氮化镓MOS (HEMT)

5x6 PQFN Package (bottom view)

8x8 PQFN Package

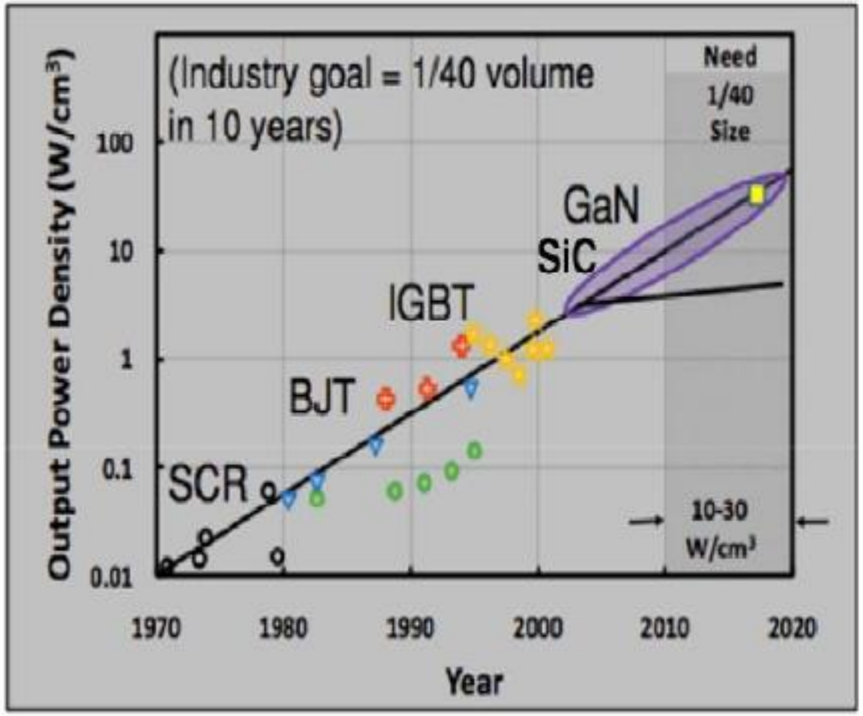
TO-220 Package

TO-247 3L Package

氮化镓MOSFET (600~650Vdc, 能承受周期为1uS, 100nS的连续的方波, 保证750~800V)

产品型号	封装	电压(V)	电流(A)	导通电阻 Rdson(mΩ)	功率范围
TPH3245ED	QFN5*6	600	6	500	<150W
TPH3202LD	QFN8*8	600	9	290	40-500W
TPH3202PS	TO-220	600	9	290	40-500W
TPH3206LD	QFN8*8	600	17	150	500-1500W
TPH3206PS	TO-220	600	17	150	500-1500W
TPH3208LD	QFN8*8	650	21	110	1000～2500W
TPH3208PS	TO-220	650	21	110	1000～2500W
TPH3212LD	QFN8*8	650	28	72	1500~3000W
TPH3212PS	TO-220	650	28	72	1500~3000W
TPH3205WS	TO-247	650	36	52	2500~4500W
TPH3207WS	TO-247	650	47	35	2500~6000W
TPD3215M	模块	600	70	30	4500W(半桥)

电源功率密度趋势-transphorm氮化镓MOS



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式

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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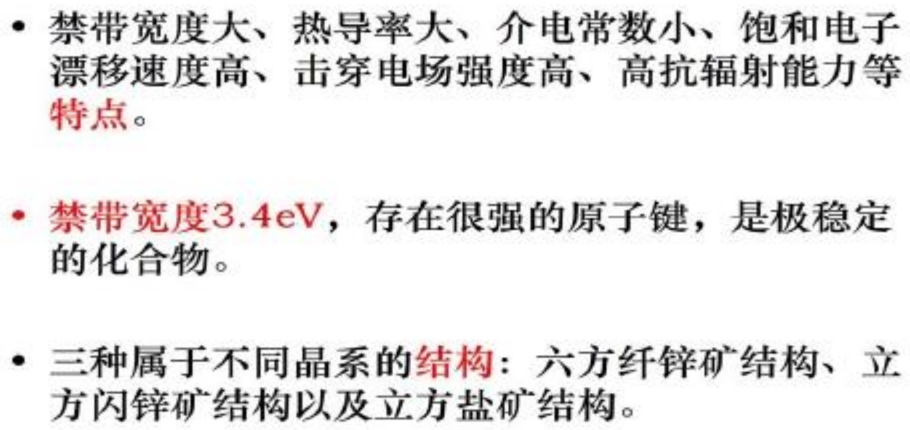
Si, SiC, GaN三种不同材料半导体比较

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

FUJITSU
shaping tomorrow with you

transphorm公司介绍 www.transphormusa.com

Japan office

- 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

KKR

投资商：

Foundation CAPITAL

KPCB KLEINER PERKINS CAUFIELD BYERS

INCJ

Google ventures

FUJITSU

SOROS Soros Fund Management

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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

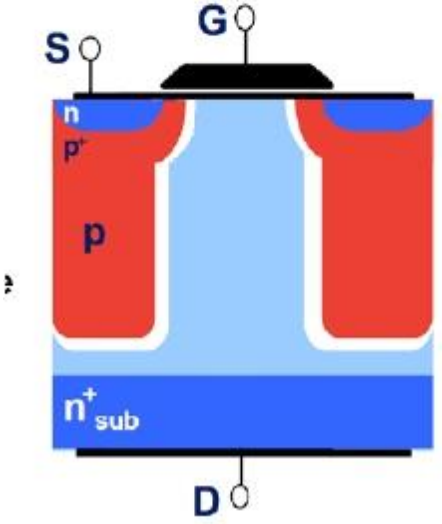
SVP Sales & Marketing

25+ years P&L mgt, strategy, sales & marketing, leadership

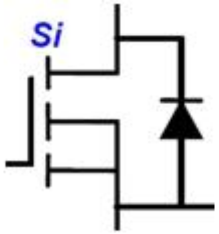
CREE
FAIRCHILD SEMICONDUCTOR
KLA Tencor
CYPRESS PERFORM
intel
AMD
National Semiconductor
FUJITSU
NXP

硅MOS, 氮化镓MOS的结构对比

硅MOS

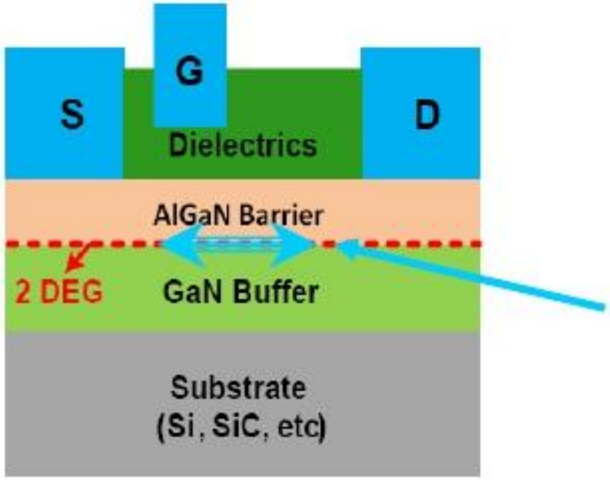


Si super junction vertical Structure



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，下方直接接金属散热片。

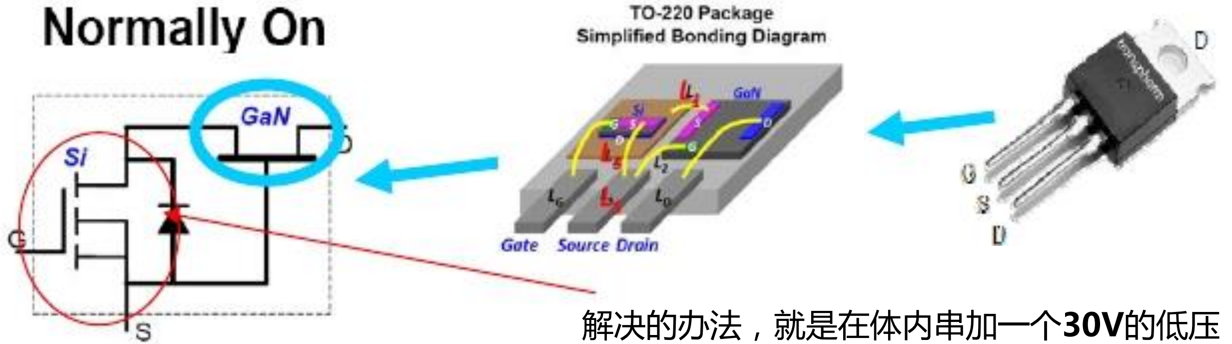
氮化镓



氮化镓 – 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）.

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

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，资料上的反向恢复时间均与此小**MOSFET**上的二极管有关。

横向结构器件
无寄生二极管
具有对称传导特性

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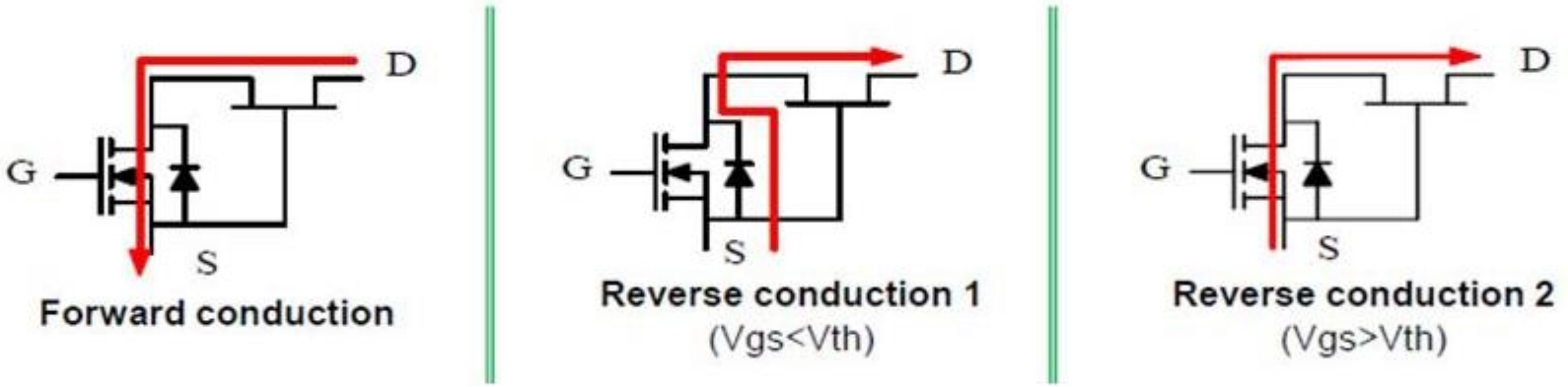
transphorm GaN 驱动线路很简单



Forward conduction

Reverse conduction 1
(Vgs<Vth)

Reverse conduction 2
(Vgs>Vth)

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， 所有驱动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	TPH3206PS 氮化镓
Static	V_{DS}	600V @ 25 °C	650V (spike rating 750V）
	R_{DS}(25 °C)	0.14/0.16ohm	0.15/0.18ohm
	Qg	75 nC	6.2 nC
	Qgd	38 nC	2.2nC
Dynamic	$C_{o(er)}$	[1] 66 pF	[1] 56 pF
	$C_{o(tr)}$	[1] 314 pF	[1] 110 pF
Reverse [1]Operation V_{GS}= 0V, V	Qrr	[2] 8200 nC	[3] 54 nC
	trr $_{DS}$= 0 –480V	[2] 460 ns	[3] 30 ns

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

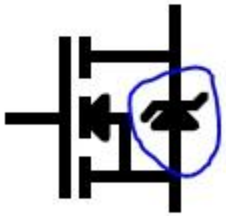
← 更小的反向恢复损耗

[2] V_{DS} = 400V, I_{DS} = 11.3A, di/dt = 100A/µs

[3] V_{DS} = 480V, I_{DS} = 9A, di/dt = 450A/µs

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),

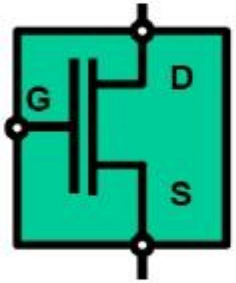
3,体内二极管反向续流损耗,

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



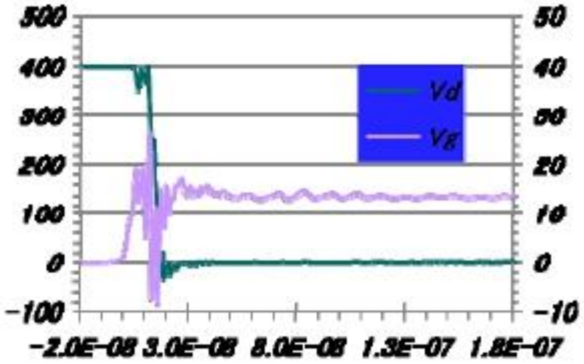
氮化镓MOS发热源:

1,Rds(on)损耗

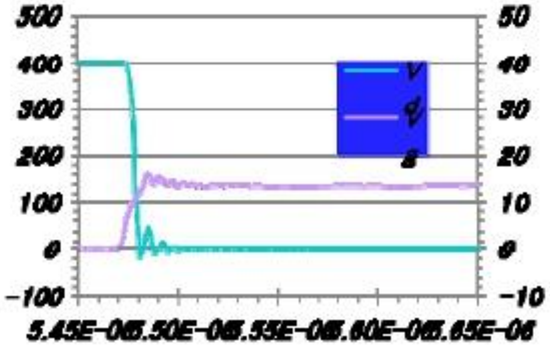
2，极其小开关损耗，不足Si管 1/10

3, 只有54nC反向恢复损耗，不足S管的 1/100损耗

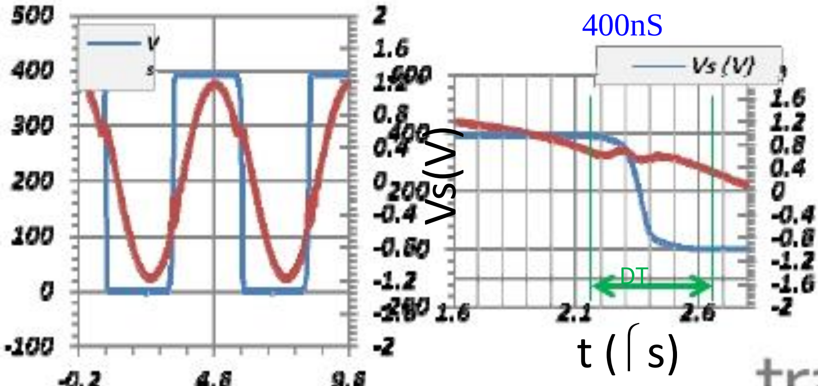
4，超低的结电容保证较小的死区损耗.



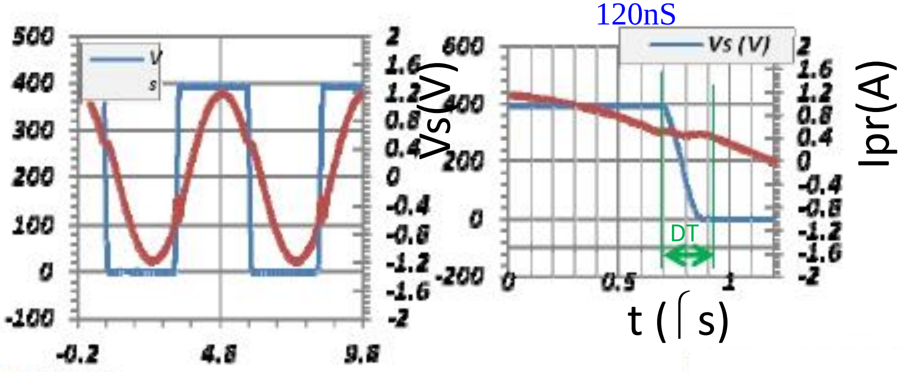
开关损耗对比



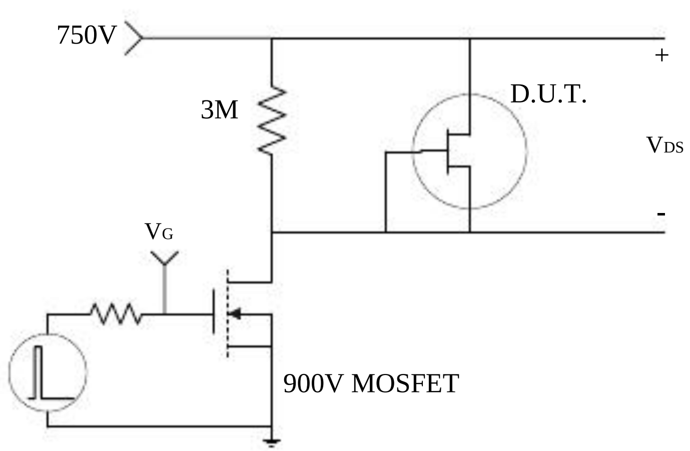
明显小于左边



死区损耗对比



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



Pulse Width ≥ 1uS
Duty Ratio = 0.1

Fig. 1 Spike Voltage Test Circuit

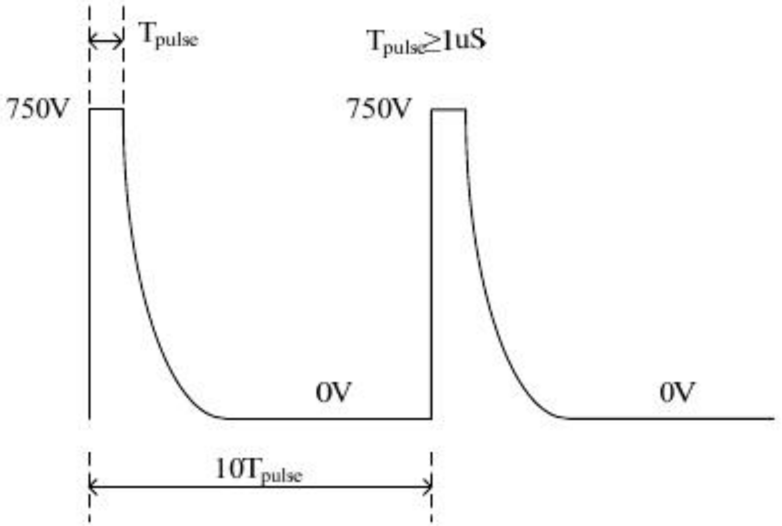
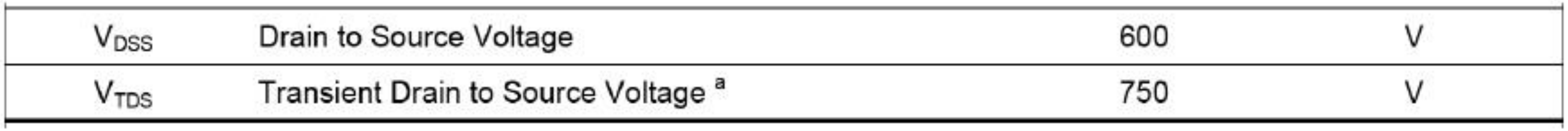


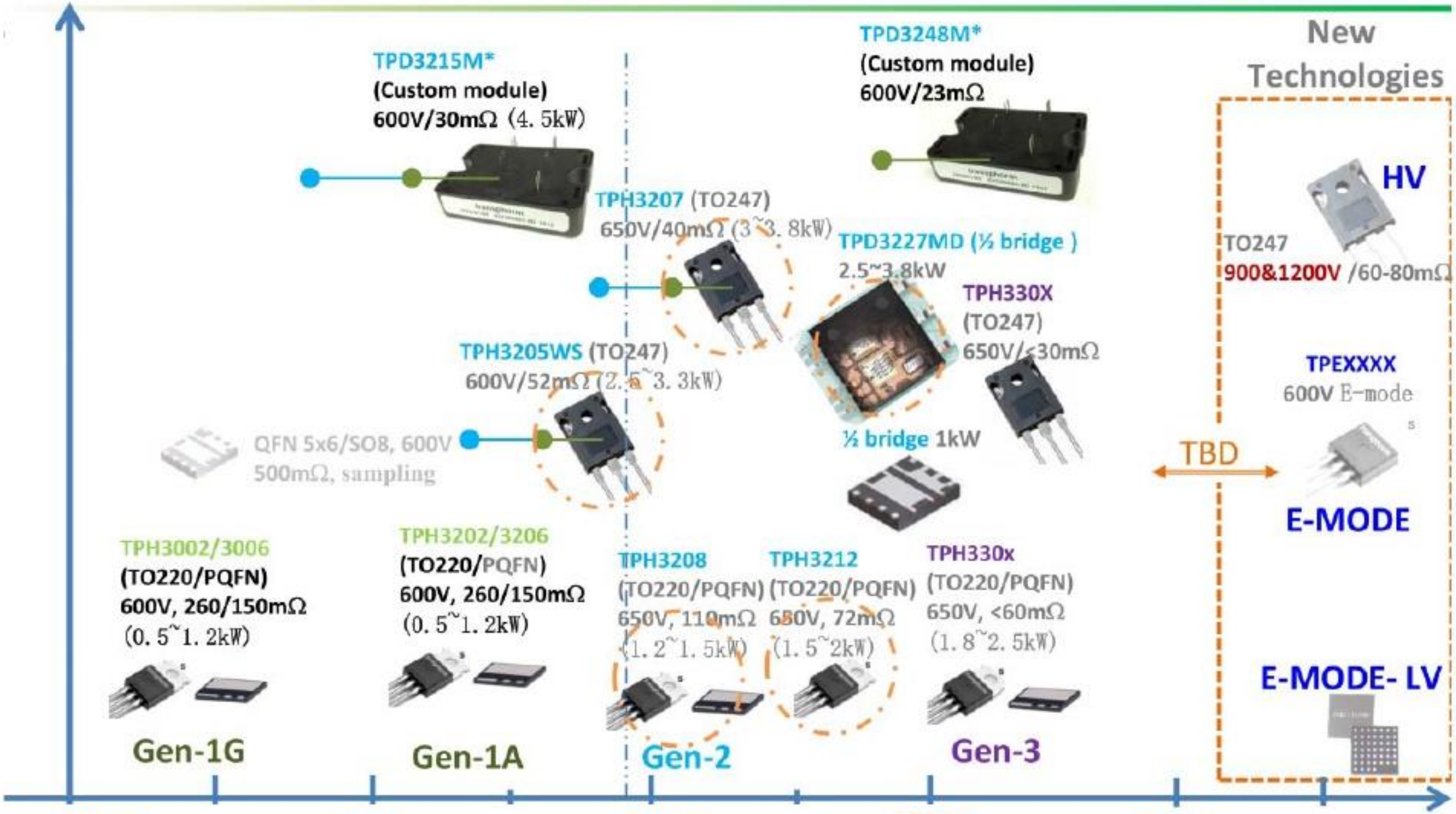
Fig.2 V_{DS} waveform



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）

Transphorm Product Roadmap Summary



TPD3215M* (Custom module)
600V/30mΩ (4.5kW)

TPD3248M* (Custom module)
600V/23mΩ

New Technologies

HV
TO247
900&1200V /60-80mΩ

TPH3207 (TO247)
650V/40mΩ (3~3.8kW)

TPD3227MD (½ bridge)
2.5~3.8kW

TPH330X (TO247)
650V/<30mΩ

TPH3205WS (TO247)
600V/52mΩ (2.5~3.3kW)

QFN 5x6/SO8, 600V
500mΩ, sampling

½ bridge 1kW

TPEXXXX
600V E-mode

TBD

E-MODE

TPH3002/3006 (TO220/PQFN)
600V, 260/150mΩ
(0.5~1.2kW)

TPH3202/3206 (TO220/PQFN)
600V, 260/150mΩ
(0.5~1.2kW)

TPH3208 (TO220/PQFN)
650V, 110mΩ
(1.2~1.5kW)

TPH3212 (TO220/PQFN)
650V, 72mΩ
(1.5~2kW)

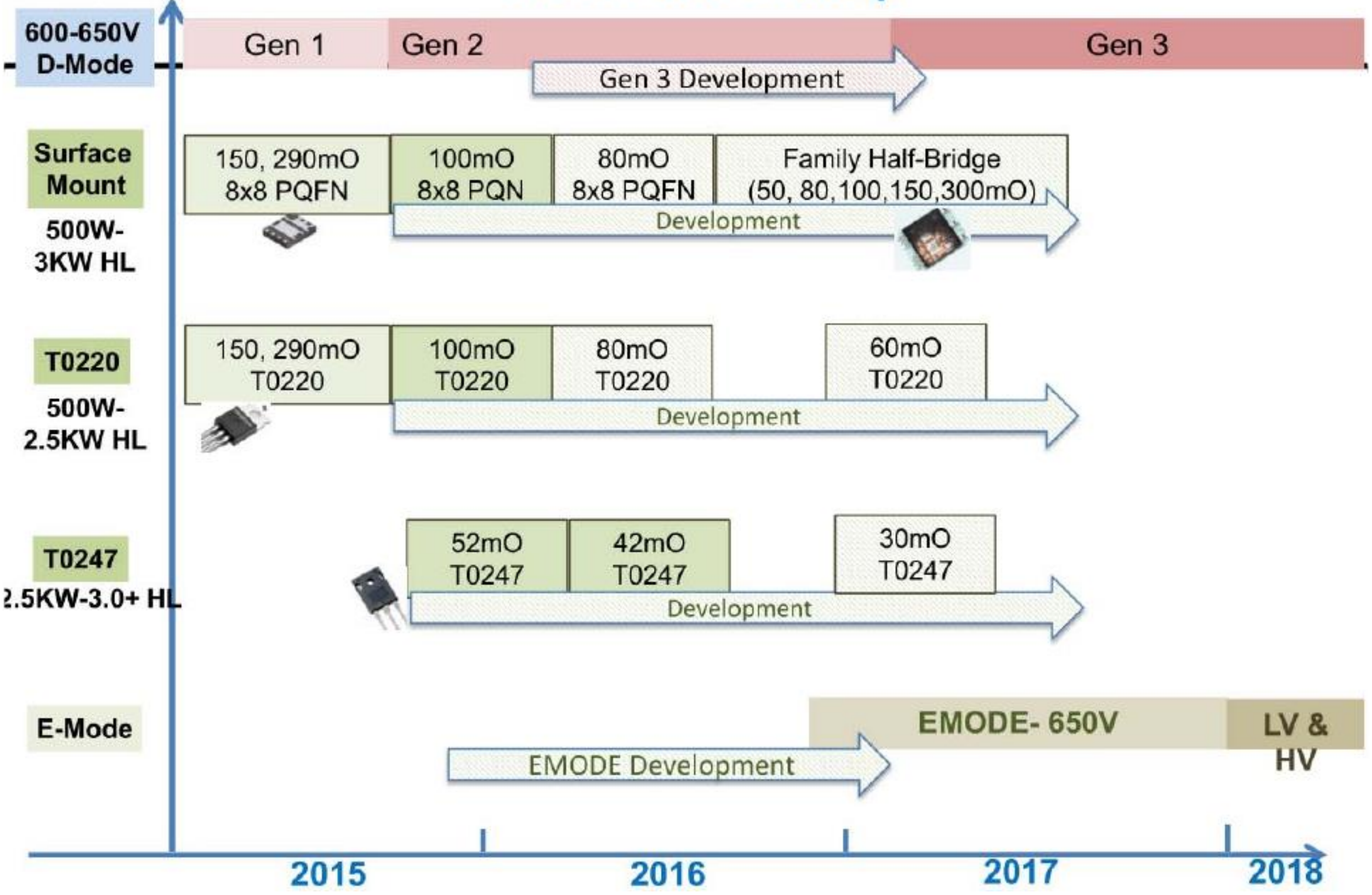
TPH330x (TO220/PQFN)
650V, <60mΩ
(1.8~2.5kW)

E-MODE- LV

Alpha sample: ●— Beta sample: ●— *M: Module Top projects [Note] kW rating: half for PFC at low line

Gen-1: TPH300X, Gen-2: TPH320X, Gen-3: TPH330X

Product Roadmap



R(on) Typ

600-650V D-Mode

Gen 1 | Gen 2 | Gen 3

Gen 3 Development

Surface Mount

500W-3KW HL

150, 290mO 8x8 PQFN

100mO 8x8 PQN

80mO 8x8 PQFN

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

Development

T0220

500W-2.5KW HL

150, 290mO T0220

100mO T0220

80mO T0220

60mO T0220

Development

T0247

2.5KW-3.0+ HL

52mO T0247

42mO T0247

30mO T0247

Development

E-Mode

EMODE Development

EMODE- 650V

LV & HV

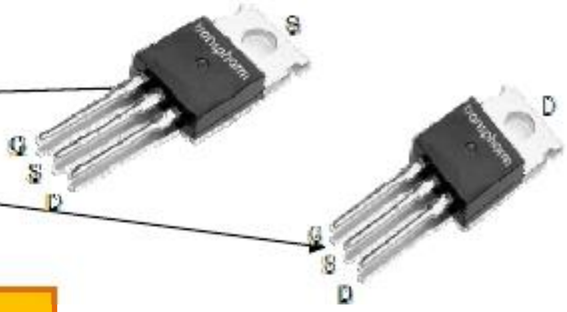
2015 | 2016 | 2017 | 2018

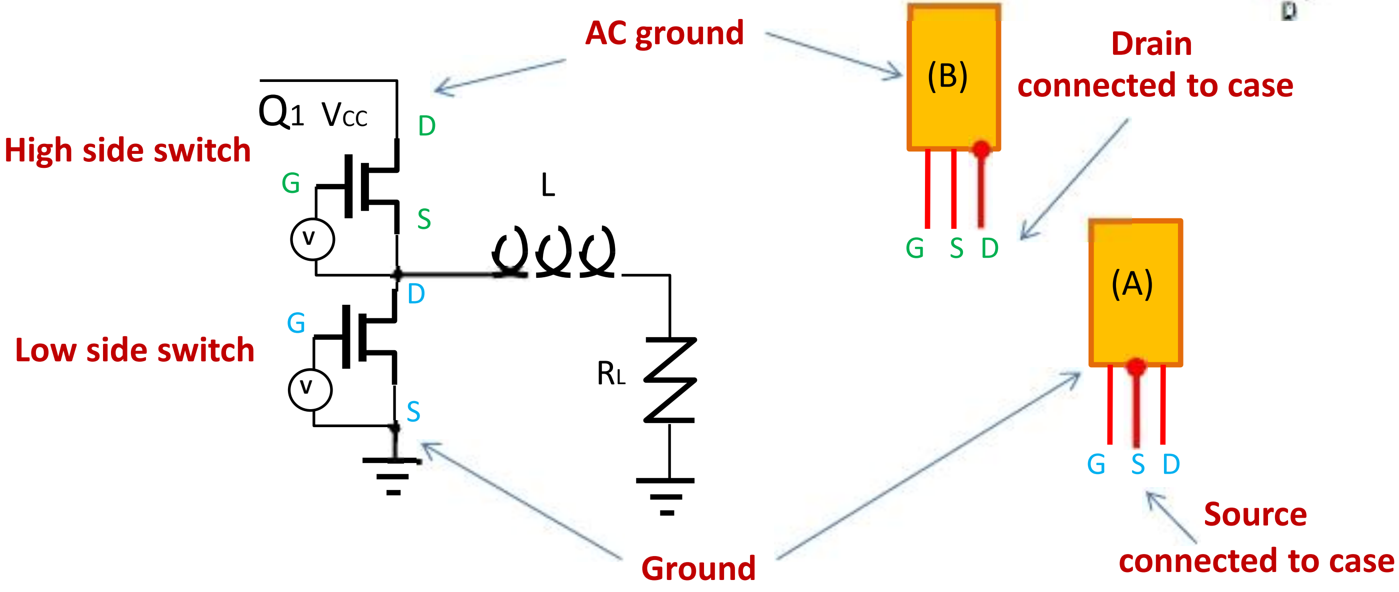
Qualified GaN on Silicon products from Transphorm: TO220 & PQFN (Production), TO247 (Eng Samples)

Specification	**Production**				**Eng Samples**
Part No.	TPH3206PS/PD	TPH3202PS/PD	TPH3206LS/LD	TPH3202LS/LD	TPH3205WS
					
	Source Tab (PS) Drain Tab (PD)		Source Dap (LS) Drain Dap (LD)		Source Tab Only
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)





TPH3202PS --背部金属接S极 （TO-220 600V/9A)

TPH3202PD –背部金属接D极

TPH3202LD --背部金属接D极 （QFN 8x8)

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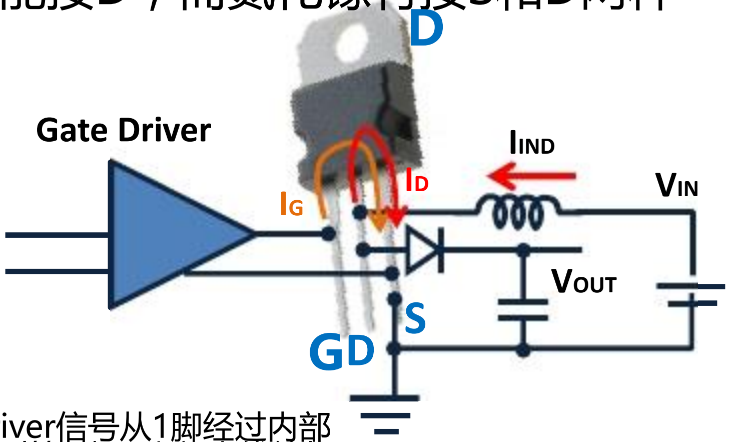
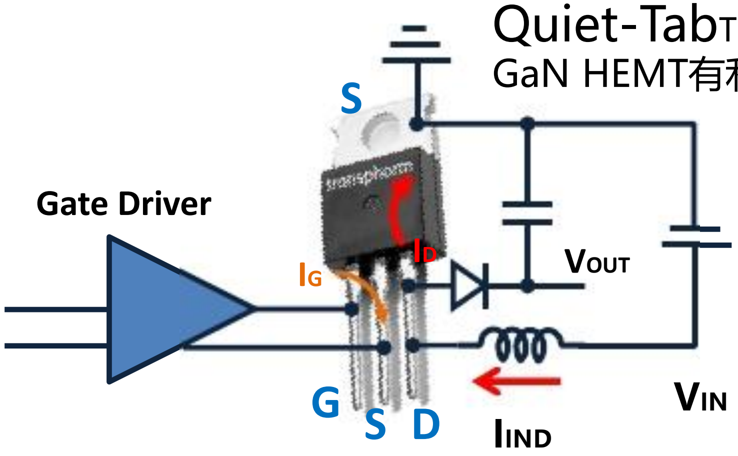
The Quiet-TabTM TO-220 Package Matches GaN’s High Switching Speed

传统的TO-220硅MOSFET
背部只能接D，而氮化镓有接S和D两种



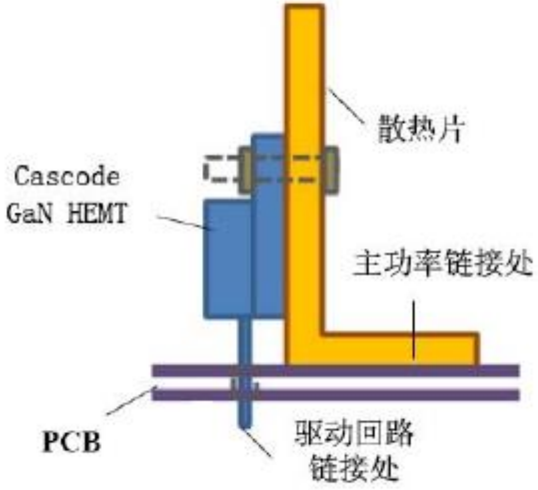
Driver信号从1脚经过内部绕到第3脚，内部走线较长，会带来较大的寄生电感

Quiet-TabTM TO220
GaN HEMT有利于高频开关



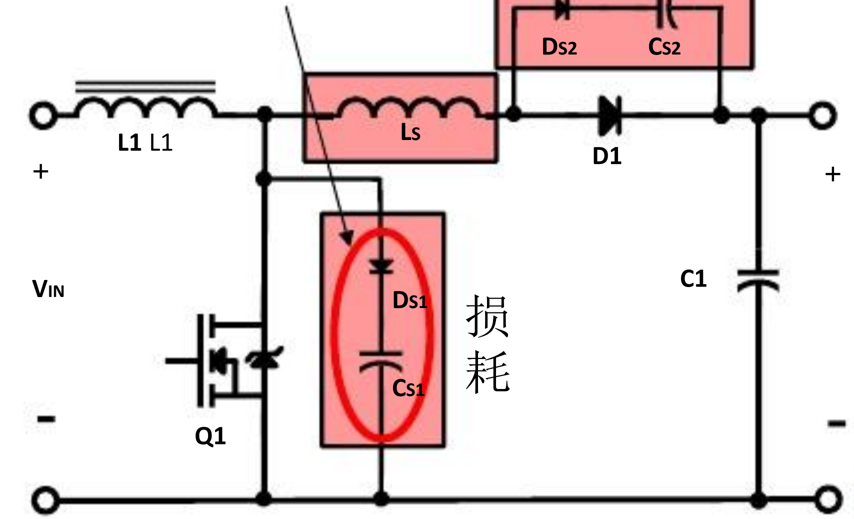
Driver信号从1脚进，2脚出，内部走线短。更做优化。有助于高频

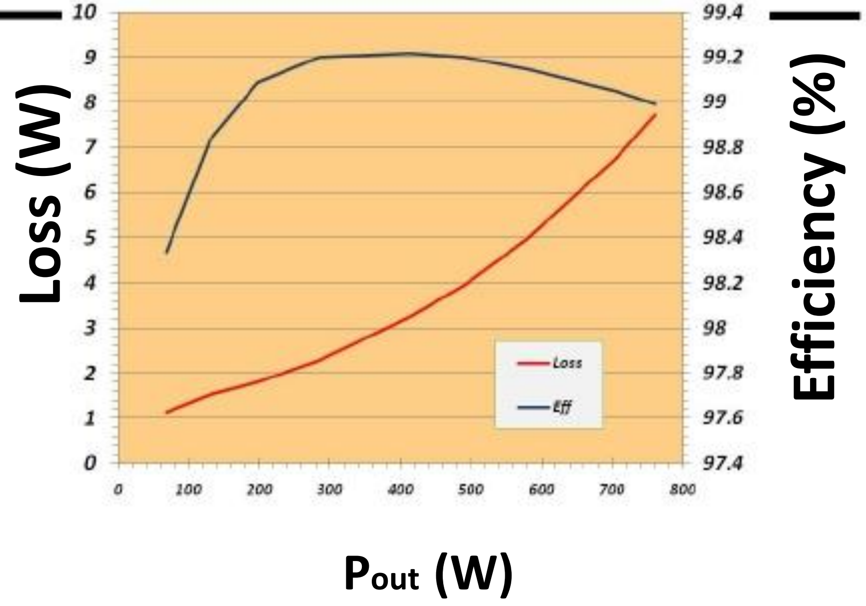
- 传统的结构，**D**极的瞬间电流可能给**Vgs**带来大的干扰
- **Kelvin**引脚（背部接**S**）**,** 分开的**S**极，一个作为**GATE**脚用，另一个作为**D**极大电流用，分开有助于减少**Vgs**振铃
- 硅材料的结构决定不能提供**Kelvin**脚.
- **G,S,D**更有助于安规及布线。



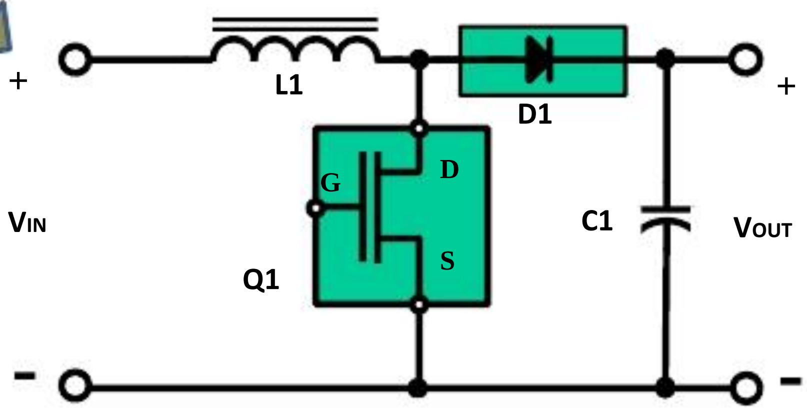
氮化镓器件能将设计最简单化

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





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



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%

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。

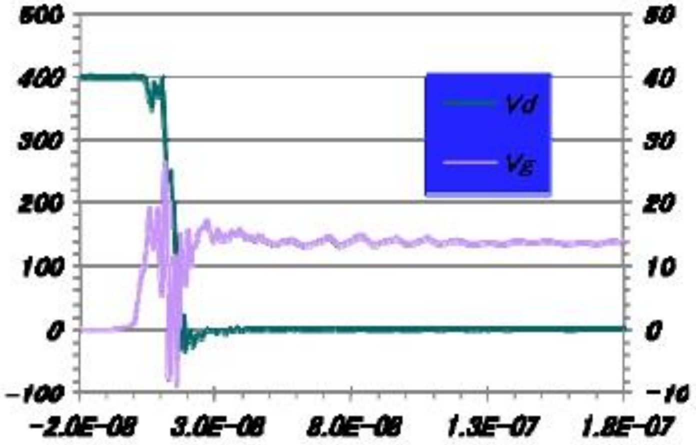
体积变小一半以上

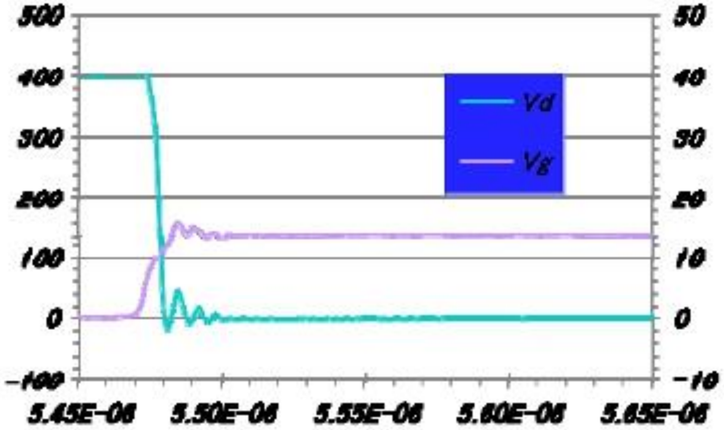
Coolmos换成氮化镓，唯一的一个器件成本上升，其它器件成本均下降

Coolmosfet199C3+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	
400WPFC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

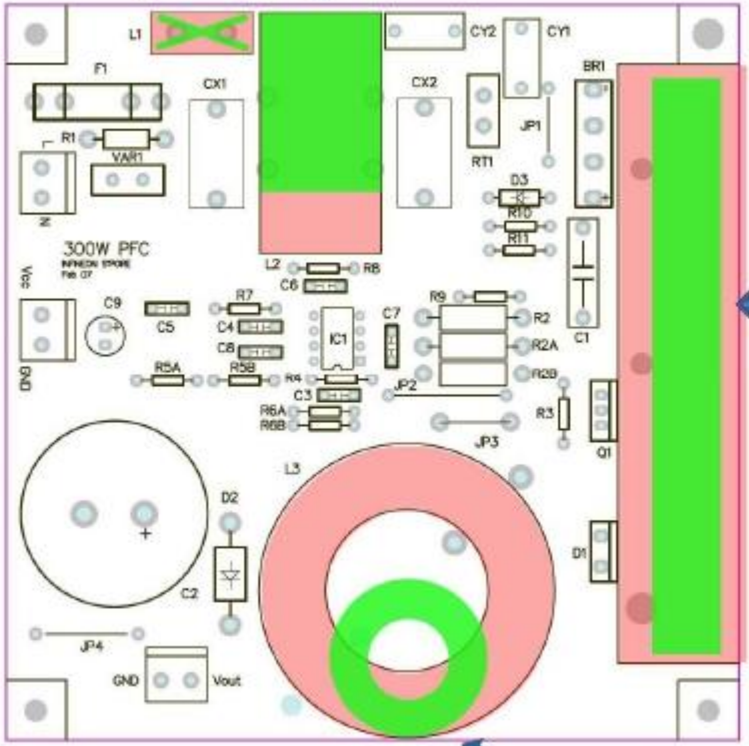
氮化镓的米勒效应比Cool-Mos的好很多。很小振荡，相应的开关损耗及EMI会好

氮化镓体内没有寄生二极管即非常小的Trr，在续流方面有很大优势。

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

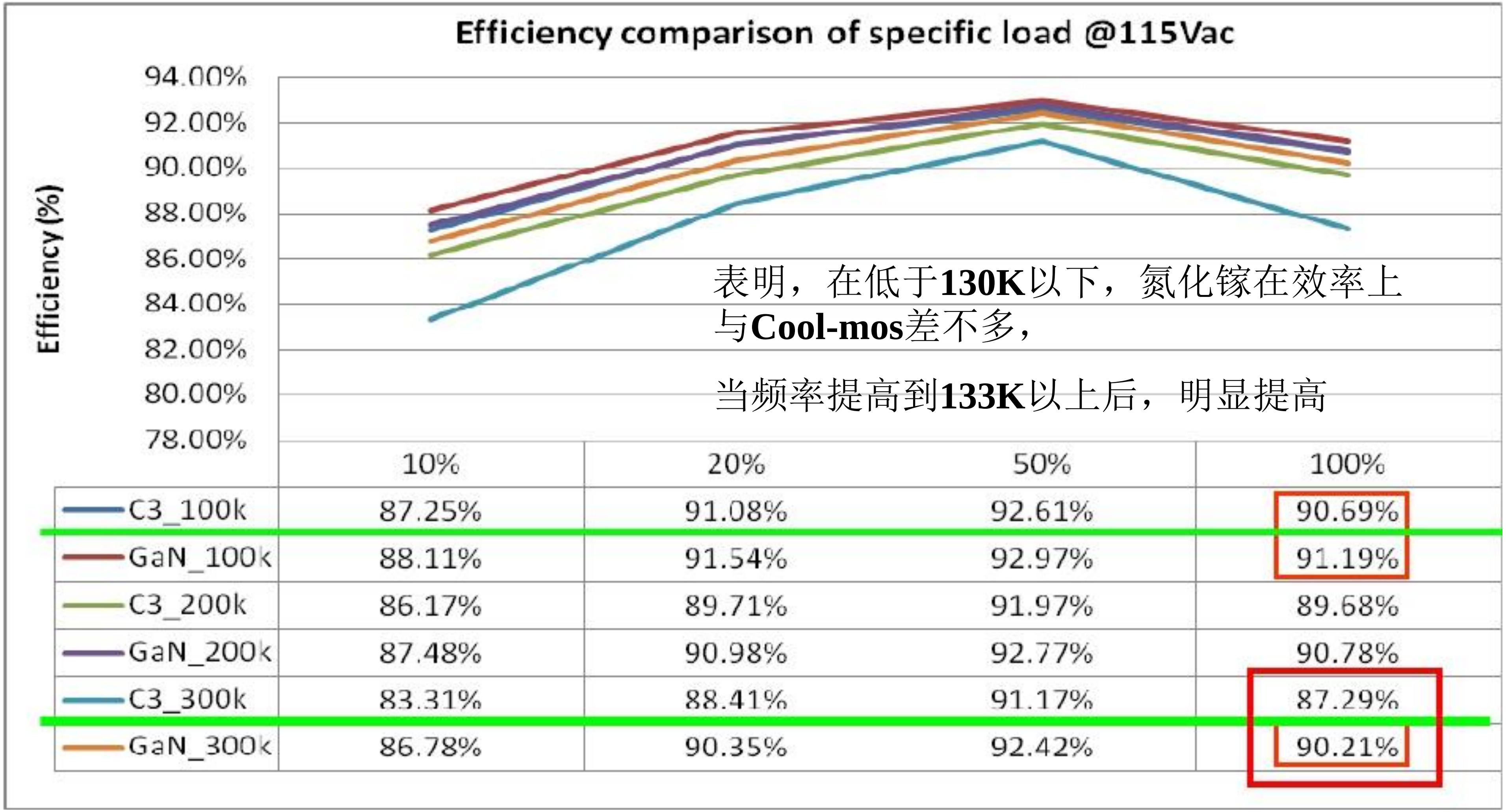


体积明显变小

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

Customer A 460W带PFC电源测试对比



表明，在低于**130K**以下，氮化镓在效率上与**Cool-mos**差不多，

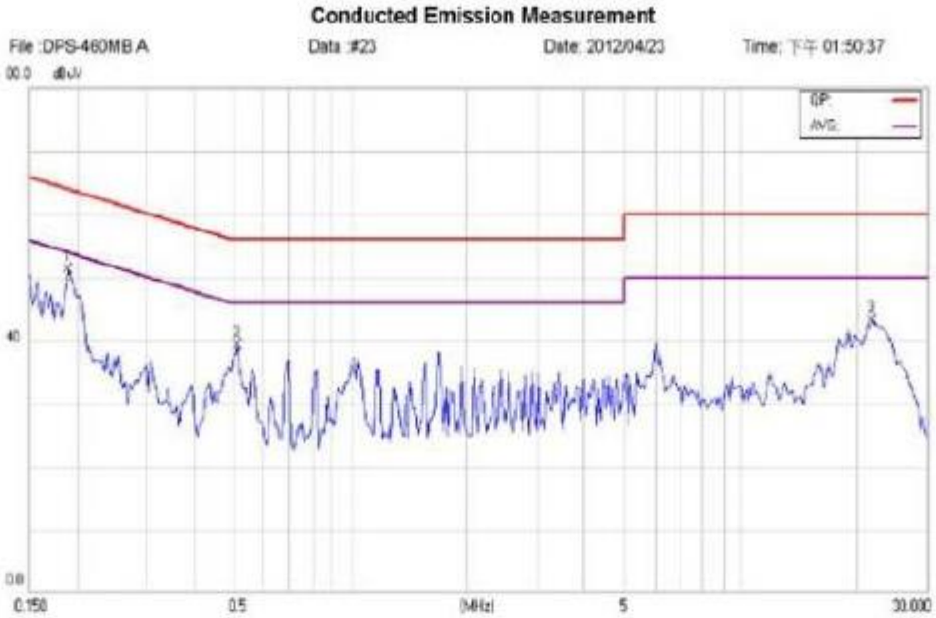
当频率提高到**133K**以上后，明显提高

	10%	20%	50%	100%
C3_100k	87.25%	91.08%	92.61%	90.69%
GaN_100k	88.11%	91.54%	92.97%	91.19%
C3_200k	86.17%	89.71%	91.97%	89.68%
GaN_200k	87.48%	90.98%	92.77%	90.78%
C3_300k	83.31%	88.41%	91.17%	87.29%
GaN_300k	86.78%	90.35%	92.42%	90.21%

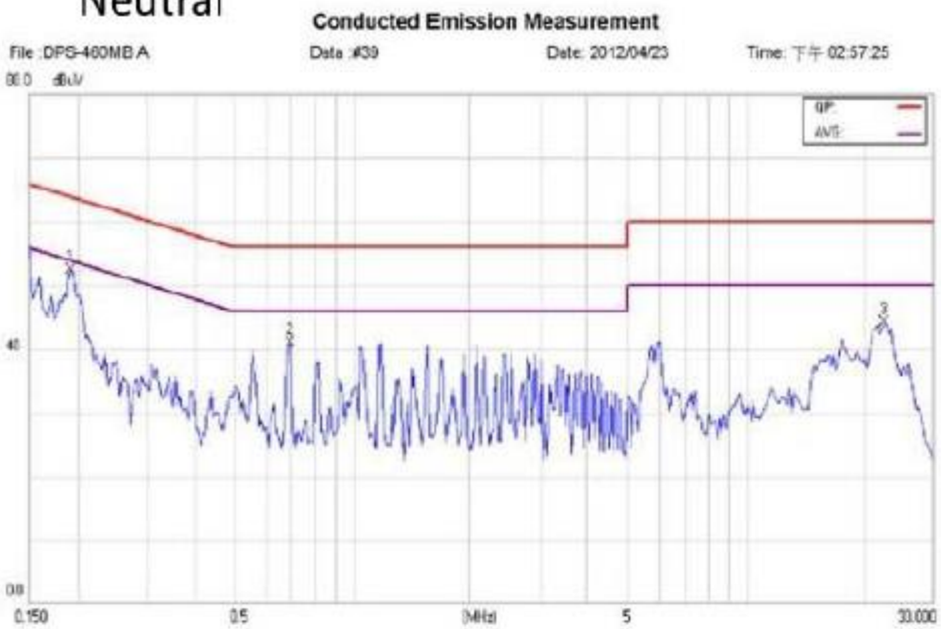
客户实测EMI

460W PFC电源
Cool-mos 100K HZ

Line



Neutral



Input: 110V, 60Hz

Mode: Original Source Cool MOS, fs:100khz

Limit: CISPR22 Class B Conduction (QP)

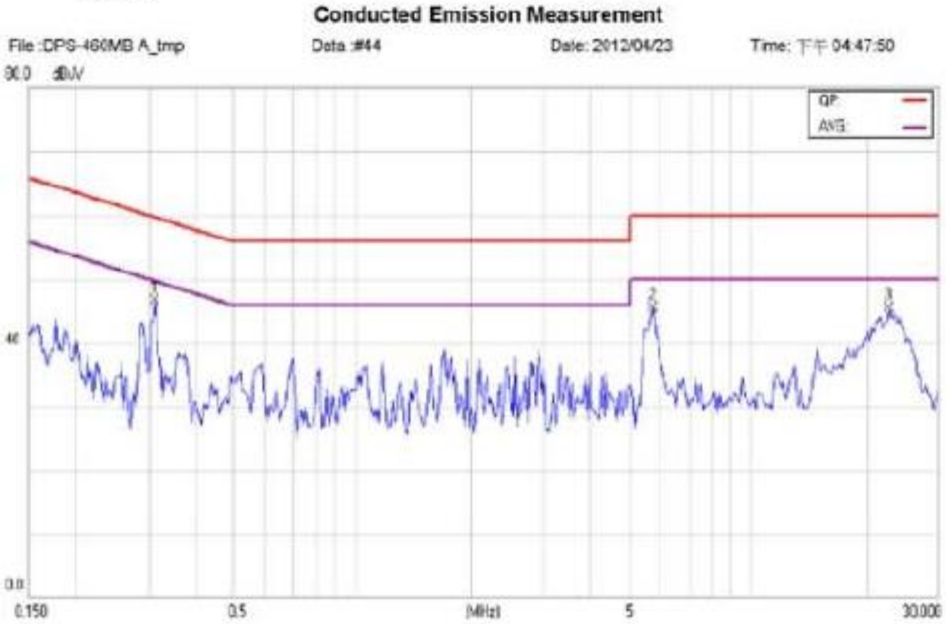
transphorm

客户实测**EMI**

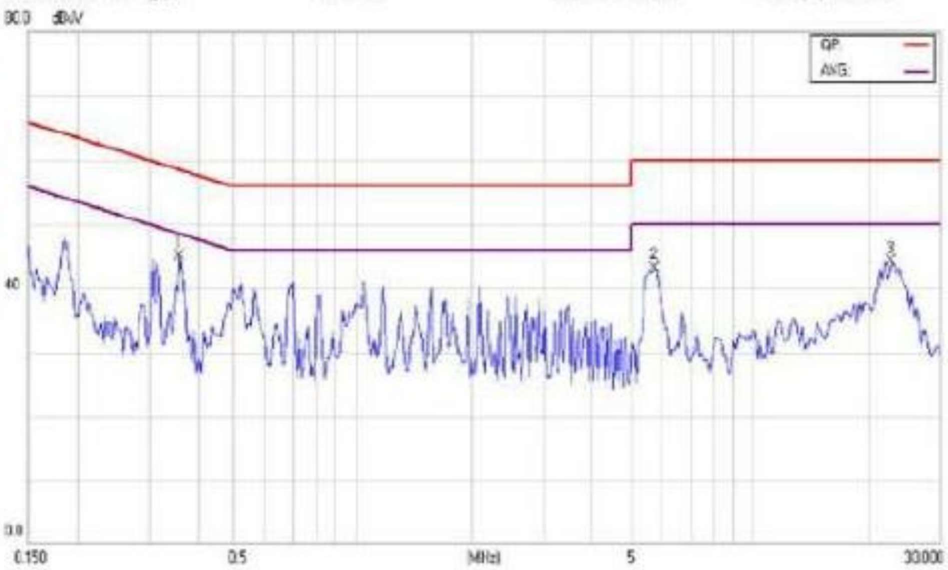
采用**GAN**提高工作频率并没有提高**EMI**

460W PFC电源
GaN 300K HZ

Line



Neutral



Input: 110V, 60Hz

Mode: New Source GaN, fs:300khz

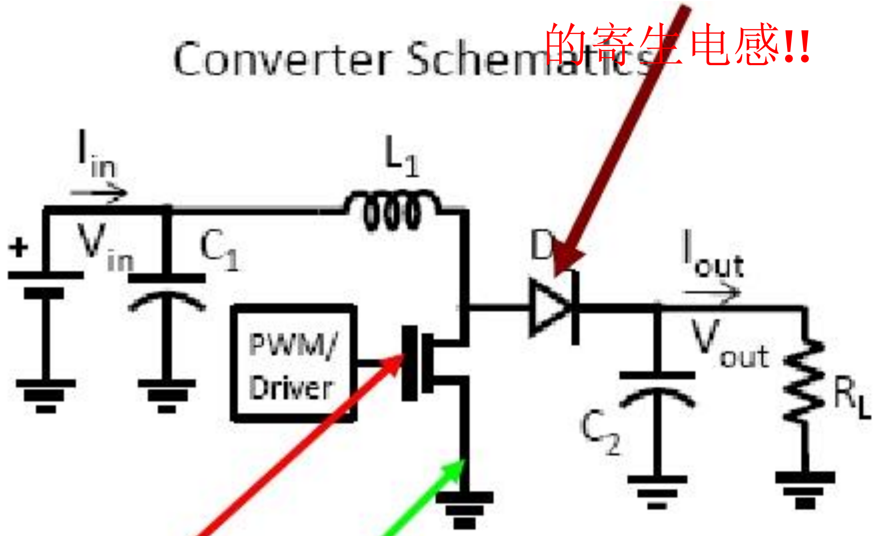
Limit: CISPR22 Class B Conduction (QP)

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**

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**!!**



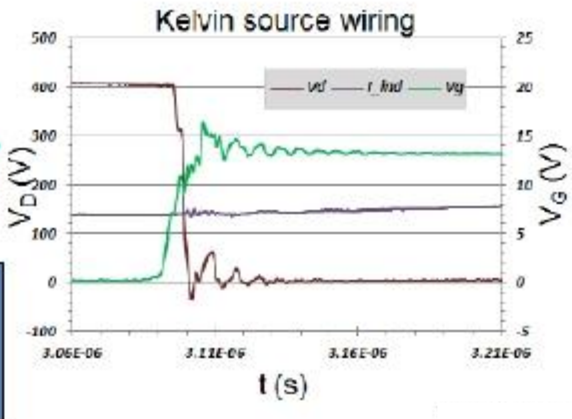
按书本原理即可实现**DC**升压电路

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

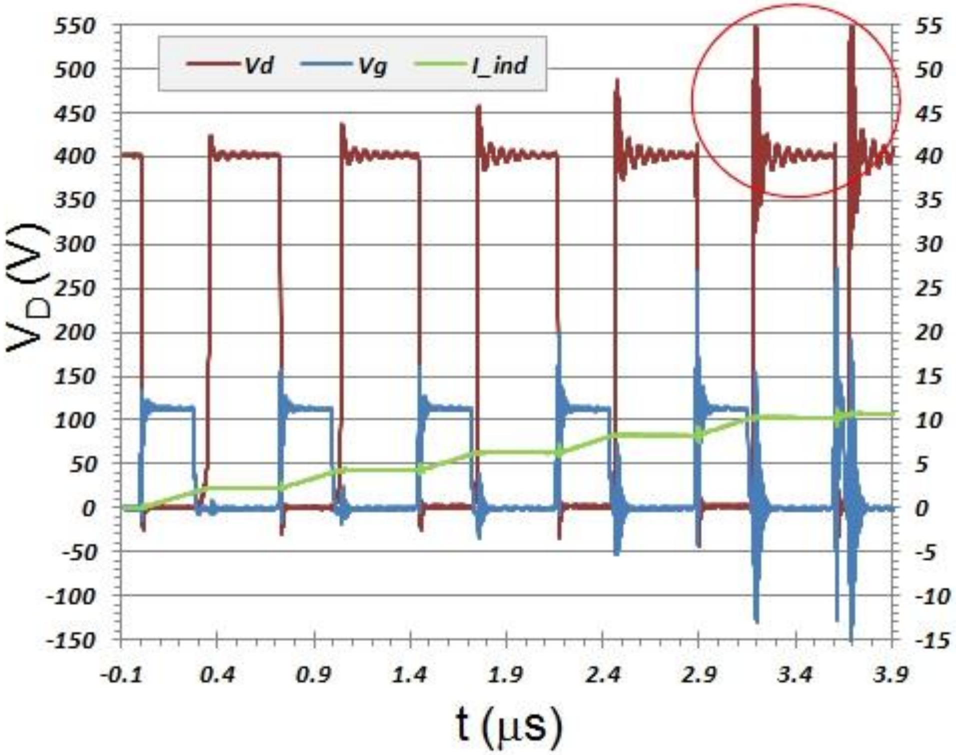


PFC电路**,**二极管尽可能靠近**GaN**管**.**功率越大**,**
越要靠近**!!!**

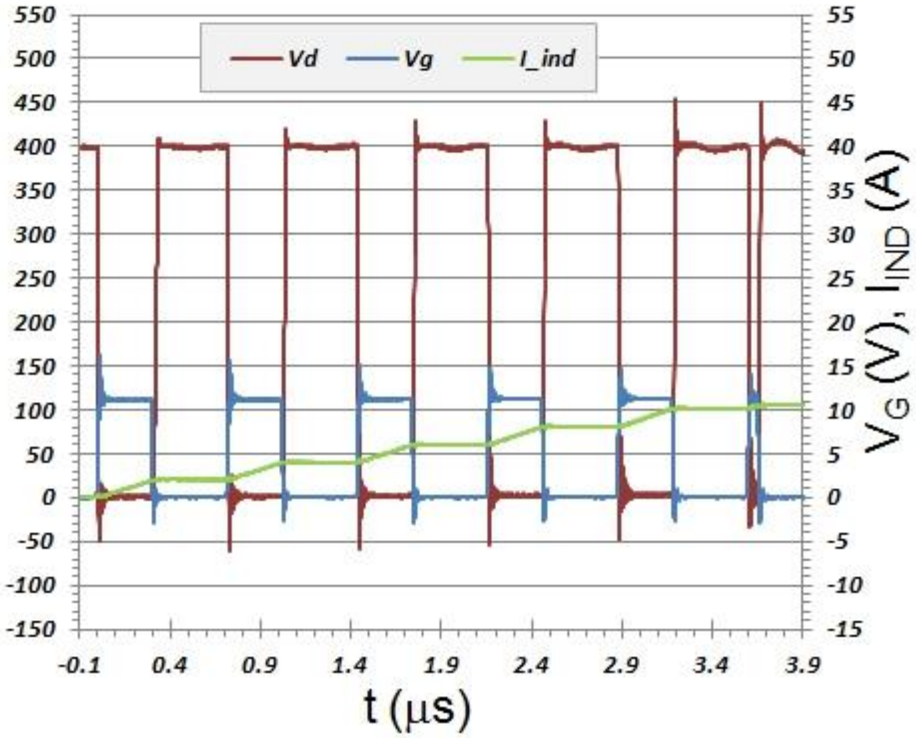
高速开关:

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

CoolMOS 60R199, Rg=0
(Leads cut to shortest with standoff)



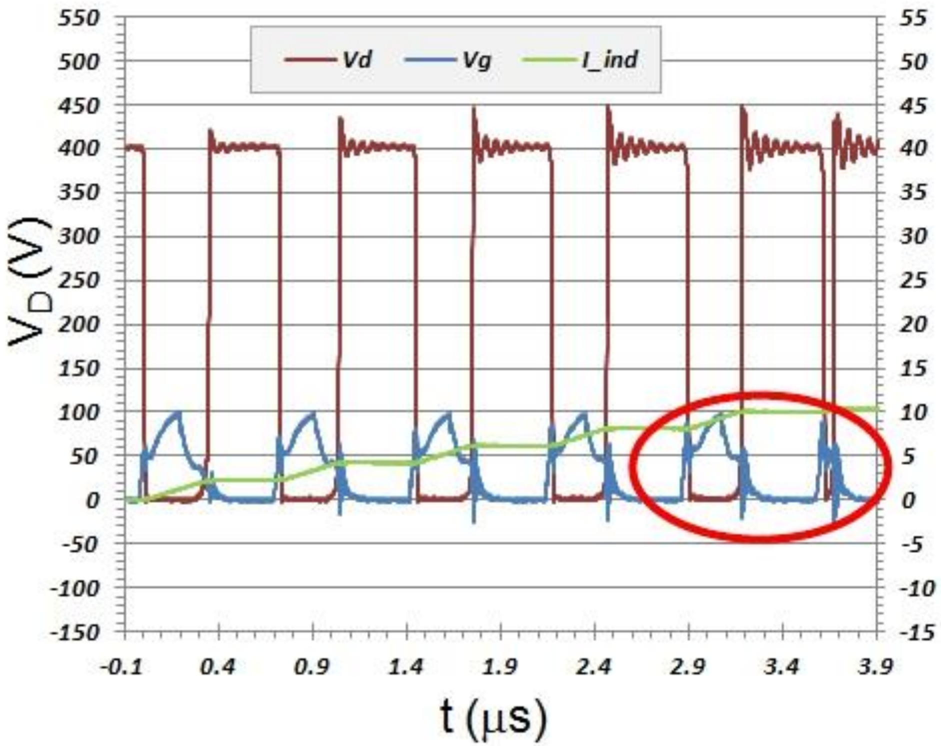
TPH3006, Rg=0
(Tab used for grounding)



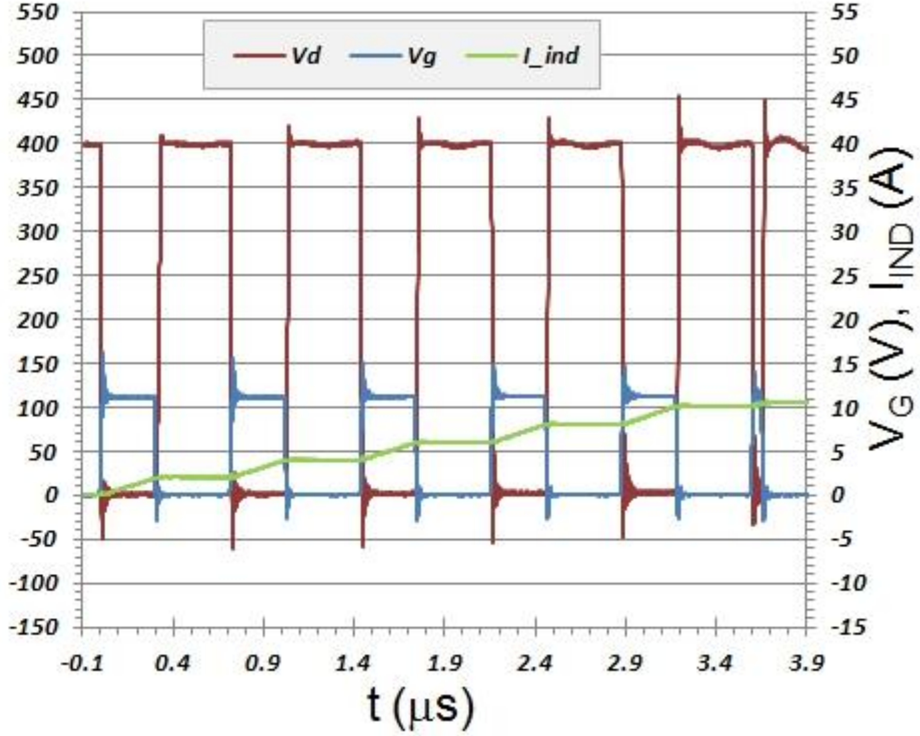
- **Cool-Mos Gate**脚不加电阻，**Vds**过冲电压很高，要选**600V**以上器件。同时带来**EMI**问题。
- 氮化镓**GATE**脚没有加电阻。波形整齐，很小的过冲电压。

Operation Waveforms:
Slowed-down CoolMOS Vs. Fast GaN

CoolMOS 60R199, Rg=25
(Leads cut to shortest with standoff)

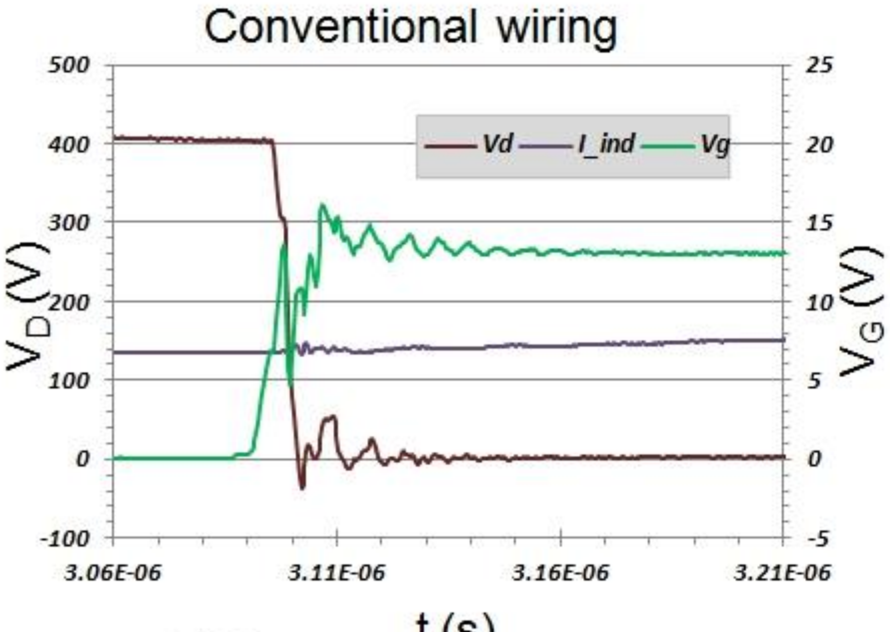


TPH3006, Rg=0
(Tab tied to grounded heat-sink)

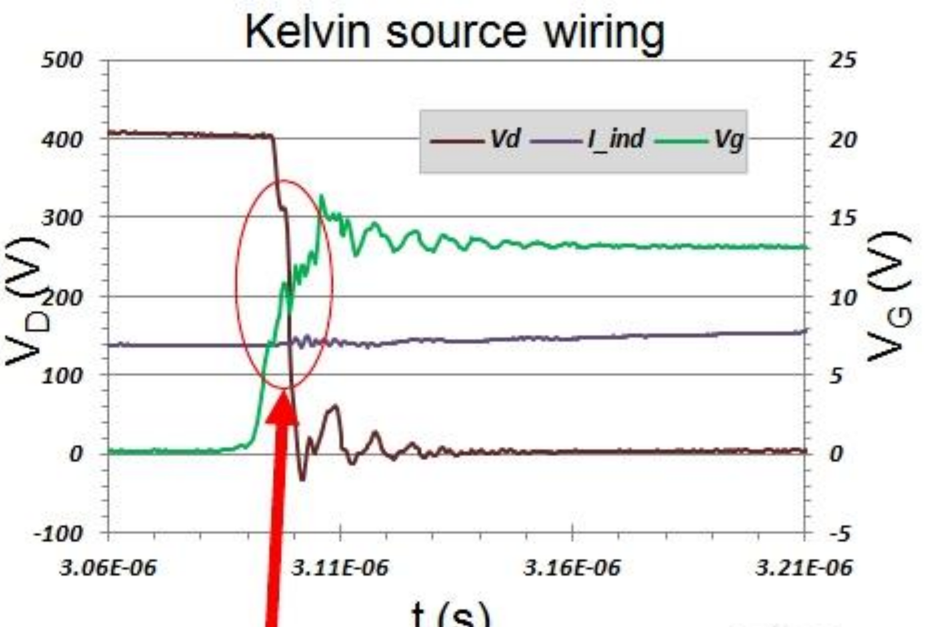


- 所以COOL-MOS要在前门极加一个电阻，25欧会将VDS电压降下来，但门极驱动波形变形。。。所以会选一个择中值如10欧，此时VDS依然会较高.同时也会带来损耗。
- 氮化镓器件不需要外加电阻。低EMI。

GaN高速开关时的开通波形(Boost电路)



采用标准封装脚波形



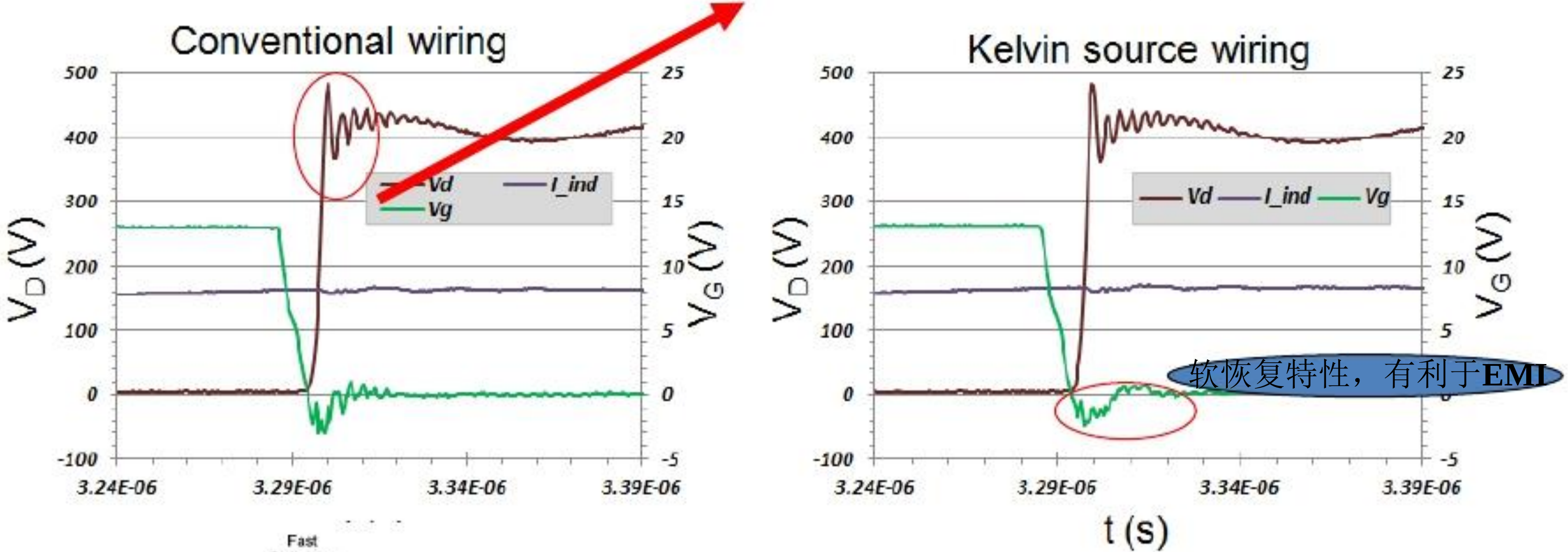
采用**Kelvin**脚时波形

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 Vgs dips in conventional wiring.**
- **Kelvin source wiring eliminates the large Vgs dip.**

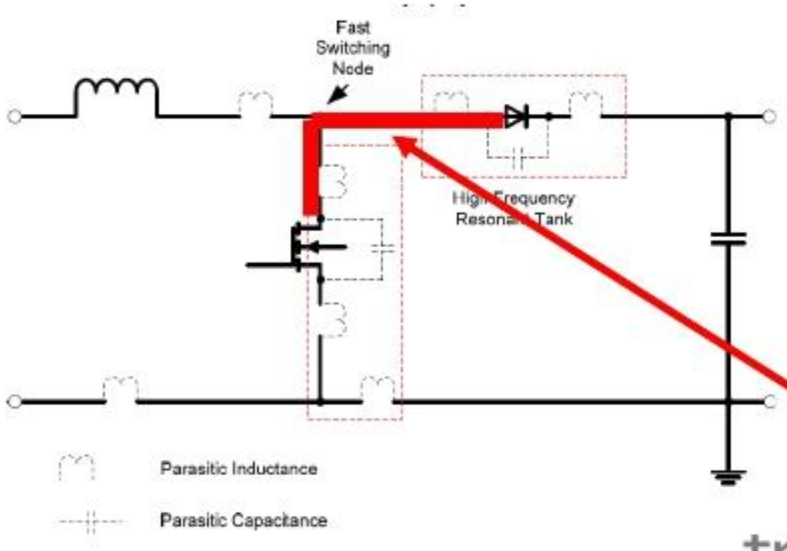
高速BOOST电路: Turn-off Waveforms
关断时波形

Vds产生的尖峰与二极管走线产生的电感有关


Conventional wiring

Kelvin source wiring

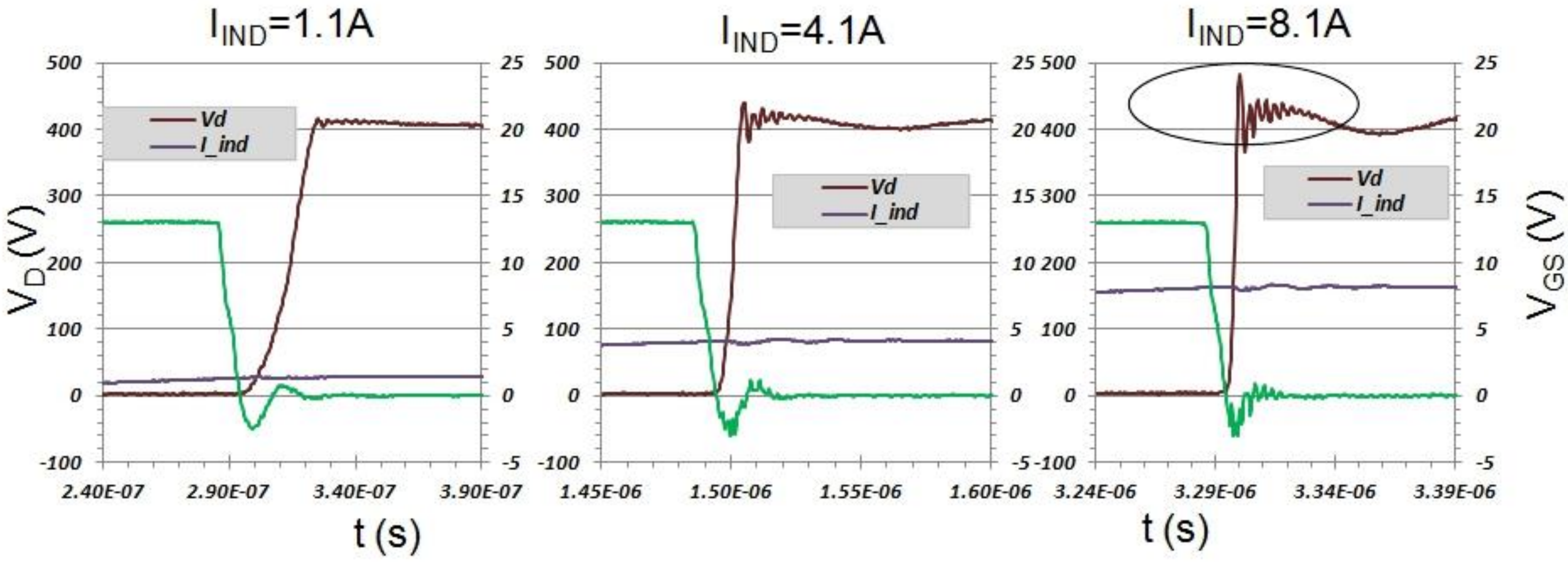
软恢复特性，有利于**EMI**

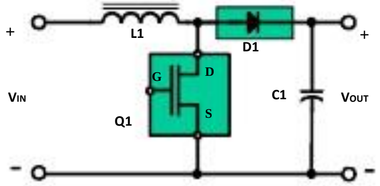


- Turn-off event: Inductor current charges capacitances. Di/dt not high.
- No issue for Vgs even with conventional wiring.
- Vds spike is due to inductance of the diode path. Close diode placement is desired.

让二极管尽可能靠近**FET**脚以减少走线电感带有的**Vds**尖峰电压

关断时的尖峰电压- 电感电流的作用



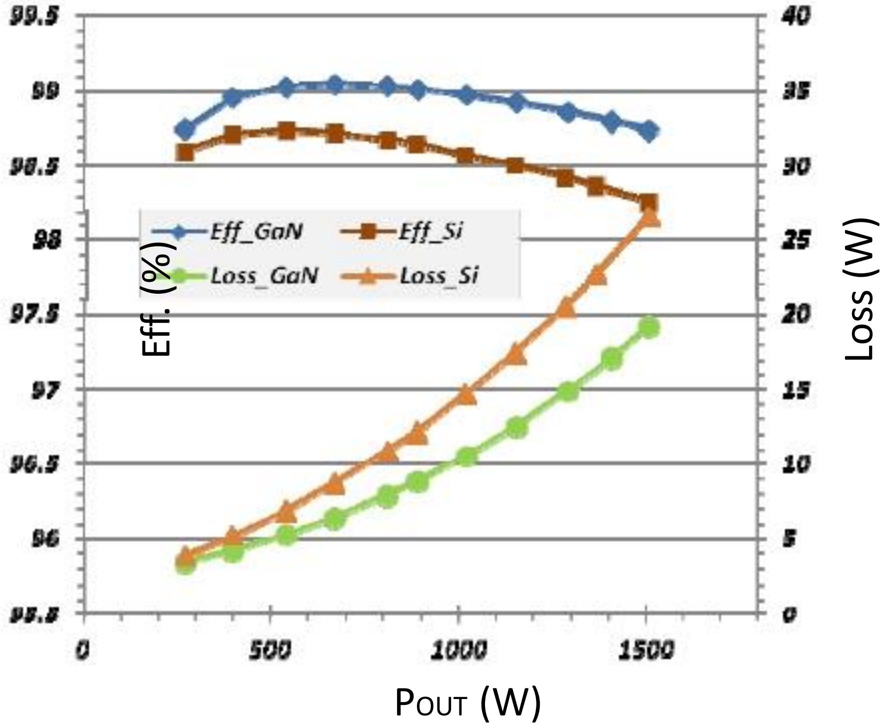


- 试验测试是以传统的封装器件（非**KELVIN**脚式）
- 尖峰电压很低，且与电感电流大小成正比
- 可以看出功率越大，在电路上就必须将二极管尽可能靠近**FET**脚。以减少走线带来的寄生电感。

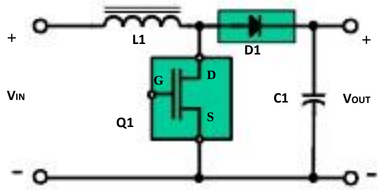
Cool-Mos与氮化镓FET BOOST电路上的损耗对比： 100 kHz

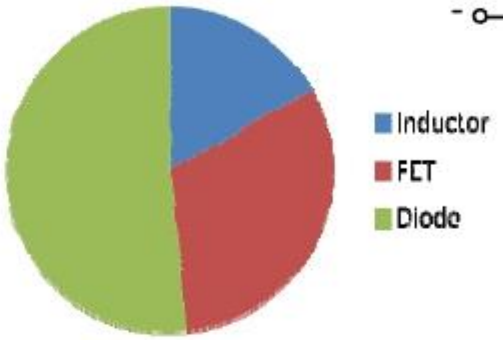
GaN devices: TPH3006PS & TPS3411PK
Si devices: CoolMOS & QSpeed diodes

V$_{IN}$/V$_{OUT}$=230V/400V, f=100kHz



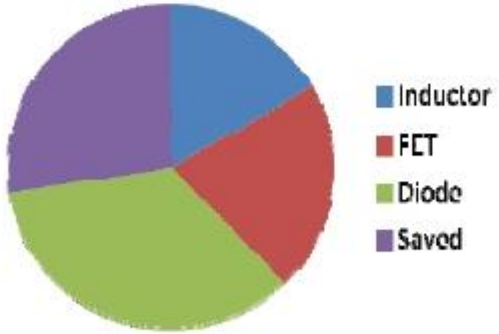
Loss breakdown





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

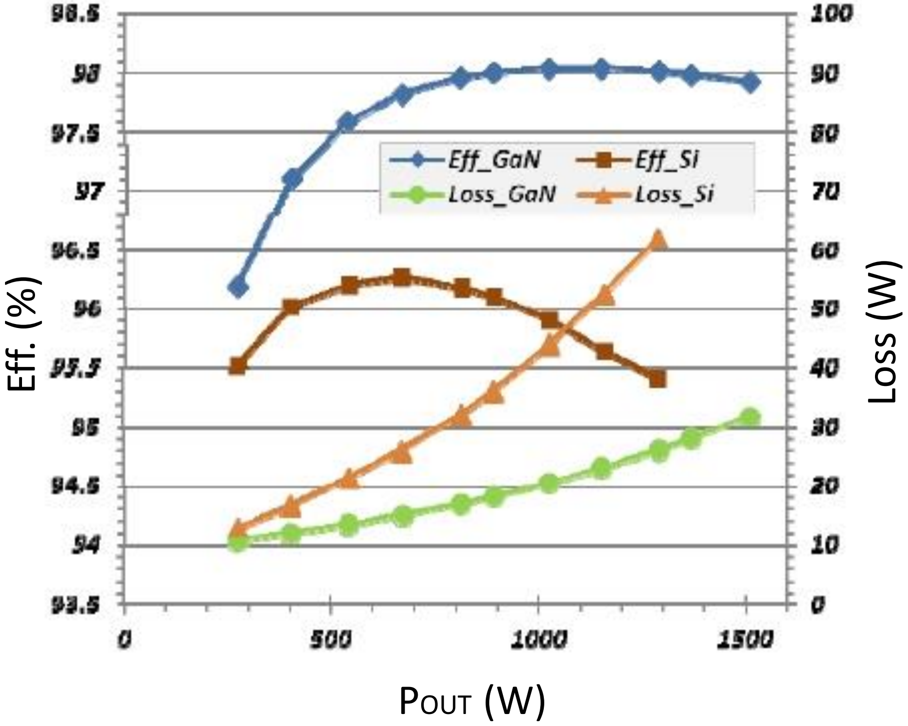
在**100K**时省出**1/4**的损耗（紫）

- **Transphorm Total GaN$_{\mathrm{TM}}$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**

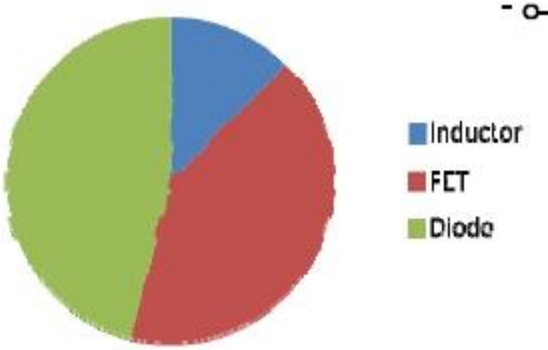
Cool-Mos与氮化镓FET BOOST电路上的损耗对比　500 kHz

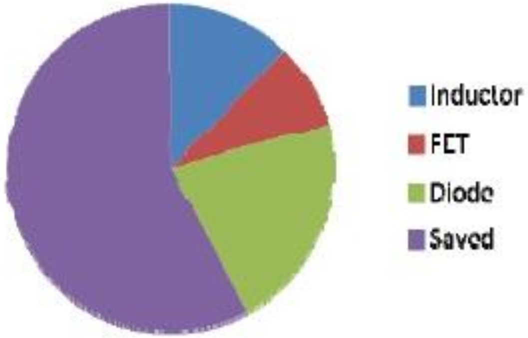
GaN devices: GaN-on-Si HEMT & diode
Si devices: CoolMOS & QSpeed diode

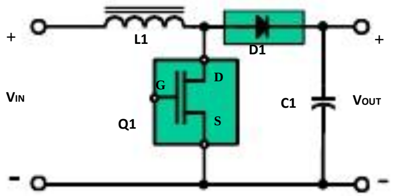
V_{IN}/V_{OUT}=230V/400V, f=500kHz



Loss breakdown







Boost电路 **500K**

Cool-Mos方案上
的损耗图

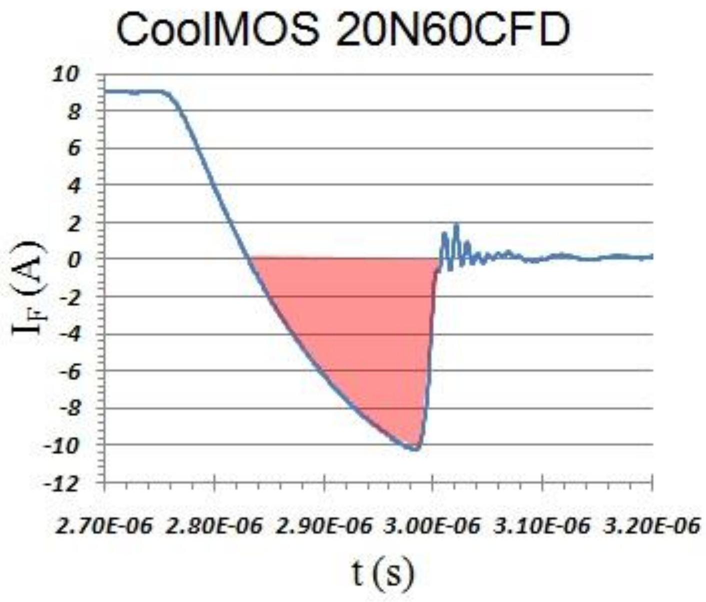
Boost电路 **500K**

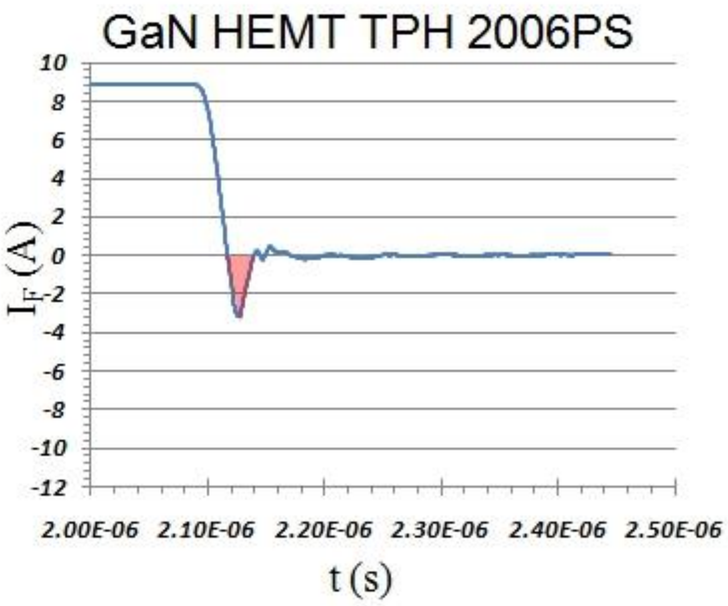
氮化镓方案上的
损耗图

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

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）


CoolMOS 20N60CFD


GaN HEMT TPH 2006PS

Qrr=1000nC at 9A, 400V

Qrr=54nC at 9A, 400V

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

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

Devices	Parameters	On resistance (∧)	Gate charge (nC)	Output charge(nC)	Energy relatedCoss (pF)	Reverse recovery charge(⌈C)	**FOM1A**	**FOM1B**	**FOM2**
	Symble	Rds,on	Qg	Qoss	Coer	Qrr	**Ron*Qg**	**Ron*Qoss**	**Ron*Qrr**
GaNHEMT TPH3206	GaNGen1	0.15	6.2	52.8	56	0.054	**0.93**	**7.9**	**8**
SiCoolMOS 60R199CP	SJSiGen5	0.18	32	86.4	69	5.5	**5.76**	**15.6**	**990**
SiCoolMOS 60R190C6	SJSiGen6	0.17	63	127.68	56	6.9	**10.71**	**21.7**	**1173**
SiCoolMOS 65R2250C7	SJSiGen7	0.199	20	126.32	29	6	**3.98**	**25.1**	**1194**
SiCoolMOS 20N60CFD	SJSifor LowQrr	0.19	95	76.8	83	1	**18.05**	**14.6**	**190**

- 1st 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,Rds(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

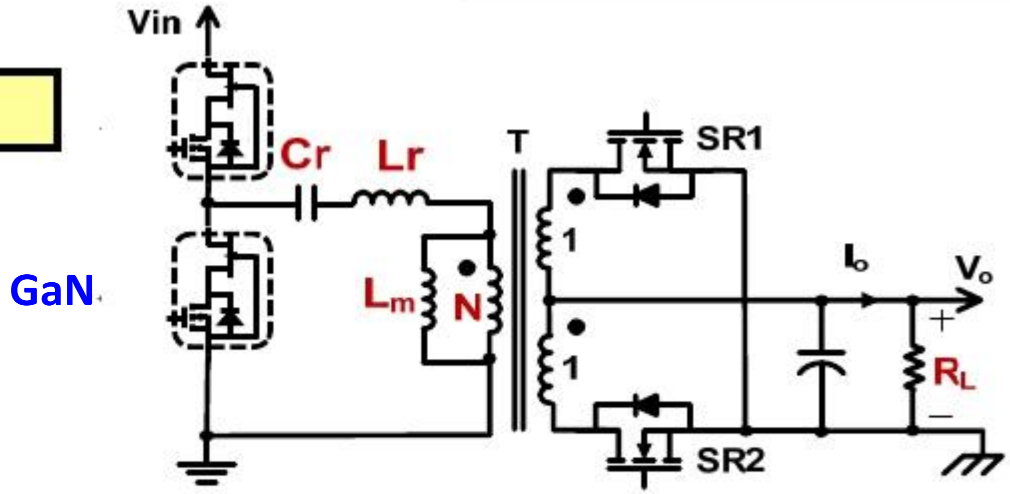
4,二极管多少存在续流损耗

氮化镓主要是在死区上的损耗大大降低

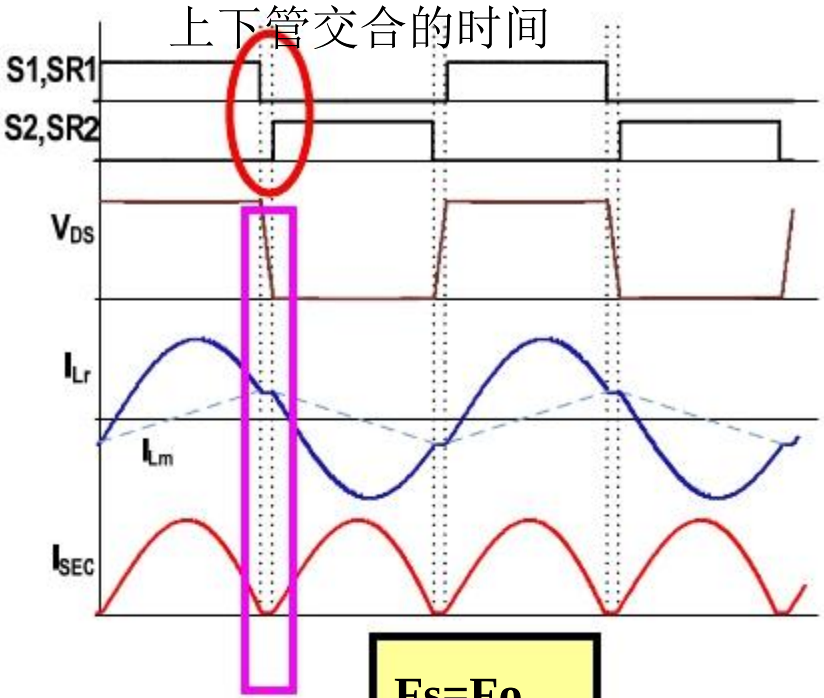
氮化镓的LLC电路应用

High step down LLC Converter

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



LLC Resonant Converter



Fs=Fo

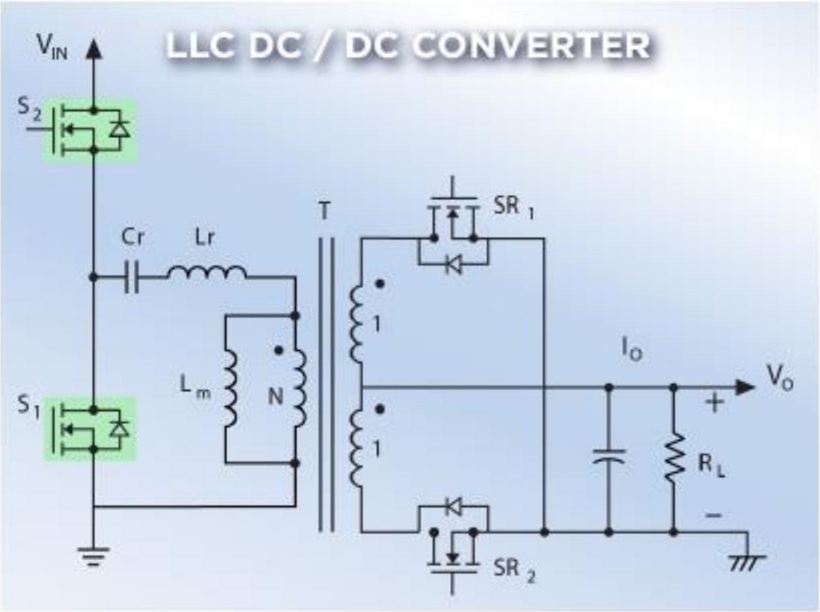
LLC-DCX , Fs=Fo

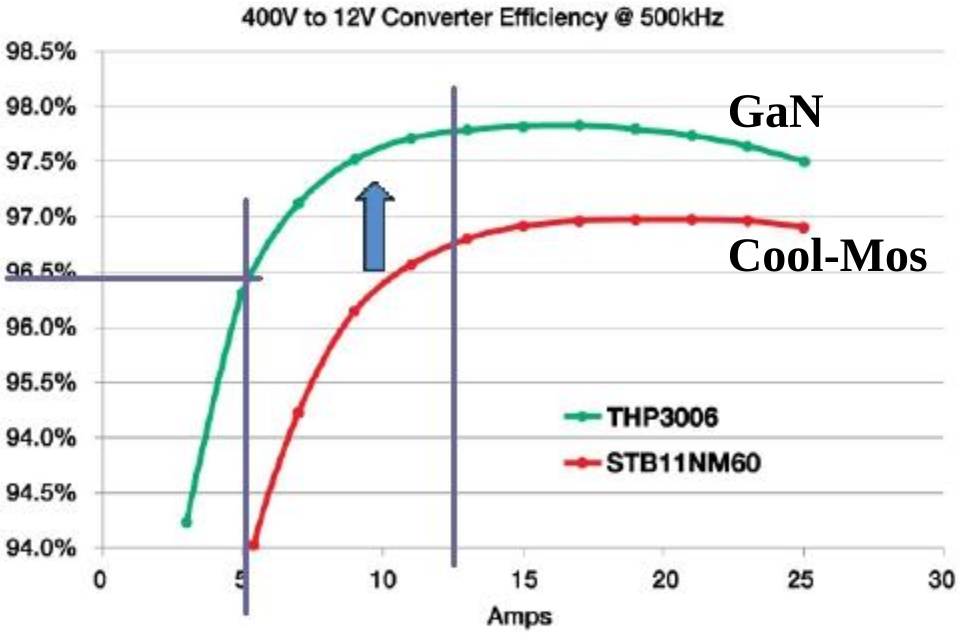
Gain equals one

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Rds(on)





Reduced losses by > 30%

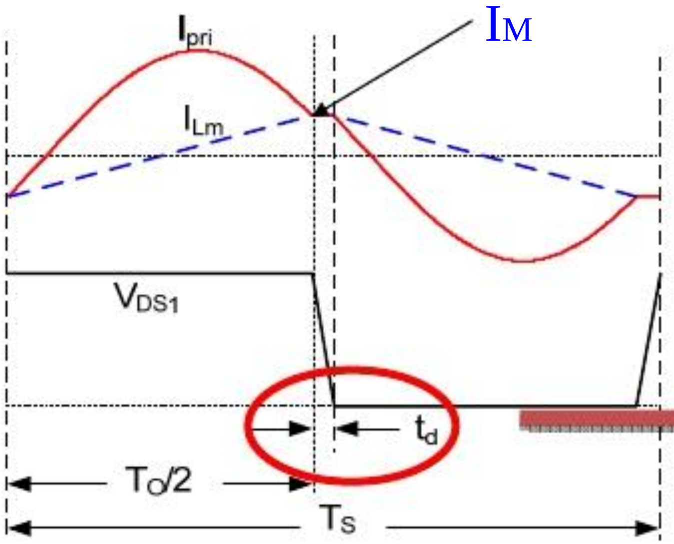
Low residue charge for GaN allows for a fast reset time & a much reduced recirculation energy

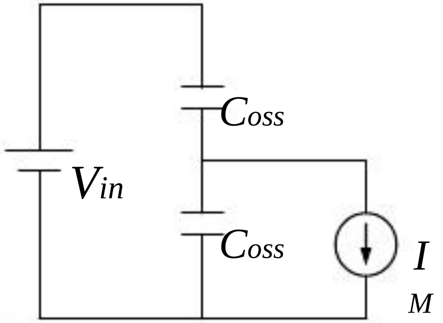
Parameters	Value	Parameter	Value
Vin(V)	400	Vo(V)/Io_{max}(A)	12/25
Lm(uH)	100	Lr(uH)	5.05
Cr(nF)	15	Fr(kHz)	530
Td(ns)	120	Fs(kHz)	470

GaNvsCoolMosfet效率差别			
500KLLC	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。

$$I_M \;\mathrm{H}\; \frac{NV_o}{L_m}\,\frac{T_o}{4}$$

$$t_d \;\mathrm{H}\; \frac{2C_{OSS}V_{in}}{I_M}$$

Larger Lm,
Less circuilating energy

Smaller td,
Less duty cycle lose

Coss是与器件有明显关系

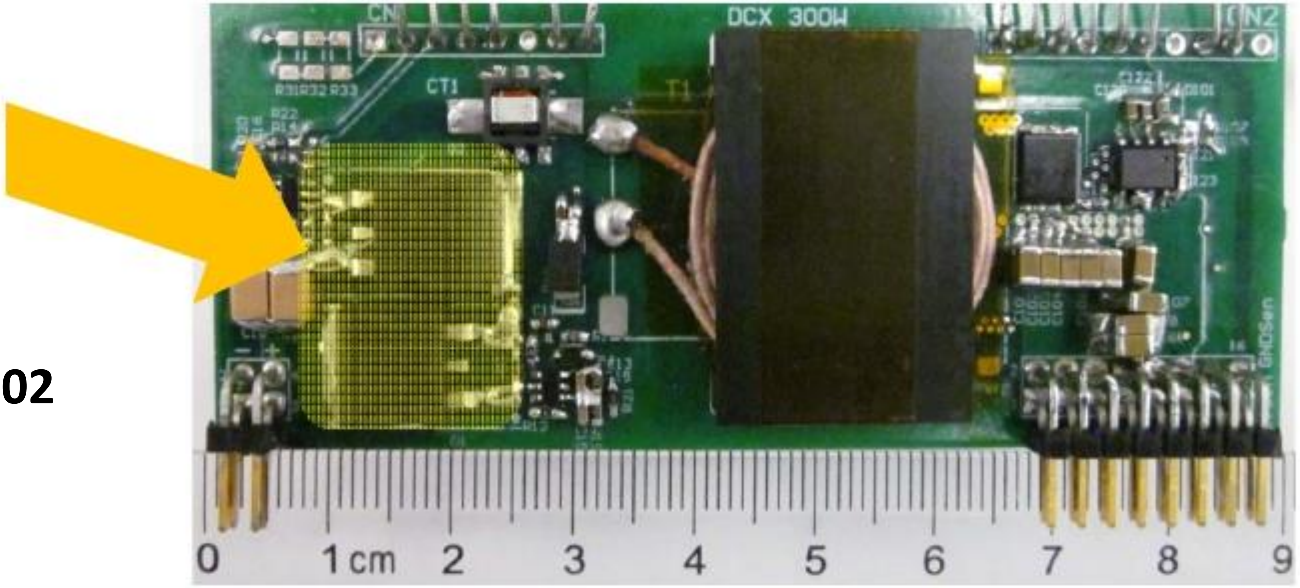
选择不同的器件会带来不同的损耗

$$C_{OSS} \;\mathrm{H}\; \frac{T_o t_d}{16L_m}$$

	C(pF) *OSS(tr)*
硅*MOSFET/Cool-Mosfet*	*100*
*CascodeGaN*氮化镓*FET*	*25*

With much smaller Coss,
GaN can achieve both

Experiment Platform

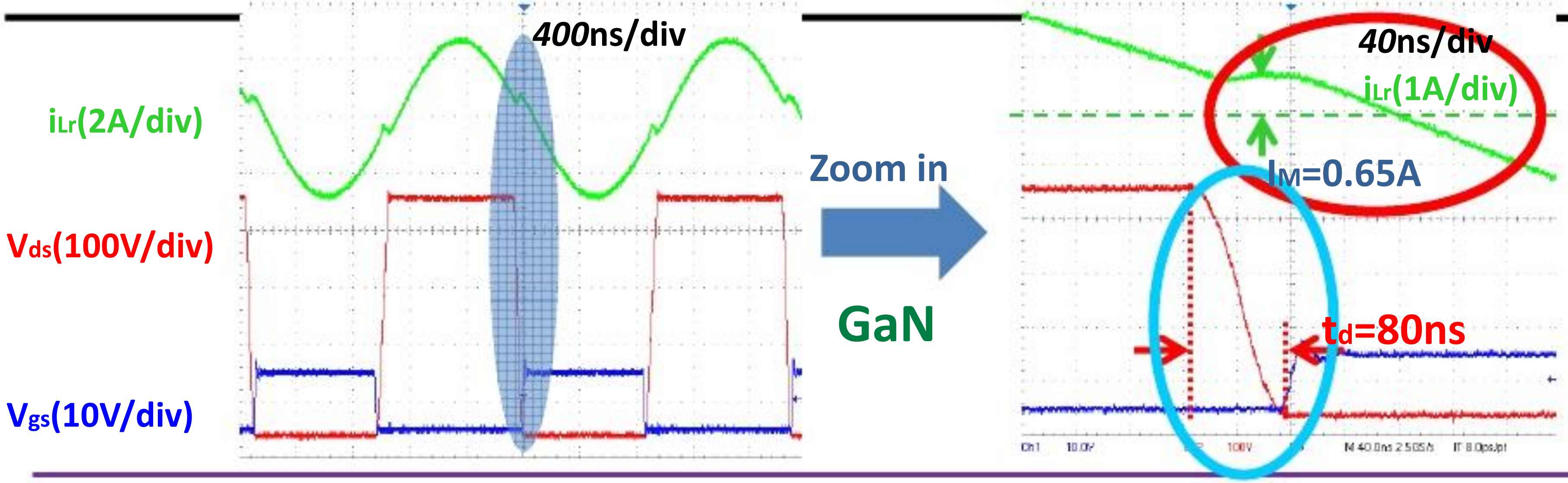


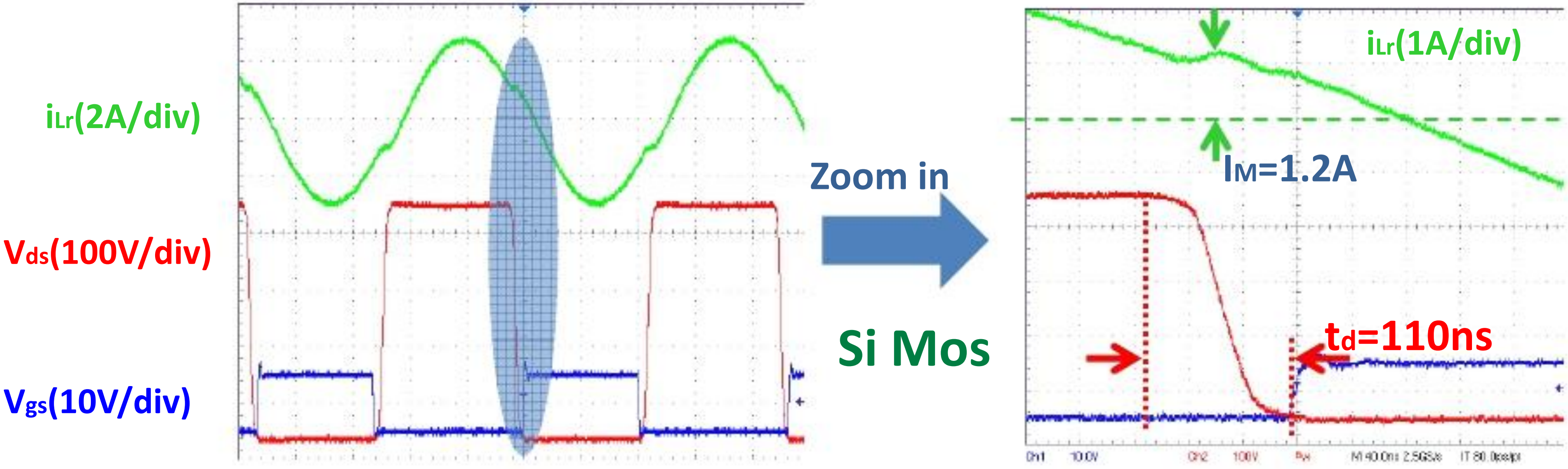
Cascode GaN:TPH2002
内阻：**290**毫欧
体积**30*90**
DC400V – 12V/25A
无散热片

Parameters	Value	Parameters	Value
Vin(V)	400	Vo(V)/Io(A)	12/25
TransformerTurnRatio	16:1	Fs(kHz)	500
CoreMaterial	N49	Primaryswitch	TPH2002
CoreShape	ER32/5/21	SR	BSC017N04NS

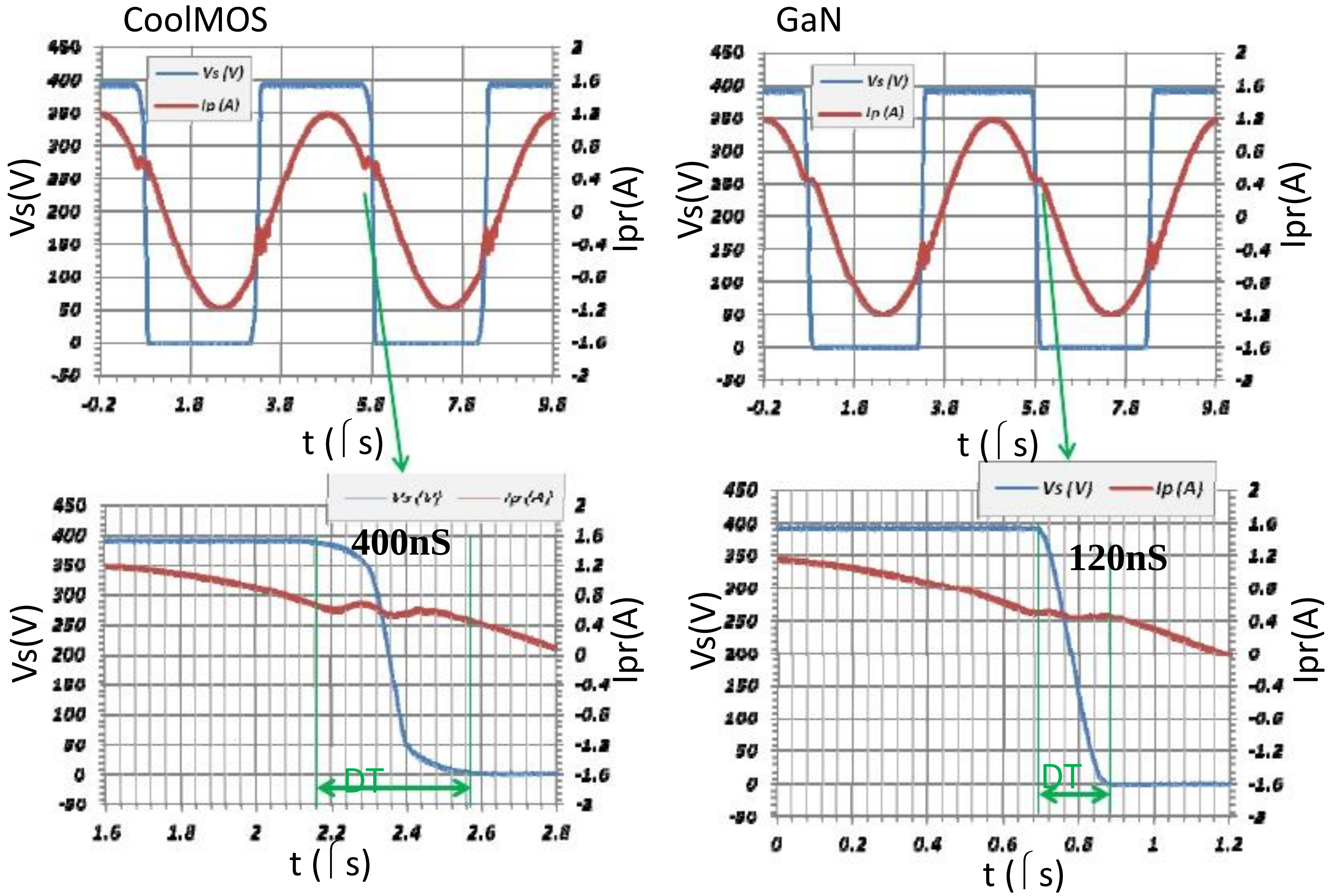
Experiment Waveforms @500kHz

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

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

transphorm

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

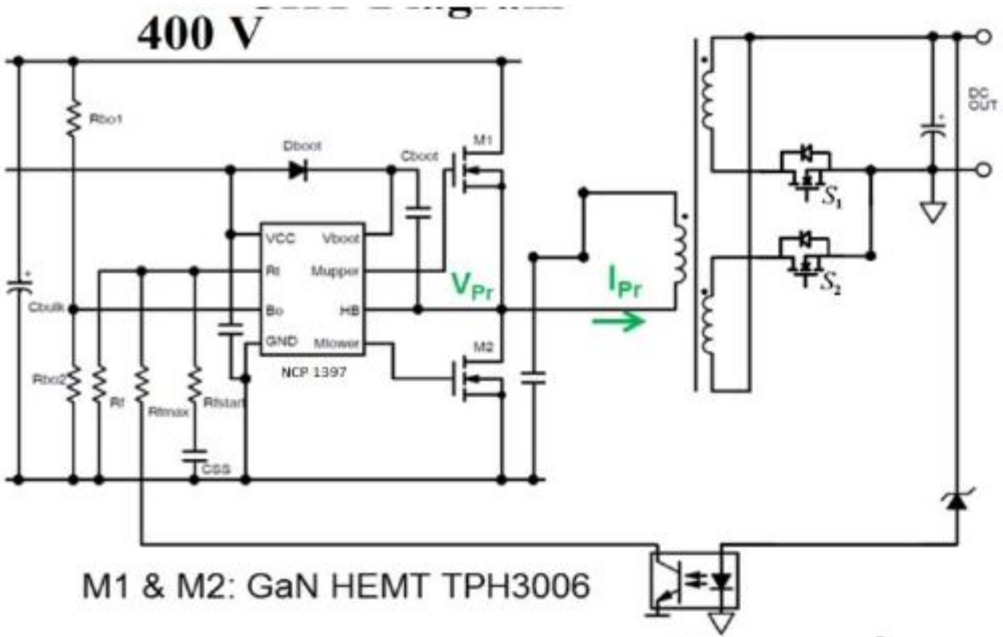
40W的小充电器，改用**TPH3002LD**氮化镓后，效率提高**0.5%/100KHZ.**温度有所有下降。 **200K**时提高**1%**效率

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**



M1 & M2: GaN HEMT TPH3006

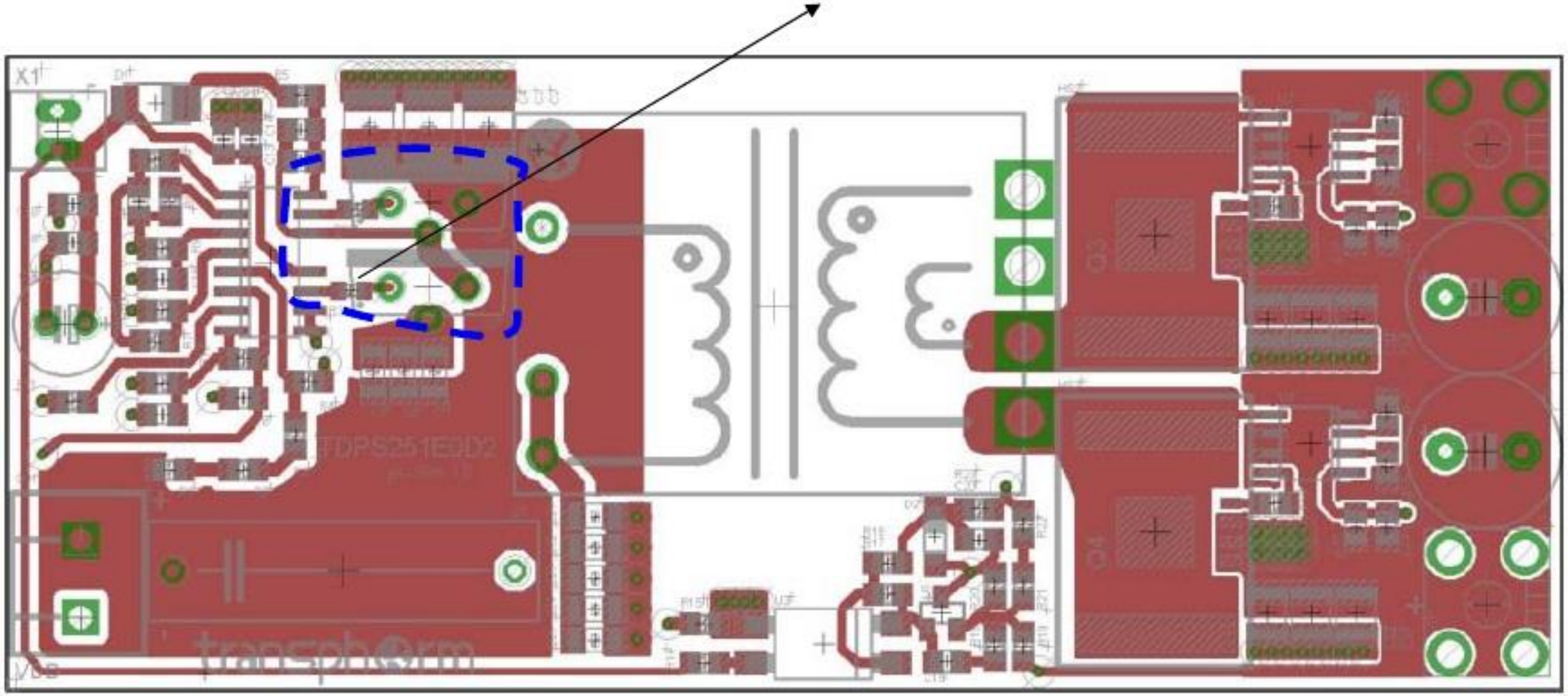
transphorm

简单框图

产品的应用1: 250W 纯LLC电路 12Vout，97.5%效率

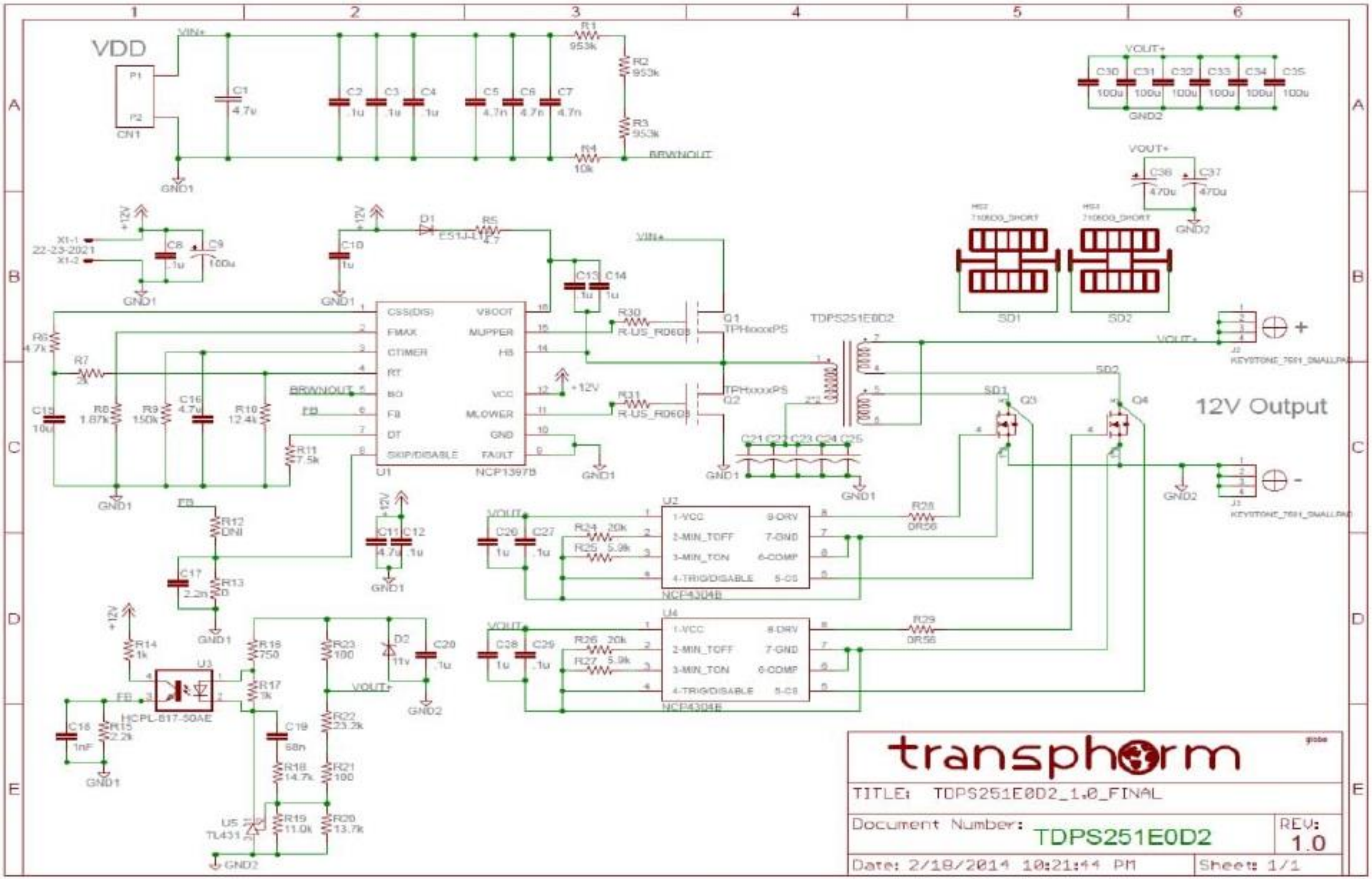
Parameter	TPH3002PS	IPP60R380C6
ID	9A (continuous)	10.6A (for D=0.75)
Ron	290mΩ	340mΩ
Qg	6.2nC	32nC
Eoss(400V)	3.1uJ	2.8uJ
Qrr	29nC	3.3uC

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)**

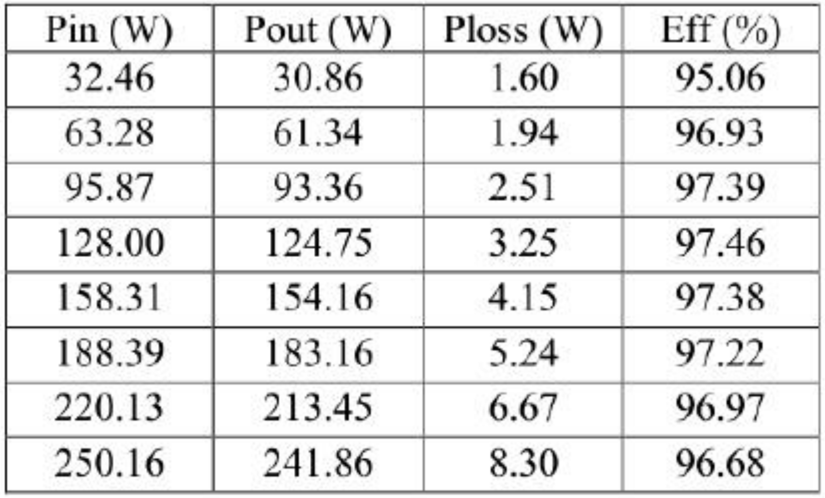


驱动做到最小距离

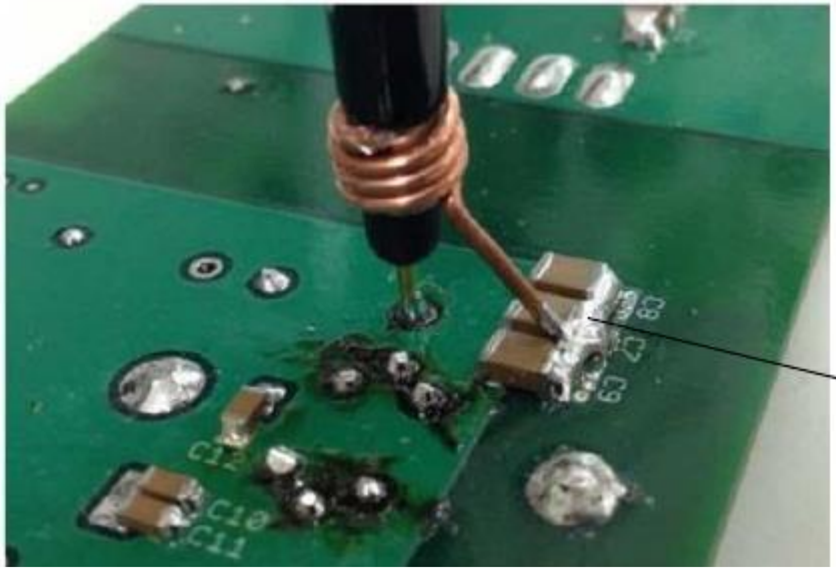
产品的应用1: 250W 纯LLC电路 12Vout，97.5%效率

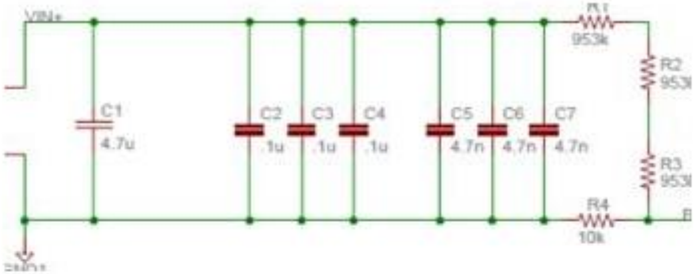


产品的应用1: 250W 纯LLC电路 12Vout，97.5%效率



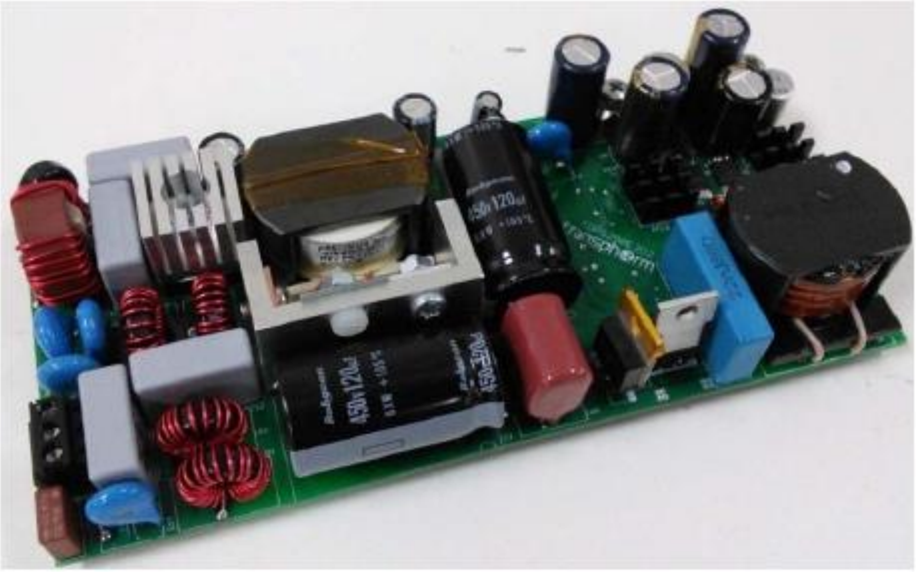
Pin (W)	Pout (W)	Ploss (W)	Eff (%)
32.46	30.86	1.60	95.06
63.28	61.34	1.94	96.93
95.87	93.36	2.51	97.39
128.00	124.75	3.25	97.46
158.31	154.16	4.15	97.38
188.39	183.16	5.24	97.22
220.13	213.45	6.67	96.97
250.16	241.86	8.30	96.68





去藕电容尽可能靠近
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

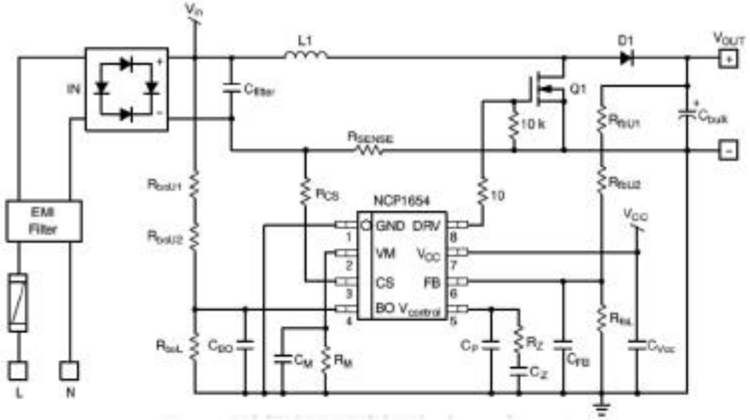
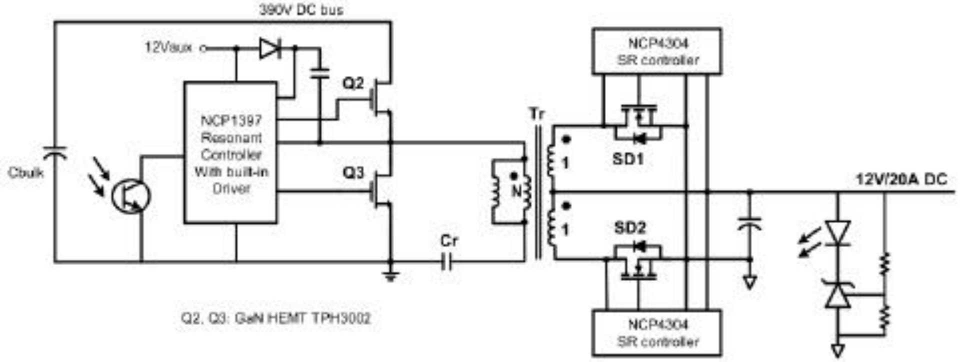
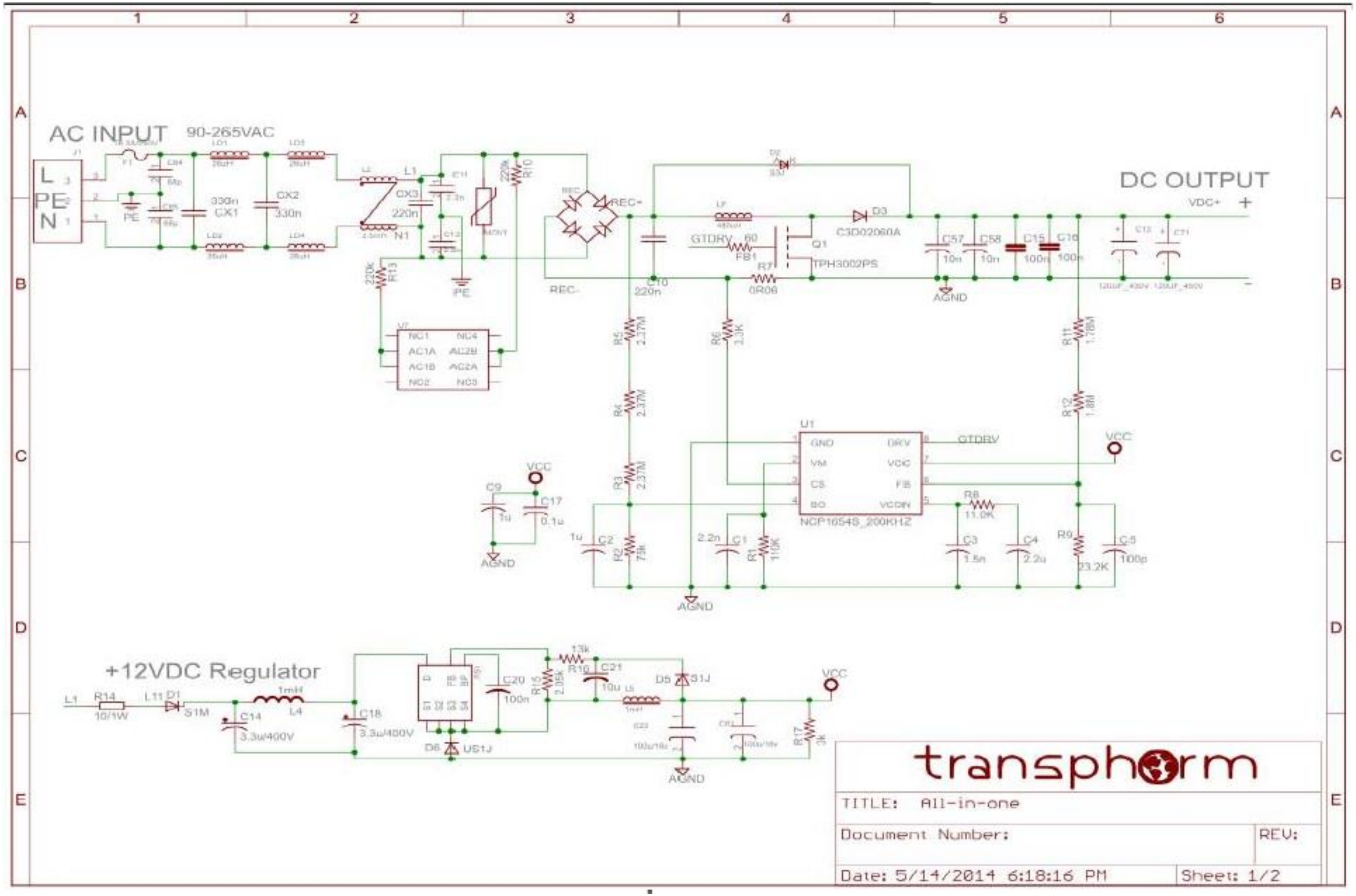


Figure 4 Generic NCP1654 Application Schematic

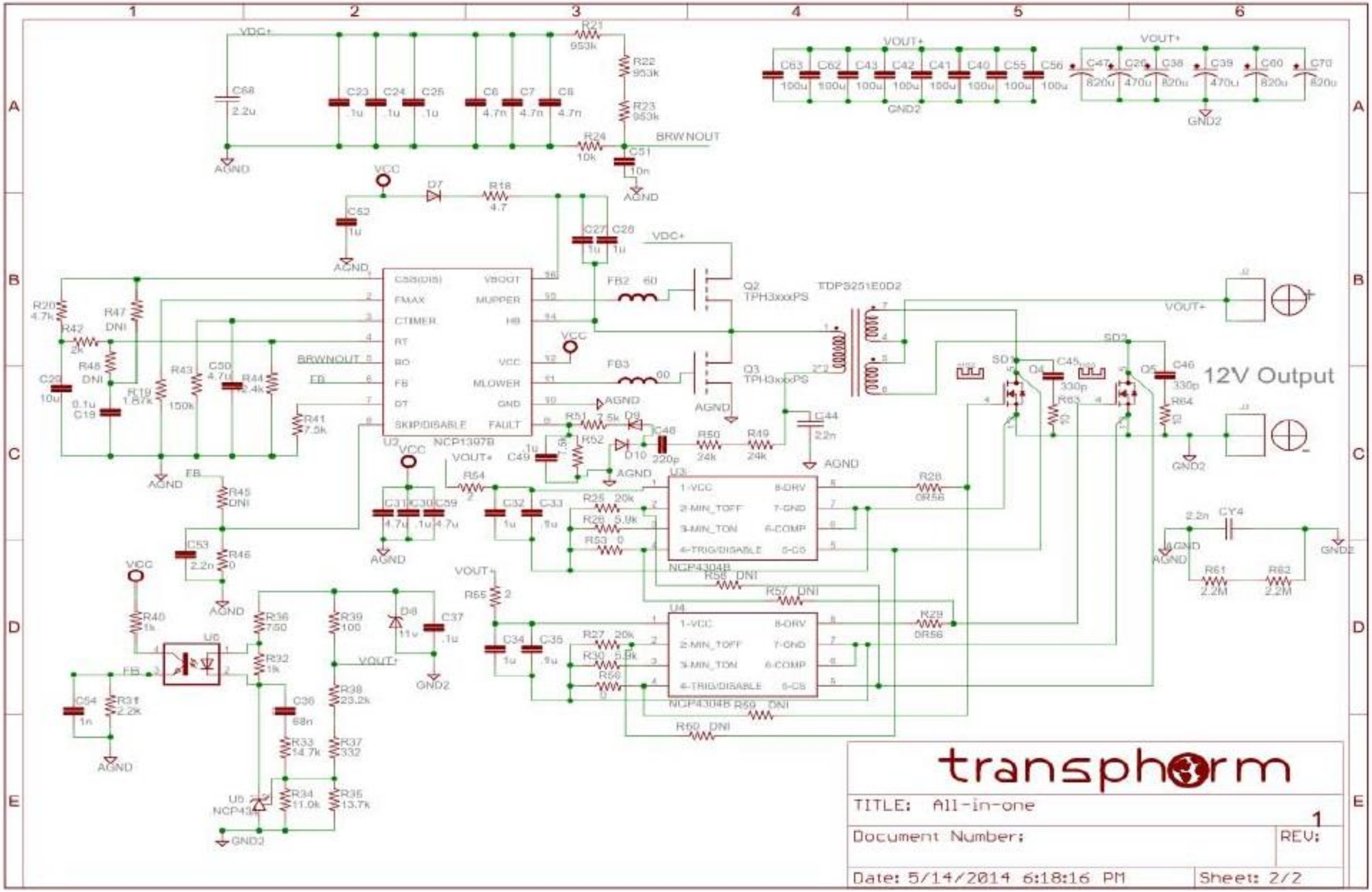


Q2, Q3: GaN HEMT TPH3002

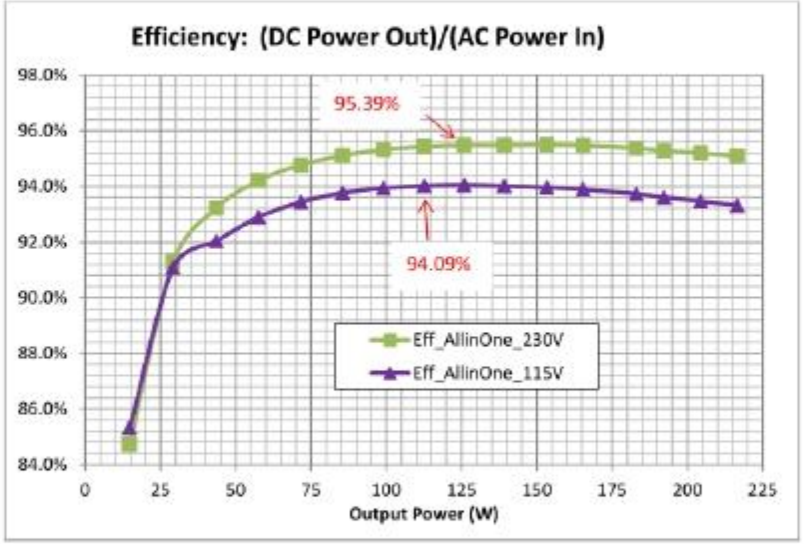
产品的应用2: PFC+LLC 一体板 250W 12Vout， 96%效率



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



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



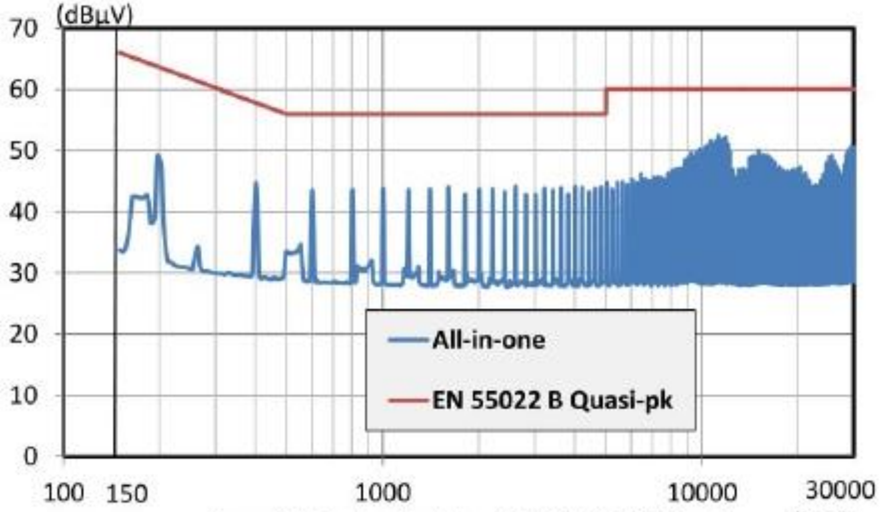


Figure 10. Conducted emissions @115V AC, 216W Load

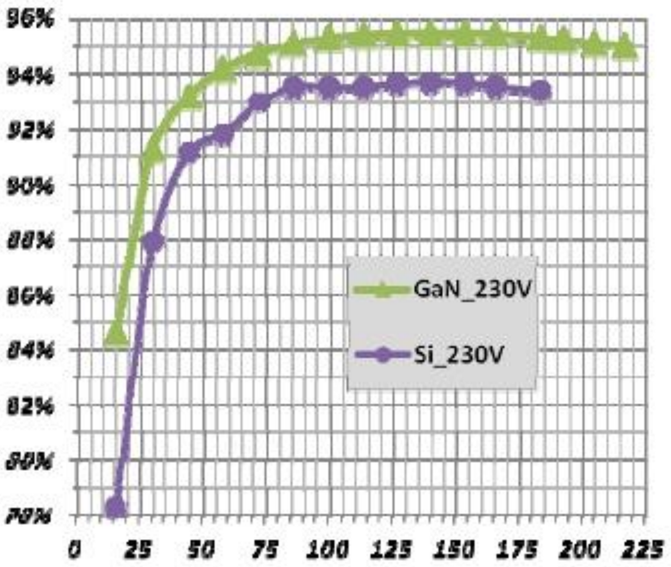
探头最小环测试

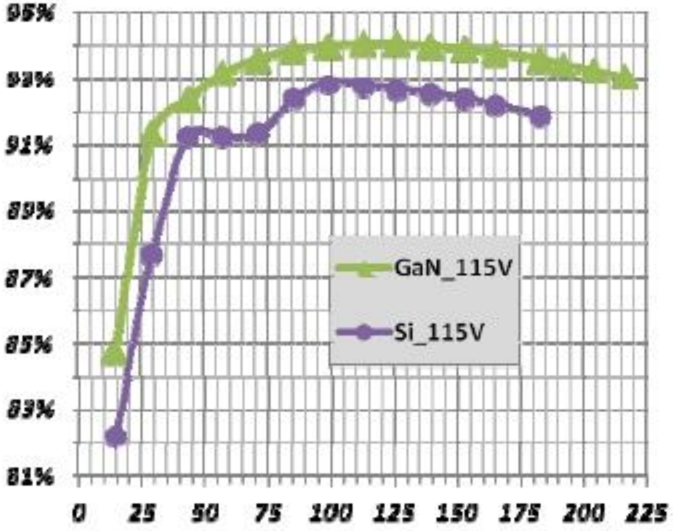
高频去藕电容尽可能
靠近上下管间

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

氮化镓方案
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