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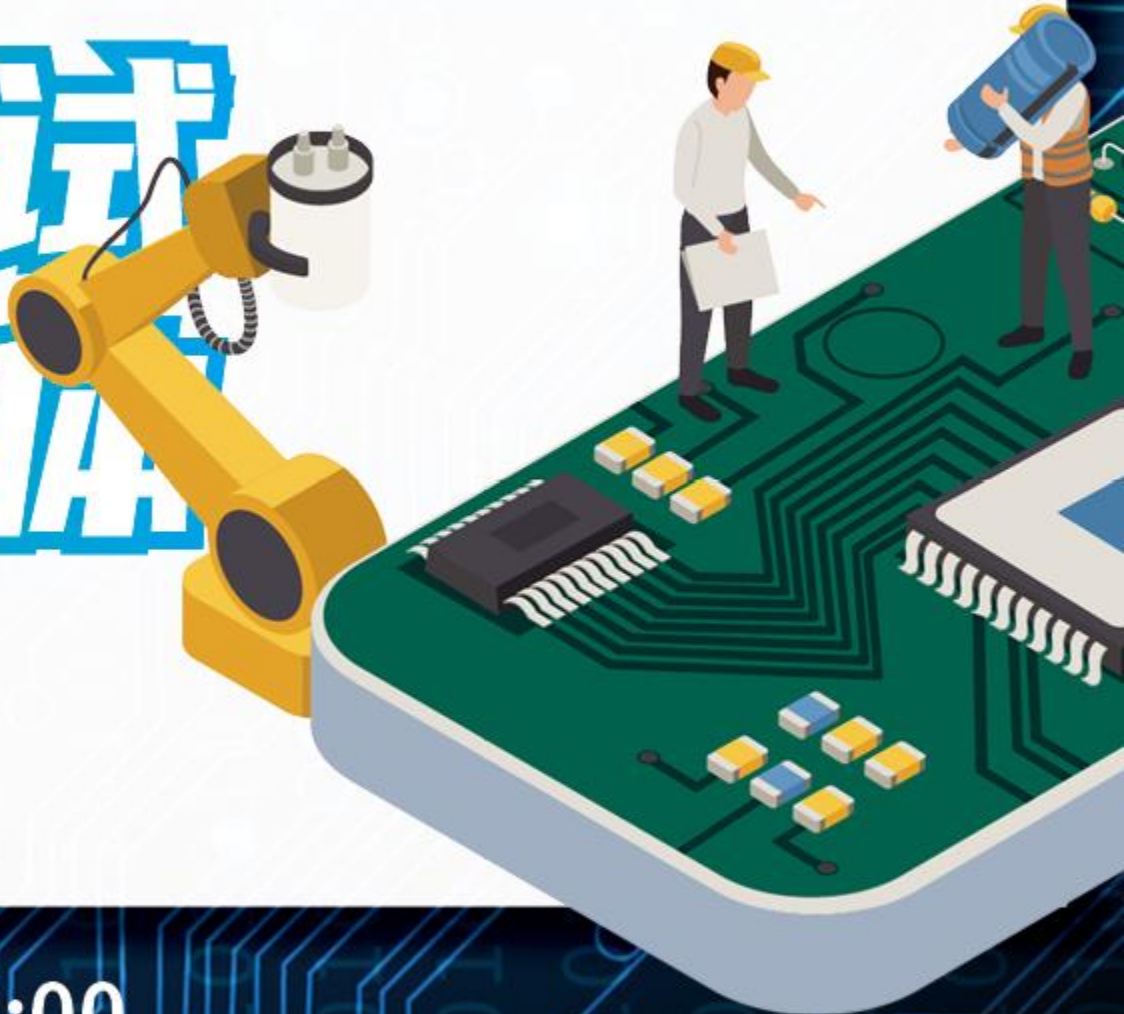
大讲堂

器件静态测试
宽禁带半导体

规范解读



[讲师介绍]

王瑞恒

半导体行业测试专家

直播时间：4月30号（周五）14:30-16:00

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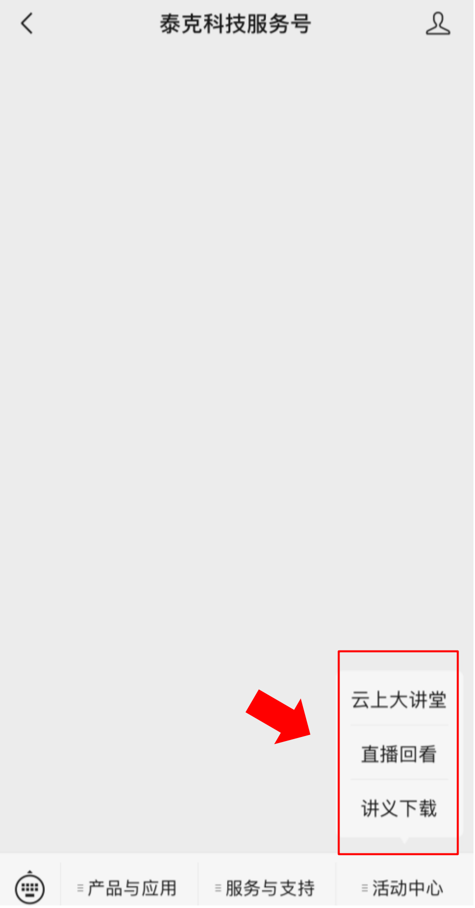

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  - ○IEC60747-8内容解读
  - ○怎样使用IEC60747-8

◊ 泰克公司PCT测试系统介绍
  - ○设备组成及工作范围
  - ○ 使用方法及测试技巧

什么是宽禁带半导体及静态测试

什么是宽禁带半导体

什么是静态测试

名词解释

宽禁带半导体

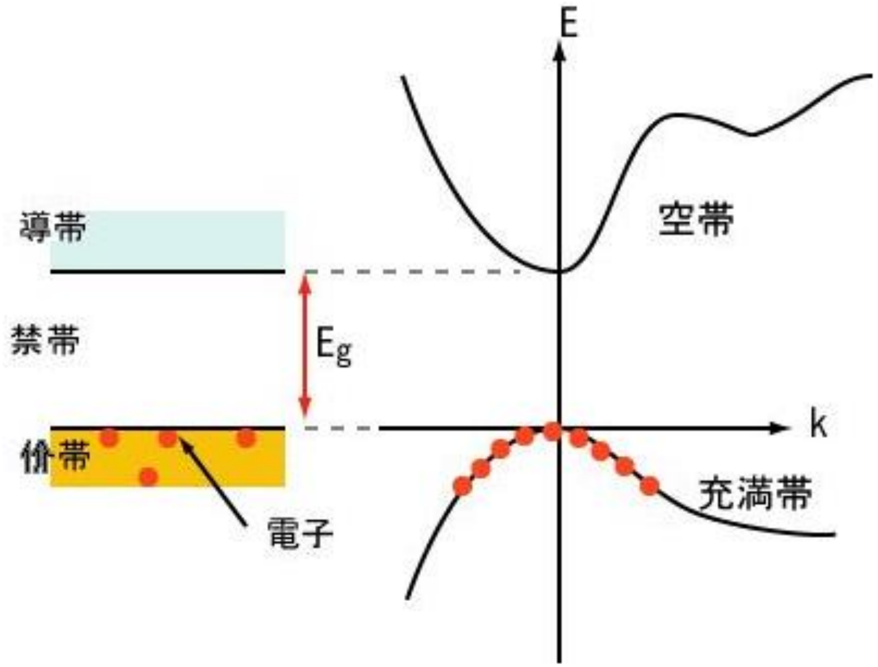
材料分类：

金属：低导通电阻，击穿电压低

绝缘体：击穿电压高，导通电阻高

半导体：低导通电阻，高击穿电压

（石墨烯、碳纳米管）



半导体材料中禁带宽度在2.3eV以上的材料——SiC GaN

名词解释

静态测试

静态：也叫稳态或者DC状态，施加激励（电压/电流）到稳定状态后再进行测试。

常作为器件的“体检”！是特性测试中的基本测试；

特点：测试稳定，精度高，测试慢；

设备：源和测量单元一体，也就是SMU设备；

名词解释

宽禁带材料器件的静态测试参数

电源工程师工作流程

静态测试应用于功率器件
功能验证/参数测试

STEP1: 功率器件选择

- 功率二级管的特性验证
- 元器件IGBT，MOSFET，特性验证
- 双脉冲测试

STEP2: 电源原型版设计

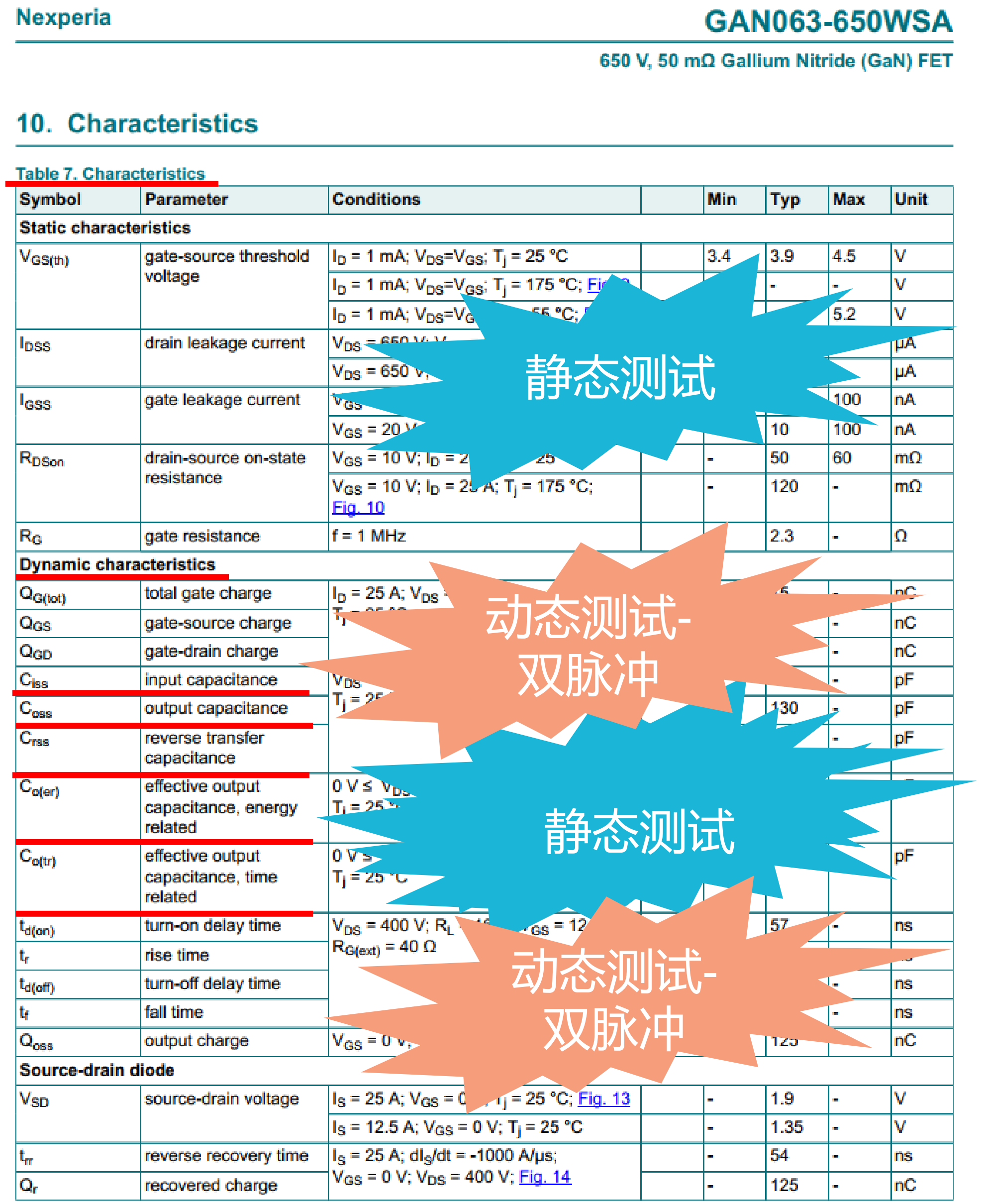
- 开关系统设计优化
- 开关损耗测试
- 磁损耗测试
- 环路响应测试
- 板级mV级纹波测试
- SiC, GaN系统设计优化验证

STEP3: 电源质量分析

- 电测效率测试
- 电流谐波标准：IEC610000测试
- 电源输出纹波测试

STEP4: 产品最终认证

- EMC预一致性测试
- 电源待机标准测试
- 电源谐波标准测试
- 直流低待机电流测试
- 老化实验验证



Nexperia **GAN063-650WSA**

650 V, 50 mΩ Gallium Nitride (GaN) FET

10. Characteristics

Table 7. Characteristics

Symbol	Parameter	Conditions		Min	Typ	Max	Unit
Static characteristics							
$V_{GS(th)}$	gate-source threshold voltage	I_D = 1 mA; V_{DS}=V_{GS}; T_j = 25 °C		3.4	3.9	4.5	V
		I_D = 1 mA; V_{DS}=V_{GS}; T_j = 175 °C; Fi		[illegible]	-	-	V
		I_D = 1 mA; V_{DS}=V_G 55 °C;		[illegible]	[illegible]	5.2	V
I_{DSS}	drain leakage current	V_{DS} = 650 V; V		[illegible]	[illegible]	[illegible]	μA
		V_{DS} = 650 V;		[illegible]	[illegible]	[illegible]	μA
I_{GSS}	gate leakage current	V_{GS}		[illegible]	[illegible]	100	nA
		V_{GS} = 20 V		[illegible]	10	100	nA
R_{DSon}	drain-source on-state resistance	V_{GS} = 10 V; I_D = 2 25		-	50	60	mΩ
		V_{GS} = 10 V; I_D = 25 A; T_j = 175 °C; Fig. 10		-	120	-	mΩ
R_G	gate resistance	f = 1 MHz		[illegible]	2.3	-	Ω
Dynamic characteristics							
$Q_{G(tot)}$	total gate charge	I_D = 25 A; V_{DS} T_j		[illegible]	[illegible]	-	nC
Q_{GS}	gate-source charge			[illegible]	[illegible]	-	nC
Q_{GD}	gate-drain charge			[illegible]	[illegible]	-	nC
C_{iss}	input capacitance	V_{DS} T_j = 25		[illegible]	[illegible]	-	pF
C_{oss}	output capacitance			[illegible]	130	-	pF
C_{rss}	reverse transfer capacitance			[illegible]	[illegible]	-	pF
$C_{o(er)}$	effective output capacitance, energy related	0 V ≤ V_{DS} T_j = 25		[illegible]	[illegible]	[illegible]	[illegible]
$C_{o(tr)}$	effective output capacitance, time related	0 V ≤ T_j = 25 °C		[illegible]	[illegible]	[illegible]	pF
$t_{d(on)}$	turn-on delay time	V_{DS} = 400 V; R_L V_{GS} = 12 $R_{G(ext)}$ = 40 Ω		[illegible]	57	-	ns
t_r	rise time			[illegible]	[illegible]	[illegible]	[illegible]
$t_{d(off)}$	turn-off delay time			[illegible]	[illegible]	-	ns
t_f	fall time			[illegible]	[illegible]	-	ns
Q_{oss}	output charge	V_{GS} = 0 V;		[illegible]	125	[illegible]	nC
Source-drain diode							
V_{SD}	source-drain voltage	I_S = 25 A; V_{GS} = 0 T_j = 25 °C; Fig. 13		-	1.9	-	V
		I_S = 12.5 A; V_{GS} = 0 V; T_j = 25 °C		-	1.35	-	V
t_{rr}	reverse recovery time	I_S = 25 A; dI_S/dt = -1000 A/μs; V_{GS} = 0 V; V_{DS} = 400 V; Fig. 14		-	54	-	ns
Q_r	recovered charge			-	125	-	nC

宽禁带半导体静态测试规范 IEC60747-8

IEC60747-8内容解读

怎样使用IEC60747-8

IEC60747-8内容解读

内容解读

测试标准/规范

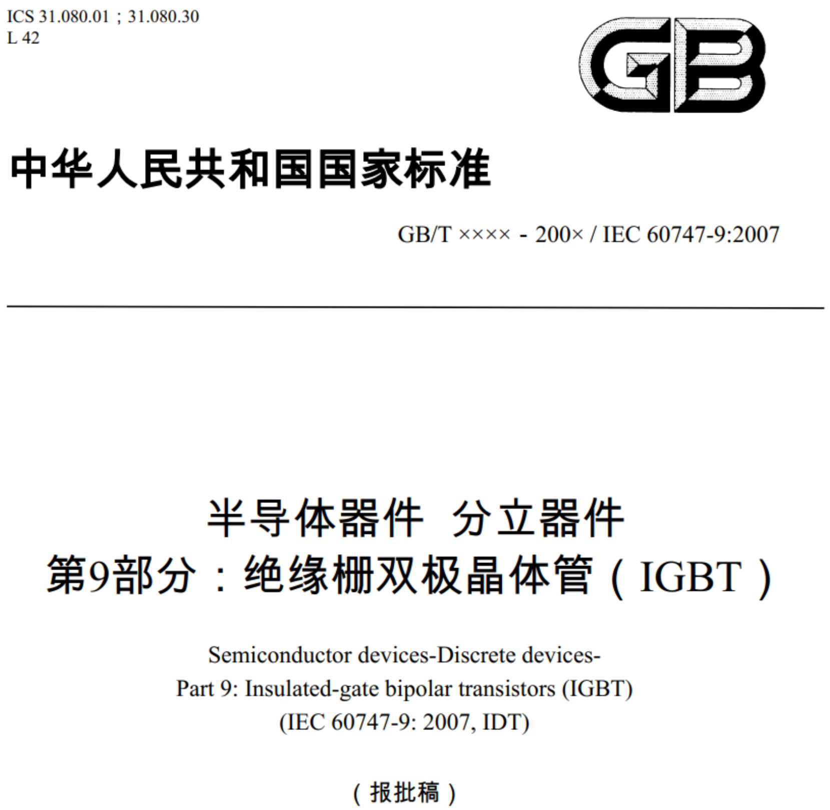
IEC 60747-8

Edition 3.0 2010-12

INTERNATIONAL
STANDARD

NORME
INTERNATIONALE

Semiconductor devices – Discrete devices –
Part 8: Field-effect transistors



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中华人民共和国国家标准

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半导体器件 分立器件
第9部分：绝缘栅双极晶体管（IGBT）

Semiconductor devices-Discrete devices-
Part 9: Insulated-gate bipolar transistors (IGBT)
(IEC 60747-9: 2007, IDT)

（报批稿）

IEC60747-8内容解读

内容解读

请看规范文档

怎样使用IEC60747-8

怎样使用规范

测试标准/规范

IEC 60747-8

Edition 3.0 2010-12

INTERNATIONAL STANDARD

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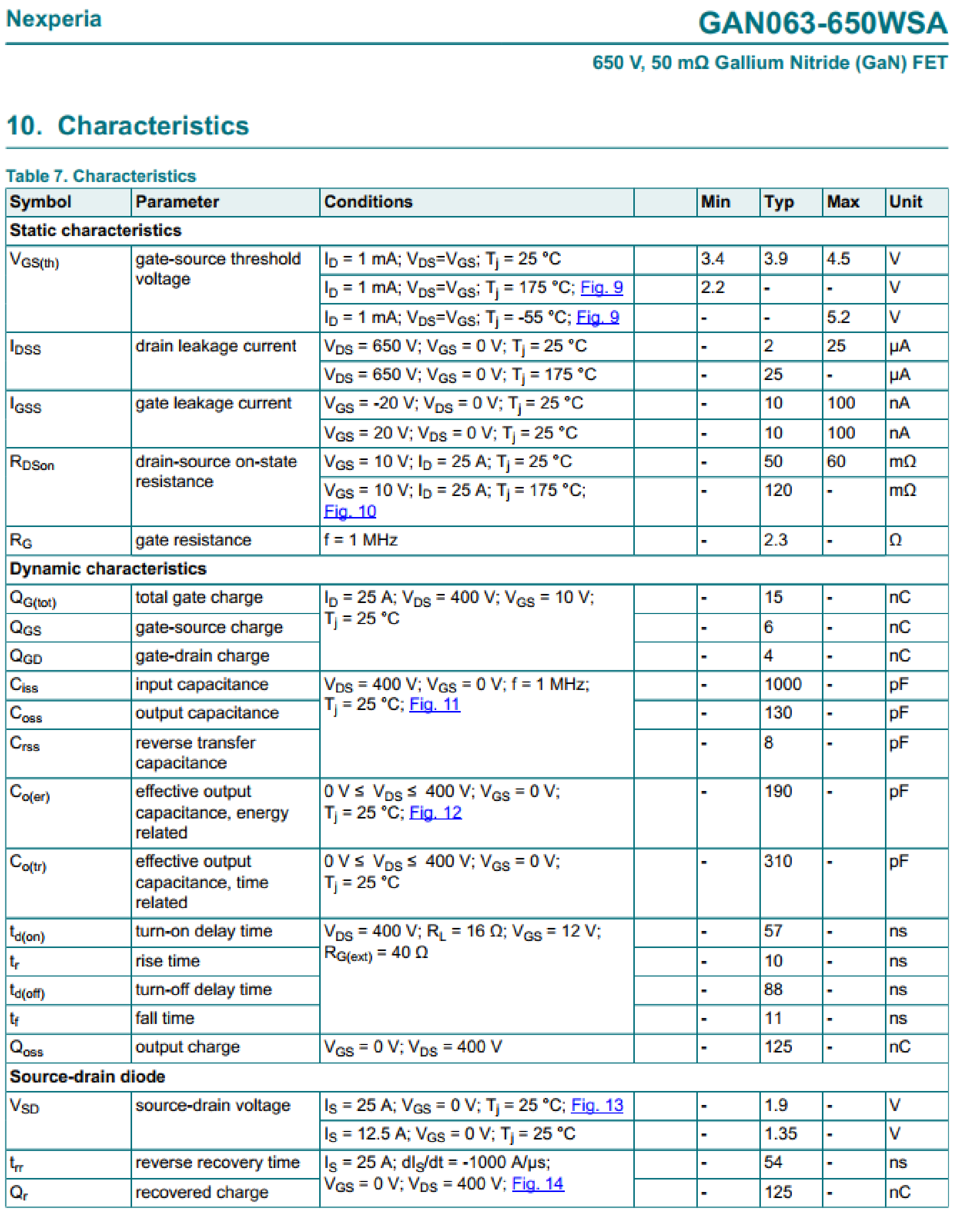

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Static characteristics							
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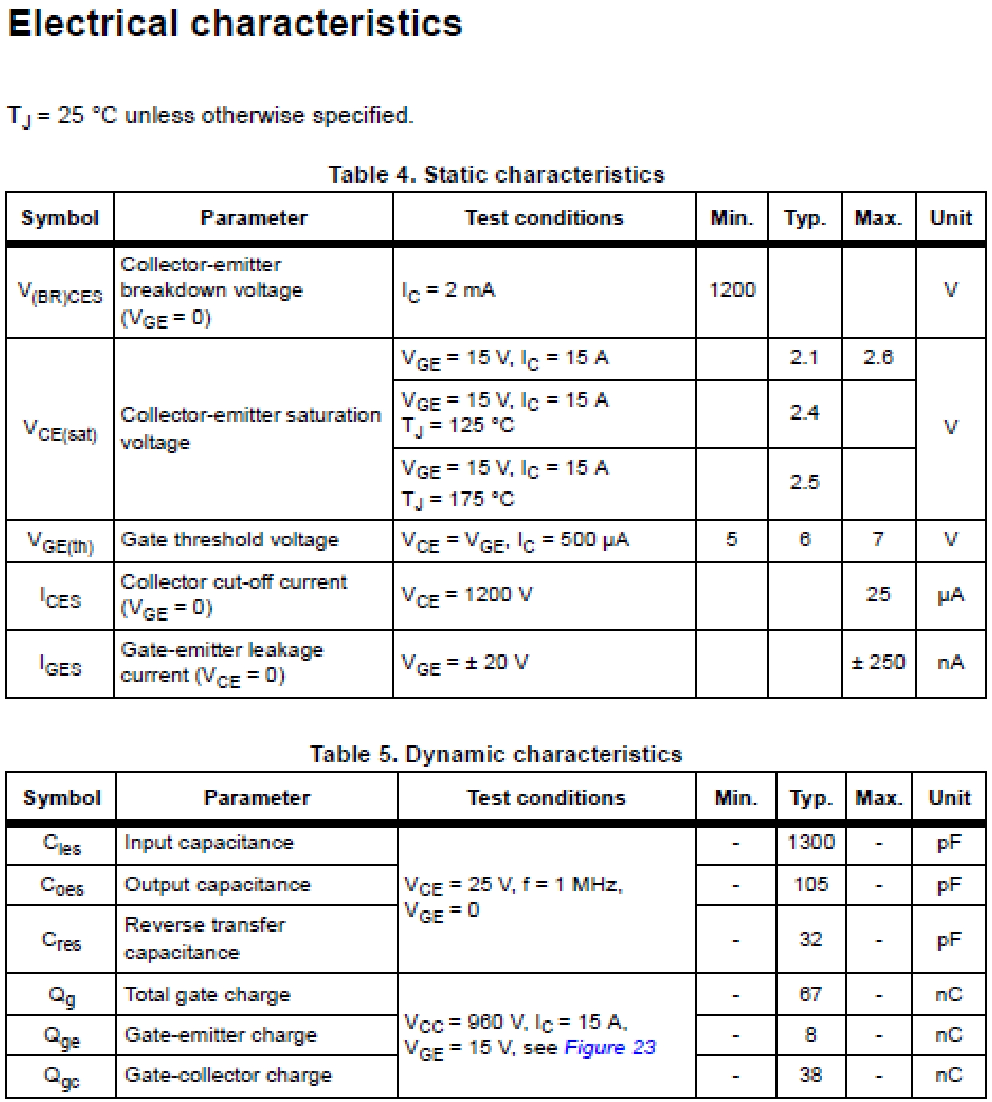
		I_D = 1 mA; V_{DS}=V_{GS}; T_j = 175 °C; Fig. 9		2.2	-	-	V
		I_D = 1 mA; V_{DS}=V_{GS}; T_j = -55 °C; Fig. 9		-	-	5.2	V
I_{DSS}	drain leakage current	V_{DS} = 650 V; V_{GS} = 0 V; T_j = 25 °C		-	2	25	μA
		V_{DS} = 650 V; V_{GS} = 0 V; T_j = 175 °C		-	25	-	μA
I_{GSS}	gate leakage current	V_{GS} = -20 V; V_{DS} = 0 V; T_j = 25 °C		-	10	100	nA
		V_{GS} = 20 V; V_{DS} = 0 V; T_j = 25 °C		-	10	100	nA
R_{DSon}	drain-source on-state resistance	V_{GS} = 10 V; I_D = 25 A; T_j = 25 °C		-	50	60	mΩ
		V_{GS} = 10 V; I_D = 25 A; T_j = 175 °C; Fig. 10		-	120	-	mΩ
R_G	gate resistance	f = 1 MHz		-	2.3	-	Ω
Dynamic characteristics							
$Q_{G(tot)}$	total gate charge	I_D = 25 A; V_{DS} = 400 V; V_{GS} = 10 V; T_j = 25 °C		-	15	-	nC
Q_{GS}	gate-source charge			-	6	-	nC
Q_{GD}	gate-drain charge			-	4	-	nC
C_{iss}	input capacitance	V_{DS} = 400 V; V_{GS} = 0 V; f = 1 MHz; T_j = 25 °C; Fig. 11		-	1000	-	pF
C_{oss}	output capacitance			-	130	-	pF
C_{rss}	reverse transfer capacitance			-	8	-	pF
$C_{o(er)}$	effective output capacitance, energy related	0 V ≤ V_{DS} ≤ 400 V; V_{GS} = 0 V; T_j = 25 °C; Fig. 12		-	190	-	pF
$C_{o(tr)}$	effective output capacitance, time related	0 V ≤ V_{DS} ≤ 400 V; V_{GS} = 0 V; T_j = 25 °C		-	310	-	pF
$t_{d(on)}$	turn-on delay time	V_{DS} = 400 V; R_L = 16 Ω; V_{GS} = 12 V; $R_{G(ext)}$ = 40 Ω		-	57	-	ns
t_r	rise time			-	10	-	ns
$t_{d(off)}$	turn-off delay time			-	88	-	ns
t_f	fall time			-	11	-	ns
Q_{oss}	output charge	V_{GS} = 0 V; V_{DS} = 400 V		-	125	-	nC
Source-drain diode							
V_{SD}	source-drain voltage	I_S = 25 A; V_{GS} = 0 V; T_j = 25 °C; Fig. 13		-	1.9	-	V
		I_S = 12.5 A; V_{GS} = 0 V; T_j = 25 °C		-	1.35	-	V
t_{rr}	reverse recovery time	I_S = 25 A; dI_S/dt = -1000 A/μs; V_{GS} = 0 V; V_{DS} = 400 V; Fig. 14		-	54	-	ns
Q_r	recovered charge			-	125	-	nC

测试示例: IGBT 典型特性参数



Electrical characteristics

T_J = 25 °C unless otherwise specified.

Table 4. Static characteristics

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)CES}$	Collector-emitter breakdown voltage (V_{GE} = 0)	I_C = 2 mA	1200			V
$V_{CE(sat)}$	Collector-emitter saturation voltage	V_{GE} = 15 V, I_C = 15 A		2.1	2.6	V
		V_{GE} = 15 V, I_C = 15 A T_J = 125 °C		2.4		
		V_{GE} = 15 V, I_C = 15 A T_J = 175 °C		2.5		
$V_{GE(th)}$	Gate threshold voltage	V_{CE} = V_{GE}, I_C = 500 µA	5	6	7	V
I_{CES}	Collector cut-off current (V_{GE} = 0)	V_{CE} = 1200 V			25	µA
I_{GES}	Gate-emitter leakage current (V_{CE} = 0)	V_{GE} = ± 20 V			± 250	nA

Table 5. Dynamic characteristics

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
C_{ies}	Input capacitance	V_{CE} = 25 V, f = 1 MHz, V_{GE} = 0	-	1300	-	pF
C_{oes}	Output capacitance		-	105	-	pF
C_{res}	Reverse transfer capacitance		-	32	-	pF
Q_g	Total gate charge	V_{CC} = 960 V, I_C = 15 A, V_{GE} = 15 V, see *Figure 23*	-	67	-	nC
Q_{ge}	Gate-emitter charge		-	8	-	nC
Q_{gc}	Gate-collector charge		-	38	-	nC

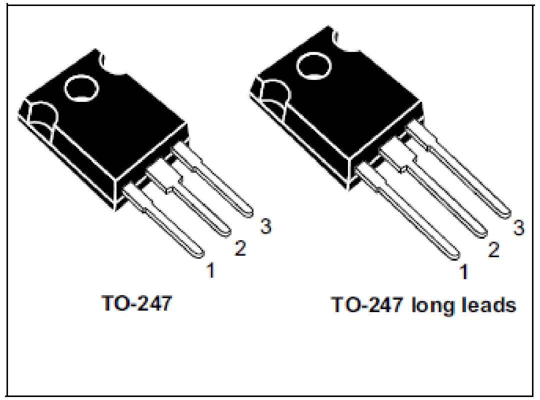
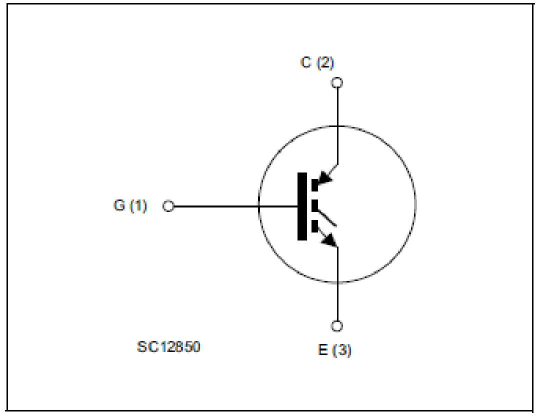
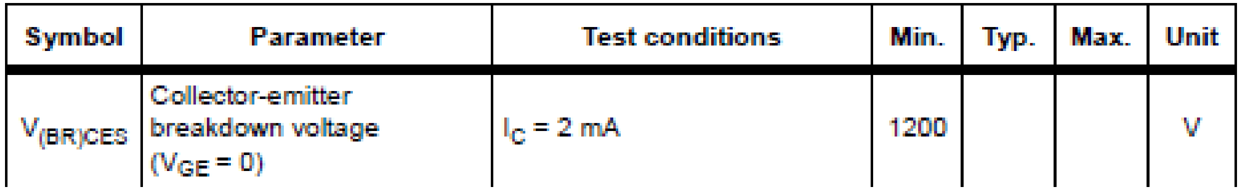


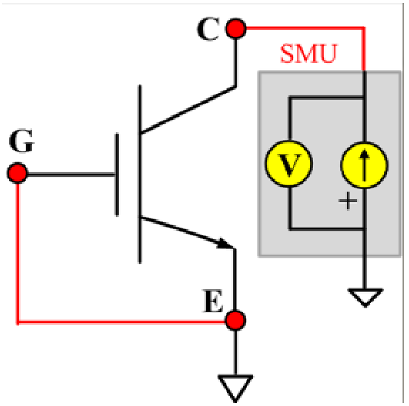
Figure 1. Internal schematic diagram



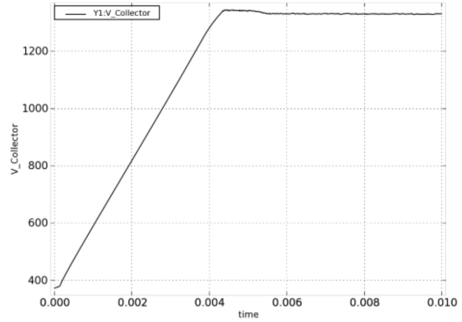
测试示例: V_{CES}（BV_{CES}）



Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)CES}$	Collector-emitter breakdown voltage (V_{GE} = 0)	I_C = 2 mA	1200			V



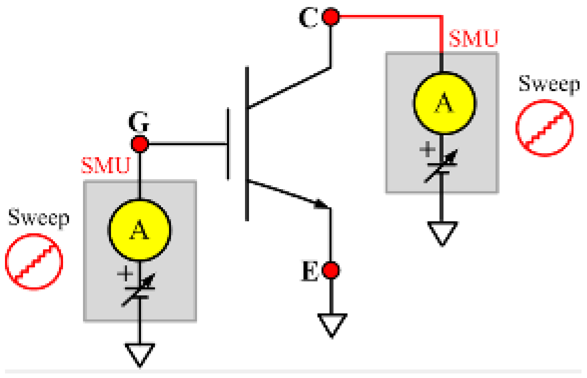
- **参数物理意义：** 在不加栅压的情况下(VGE=0)，看 Collector 与 Emitter的击穿电压. 一般以电流在某特定值下的Collector的电压记为VCES



- **一般测试方法：** 在Collector上加规定电流（BiasI=2mA）Gate及Emitter 接common Lo. 测试Collector 端的电压

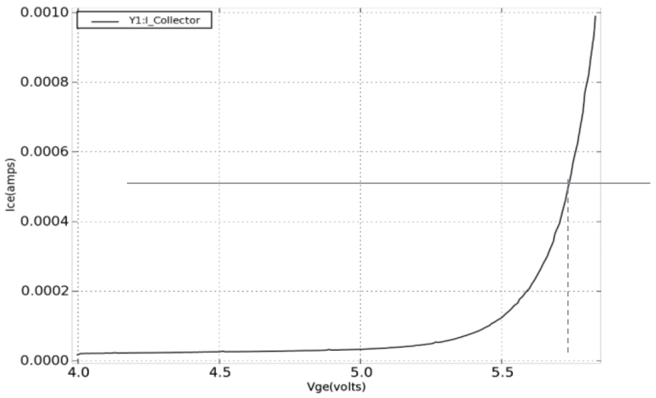
测试示例: V_{GE} （$V_{GE(th)}$）

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{GE(th)}$	Gate threshold voltage	$V_{CE} = V_{GE}$, I_C = 500 µA	5	6	7	V



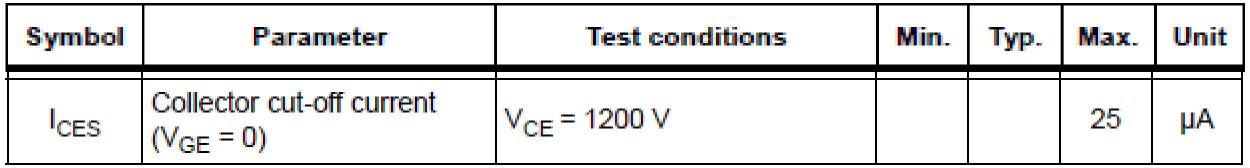
- 参数物理意义： Collector与Emitter间有微小电流开始通过时的VGE值。用于作为衡量IGBT开始导通时的VGE值的尺度。

- 一般测试方法： 在Gate及Collector上加同步的扫描电压（SweepV 4~7V i.e.） Emitter 接common Lo. 测试Collector 端的电流。当其值等于额定值时的VG记为VGE(th)



$V_{GE(th)}$

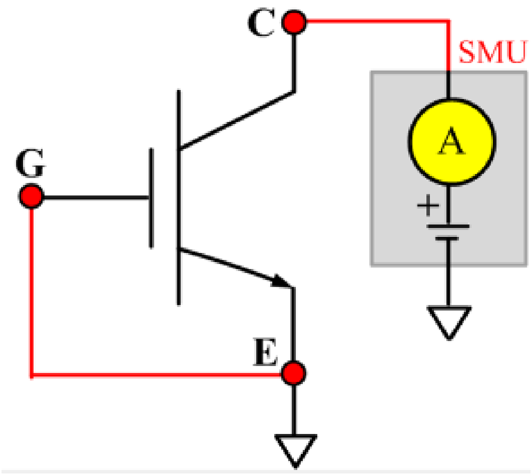
Test example: I_{CES}

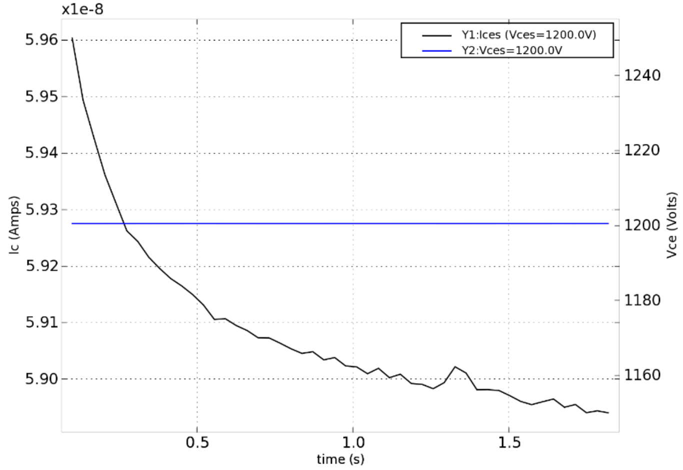


Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
I_{CES}	Collector cut-off current (V_{GE} = 0)	V_{CE} = 1200 V			25	µA

- 参数物理意义： Gate及Emitter 处于短路的状态时在Collector 外加指定的电压时C-E间的漏电流

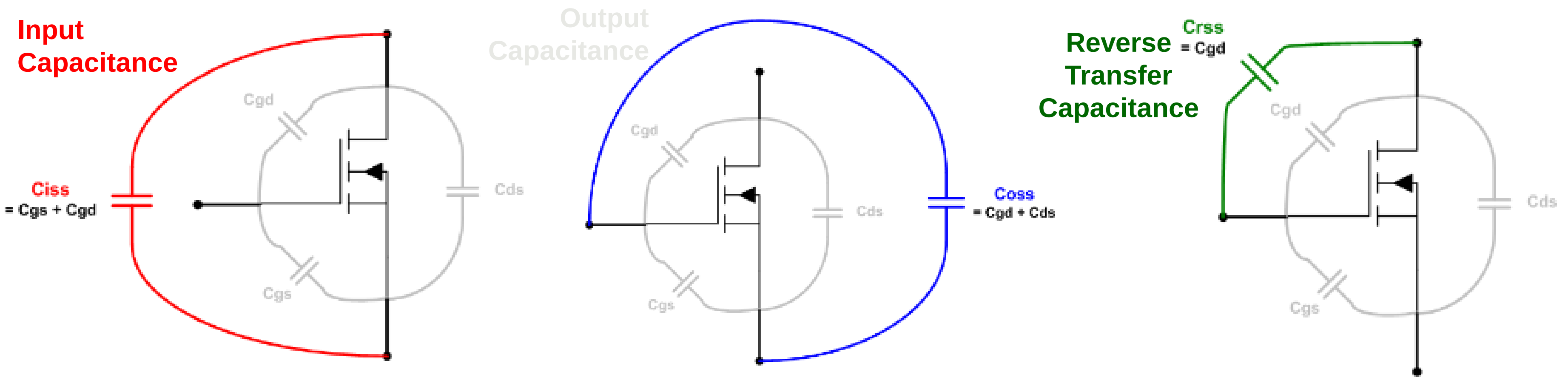
- 一般测试方法： 在Collector上加额定固定电压（BiasV ＝1200V i.e.） 将Gate Emitter 接common Lo. 测试Collector 端的电流。





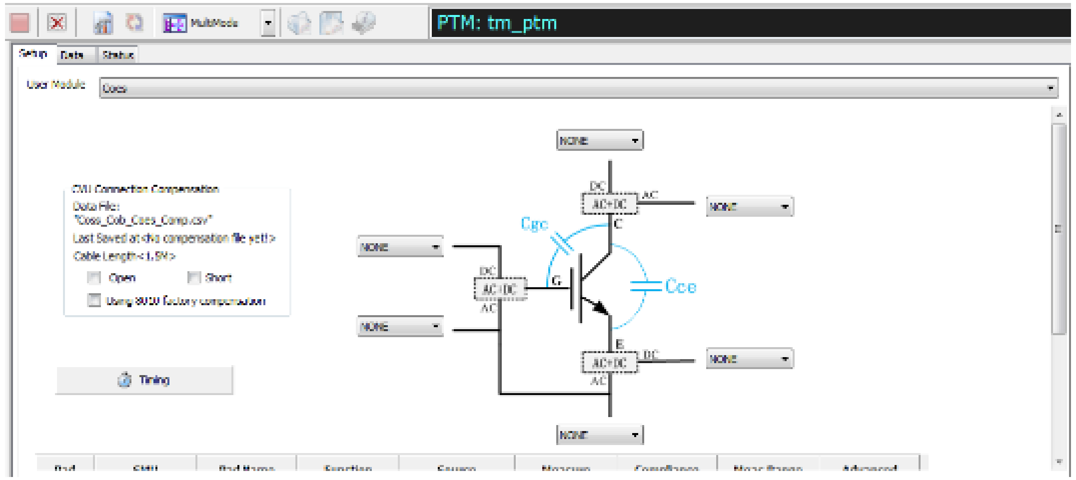
测试示例: 动态特性 – 电容测试

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
C_{ies}	Input capacitance	V_{CE} = 25 V, f = 1 MHz, V_{GE} = 0	-	1300	-	pF
C_{oes}	Output capacitance		-	105	-	pF
C_{res}	Reverse transfer capacitance		-	32	-	pF



- **参数物理意义：** 功率半导体器件的电容特性决定了器件在电路中的开关时间等特性。为电路设计者选择合适的器件提供指导。 尤其是在做开关电源应用时。

测试示例:动态特性 – 电容测试

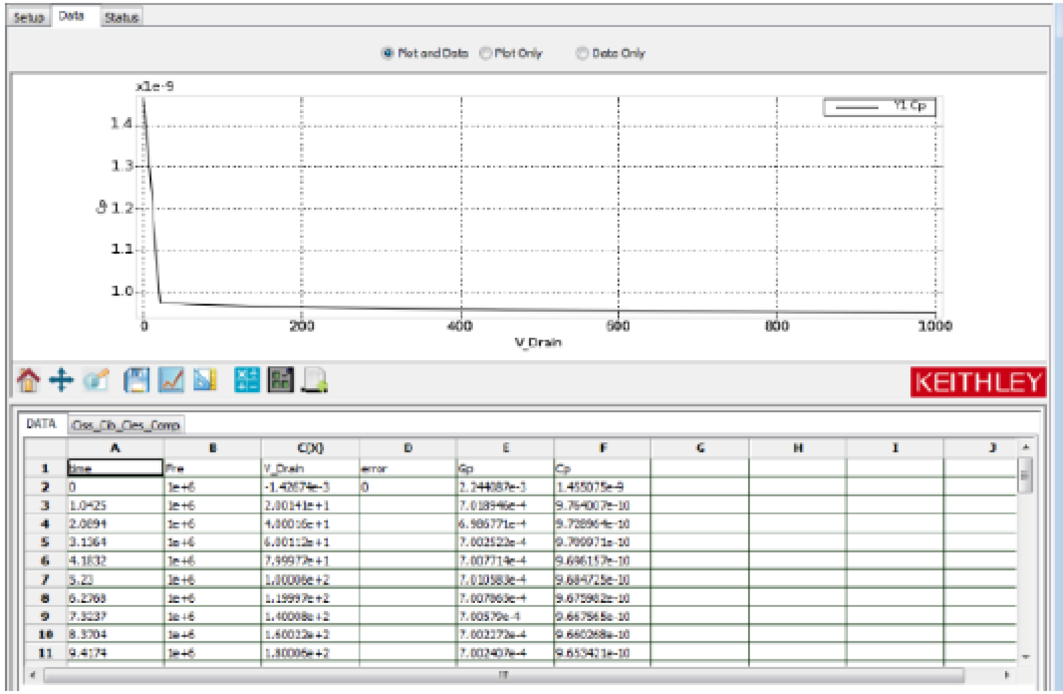


PTM: tm_ptm

User Module: Coes

CVU Connection Compensation
Data File:
"Coss_Cob_Coes_Comp.csv"
Last Saved at:<No compensation file yet!>
Cable Length:<1.5M>
☐ Open ☐ Short
☐ Using 8020 factory compensation

通过8020简单的硬件连线，及ACS-Basic中的参数测试，我们可以测量出器件在offstate 下的电容值。



● Plot and Data ○ Plot Only ○ Data Only

	A	B	C(X)	D	E	F	G	H	I	J
1	time	Fre	V_Drain	error	Gp	Cp				
2	0	1e+6	-1.42674e-3	0	2.244087e-3	1.455075e-9				
3	1.0425	1e+6	2.00141e+1		7.018946e-4	9.764007e-10				
4	2.0894	1e+6	4.00016e+1		6.986771e-4	9.720964e-10				
5	3.1364	1e+6	6.00112e+1		7.002522e-4	9.700971e-10				
6	4.1832	1e+6	7.99972e+1		7.007714e-4	9.696157e-10				
7	5.23	1e+6	1.00006e+2		7.010583e-4	9.684725e-10				
8	6.2768	1e+6	1.19997e+2		7.007863e-4	9.675982e-10				
9	7.3237	1e+6	1.40008e+2		7.00579e-4	9.667565e-10				
10	8.3704	1e+6	1.60022e+2		7.002272e-4	9.660268e-10				
11	9.4174	1e+6	1.80006e+2		7.002407e-4	9.653421e-10				

泰克公司PCT测试系统介绍

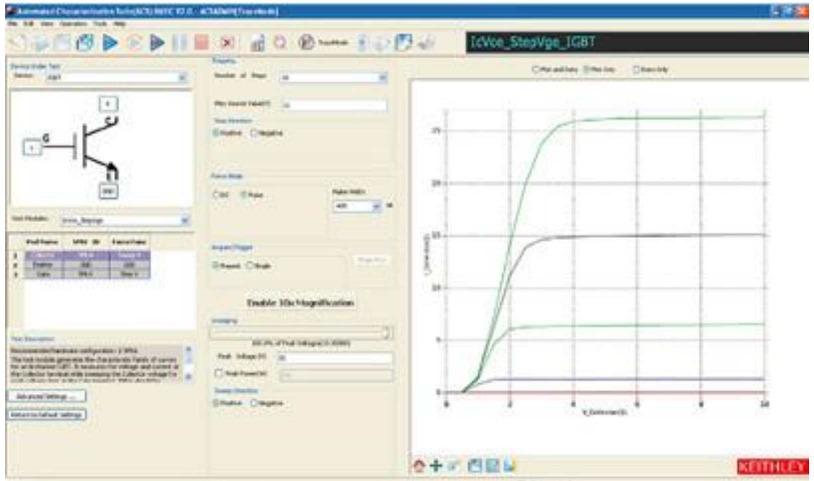
设备组成及工作范围

使用方法及测试技巧

泰克公司PCT测试系统介绍

设备组成及工作范围

- 完善的解决方案，包括SMU仪器、电缆、测试夹具、软件、测试程序库和样本器件
- 提供了宽动态范围：
  - 从µV到3kV
  - 从fA到100A
- 灵活的可重新配置的系统，满足不断变化的功率测试要求



配置选型指南

型号[1]		集电极/漏极电源[2]		阶跃发生器基极/栅极电源	辅助电源
		高压模式	高流模式		
低功率	2600-PCT-1B	200 V/10 A	200 V/10 A	200 V/10 A	N/A
高流	2600-PCT-2B	200 V/10 A	40 V/50 A	200 V/10 A	200 V/10 A
高压	2600-PCT-3B	3 kV/120 mA	200 V/10 A	200 V/10 A	200 V/10 A
高流和高压	2600-PCT-4B	3 kV/120 mA	40 V/50 A	200 V/10 A	200 V/10 A

泰克公司PCT测试系统介绍

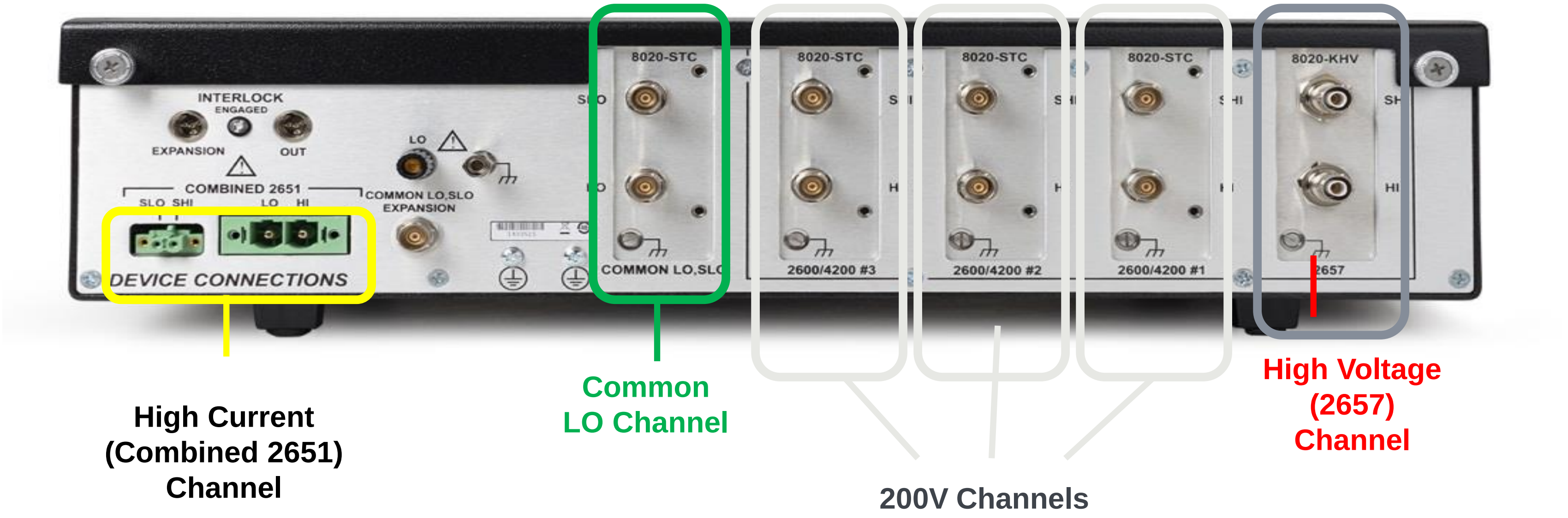
- 设备组成及工作范围

- 8010
  - Bias Tee Options
    - CVU-3K-KIT – Enables 3kV HVCV measurements
    - CVU-200-KIT – Enables 400V differential HVCV measurements
    - Includes both bias tees and integrated IV-CV switch
  - Socket
    - TO-220
    - TO-247
    - Axial lead
    - TEK Curve Tracer Adapter
    - Custom device

泰克公司PCT测试系统介绍

- 设备组成及工作范围

注意与探针台的配合



High Current
(Combined 2651)
Channel

Common
LO Channel

200V Channels

High Voltage
(2657)
Channel

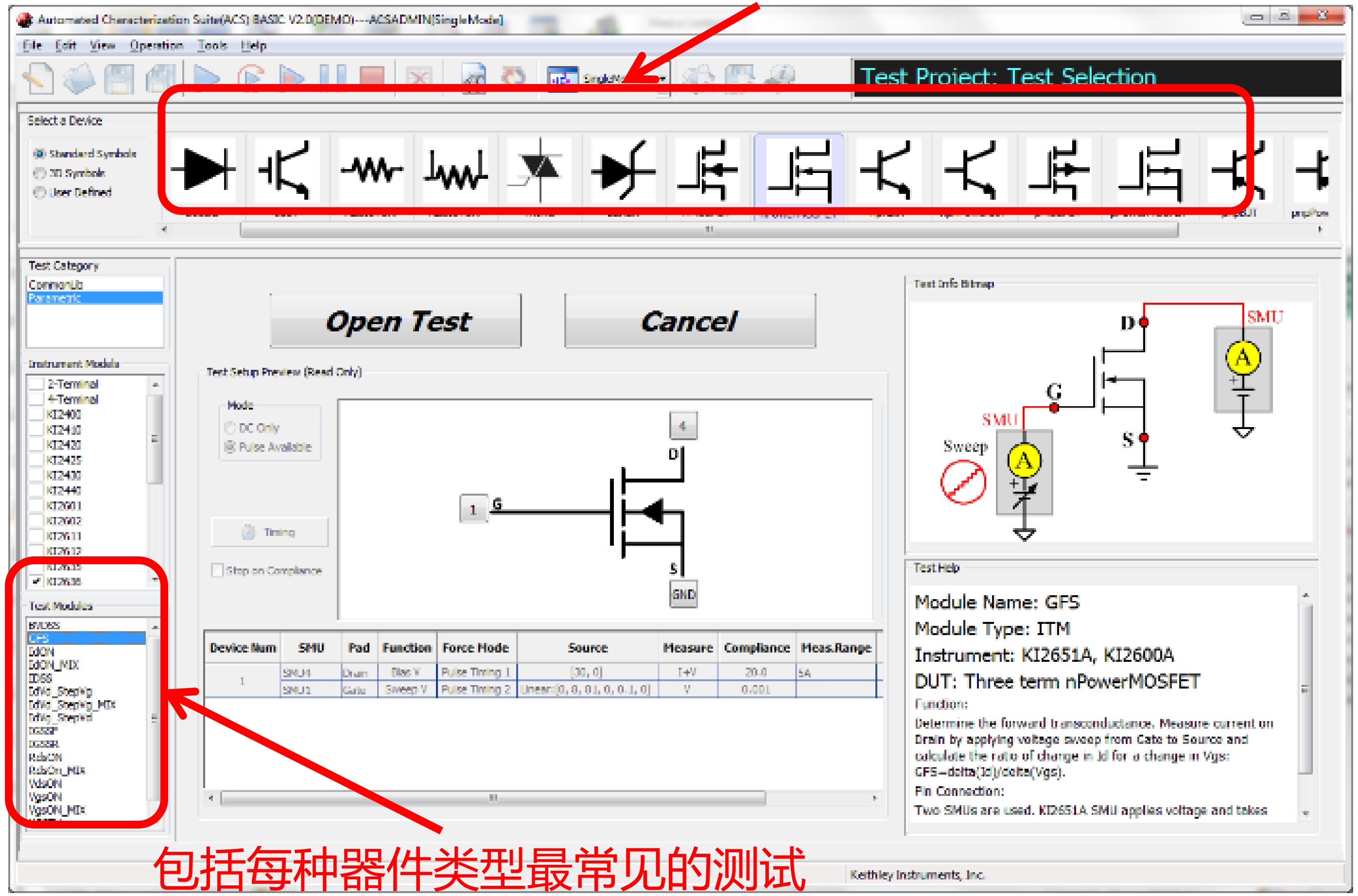
可匹配的探针台：Cascade、MPI、lakeshore等

泰克公司PCT测试系统介绍

- 使用方法及测试技巧

测试管理软件包括实时绘图的跟踪模式及提取参数的参数模式

支持所有最常见的器件



Device Num	SMU	Pad	Function	Force Mode	Source	Measure	Compliance	Meas.Range
1	SMU4	Drain	Bias V	Pulse Timing 1	[30, 0]	I+V	20.0	5A
	SMU1	Gate	Sweep V	Pulse Timing 2	Linear:[0, 0, 01, 0, 0.1, 0]	V	0.001	

Module Name: GFS

Module Type: ITM

Instrument: KI2651A, KI2600A

DUT: Three term nPowerMOSFET

Function:

Determine the forward transconductance. Measure current on Drain by applying voltage sweep from Gate to Source and calculate the ratio of change in Id for a change in Vgs: GFS=delta(Id)/delta(Vgs).

Pin Connection:

Two SMUs are used. KI2651A SMU applies voltage and takes

包括每种器件类型最常见的测试

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