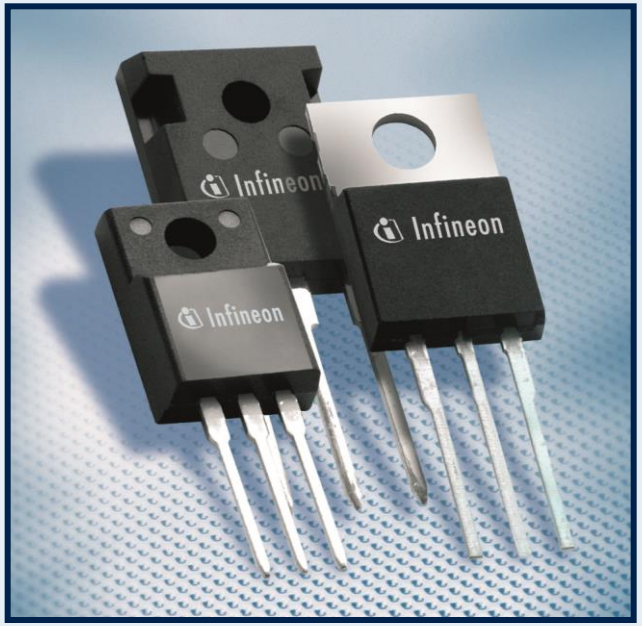
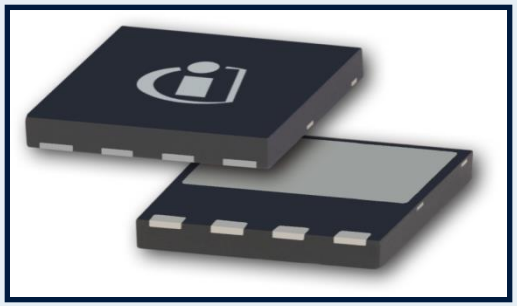
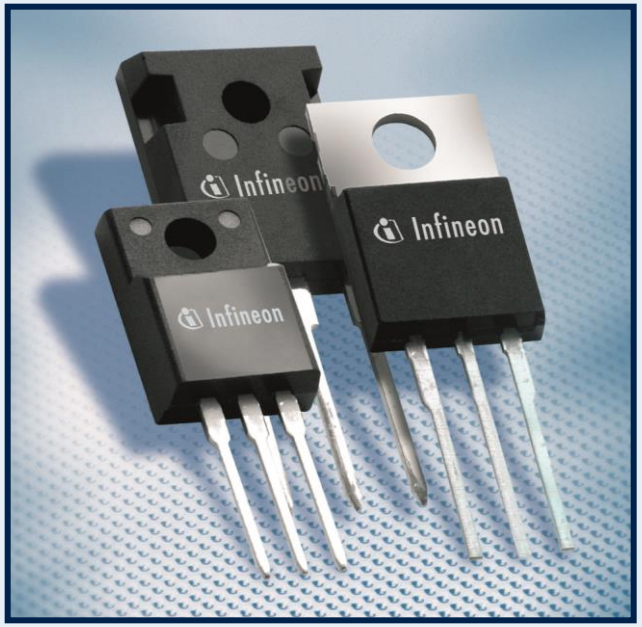




英飞凌功率器件参数解读

2014 中国巡回研讨会

Infineon



英飞凌 MOSFET

如何选择...封装

<u>封装</u>

1. 一般情况

- 功率损耗（P_D）
- 散热（$R_{th(jc)}$/ $R_{th(ja)}$）

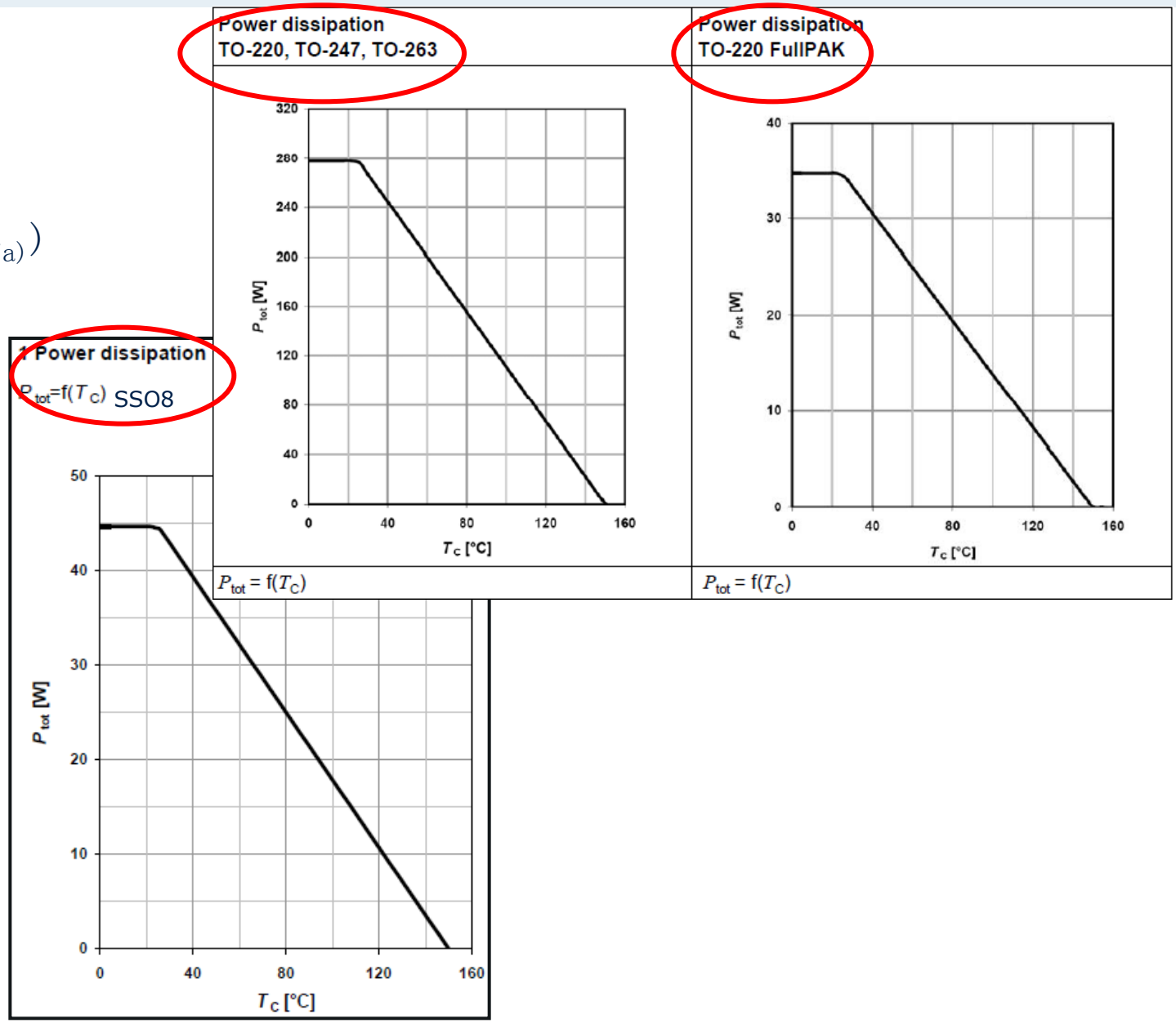
2. 高压MOS

- 爬电距离
- 针对快速开关需要优化PCB

3. 低压MOSFET

- 导通电阻$R_{DS(on)}$和寄生电感L_{stray}
- 空间

$$P_D = \frac{T_{J,\max} - T_C}{R_{th(jc)}}$$



如何定义...击穿电压$V_{BR(DSS)}$

额定电压，VBR(DSS)

- 额定电压的定义前提是指在室温（25°C)条件下. CoolMOS的最大击穿电压都是正温度系数关系.

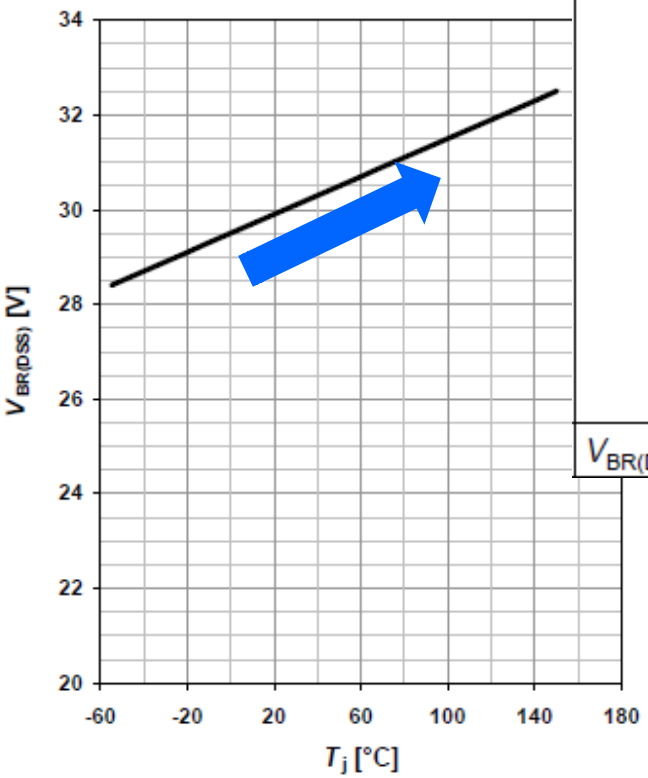
- 选择MOSFET的一个重要原则是根据电压尖峰.

- 一般降额情况下，稳态时关断后的最大电压不能超过额定电压的70% -90%.

15 Drain-source breakdown voltage

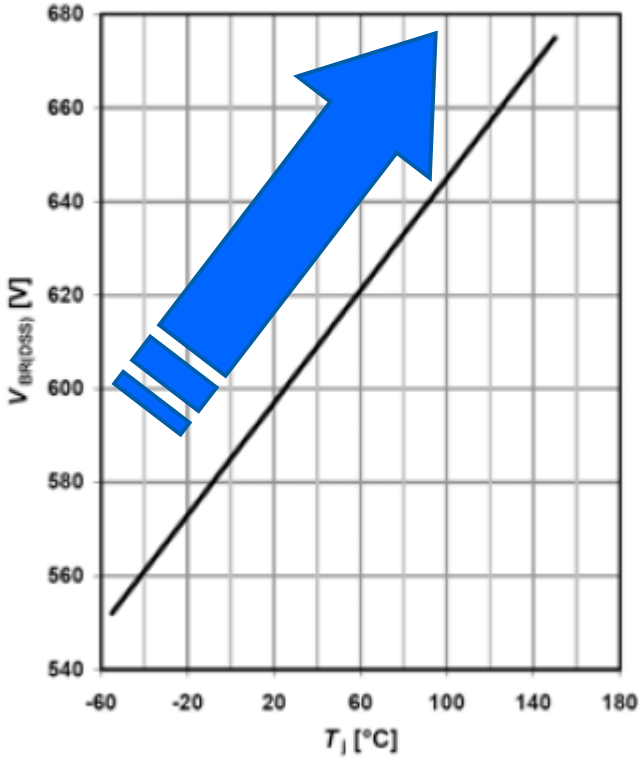
$V_{BR(DSS)}$=f(T_j); I_D=1 mA

BSC057N03MS



Drain-source breakdown voltage

IPX60R099C6



$V_{BR(DSS)}$=f(T_j); I_D=0.25 mA

最大结温

高压CoolMOS

- 最大结温通常是150 度或者需要参考具体器件的规格书.

IPX60R099C6

Operating and storage temperature	T_j, T_{stg}	-55	-	150	°C

低压OptiMOS

- 最大结温通常也是150 度或者需要参照具体器件规格书.

BSC057N03MS

Operating and storage temperature	T_j, T_{stg}		-55 ... 150	°C

碳化硅二极管

- 最大结温是175 度.

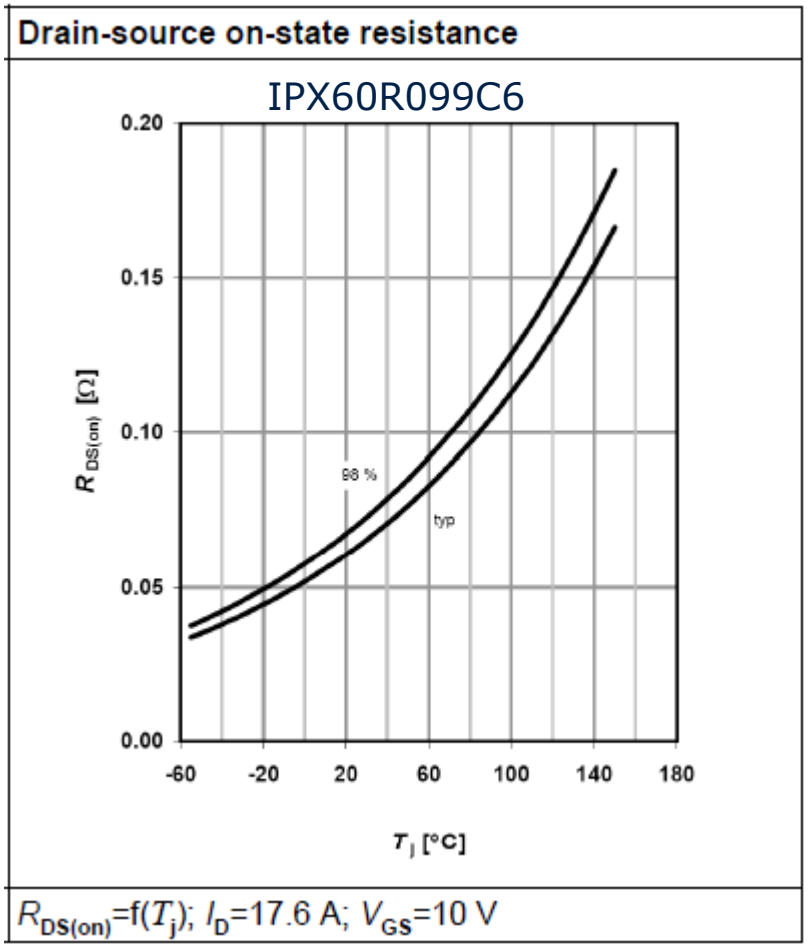
IDH04S60C

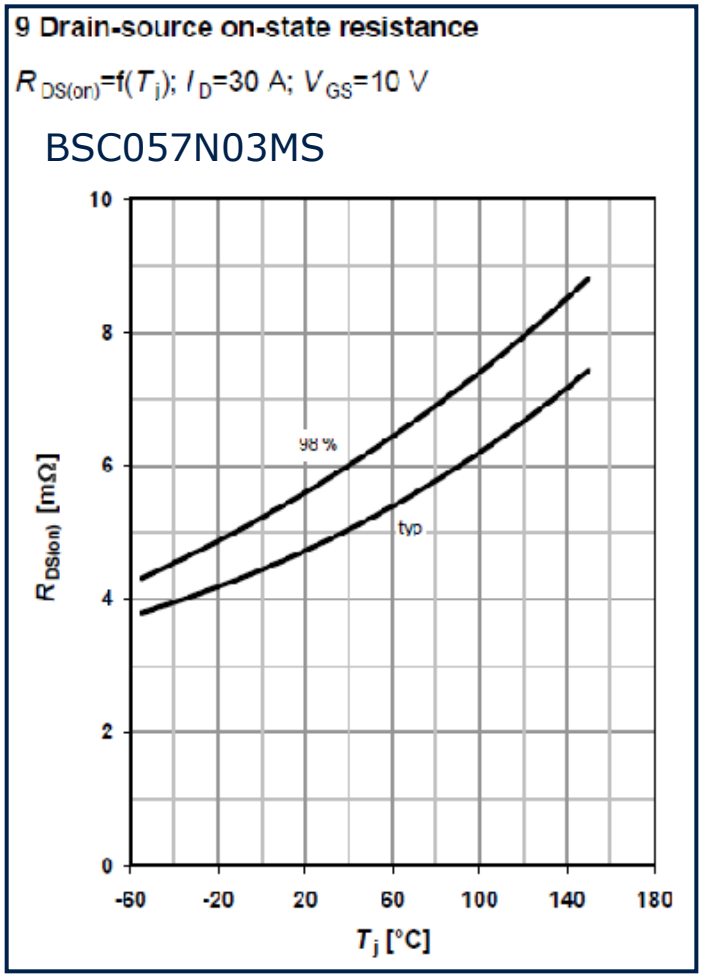
Operating and storage temperature	T_j, T_{stg}		-55 ... 175	°C

在正常使用时,英飞凌推荐70%-90% 的最大结温降额.

MOSFET的导通电阻$R_{DS(on)}$

- MOSFET的导通电阻$R_{DS(on)}$ 随着温度的升高而增加. 这种正温度系数特性有助于MOSFET的并联使用.

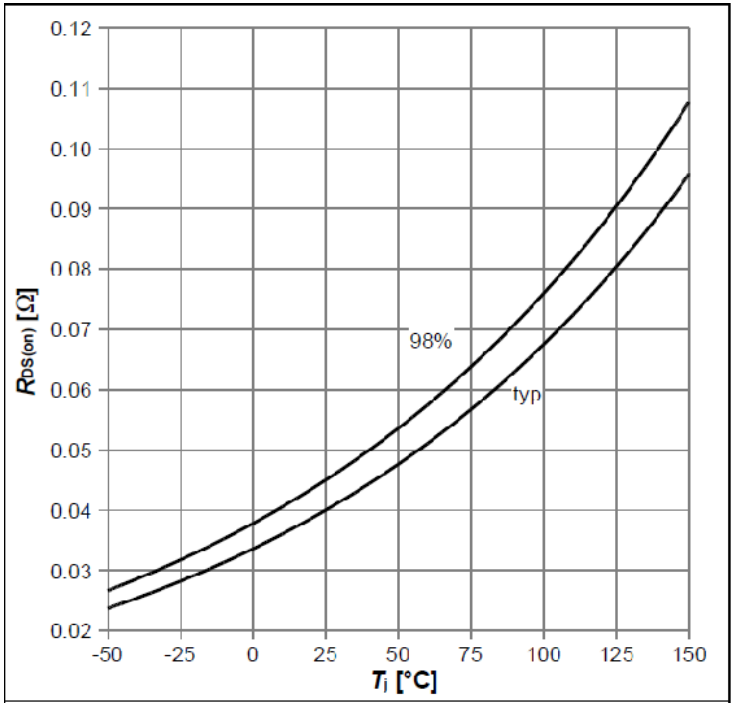




漏极连续电流 Id @ 不同温度情况下

- 对于MOSFET而言，漏极电流都是计算得来，且满足以下条件：
  - R_{dson} 在 150度的时候
  - R_{thJC}（热阻要事先给出）
  - $T_{j\ max}$（不能超过最大结温）
  - T_c（壳温为已知）

IPW65R045C7

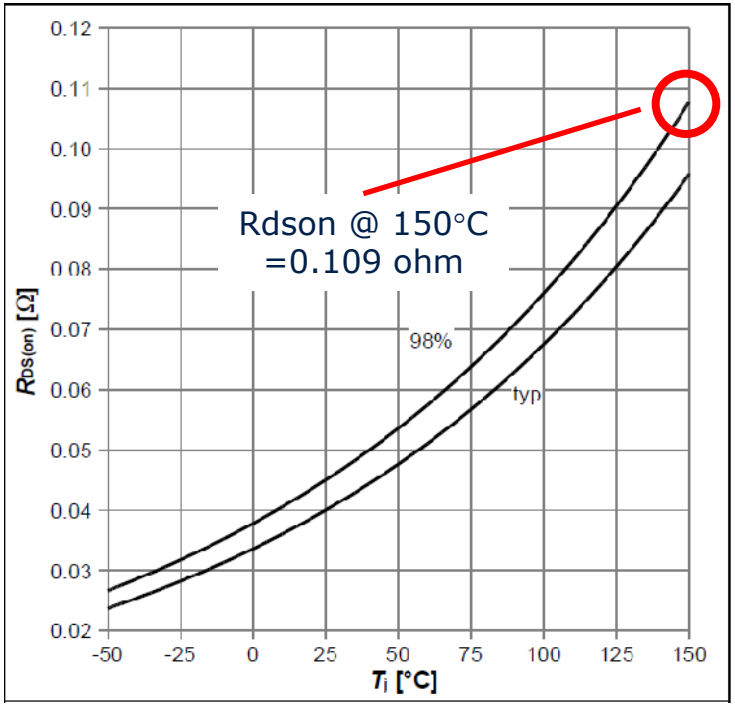


Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Continuous drain current [1]	I_D	- -	- -	46 29	A	T_C=25°C T_C=100°C
Operating junction temperature	T_j	-55	-	150	°C	-
Thermal resistance, junction - case	R_{thJC}	-	-	0.55	°C/W	-

漏极连续电流 I_d 的计算

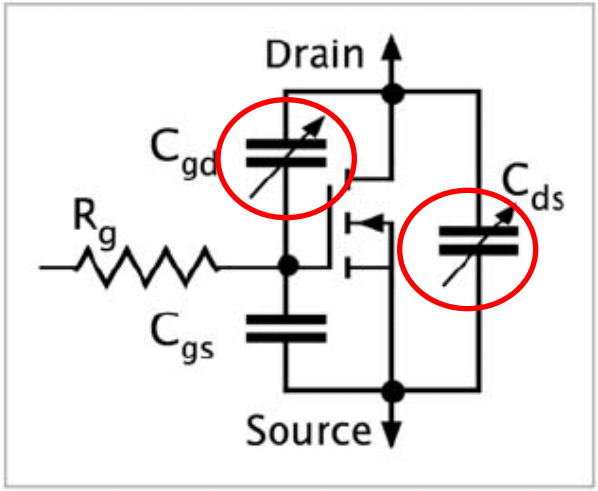
- T_c =25°C
  - $P_D = (T_{j\,max} - T_c)/ R_{thJC}$
  - P_D = (150-25)/0.55=227W
  - $I_d = \sqrt{(227/0.109)}$=45.6A
- Tc =100°C
  - P_D = (150-100)/0.55=91W
  - $I_d = \sqrt{(91/0.109)}$=28.9A
- 说明: 有时规格书中 I_d 的值要小于实际计算得到的值,这是由于封装金属连接线的有电流限制.正是由于这个原因,有些低压MOS的I_d 25°C 与 100°C 相等(比如 BSC016N06NS).

IPW65R045C7



Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Continuous drain current [1]	I_D	- -	- -	46 29	A	T_C=25°C T_C=100°C
Operating junction temperature	T_j	-55	-	150	°C	-
Thermal resistance, junction - case	R_{thJC}	-	-	0.55	°C/W	-

MOSFET的电容....(1)



Ciss = Cgs + Cgd, Crss = Cgd, and Coss = Cds + Cgd.

Q = C X V

能量 = 0.5 X Q X V

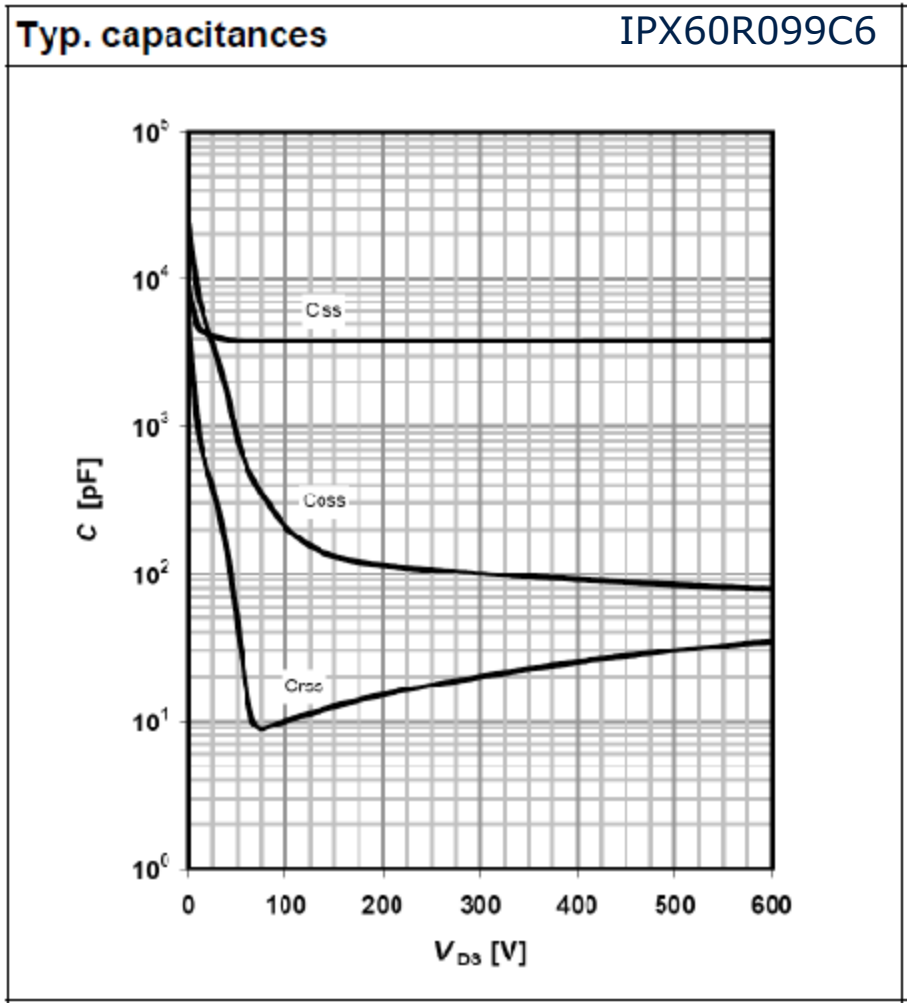
功率 = 能量 X 开关频率

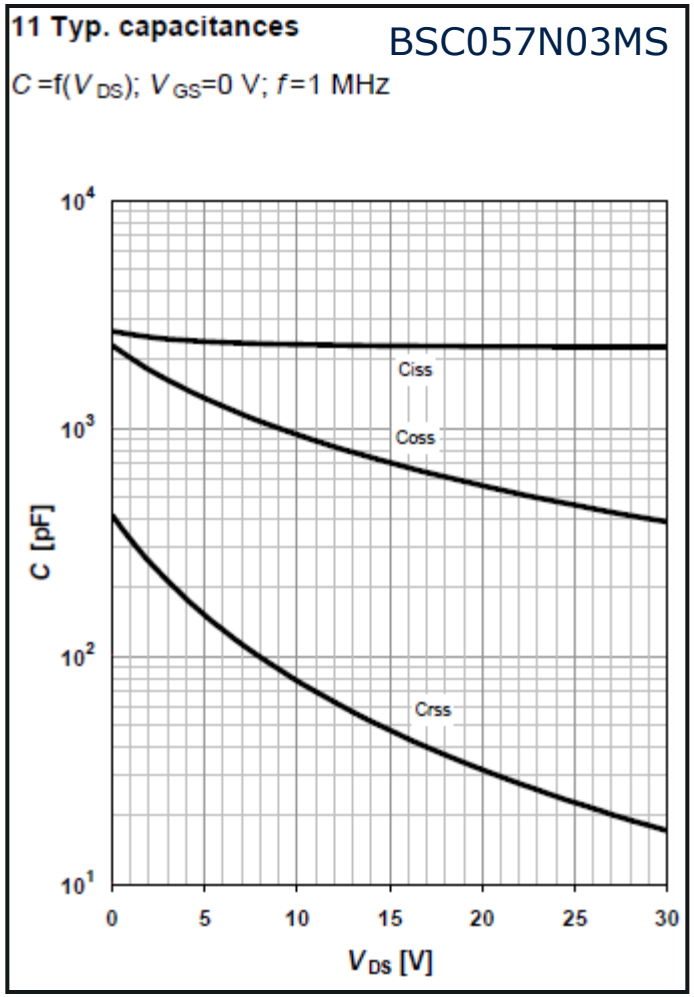
Parameter BSC057N03MS	Symbol	Conditions	Values			Unit
			min.	typ.	max.	
Input capacitance	C_{iss}	V_{GS}=0 V, V_{DS}=15 V, f=1 MHz	-	2300	3100	pF
Output capacitance	C_{oss}		-	710	940	
Reverse transfer capacitance	C_{rss}		-	47	-	

Parameter IPX60R099C6	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Gate to source charge	Q_{gs}	-	20	-	nC	V_{DD}=480 V, I_D=26.3 A, V_{GS}=0 to 10 V
Gate to drain charge	Q_{gd}	-	85	-		
Gate charge total	Q_g	-	170	-		
Gate plateau voltage	$V_{plateau}$	-	5.5	-	V	

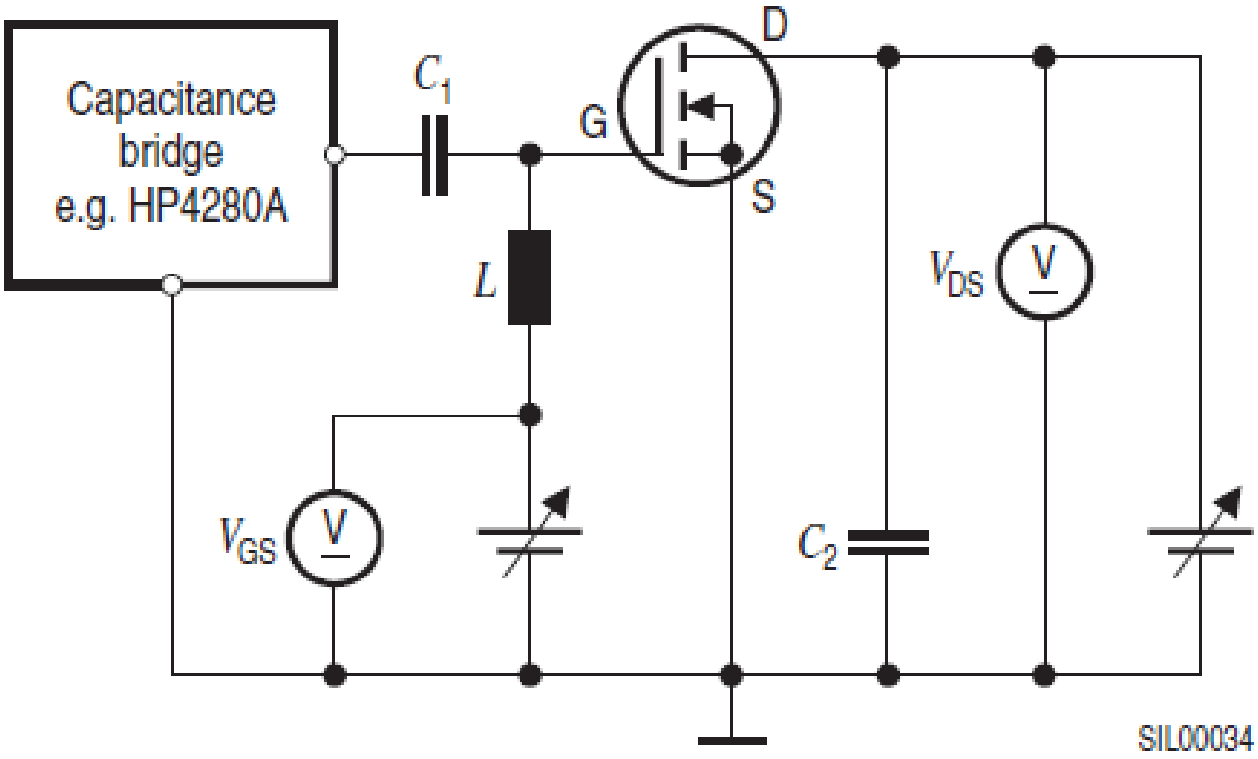
MOSFET的电容....(2)

- C_{rss} 和 C_{oss} 跟随V_{Ds} 的变化而变化



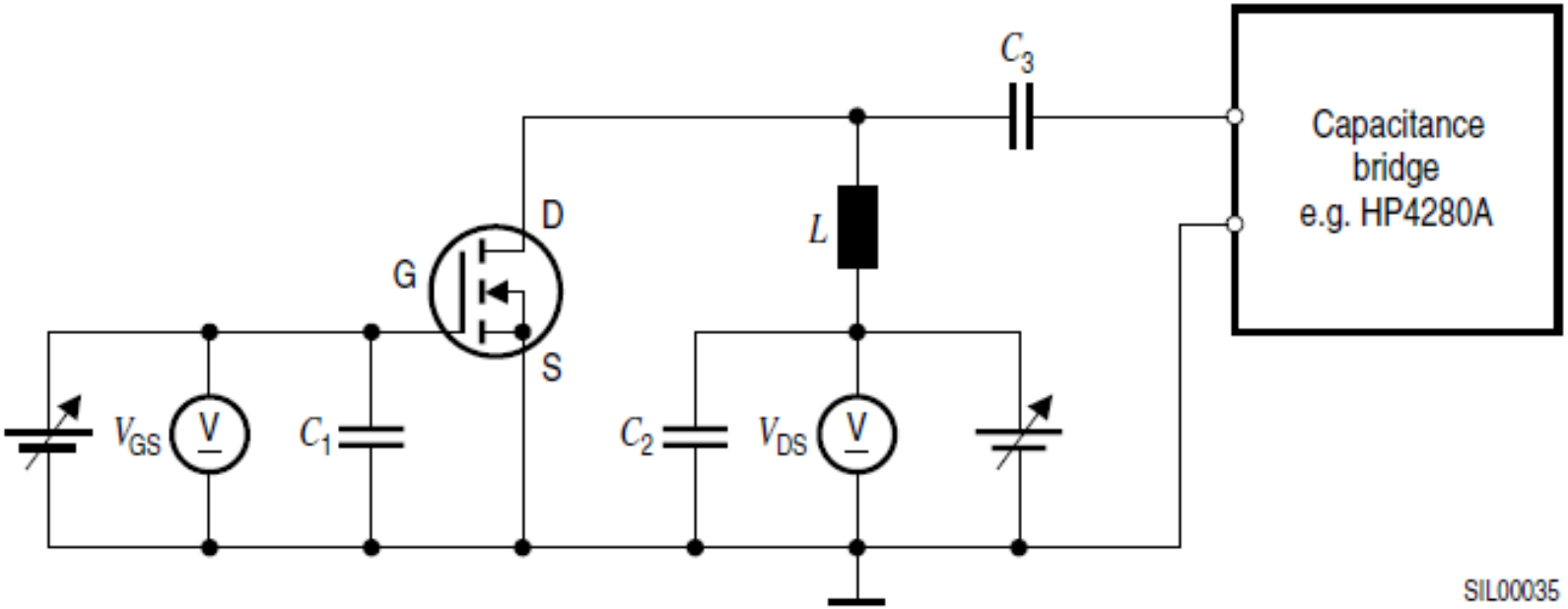


C_{iss} 测量



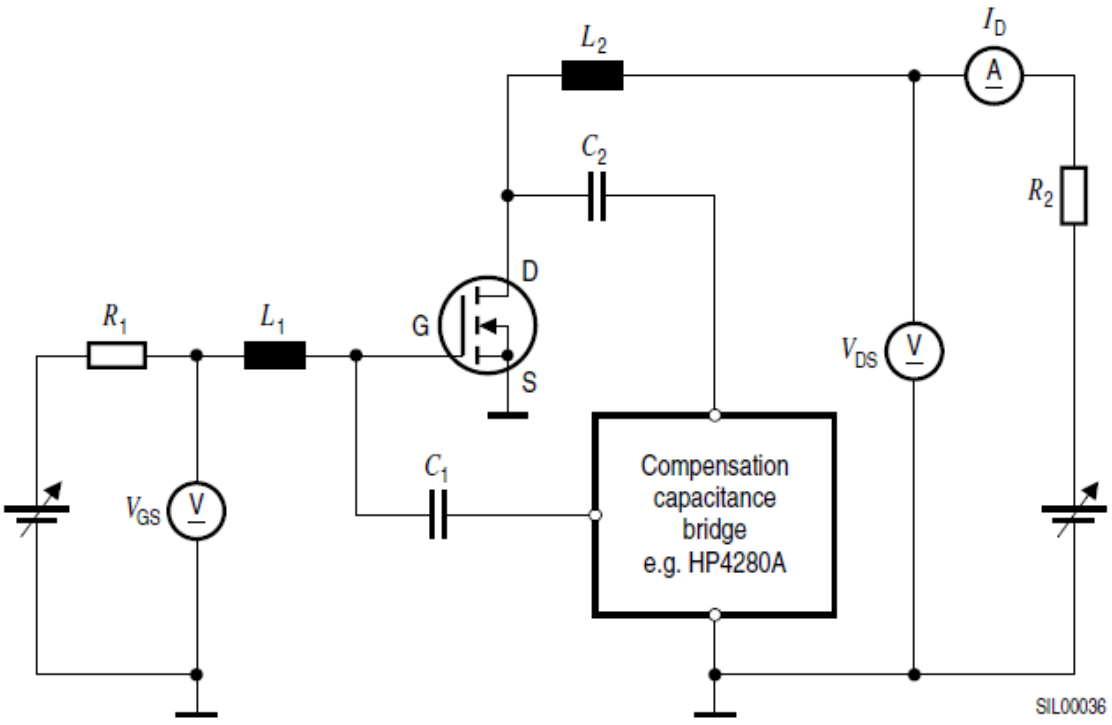
- 电容 C_1 和 C_2 必须在测试频率下可以达到瞬间短路的效果.
- 电感 L 作为电流的解藕使用.

C_{oss} 测试



- 电容 C_1 和 C_2 必须在测试频率下可以达到瞬间短路的效果.
- 电感 L 作为电流的解藕使用.

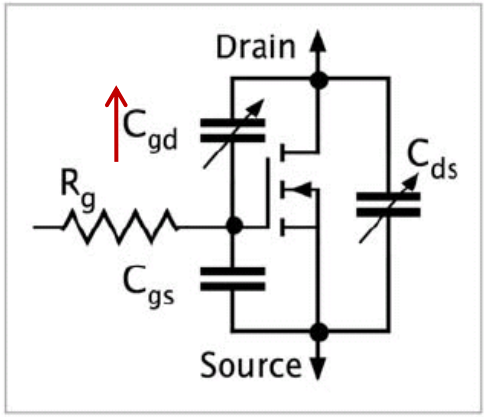
C_{rss} 测试

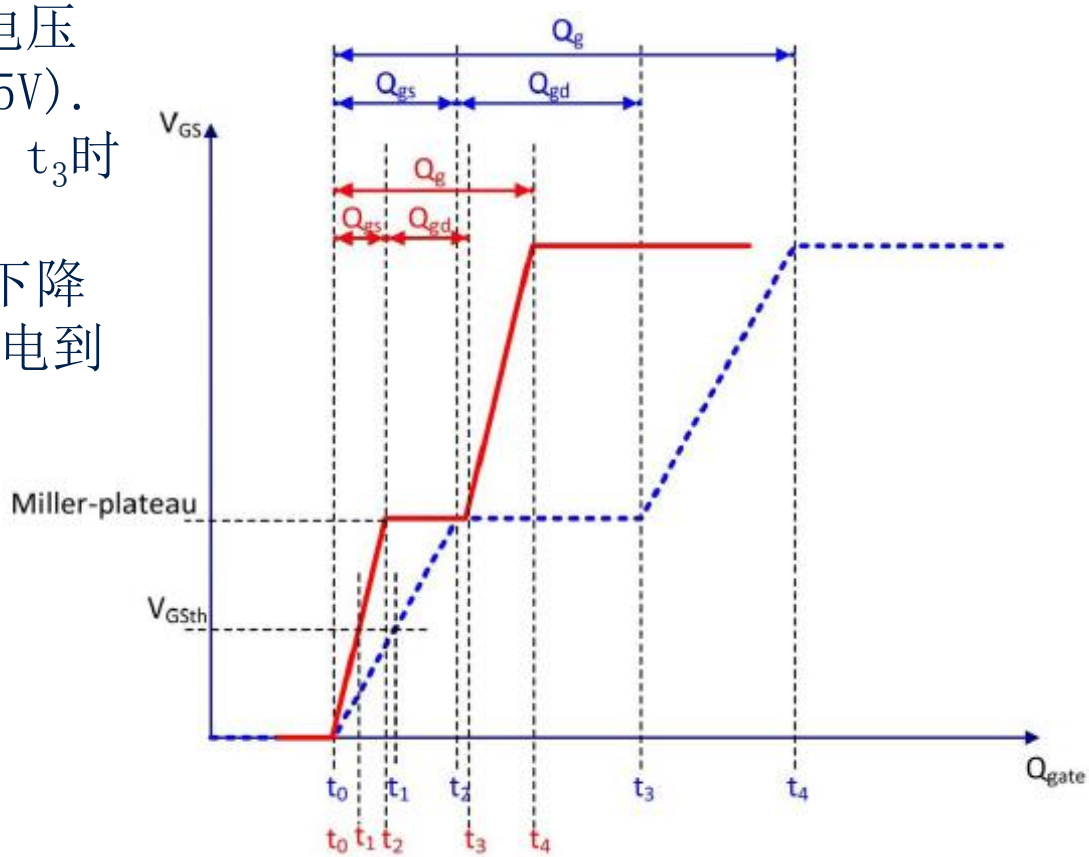


- 电容 C_1 和 C_2 必须在测试频率下可以达到瞬间短路的效果.
- 电感 L 作为电流的解藕使用.

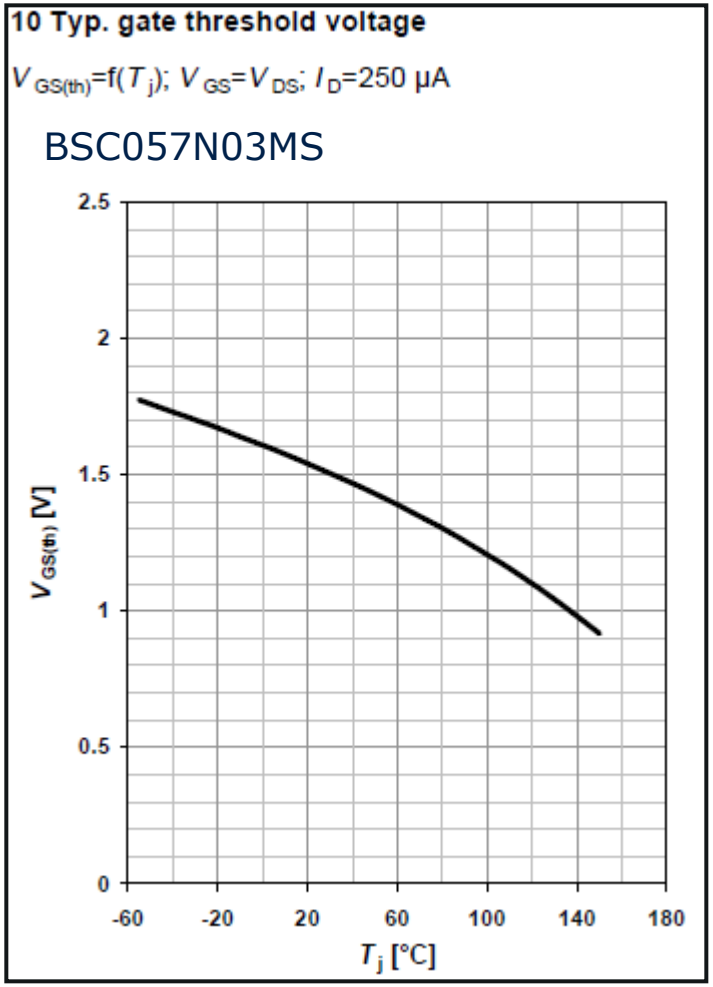
MOSFET开通

1. 密勒平台的长度取决于内部的 C_{gd}大小.
2. t_0-t_2 时间段内门极驱动的电流用来给C_{gs} 充电和 C_{gd}. 放电.
3. 在t_2 以后MOSFET开通, V_{DS} 开始下降, 直到 0V.
4. t_2 到 t_3间, V_{DS} 开始下降时段内, 同时C_{gd} 放电直至其电压等于V_{gs}.
5. 在此期间, 因为 C_{gd} 被从高电压(395V)放电到较低的负压(-5V). 所以C_{gs}上电压保持不变直到 t_3时刻.
6. t_3 到 t_4 时间段内V_{DS} 已经下降到零, 驱动电流继续给C_{gs} 充电到其最大值.





门槛电压$V_{GS(th)}$



1. $V_{GS(th)}$ 是MOSFET开通和关断的开始时刻电值.

2. 一般来说，$V_{GS(th)}$ 会随着温度的升高而降低.

3. 应该小心使用MOSFET的这个特性. 低压MOSFET的开通和关断更容易被触发.

稳态热阻 R_{thJC} & R_{thJA}

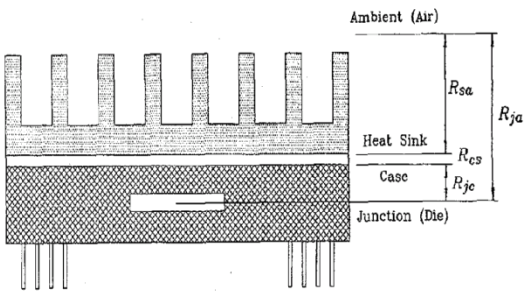
Table 3 Thermal characteristics TO-220 (IPP60R099C6)

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Thermal resistance, junction - case	R_{thJC}	-	-	0.45	°C/W	
Thermal resistance, junction - ambient	R_{thJA}	-	-	62		leaded
Soldering temperature, wavesoldering only allowed at leads	T_{sold}	-	-	260	°C	1.6 mm (0.063 in.) from case for 10 s

- 事實上，在系统设计R_{thJC} 並不是主要的考虑因素.
- 系统散热性能主要是受R_{thJA}限制：

  $R_{thJA}=R_{thJC}+R_{thCS}+R_{thSA}\approx 20K/W \sim 40K/W$

  显而易见： $R_{thJA} >> R_{thJC}$
- 温升：$\triangle T = P_{loss} * R_{thJA}$



在设计考虑上应该更集中在如何降低R_{thJA}！

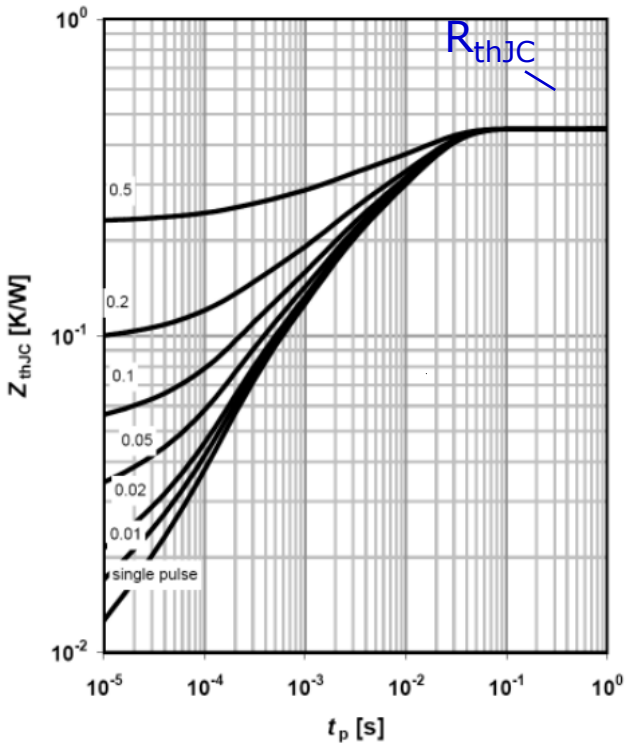
瞬态热阻 Z_{thJC}

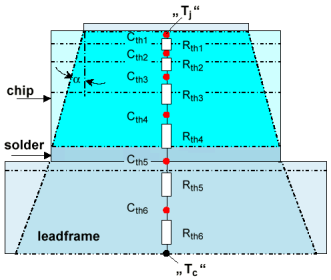
4 Max. transient thermal impedance

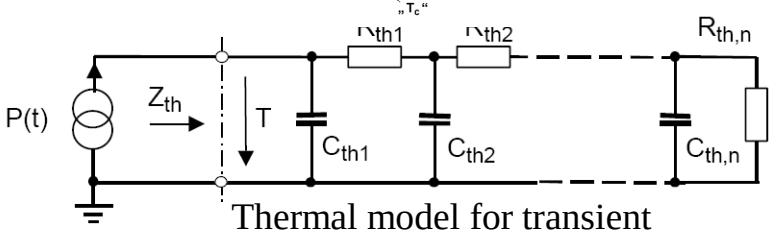
$Z_{thJC}=f(t_p)$

parameter: $D=t_p/T$

IPP60R099C6



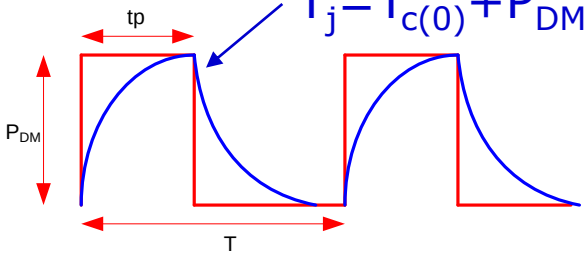




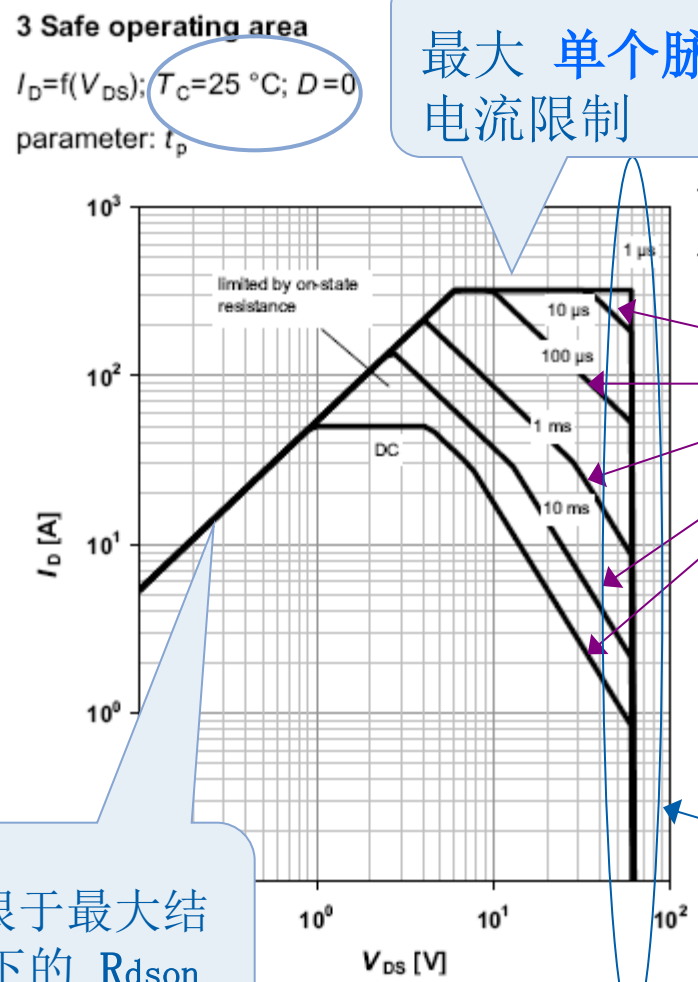
Thermal model for transient

- 用 Z_{thJC} 去計算瞬态的結溫溫度Tj
- 當tp過長的時候, Z_{thJC} 會轉變為 R_{thJC}
- 計算可以直接應用在損耗为方波的情况

$T_j=T_{c(0)}+P_{DM}*Z_{thJC(tp,D)}$



如何使用安全工作区 SOA ？



最大 单个脉冲电流限制

Pulsed drain current	$I_{D,pulse}$	T_C=25 °C[2)]	320

功率限制，器件最大耗散的功率

击穿电压

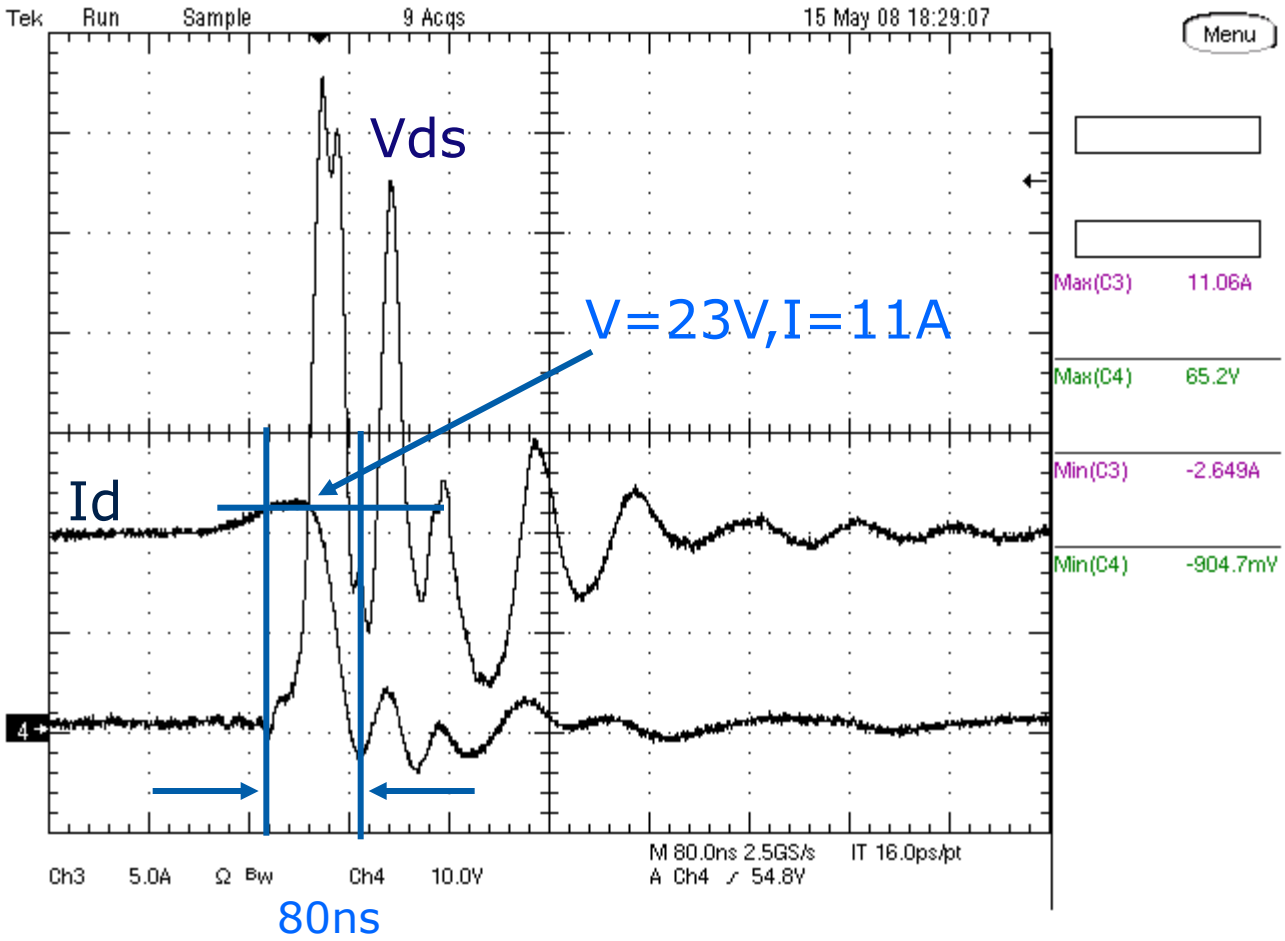
Drain-source breakdown voltage	$V_{(BR)DSS}$	V_{GS}=0 V, I_D=1 mA	60	-	-	V

受限于最大结温下的 Rdson

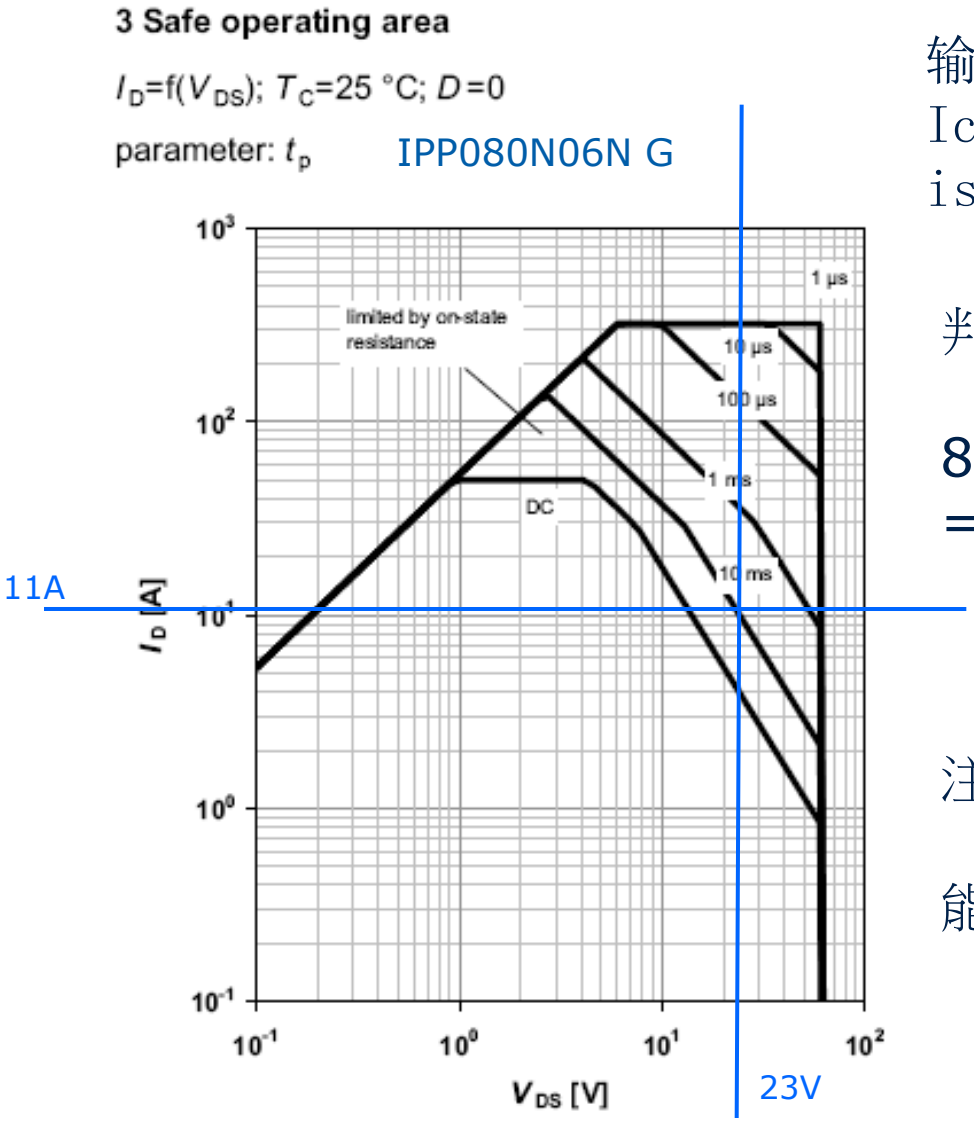
*SOA of IPP080N06N G

案例：输出短路情况

IPP080N06N G



安全工作区域SOA



输出短路波形:
Icross=11A, Vcross=23V, tp=80ns is 在SOA之内

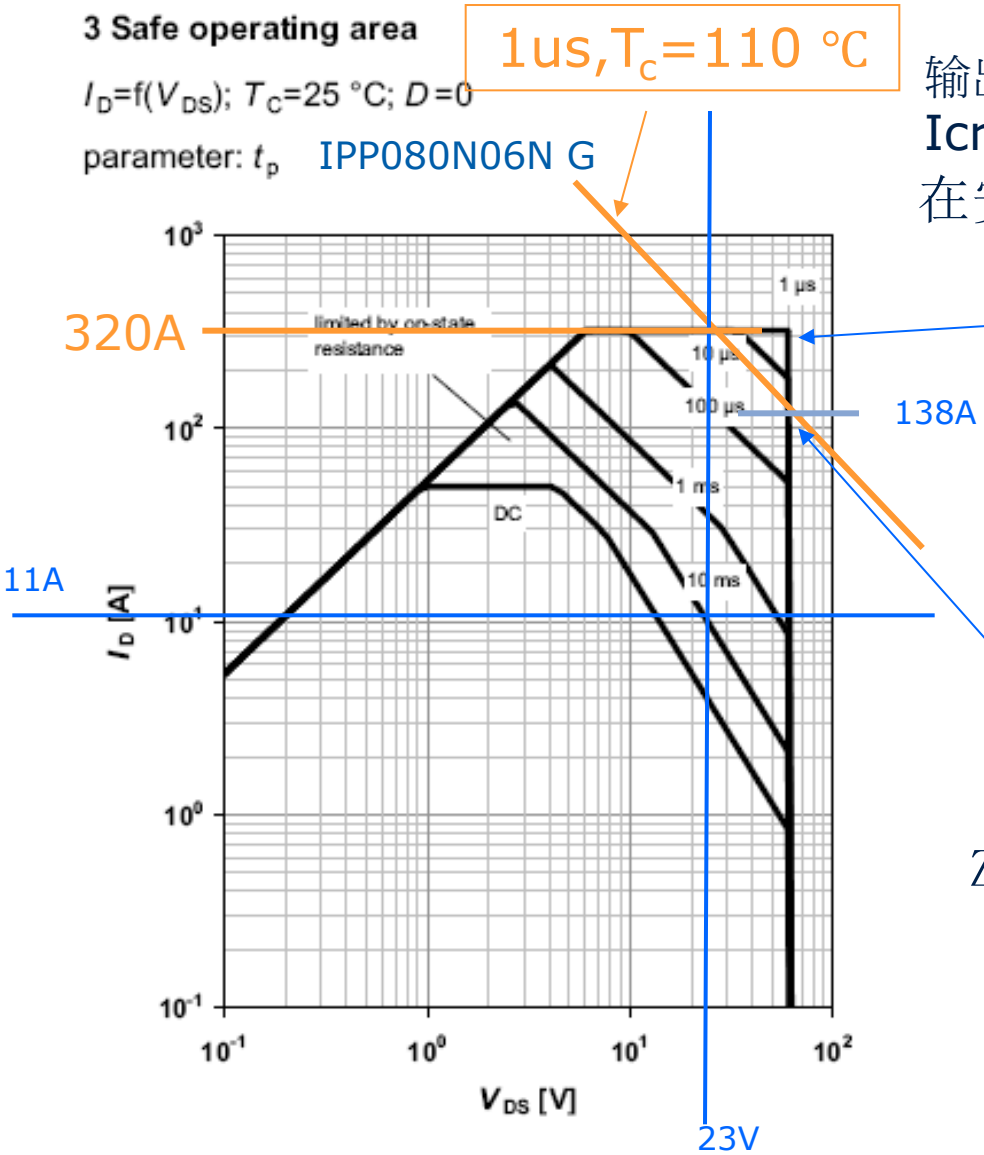
判断如下:

80ns/1us*(11A/320A)*ESOA =0.003* ESOA

注意:

能量 = 功率 X 时间
= 电压 X 电流 X 时间

如何把25 °C的SOA转变成110 °C的SOA



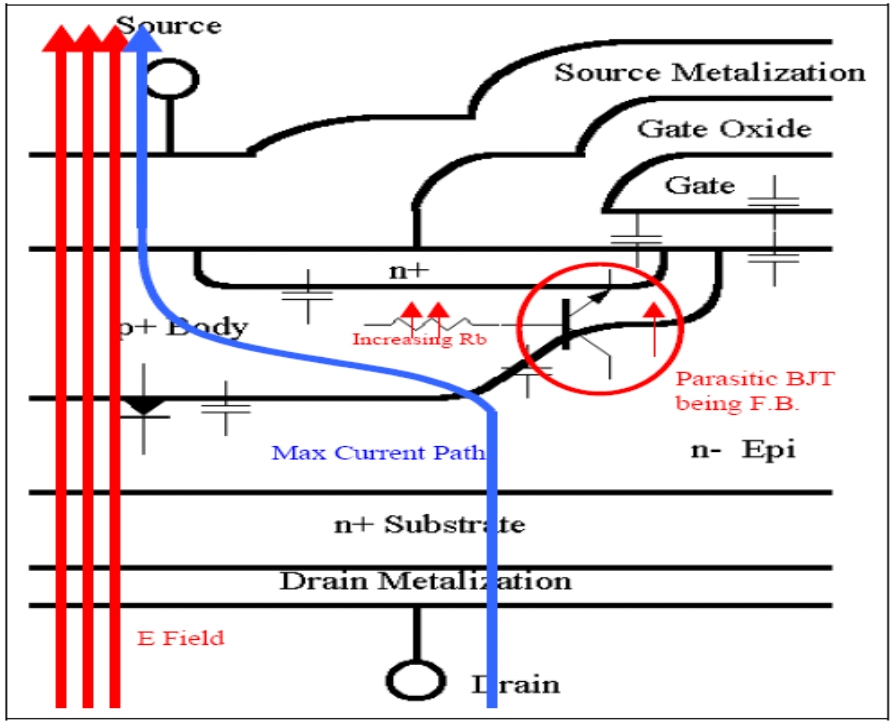
输出波形:
Icross=11A/80nS ,Vcross=23V
在安全工作区域 SOA之内

P_d=V*I=60V*320A=19200
P_d@T_c=25 °C
=(T_{j_max}-25)/$Z_{th(jc)}$
=(175-25)/$Z_{th(jc)}$=19200
可得到 $Z_{th(jc)}$=0.0078
P_d@T_c=110 °C
=(175-110)/0.0078=8333
I_d=P_d/V=8333/60=138

$Z_{th(jc)}$ =瞬态热阻

什么是雪崩击穿?...(1)

传统的 MOSFET 横截面图



1. 一个寄生的 NPN双极晶体管结构.
2. 在正常工作情况下,基极和发射极之间通过铝金属层短路到MOSFET的源极.
3. 因为侧向P-Well有个寄生电阻会导致雪崩更易发生.
4. 如果雪崩时足够大的电流流过内部寄生的双极晶体管的基极和发射极之间,会触发此双极晶体管的导通.

功率 MOSFET的雪崩能力是指:

- 不超过最大临界电流,
- 不超过最大结温.

如何定义雪崩特性? 雪崩能力

重复性
能量限制

能量损坏,
主要体现在过热的情况

IPX60R099C6

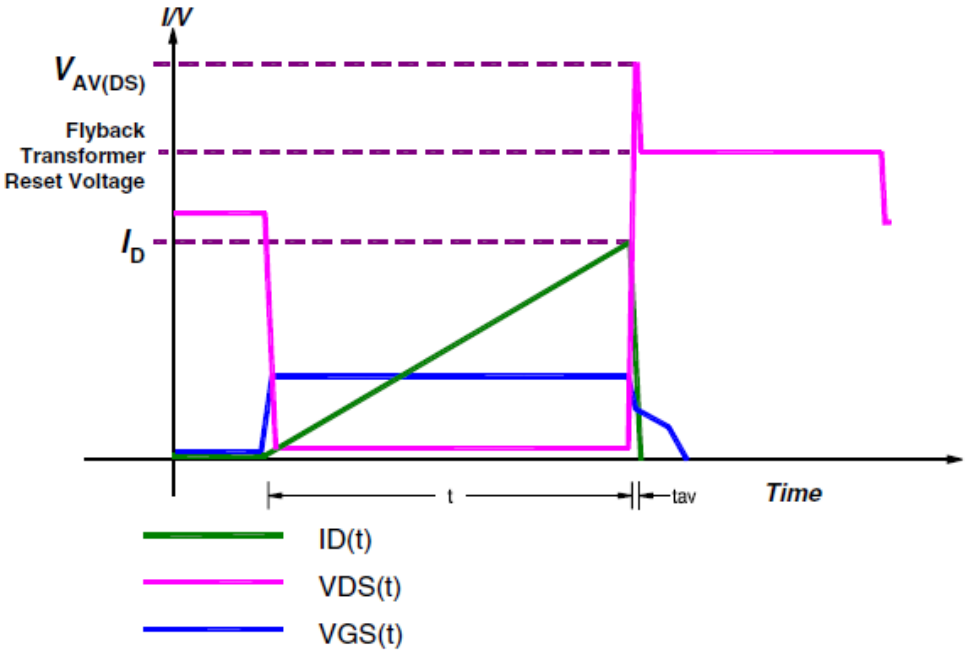
2 Maximum ratings

at T_j = 25 °C, unless otherwise specified.

Avalanche energy, single pulse	E_{AS}	-	-	1160	mJ	I_D=9.3 A, V_{DD}=50 V
Avalanche energy, repetitive	E_{AR}	-	-	1.76		I_D=9.3 A, V_{DD}=50 V

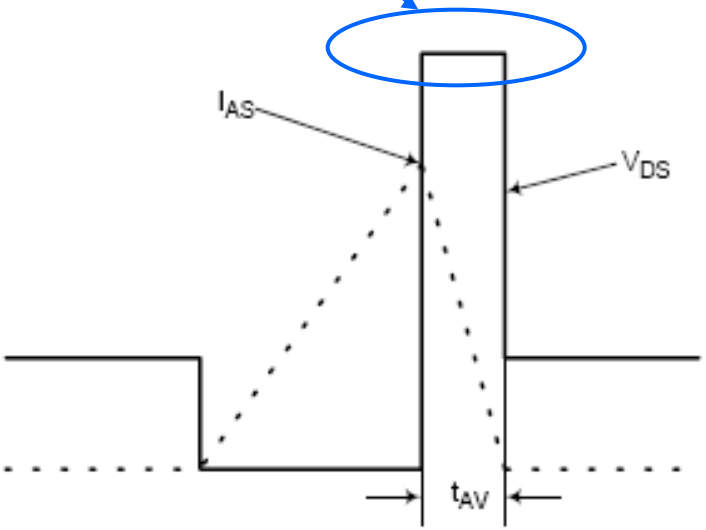
这个电流最大值定义是在MOSFET工作在雪崩状态但BJT没有锁死的情况下得到的.
所有雪崩情况（单个或者重复脉冲）都应该在这个值这下以确保器件能安全工作.

如何通过测试波形判断是否雪崩



反激变换器中典型的雪崩情况

Vds钳位



单脉冲的雪崩能量

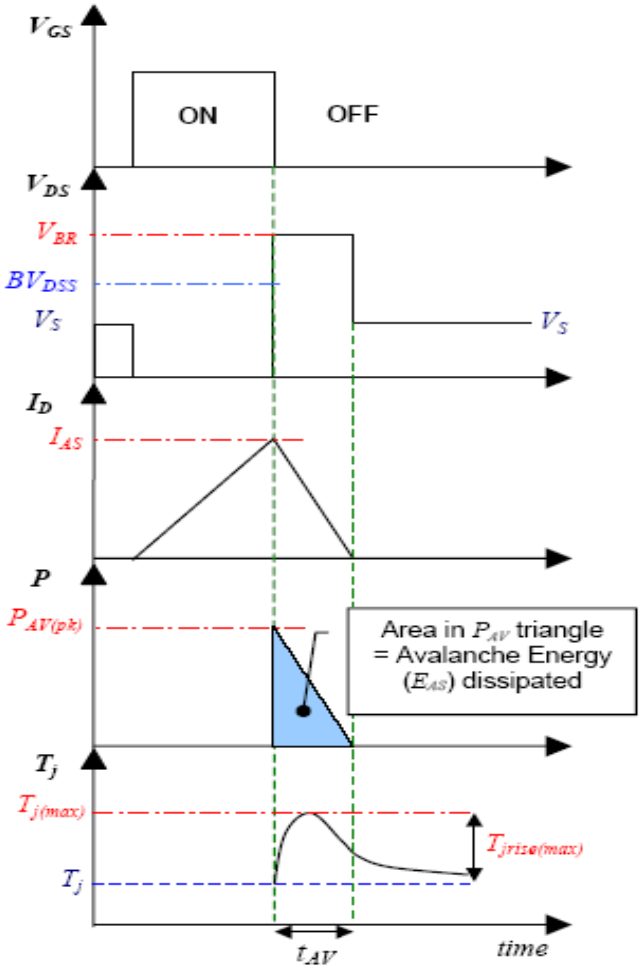
- **单个** 脉冲雪崩能量

$$E_{AS} = \frac{1}{2} V_{BR} \bullet I_{AS} \bullet t_{AV}$$

$$= \frac{1}{2} L \bullet I_{AS}^{2} \bullet \frac{V_{BR}}{V_{BR} - V_S}$$

$$V_{BR} \approx 1.3 \times BV_{DSS}$$

L：磁性元件提供雪崩能量



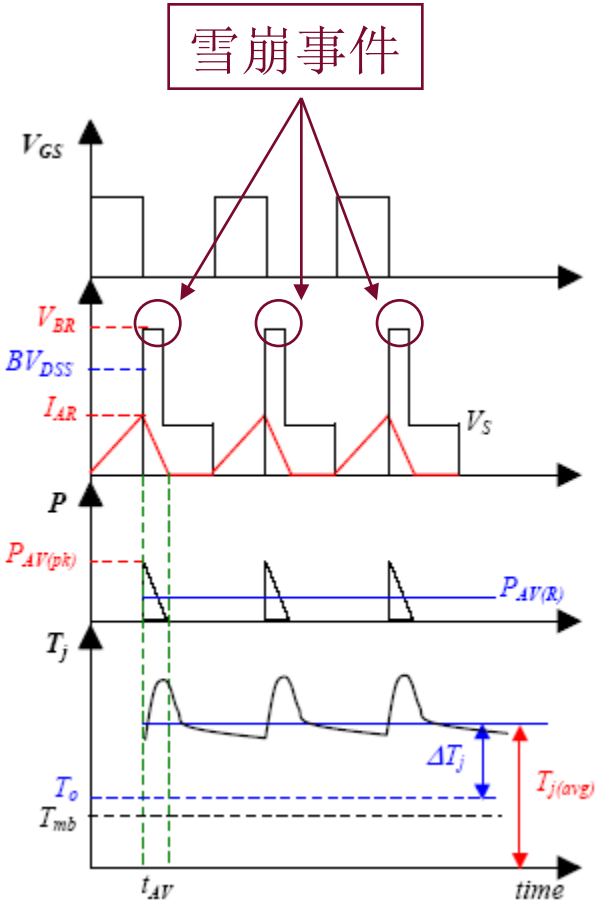
IPX60R099C6

Avalanche energy, single pulse	E_{AS}	-	-	1160	mJ	I_D=9.3 A, V_{DD}=50 V

重复脉冲情况下的雪崩能量

- **重复** 雪崩

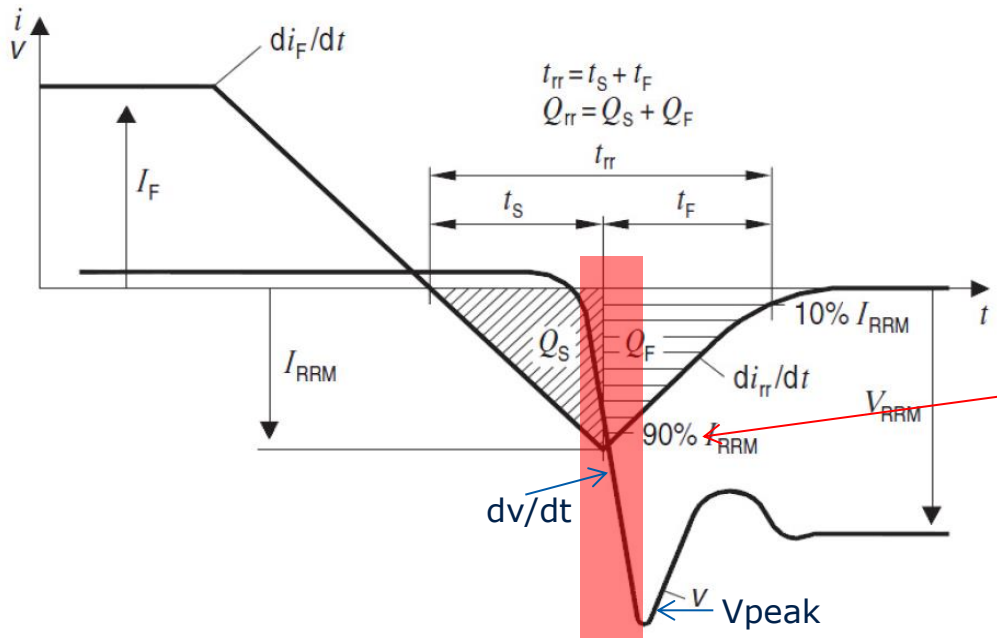
$$E_{AR} = \frac{1}{2} \bullet V_{BR} \bullet I_{AR} \bullet t_{AV}$$



IPX60R099C6

Avalanche energy, repetitive	E_{AR}	-	-	1.76		I_D=9.3 A, V_{DD}=50 V

寄生二极管的反向恢复的特性



反向恢复状态

主要關注的焦点

- di/dt 速度
- dv/dt 速度
- Vds 过冲电压

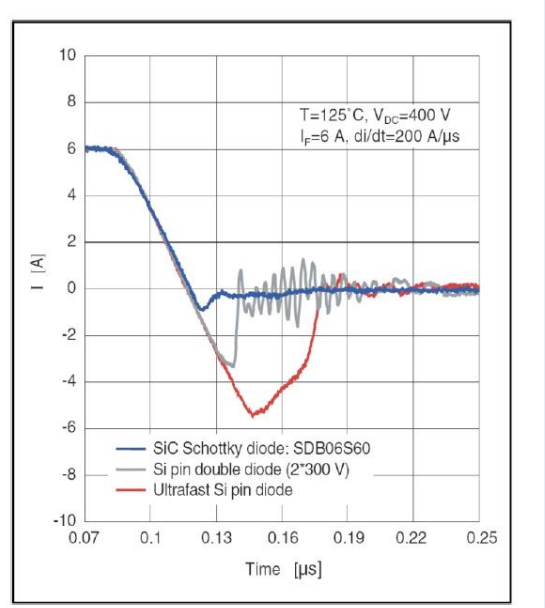
IPW60R190P6

Reverse diode dv/dt[3)]	dv/dt	-	-	15	V/ns	V_{DS}=0...400 V, $I_{SD} \leq I_D$, T_j=25 °C (see table 22)
Maximum diode commutation speed[3)]	di_f/dt			300	A/µs	

Diode forward voltage	V_{SD}	-	0.9	-	V	V_{GS}=0 V, I_F=18.1 A, T_j=25 °C
Reverse recovery time	t_{rr}	-	580	-	ns	V_R=400 V, I_F=18.1 A, di_F/dt=100 A/µs (see table 22)
Reverse recovery charge	Q_{rr}	-	13	-	µC	
Peak reverse recovery current	I_{rrm}	-	43	-	A	

Solar
Lighting
UPS
Server
Telecom
PC Power

英飞凌碳化硅二极管


T=125°C, V_{DC}=400 V
I_F=6 A, di/dt=200 A/µs
SiC Schottky diode: SDB06S60
Si pin double diode (2*300 V)
Ultrafast Si pin diode
I [A]
Time [µs]
10
8
6
4
2
0
-2
-4
-6
-8
-10
0.07
0.1
0.13
0.16
0.19
0.22
0.25

持续正向电流：I_F

- 以 IDH06SG60C为例

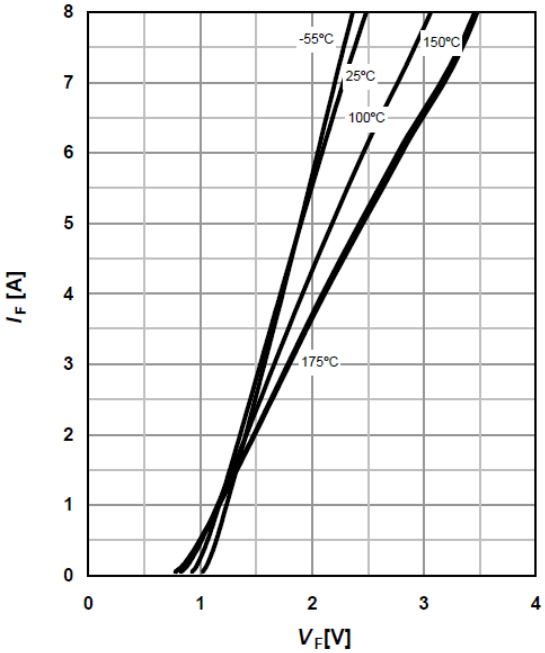
Maximum ratings

Parameter	Symbol	Conditions	Value	Unit
Continuous forward current	I_F	T_C<130 °C	6	A

- 二极管正向导通压降，V_F = 2.3V（最大值 @ T_j=25°C）
- 二极管正向导通压降，V_F = 2.8V（典型值 @ T_j=150°C）
  - V_F 正向温度系数特性使得 碳化硅二极管容易并联使用.
- 最大允许的结温，T_{JMax}=175°C
- R_{thJC}=2.1k/W
- 功耗：

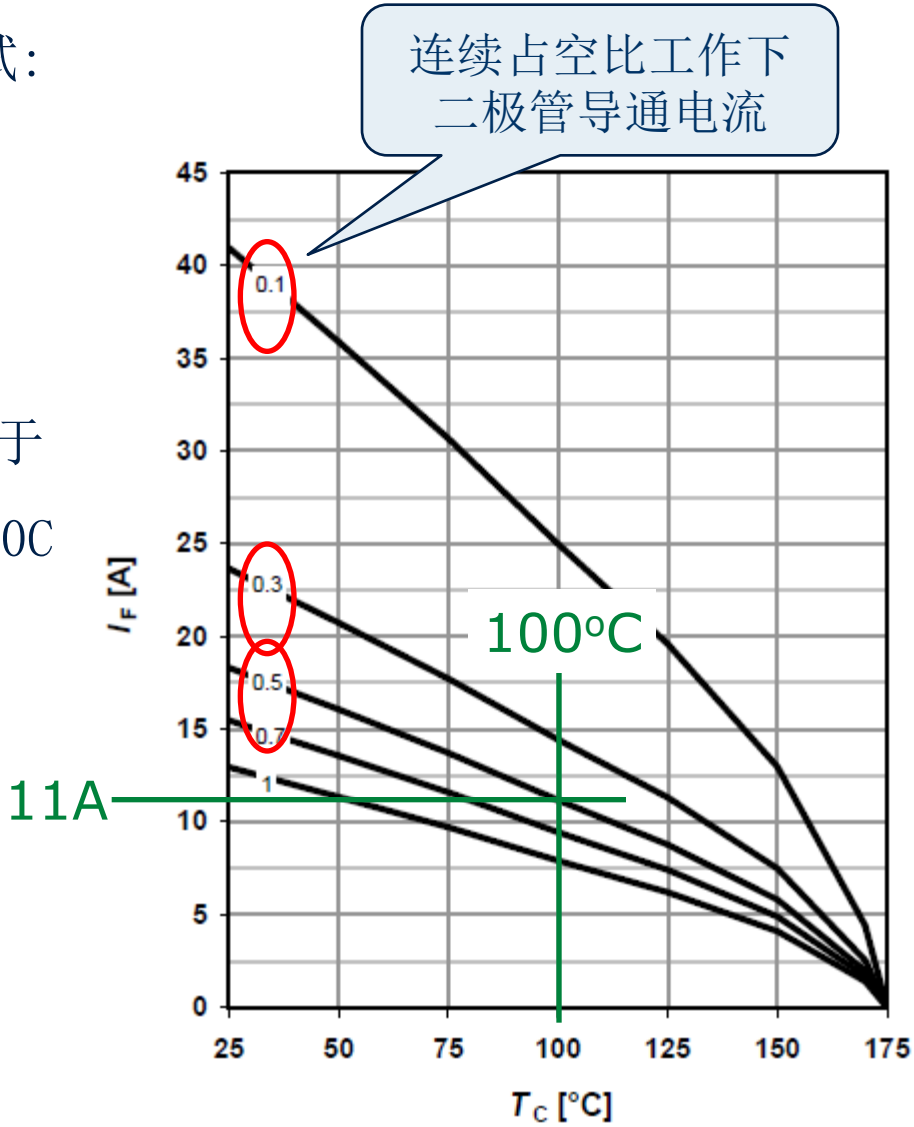
$$P_{tot} = f(T_{case}) = (T_{JMax}-T_{case})/R_{thJC}$$

- $I_F=f(T_{case})= P_{tot}(T_{case})/V_F(@T_j)$



连续占空比工作条件下正向电流

- 连续占空比条件下SiC 二极管电流测试:
  - 结温要小于或者等于 175°C（T_{Jmax}）
  - 开关频率：5kHz
- 例如：占空比等于 =0.5（开关频率大于5kHz）和 壳温=100°C（T_C），IDH06SG60C能导通大于11 A电流.



摘录自 IDH06SG60C 规格书

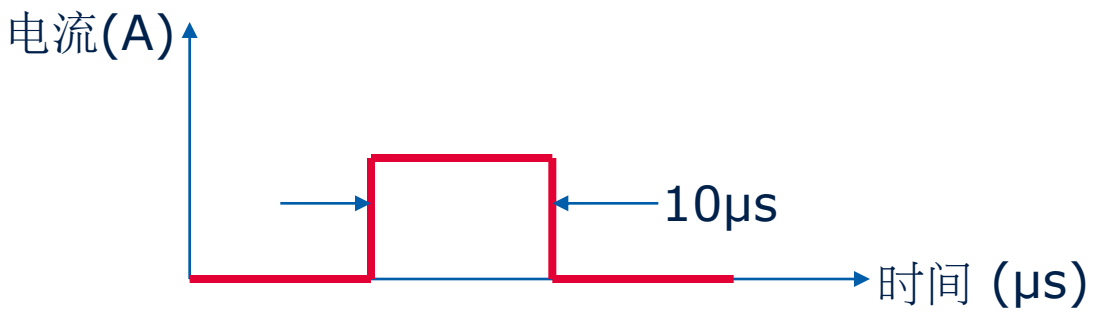
非连续导通模式下正向最大峰值电流 $I_{F,max}$

- 电流脉冲定义. （tp=10μs 和 T_C =100°C ）

Maximum ratings

Parameter	Symbol	Conditions	Value	Unit
Non-repetitive peak forward current	$I_{F,max}$	T_C=25 °C, t_p=10 μs	190	A

摘自 IDH06SG60C 规格书



- 此电流脉冲值是基于70%降额下的破坏性实验获得.

参考

- IPX60R099C6 规格书
- BSC057N03MS 规格书
- IPP080N60N G 规格书
- IDH06SG60C 规格书
- AN-CoolMOS-03, “How to Select the Right CoolMOS and its Power Handling Capability”, 英飞凌应用笔记, 2002.
- “Explanation of Data Sheet Parameters”, 英飞凌应用笔记, 2002.
- “CoolMOS CFD2 First 650 V Rated Super Junction MOSFET with Fast Body Diode Suitable for Resonant Topologies”, 英飞凌应用笔记, 2011.
- AN CoolMOS-04, “Considerations for CoolMOS in SMPS Applications”, 英飞凌应用笔记, 2001.
- www.infineon.com

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