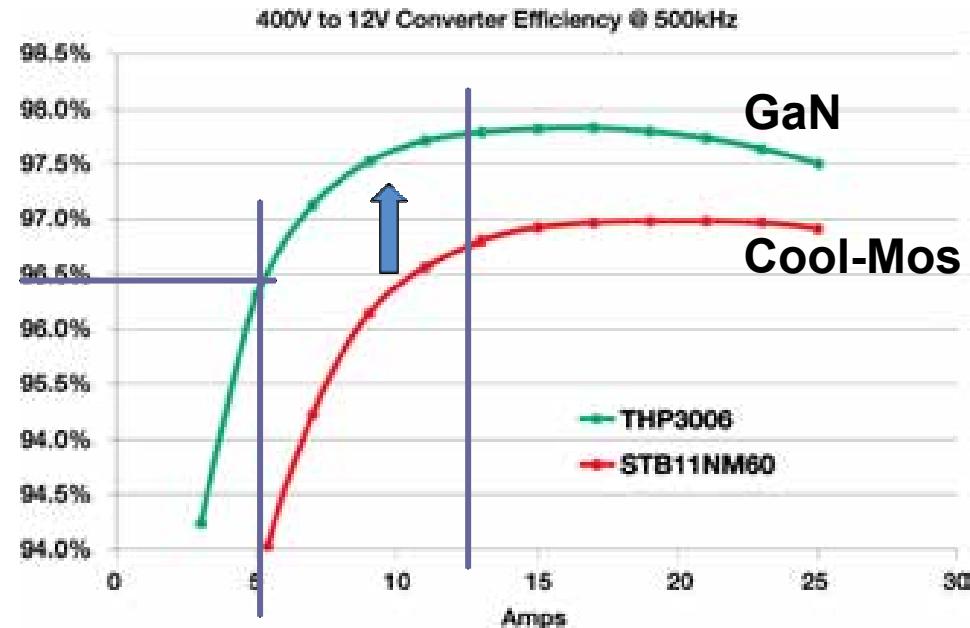
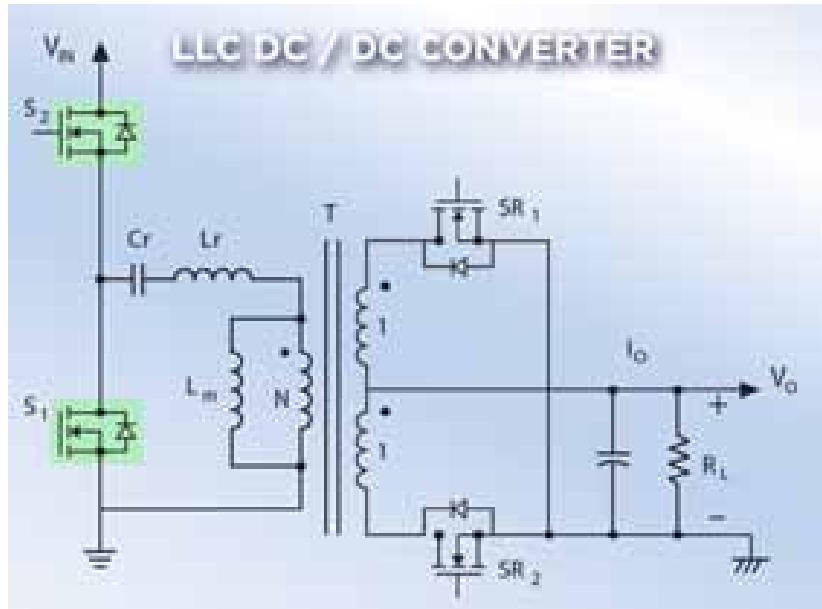


## LLC-DCX , F<sub>s</sub>=F<sub>o</sub>

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

# 基于氮化镓的LLC电路

(效率1%-3%提高等同频率, 等同R<sub>dson</sub>)



Parameters	Value	Parameter	Value
V <sub>in</sub> (V)	400	V <sub>o</sub> (V)/I <sub>o,max</sub> (A)	12/25
L <sub>m</sub> (uH)	100	L <sub>r</sub> (uH)	5.05
C <sub>r</sub> (nF)	15	F <sub>r</sub> (kHz)	530
T <sub>d</sub> (ns)	120	F <sub>s</sub> (kHz)	470

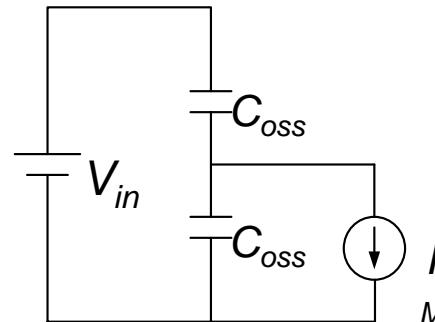
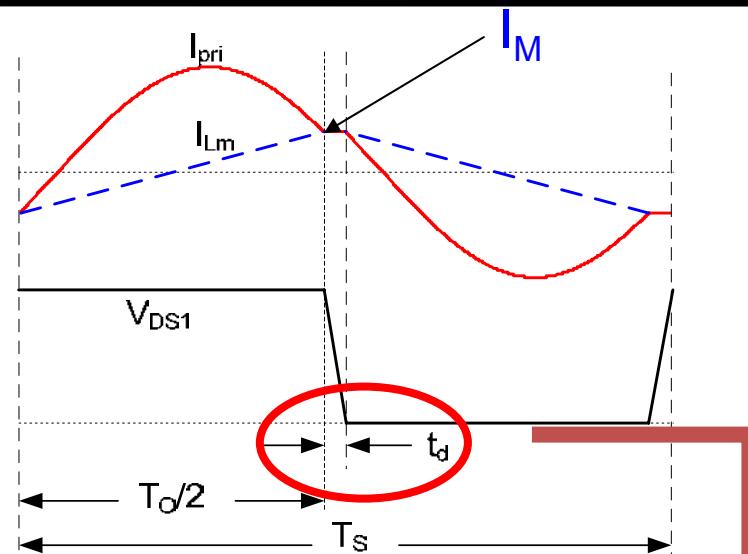
Reduced losses by > 30%

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.

# 用氮化镓来优化死区时间Td和Lm



从公式上看  
死区时间 **Td** 与  
**Coss** 有关系。

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

**Larger  $L_m$ ,**  
**Less circulating energy**

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

**Smaller  $t_d$ ,**  
**Less duty cycle lose**

**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

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

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

With much smaller **Coss**,  
GaN can achieve **both**

# Experiment Platform



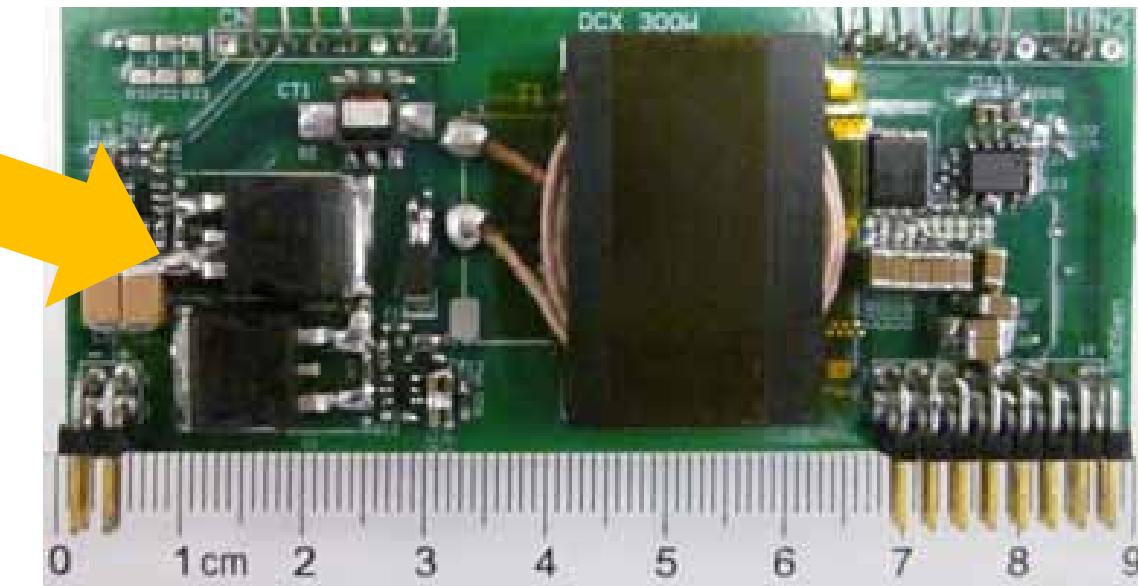
**Cascode GaN:TPH2002**

内阻: 290毫欧

体积30\*90

DC400V – 12V/25A

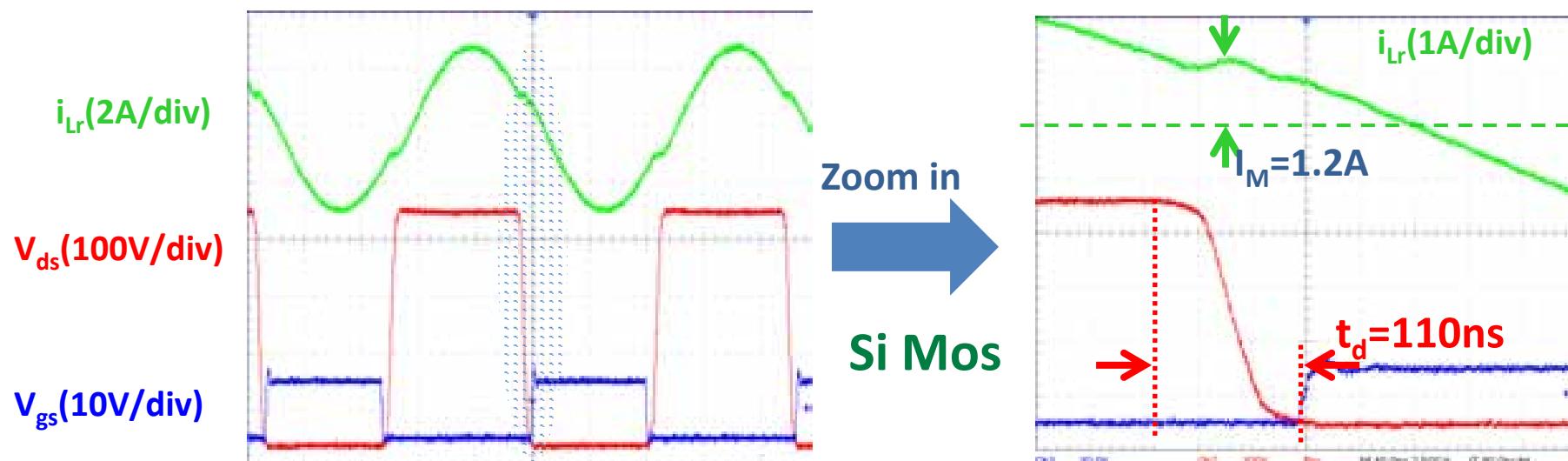
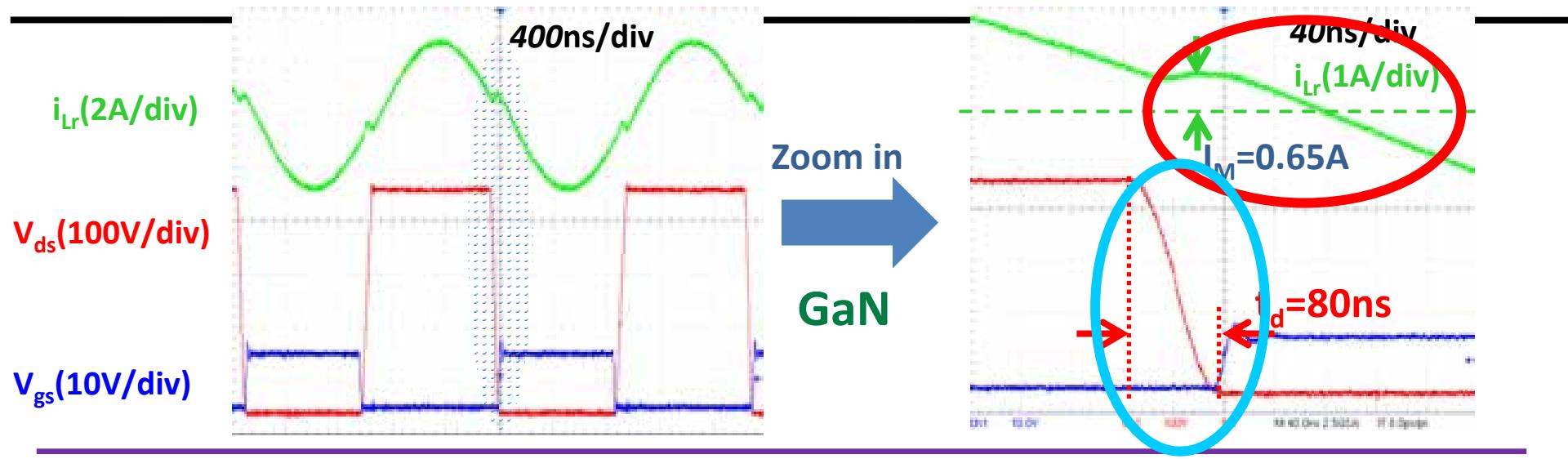
无散热片



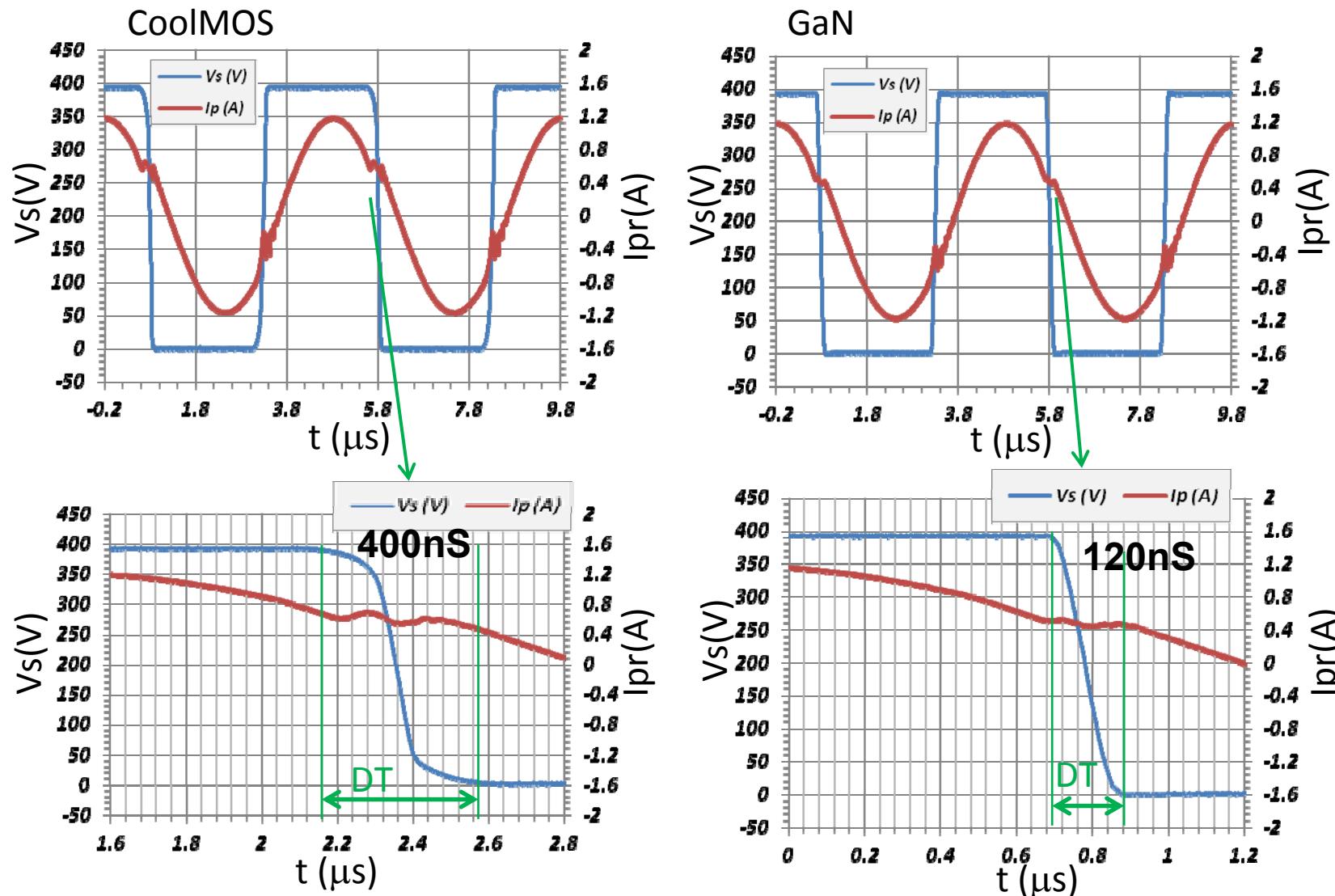
Parameters	Value	Parameters	Value
Vin(V)	400	Vo(V)/I <sub>O</sub> (A)	12/25
Transformer Turn Ratio	16:1	Fs(kHz)	500
Core Material	N49	Primary switch	TPH2002
Core Shape	ER32/5/21	SR	BSC017N04NS

# Experiment Waveforms @500kHz

死区, 上升下降时间及磁化电流等优化很多 (氮化镓与Cool-Mos对比)



# 实际LLC电路上测试的氮化镓波与与Cool-Mos的波形对比



- Si shows large DT: less time for energy transfer: more loss

transphorm

# 产品的应用： Adapter, 高频化使得体积大大变小



5W AC Adapter (80%)  
1" x 1" x 1"



10W AC Adapter  
2" x 2" x 1"

90W: PFC+LLC

65W: FLYBACK

48W: FLYBACK

36W: FLYBACK

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**.温度有所下降。**200K**时提高**1%**效率

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Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

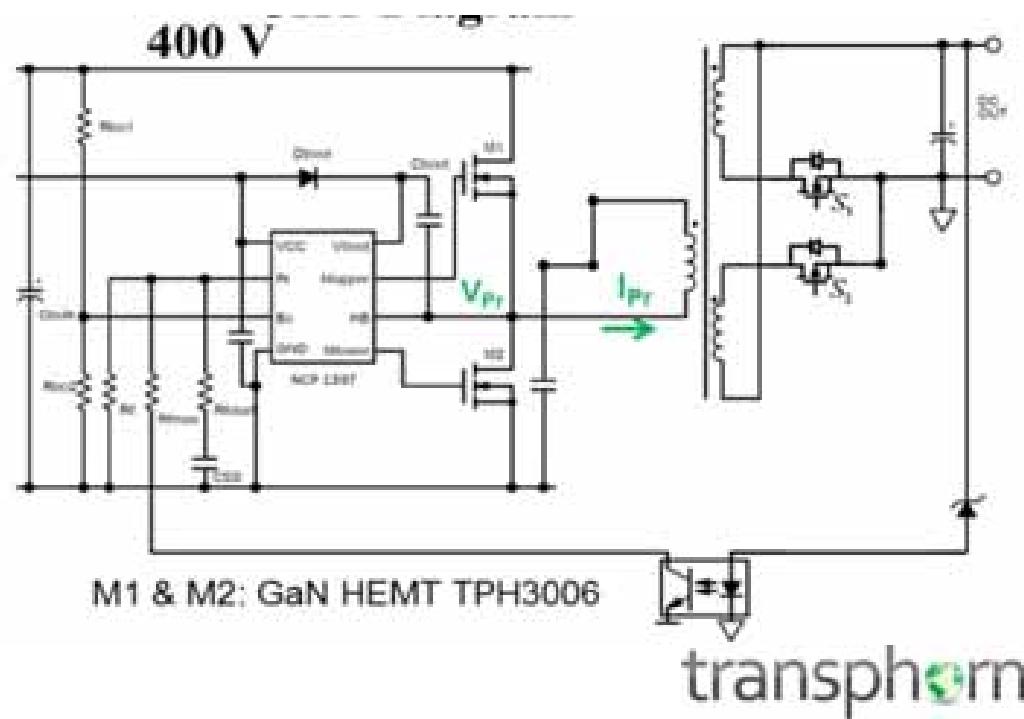
# 产品的应用1: 250W 纯LLC电路 12Vout, 97.5%效率



DC 380Vin  
DC12Vout/20A  
无散热片  
**LLC NCP1392**

**TPH3202PS**  
**650V/10A**

工作频率: 200HZ



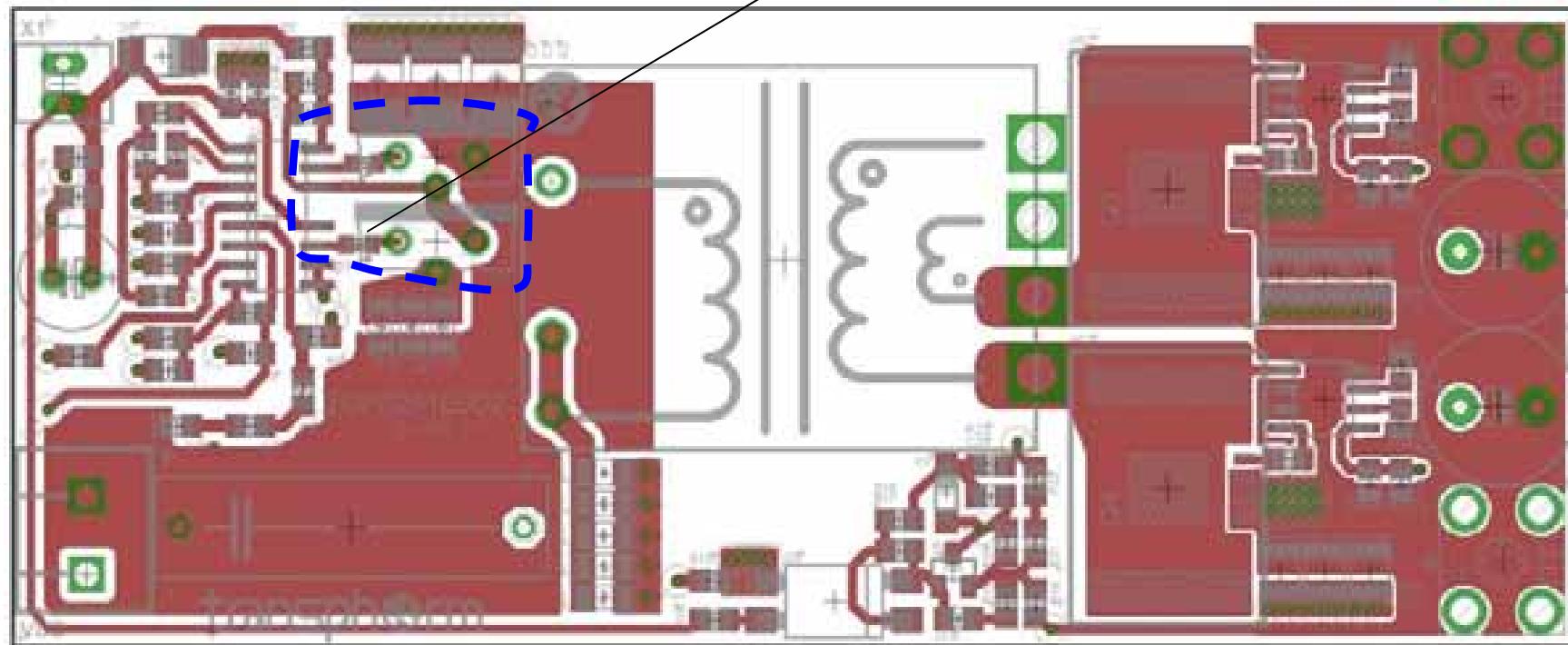
简单框图

## 产品的应用1: 250W 纯LLC电路 12Vout, 97.5%效率

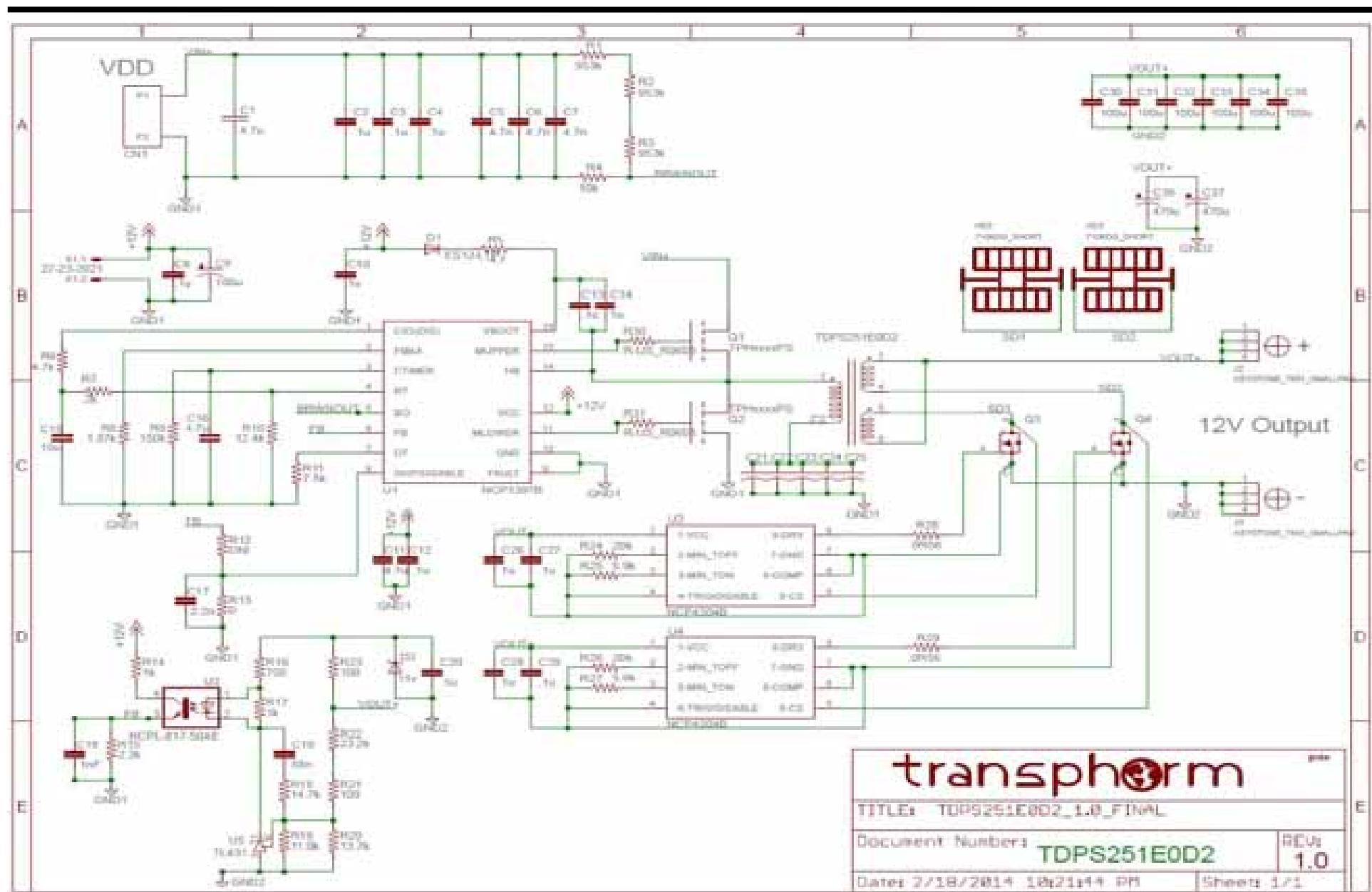
Parameter	TPH3002PS	IPP60R380C6
ID	9A (continuous)	10.6A (for D=0.75)
R <sub>on</sub>	290mΩ	340mΩ
Q <sub>g</sub>	6.2nC	32nC
E <sub>oss</sub> (400V)	3.1uJ	2.8uJ
Q <sub>rr</sub>	29nC	3.3uC

等同功率用氮化镓与**Cool-Mos**设计参数上对比  
可以看出氮化镓有明显的优势（最右边**Cool-Mos**）

驱动做到最小距离

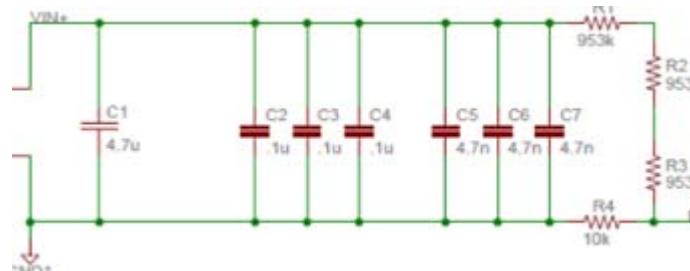


# 产品的应用1: 250W 纯LLC电路 12Vout, 97.5%效率



## 产品的应用1: 250W 纯LLC电路 12Vout, 97.5%效率

Pin (W)	Pout (W)	Ploss (W)	Eff (%)
32.46	30.86	1.60	95.06
63.28	61.34	1.94	96.93
95.87	93.36	2.51	97.39
128.00	124.75	3.25	97.46
158.31	154.16	4.15	97.38
188.39	183.16	5.24	97.22
220.13	213.45	6.67	96.97
250.16	241.86	8.30	96.68



去耦电容尽可能靠近  
两管间

## 产品的应用2: PFC+LLC 一体板 250W 12Vout, 96%效率



**AC 90—260V输入  
DC12Vout/20A  
LLC部分无散热片  
PFC NCP1654 200KHZ  
LLC NCP1397 200KHZ**

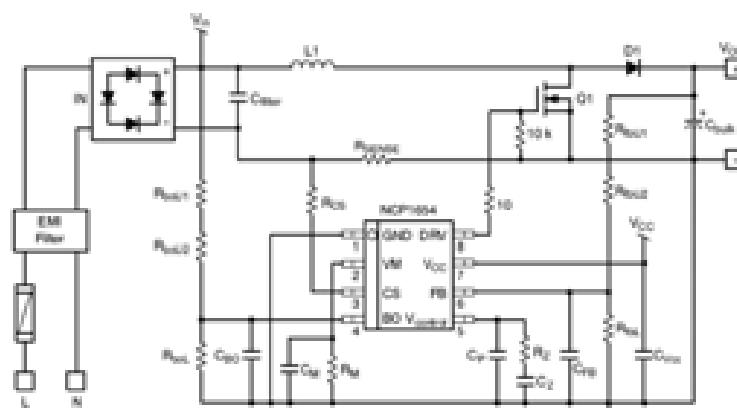
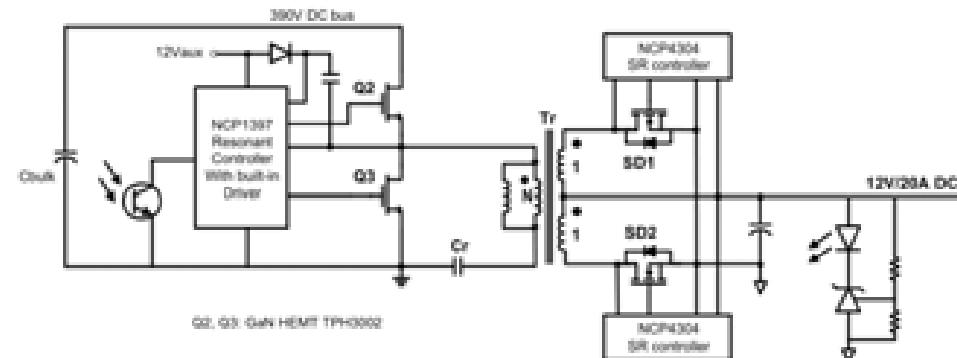
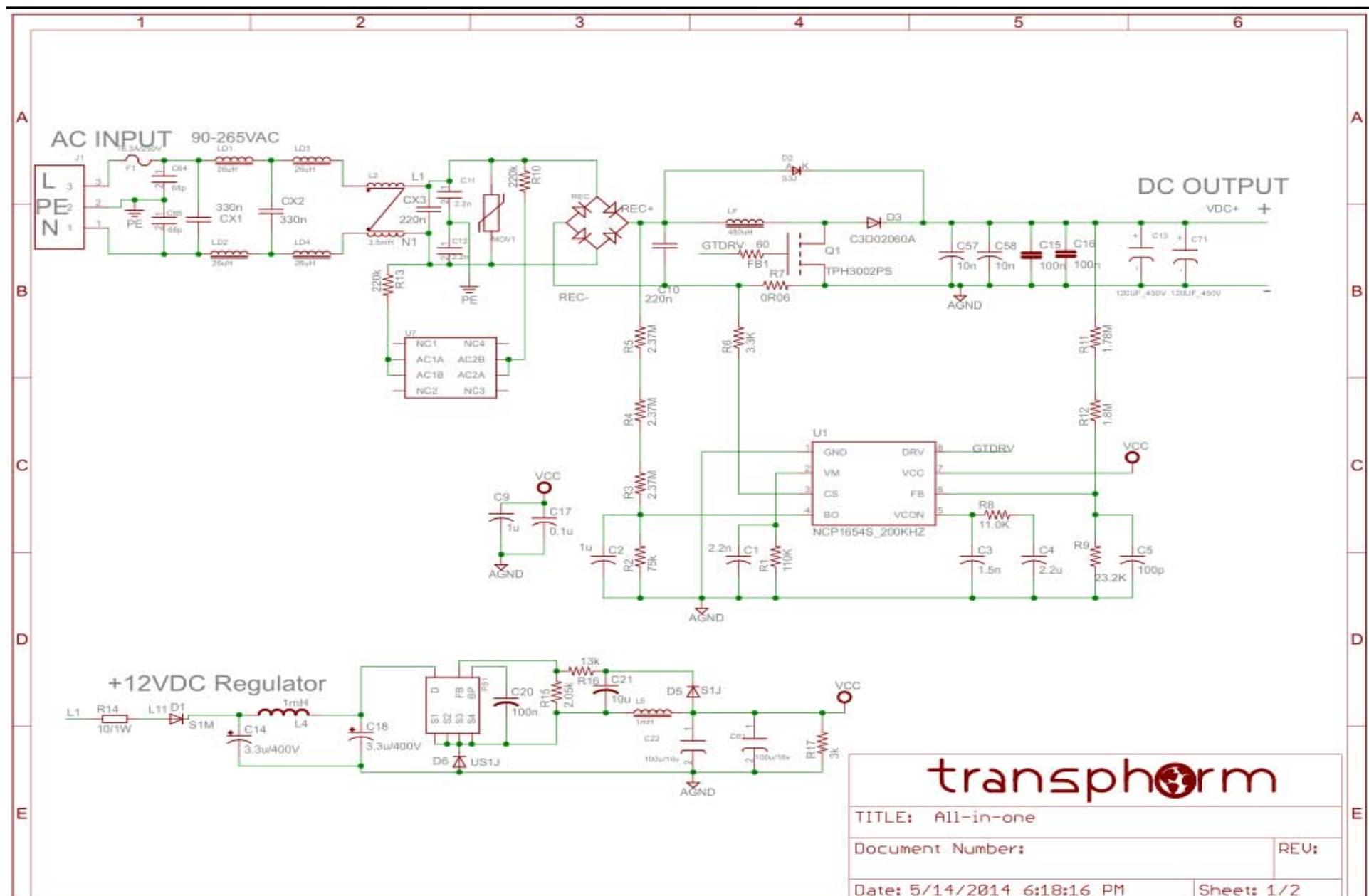


Figure 4 Generic NCP1654 Application Schematic

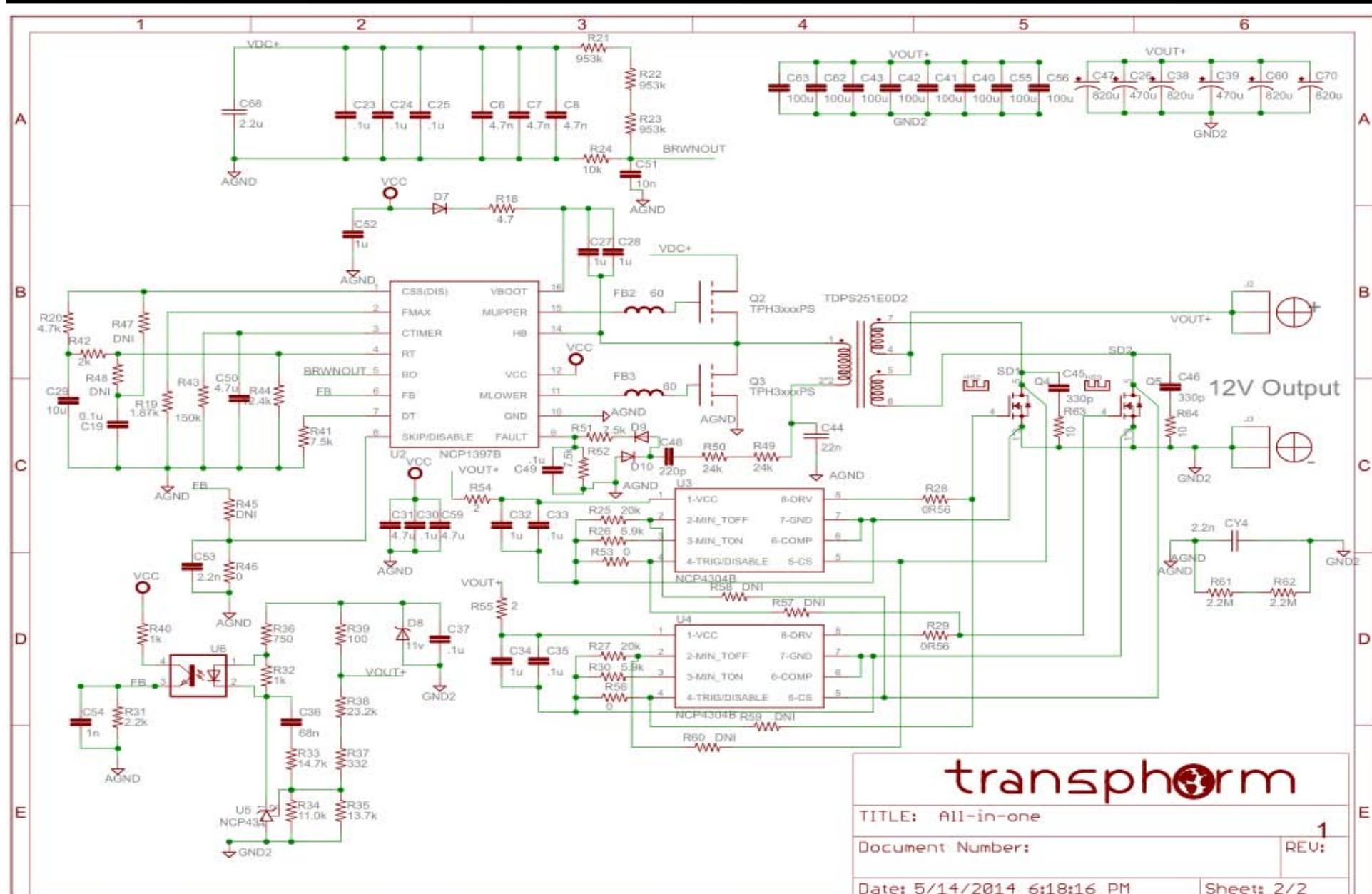


transphorm

## 产品的应用2: PFC+LLC 一体板 250W 12Vout, 96%效率



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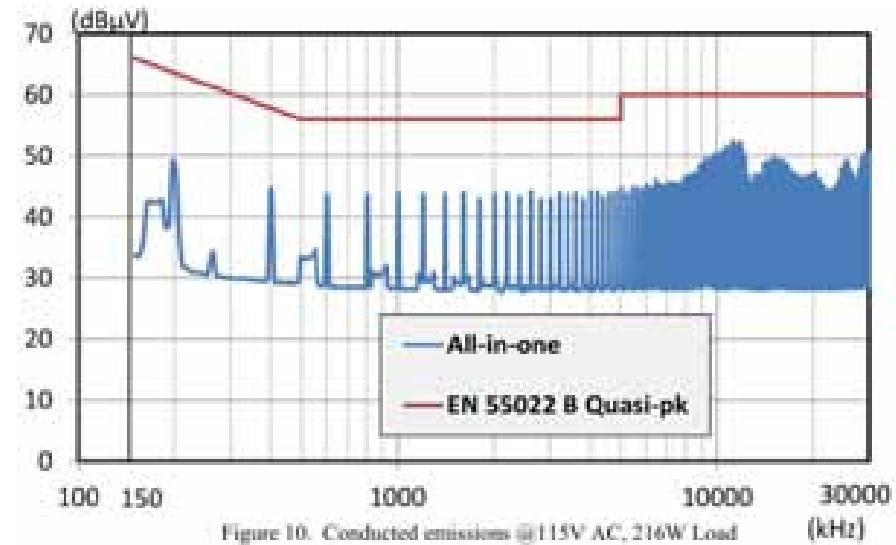
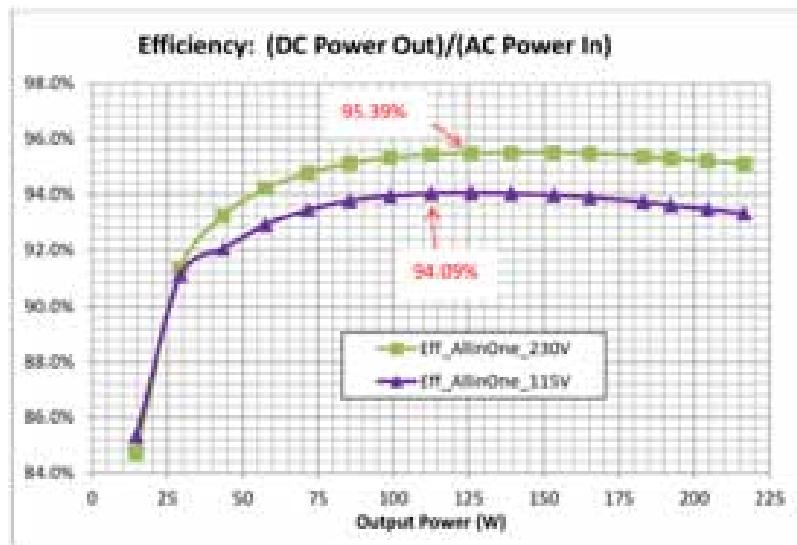
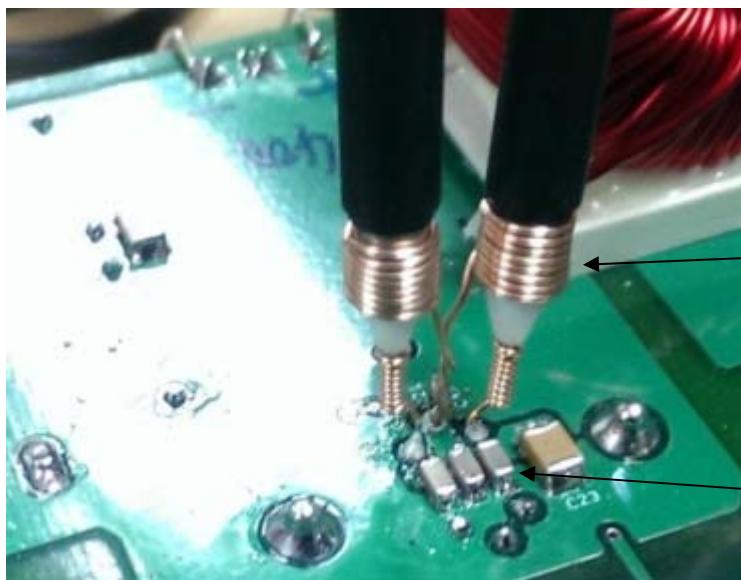


Figure 10. Conducted emissions @ 115V AC, 216W Load



探头最小环测试

高频去耦电容尽可能  
靠近上下管间

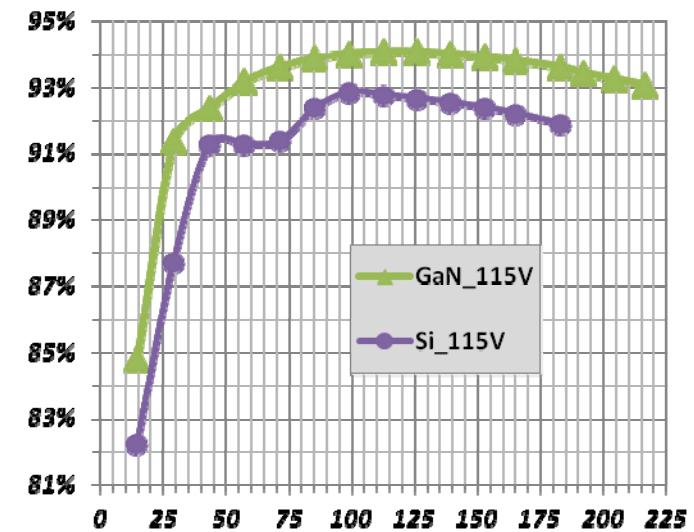
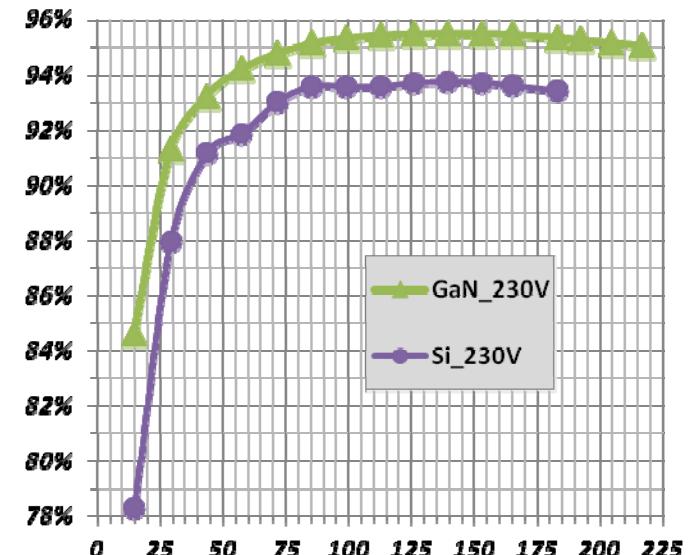
## 产品的应用2: PFC+LLC 一体板 250W 12Vout, 96%效率



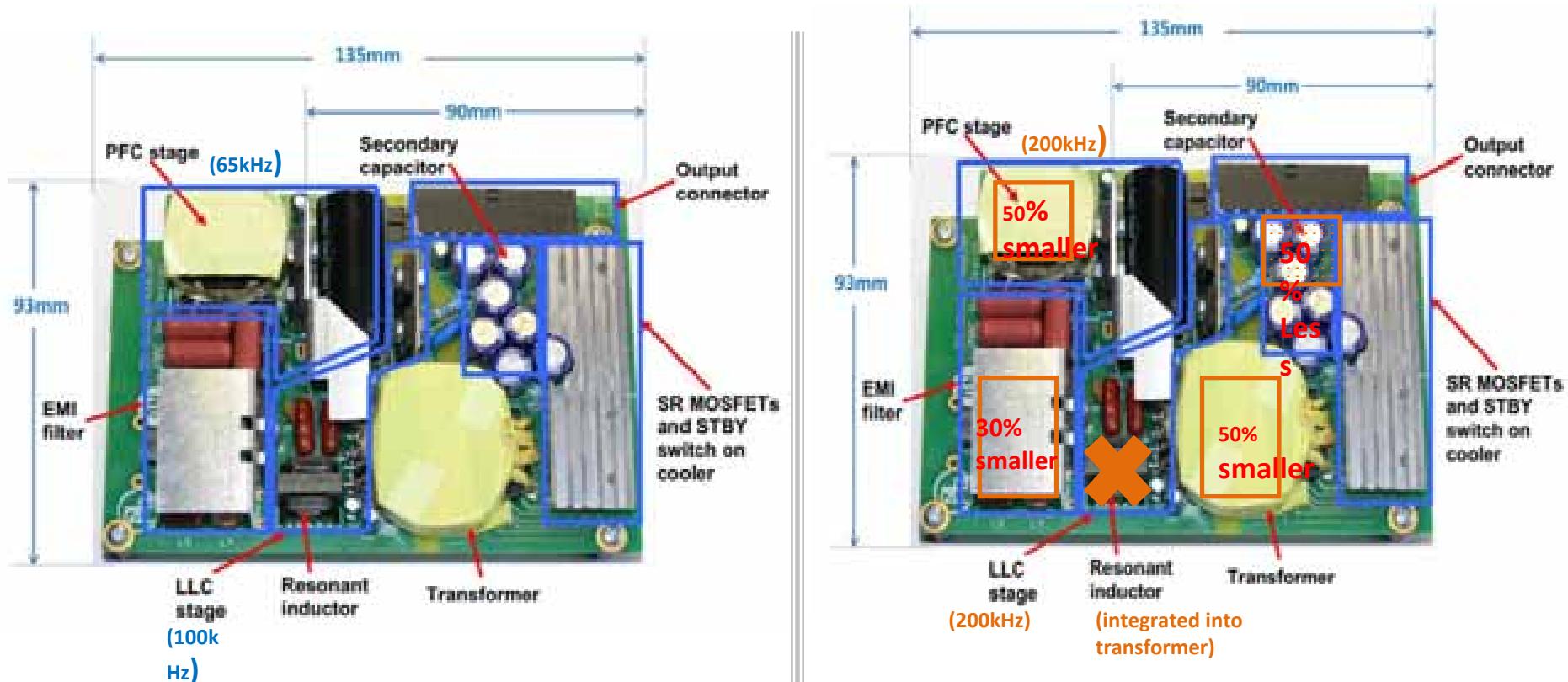
氮化镓方案  
R<sub>ds(on)</sub>:300mOHM

原Cool-mos  
199C6方案  
R<sub>ds(on)</sub>: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**



## 产品的应用2: PFC+LLC 一体板 250W 12Vout, 96%效率



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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Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

## 产品的应用3：单极PFC 1000W, 98.3%效率

90—260V输入，输出400V 133KHZ

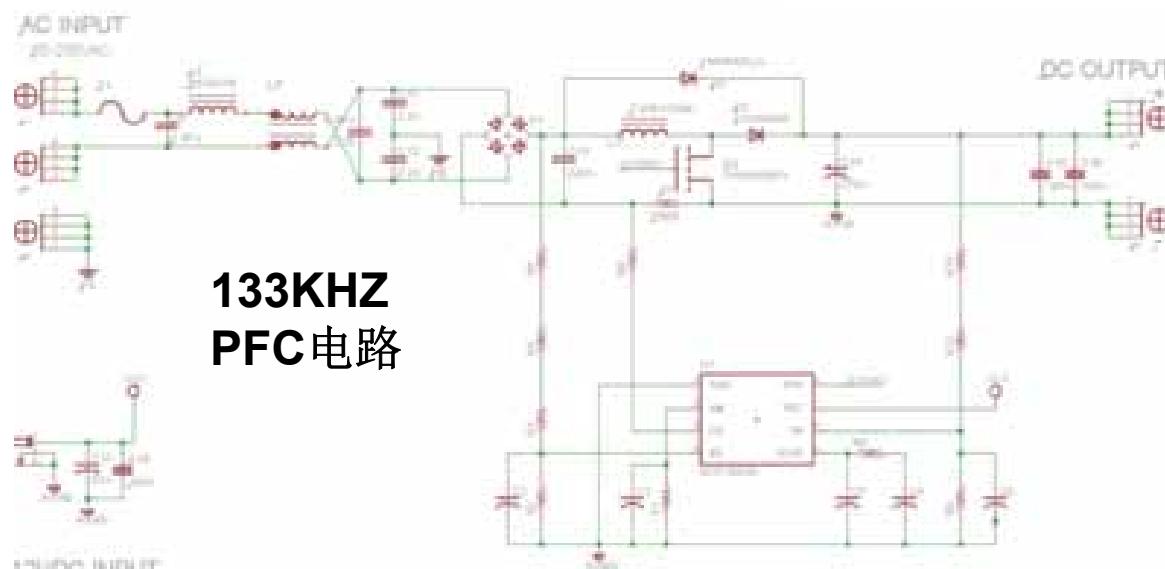


AC 90—260V输入

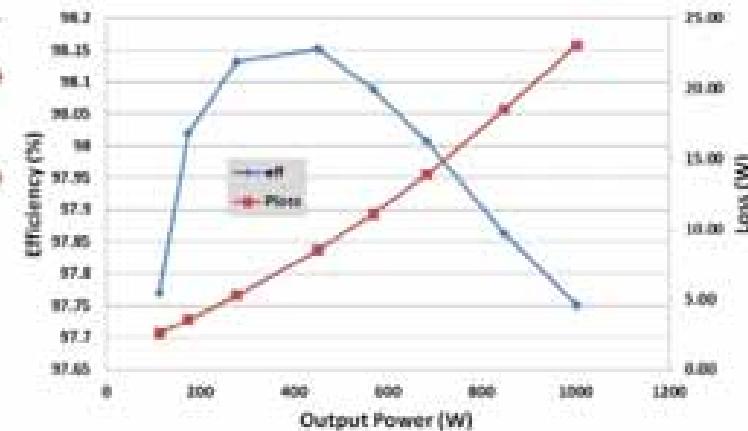
纯PFC电路，

NCP1653 133KHZ

采用一个TPH3206PS 650V/17A氮化  
镓，二极管采用所碳化硅



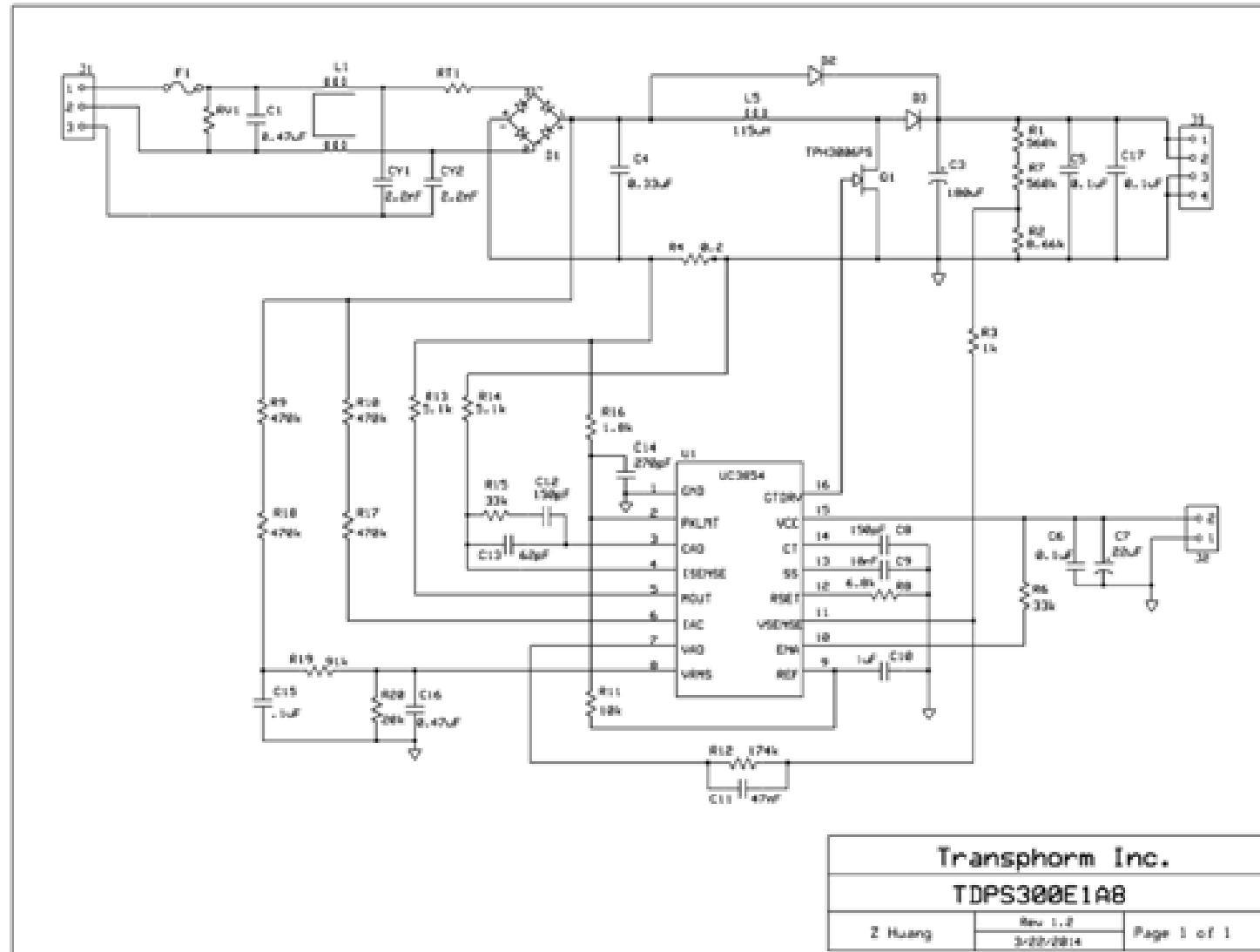
133KHZ  
PFC电路



UAIICP1653

# 产品的应用3：单极PFC 1000W, 98.3%效率

90—260V输入，输出400V 133KHZ



采用**750KHZ**  
的**PFC**电路  
**UC3854**  
**97.3%**效率

transphorm

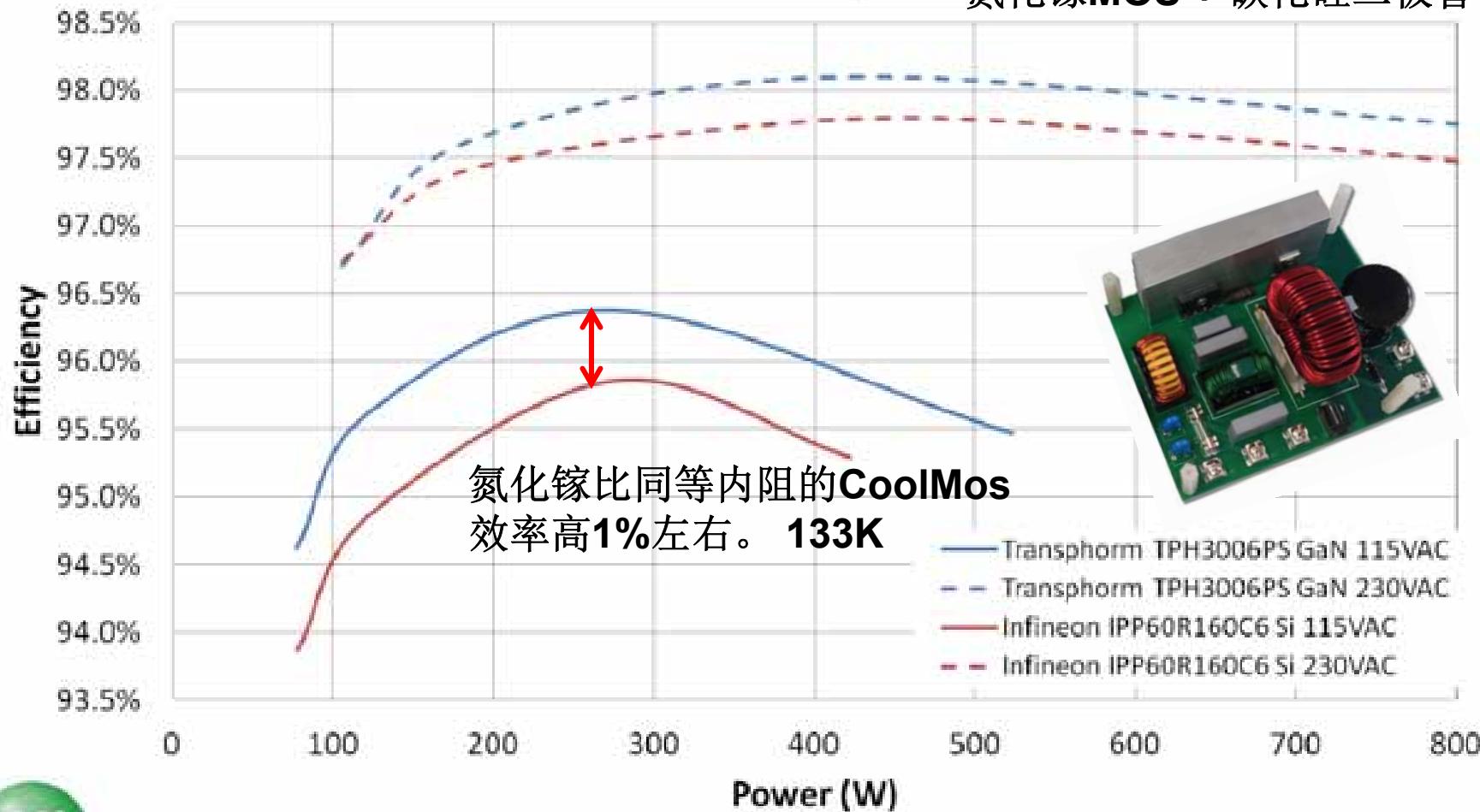
## 产品的应用3：单极PFC 1000W, 98.3%效率

90—260V输入，输出400V 133KHZ

PFC芯片：NCP1654-133

Switch Efficiency

氮化镓MOS + 碳化硅二极管

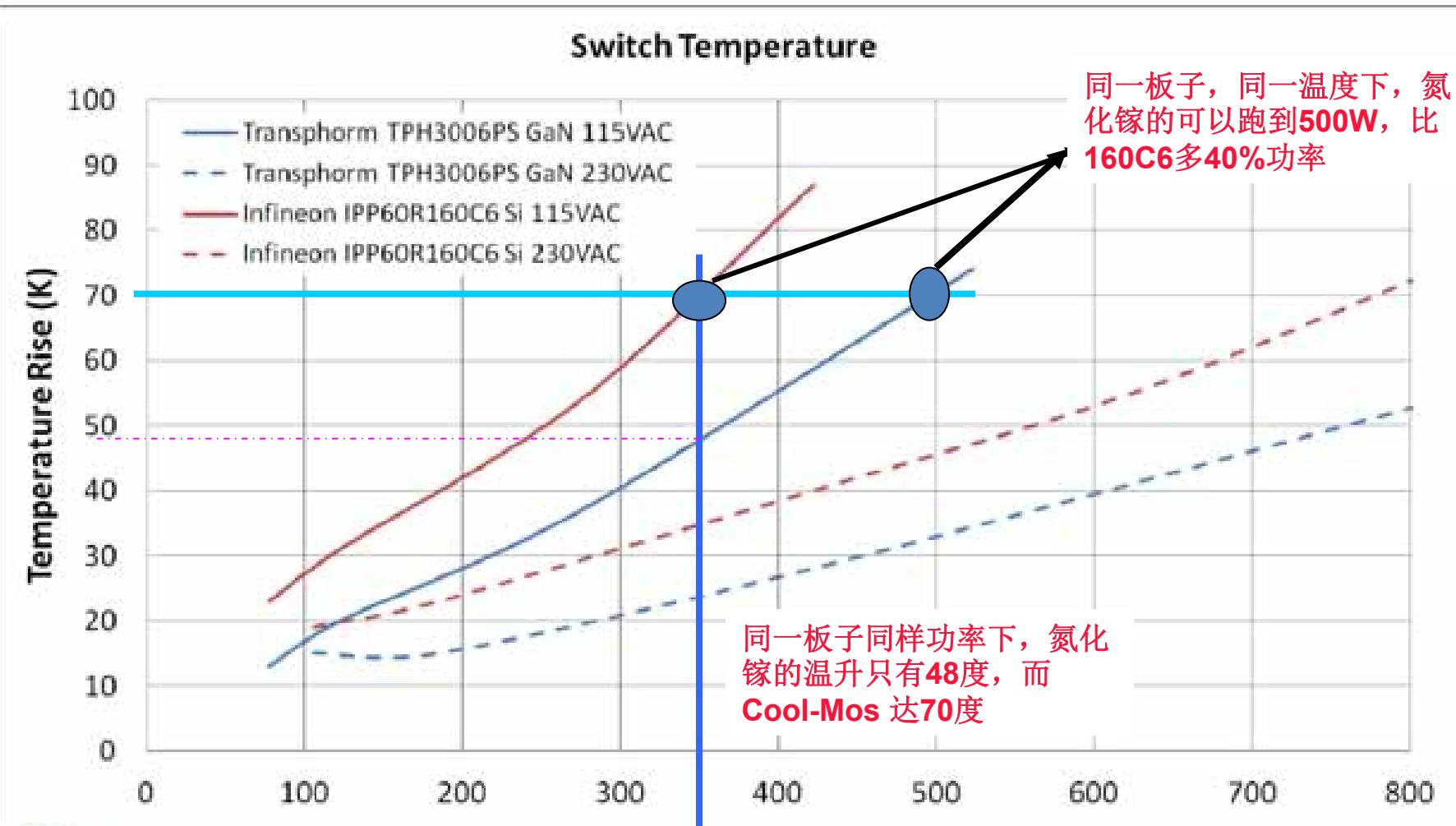


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Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

## 产品的应用3：单极PFC 1000W，98.3%效率

90—260V输入，输出400V 133KHZ



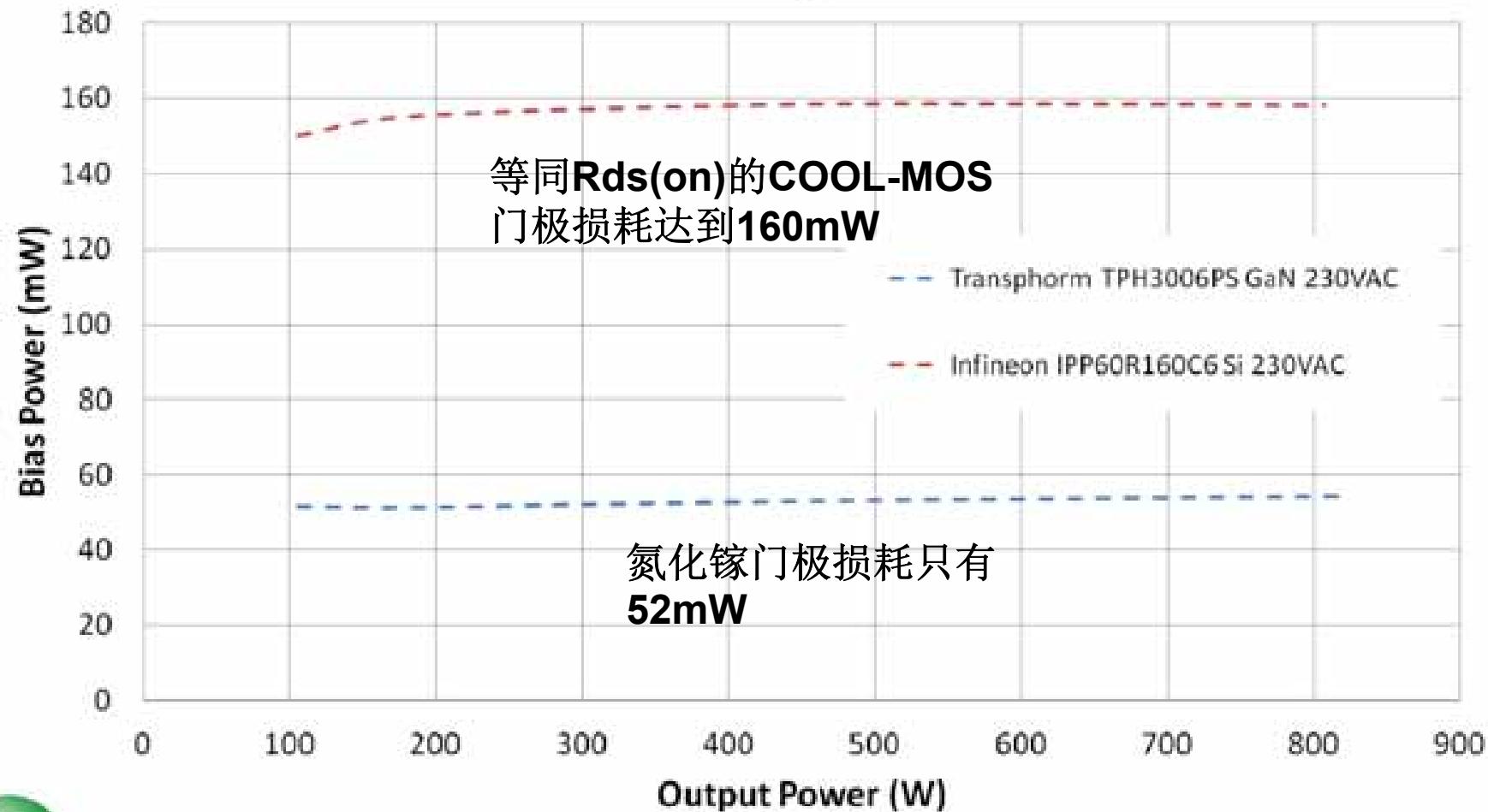
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Transphorm Shanghai  
Tel:13501775977  
Mail: hz021@qq.com

## 产品的应用3：单极PFC 1000W，98.3%效率

90—260V输入，输出400V 133KHZ

### PFC板上的门极损耗对比 Bias Power Bias Consumption



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Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

# 产品的应用4：DC/AC 1000W-300逆变器 99%效率

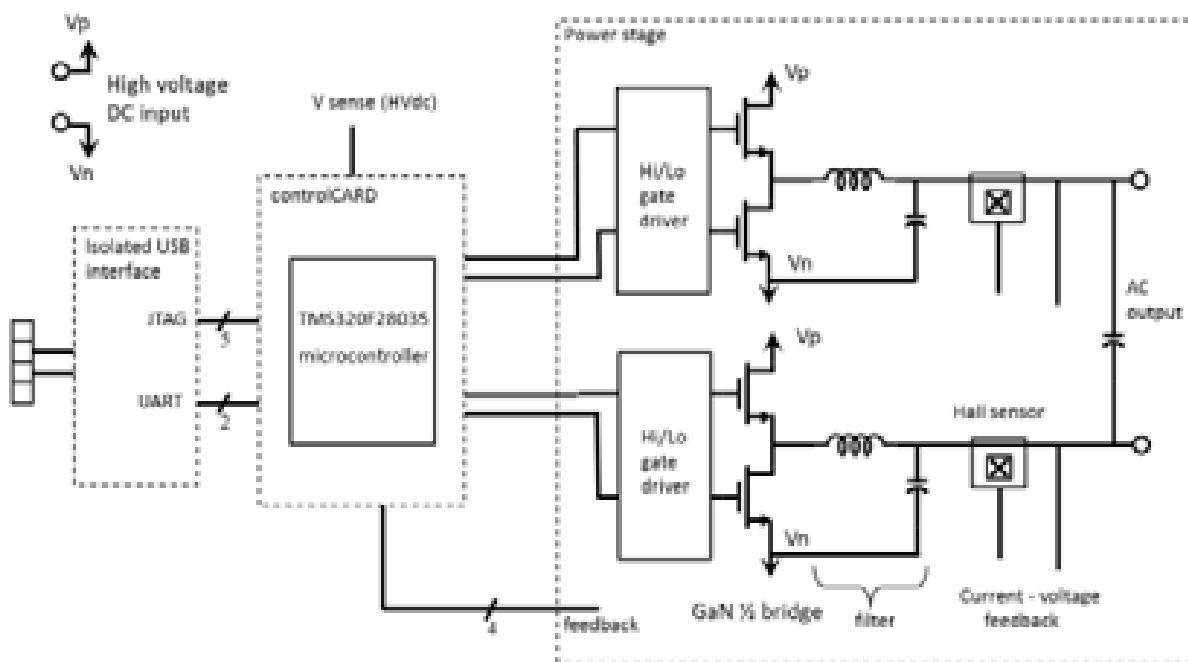


4pcs TPH3206PS 650V/17A

工作频率100KHZ

电感体积变小，周边电路简化

98.7%效率



DSP:TMS320F28035

隔离驱动SI-8230

## 产品的应用4：DC/AC 1000W-300逆变器 99%效率

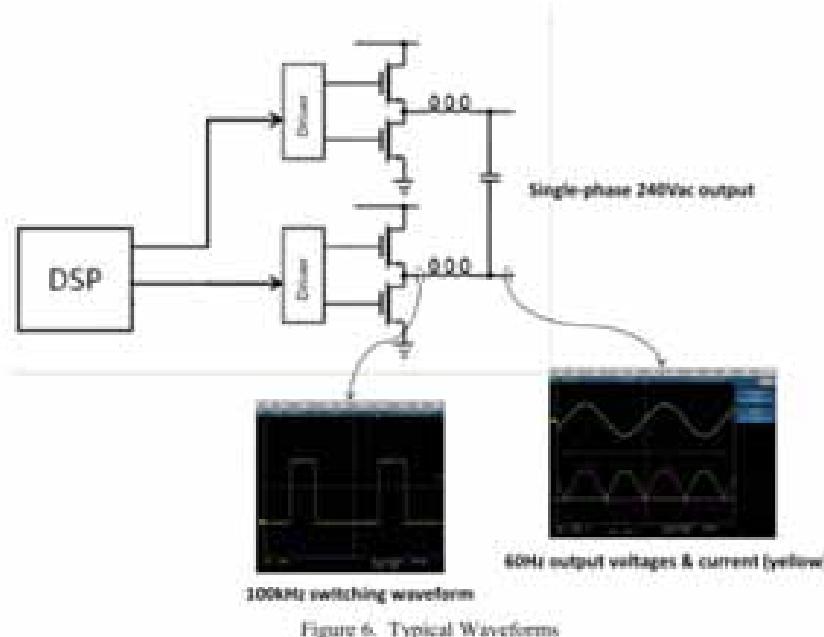


Figure 6. Typical Waveforms

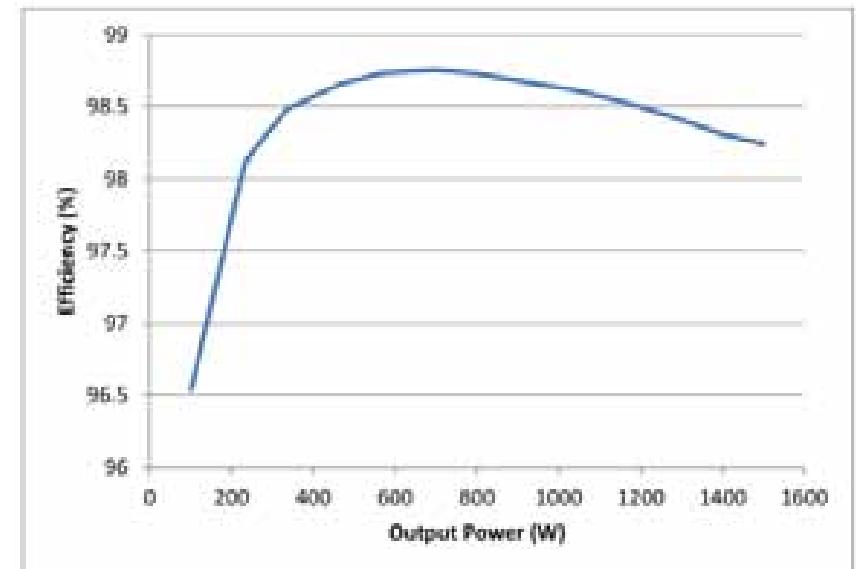


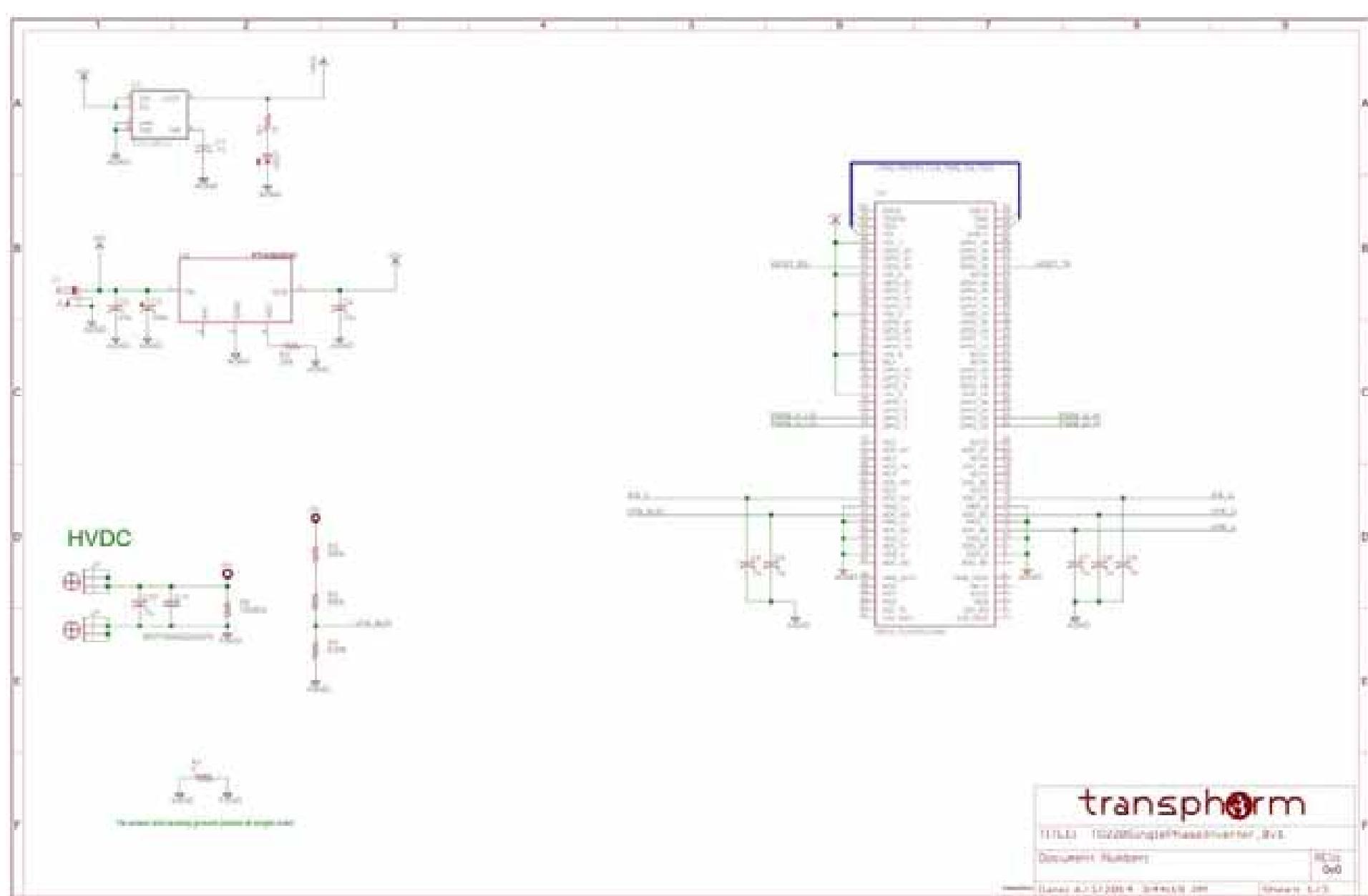
Figure 7. Typical Efficiency 240Vac output



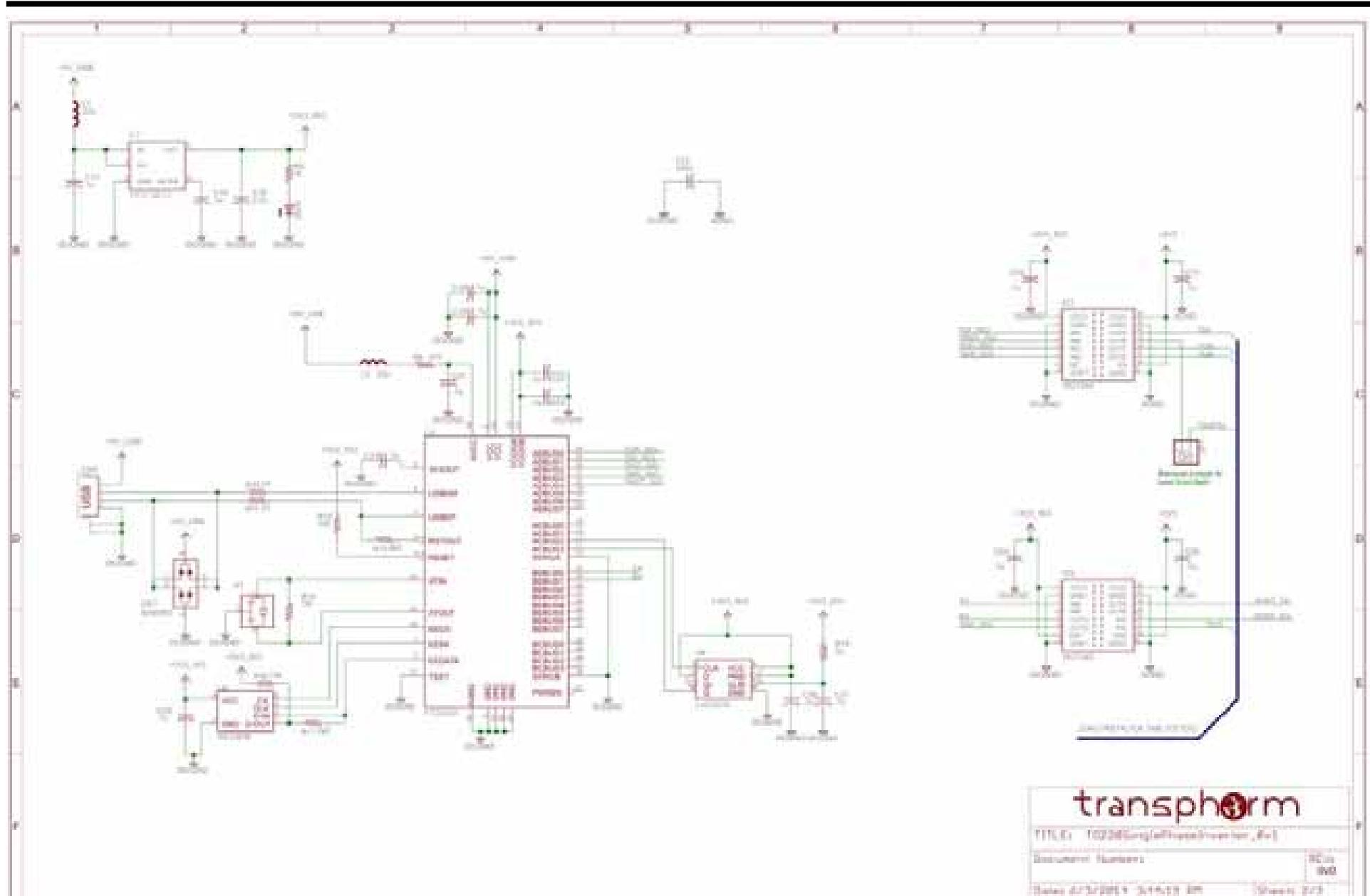
transphorm

3000W方案  
采用TO-247氮化镓

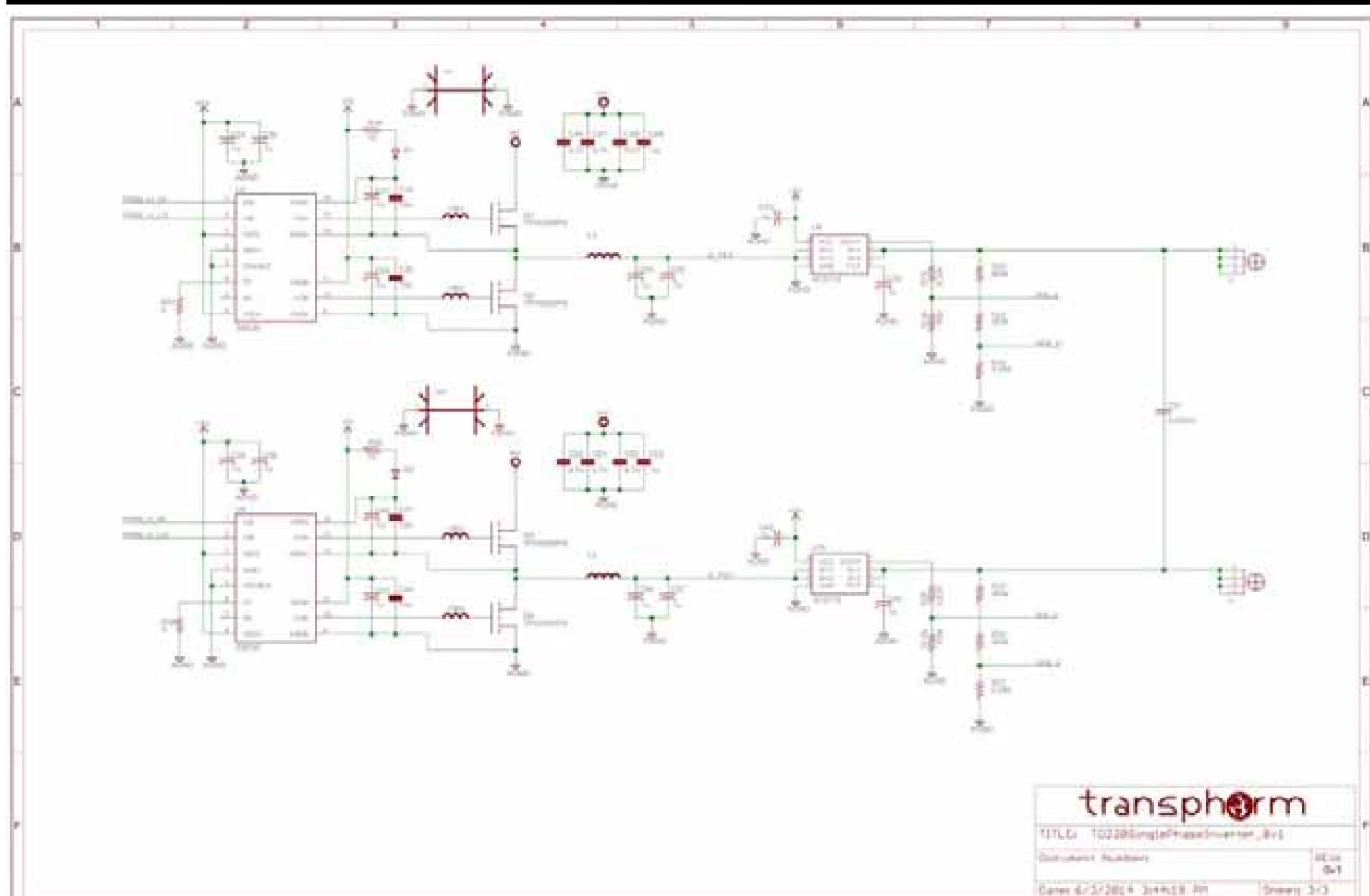
## 产品的应用4：DC/AC 1000W-300逆变器 99%效率



## 产品的应用4：DC/AC 1000W-300逆变器 99%效率



## 产品的应用4：DC/AC 1000W-300逆变器 99%效率



# 产品的应用4：DC/AC 1000W-300逆变器 99%效率



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)

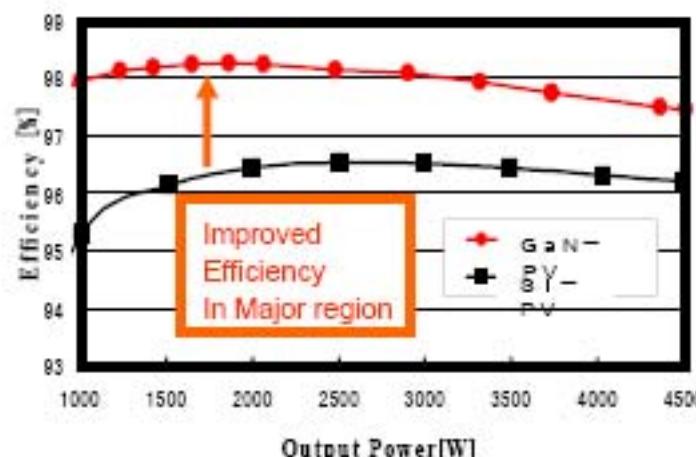
同样大的逆变器产品,氮化镓的体积减小了一半左右,同时整体成本下降**100USD**,售价反提高了**100USD**. 效率反提高了1.5个点. **4500W**, 频率从**16K**提到到**50K**

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



## 产品的应用4：DC/AC 5000W逆变器 99%效率



- 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.

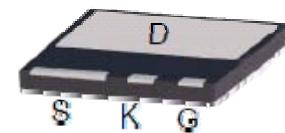
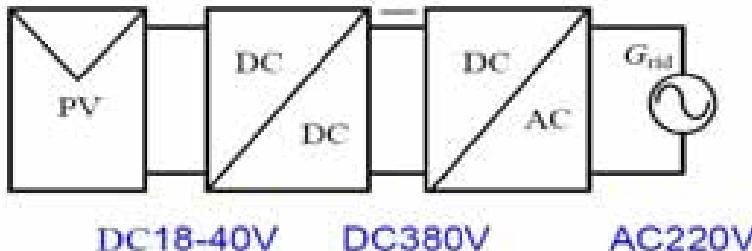
40% volume reduction

>40% loss reduction

transphorm

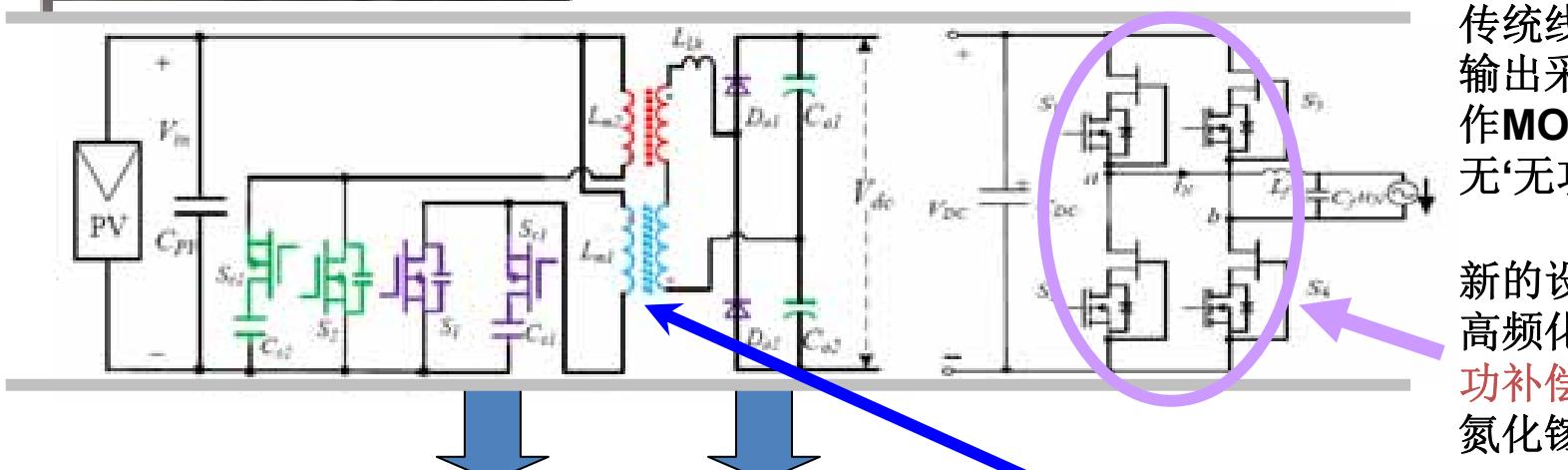
Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

## 产品的应用4：DC/AC 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’

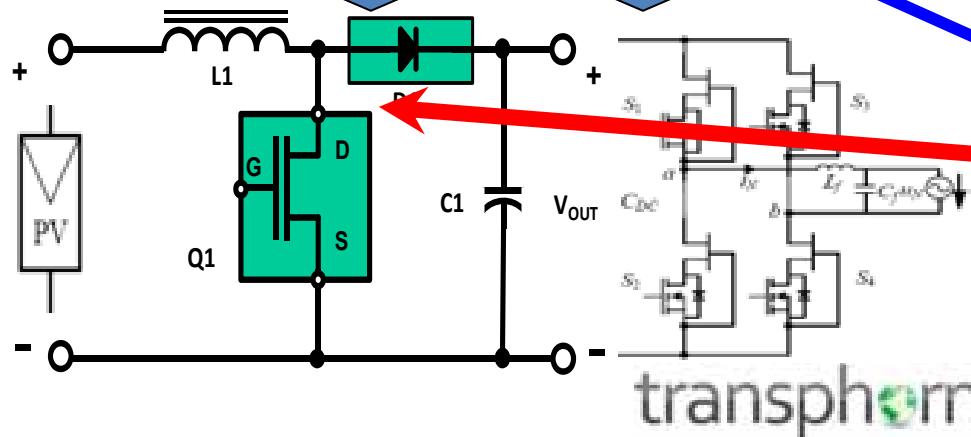
新的设计需要输出逆变  
高频化以尽可能提高**无  
功补偿**  
氮化镓适合高频，高效



传统的采用变压器升压**400V**

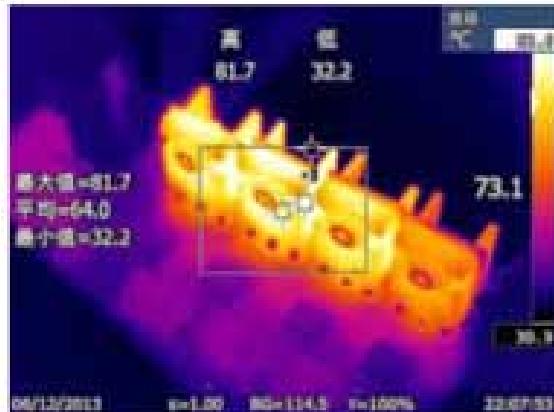
因氮化镓支持大比例升压且高效率达**98以上**。  
不同于传统的**硅MOSFET**, 可直接**boost**升压

\* 降低成本，空间节省



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## 产品的应用4：DC/AC 微型逆变器应用



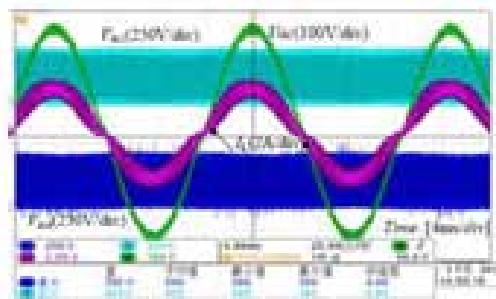
IPB60R190C6 500w温度测试



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%



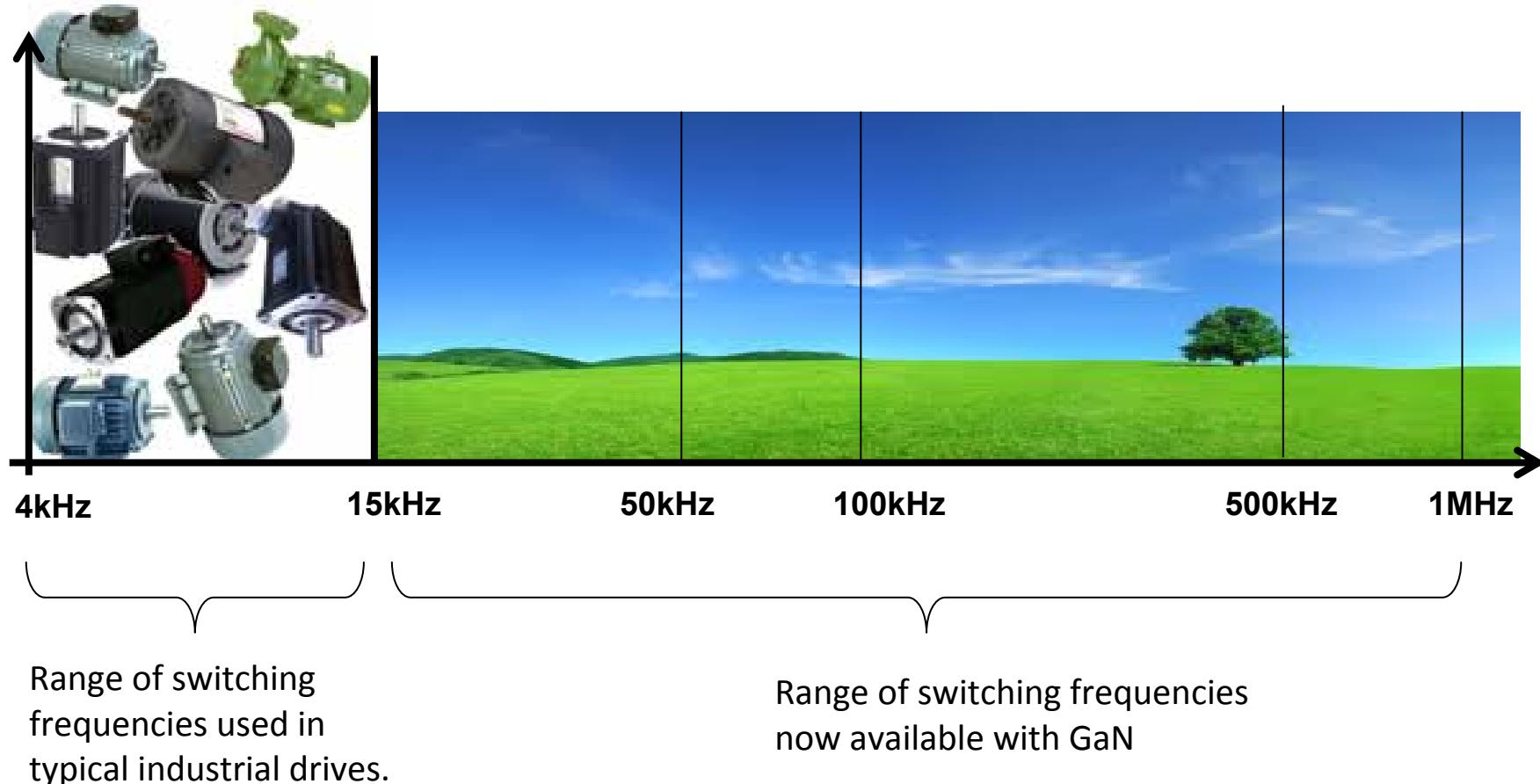
基于Cascode GaN HEMT单相逆变器实验结果



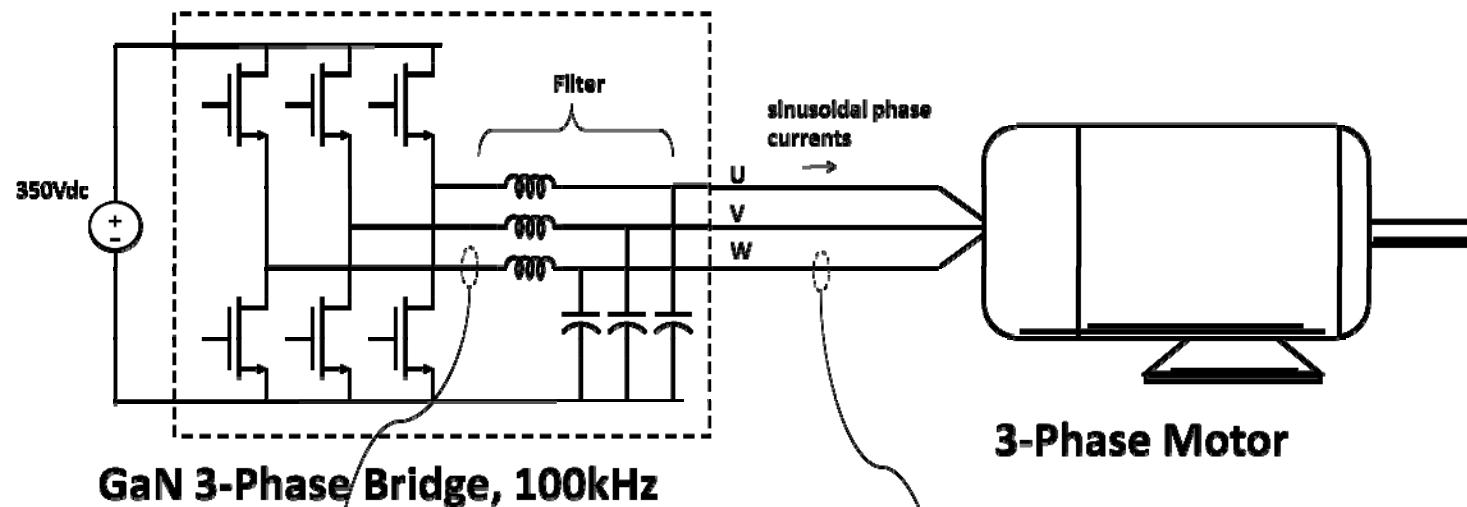
基于GaN HEMT逆变器实物

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%**

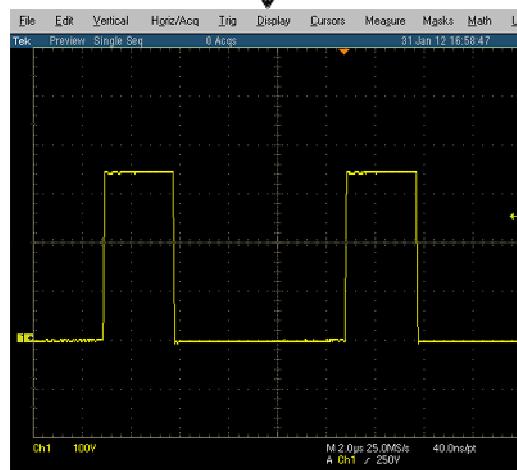
## 产品的应用4：DC/AC 电机马达应用



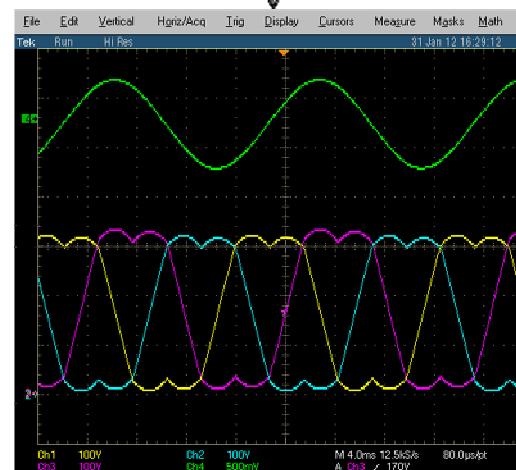
## 产品的应用4：DC/AC 电机马达应用 -采用高频化的优势



GaN 3-Phase Bridge, 100kHz



100kHz switching waveform



phase voltages  
phase current (green)

### Features:

- High frequency enables small output filters
- Pure sine output

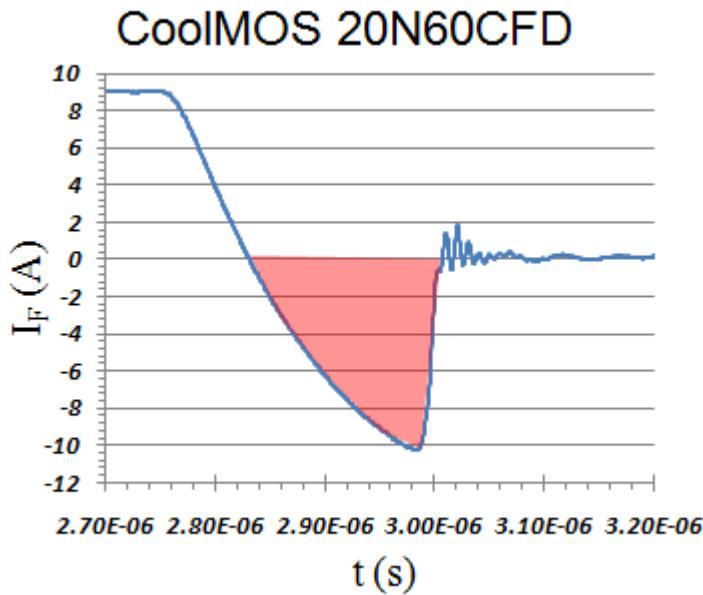
### Benefits:

- Less motor loss due to distortion.
- Less insulation stress and EMI due to transients.
- Less loss in the inverter due to external capacitance.

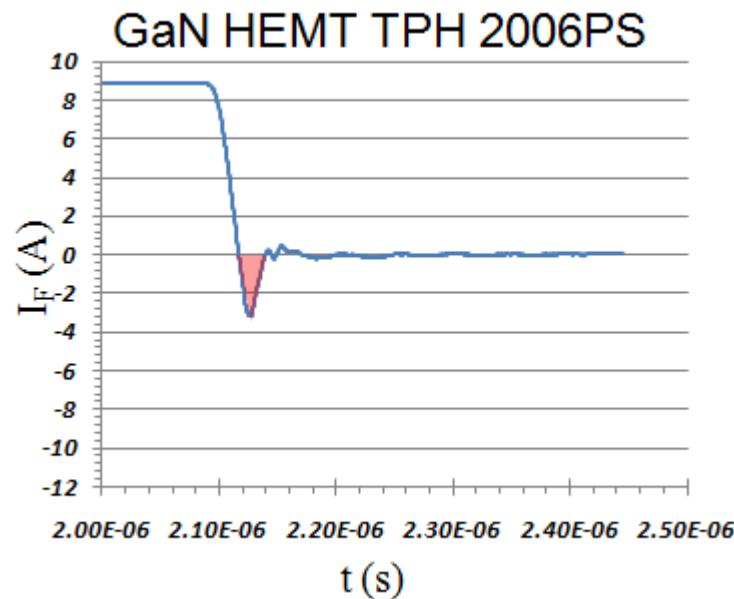
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## Qrr Measurement Confirms GaN HEMT's 25x Advantage

---



$Q_{rr}=1000\text{nC}$  at 9A, 400V

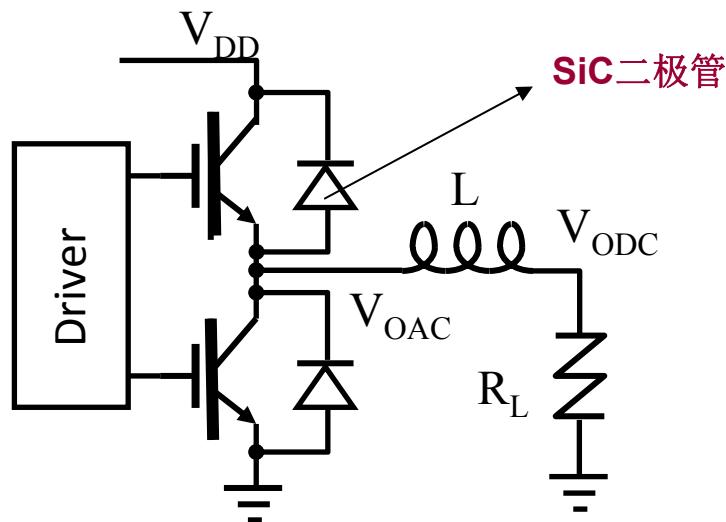


$Q_{rr}=40\text{nC}$  at 9A, 400V

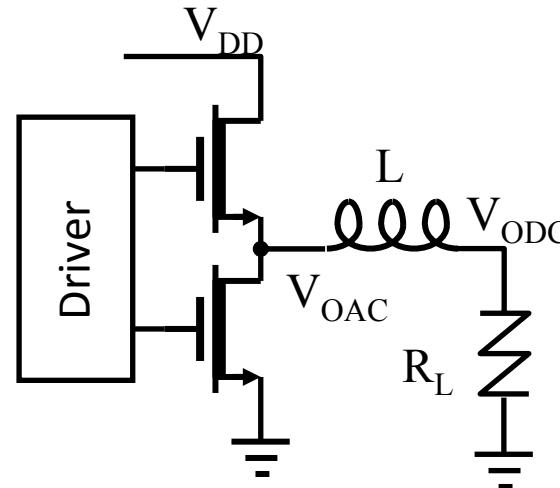
- Both measured in the same test board
- Transphorm GaN HEMT was tested at  $450\text{A}/\mu\text{s}$  with little ringing
- CoolMOS was not stable at  $450\text{A}/\mu\text{s}$ .  $dI/dt$  reduced to  $100\text{A}/\mu\text{s}$  for stability.
- GaN HEMT has Qrr of 25x less than CFD-type CoolMOS (Low Qrr design).

# Performance Benchmarking Between IGBT and GaN Bridges

Si IGBT Bridge Converter



GaN Bridge Converter



- Buck converter is configured from a half bridge
- 2 state-of-the-art HF IGBTs + 2 state-of-the-art SiC SBDs were used in IGBT bridge
- 2 Transphorm GaN HEMTs were used in GaN bridge

Spec comparison:

$V_{bd}$

*IGBT*

*GaN*

600 V

600 V

$I_{max} \text{ at } 25^\circ\text{C}$

23 A

19A

$I_{max} \text{ at } 100^\circ\text{C}$

12 A

14A

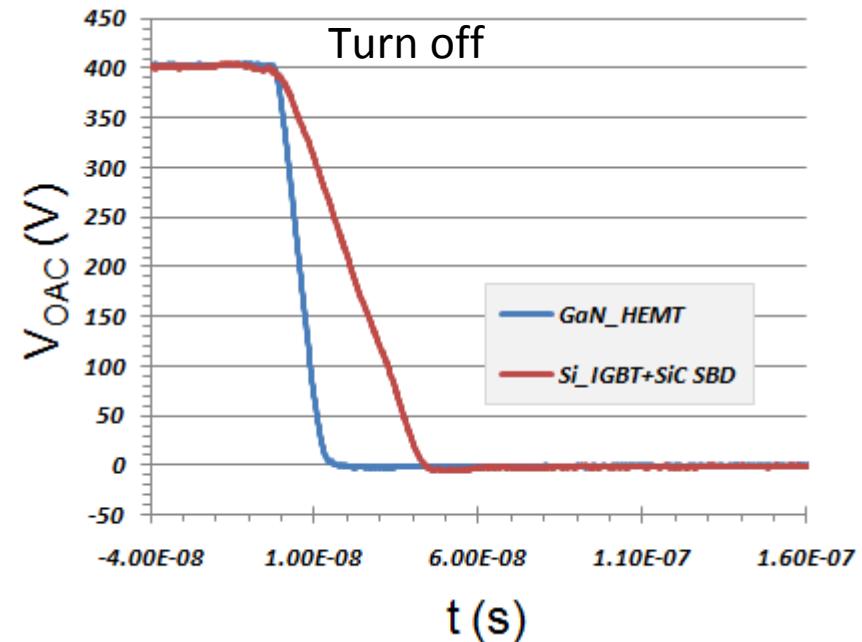
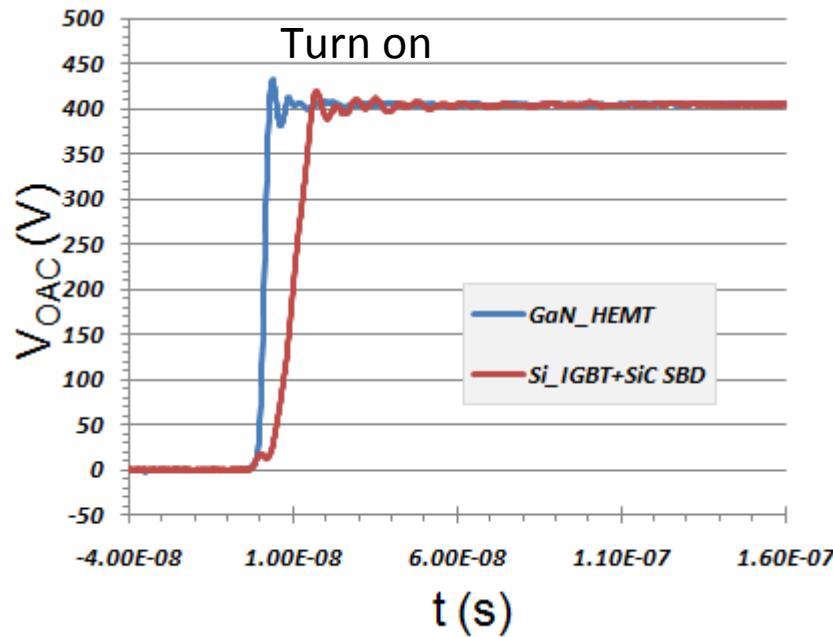
$V_{ce} (Ron)$

2.1 V at 12A

(0.15  $\Omega$ )

transphorm

# Output Waveform comparison: IGBT and GaN Bridges



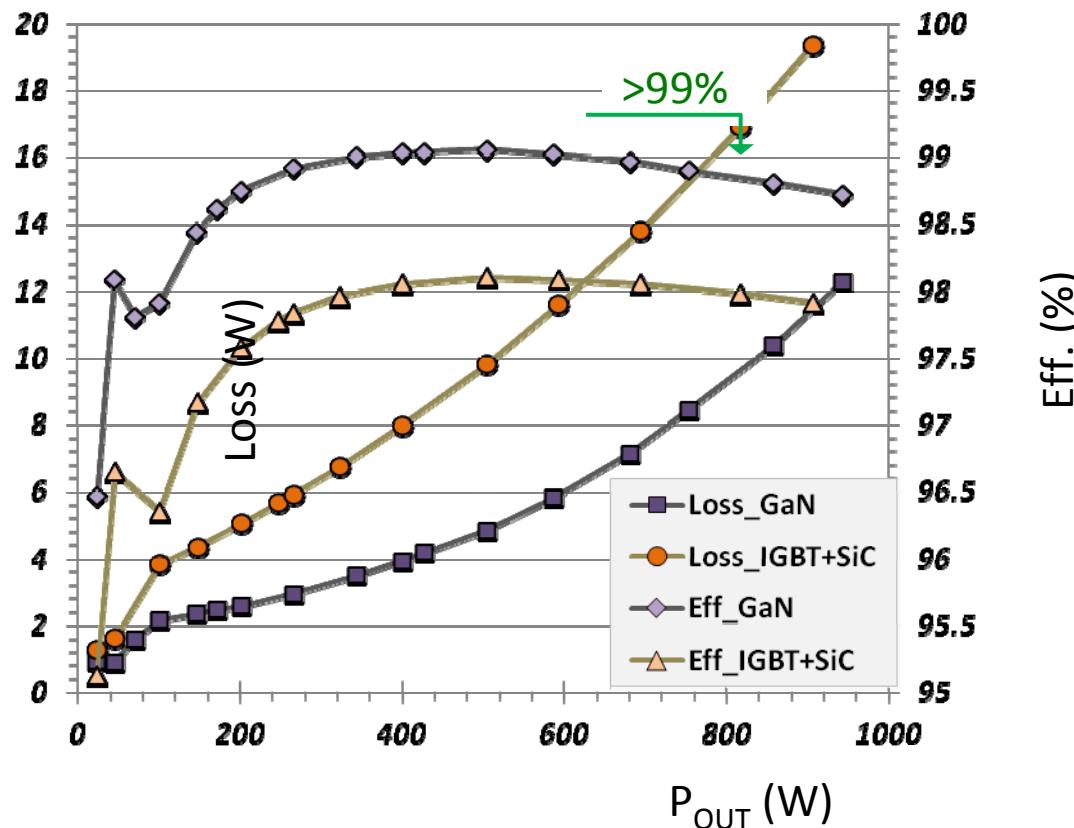
*Rise time:*  
GaN =  $2.8\text{ nS}$   
Si IGBT =  $7\text{ nS}$

*Fall time:*  
GaN =  $8\text{ nS}$   
Si IGBT =  $42\text{ nS}$

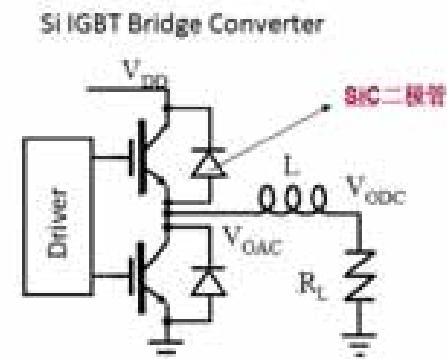
- GaN has 2.5x faster rise time: Reduced commutation loss
- GaN has 5x faster fall time: Much less output charging loss

# Buck Conversion Performance as A Function of Load

Buck ratio: 400V:200V, f=100kHz

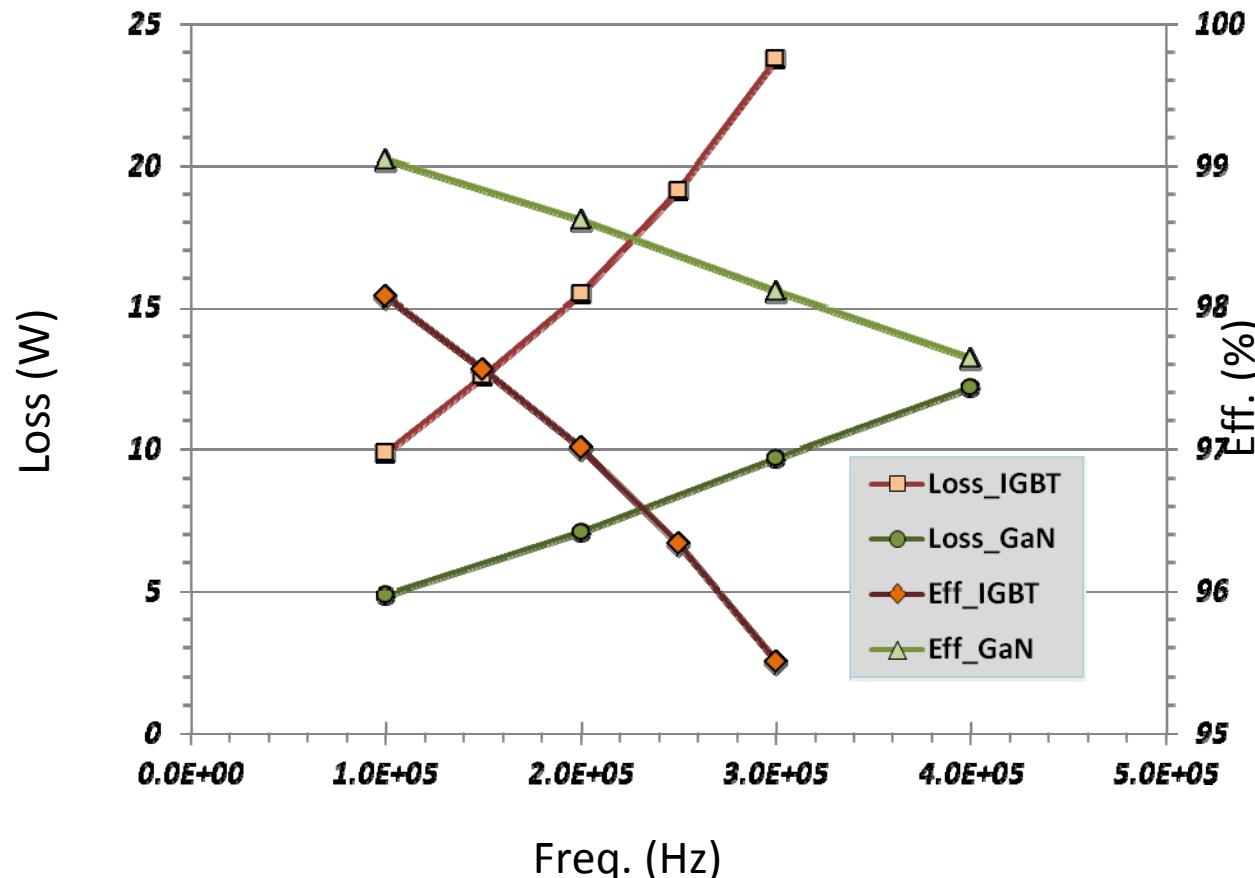


此图比较的是加了  
SIC二极管的IGBT电  
路



- Performance measure based on dc in dc out (all losses included)
- GaN has 0.8-1.5% efficiency advantage
- GaN converter achieves 99% efficiency

## Buck Conversion Performance as A Function of Frequency



可以看出随工作频率的提高，**IGBT**损耗加大，效率降低非常明显

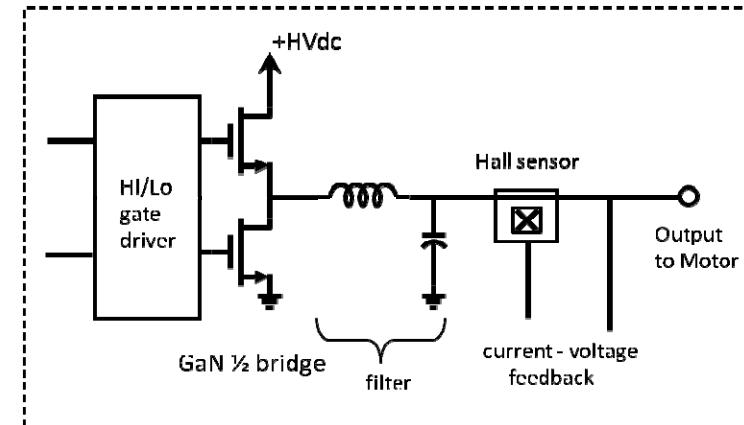
采用氮化镓的可以工作在高频且高效率

High PWM frequencies enable inductor size reduction

## 产品的应用4：DC/AC 电机马达应用 4000W，超小体积

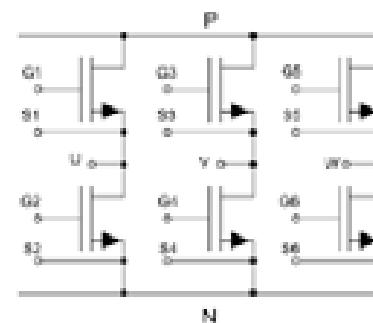
### 600V three-phase GaN inverter, including filters

(available in 2kW and 4kW versions)



Power Stage (1 of 3)

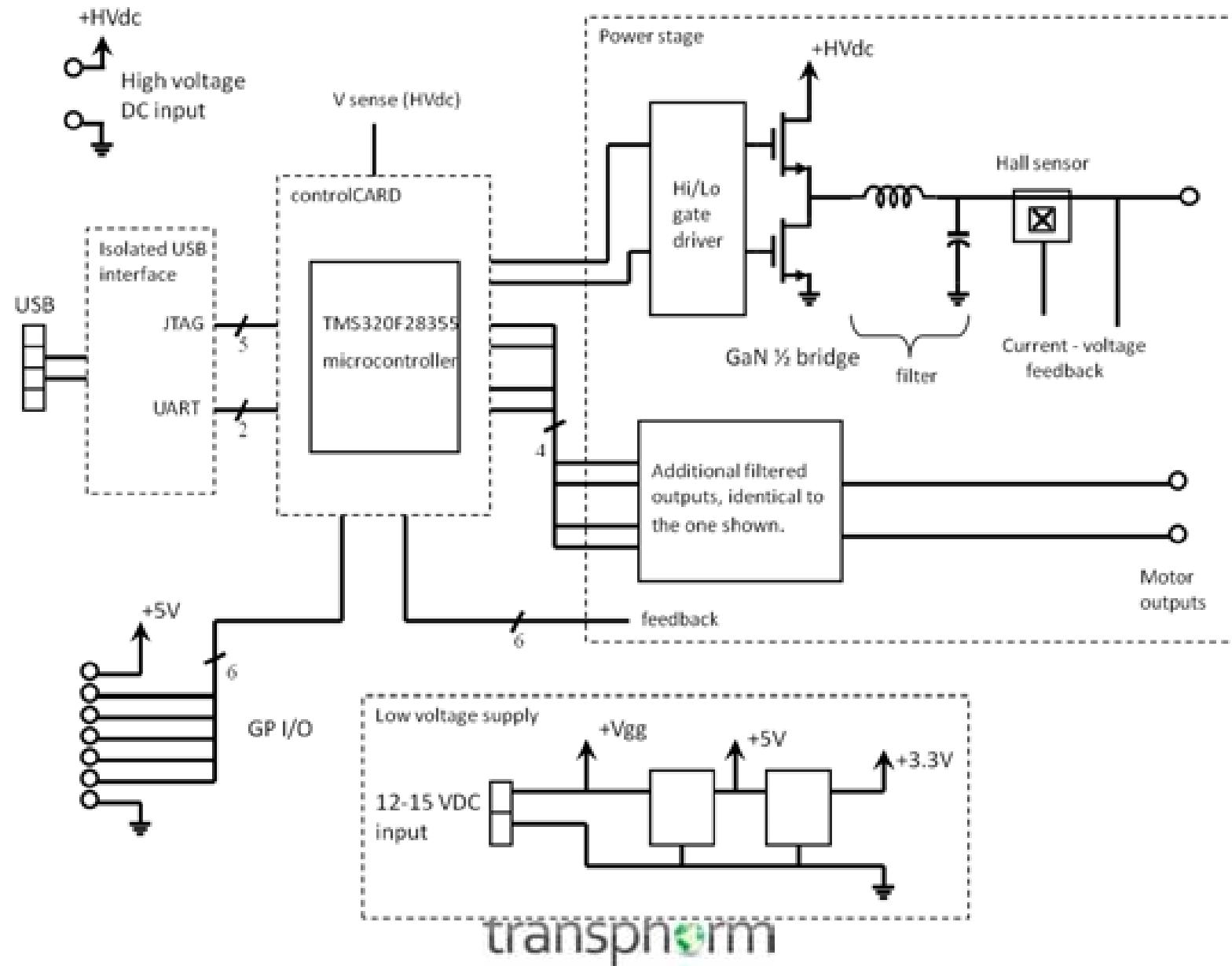
### 600V three-phase GaN module



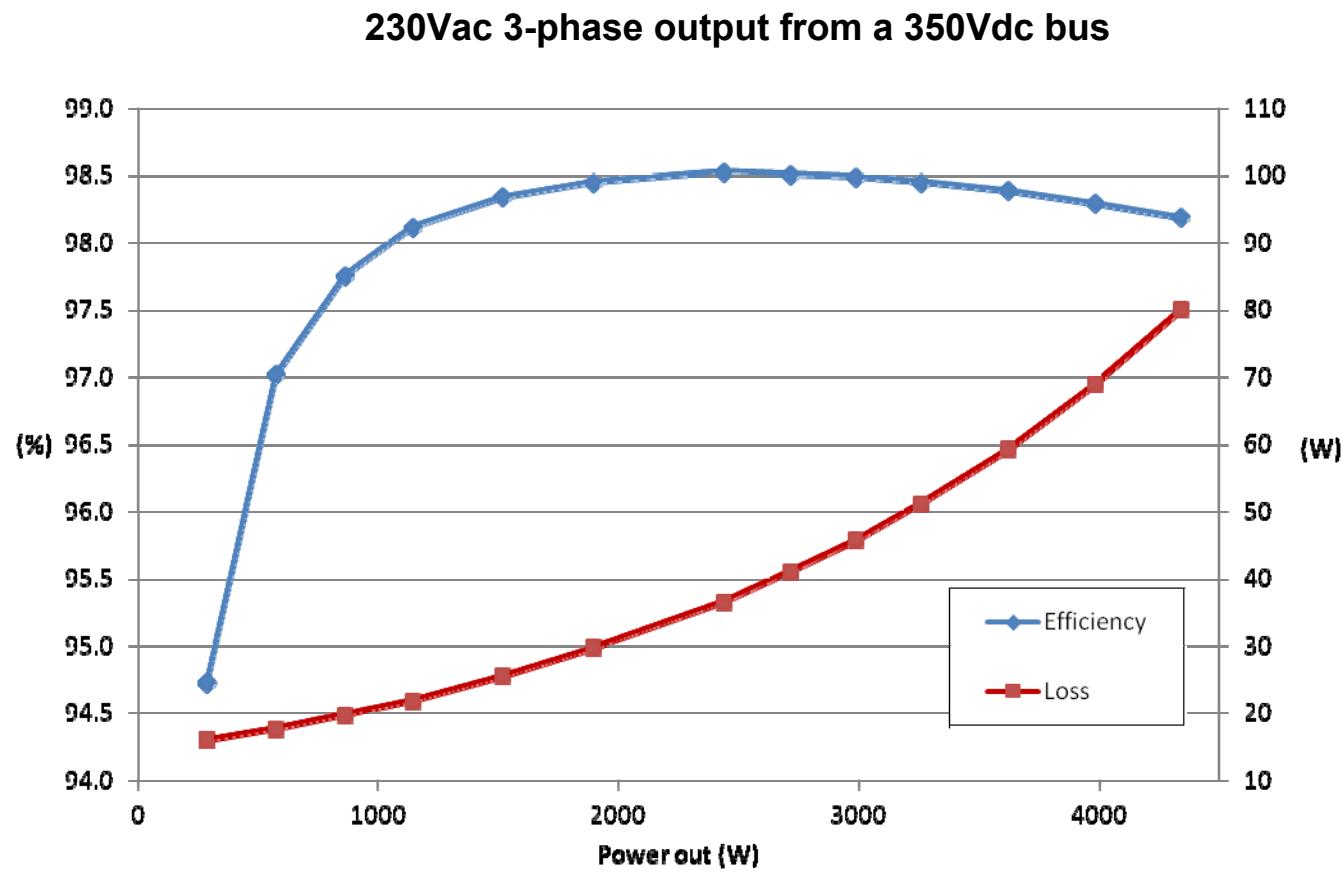
无需额外加的**SIC**二极管

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## 产品的应用4：DC/AC 电机马达应用 4000W应用框图



## 产品的应用4：DC/AC 电机马达应用 4000W效率图



100kHz switching. Loss due to the output filter is included in the efficiency calculation.

## APEC 2012. Loaded 1hp induction motor demo.

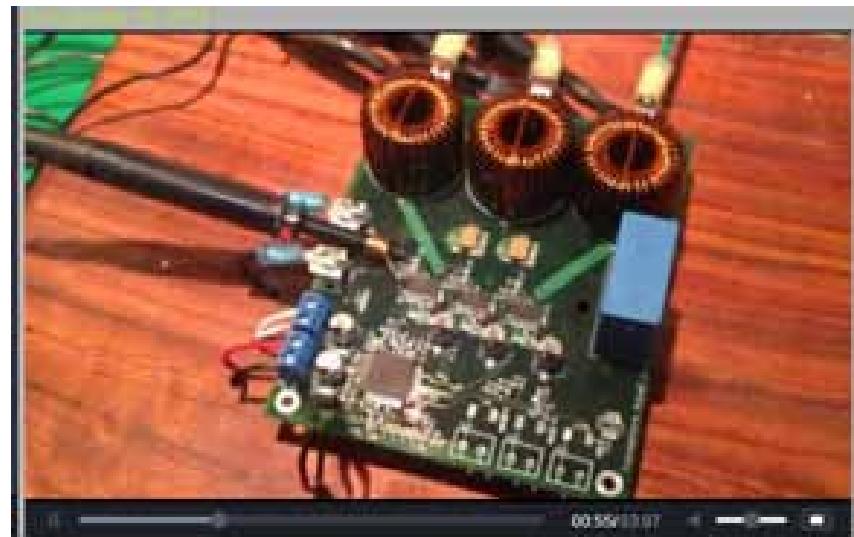
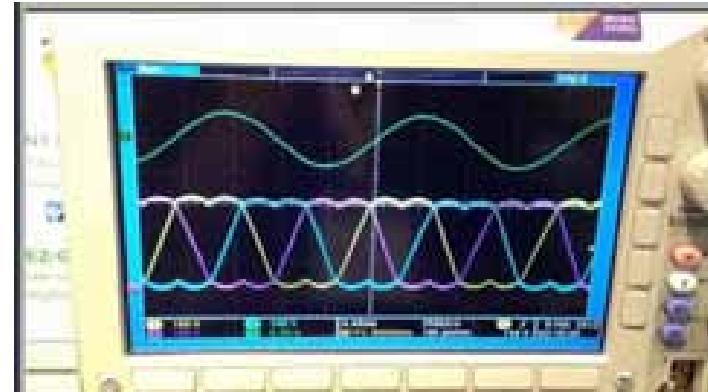
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Transphorm Demos GaN Devices Driving an AC Motor with a Pure Sine Wave - APEC 2012  
by Curtis Elzey



Jim Hanes, Member of Technical Staff at Transphorm, shows us an efficiency demonstration at APEC 2012. He takes advantage of high frequency switching to integrate a compact output filter.

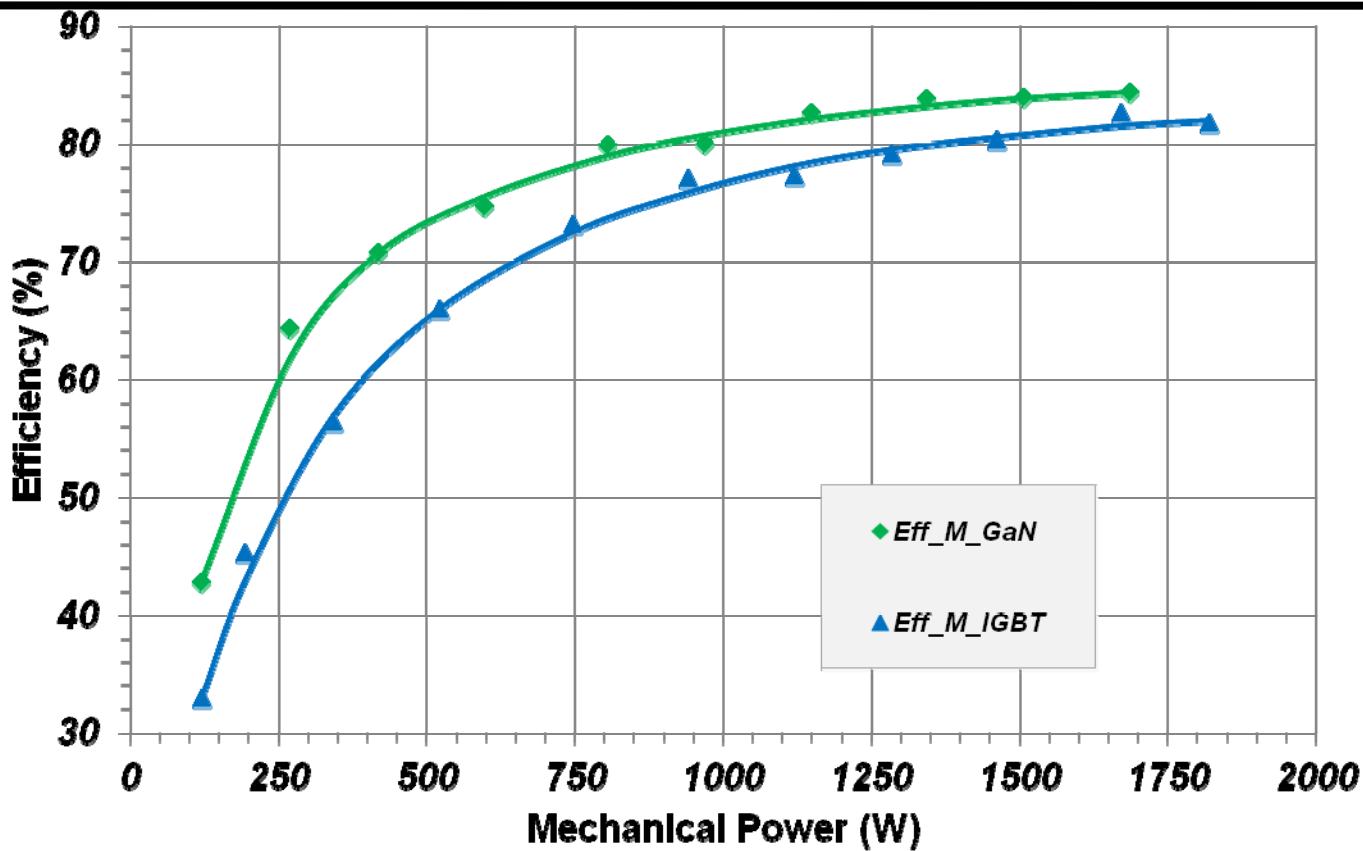
Videocredit by: Curtis Elzey.



<http://www.engineeringtv.com/video/Transphorm-Demos-GaN-Devices-Dr;search%3Atransphorm>

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$$\eta_M = \frac{P_M}{P_{AC}} \quad \text{Motor Efficiency}$$

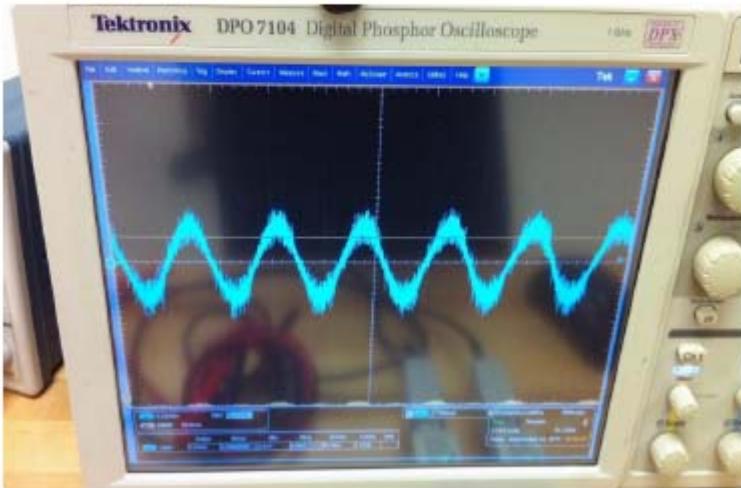


Transphorm's TruSine operation using a filtered output from a 100kHz inverter yields 2% system advantage at full load, 4% at mid-load and 8% at low load compared to a state-of-the art IGBT inverter operated at 16 kHz without a filter

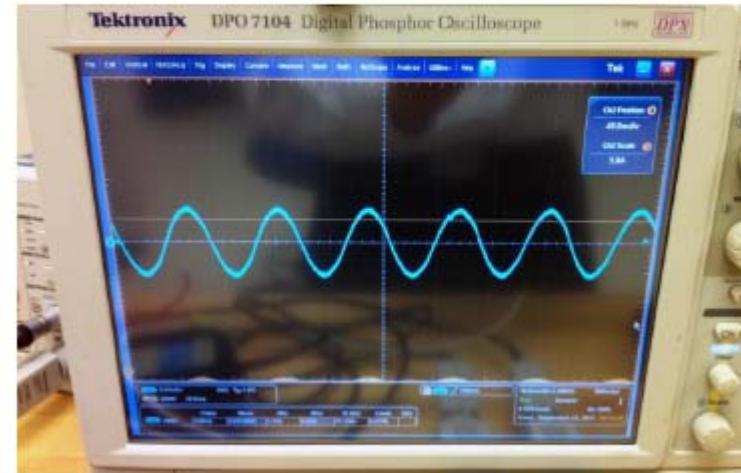
# Motor-Drive Current Waveforms

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IGBT Inverter: PWM Power



GaN Inverter: Sine-wave Power



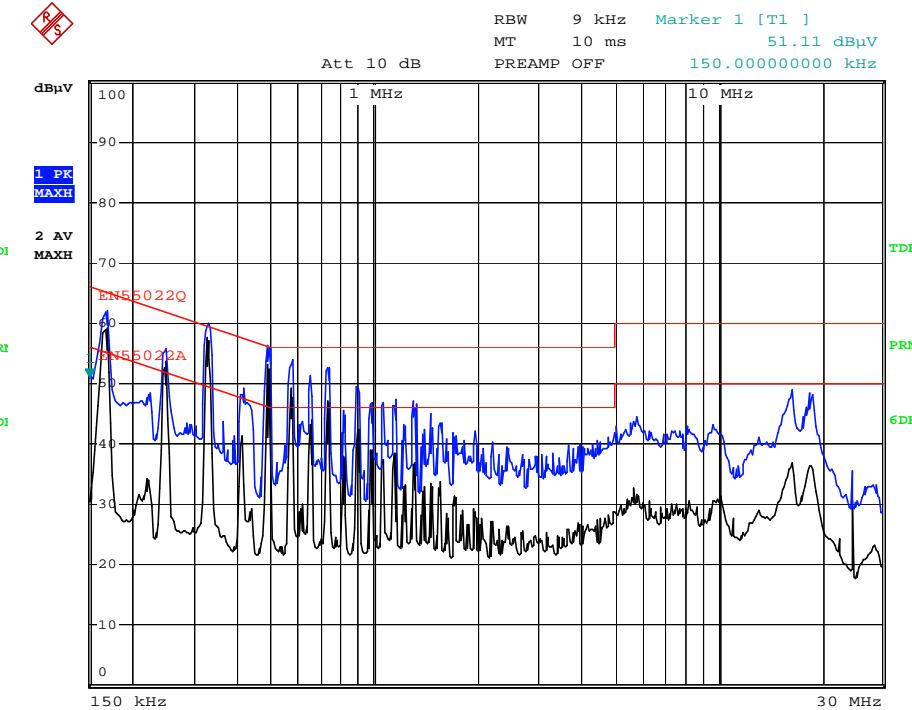
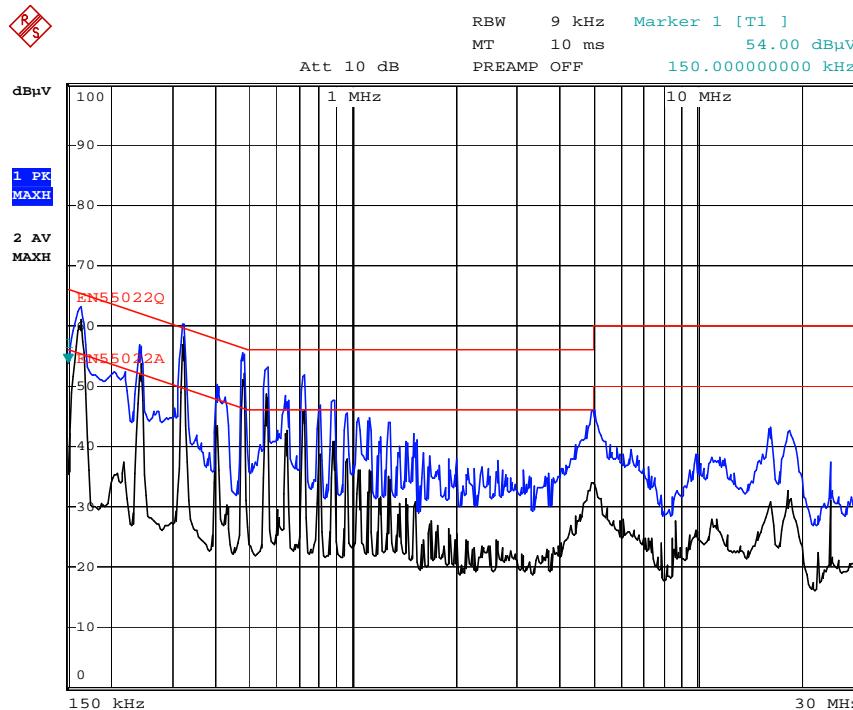
- GaN inverter operating at 100kHz with output filter
- IGBT inverter operating at 15kHz with 320V PWM output
- Reduced harmonic content of current waveform improves motor efficiency
- Reduced transient currents and voltages on motor cable and windings reduce EMI and avoid degradation issues.

# Myth Buster: Faster Switching ≠ Higher EMI\*

Superjunction Silicon

vs.

GaN (TPH2002PS)



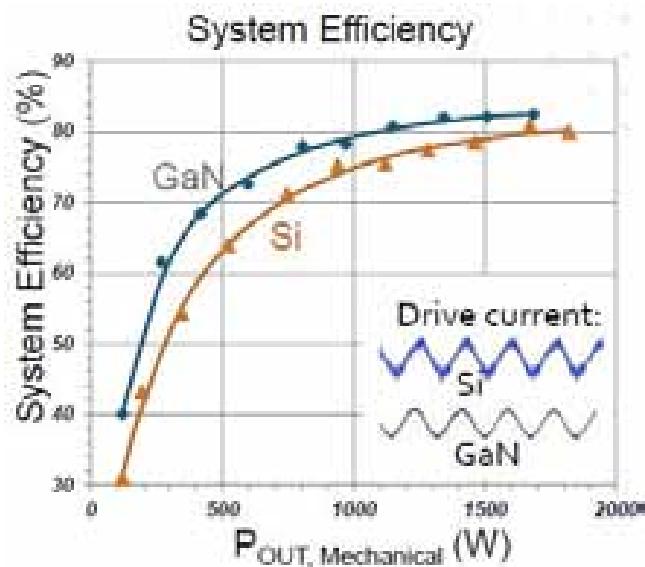
— Peak  
— Average

Conducted noise: Converter (PFC + Dual Flyback), 90 Watt, Vin = 230 Vac , Fsw = 60 kHz;

$t_{on}$  &  $t_{off}$  of GaN is 0.33  $t_{off}$  of Silicon, so the GaN is switching faster without increasing the EMI.

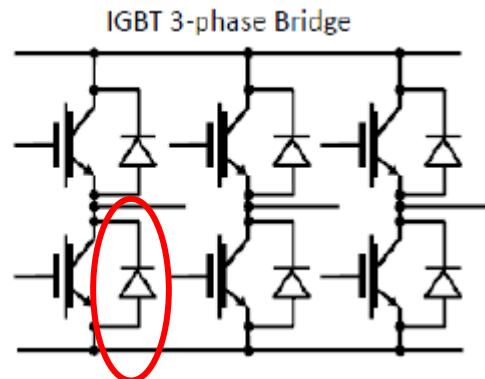
\*Courtesy of Fairchild Semiconductor company

## 产品的应用4：DC/AC 电机马达应用

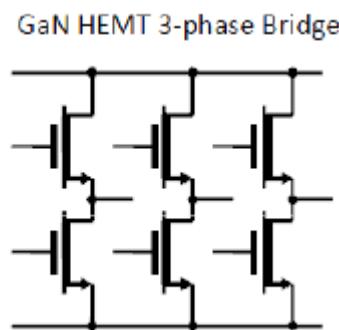


Pure sine-wave motor drive (2-8% points  
efficiency gain for the system)

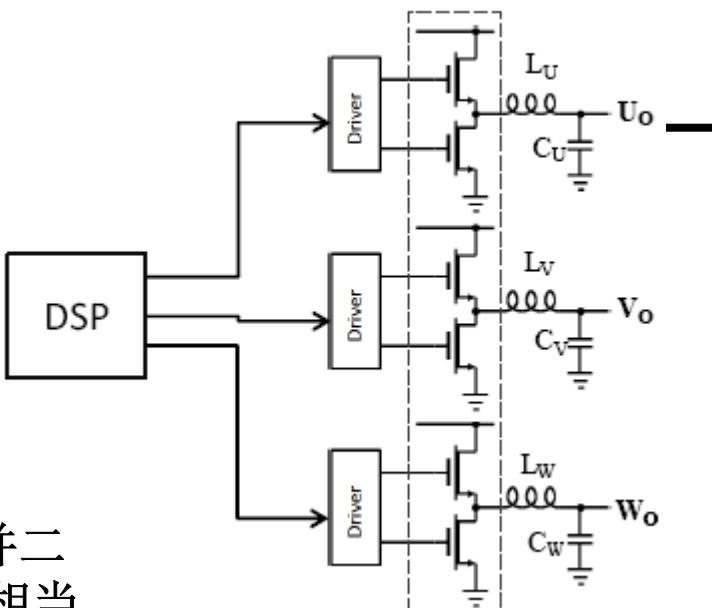
## 产品的应用4：DC/AC 电机马达应用



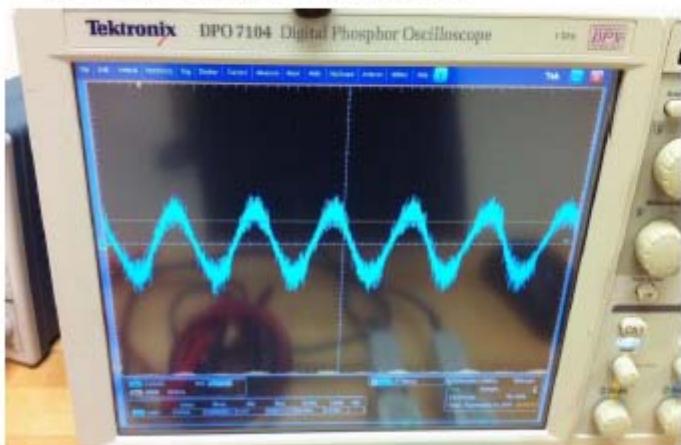
有时**IGBT**为了提高效率  
还要并一个快速的二极管.



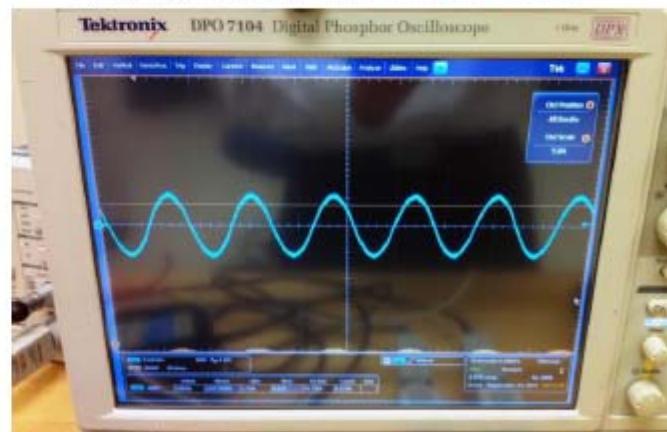
采用氮化镓,无需并二  
极管.可直接使用.相当  
于**0**恢复 (极小)



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

# 产品的应用5： 3300W无桥PFC 99%效率



AC90—260V输入

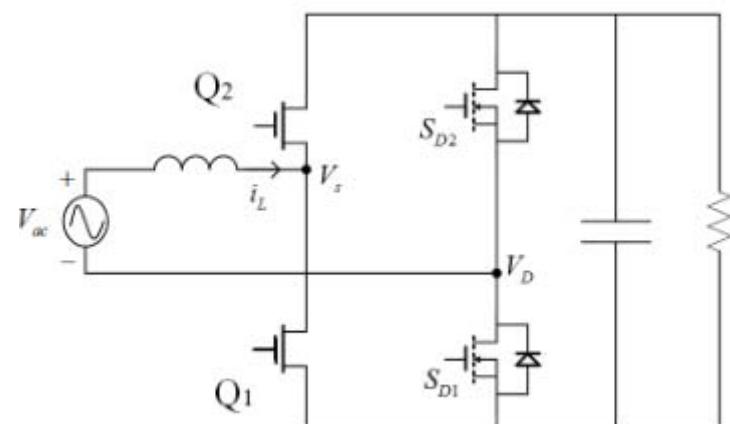
2只TO-247 52毫欧氮化镓

工作频率100KHZ

电流采样-电阻

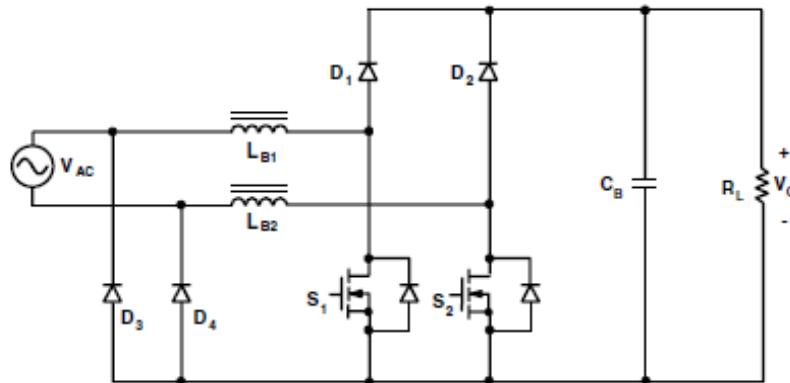
DSP: 28035

驱动:隔离SI8230



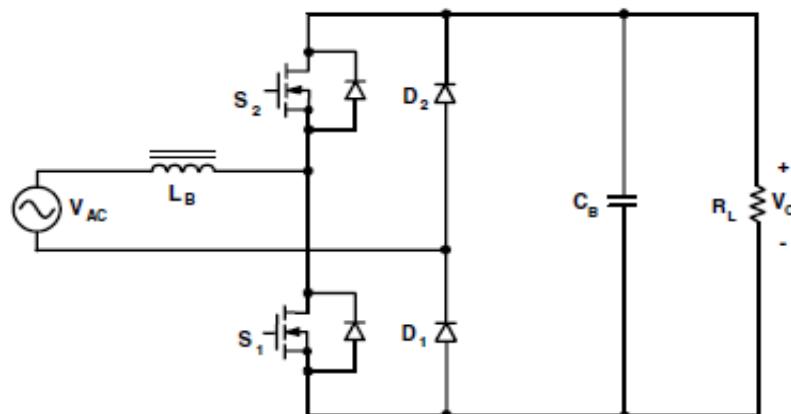
transphorm

## 产品的应用5：3300W无桥PFC 99%效率 用FET代替整流桥同时实现高效PFC功能



传统Dual-boost无桥PFC

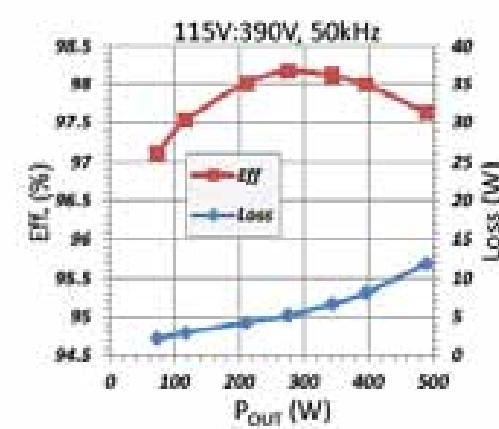
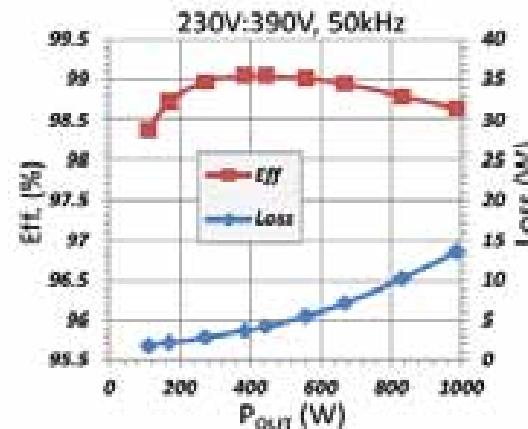
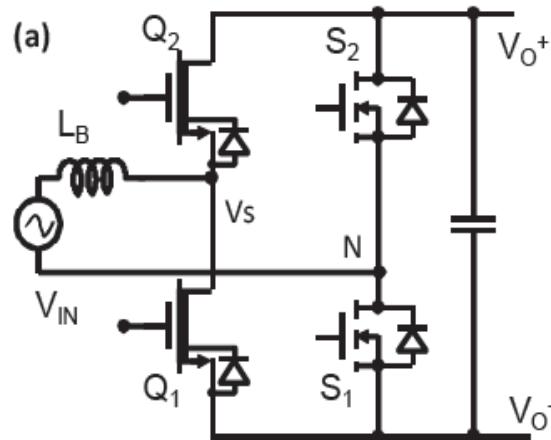
- 传统用的无桥需要2MOSFET，2电感，2碳化硅二极管（D1,D2）才能实现高效率
- 采用氮化镓的图腾无桥PFC只要一个电感，2个氮化镓MOS,另D1,D2可以用二极管也可以从等同内阻的硅MOSFET以实现更高效率
- 就现阶段氮化镓无桥的方案已比传统的低了（传统的会用上两个高碳货硅二极管及多用一个电感）
- 同时因氮化镓适合高频。采用氮化镓高频化的无桥PFC后，体积大大变小，综合成本更有优势/效率依然很高



氮化镓的图腾无桥 PFC

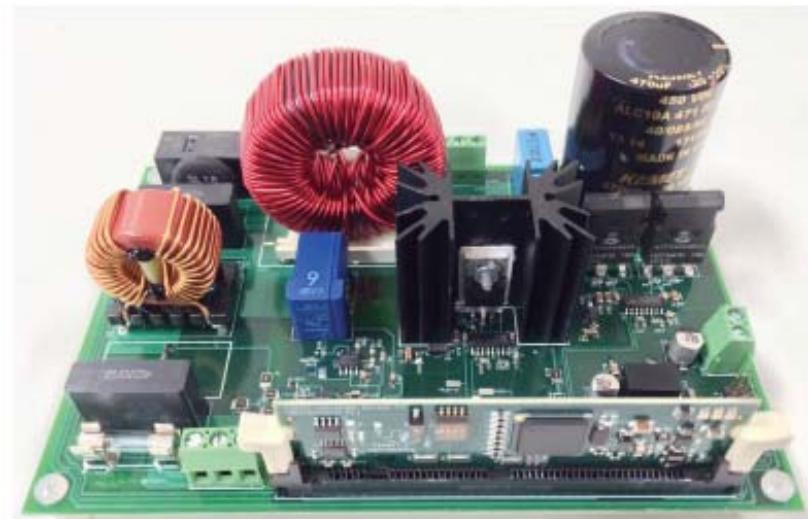
此设计是利用氮化镓体内二极管超低的反向恢复特性来实现高效低成本。

## 产品的应用5：3300W无桥PFC 99%效率



- 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

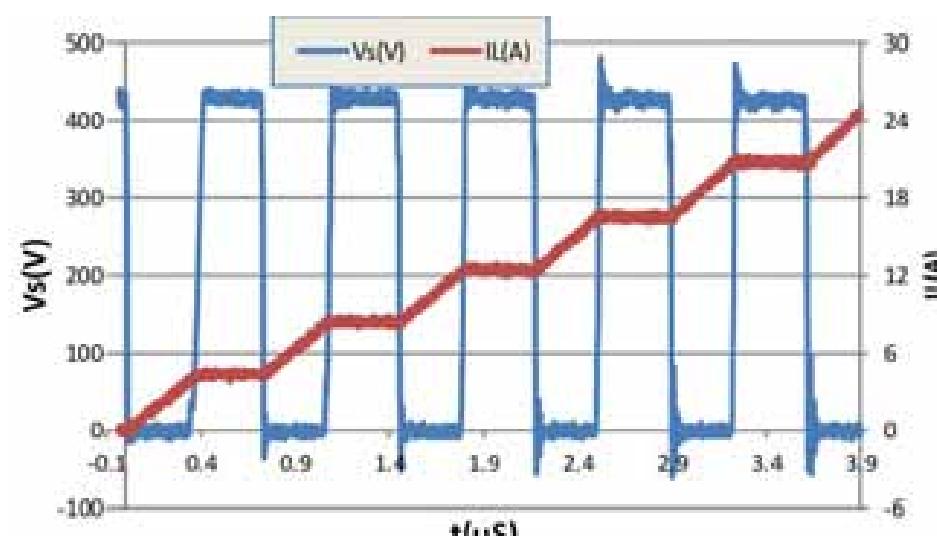
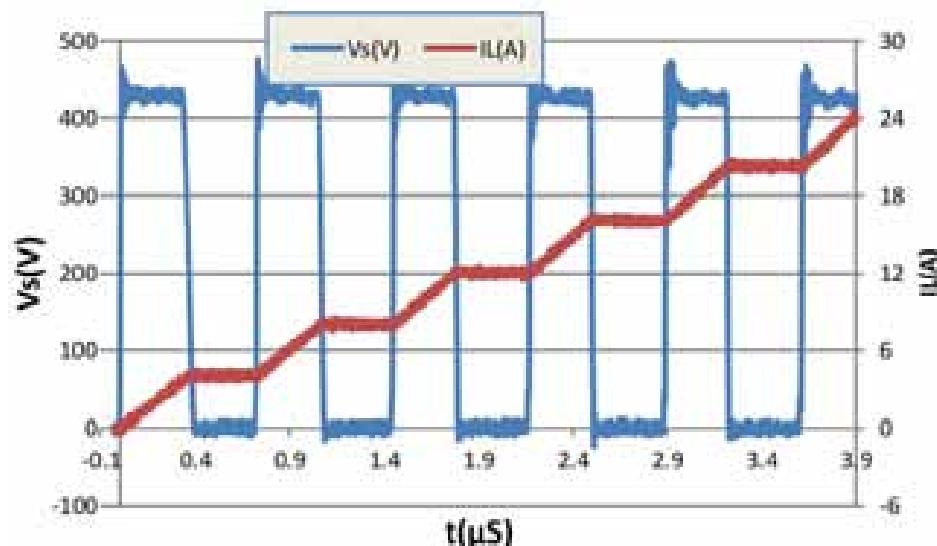
	230V:400V boost	Totem pole	Totem pole with EMI filter and current sense
50kHz	99.16%	99.1%	98.9%
100kHz	99.03%	98.97%	98.77%
150kHz		98.84%	98.64%
200kHz		98.7%	98.5%
250kHz		98.57%	98.37%



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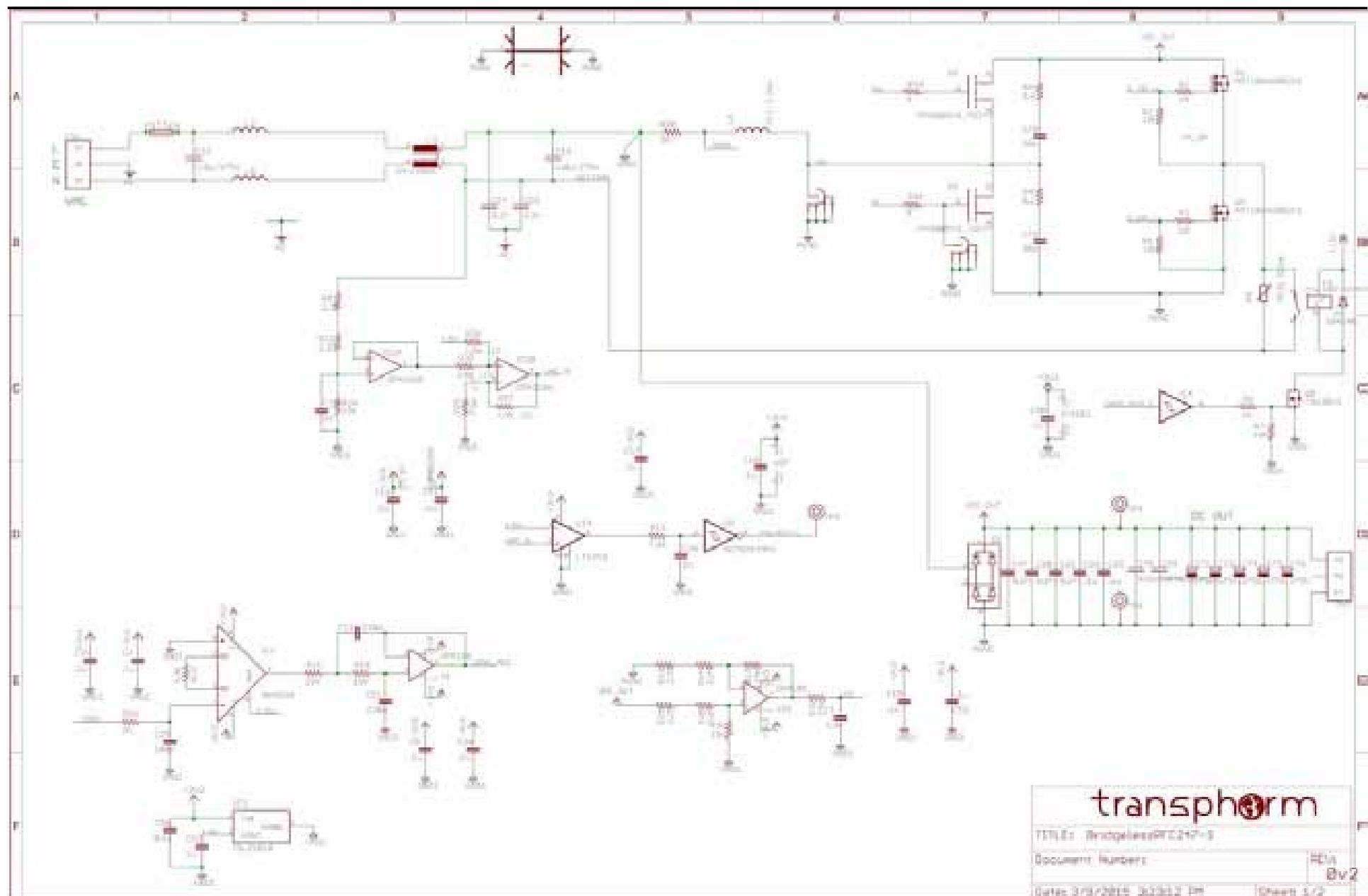
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Tel:13501775977  
Mail: hz021@qq.com

## 产品的应用5： 3300W无桥PFC 99%效率

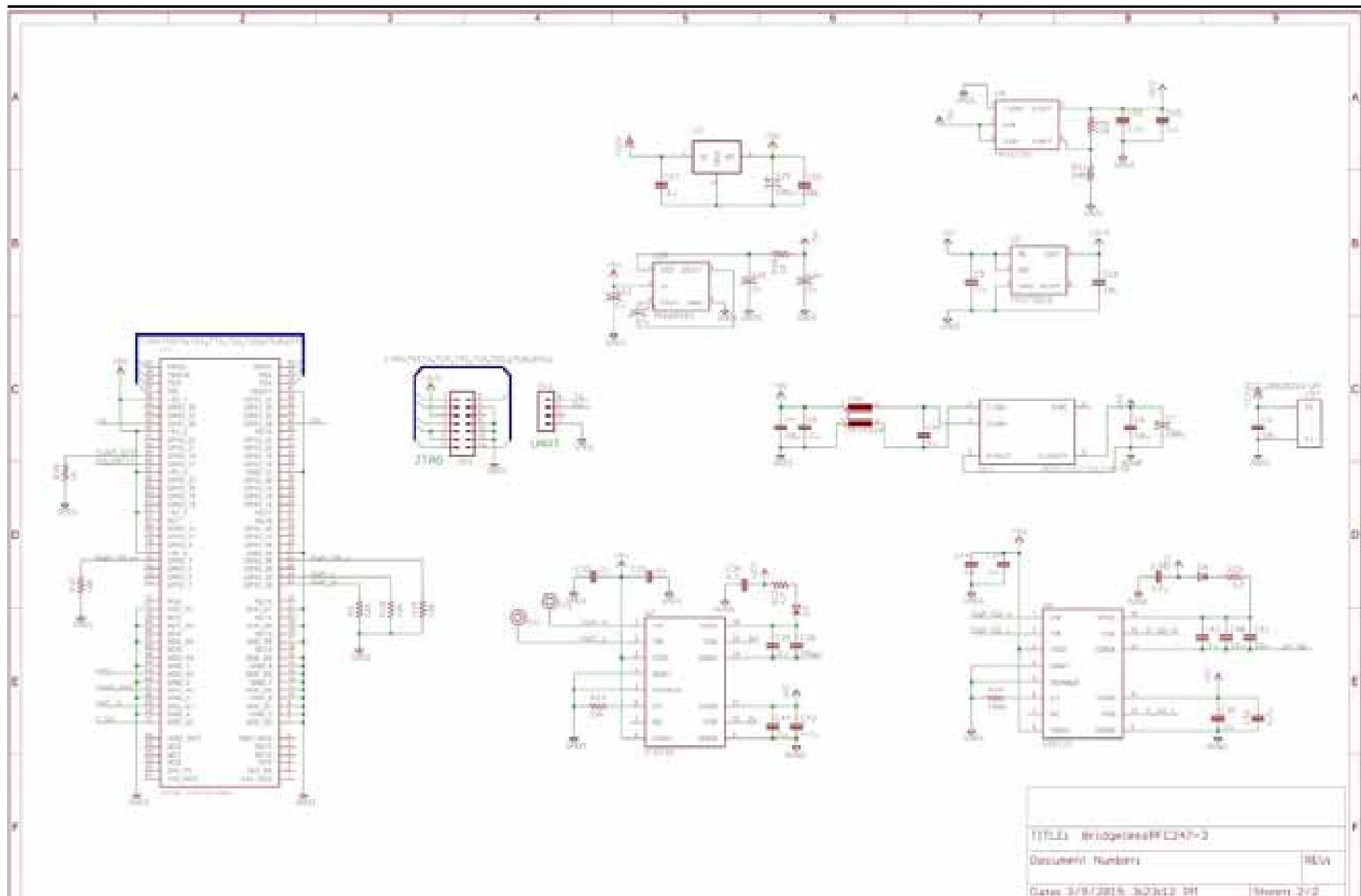


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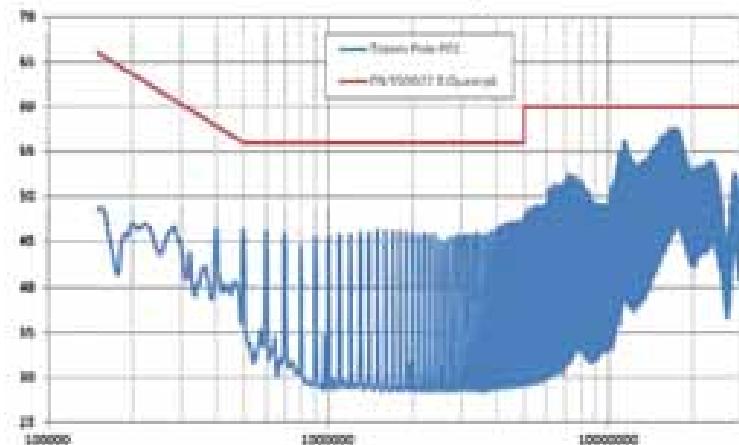
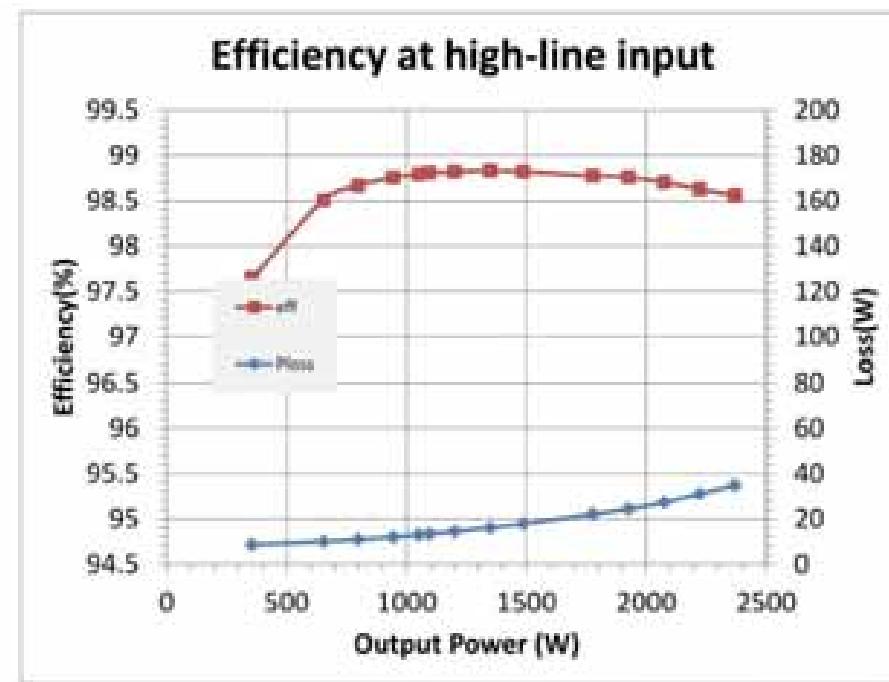
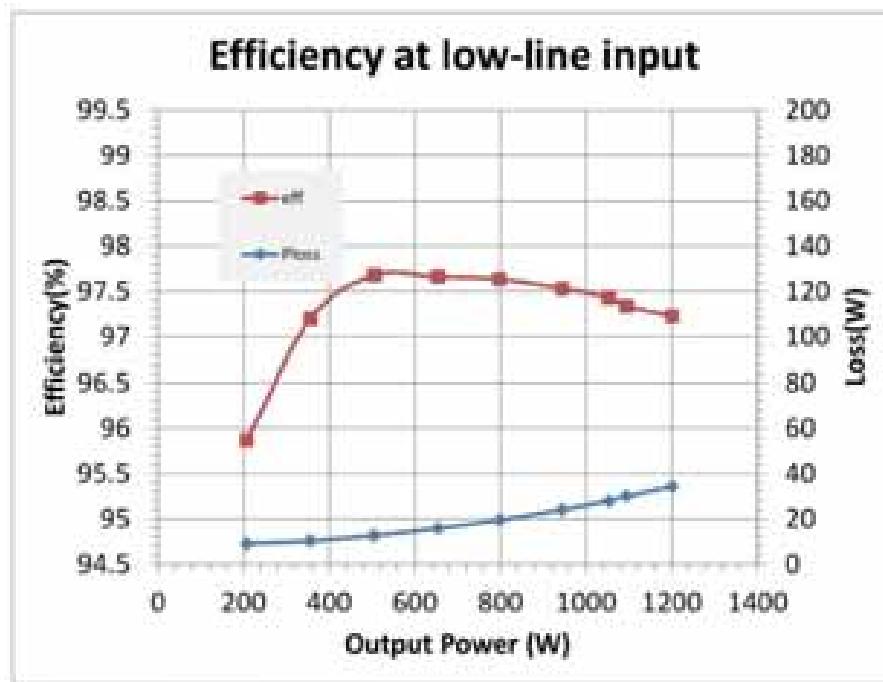
## 产品的应用5： 3300W无桥PFC 99%效率



**产品的应用5：3300W无桥PFC 99%效率**

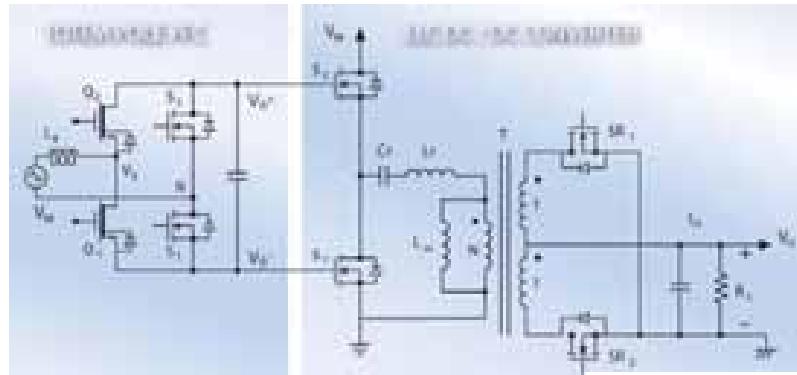


## 产品的应用5：3300W无桥PFC 99%效率

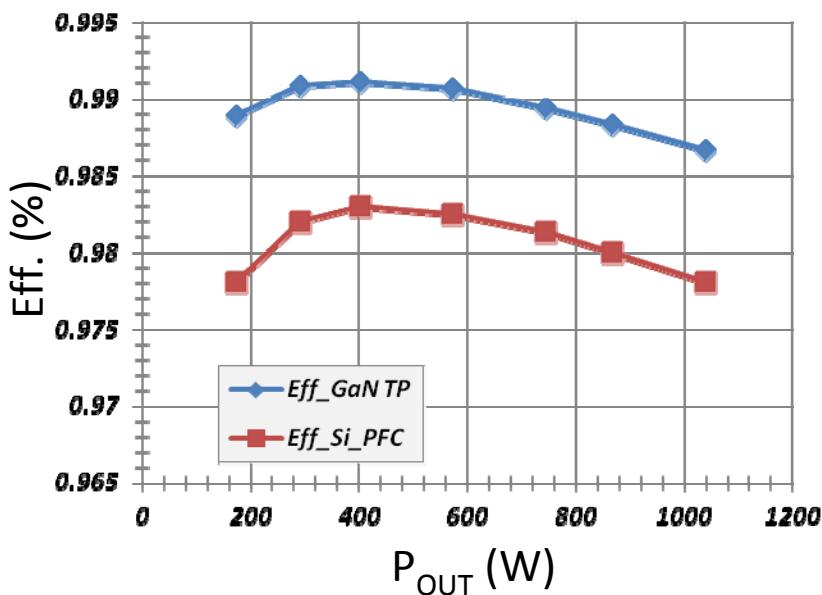


Still working on EMI improvement on HF range

# 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



采用氮化镓方案的1000W 无桥  
PFC电源的效率 99.2%

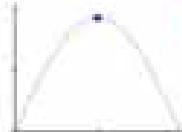


采用氮化镓的LLC电源效率  
1000W 98.8%

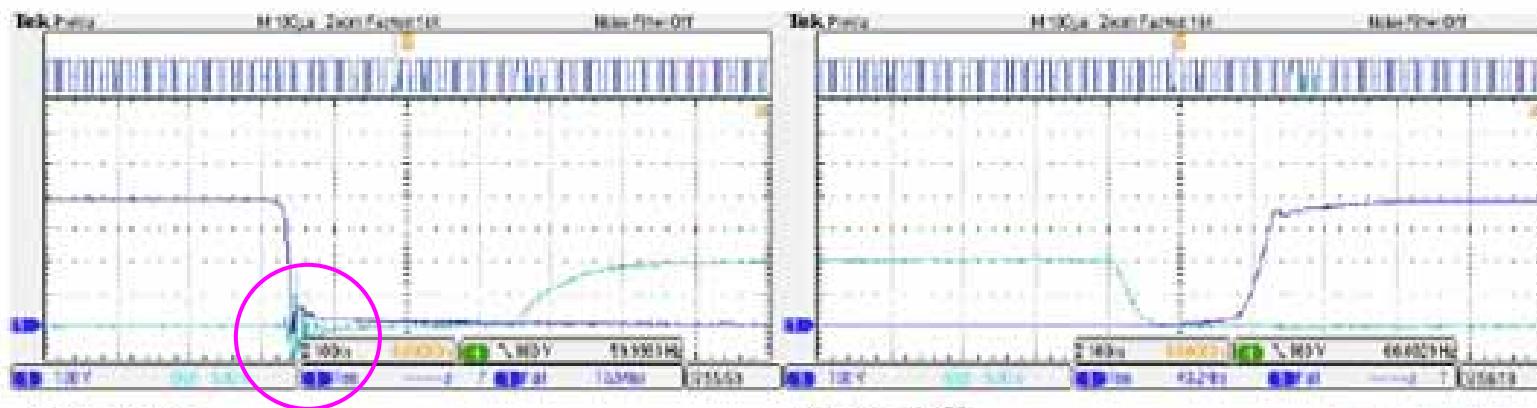
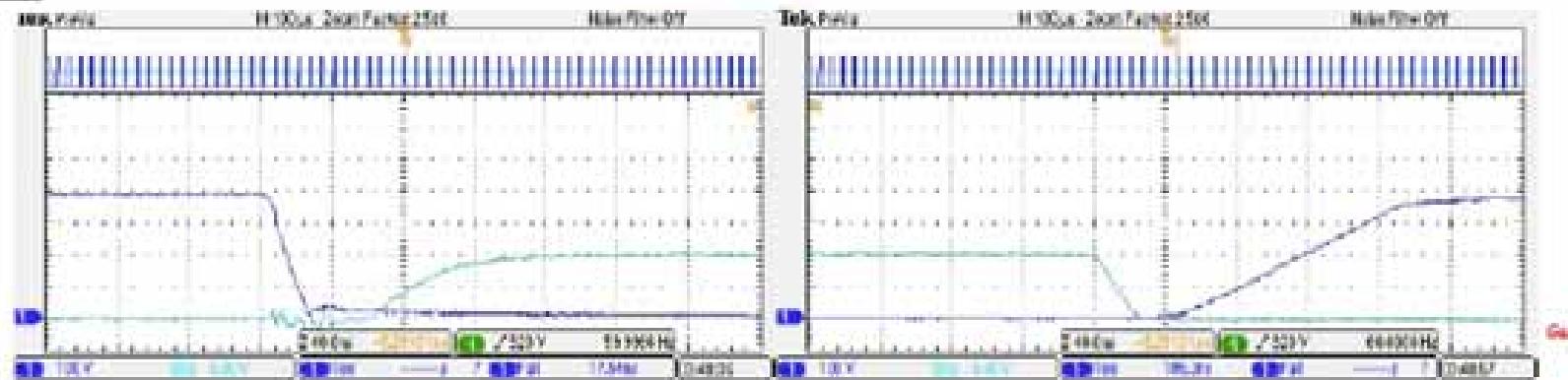
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## 150mΩ GaN versus 130mΩ Silicon MOSFET

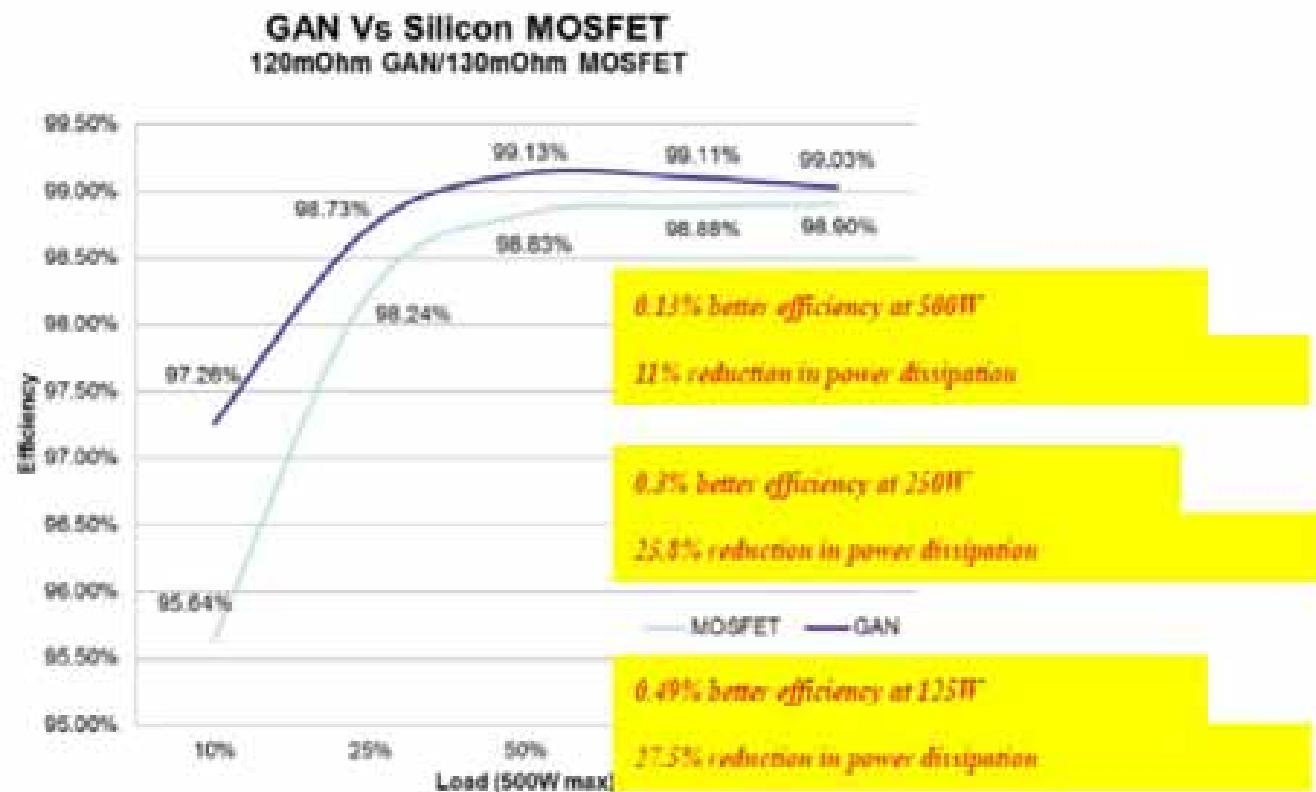


115Vdc/60Hz 250W



## *GAN versus Silicon MOSFET*

230Vac/60Hz 500W

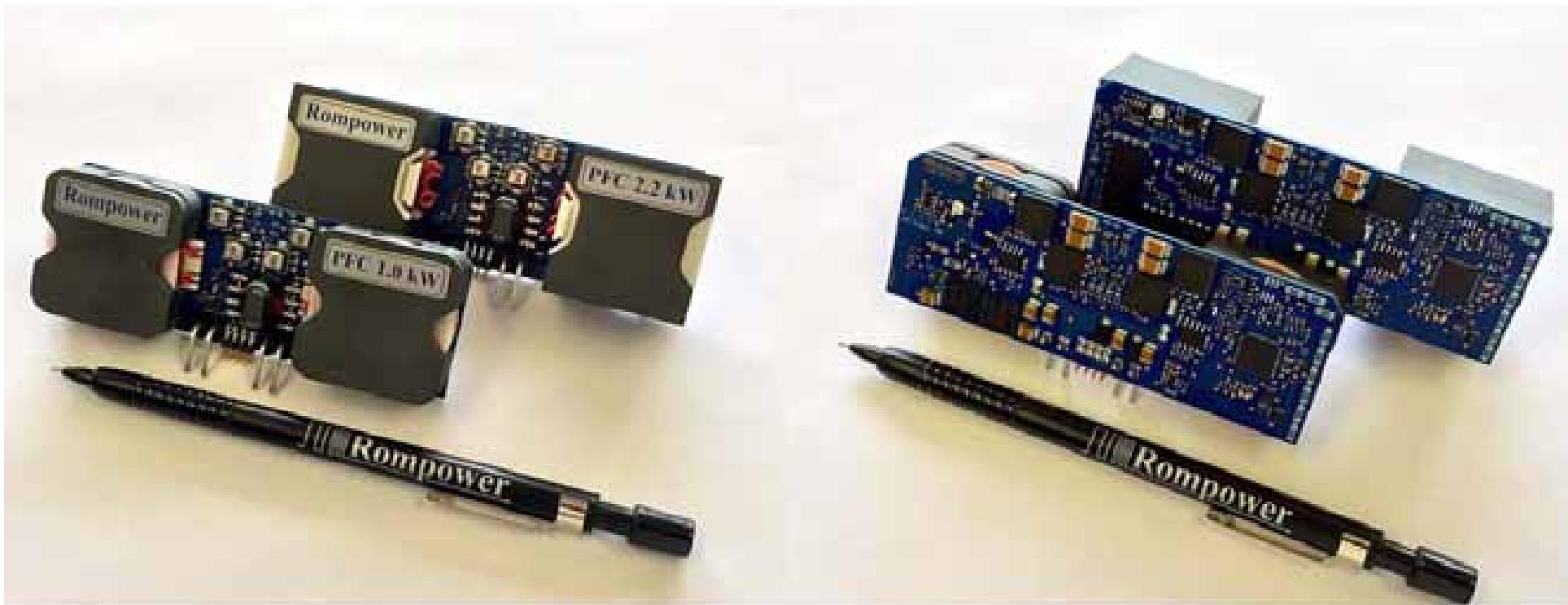


## CONCLUSION

- *The main advantages of GaNs Versus the CoolMOS especially C7 generation it is the Co(tr) which is approximately 5.5 times smaller*
- *The lower Co(tr) will decrease the energy requires to achieve soft switching and as a result will reduce the peak current and reduce the RMS current*
- *The lower peak currents will reduce also the flux swing in the magnetic elements decreasing the core losses*

---

## ***1kW and 2.2kW PFC Modules***



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# 1kW PFC Module

*Dimensions: 98.1mm x 34mm x 16mm (L x H x W)*



\***High Power Density:**  $307.69 \text{ W}/\text{in}^3$

\***Efficiency > 99.0%**

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## POWER FACTOR CORRECTION

- INTERLEAVED, TRUE SOFT SWITCHING BRIDGELESS TOTEM POLE TOPOLOGY USING INTELLIGENT POWER PROCESSING.
- EFFICIENCY ABOVE 99%
- VERY HIGH POWER DESNITY

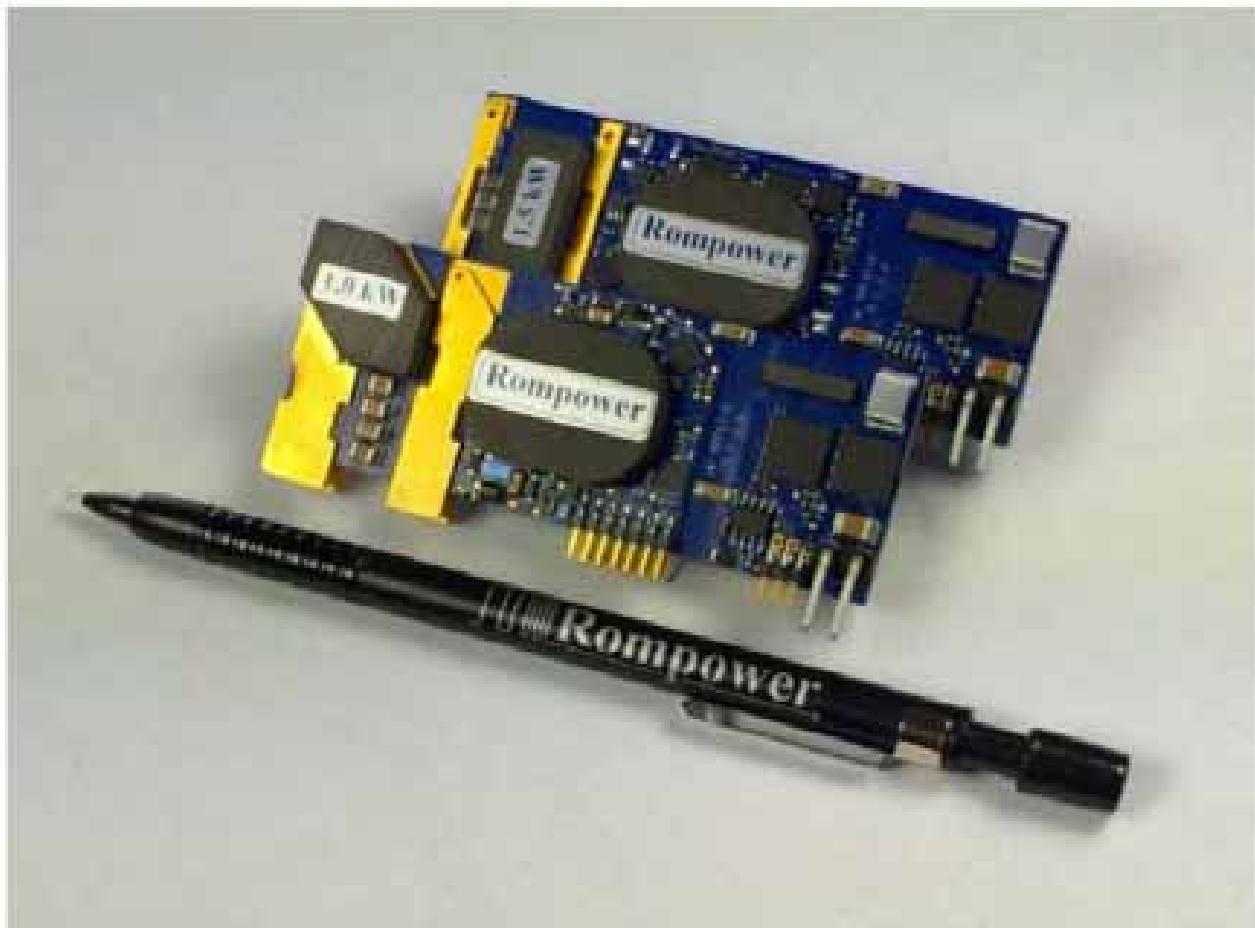
	Power Density	
	W/inch <sup>3</sup>	W/cm <sup>3</sup>
New 2.2kW High Frequency	678.478	41.403
New 2.2kW	572.29	34.937
Old 2.2kW	443.55	27.06
1 kW	318.26	19.42

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## 1KW & 1.5KW DC-DC CONVERTER MODULE



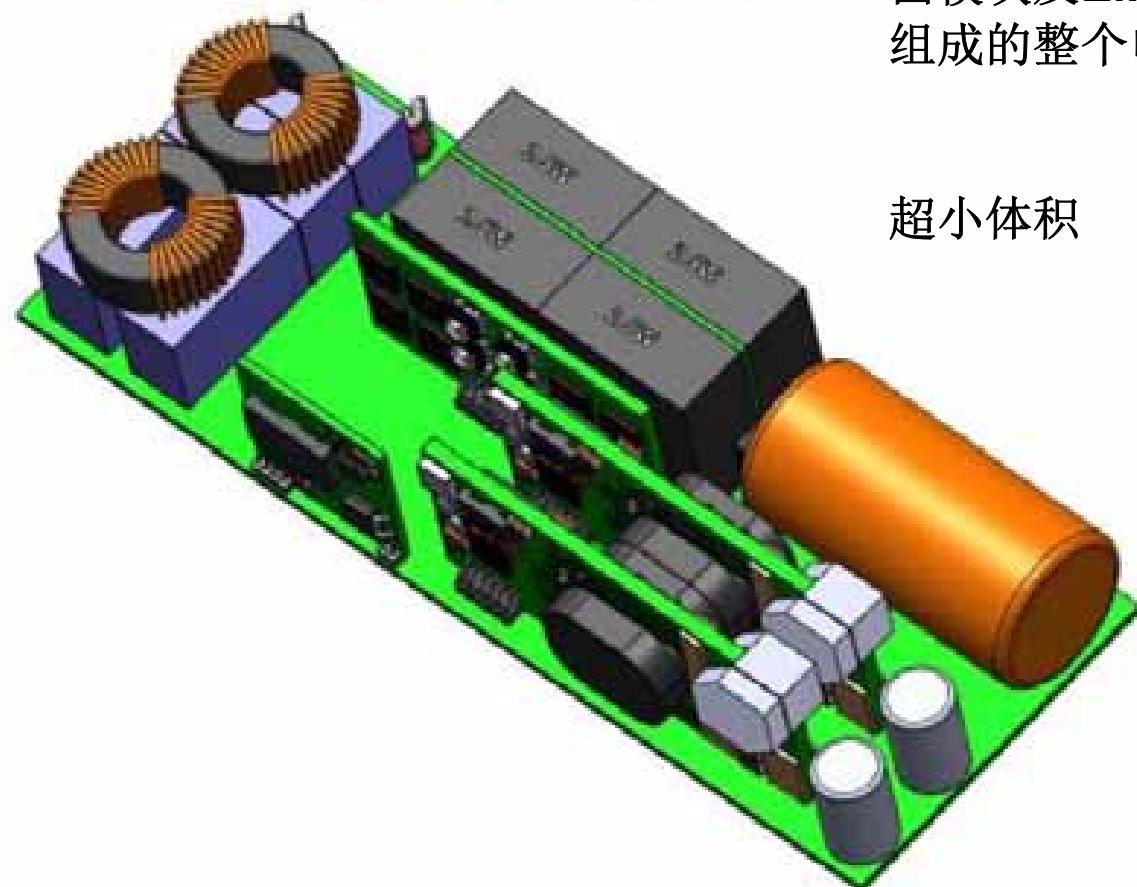
*Efficiency =99.0% at 50% Load*

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## 2 KW General View



由模块及**EMI**电路，电容  
组成的整个电源方案

超小体积

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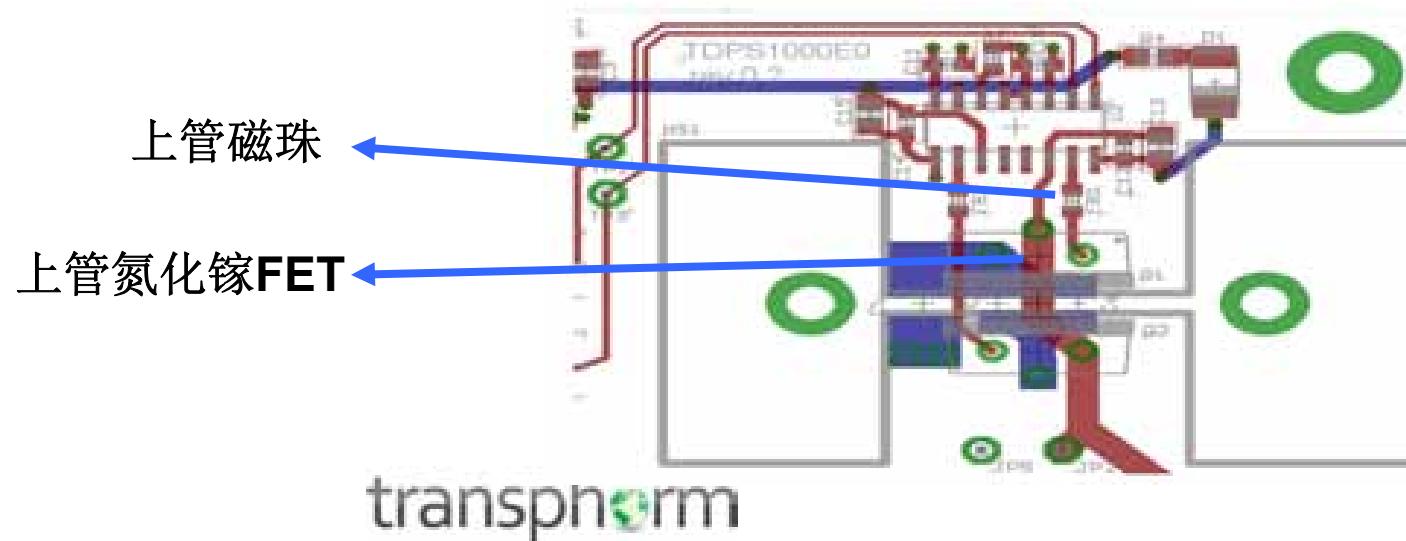
# 布线：氮化镓FET不能直接兼容现在MOSFET电路

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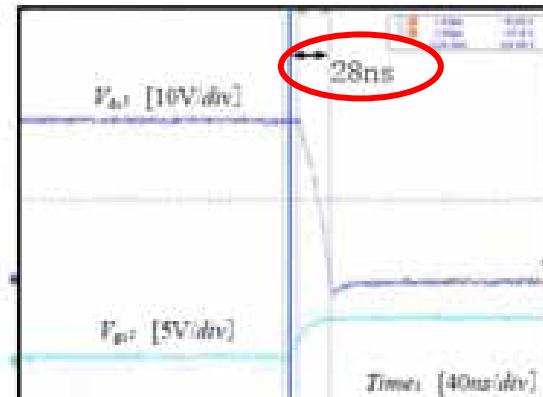
- 去评估GaN, 布线必须要优化下。直接将氮化镓FET放在现有的MOSFET设计板上可能会烧掉，不要将氮化镓的脚扭曲后安装。
- 重新设计系统以适合氮化镓FET的特性，这样会争取到更大的收获(氮化镓只有细微的差别当你继续用它在15kHz inverter或 65kHz PFC, 或 100kHz flyback, 或 100kHz LLC...必须提高频率，正常建议三倍左右)
- 当前，同等R<sub>ds(on)</sub>的氮化镓的价格是现在Cool-mos的2.5倍左右，但氮化镓的价格未来几年会大幅降低。
  - 在某些应用，如无桥图腾柱PFC，PV inverter,客户如重新采用氮化镓来设计反而会得到更低的BOM整体成本
  - 否则客户必须要花其它一些额外高昂的电路来实现高性能，高效率。
  - 我们的市场目标是：高性能产品，需要用氮化镓来解决一些性能的，如温度问题，体积问题，效率问题，否则没有必要用氮化镓

# Layout, Layout, Layout

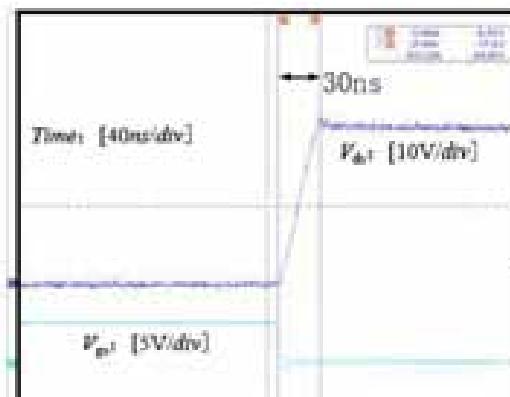
- 对于**cascode structure**的氮化镓FET不需要特别的驱动
  - 2V threshold (5V full on, 0V turn off)
  - +/- 18V max. gate voltage
  - 可采用通用的驱动即可完成 0.5A 驱动电流即可。ONsemi, TI, Silicon-labs...
- **PCB走线非常重要（因氮化镓是高速的器件）**
  - 与任一脚相连的线需要短距离和小的回路
  - 驱动回路与功率回路分开（采用S封装FET）
  - 需加去耦电容
- 对于硬开关的桥电路
  - 紧凑的走线，特别是对上管（驱动到G极尽可能短）
  - 门极无需电阻，相反加一个磁珠来代门电阻，且尽可能靠近GATE脚



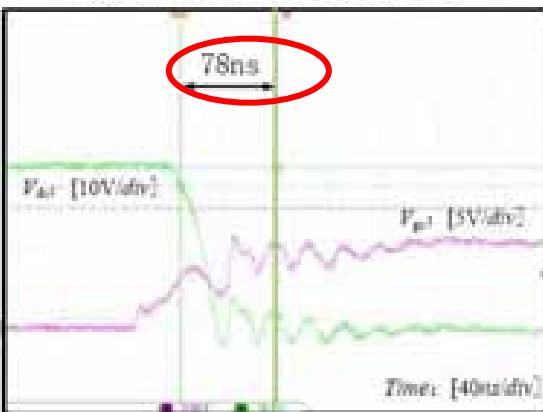
# GaN,Si FET在开通，关断速度对比 (Layout上注意)



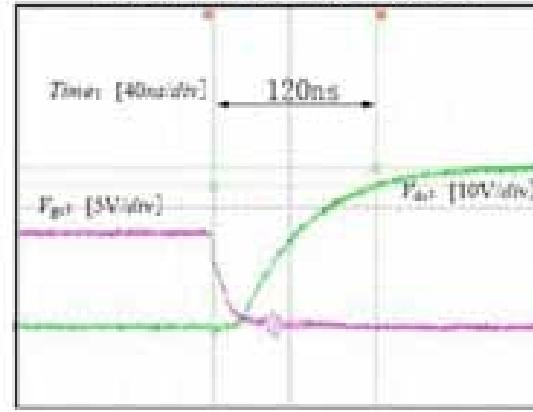
GaN HEMT开通速度



GaN HEMT关断速度



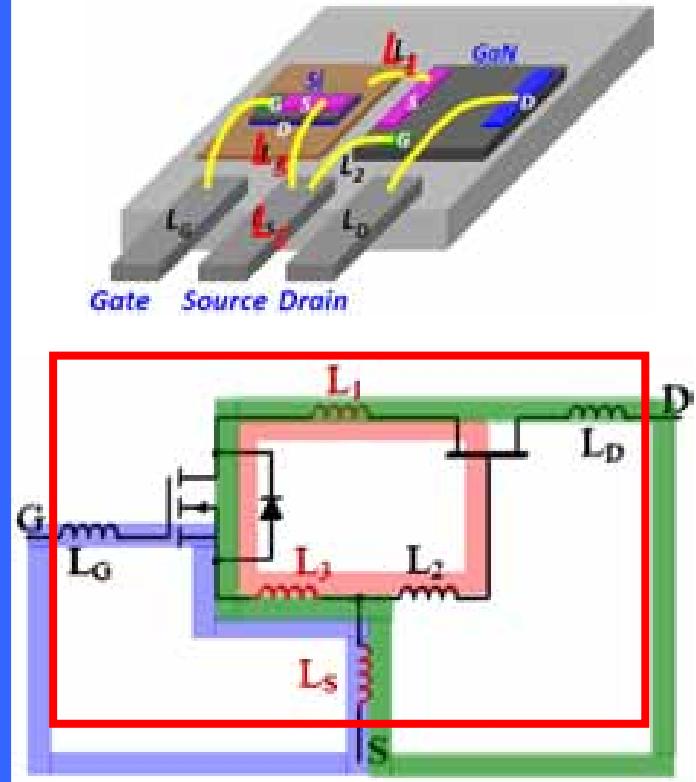
Si MOSFET开通速度



Si MOSFET关断速度

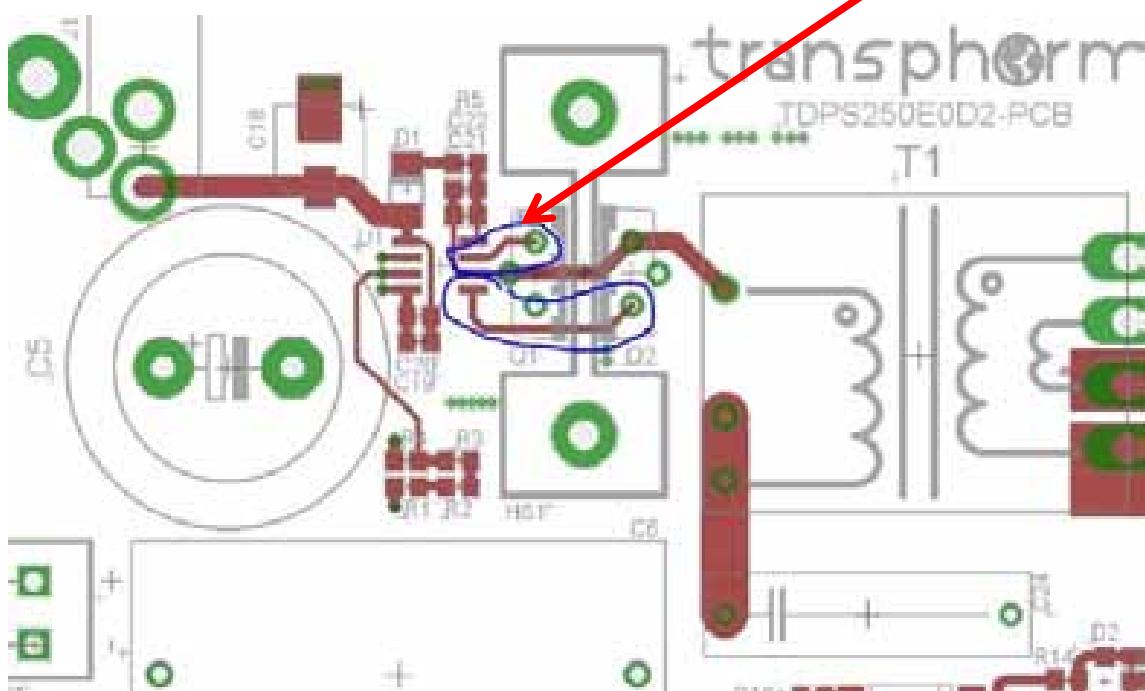
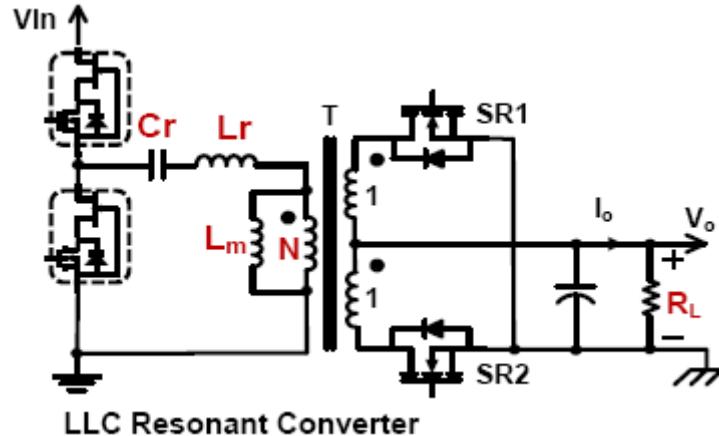
1. 氮化镓的开关速度很快,  $dv/dt$ 超100V/nS.
2. 氮化镓体内是有Si+GaN两FET组成。相互的连线必然存在一定的寄生电感. 这些需要我们在布线的时候要尽可能地靠近以尽可能减少因走线带来的寄生参数

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

布线注意:



1,驱动与**MOS**的引脚距离要直,要短.(上管)

2,氮化镓**MOS**, G,S,D,要注意.

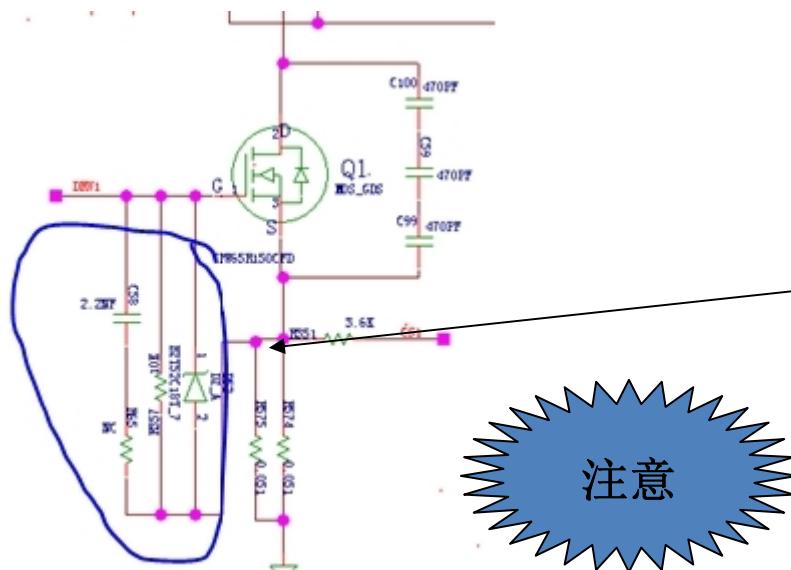
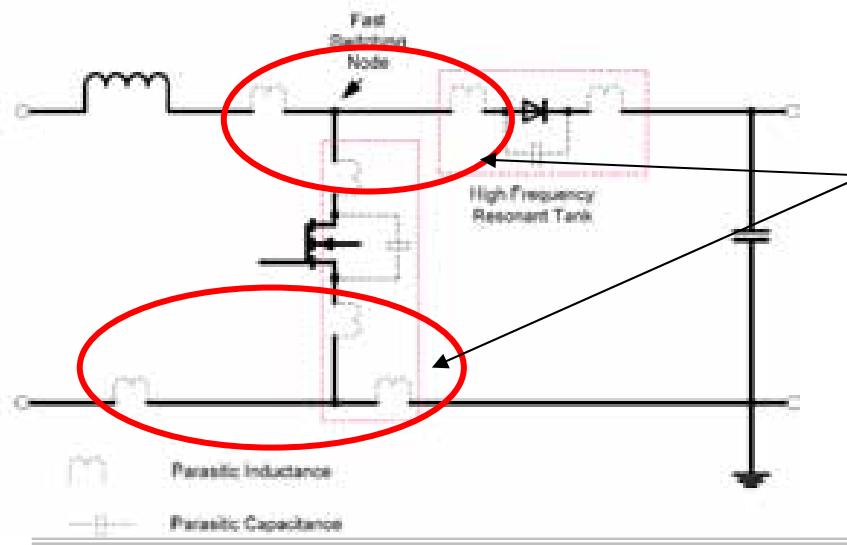
3,当有上,下管应用时,上管到驱动的距离要尽可能短,下管可稍长点.

4,与**MOS**三个脚相连的器件走线要尽可能短.

5,功率管两端尽可能要加去耦电容82nF两三个并放。

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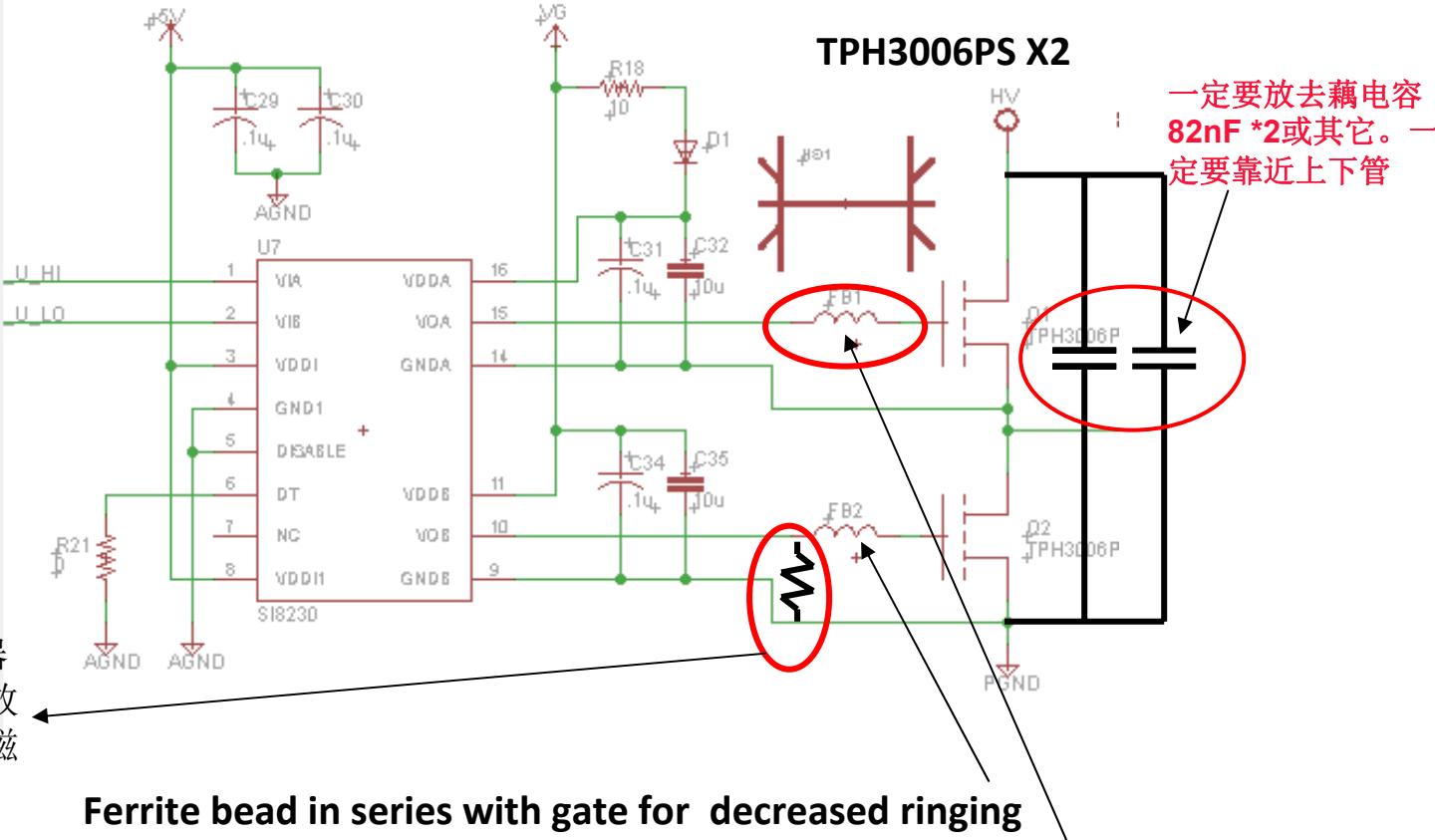
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## Schematic portion: Single Half Bridge

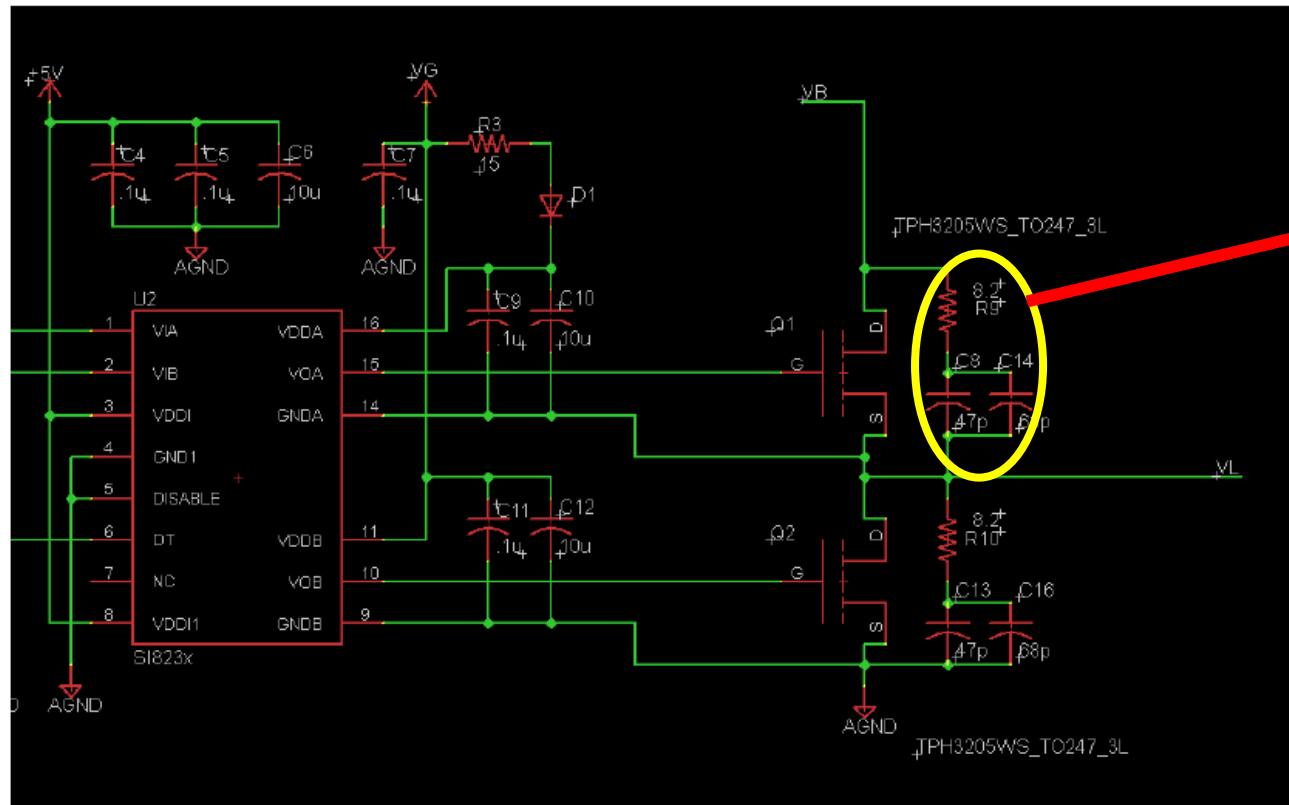


Digikey Part No: MMZ1608Q121B (0603) or MMZ2012D121B (0805)

磁珠80-120欧 (100MHZ) 尽可能靠近GATE脚，磁珠低频直通高  
频阻抗特性能抑制GATE脚的振荡及速度

**transphorm**

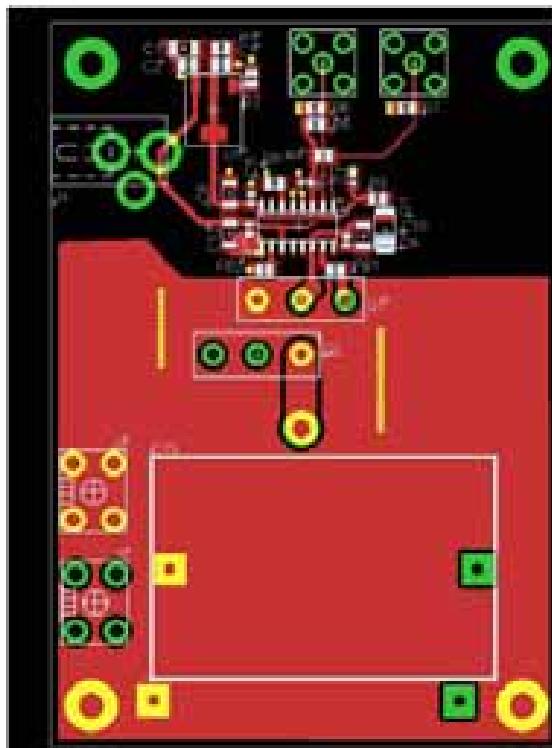
# Half Bridge Circuit



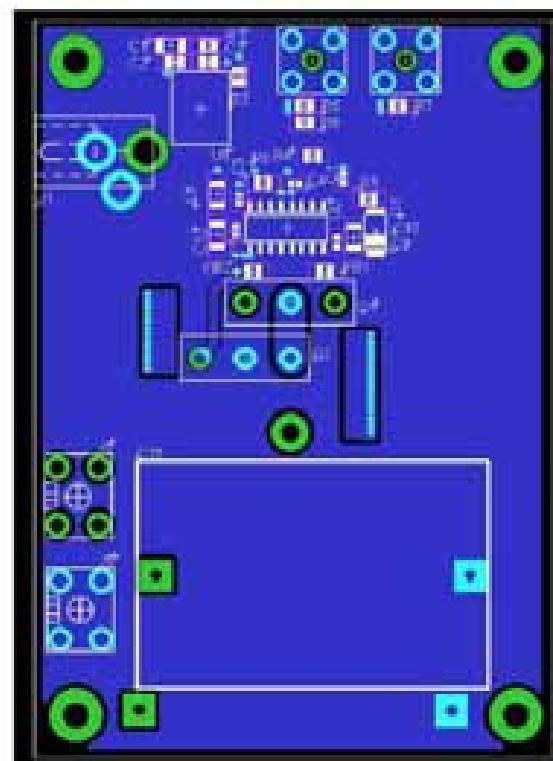
TO-247建议加RC电  
路，TO-247封装集成  
了寄生电感。  
TO-220无需加

For the new TO247, Ferrite Bead and Rg are not needed.

# Half Bridge Circuit



Top Layer



Bottom Layer



Photo of testing circuit

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因氮化镓MOS速度很快,达6nS, 所以接地线及管子的引线偏长会带来寄生电感的问题,易引起振荡.探头得改下,否则易因振荡而烧掉MOS

与接地  
线相连



下管  
高频去耦电容, 尽  
可能靠近上下管  
上管

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# 氮化镓的可靠性测试

最终数据表现非常强劲

氮化镓DC 600V最大，但允许750V 连续100nS的连续方波（频率>10K即可）  
即可满足常规的应用

PRODUCT SUMMARY (TYPICAL)	
V <sub>DS</sub> (V)	600
R <sub>DS(on)</sub> ( $\Omega$ )	0.29
Q <sub>rr</sub> (nC)	29

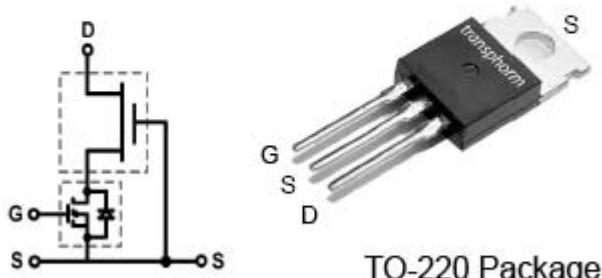
#### Features

- Low Q<sub>rr</sub>
- Free-wheeling diode not required
- Low-side Quiet Tab™ for reduced EMI
- GSD pin layout improves high speed design
- RoHS compliant

#### Applications

- High frequency operation
- Compact DC-DC converters
- AC motor drives
- Battery chargers
- Switch mode power supplies

### GaN Power Low-loss Switch



TO-220 Package

V <sub>DSS</sub>	Drain to Source Voltage	600	V
V <sub>TDS</sub>	Transient Drain to Source Voltage <sup>a</sup>	750	V

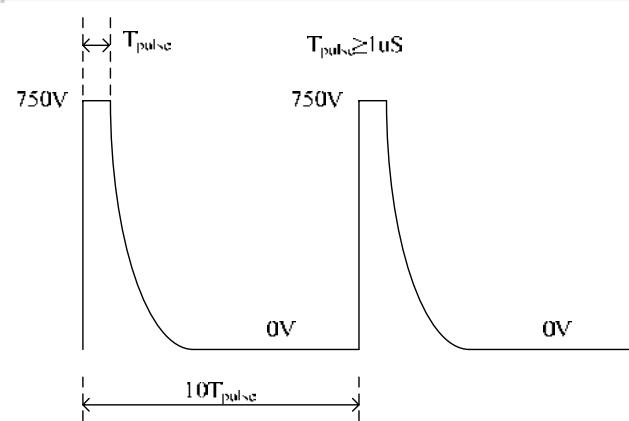


Fig.2 V<sub>DS</sub> waveform

transphorm

#### Notes

- a: For 1 usec. duty cycle D=0.1
- b: For 10 sec, 1.6mm from the case

Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

## GaN-on-Si HEMT and Diode Passed JEDEC Qual Standards (Feb 2013)

### 6) Reliability Testing

- a) All reliability tests are performed to a Lot Tolerant Percent Defective (LTPD) level of 3% at a 90% confidence level as defined in JESD-47
  - i) Minimum lot size is 77 parts for each test
  - ii) All tests are Accept on zero fails, Reject on one fail
  - iii) Four wafer fab lots were used, and the parts allocated to each test as documented below.
- b) Test conditions
  - i) HTRB:  $T_j=150^{\circ}\text{C}$ , 480V, min: 1000 hrs
  - ii) HAST:  $130^{\circ}\text{C}/85\%$  RH, 33.3 psi, continuous bias @100V, min: 96 hrs.
  - iii) Temperature Cycle:  $-55^{\circ}\text{C} / 150^{\circ}\text{C}$ , 2 cycles per hour, min: 1000 cycles
  - iv) Power Cycle:  $25^{\circ}\text{C} / 150^{\circ}\text{C}$ ,  $\Delta T = 125^{\circ}\text{C}$ , min: 5000 cycles
  - v) HTSL:  $150^{\circ}\text{C}$ , min: 1000 hrs
- c) Test Results

Lot	HTRB	HAST	HTSL	TC	PC
TPS3413PK LOT #1	Accept	(8A diode)		Accept	
TPS3413PK LOT #2	Accept	Accept	Accept	Accept	Accept
TPS3413PK LOT #3	Accept	Accept	Accept	Accept	Accept
TPS3413PK LOT #4		Accept	Accept		Accept

产品均通过功率增导  
体的**JEDEC**认证

(目前唯一一家氮化  
镓半导体公司)

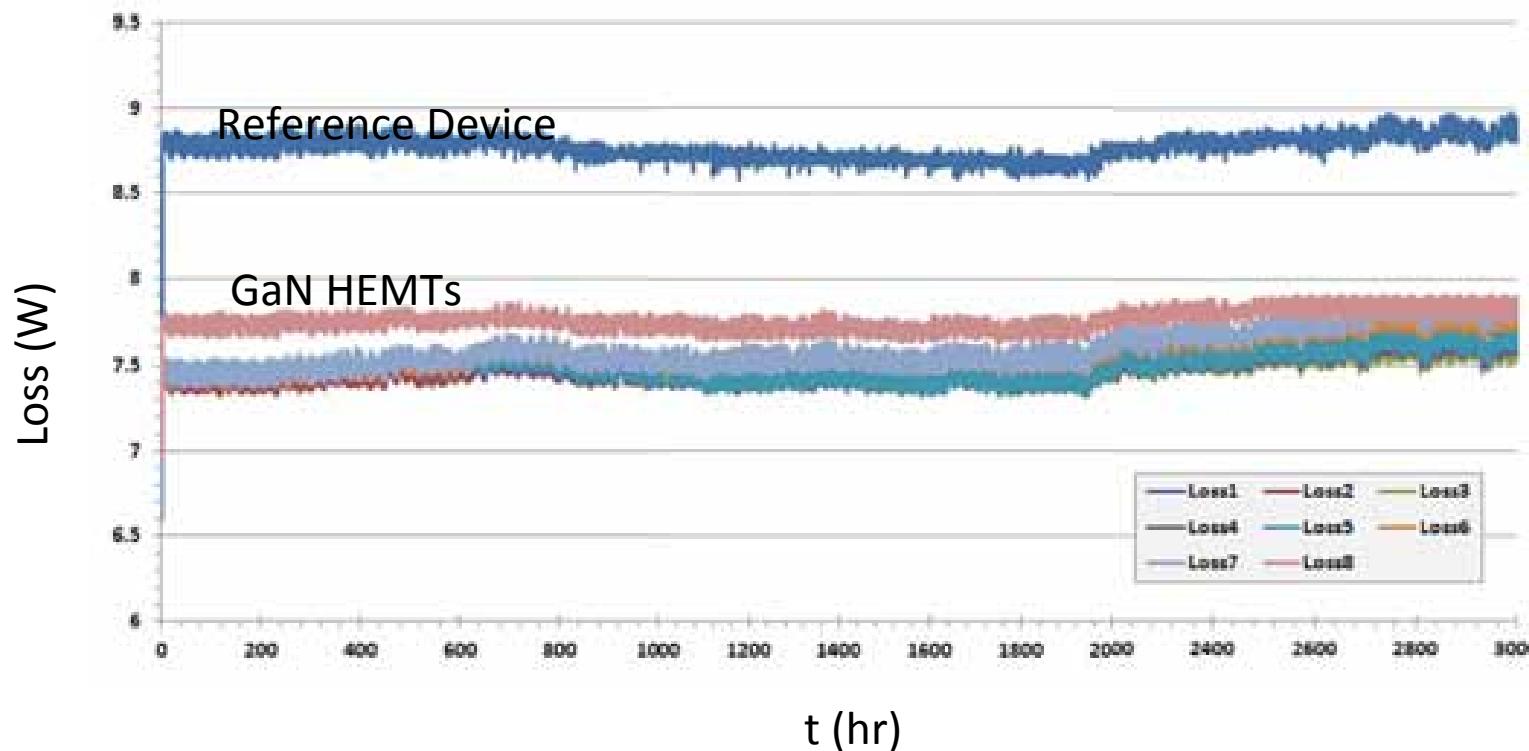
# GaN-on-Si HEMTs Passes JEDEC Qual Standards (Feb 2013)

TPH3006PS & TPH3006PD												
TEST	I <sub>DSS</sub> ( $\mu$ A) V <sub>R</sub> =600V V <sub>G</sub> =V <sub>S</sub> =0V T <sub>j</sub> =25°C				I <sub>GSS</sub> ( $\mu$ A) V <sub>G</sub> =20V, V <sub>D</sub> =V <sub>S</sub> =0V				R <sub>DS</sub> (mΩ) I <sub>F</sub> =4A, V <sub>GS</sub> =8V, PW=100us, T <sub>j</sub> =25°C			
	PRE STRESS		POST STRESS		PRE STRESS		POST STRESS		PRE STRESS		POST STRESS	
	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$	Mean	$\sigma$
HAST-1	2.24	1.10	2.09	1.20	1.5E-05	4.0E-05	7.0E-05	4.0E-04	127.6	2.9	136.2	6.2
HAST-2	2.57	1.26	2.51	1.38	1.0E-05	4.3E-05	1.7E-05	2.3E-05	146.1	2.9	147.1	3.9
HAST-3	2.34	1.05	2.29	1.05	6.8E-05	2.2E-05	5.0E-05	4.8E-05	139.0	2.4	142.8	3.2
TC-1	2.34	1.05	2.34	1.05	3.0E-05	3.8E-05	6.6E-05	2.5E-05	138.9	2.7	142.6	2.0
TC-2	2.34	1.07	2.14	1.07	8.0E-05	5.1E-05	6.0E-05	1.5E-05	128.8	3.6	132.1	4.1
TC-3	2.40	1.05	2.34	1.07	6.0E-05	3.7E-05	1.1E-05	4.6E-06	144.4	1.7	142.5	1.4
PC-1	2.14	1.07	2.00	1.10	5.7E-05	3.6E-05	1.7E-05	5.6E-06	130.6	2.8	135.5	3.0
PC-2	2.14	1.20	2.40	1.20	6.3E-05	1.1E-05	8.1E-04	7.5E-03	145.7	2.9	142.8	3.0
PC-3	1.95	1.07	2.09	1.07	6.1E-05	9.0E-06	6.3E-05	5.2E-06	133.9	2.1	136.5	1.9
HTRB-1	2.63	1.29	2.69	1.35	1.9E-05	4.7E-05	2.5E-05	3.6E-05	138.6	2.3	132.8	2.0
HTRB-2	2.34	1.17	2.63	1.74	1.2E-05	5.1E-05	5.9E-05	3.9E-06	132.1	2.7	131.1	2.0
HTRB-3	2.29	1.10	2.57	1.62	1.1E-05	7.4E-06	6.0E-05	1.6E-05	131.9	2.3	132.1	3.7
HTSL-1	2.40	1.07	2.34	1.07	6.6E-05	1.9E-05	1.3E-05	8.6E-06	139.5	1.7	143.0	2.2
HTSL-2	2.45	1.02	2.29	1.02	6.2E-05	2.1E-05	6.0E-05	3.6E-06	138.9	5.8	139.2	4.0
HTSL-3	2.40	1.10	2.19	1.07	5.6E-05	2.2E-05	8.3E-06	1.9E-05	128.3	1.2	128.6	2.4

- 漏电流没有增加
- 内阻没有增加

# High-temperature Operation Test @175C

200:400V converter operation at 175°C/300kHz/410W



- 在175度的环境中工作3000小时后几乎没有衰减/损耗基本没有变化。
- 数据看下页

## GaN HEMT 3000hr HTOL at 175C Completed W/O Degradation

---

**3000**小时前后测试没有发现什么变化。漏电流，**R(on)**，动态阻抗。

**175**度环境中测试

**DC200V 升压到DC400V, 300KHZ, 410W**

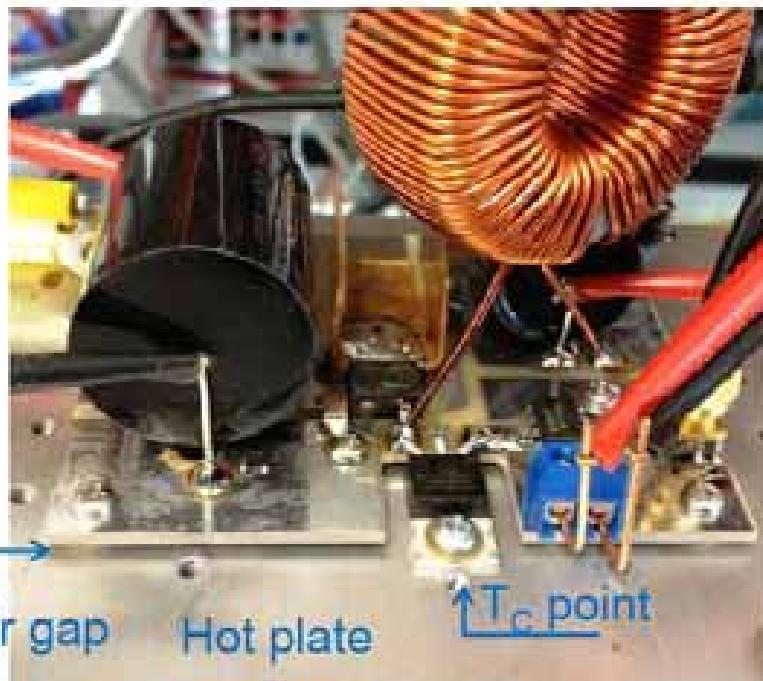
### Before/after parametric comparison

	Leakage current @ 600V (uA)		Ron static @ 4A (mΩ)		Ron static @ 15A(mΩ)		Ron_dynamic @ 480V, 4A, 60s (mΩ)	
Dev	0hrs	3000hrs	0hrs	3000hrs	0hrs	3000hrs	0hrs	3000hrs
8	2.291	1.713	138.1	141.4	140.7	145.2	155.3	154.1
9	2.387	1.735	138.9	138.7	141.4	142.5	151.9	148.0
10	2.354	1.764	138.2	139.0	140.2	142.8	150.6	149.8
11	2.403	1.791	138.3	137.6	140.6	141.7	148.0	144.7
12	2.515	1.843	137.4	137.8	139.2	141.4	145.2	144.0
13	2.488	1.843	141.5	139.2	143.7	143.3	151.9	148.0
14	2.469	1.812	136.9	138.4	140.3	142.3	145.9	146.0

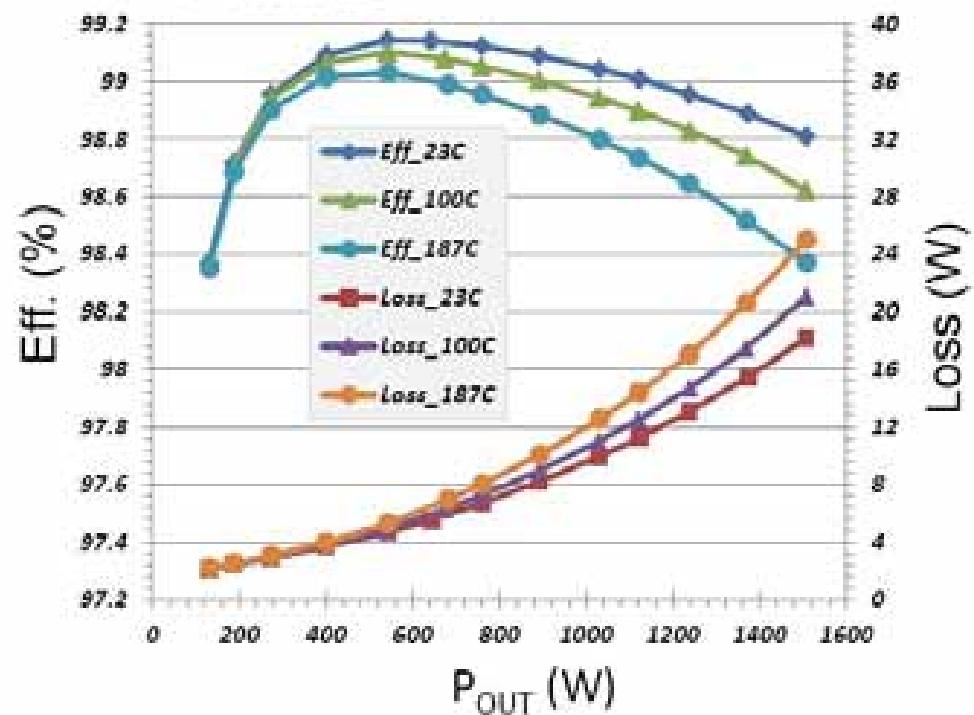
- No measurable degradation after 3000hr operation at 175°C

# GaN-on-Si Hybrid HEMT High Temperature Operation up to 1.5kW at $T_c=187^\circ\text{C}$ ( $T_j=215^\circ\text{C}$ )

Hi-Temp operation of GaN HEMT



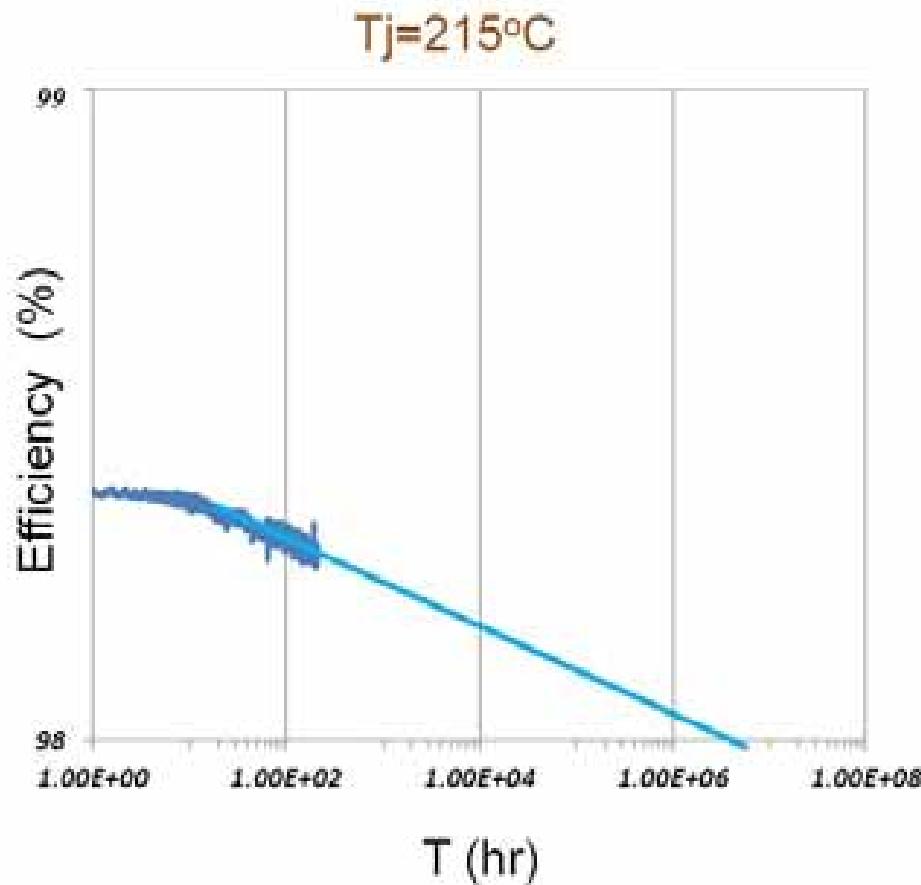
230V:400V boost Converter  
 $f=100\text{kHz}$



- GaN-on-Si can operate at high volt & high current at  $T_j=215^\circ\text{C}$  with ease
- HT performance lends support for inherent robustness

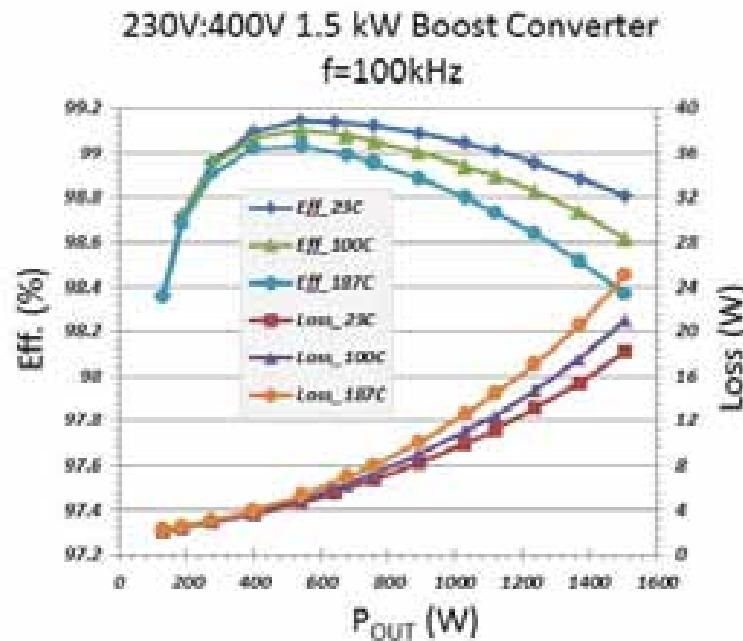
## Preliminary Life Time Indication

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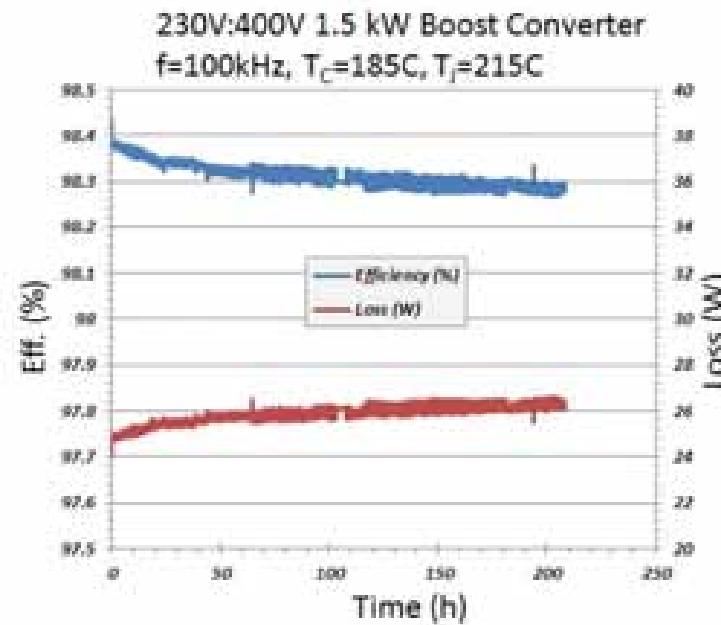


$10^6$  hr for Eff. to degrade by 0.2%  
(Significant part of degradation is none-device related)

# 超高温试验 187度环境



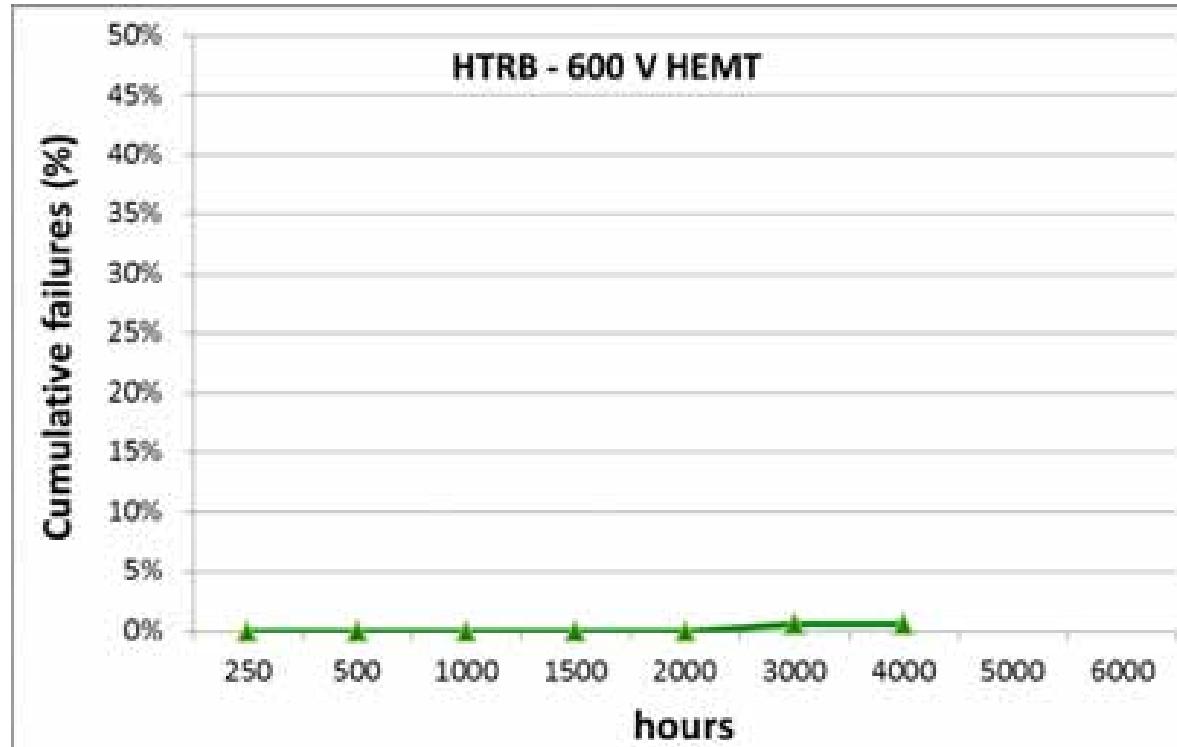
氮化镓工作高压大电流且  $T_j=215^{\circ}\text{C}$   
( $T_c=187^{\circ}\text{C}$ ) 中测试通过  
• 高温性能表现强劲



在如此极端条件下工作几百小时后  
才有一点点小小变化。依然强劲

# 继续延长600V器件HTRB测试

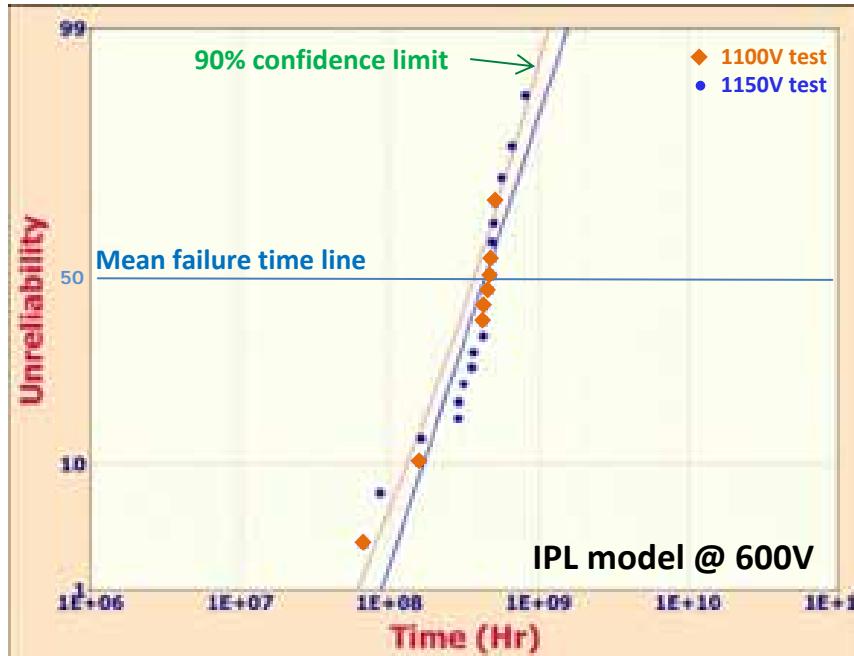
标准是1000小时



- Goal is to test until 50% of devices fail
  - High Temp Reverse Bias (HTRB)
    - 150 °C, 80% rated voltage
  - Test to 10,000 hours, but expect to need accelerated conditions to get 50% failures

# 加速老化测试寿命

## TDDB Model Projected Lifetime



给管子加上1150V的高压进行加速测试

- Stressed at 1150V, 1100V (& 1050V)
  - Higher voltages result in proliferation of different failure mode that is not relevant at operating conditions
- Obtain acceleration factor based on 2 groups of stresses (3<sup>rd</sup> groups under way)
- Plotted at 600V
  - inverse power law model used
- Standard voltage acceleration models give range of projected mean lifetimes
  - Most common models → 1e8 ~1e10hr
  - Most conservative model → 1e7hrs (Reciprocal Voltage TDDB model)
  - In progress with 3<sup>rd</sup> stress level for model determination

加速老化测试最终我们保守地预估寿命如下

- **600V operation lifetime > 10<sup>7</sup>hr**
- **480V operation lifetime > 10<sup>8</sup>hr**

# Additional life testing in process to determine activation energy

---

- HTOL
  - 150 °C, 100% rated voltage, 3,000 hours - done
  - 175 °C, 100% rated voltage, 3,000 hours - done
  - 200 °C, 100% rated voltage, test to failure - done
- High Voltage Off State testing
  - Accelerated electric field tested at multiple voltages
  - Testing at 25 °C and 150 °C
  - Determine electric field acceleration factors and project lifetime
- High Temperature DC testing
  - Low voltage testing at nominal current at elevated temperatures (>350 °C)
  - Multiple temperatures to determine temperature acceleration factor and project lifetime
- Electro-migration
  - High current testing at multiple current and temperature values

# RFJS3006F

iGaN-HV™ 650V SDFET  
With Ultra-Fast Free-wheeling Diode



Parameter	
$V_{DS}$	650V
$I_{SD(ON)}$	30A
$R_{DS(on)}$	45mΩ
$E_{on}/E_{off}$	20μJ/30μJ
Freewheeling Diode Function	TRR: 12ns
	QRR: 37nC

Ron小，但电流也小，条件不同  
45mΩ/25°C 20A, -63mΩ/25°C, 24A

Parameter	Rating	Unit
Drain-Source Operating Voltage ( $V_{DS}$ ), $T_c = 150^\circ\text{C}$	650	V
Continuous Drain Current ( $I_D$ ), $T_c = 25^\circ\text{C}^1$	30	A
Continuous Drain Current ( $I_D$ ), $T_c = 100^\circ\text{C}^1$	20	A
Pulsed Drain Current ( $I_{D(pulse)}$ ), $T_c = 25^\circ\text{C}^2$	100	A
Gate-Source Voltage ( $V_{GS}$ ), Static	-20 to 20	V
Power Dissipation TO247 ( $P_{Diss}$ ), $T_c = 25^\circ\text{C}$	76	W
Operating and Storage Temperature ( $T_c, T_{Storage}$ )	-55 to 150	°C
Mounting Torque TO247, M3 and M3.5 Screws	60	Ncm
Pulsed Forward Diode Current ( $I_{Fwd}$ ), $T_c = 25^\circ\text{C}$	100	A
Thermal Resistance Junction-to-Case ( $R_{th(jc)}$ )	1.8	°C/W
	internal, environment reference	

漏电流比较: 500uA vs 5uA

Zero Gate Voltage Drain Current ( $I_{SD(0)}$ )	500	TBD	μA	$V_{DS} = 650V, V_{GS} = 0V, T_c = 25^\circ\text{C}$
		TBD	μA	$V_{DS} = 650V, V_{GS} = 0V, T_c = 150^\circ\text{C}$

Qrr,Trr测试条件不同，不作比较

Reverse Recovery Time ( $t_{rr}$ )	12	ns		$V_D = 400V, I_D = 20A, T_c = 25^\circ\text{C}$
Reverse Recovery Charge ( $Q_{rr}$ )	31	nC		$V_D = 400V, I_D = 20A, dI/dt = 1000A/\mu\text{s}$

# TPH3205WS



## PRODUCT SUMMARY (TYPICAL)

$V_{DS}$ (V)	600		
$R_{DS(on)}$ (mΩ)	63		
$Q_{rr}$ (nC)	120		
$I_{SD}$ Continuous Drain Current @ $T_c = 25^\circ\text{C}$	34	A	
$I_{SD}$ Continuous Drain Current @ $T_c = 150^\circ\text{C}$	24	A	
$I_{SD}$ Pulsed Drain Current (pulse width: 100 μs)	140	A	
$V_{DS}$ Drain to Source Voltage	600	V	
$V_{DS}$ Transient Drain to Source Voltage *	750	V	
$T_c$ Operating Temperature	Case	-55 to 150	°C
$T_j$	Junction	-55 to 175	°C
$R_{th(jc)}$ Junction-to-Case		0.95	°C/W

Transphorm 63mΩM,但更大电流 30A VS 34A

工作温度: Transphorm 175°C 150 VS 175

热阻抗Rjc: Transphorm 更小 1.6 VS 0.95

脉冲电流: Transphorm 更大, 100A VS 140A

脉冲电压: Transphorm 提供750V 100nS连续许可脉冲

loss	Drain-to-Source Leakage Current, $T_c = 25^\circ\text{C}$	-	5	150	μA	$V_{DS}=600V, V_{GS}=0V, T_c = 25^\circ\text{C}$
loss	Drain-to-Source Leakage Current, $T_c = 150^\circ\text{C}$	-	20	-	μA	$V_{DS}=600V, V_{GS}=0V, T_c = 150^\circ\text{C}$

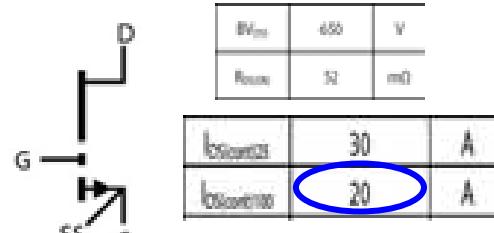
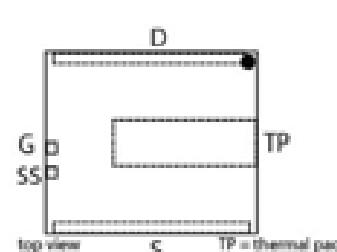
$t_{rr}$	30	-	ns	$I_D=24 A, V_{DD}=480 V, di/dt=450 A/\mu\text{s}, T_c=25^\circ\text{C}$
$Q_{rr}$	120	-	nC	

更多资料云下载: <http://pan.baidu.com/s/1sj39UW1>

transphorm

Transphorm Shanghai.  
Tel: 13501775977  
Mail: hz021@qq.com

**GS66508P-E03**  
650V enhancement mode GaN transistor  
PRELIMINARY DATASHEET



$V_{GS}$   $\pm 10$

Operating Junction Temperature:  $T_J$  -55 to +150 °C

Storage Temperature Range:  $T_J$  -55 to +150 °C

$R_{DS(on)}$	52	mΩ	$V_{GS}=7V, T_J=25^{\circ}C$
			$I_D=9A$

$R_{DC}$  0.5

Pulsed Drain Current: ( $T_{Jm}=25^{\circ}C$ ) (Note 1)  $I_{D(pulse)}$  45 A

漏电流比较：变化率太大，高温时达10倍

Drain-to-Source Leakage Current ( $T_J=25^{\circ}C$ )	$I_{DS(on)}$	2	μA	$V_{DS}=650V$ $V_{GS}=0V, T_J=25^{\circ}C$
Drain-to-Source Leakage Current ( $T_J=150^{\circ}C$ )		200	μA	$V_{DS}=650V$ $V_{GS}=0V, T_J=150^{\circ}C$

# TPH3205WS



PRODUCT SUMMARY (TYPICAL)

$V_{DS}$ (V)	600	
$R_{DS(on)}$ (mΩ)	63	
$Q_g$ (nC)	120	

63	78	mΩ	$V_{GS}=8V, I_D=24A, T_J = 25^{\circ}C$
----	----	----	---

S(K) o S

$I_{DC}$	Continuous Drain Current @ $T_J=25^{\circ}C$	34	A
$I_{DCR}$	Continuous Drain Current @ $T_J=150^{\circ}C$	24	A
$I_{DP}$	Pulsed Drain Current (pulse width: 100 μs)	140	A
$V_{DS}$	Drain-to-Source Voltage	600	V
$V_{DS(t)}$	Transient Drain-to-Source Voltage *	750	V
$T_c$	Operating Temperature	-55 to 150	°C
$T_j$	Junction	-55 to 175	°C
$R_{JC}$	Junction-to-Case	0.95	°C/W

$I_{DS(on)}$	Drain-to-Source Leakage Current, $T_J = 25^{\circ}C$	-	5	150	μA	$V_{DS}=600V, V_{GS}=0V, T_J = 25^{\circ}C$
$I_{DS(on)}$	Drain-to-Source Leakage Current, $T_J = 150^{\circ}C$	-	20	-	μA	$V_{DS}=600V, V_{GS}=0V, T_J = 150^{\circ}C$

Transphorm 63mΩM,但更大电流 30A VS 34A

工作温度: Transphorm 175°C 150 VS 175

热阻抗Rjc: Transphorm 较大 0.5 VS 0.95

脉冲电流: Transphorm 更大, 45A VS 140A

脉冲电压: Transphorm 提供750V 100nS连续许可脉冲

漏电流相关太大 200uA vs 20uA

## 不同厂商GaN FET器件比较（相同条件）：

---

1, **R<sub>d</sub>s(on)**对应的真实电流大小

R <sub>d</sub> s(on)	Drain-Source On-Resistance (T <sub>j</sub> = 25 °C)	-	63
----------------------	--	---	----

---

2, **V<sub>gate</sub>**电压对比。宽的电压较易设计

V <sub>gs</sub>	Gate to Source Voltage	±18
-----------------	------------------------	-----

---

3, 漏电流的大小，直接影响到温升

I <sub>oss</sub>	Drain-to-Source Leakage Current, T <sub>j</sub> = 25 °C	-	5
------------------	--	---	---

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4, 工作温度对比**operating temperature**

Operating Temperature	Case	-55 to 150
	Junction	-55 to 175

---

5, 脉冲电流大小对比

I <sub>pu</sub>	Pulsed Drain Current (pulse width: 100 μs)	140	A
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6, 动态**R<sub>d</sub>s(on)**阻抗特性对比

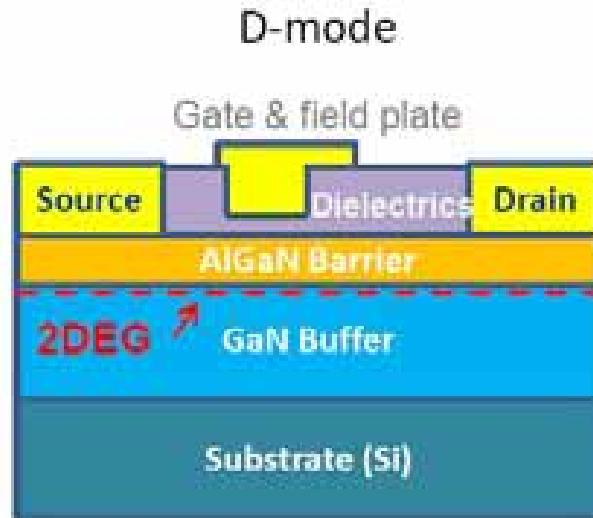
更多资料云下载: <http://pan.baidu.com/s/1sj39UW1>



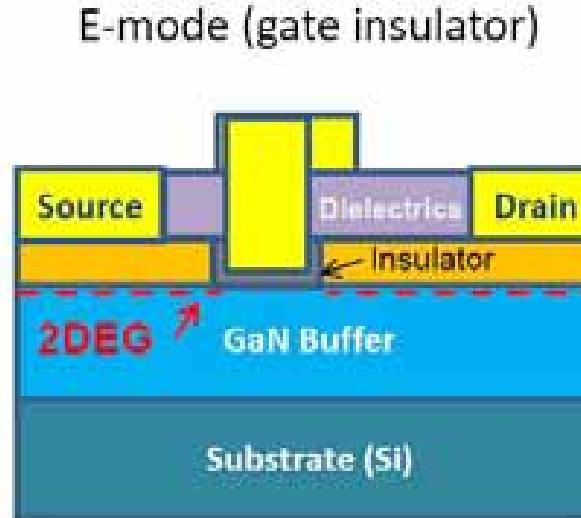
Transphorm Shanghai.  
Tel: 13501775977  
Mail: hz021@qq.com

# Typical HEMT Structures (Horizontal)

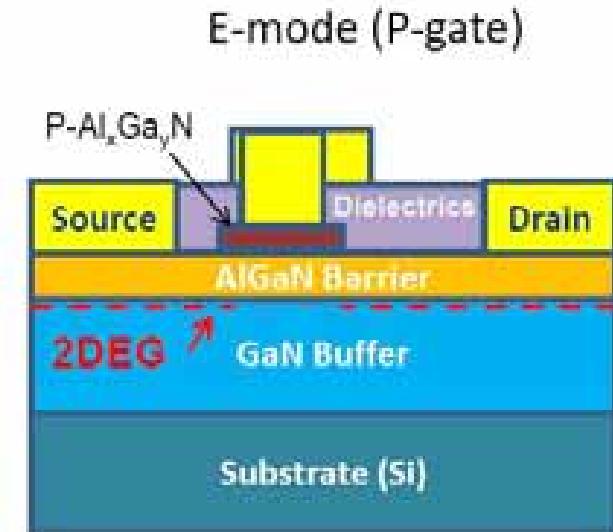
Transphorm当前D-Mode氮化镓结构



Transphorm将来E-Mode氮化镓结构，易控制。



目前市场E-Mode氮化镓结构，门极控制难



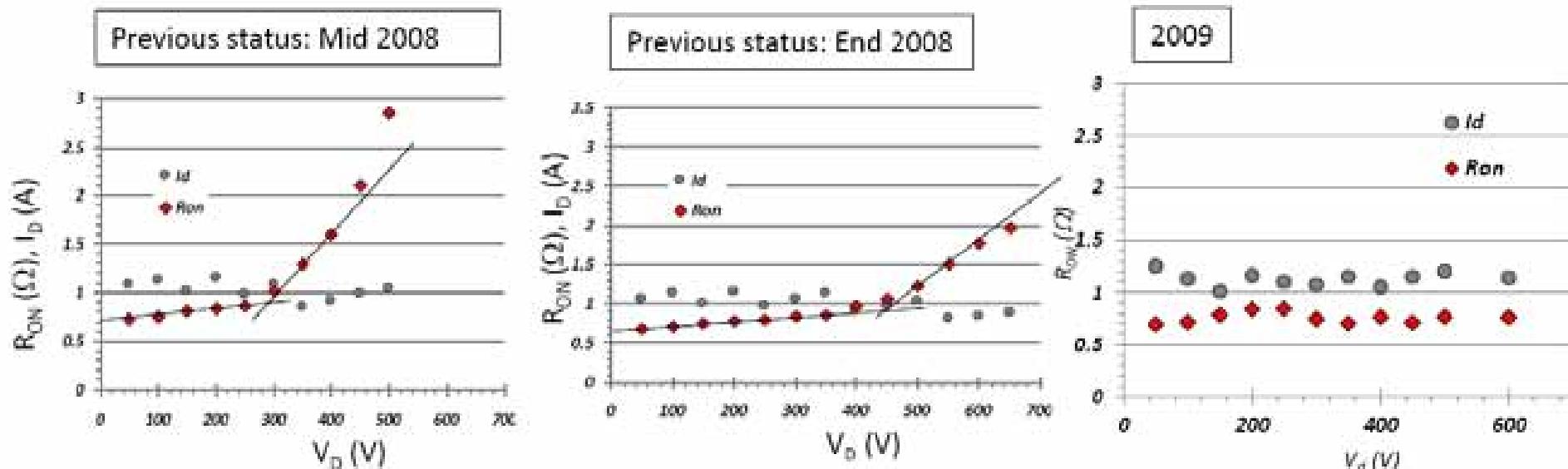
- Best mobility and charge
- Stable gate structure
- Not normally off

- Poor mobility under gate
- Insulator reliability issues
- Normally off ( $V_{th}$  uniformity issue)

- Overall lower conductivity
- Cannot tolerate  $V_g > 5V$
- Normally off

# Resolving the Dynamic Ron Issue During R&D Stage (2008-2009)

- Proprietary Epi and gate insulator designs for excellent dynamic characteristics
  - □ Dynamic Ron (current collapse) is caused by electron trapping
  - □ Gate insulator /field plate design/I-buffer are the key to reduce Dynamic Ron
- Transphorm solved the Dynamic Ron problems in 2009, 2 years before any competitors that published similar results



- The max. Ron on Transphorm datasheet INCLUDES dynamic Ron., that users will never see a higher Ron in their applications, DC or switching

$R_{DS(on)}$	Drain-Source On-Resistance ( $T_J = 25^\circ\text{C}$ )	-	0.15	0.18	$\Omega$	$V_{GS}=8\text{V}, I_D=11\text{A}, T_J = 25^\circ\text{C}$
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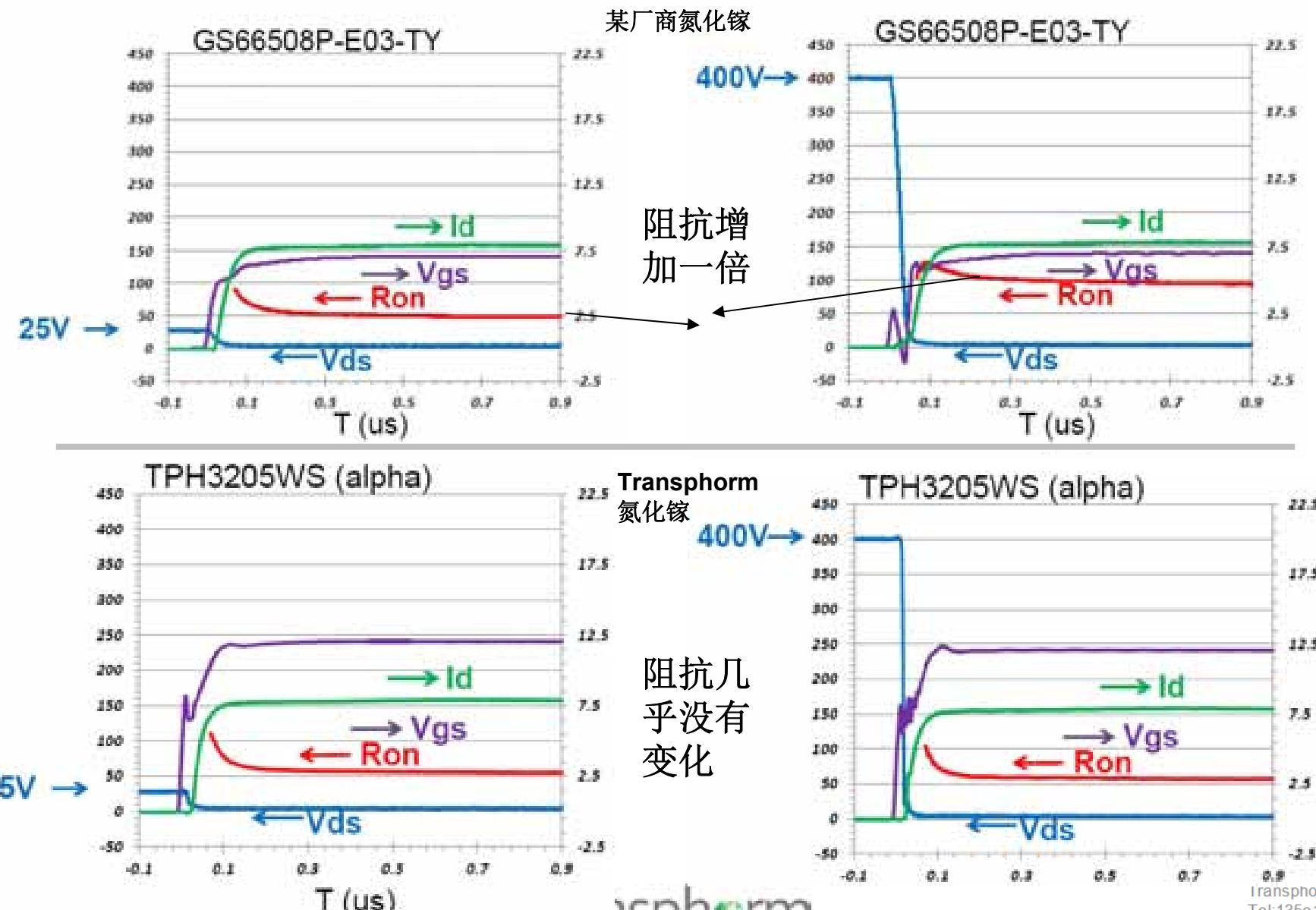
transphorm

Transphorm Shanghai.  
Tel:13501775977  
Mail: hz021@qq.com

# 动态阻抗特性

TPH3205 /Transphorm

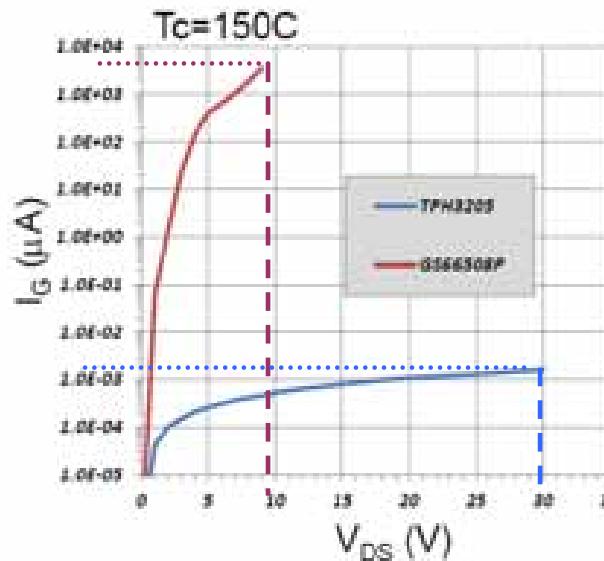
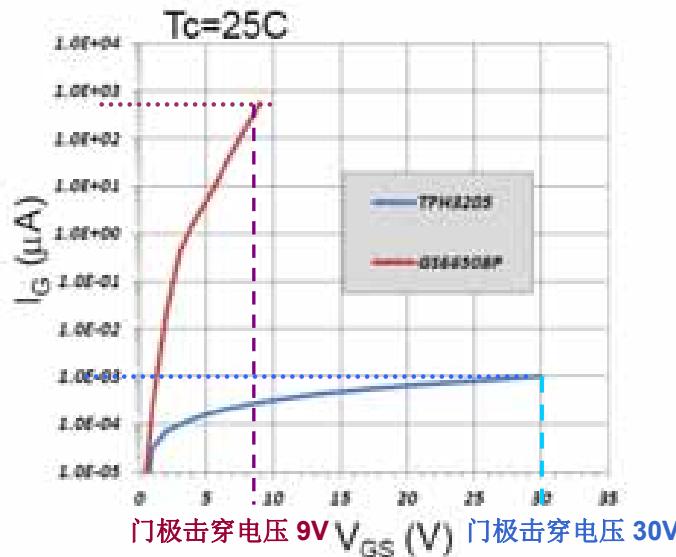
GS66508 /其它厂商



# 漏电流特性对比

TPH3205 /Transphorm

GS66508 /其它厂商

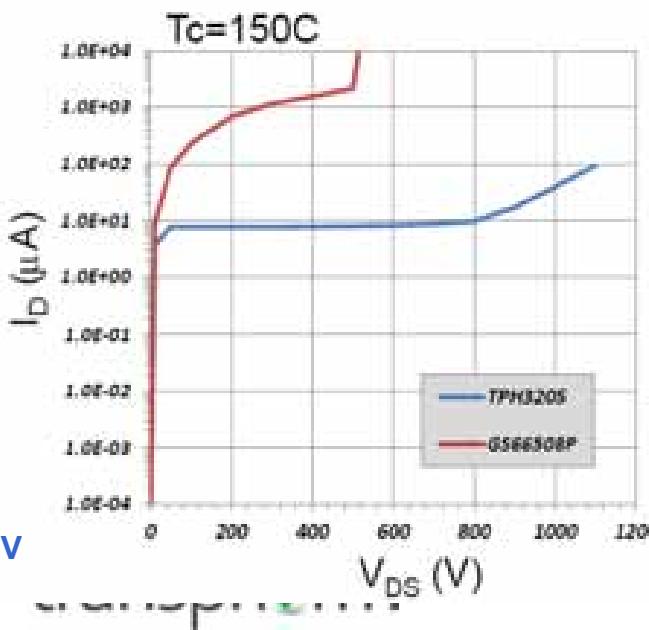
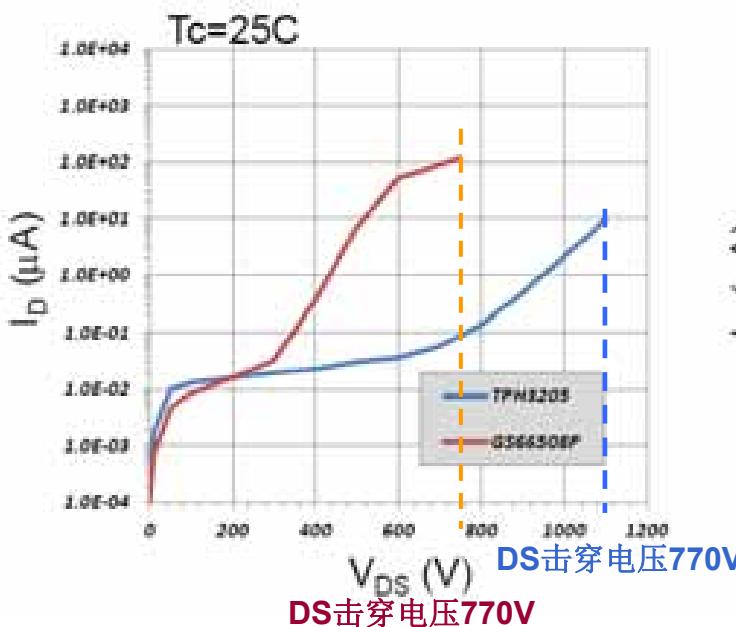


门极

1, 门极击穿电压远高于对手

**9V vs 30V**

2, 门极漏电流  $25^\circ\text{C}$ 与 $150^\circ\text{C}$ 下  
Transphorm的要远小于对手  
是其 $1/6$ 左右



漏极

1, 漏极击穿电压远高于对手

**800V vs 1100V**

2, 漏极漏电流 随温度升高后，我司产品稳定，对手的超过400V直线上升。。。