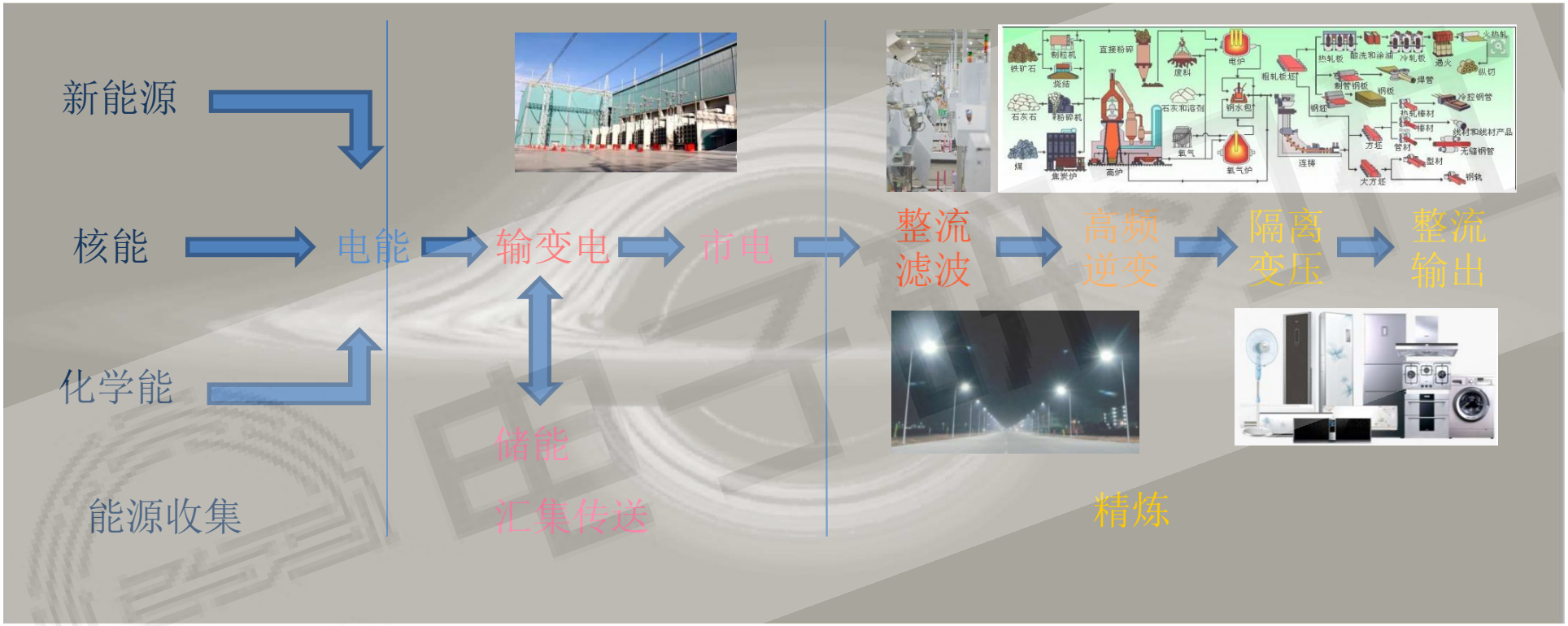
现代电力电子驱动技术

许逵炜

2020.4.1

现代能流与驱动



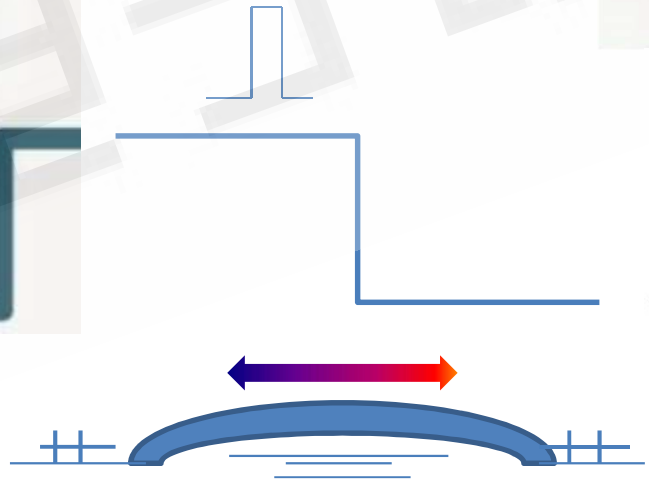
二极管
晶闸管
IGBT

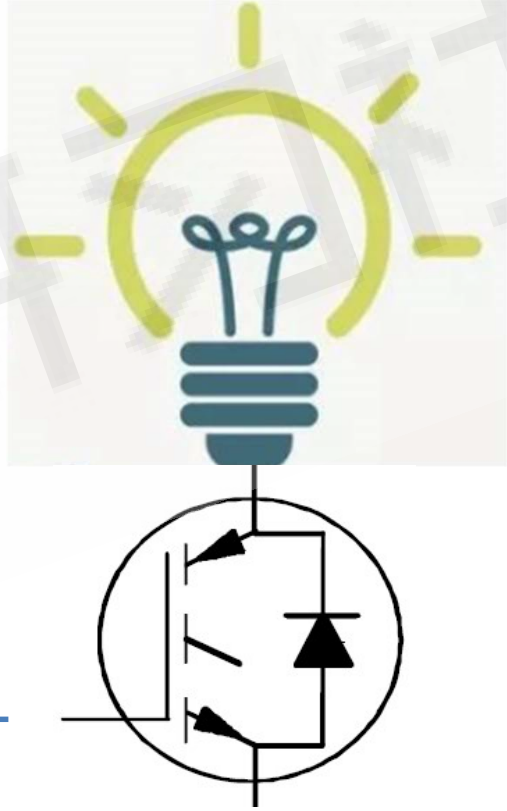
晶闸管
IGBT
SiC

二极管
晶闸管
MOSFET
IGBT
SiC
GaN

控制—驱动—功率

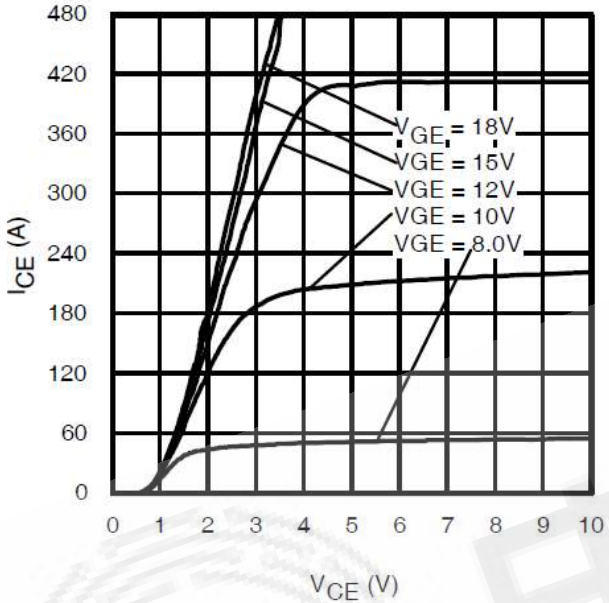
控制

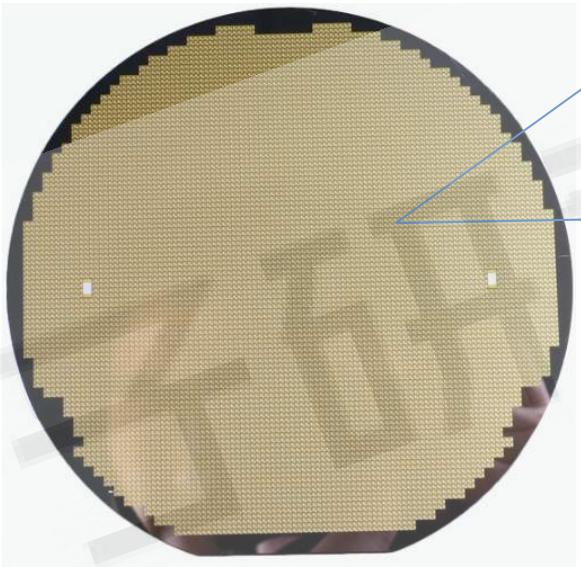


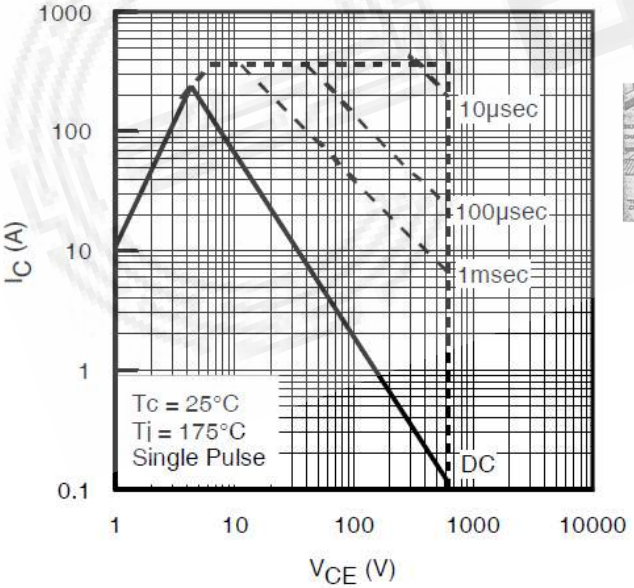


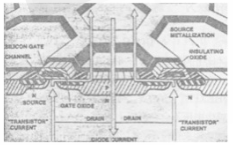
功率

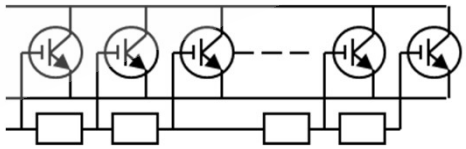
驱动与功率管的开关过程

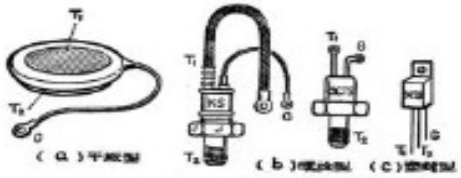








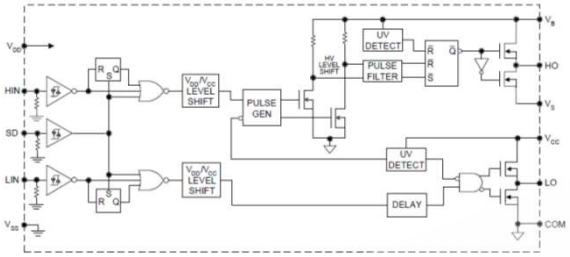




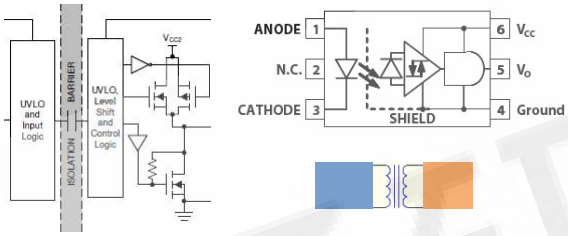
驱动：收放中的速度与激情

安全与可靠的沟通与感知

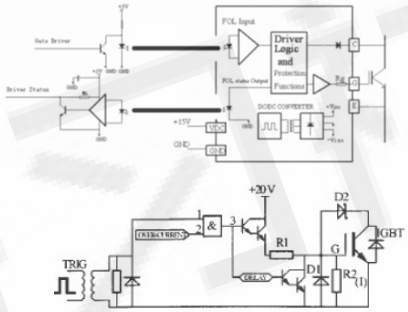
驱动



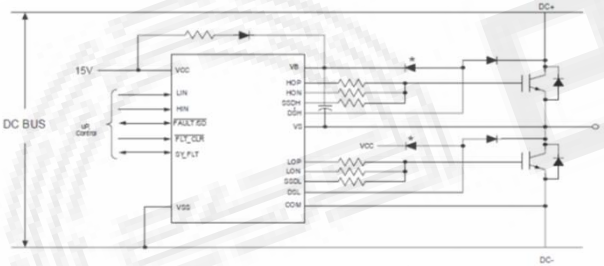
本地/热地驱动



隔离驱动

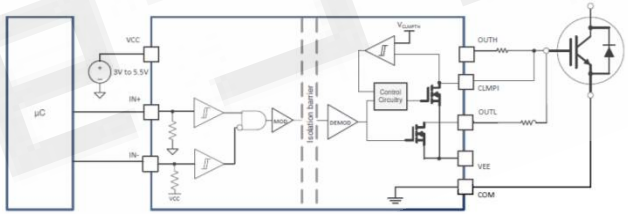


高压隔离驱动

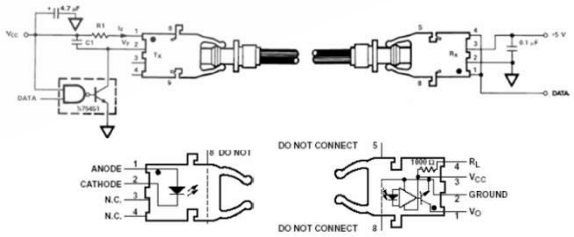


面向10kW以下中小功率

不直接接触人体



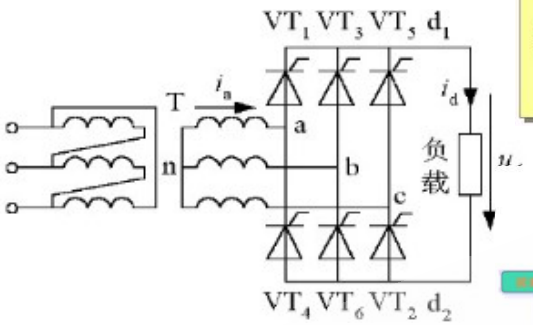
面向中高功率
有需要隔离
安全隔离需要

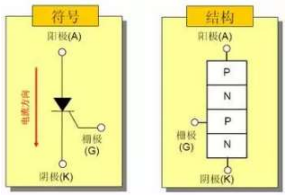


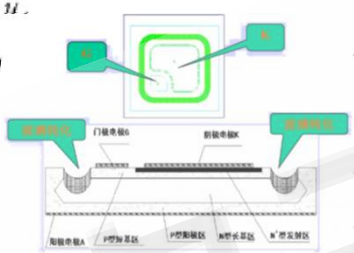
高压直流输变电
高压无功补偿
中高压变频

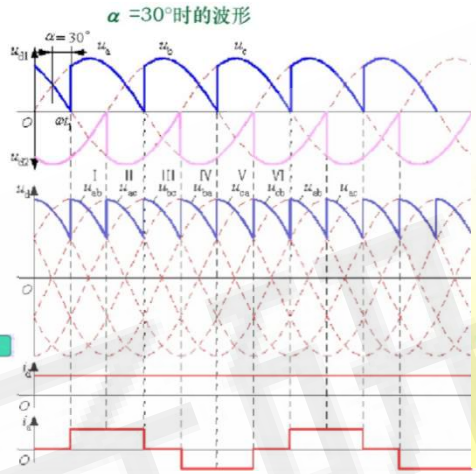
SCR与驱动

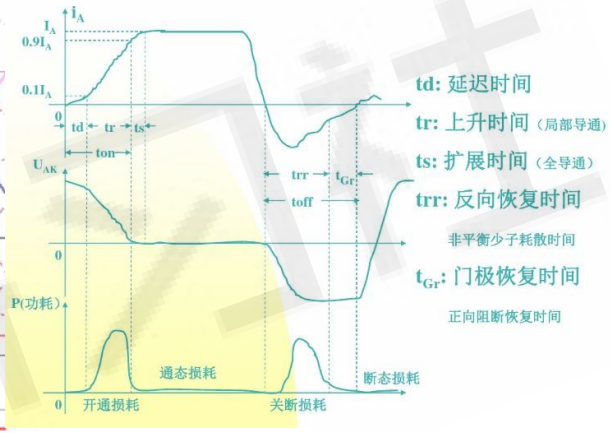
驱动架构

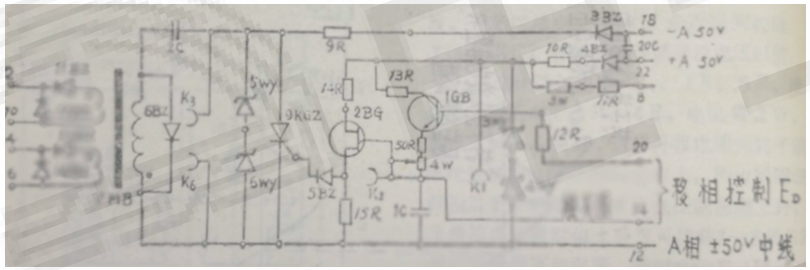


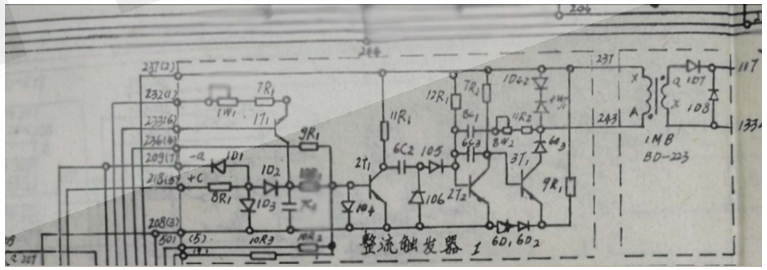












SCR

di/dt

dv/dt

位移电流

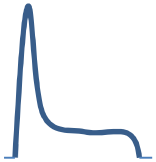
Gate drive

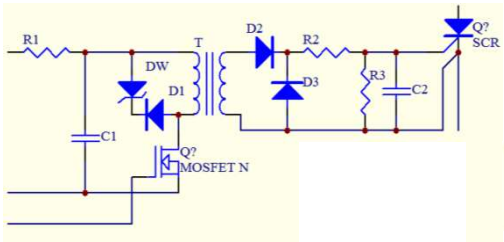
Ipk 波形系数

Igk

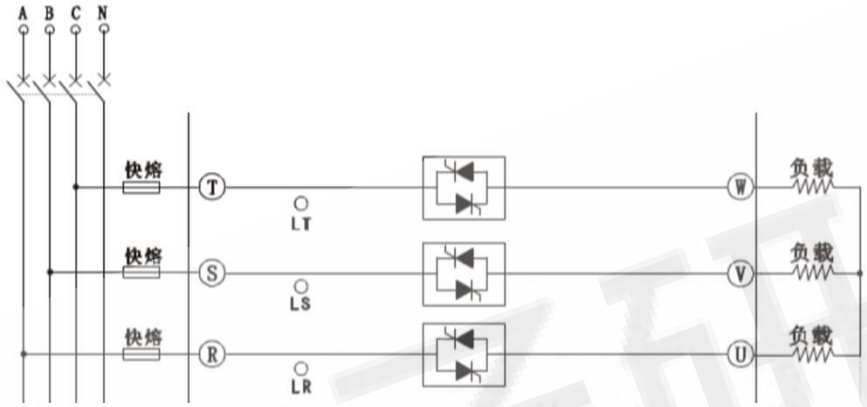
Pgk

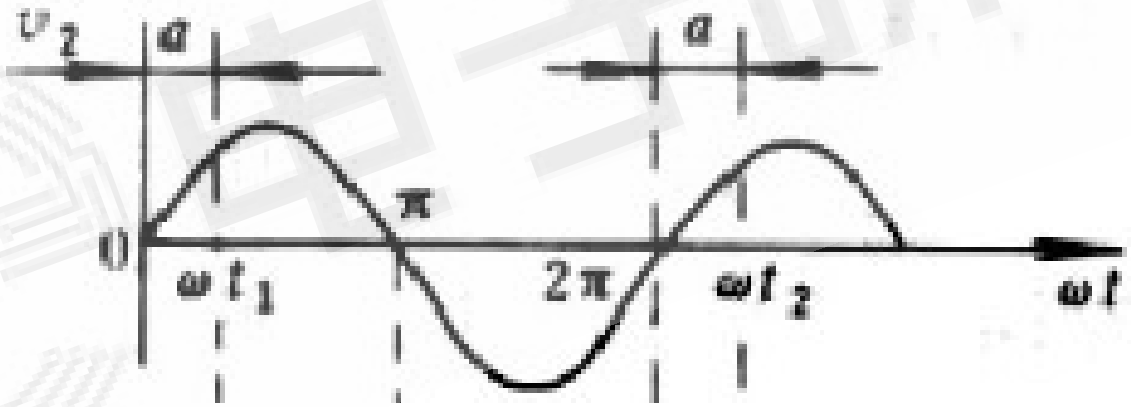
Cn1/n2

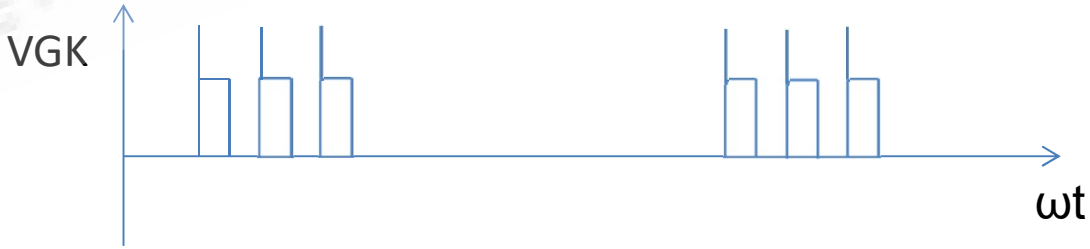




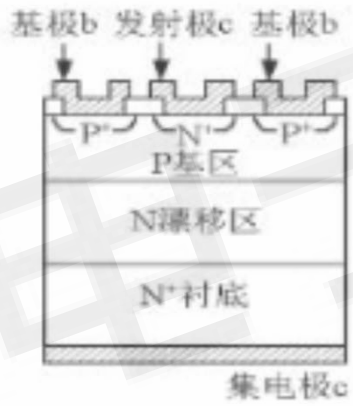
SCR在交流开关中的驱动

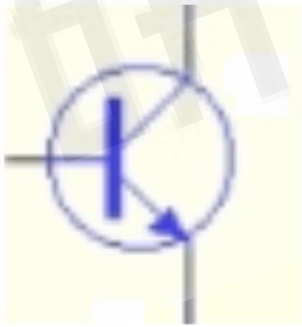




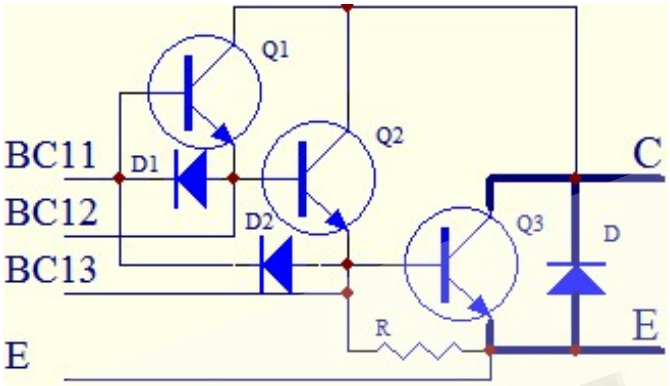


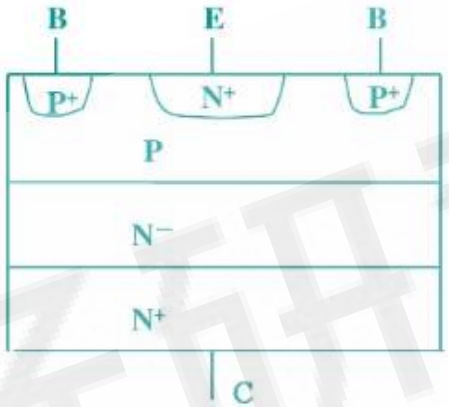
GTR与驱动

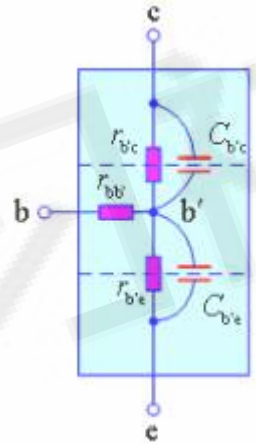


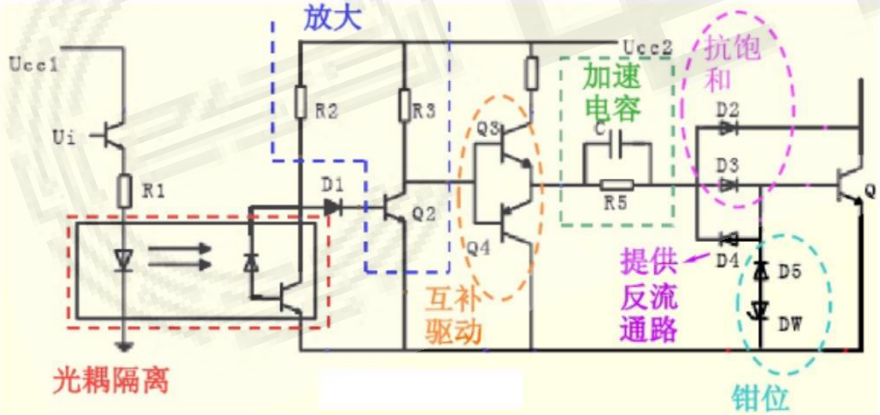


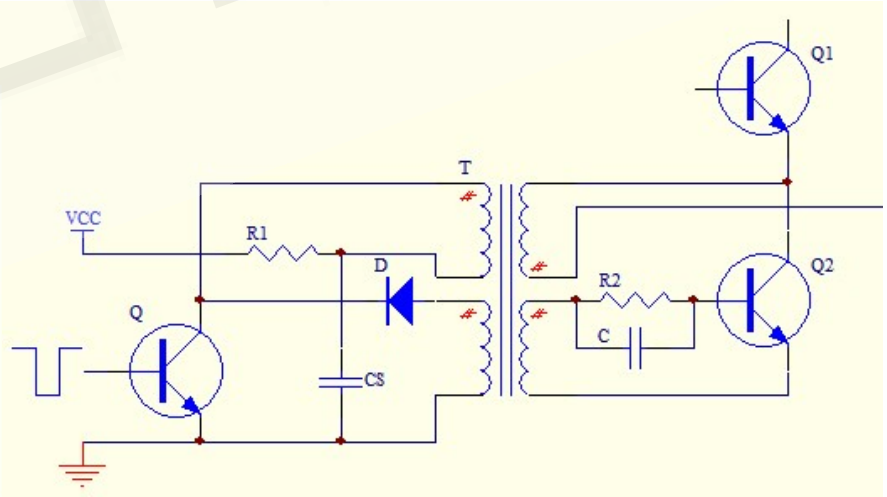
GTR驱动


Q1
Q2
Q3
BC11
BC12
BC13
D1
D2
D
R
C
E
E

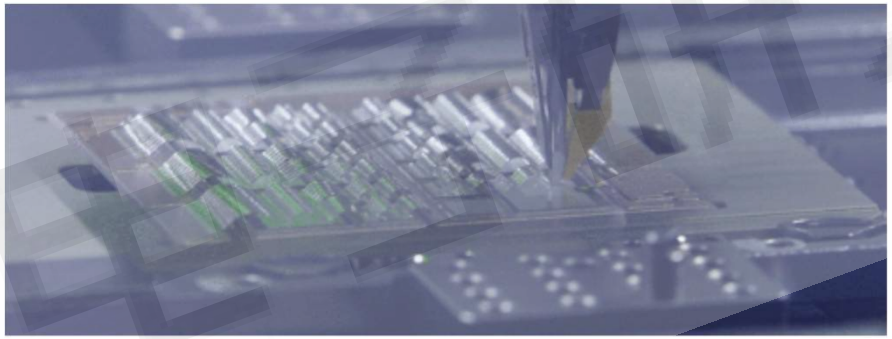

B
E
B
P+
N+
P+
P
N−
N+
C


c
b
b′
e

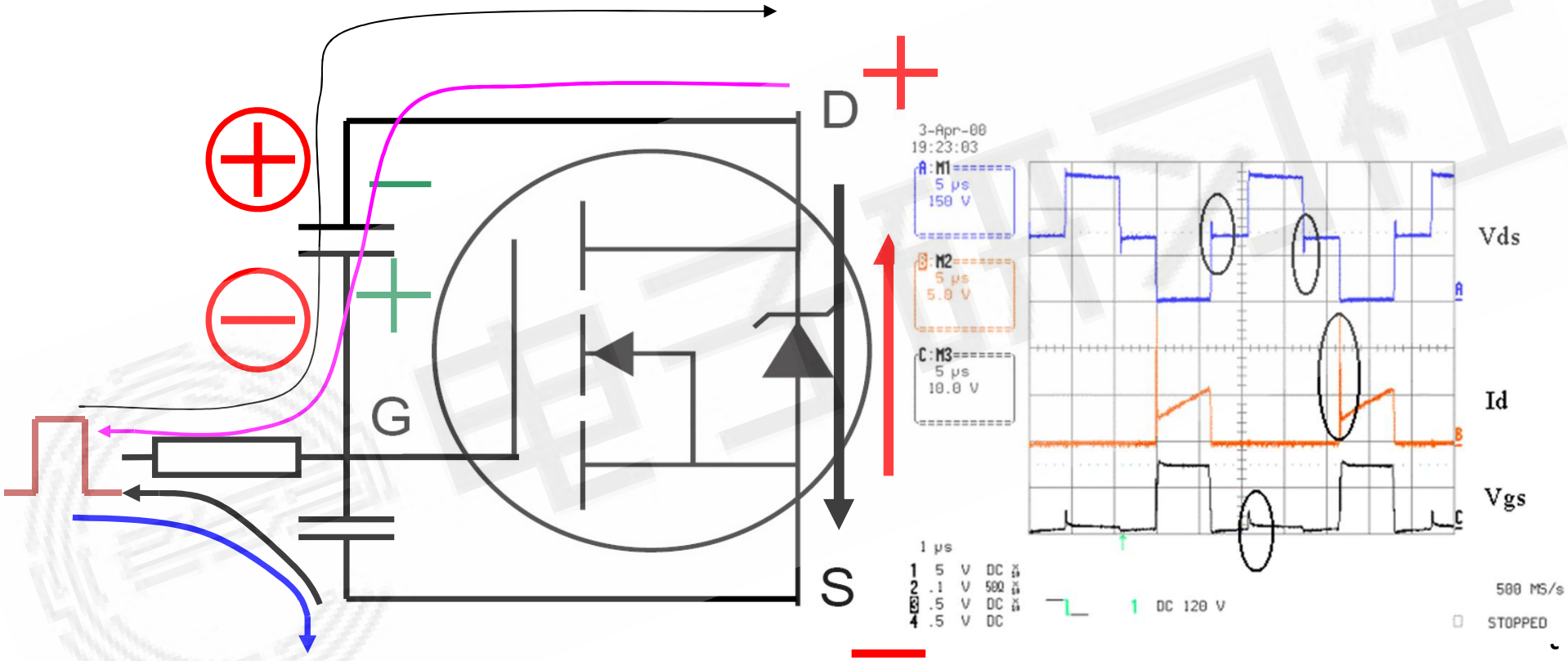

放大
Ucc1
Ui
R1
R2
R3
D1
Q2
Q3
Q4
Ucc2
加速
电容
C
R5
抗饱
和
D2
D3
D4
D5
DW
Q
提供
反流
通路
互补
驱动
光耦隔离
钳位


Q1
T
VCC
R1
D
Q
CS
R2
C
Q2

MOSFET/IGBT与驱动



MOSFET/IGBT驱动



$$Ion=\frac{Vcc-Vth-S*Id}{Ron}$$

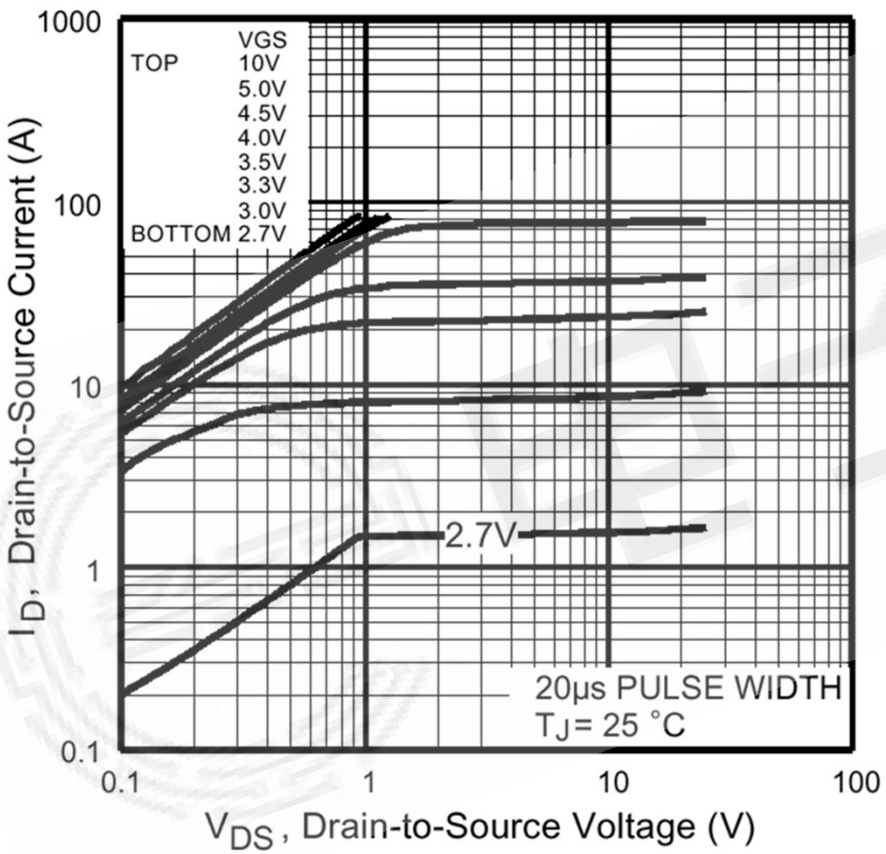
$$Ioff=\frac{Vth+S*Id+Vs}{Roff+rg}$$

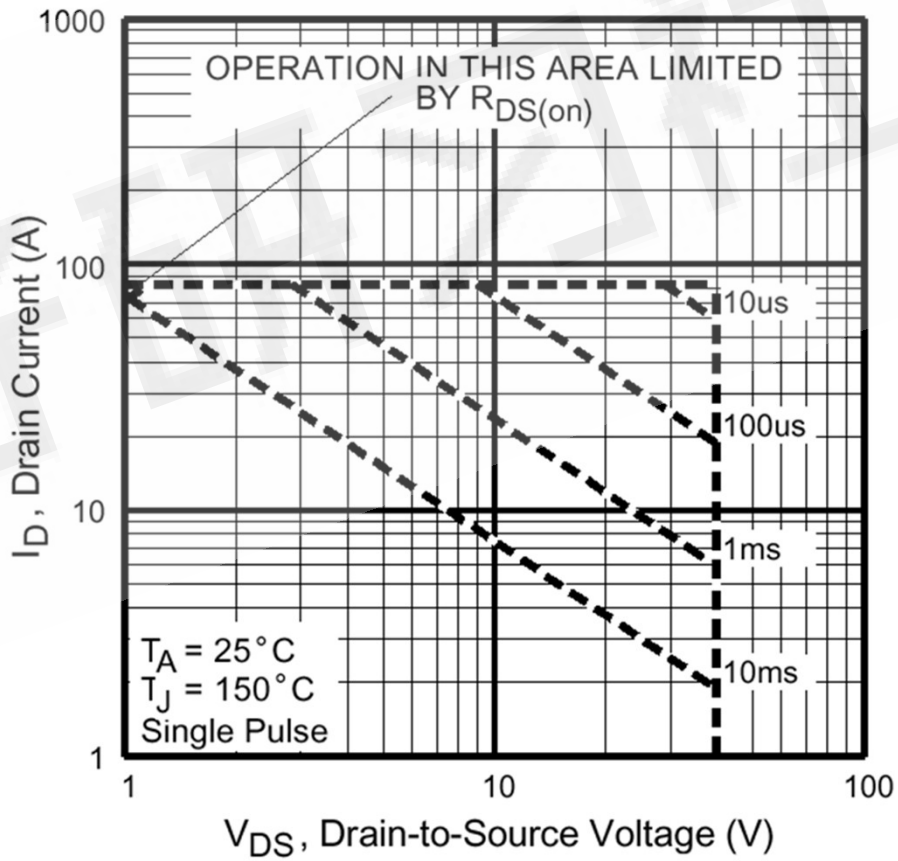
$$\frac{Ron}{Roff}=\frac{Vcc-Vth}{Vth+Vss}$$

$$ton=\frac{Qgd}{Ion}$$

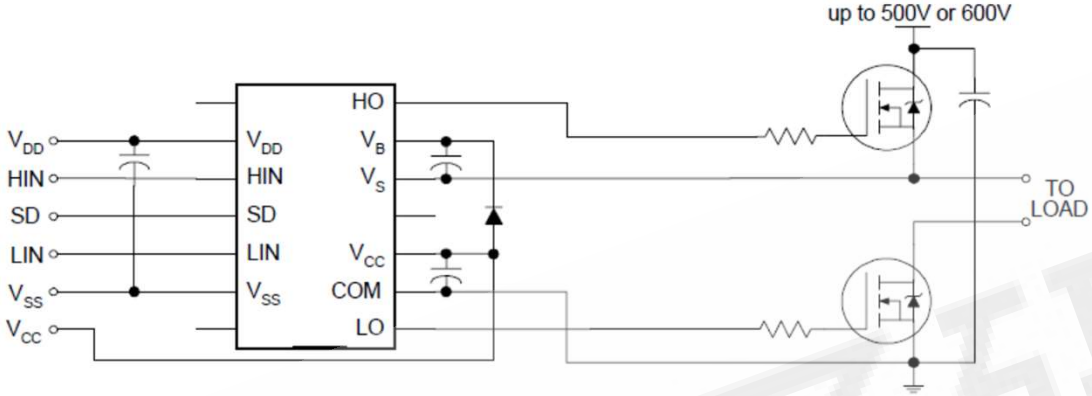
$$toff=\frac{Qgd}{Ioff}$$

Vcc Vs 通流能力短路耐力与损耗



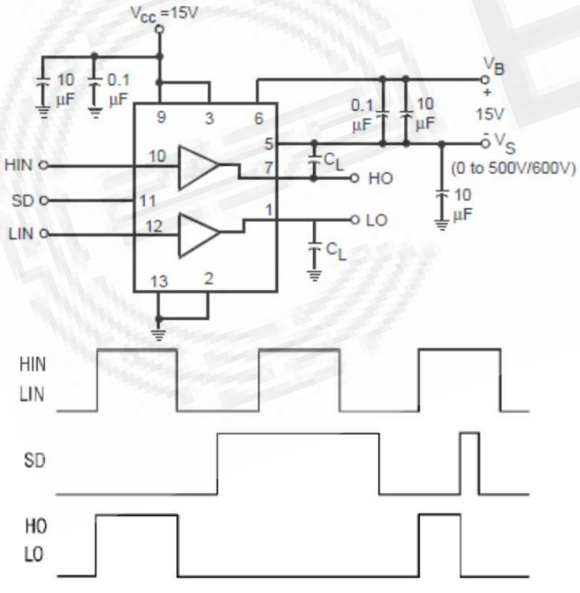


驱动参数与分散性

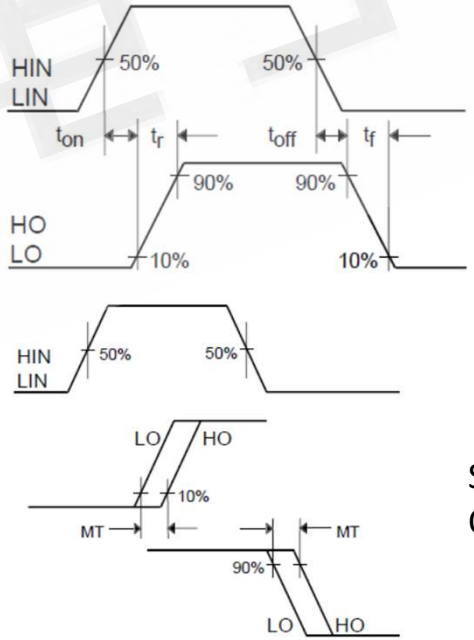


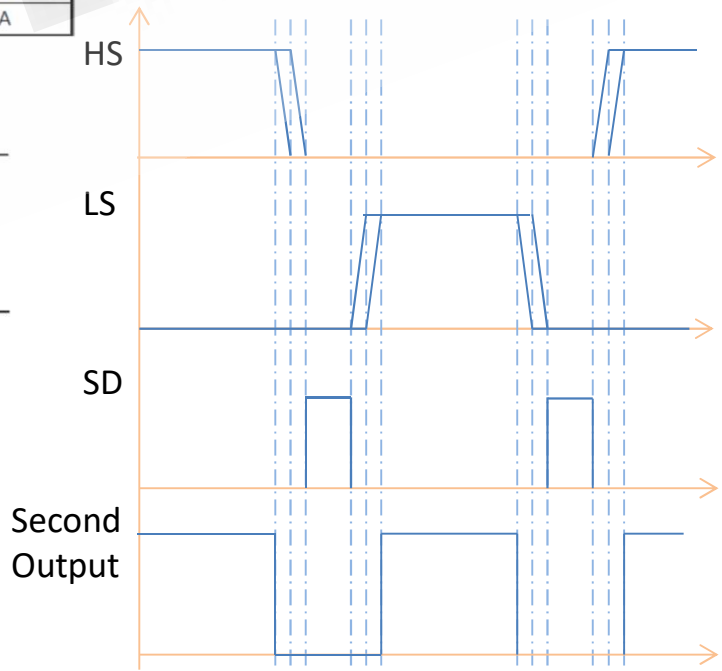
V_{IH}	Logic "1" input voltage	12	9.5	—	—	V	
V_{IL}	Logic "0" input voltage	13	—	—	6.0		
V_{OH}	High level output voltage, V_{BIAS} - V_O	14	—	—	1.2		I_O = 0A
V_{OL}	Low level output voltage, V_O	15	—	—	0.1		I_O = 0A

V_{OFFSET} (IR2110)	500V max.
(IR2113)	600V max.
I_O+/-	2A / 2A
V_{OUT}	10 - 20V
$t_{on/off}$ (typ.)	120 & 94 ns
Delay Matching	10 ns

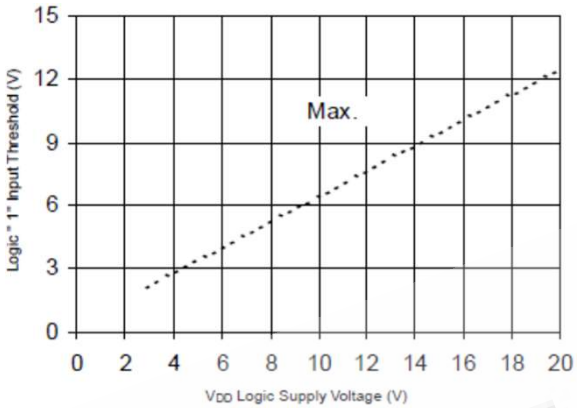


Input/Output Timing Diagram

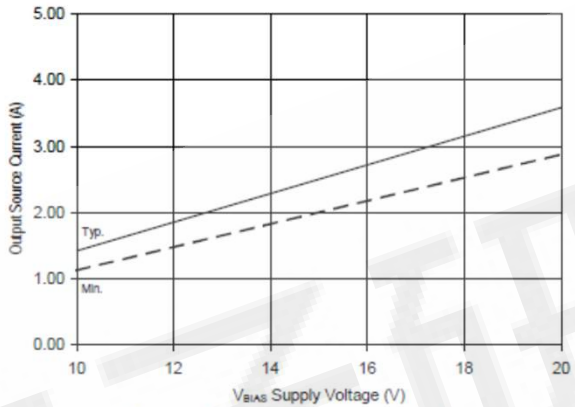




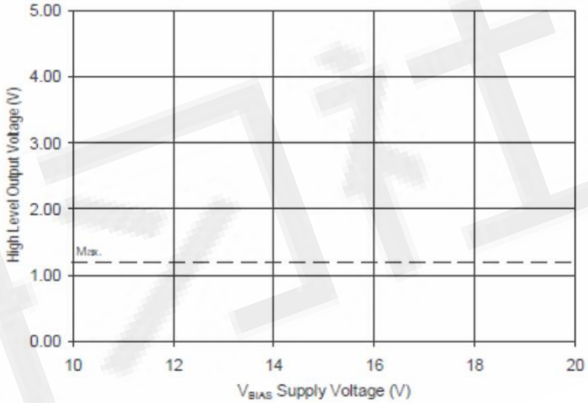
电源电压与逻辑兼容



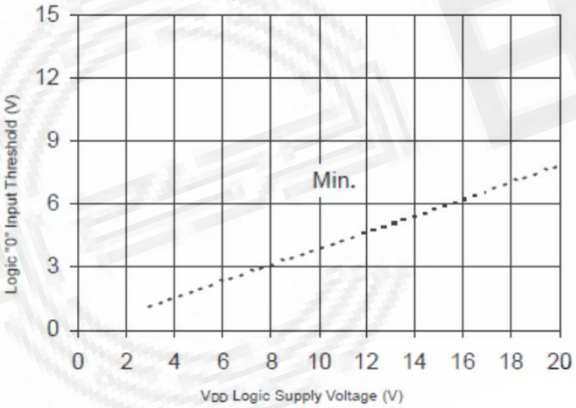
Logic "1" Input Threshold vs. Voltage



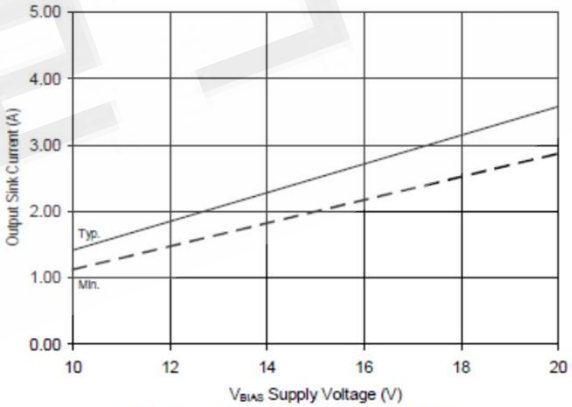
Output Source Current vs. Voltage



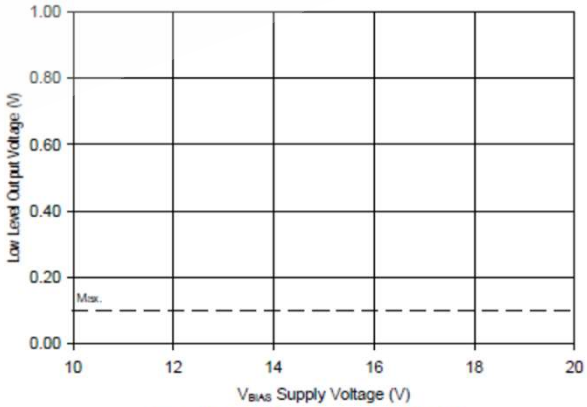
High Level Output vs. Voltage



Logic "0" Input Threshold vs. Voltage



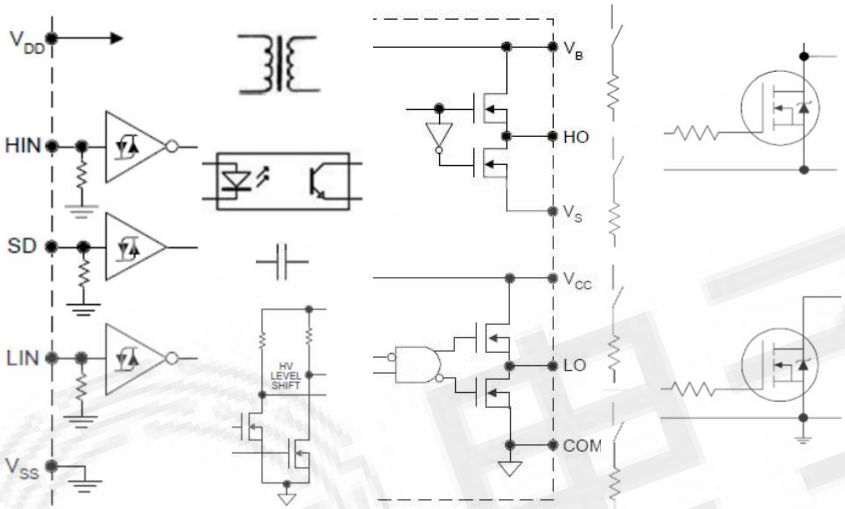
Output Sink Current vs. Voltage



Low Level Output vs. Voltage

输入兼容　　输出兼容　　输出与Vth匹配

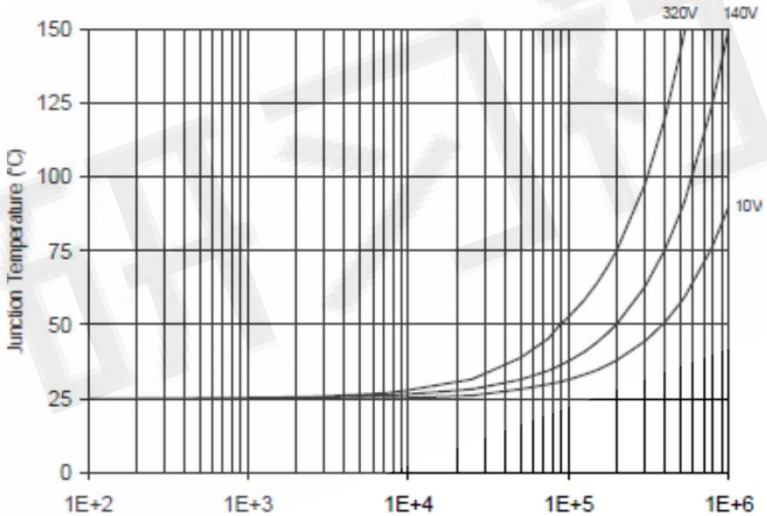
驱动损耗与热管理



静态能耗　隔离传递能耗　　驱动能耗

I_Q*Vcc　Psw+1/2CUbus^2F　Q_g*Vcc*F-Q_g^2*Rg*F

注:Qg为Vcc电压驱动时的电荷值

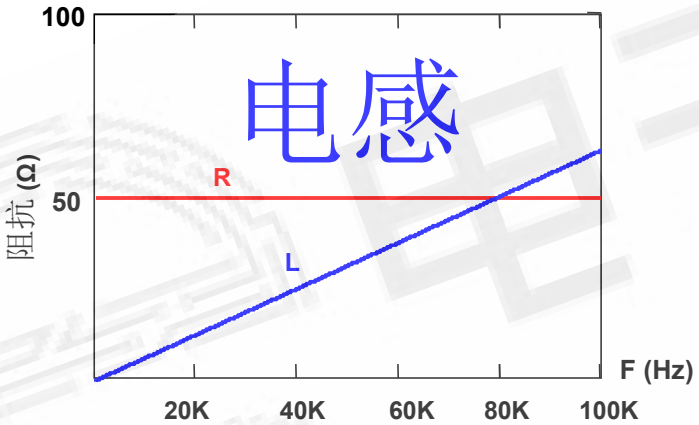


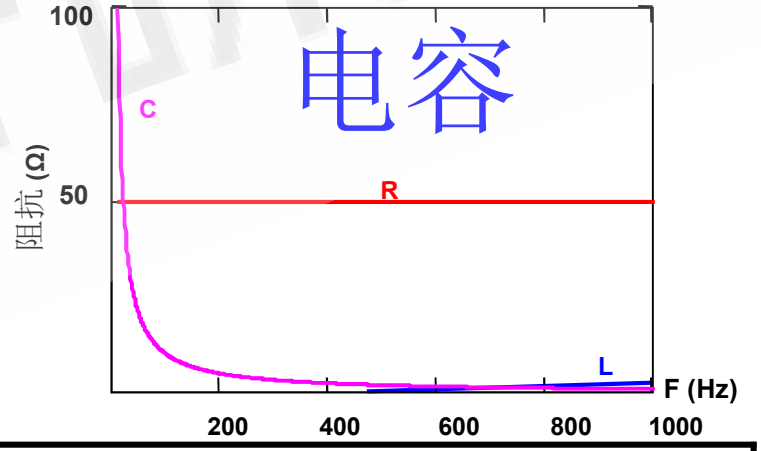
IR2110/IR2113 T_J vs. Frequency (IRFBC40) R_{GATE} = 15Ω, V_{CC} = 15V

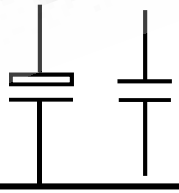
P_D	Package power dissipation @ $T_A \leq +25°C$	(14 lead DIP)	—	1.6	W
		(16 lead SOIC)	—	1.25	
R_{THJA}	Thermal resistance, junction to ambient	(14 lead DIP)	—	75	°C/W
		(16 lead SOIC)	—	100	
T_J	Junction temperature		—	150	°C
T_S	Storage temperature		-55	150	
T_L	Lead temperature (soldering, 10 seconds)		—	300	

连接中的感容

符号	阻抗	单位	特性
	2πfL	Ω	1. 阻抗是频率的函数 2. 能量存储元件 3. 需要保持”伏秒”平衡





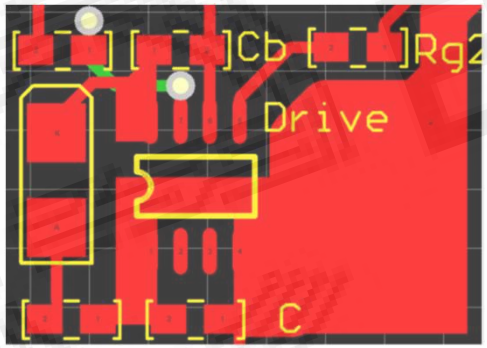
符号	阻抗	单位	特性
	$\frac{1}{2\pi fC}$	Ω	1. 阻抗是频率的函数 2. 能量存储元件

驱动使用与PCB 寄生L/C

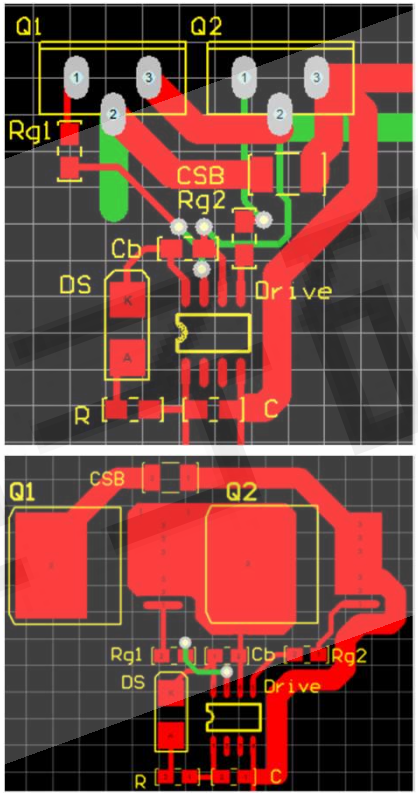
强弱电分立与开尔文连接

驱动线距离与栅极振铃

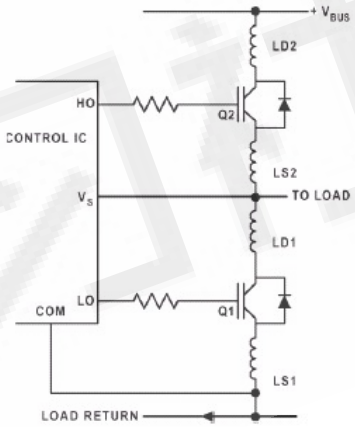
耦合与环流

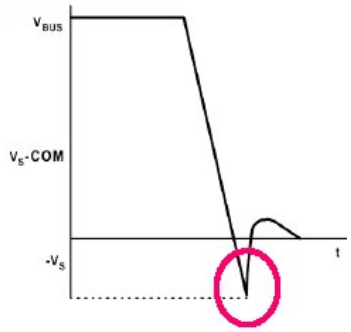


PCB辅助散热



驱动与强电连接/封装优化



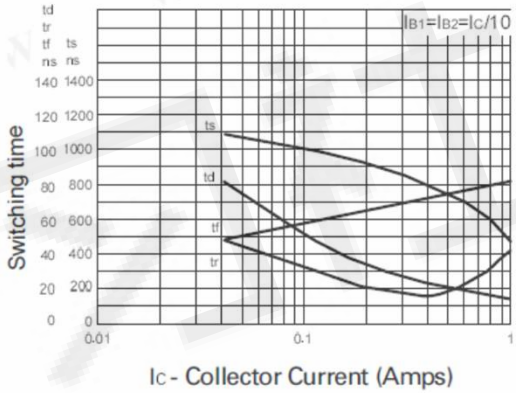


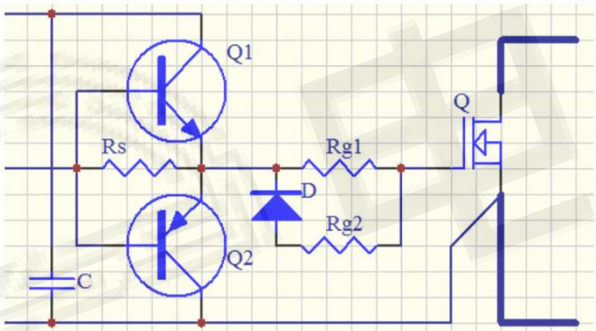
寄生电感与二极管
对驱动影像

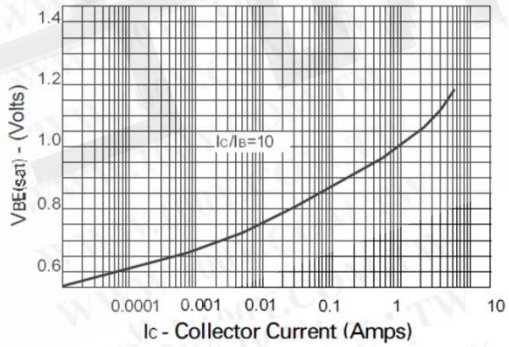
双极性图腾噪音延迟与安全

Transition Frequency	f_T	140	175		MHz	I_C=100mA, V_{CE}=5V f=100MHz
Switching Times	t_{on}		45		ns	I_C=500mA, V_{CC}=10V I_{B1}=I_{B2}=50mA
	t_{off}		800		ns	

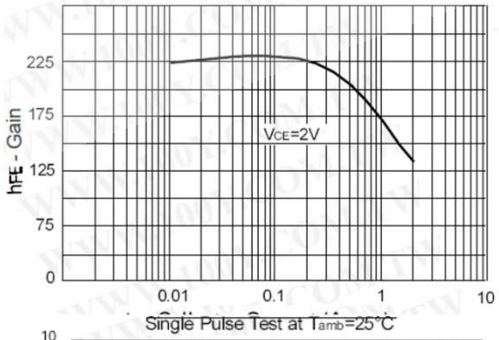
Transition Frequency	f_T	100	140		MHz	I_C=-100mA, V_{CE}=-5V f=100MHz
Switching Times	t_{on}		40		ns	I_C=-500mA, V_{CC}=-10V I_{B1}=I_{B2}=-50mA
	t_{off}		450		ns	

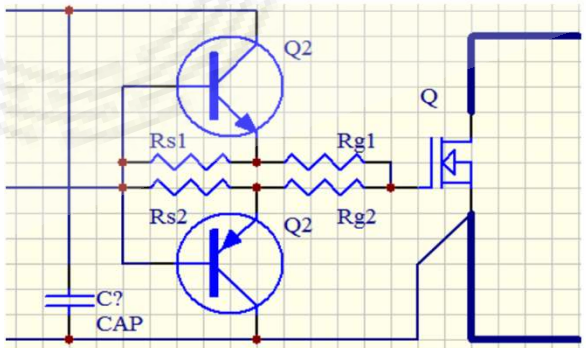


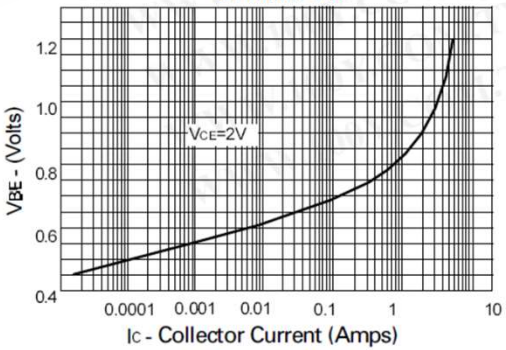




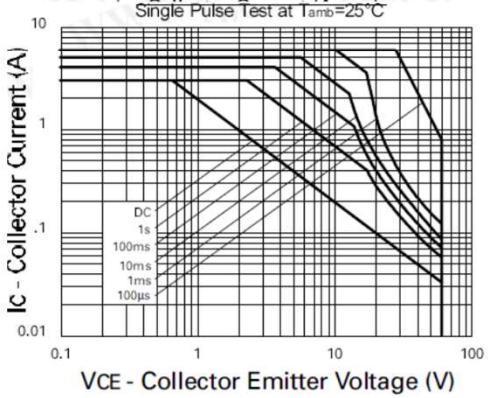
VBE(sat) v IC





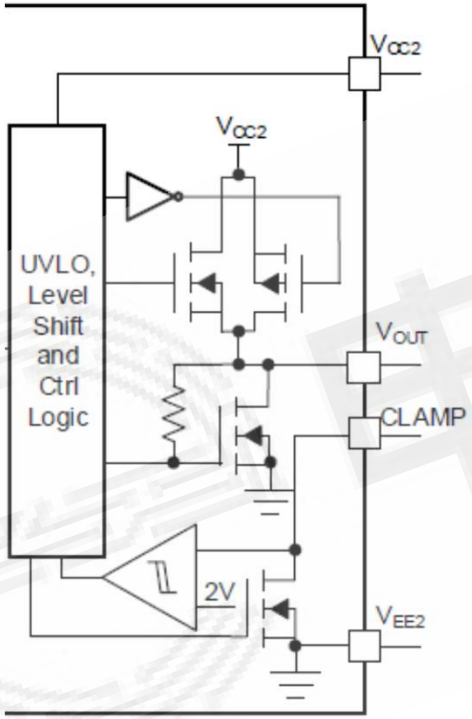


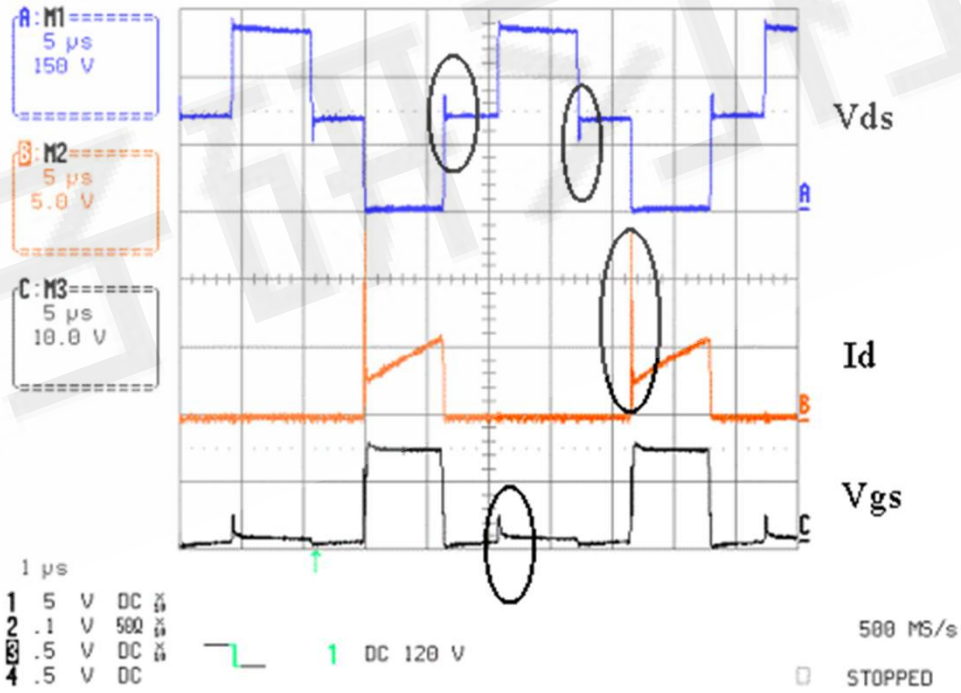
VBE(on) v IC



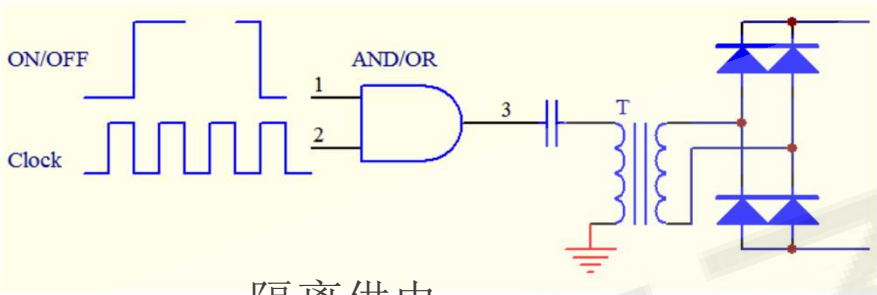
Safe Operating Area

主动驱动钳位技术

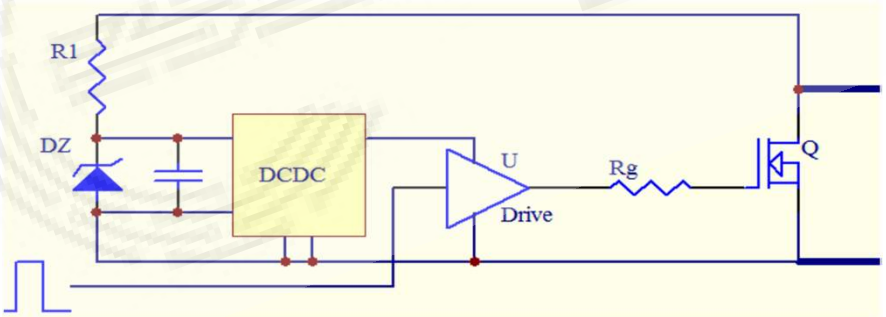

VCC2
VCC2
UVLO,
Level
Shift
and
Ctrl
Logic
VOUT
CLAMP
2V
VEE2


A:M1
5 µs
150 V
B:M2
5 µs
5.0 V
C:M3
5 µs
10.0 V
Vds
Id
Vgs
1 µs
1 5 V DC
2 .1 V 50Ω
3 .5 V DC
4 .5 V DC
1 DC 120 V
500 MS/s
STOPPED

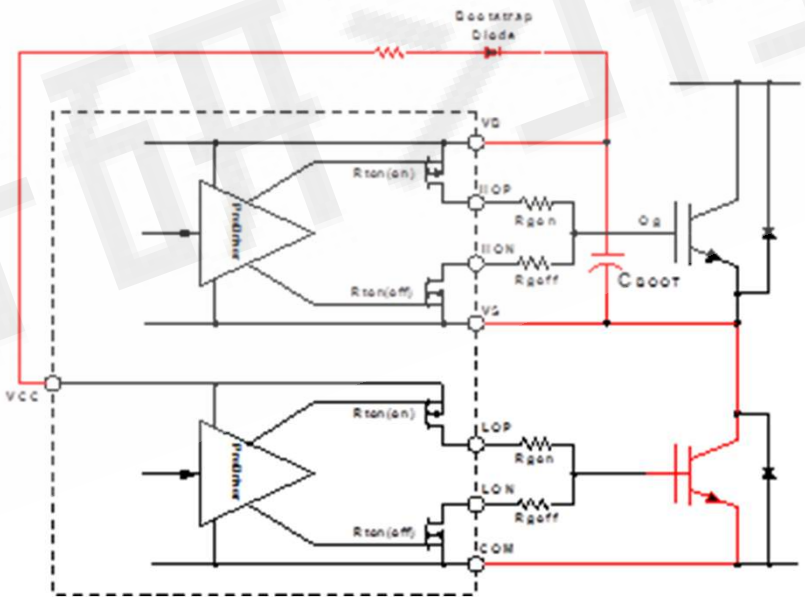
驱动供电



隔离供电



自取能供电



驱动设计提要

一、驱动与输入兼容性　　逻辑兼容性与噪音抑制　电磁兼容　全工作温度范围温漂

二、驱动与输出兼容性　　驱动电压、驱动电流、电压承受力与功率管的配合

三、驱动脉冲延迟与保真　输入脉冲宽度与实际功率输出宽度误差

四、驱动末级延迟与噪音

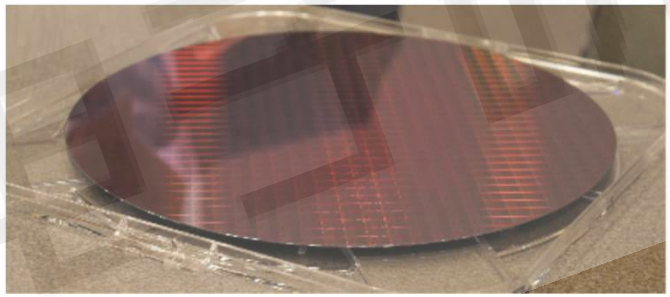
五、驱动热设计　　功率损耗与温升

六、驱动与输入、输出距离与阻抗匹配

七、驱动与开尔文布线

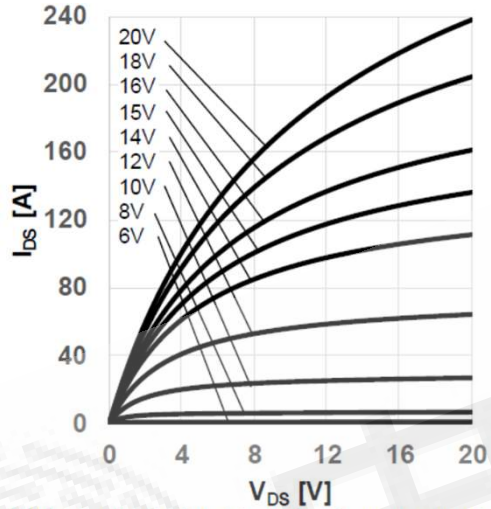
八、功率电路Layout与驱动配合

SiC MOSFET驱动

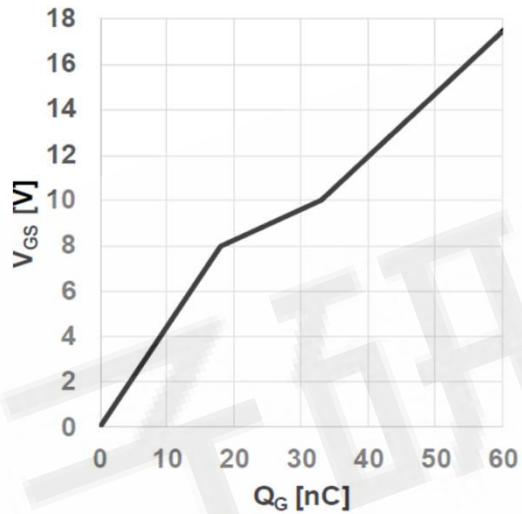


SiC Vs Si MOSFET

SiC

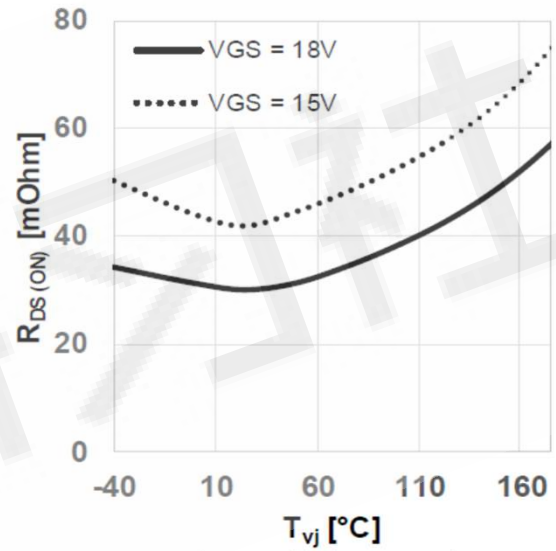


Typical output characteristic, V_{GS} as parameter



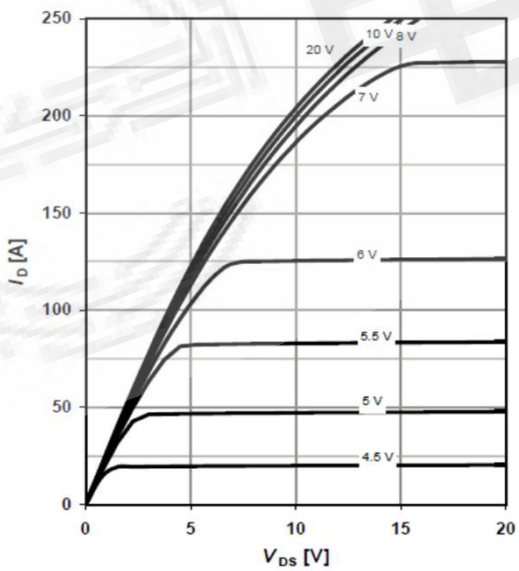
Typical gate charge

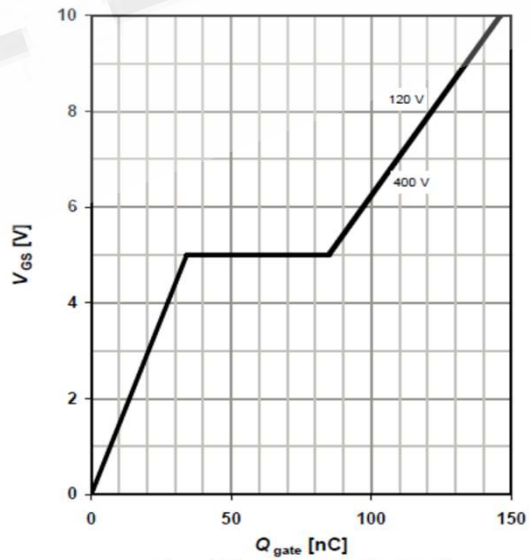
($V_{GS} = f(Q_G)$, $I_{DS} = 25A$, $V_{DS} = 800V$, turn-on pulse)



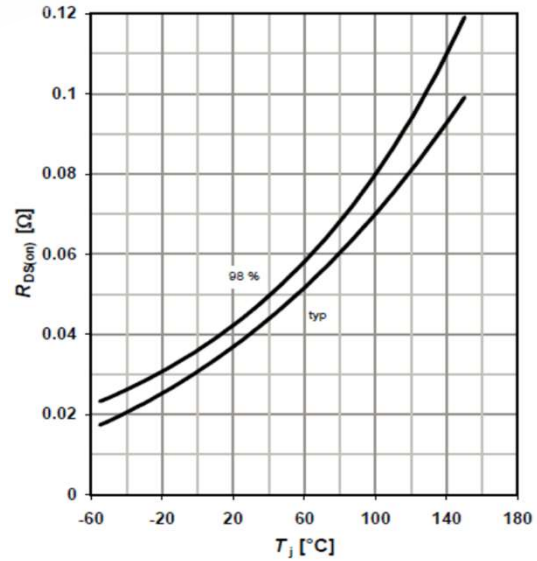
($R_{DS(on)} = f(T_{vj})$, $I_{DS} = 25A$)

Si

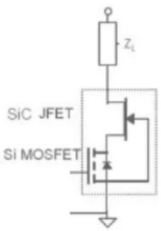


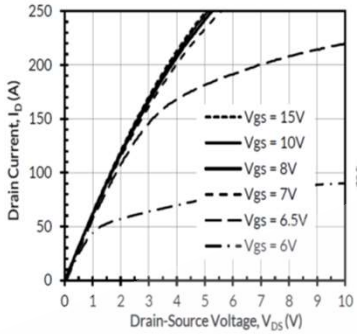


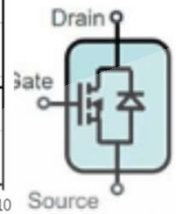
$V_{GS}=f(Q_{gate})$; I_D=44 A pulsed

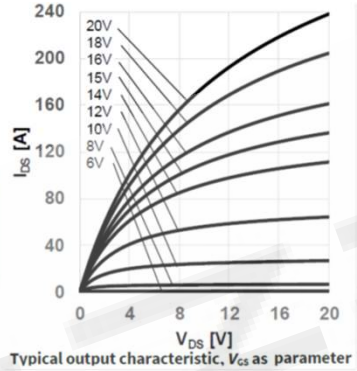


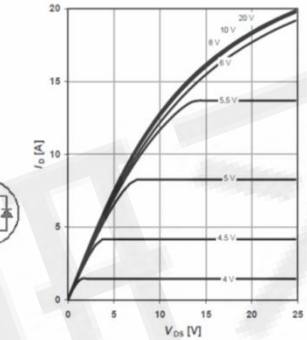
驱动—SiC FET & Si MOSFET IGBT

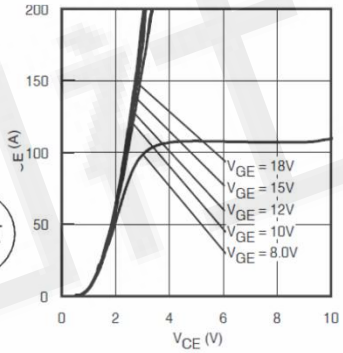




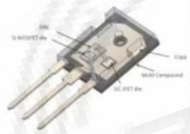


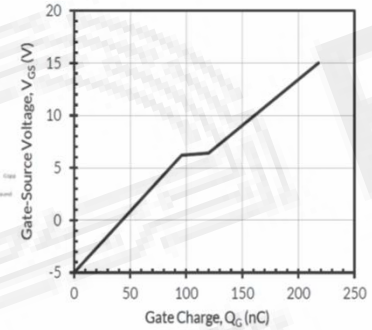


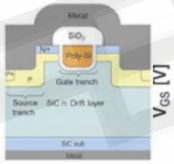


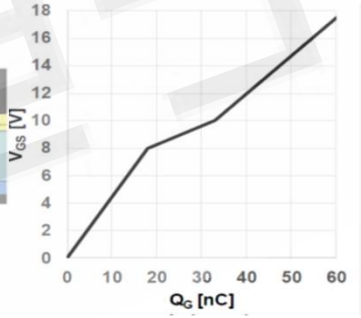


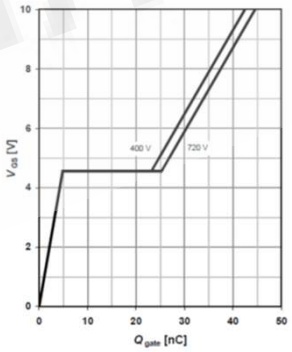
Typ. IGBT Output Characteristics

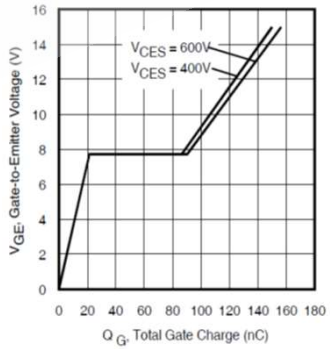








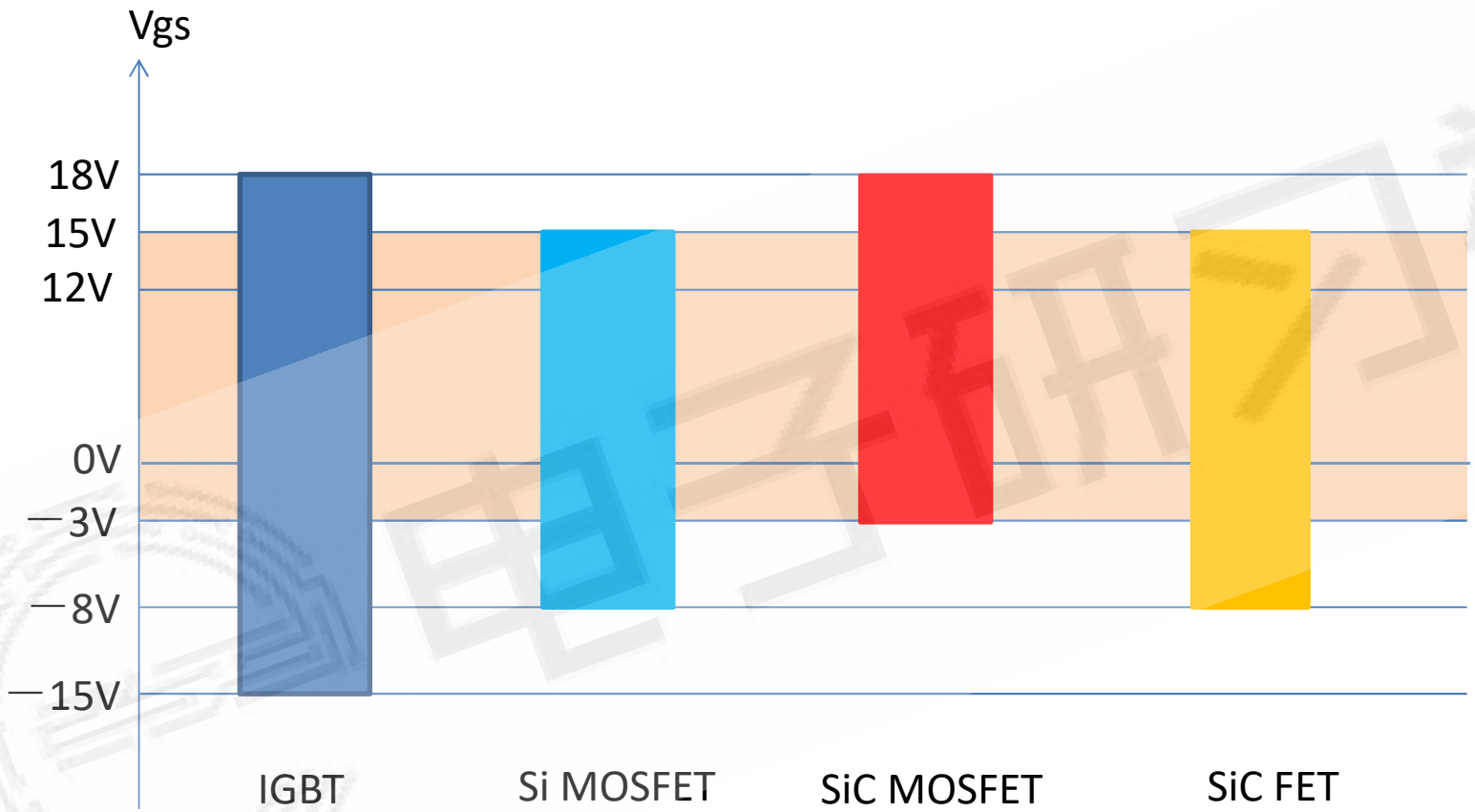




$t_{d(on)}$	V_{DD} = 800V, I_D = 25A,	-	7	-	ns
t_r	V_{GS} = 0/18V, $R_{G,ext}$ = 2Ω,	-	46	-	
$t_{d(off)}$	L_σ = 40nH,	-	17	-	

Turn-On Delay Time	—	35	—	ns
Rise Time	—	29	—	
Turn-Off Delay Time	—	380	—	
Fall Time	—	280	—	

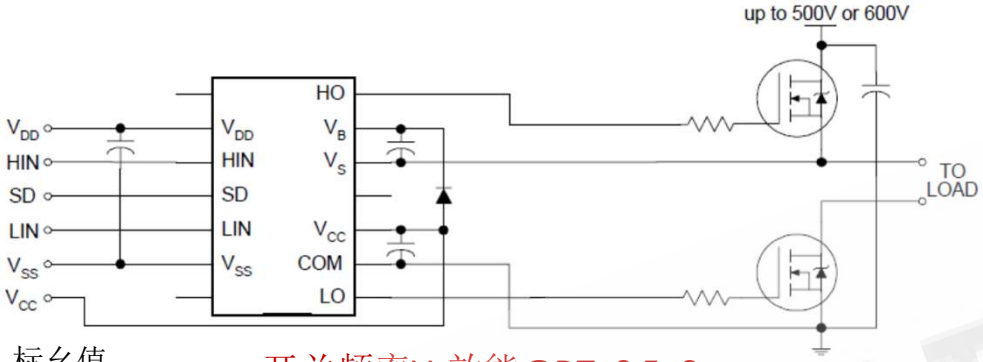
驱动电压兼容及区别



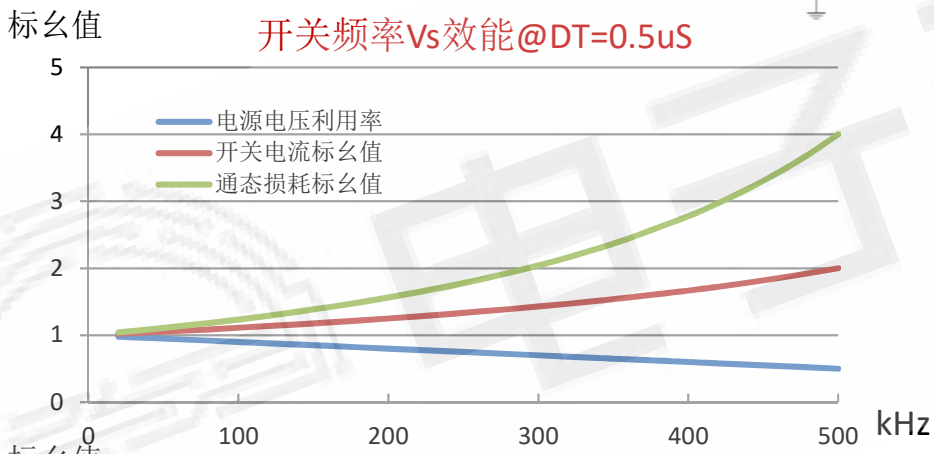
-3V~15V；0～15V驱动方案兼容

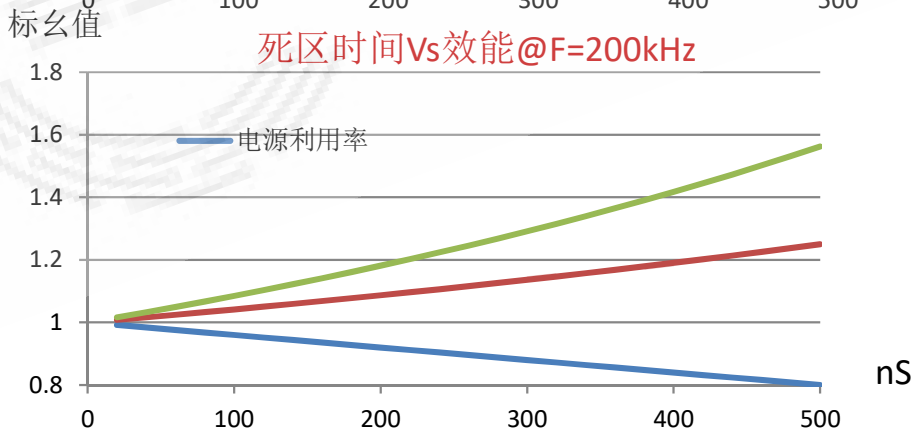
以硅基和碳化硅基的器件，在大多数范围可以兼容。

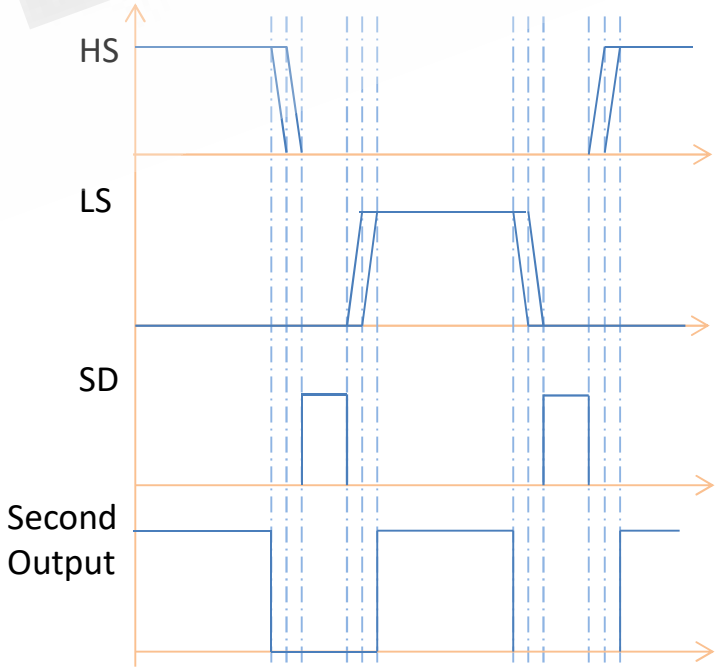
驱动分散性Vs效能



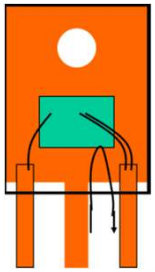
V_{OFFSET} (IR2110)	500V max.
(IR2113)	600V max.
I_O+/-	2A / 2A
V_{OUT}	10 - 20V
$t_{on/off}$ (typ.)	120 & 94 ns
Delay Matching	10 ns

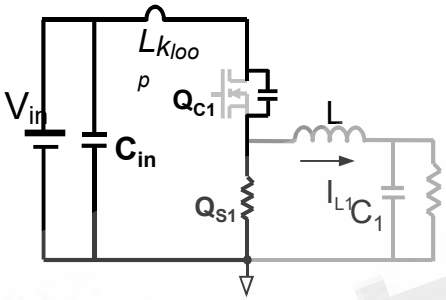


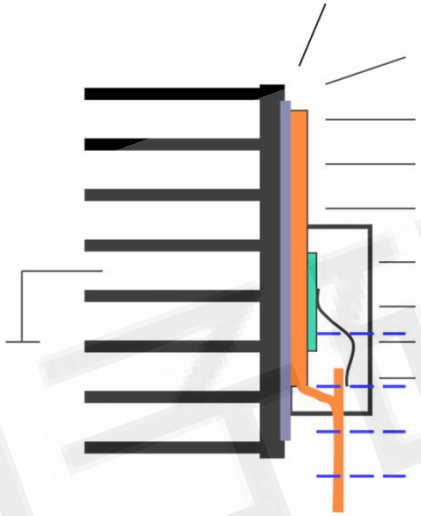


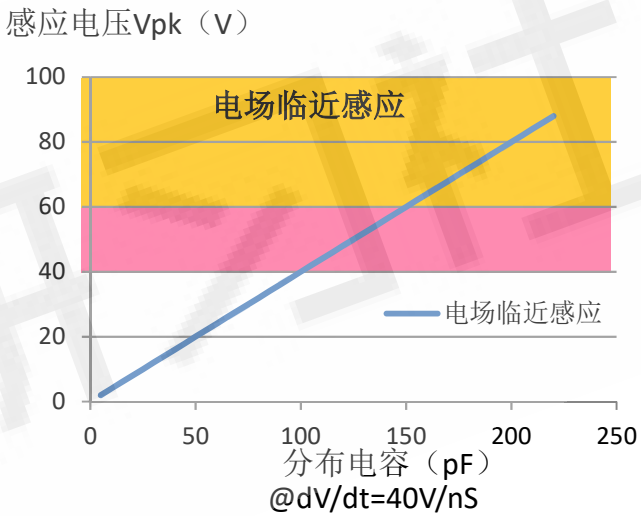


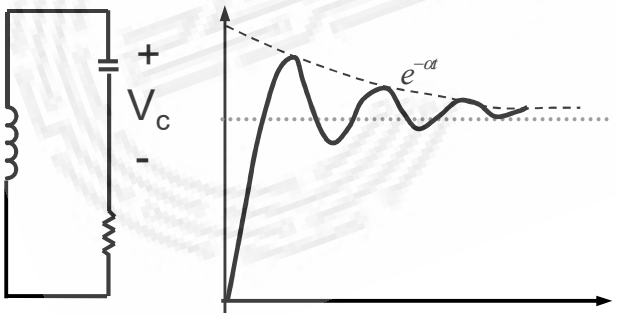
高频下的分布参数与噪音

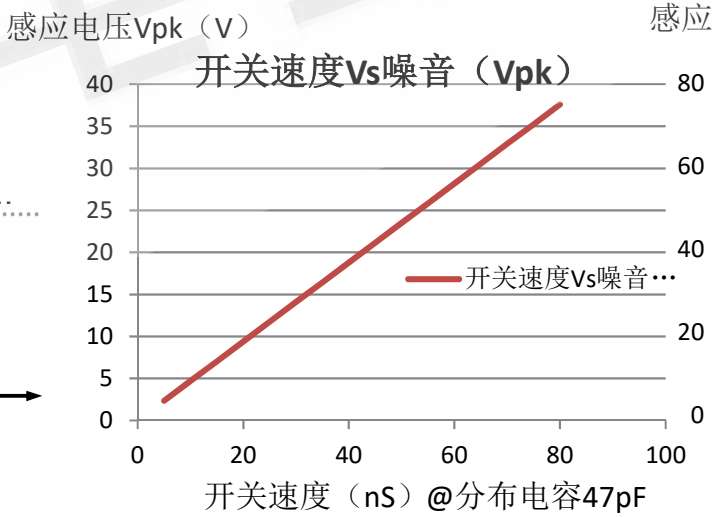


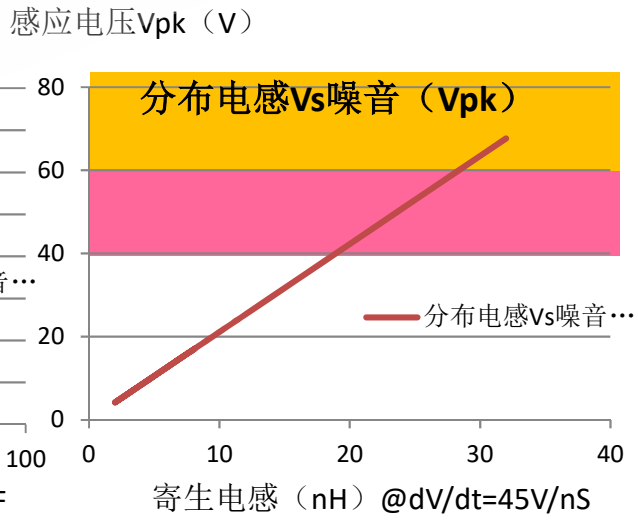












SiC MOSFET 驱动要点

一、驱动与输入兼容性　安全与系统收敛性

二、驱动与输出兼容性　安全与辐射噪音

三、驱动脉冲延迟与保真　分散性与死区设置匹配

四、驱动末级　ON与OFF匹配

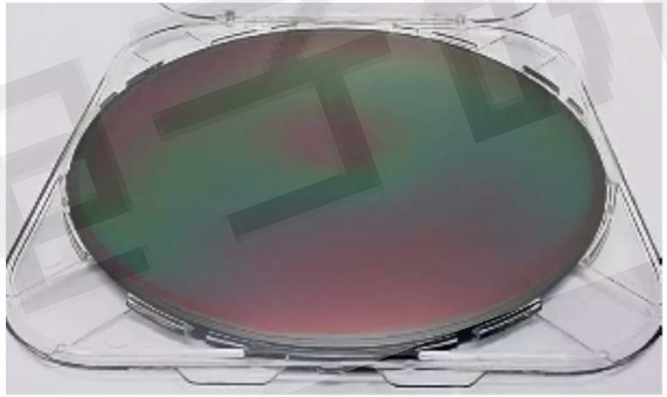
五、驱动热设计　功率损耗与温升

六、驱动与输入、输出距离与环路退耦

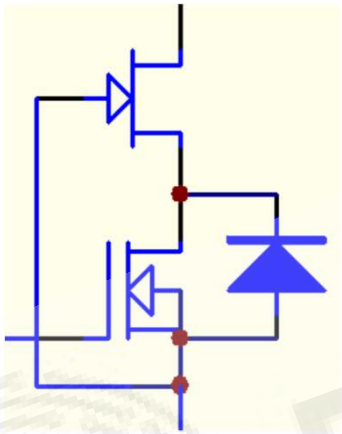
七、驱动与开尔文布线

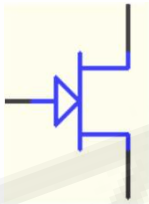
八、功率电路Layout与驱动配合

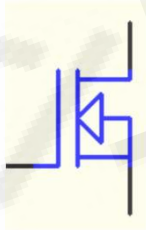
GaN HEMT驱动

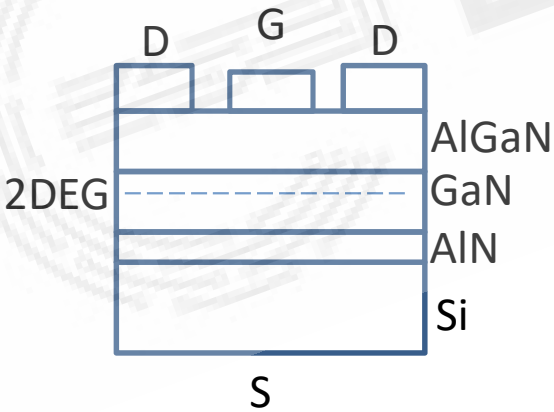


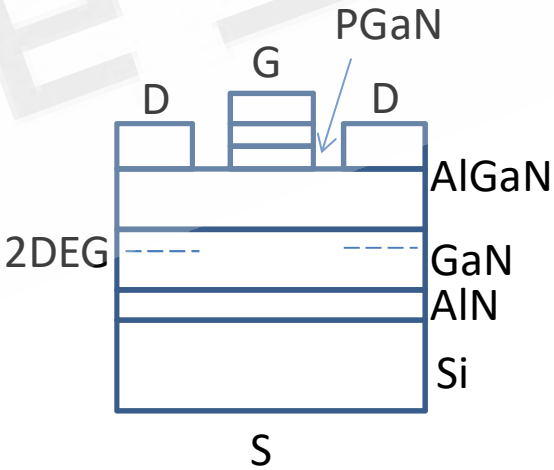
GaN HEMT

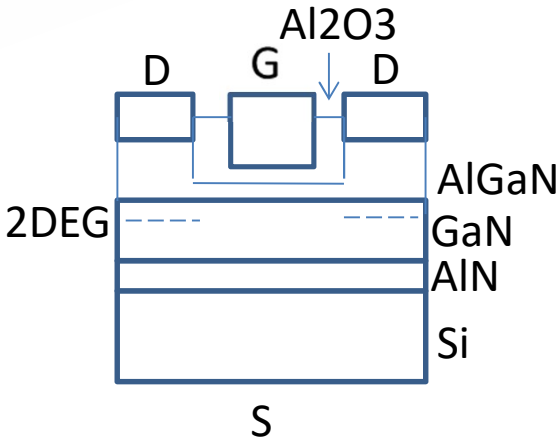




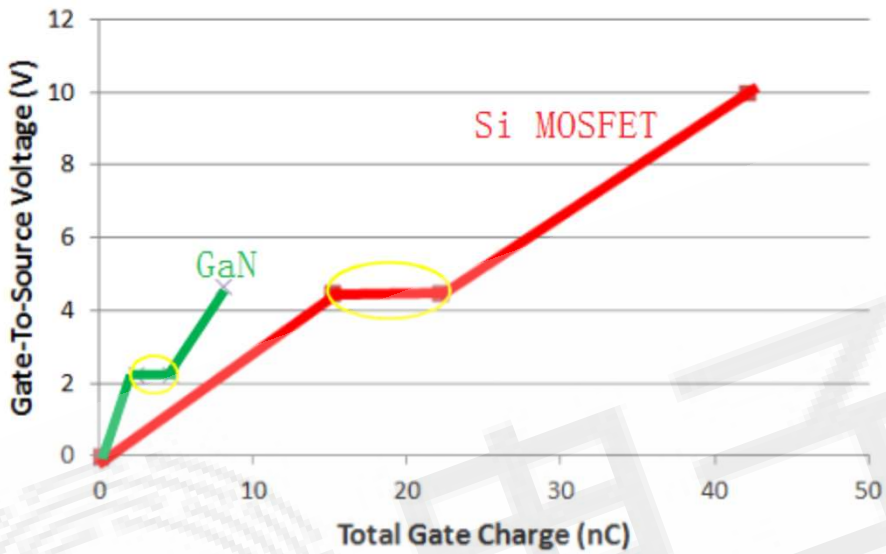


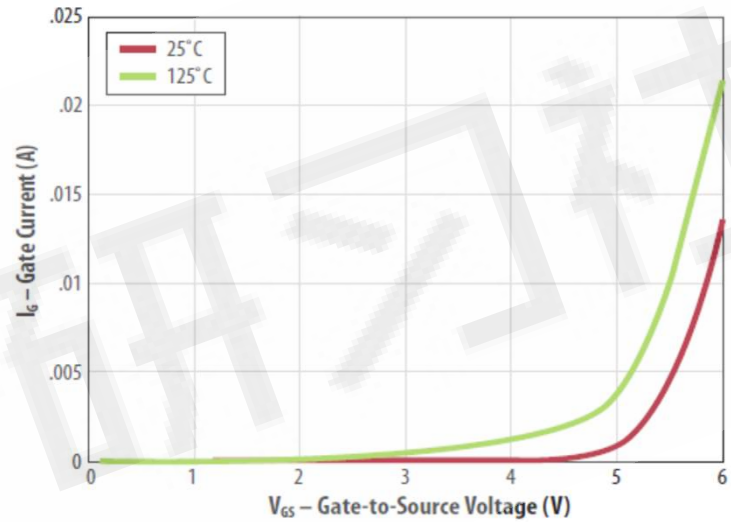






GaN FET Vs Si MOSFET





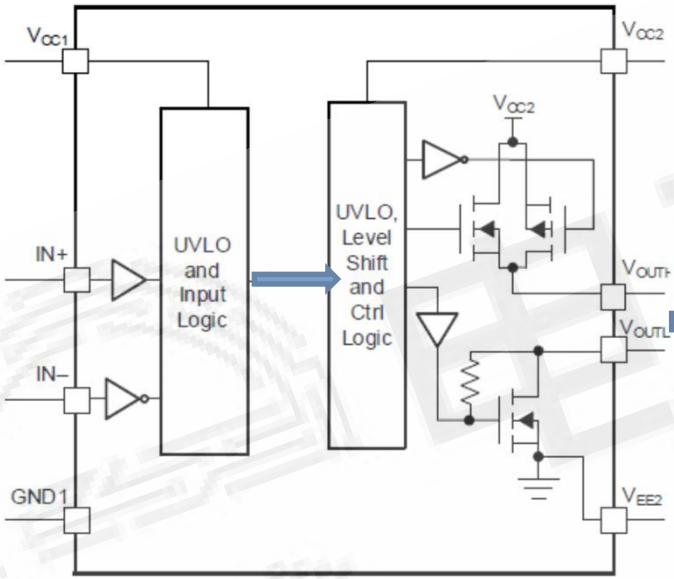
V_{GS}	Gate-to-Source Voltage	6	V
	Gate-to-Source Voltage	-5	

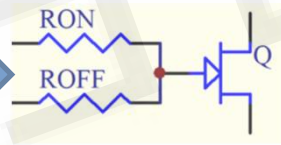
Gate source voltage	V_{GS}	±20	V
Gate source voltage AC (f >1Hz)	V_{GS}	±30	

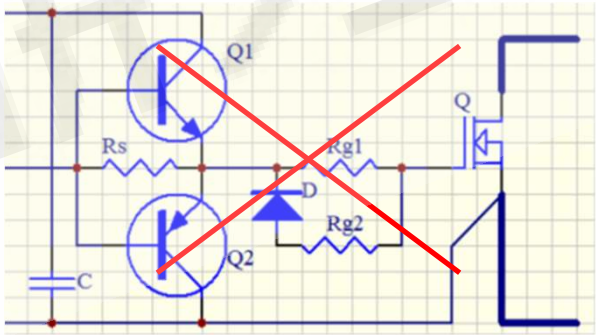
$V_{GS(th)}$	Gate Threshold Voltage	$V_{DS} = V_{GS}$, $I_D = 5$ mA	0.7	1.4	2.5	V

Gate threshold voltage	$V_{GS(th)}$	I_D=500μA, V_{GS}=V_{DS}	3	4	5	V

GaN 驱动实例


VCC1
VCC2
IN+
IN–
GND1
UVLO and Input Logic
UVLO, Level Shift and Ctrl Logic
VCC2
VOUTH
VOUTL
VEE2


RON
ROFF
Q


Q1
Q
Rs
Rg1
D
Rg2
Q2
C

GaN HEMT驱动要点

一、驱动与输入兼容性　　安全与系统收敛性

二、驱动与输出兼容性　　GaN种类；满足**5V稳压输出**。安全与辐射噪音

三、驱动脉冲延迟与保真　分散性与死区设置匹配

四、驱动末级**MOSFET输出**　**ON与OFF输出分离**，独立设置ON/OFF栅驱动电阻

五、驱动热设计　　功率损耗与温升

六、驱动与输入、输出距离与环路退耦

七、驱动与开尔文布线

八、功率电路**Layout**与驱动配合

驱动功率与集成

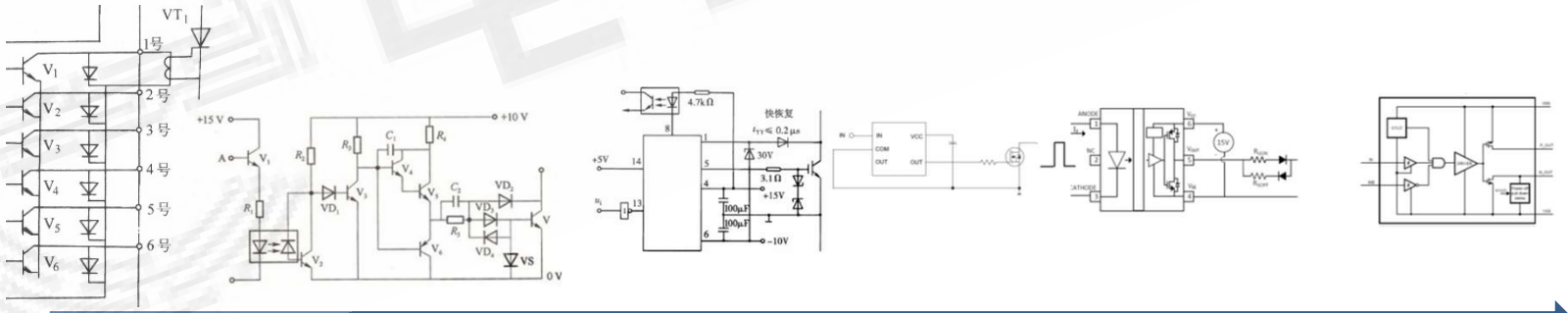
SCR　GTR　IGBT　MOSFET　SiC FET　GaN HEMT

单位功率驱动损耗

大 ——————————————— 小

集成

分立



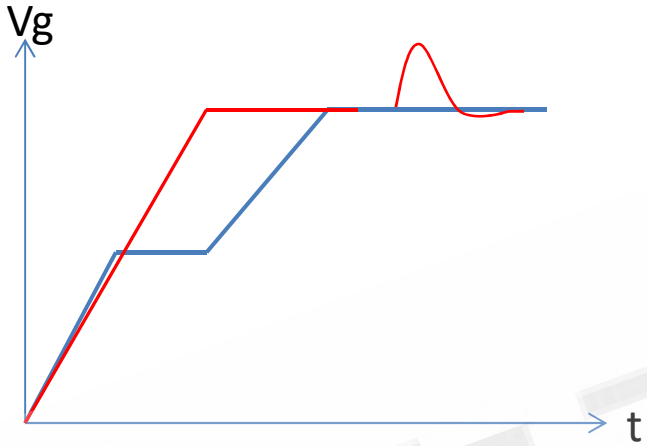
速度 ——————————————— 快

1.2uS　　12nS

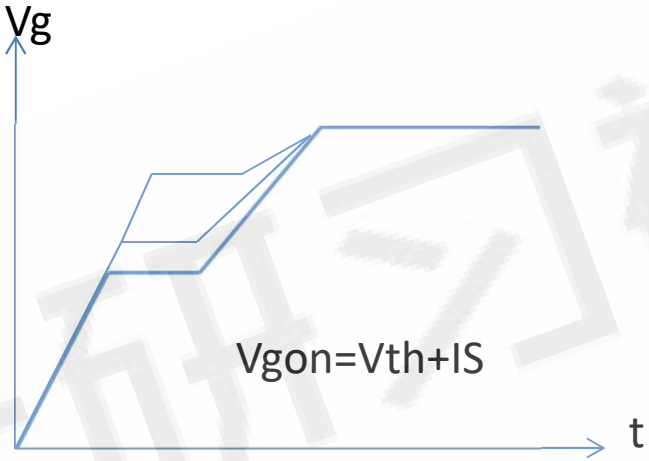
可接受驱动至器件距离 ——————————————— 短

50cm　　2cm

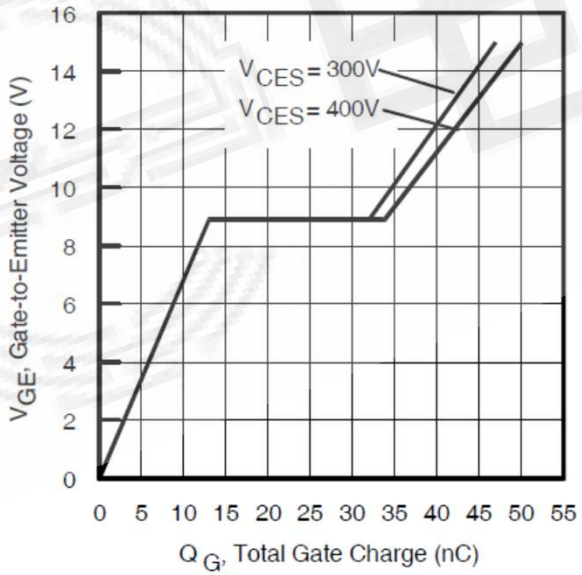
基于云的栅驱动智能化与测量



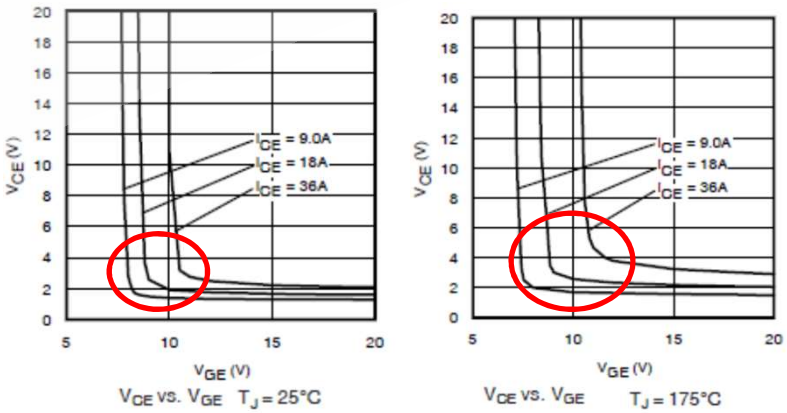
栅极垮导、弥勒效应与短路监测



弥勒平台与电流检测



母线电压检测



Vth直测Tj


谢谢