Tektronix

Wide Bandgap characteristics and test concept

한국텍트로닉스 김화연 과장(LUNA KIM)

Agenda

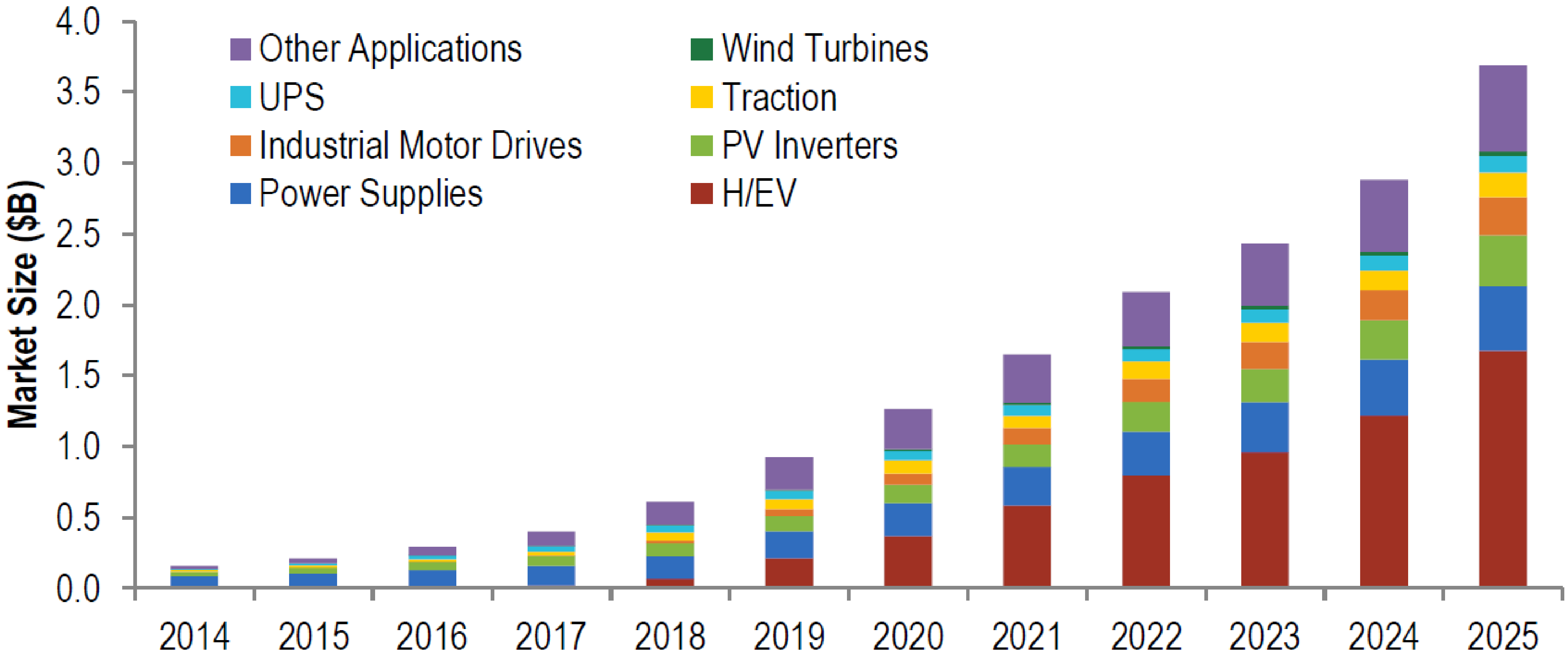
1. About WBG
   - What is WBG ?
   - Applications

2. WBG Test
   - Test configuration & parameters

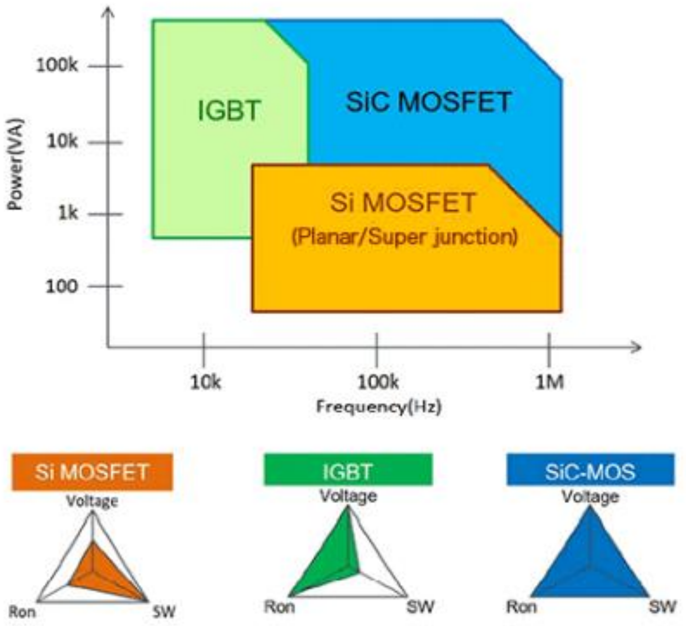
3. Tektronix Suggestions

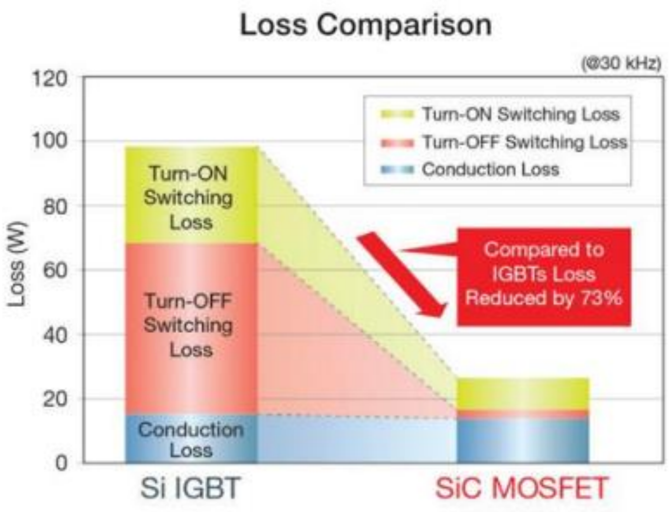
About Wide Bandgap

Wide Bandgap market



Why Wide Bandgap ?





Higher Power Levels
Faster Switching speeds

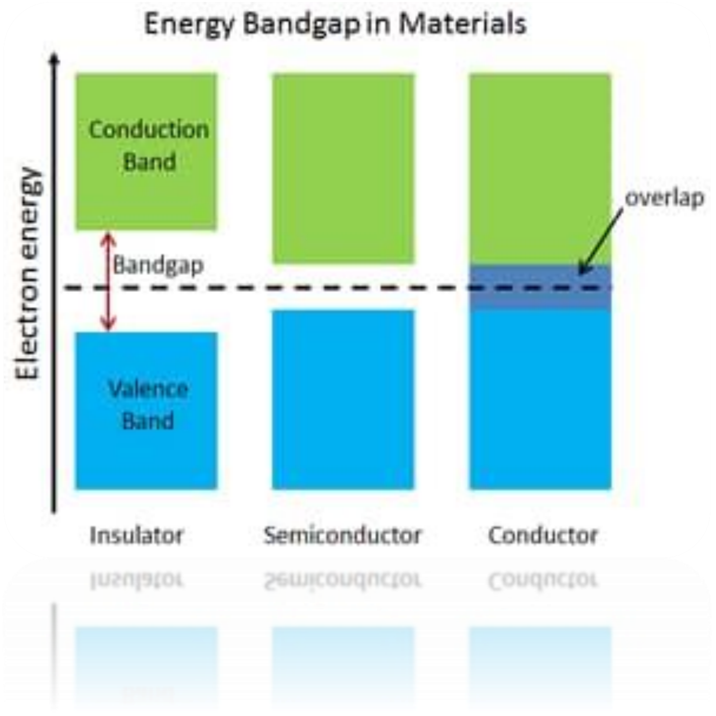
Lower Switching Losses

Smaller Form Factor

What is Wide Bandgap ?

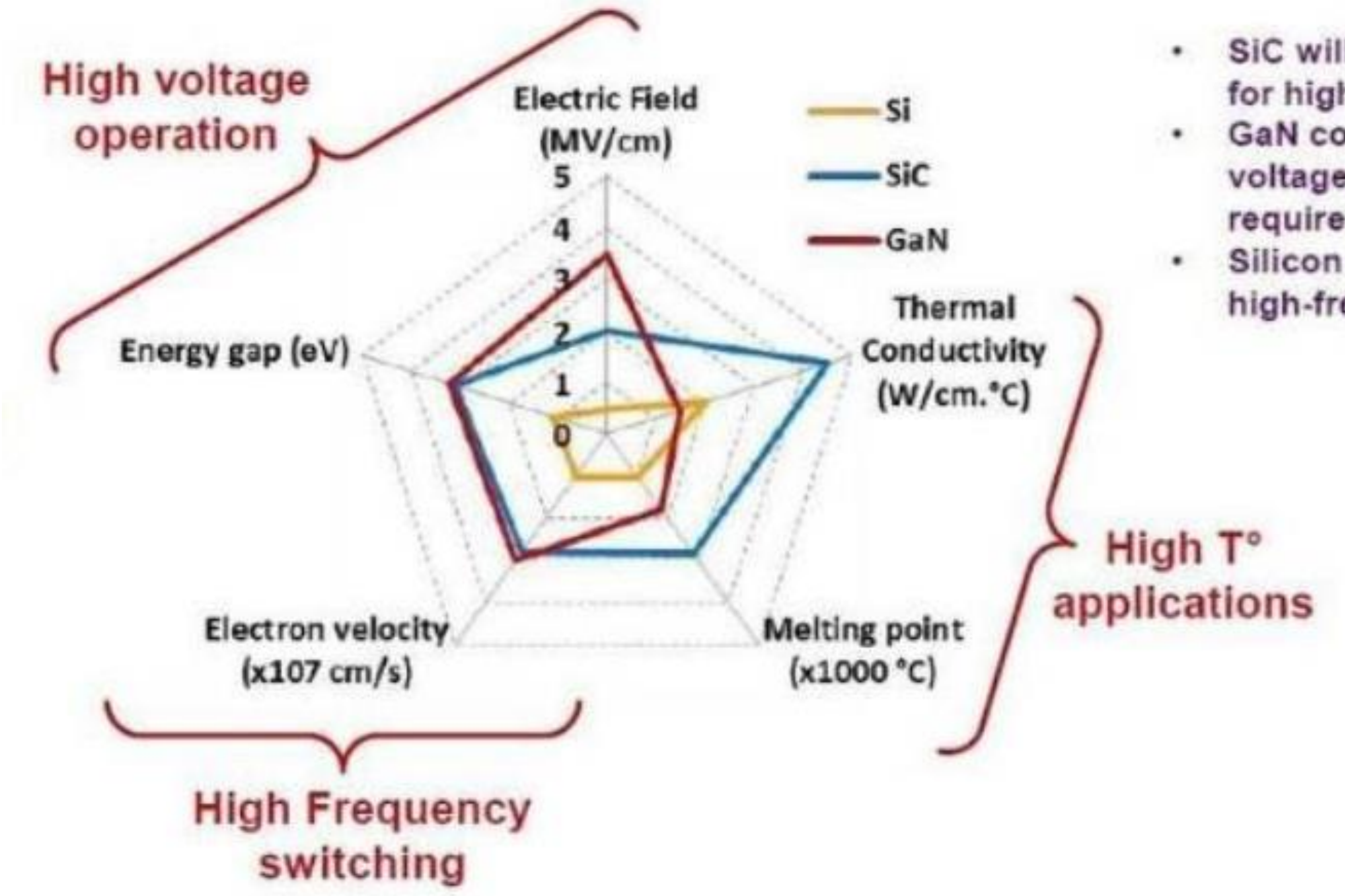
- Wide bandgap semiconductors are materials

  that possess bandgaps significantly greater than those of silicon.



- This will enable devices to operate at :
  - Higher voltage
  - Higher temperature
  - Higher frequency

Theory of Wide Bandgap



- SiC will stay the preferred choice for high T° application
- GaN could possibly reach high-voltage values but thus will require bulk-GaN as the substrate.
- Silicon cannot compete at the high-frequency range

Comparison of the figures of merit of Si, SiC and GaN [Source: Yole Développement]

Theory of Wide Bandgap

Material	Electric Field (MV/cm)	Vsat 10^7(cm/s)
Si	0.3	1.0
SiC	2.0	2.0
GaN	3.3	2.5
C	5.6	2.7

Material	Thermal Conductivity k(W/cm °C)
Si	1.5
SiC	4.5
GaN	1.3
C	20

- **Higher Electric field and higher Vsat (saturation velocity) :**

  - Higher Voltage rating

  - Increased drain current

  - Better on-state performance

  - Improved switching

- **Higher Thermal conductivity enables :**

  - Higher power density

  - Better reliability

  - Higher temperature capability

What is Wide Bandgap ?

GaN (Gallium Nitride)

- Gallium + Nitride
- Used in RF, LED …
- Some properties ;

  - high electron mobility

  - allow small form-factors

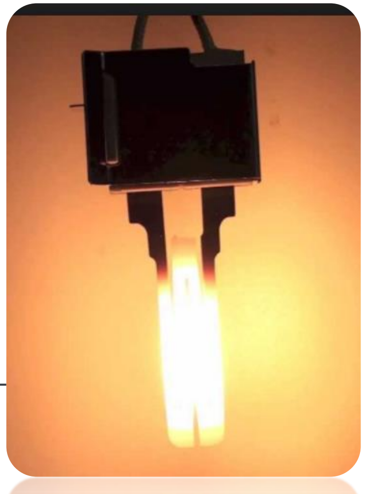
SiC (Silicon Carbide)

- Silicon + Carbon
- Used in Automotive …
- Some properties ;

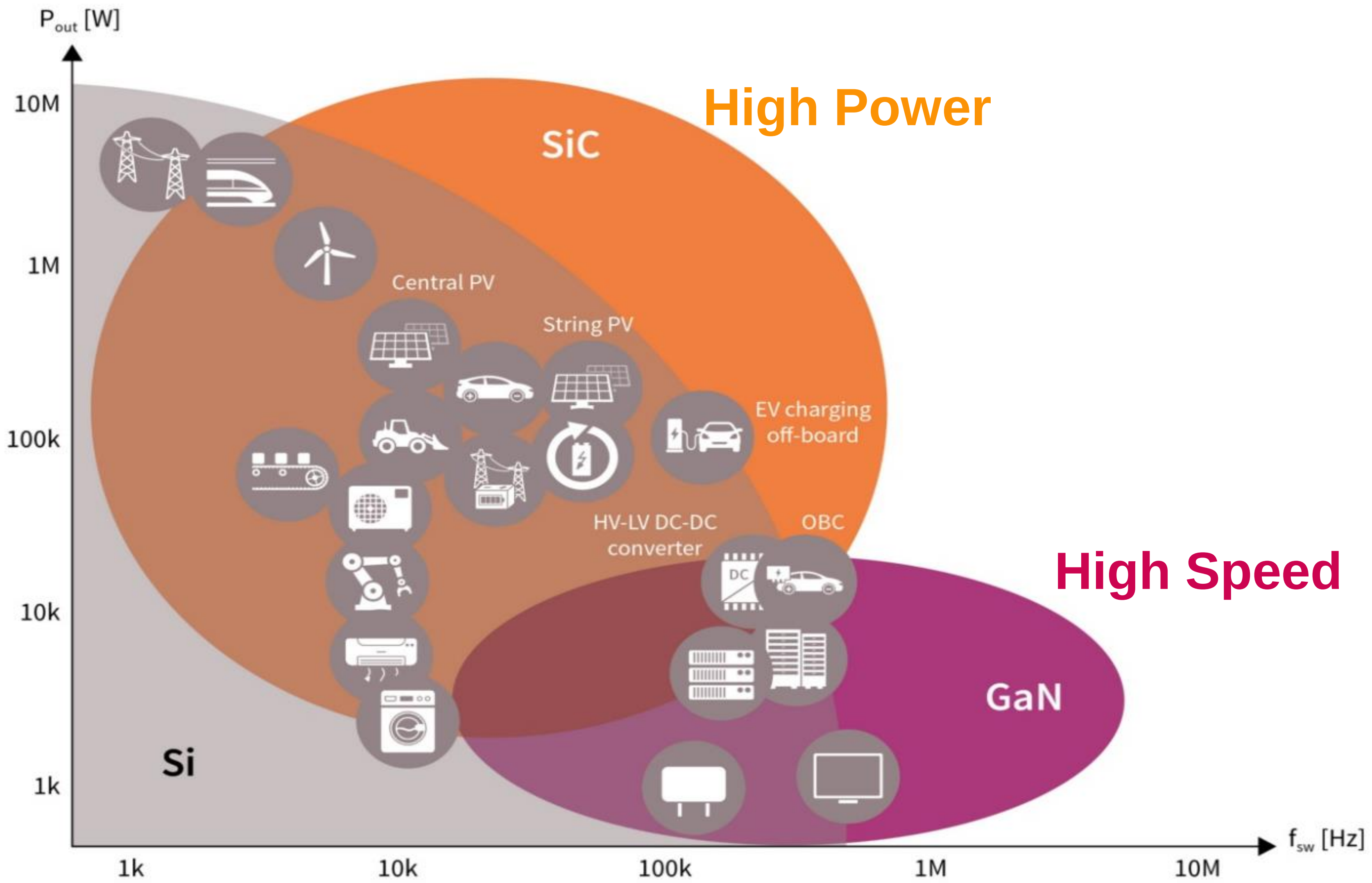
  - high strength

  - hardness

  - high thermal conductivity



Applications



Wide Bandgap Test

Test Configuration

· **2600-PCT-4B**

ACS Basic software @PC

2636B
SMU 1,2 & TSP Node : 1

2657A
SMU 3 & TSP Node : 2

2651A
SMU 4 & TSP Node : 3

8010 Test Fixture

· **4200A**

With integrated clarius software

SMU + CVU + PMU

Test parameters - GaN

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; 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

https://assets.nexperia.com/documents/data-sheet/GAN063-650WSA.pdf

Test parameters - IGBT

ELECTRICAL CHARACTERISTICS (T_J = 25°C unless otherwise noted)

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
OFF CHARACTERISTICS						
Collector–emitter breakdown voltage, gate–emitter short–circuited	V_{GE} = 0 V, I_C = 1 mA	BV_{CES}	650	–	–	V
Temperature Coefficient of Breakdown Voltage	V_{GE} = 0 V, I_C = 1 mA	$\frac{\Delta BV_{CES}}{\Delta T_J}$	–	0.6	–	V/°C
Collector–emitter cut–off current, gate–emitter short–circuited	V_{GE} = 0 V, V_{CE} = 650 V	I_{CES}	–	–	250	μA
Gate leakage current, collector–emitter short–circuited	V_{GE} = 20 V, V_{CE} = 0 V	I_{GES}	–	–	±400	nA
ON CHARACTERISTICS						
Gate–emitter threshold voltage	V_{GE} = V_{CE}, I_C = 50 mA	$V_{GE(th)}$	3.4	4.9	6.4	V
Collector–emitter saturation voltage	V_{GE} = 15 V, I_C = 50 A V_{GE} = 15 V, I_C = 50 A, T_J = 175°C	$V_{CE(sat)}$	– –	1.6 1.95	2.1 –	V

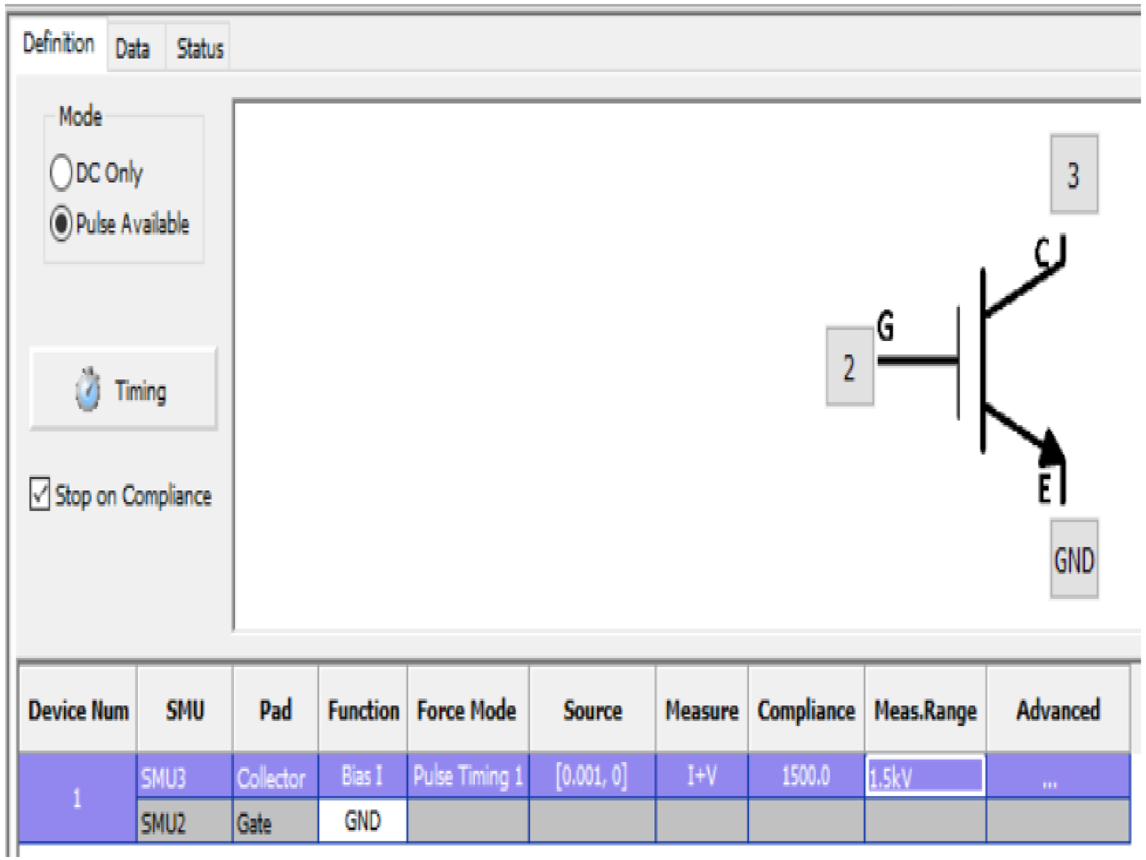
DYNAMIC CHARACTERISTICS

Parameter	Test Conditions	Symbol	Min	Typ	Max	Unit
Input capacitance	V_{CE} = 30 V, V_{GE} = 0 V, f = 1 MHz	C_{ies}	–	3209	–	pF
Output capacitance		C_{oes}	–	42	–	
Reverse transfer capacitance		C_{res}	–	12	–	
Gate charge total	V_{CE} = 400 V, I_C = 50 A, V_{GE} = 15 V	Q_g	–	99	–	nC
Gate–to–emitter charge		Q_{ge}	–	17	–	
Gate–to–collector charge		Q_{gc}	–	23	–	
SWITCHING CHARACTERISTICS, INDUCTIVE LOAD						
Turn–on delay time	T_C = 25°C, V_{CC} = 400 V, I_C = 25 A, R_G = 4.7 Ω, V_{GE} = 15 V, Inductive Load, FWD: AFGHL50T65SQD	$t_{d(on)}$	–	19	–	ns
Rise time		t_r	–	11	–	
Turn–off delay time		$t_{d(off)}$	–	87	–	
Fall time		t_f	–	5	–	
Turn–on switching loss		E_{on}	–	0.35	–	mJ
Turn–off switching loss		E_{off}	–	0.12	–	
Total switching loss		E_{ts}	–	0.47	–	
Turn–on delay time	T_C = 25°C, V_{CC} = 400 V, I_C = 50 A, R_G = 4.7 Ω, V_{GE} = 15 V, Inductive Load, FWD: AFGHL50T65SQD	$t_{d(on)}$	–	20	–	ns
Rise time		t_r	–	28	–	
Turn–off delay time		$t_{d(off)}$	–	81	–	
Fall time		t_f	–	36	–	
Turn–on switching loss		E_{on}	–	0.95	–	mJ
Turn–off switching loss		E_{off}	–	0.46	–	
Total switching loss		E_{ts}	–	1.41	–	

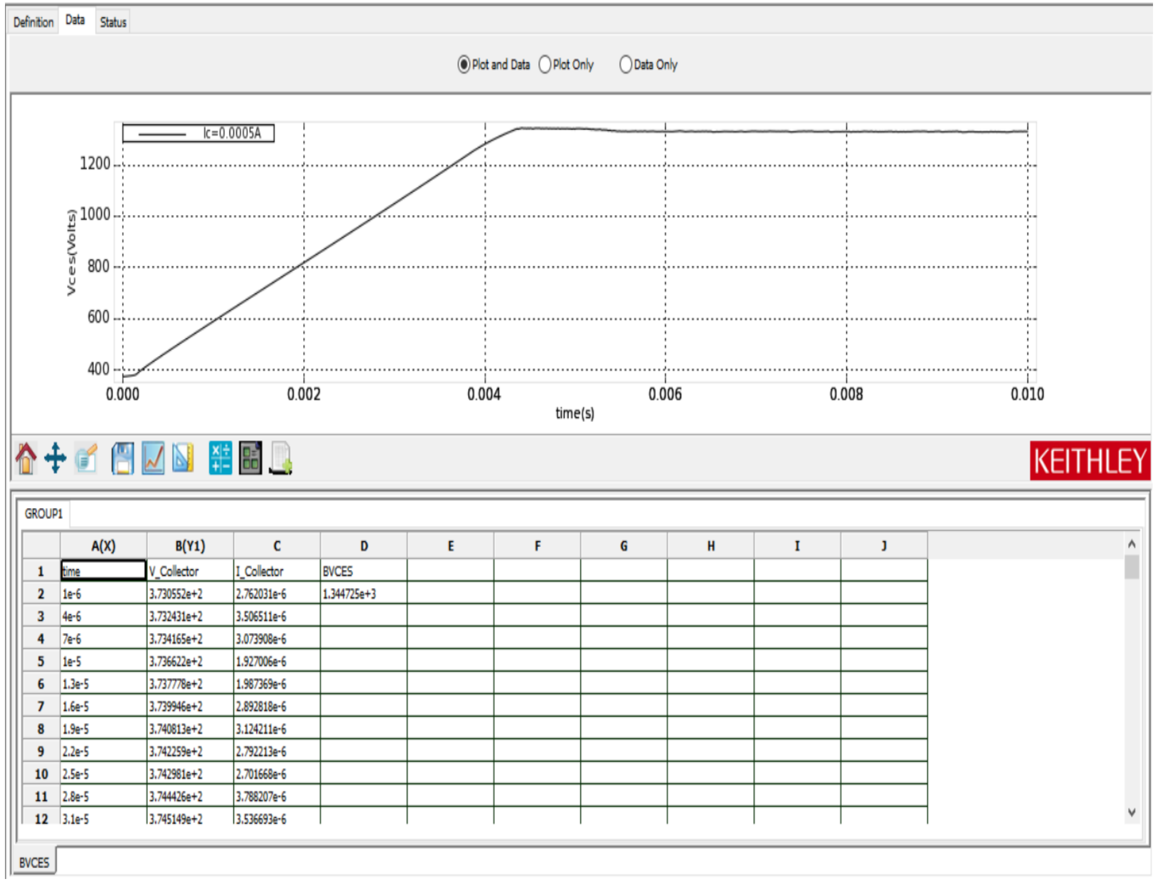
https://www.onsemi.com/pdf/datasheet/afghl50t65sq-d.pdf

■ BVces

Test condition	Test result



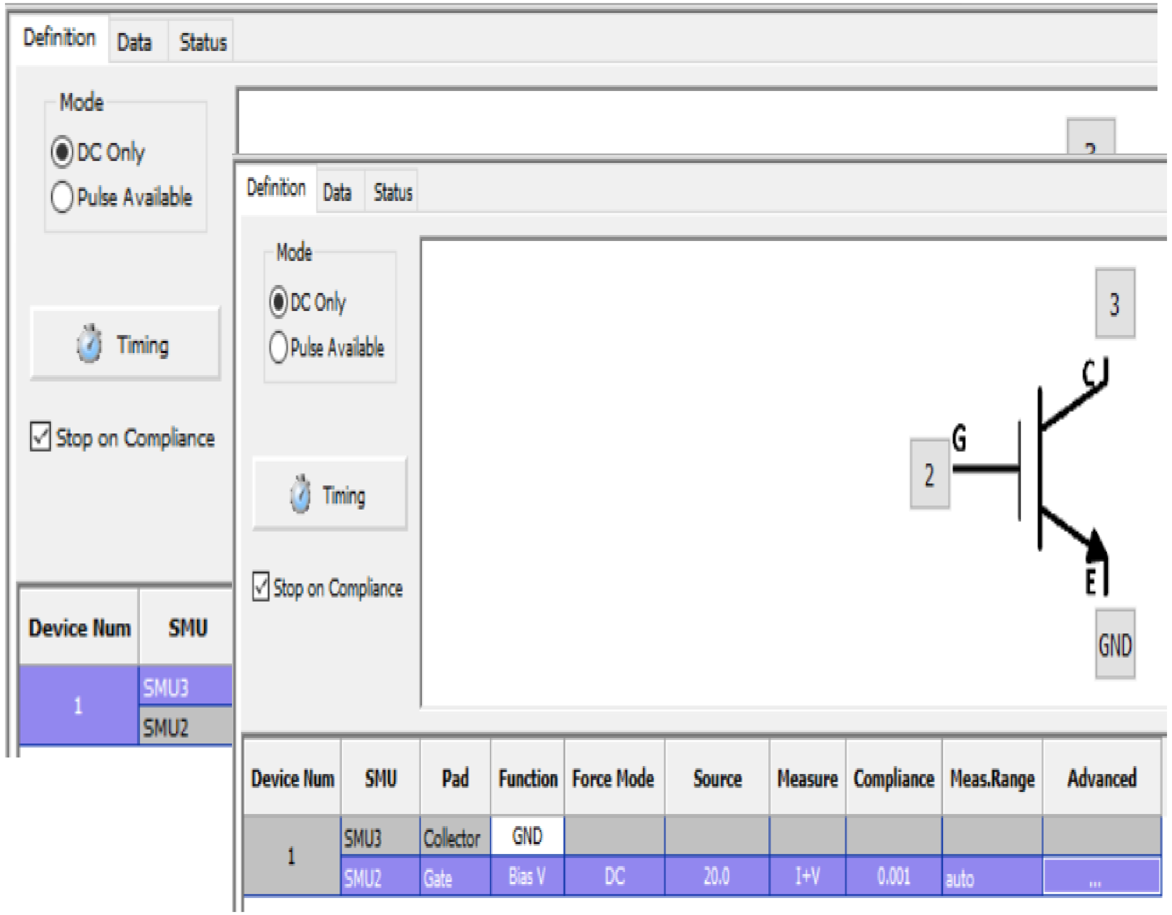
Device Num	SMU	Pad	Function	Force Mode	Source	Measure	Compliance	Meas.Range	Advanced
1	SMU3	Collector	Bias I	Pulse Timing 1	[0.001, 0]	I+V	1500.0	1.5kV	...
	SMU2	Gate	GND						

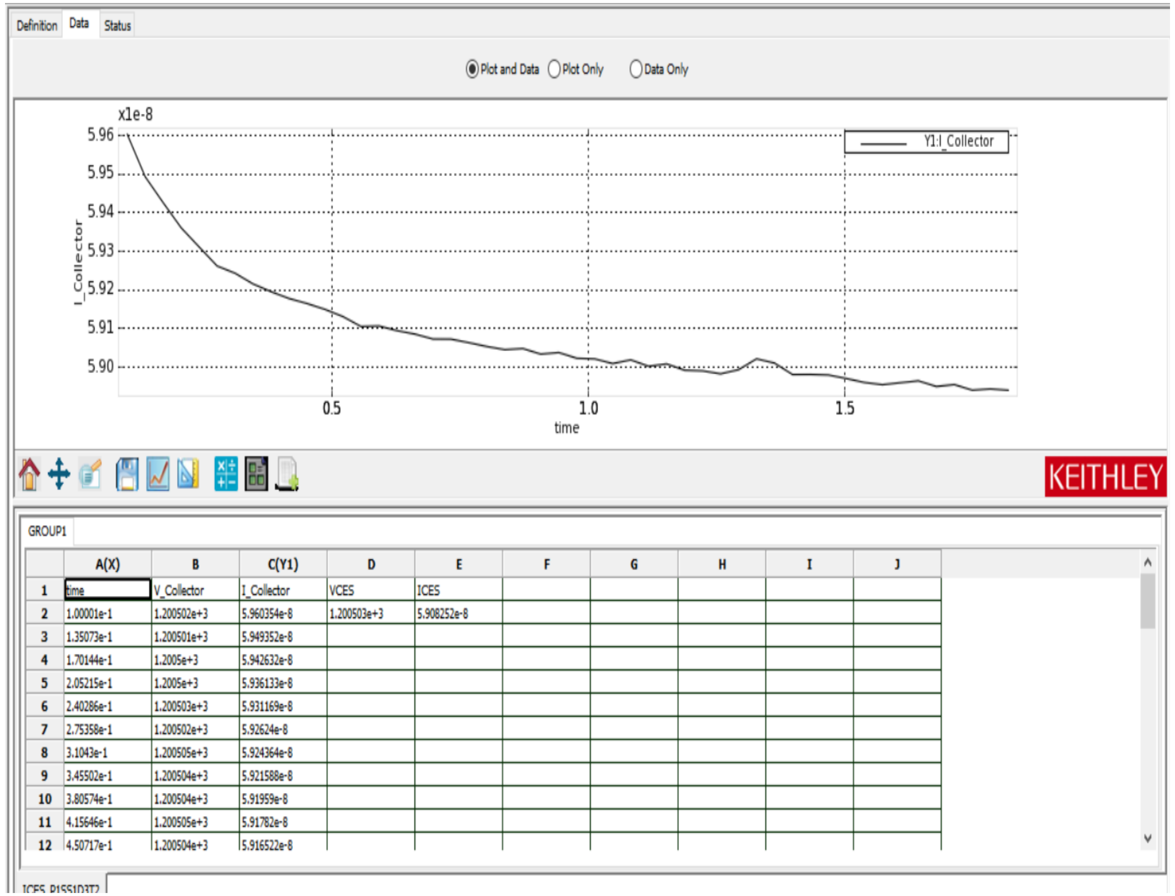


	A(X)	B(Y1)	C	D	E	F	G	H	I	J
1	time	V_Collector	I_Collector	BVCES						
2	1e-6	3.730552e+2	2.762031e-6	1.344725e+3						
3	4e-6	3.732431e+2	3.506511e-6							
4	7e-6	3.734165e+2	3.073908e-6							
5	1e-5	3.736622e+2	1.927006e-6							
6	1.3e-5	3.737778e+2	1.987369e-6							
7	1.6e-5	3.739946e+2	2.892818e-6							
8	1.9e-5	3.740813e+2	3.124211e-6							
9	2.2e-5	3.742259e+2	2.792213e-6							
10	2.5e-5	3.742981e+2	2.701668e-6							
11	2.8e-5	3.744426e+2	3.788207e-6							
12	3.1e-5	3.745149e+2	3.536693e-6							

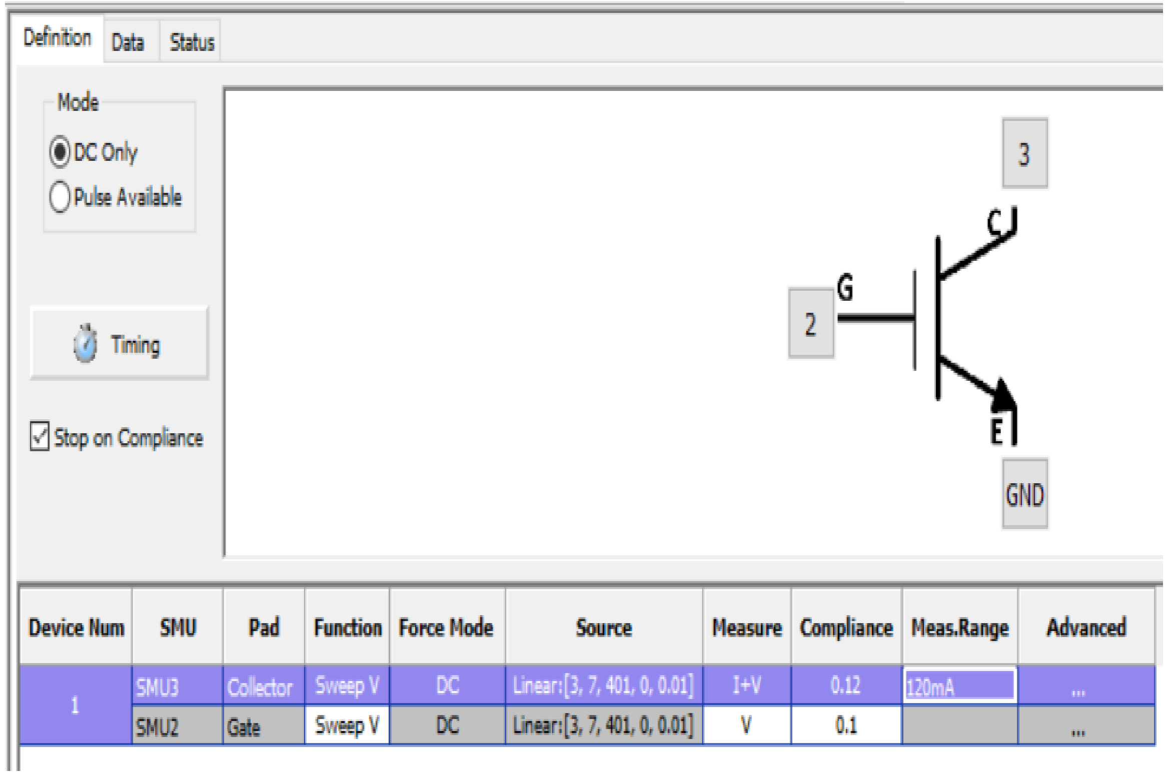
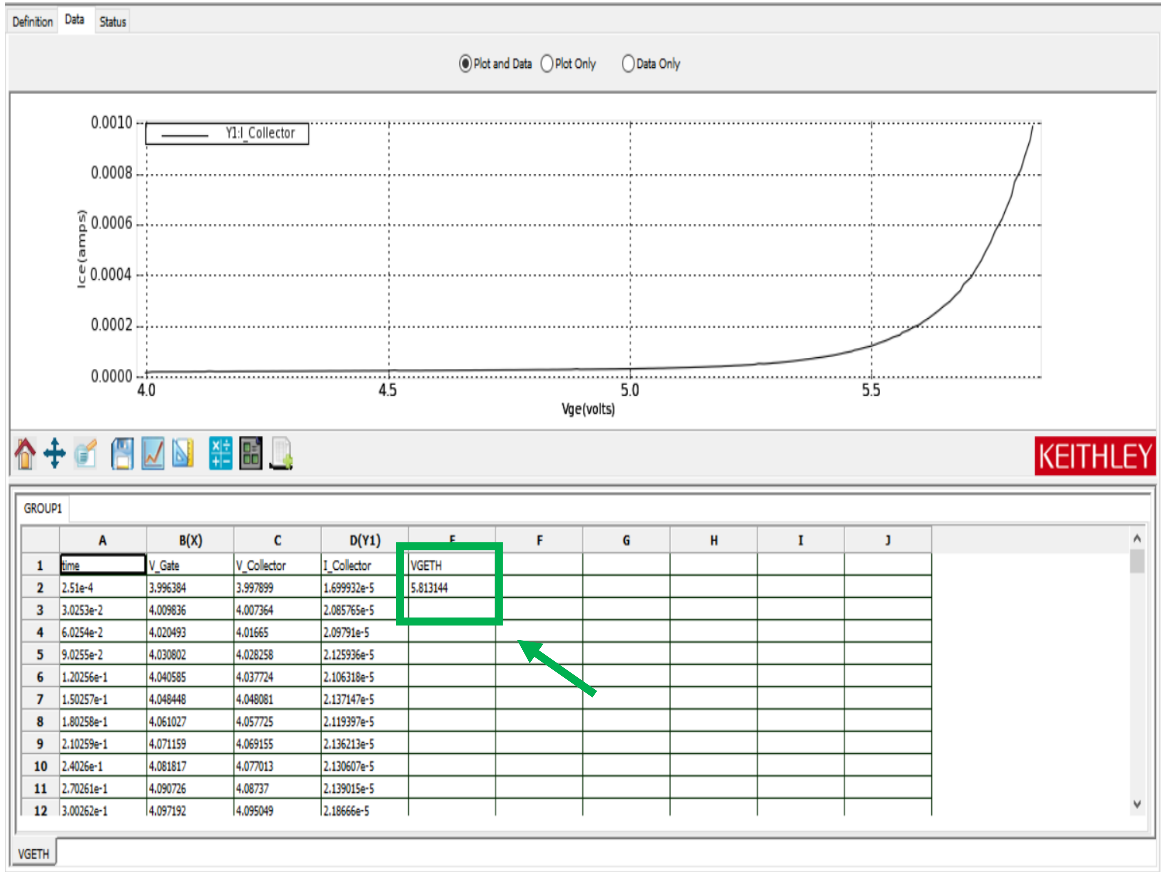
■ Ices & Iges

Test condition	Test result





■ Vge(th)

Test condition	Test result
	

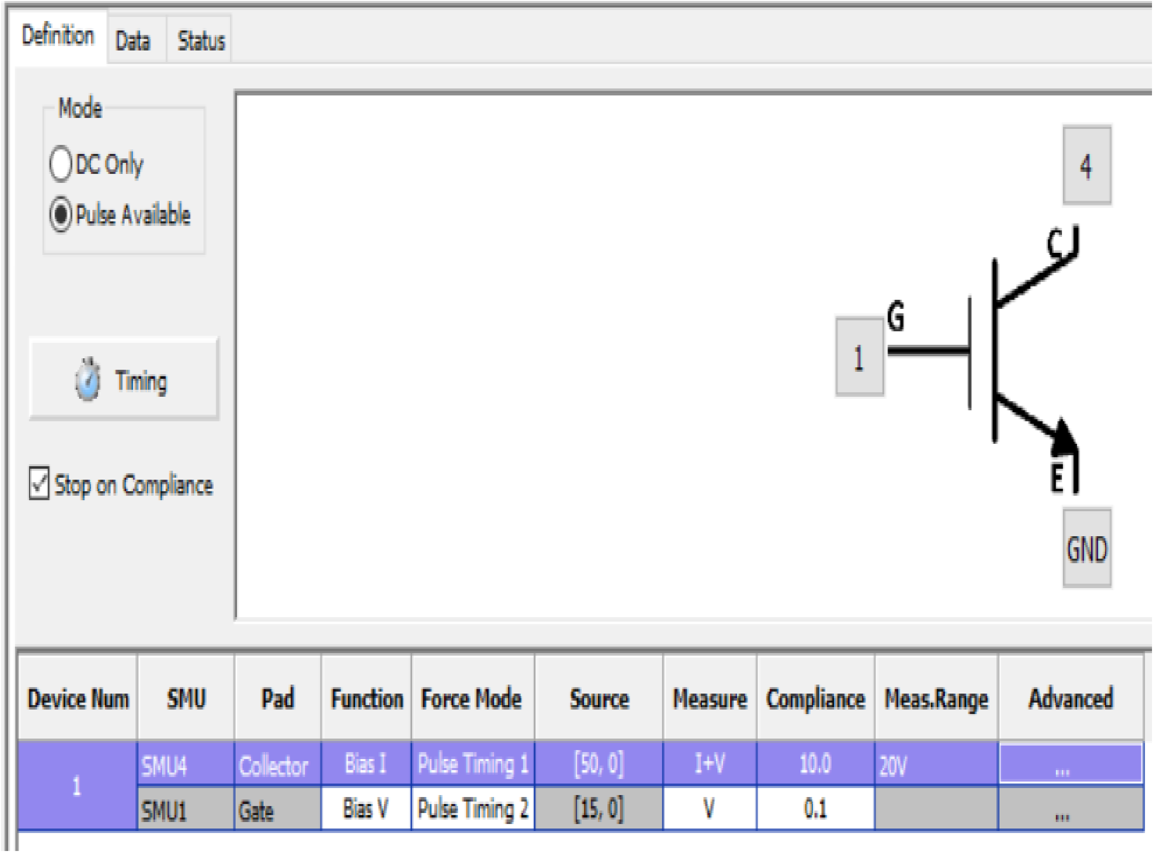
Device Num	SMU	Pad	Function	Force Mode	Source	Measure	Compliance	Meas.Range	Advanced
1	SMU3	Collector	Sweep V	DC	Linear:[3, 7, 401, 0, 0.01]	I+V	0.12	120mA	...
	SMU2	Gate	Sweep V	DC	Linear:[3, 7, 401, 0, 0.01]	V	0.1		...

Vge(th) = AT(V_Gate,FINDLIN(I_Collector,0.00085,2))

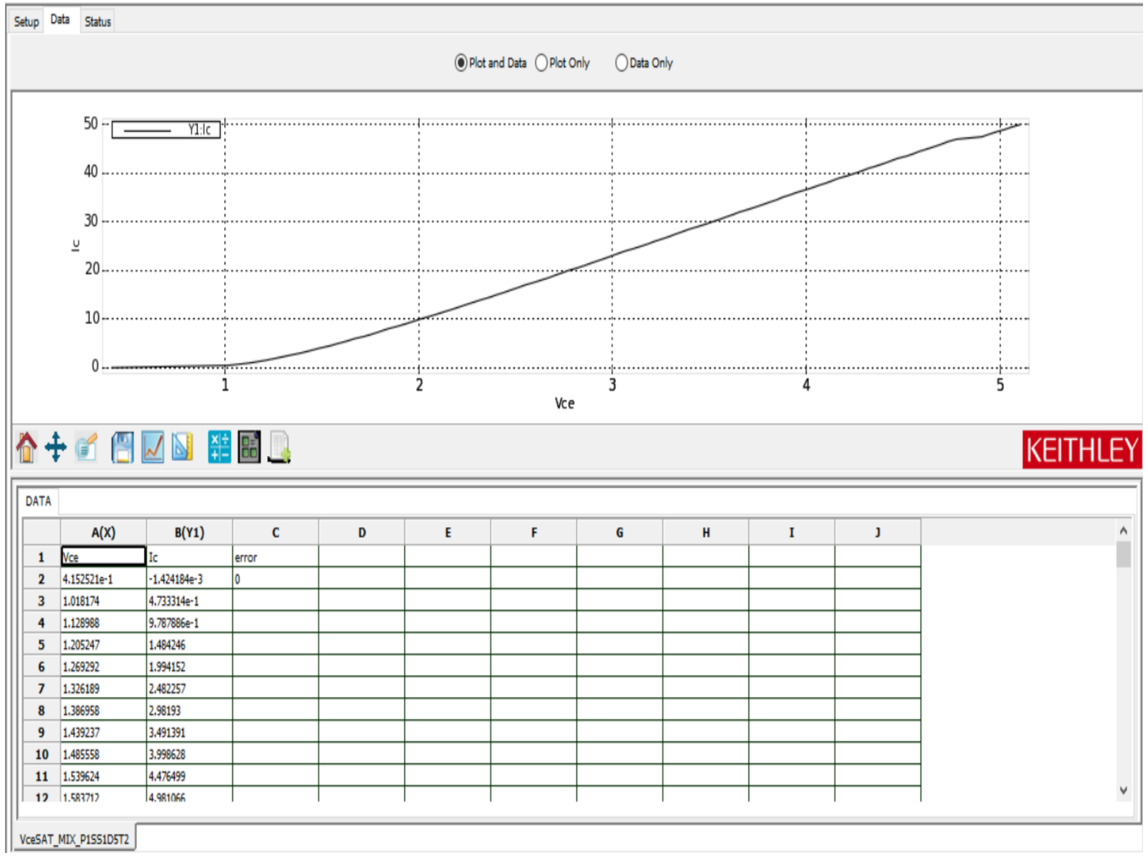
	A	B(X)	C	D(Y1)	E	F	G	H	I	J
1	time	V_Gate	V_Collector	I_Collector	VGETH					
2	2.51e-4	3.996384	3.997899	1.699932e-5	5.813144					
3	3.0253e-2	4.009836	4.007364	2.085765e-5						
4	6.0254e-2	4.020493	4.01665	2.09791e-5						
5	9.0255e-2	4.030802	4.028258	2.125936e-5						
6	1.20256e-1	4.040585	4.037724	2.106318e-5						
7	1.50257e-1	4.048448	4.048081	2.137147e-5						
8	1.80258e-1	4.061027	4.057725	2.119397e-5						
9	2.10259e-1	4.071159	4.069155	2.136213e-5						
10	2.4026e-1	4.081817	4.077013	2.130607e-5						
11	2.70261e-1	4.090726	4.08737	2.139015e-5						
12	3.00262e-1	4.097192	4.095049	2.18666e-5						

■ Vce(sat)

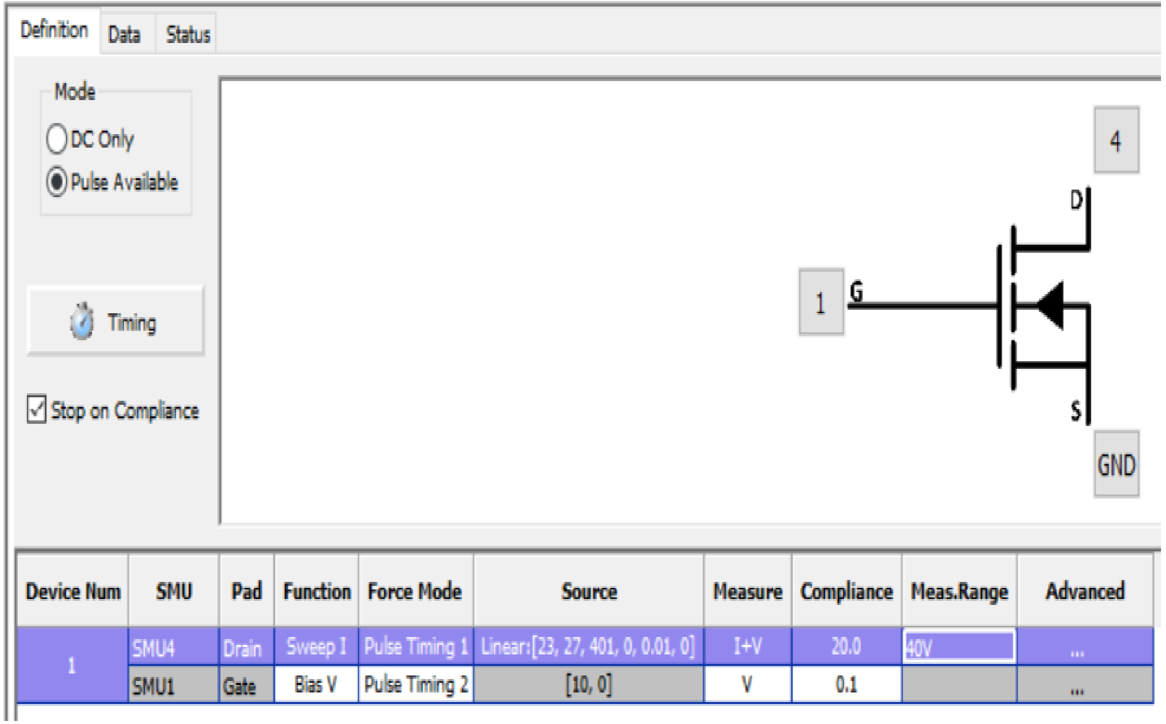
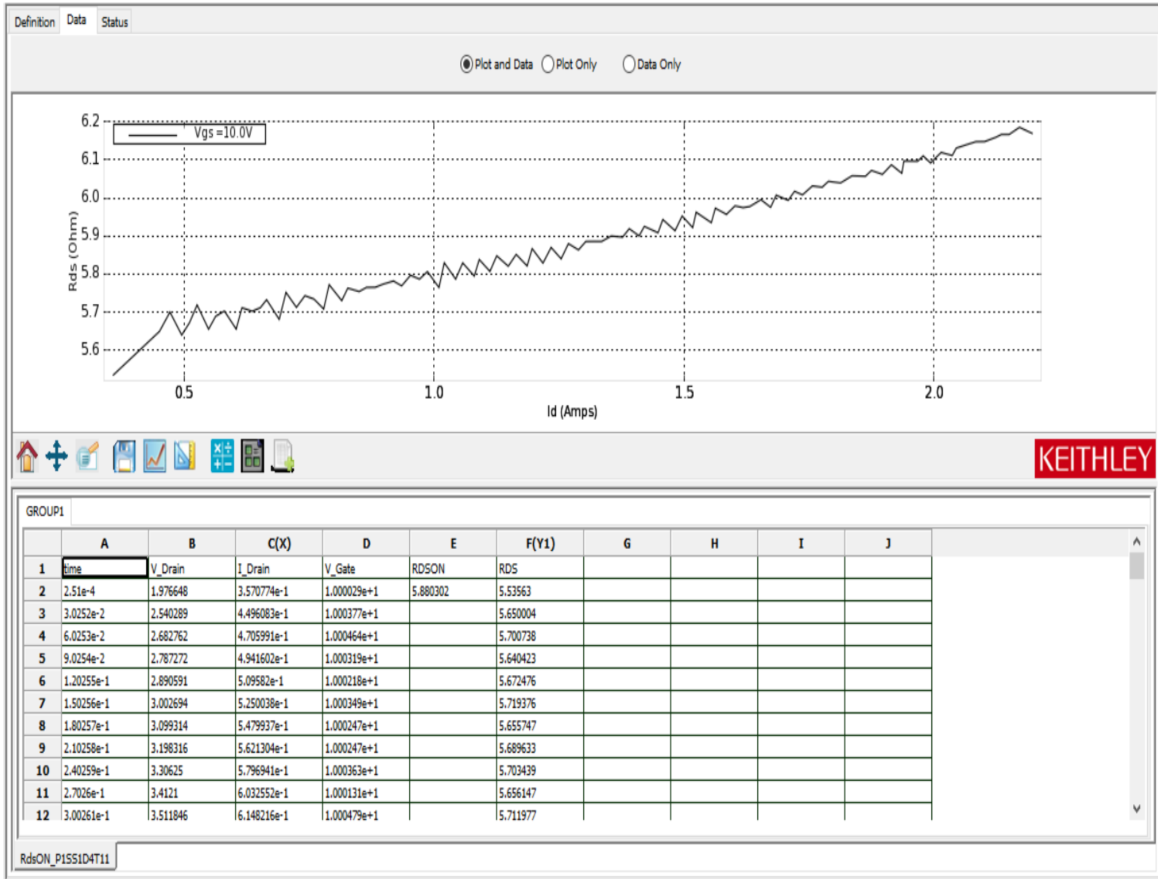
Test condition



Test result



■ Rds(on)

Test condition	Test result
	

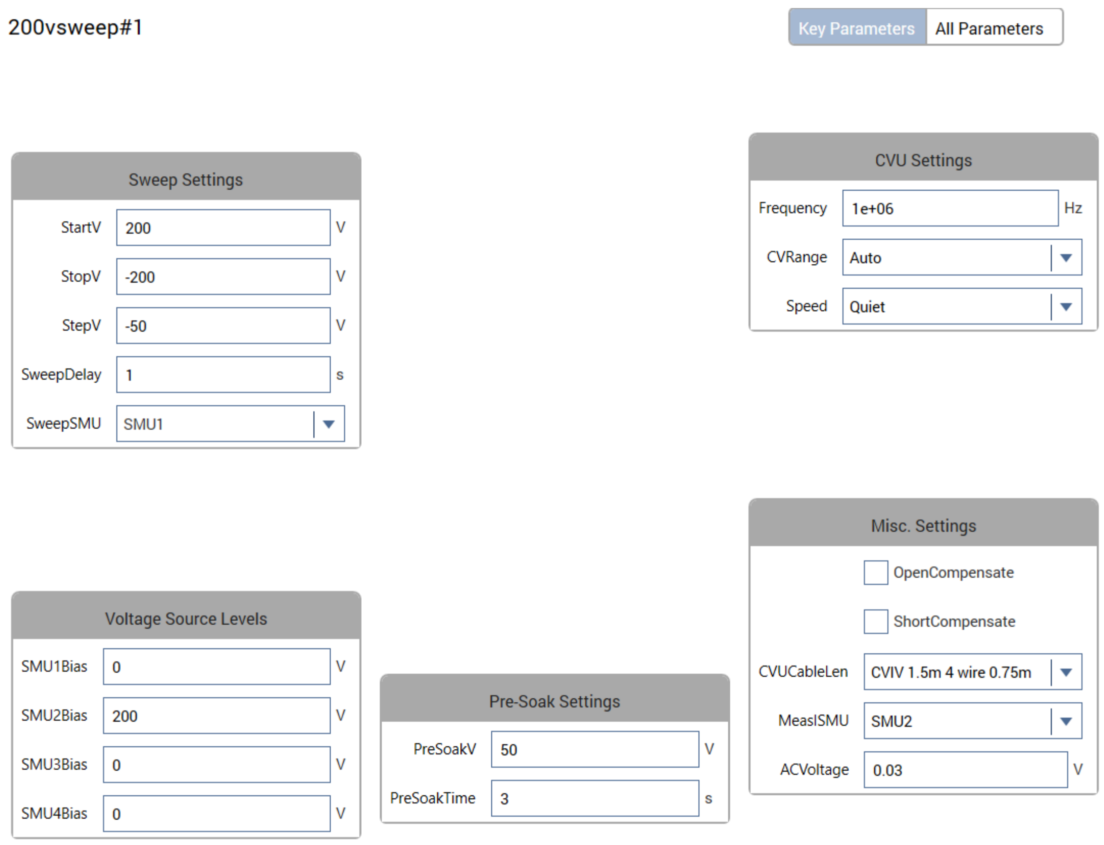
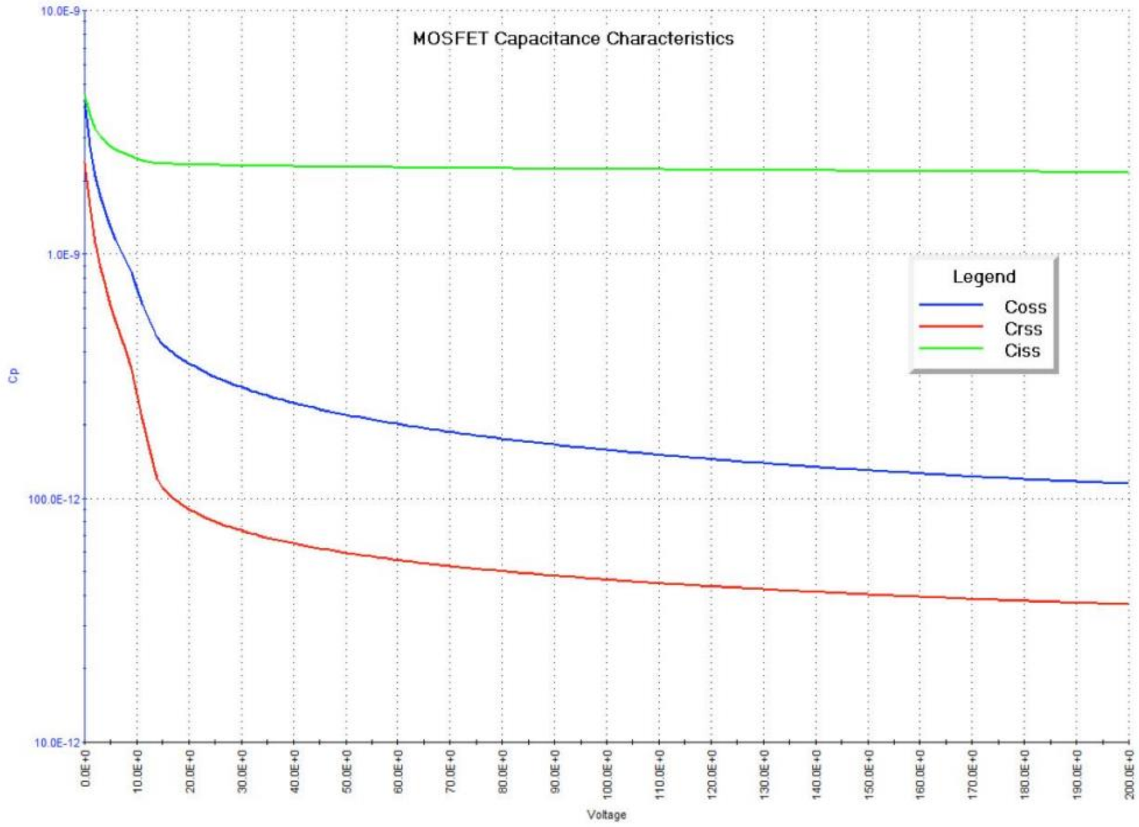
Device Num	SMU	Pad	Function	Force Mode	Source	Measure	Compliance	Meas.Range	Advanced
1	SMU4	Drain	Sweep I	Pulse Timing 1	Linear:[23, 27, 401, 0, 0.01, 0]	I+V	20.0	40V	...
	SMU1	Gate	Bias V	Pulse Timing 2	[10, 0]	V	0.1		...

	A	B	C(X)	D	E	F(Y1)	G	H	I	J
1	time	V_Drain	I_Drain	V_Gate	RDSON	RDS				
2	2.51e-4	1.976648	3.570774e-1	1.000029e+1	5.880302	5.53563				
3	3.0252e-2	2.540289	4.496083e-1	1.000377e+1		5.650004				
4	6.0253e-2	2.682762	4.705991e-1	1.000464e+1		5.700738				
5	9.0254e-2	2.787272	4.941602e-1	1.000319e+1		5.640423				
6	1.20255e-1	2.890591	5.09582e-1	1.000218e+1		5.672476				
7	1.50256e-1	3.002694	5.250038e-1	1.000349e+1		5.719376				
8	1.80257e-1	3.099314	5.479937e-1	1.000247e+1		5.655747				
9	2.10258e-1	3.198316	5.621304e-1	1.000247e+1		5.689633				
10	2.40259e-1	3.30625	5.796941e-1	1.000363e+1		5.703439				
11	2.7026e-1	3.4121	6.032552e-1	1.000131e+1		5.656147				
12	3.00261e-1	3.511846	6.148216e-1	1.000479e+1		5.711977				

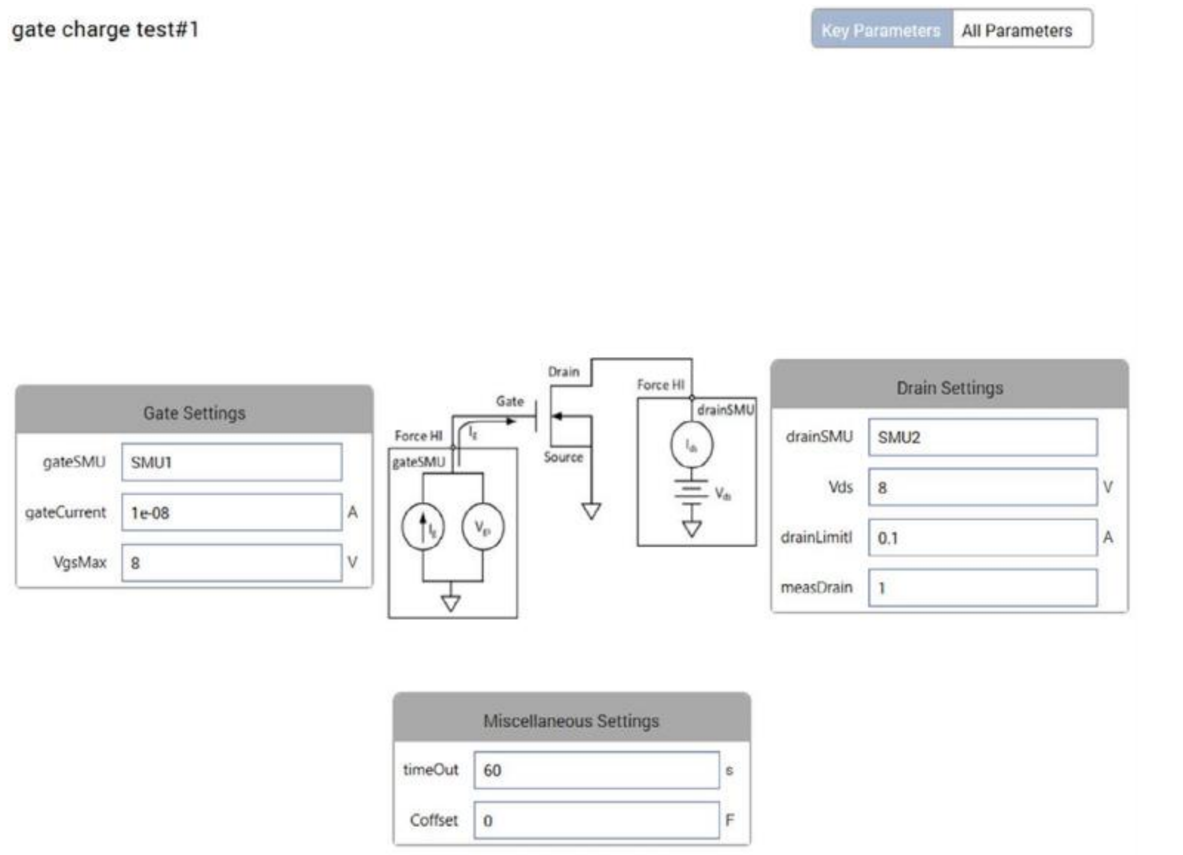
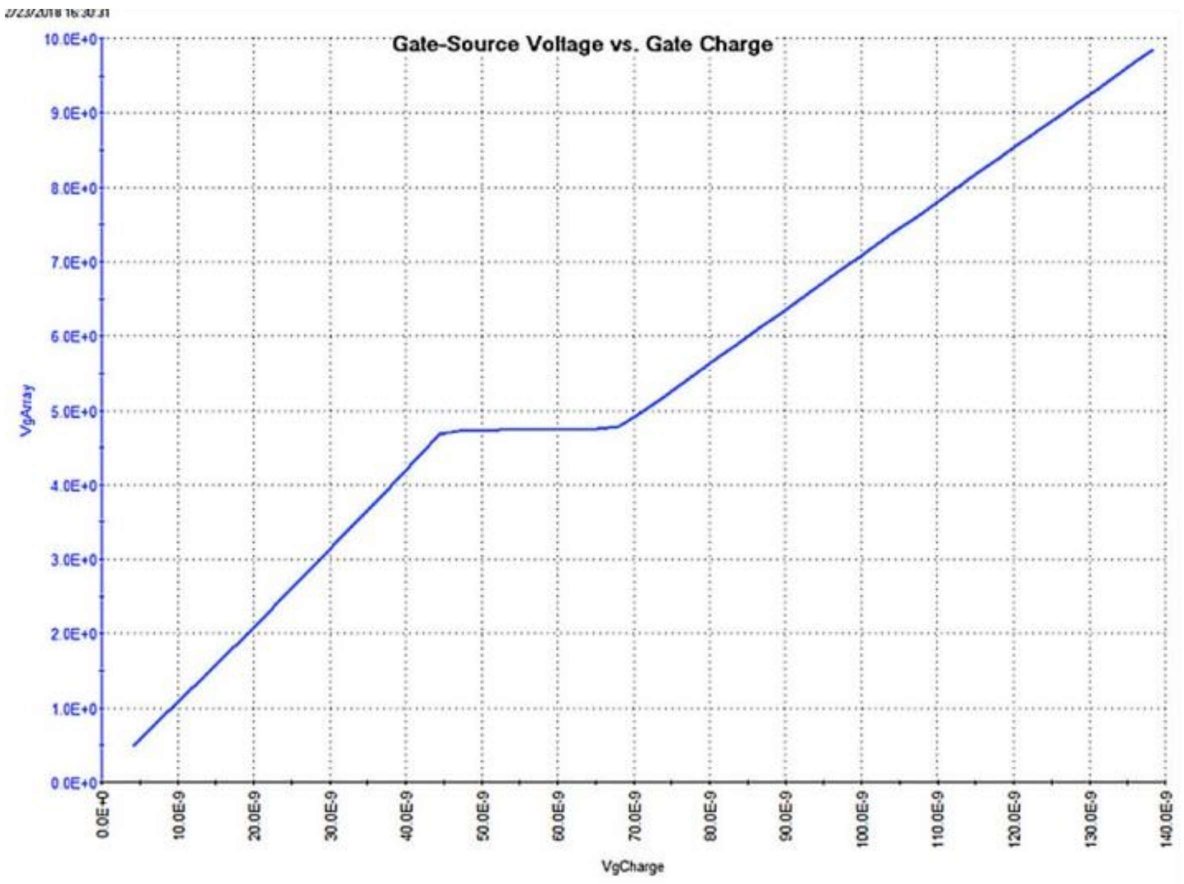
RDS=V_Drain/I_Drain

RDS(ON)=AT(V_Drain,FINDLIN(I_Drain,1.3,2))/AT(I_Drain,FINDLIN(I_Drain,1.3,2))

■ Ciss & Coss & Crss

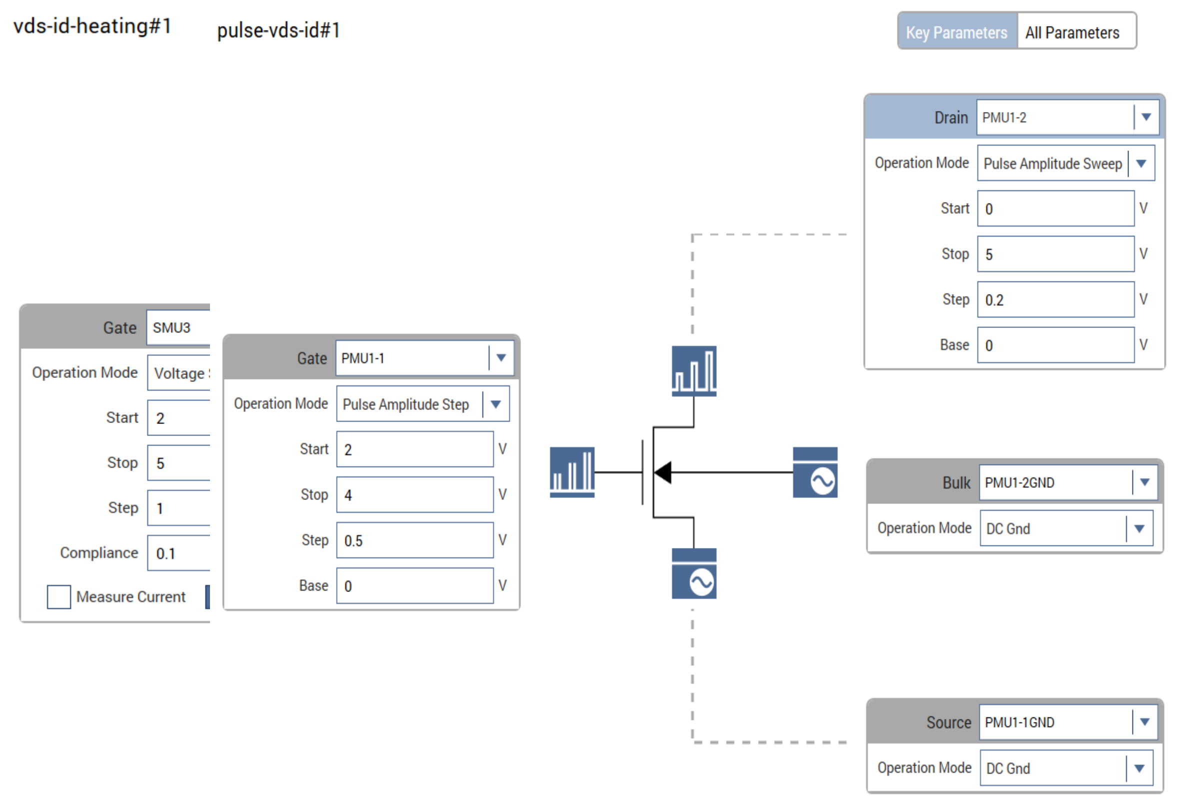
Test condition	Test result
	

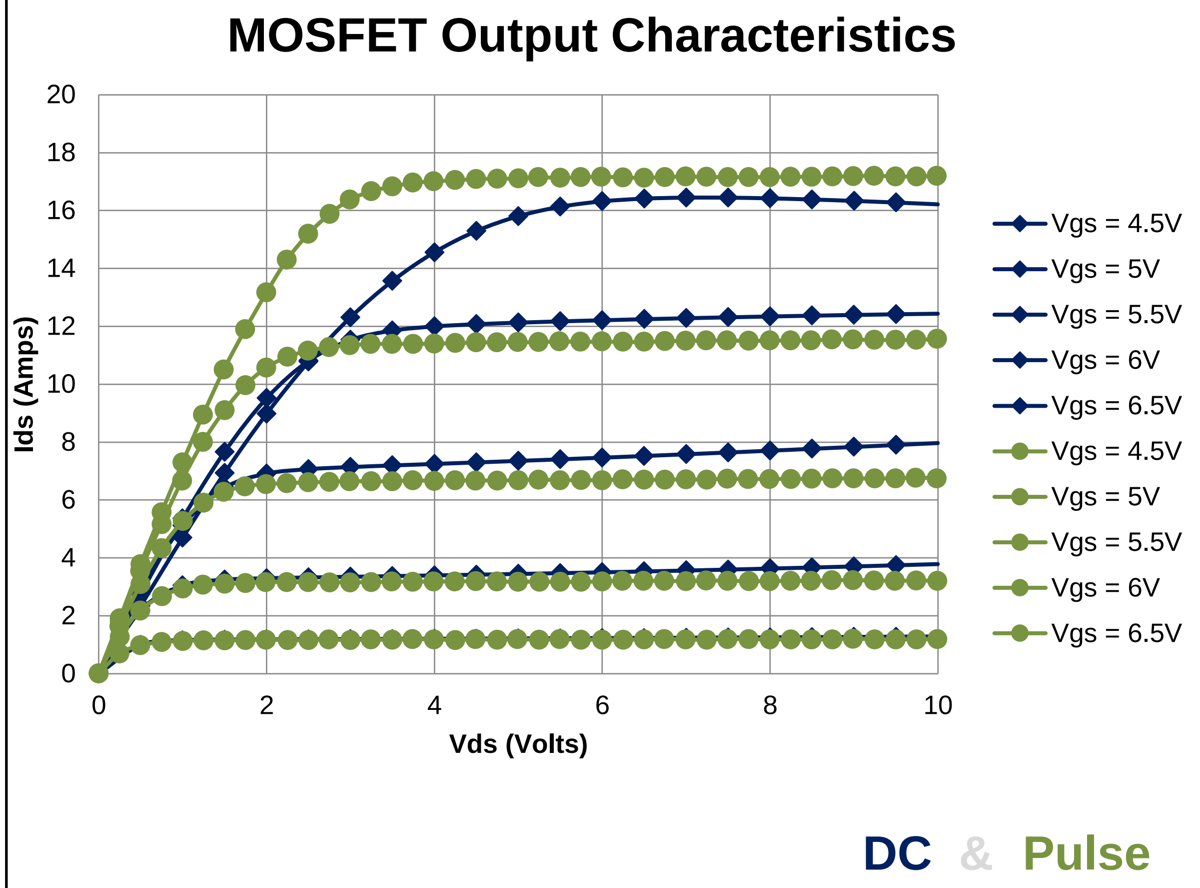
■ Qg (Qgs & Qgd)

Test condition	Test result
	

■ Self-heating effect

Test condition	Test result





Tektronix Suggestions

Tektronix Suggestion

1. **2600-PCT** for measuring various parameters except capacitance

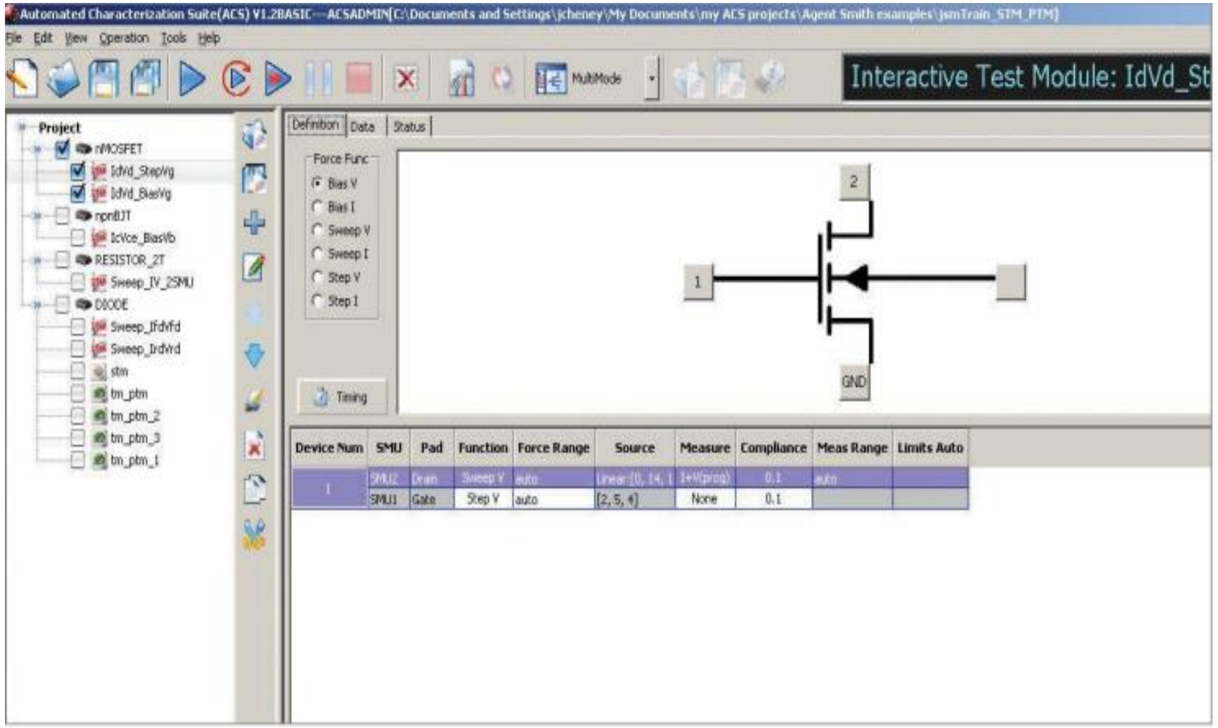
Tektronix Suggestion

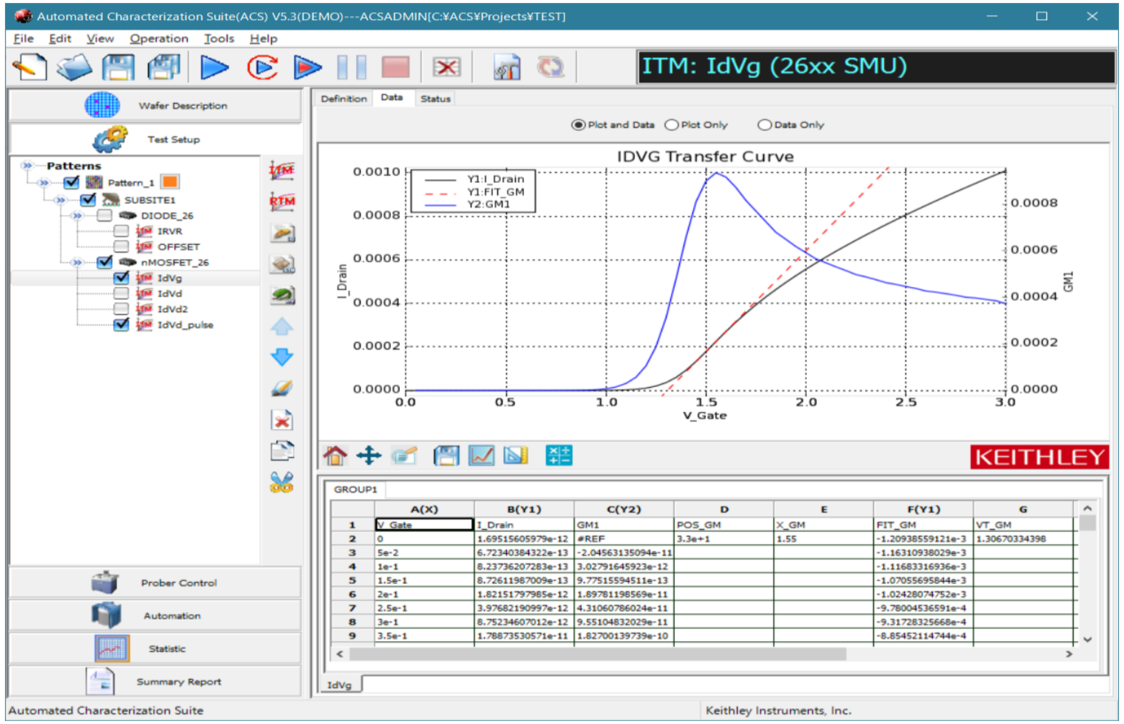
1. 2600-PCT Spec

Model		Collector/Drain Supply		Step Generator	Auxiliary Supply
		High Voltage Mode	High Current Mode	Base/Gate supply	
Low Power	2600-PCT-1B	200V/10A	200V/10A	200V/10A	N/A
High Current	2600-PCT-2B	200V/10A	40V/50A	200V/10A	200V/10A
High Voltage	2600-PCT-3B	3KV/120mA	200V/10A	200V/10A	200V/10A
High Current and High Voltage	2600-PCT-4B	3KV/120mA	40V/50A	200V/10A	200V/10A
High Current and High Voltage	2600-PCT-4B + 2651A	3KV/120mA	40V/100A	200V/20A	200V/20A

Tektronix Suggestion

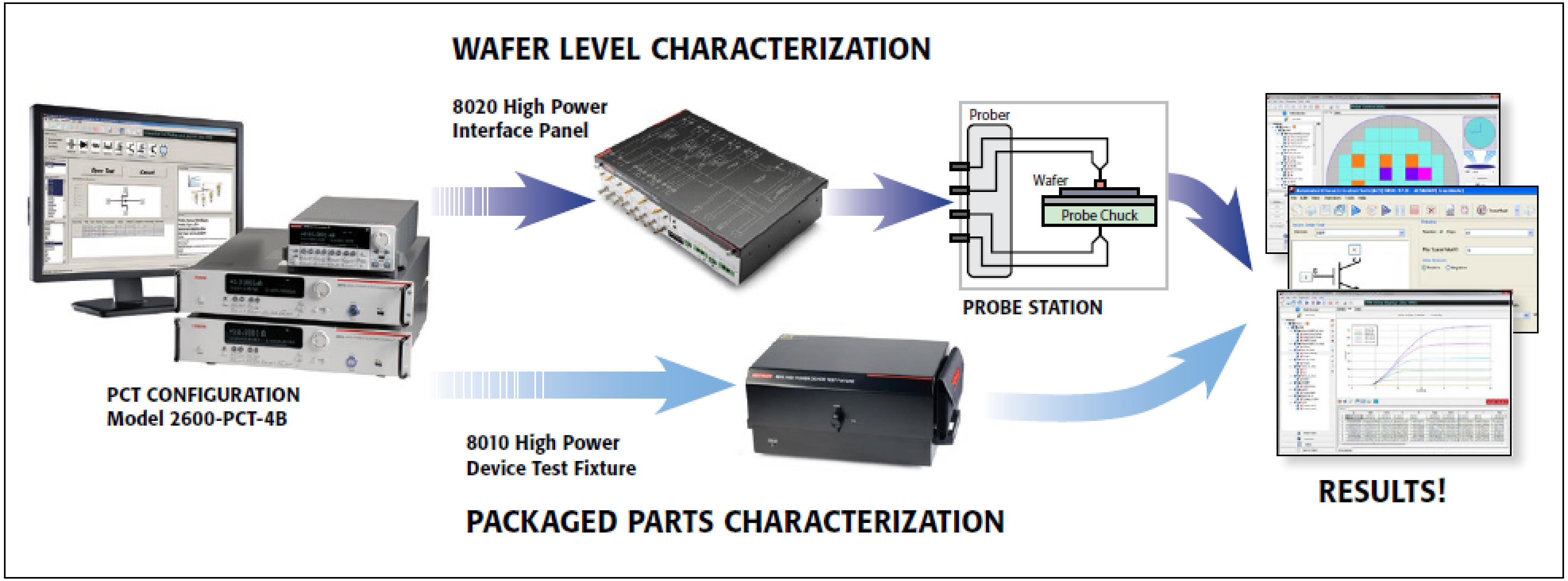
1. 2600-PCT Software





Tektronix Suggestion

1. 2600-PCT Setup



Tektronix Suggestion

2. 4200A for measuring capacitance and pulse IV

Tektronix Suggestion

2. 4200A Spec

Modules	Description	Key Measurements	Range
4200-SMU 4201-SMU	Medium power Source Measure Unit	• DC I-V • VLF C-V (Very low frequency C-V) • QSCV	±100 mA, ±210 V
4210-SMU 4211-SMU	High power Source Measure Unit		±1 A, ±210 V
4200-PA	Remote Preamplifier Module		Extends current ranges for all SMU's
4215-CVU	Capacitance-Voltage Unit	• AC Impedance • C-V, C-f, C-t	1 kHz – 10 MHz ±30 V built-in DC bias (60 V differential) ±210 V DC bias with SMU's
4200A-CVIV	I-V/C-V Multi-Switch Module	DC I-V and C-V with automatic switching	-
4225-PMU	Ultra-Fast Pulse Measure Unit	• Pulsed I-V • SegmentARB® multi-level pulsing • Transient Waveform Capture	±40 V (80 V p-p), ±800 mA 200 M Sa/s simultaneous I and V measure 2048 unique segments 20 ns PW source only 60 ns PW source/measure
4225-RPM	Remote Preamplifier/Switch Module	DC I-V, C-V, Pulsed I-V with automatic switching	Extends current range of 4225-PMU unit
4220-PGU	High Voltage Pulse Generator Unit	• Pulsed voltage source • SegmentARB® multi-level pulsing	±40 V (80 V p-p) 2048 unique segments

Tektronix Suggestion

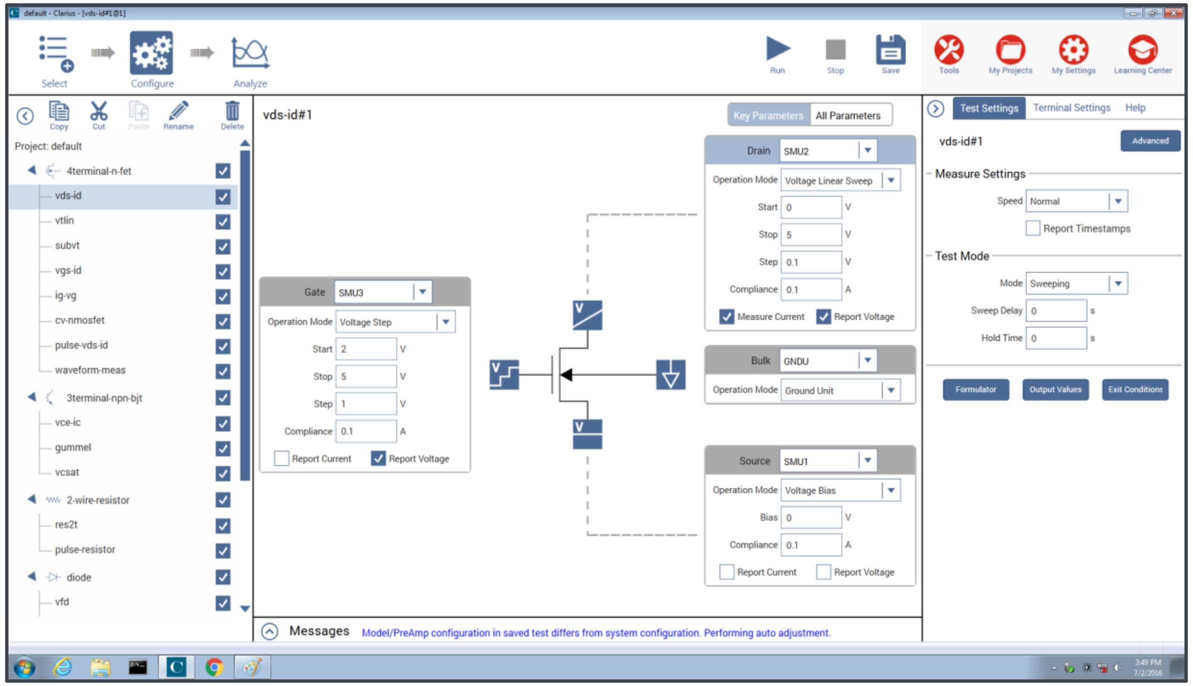
2. 4200A features

- Integrated parameter analyzer that reduces characterization complexity, troubleshooting and test set up time.
- Fully characterize a device, material or process
  - DC I-V Source Measure Units (SMU)
  - AC Impedance Capacitance-Voltage Unit (CVU)
  - Pulsed I-V Pulse Measure Unit (PMU)
- Industry’s easiest methods to switch between I-V, C-V and Pulsed I-V measurements

- Jumpstart testing with over 250 user-modifiable, searchable application tests
  No complex programming required
- Industry’s first instrument with built-in measurement videos
  - “YouTube-like” experience
  - Get answers faster and investigate unexpected results more quickly

Tektronix Suggestion

2. 4200A Software

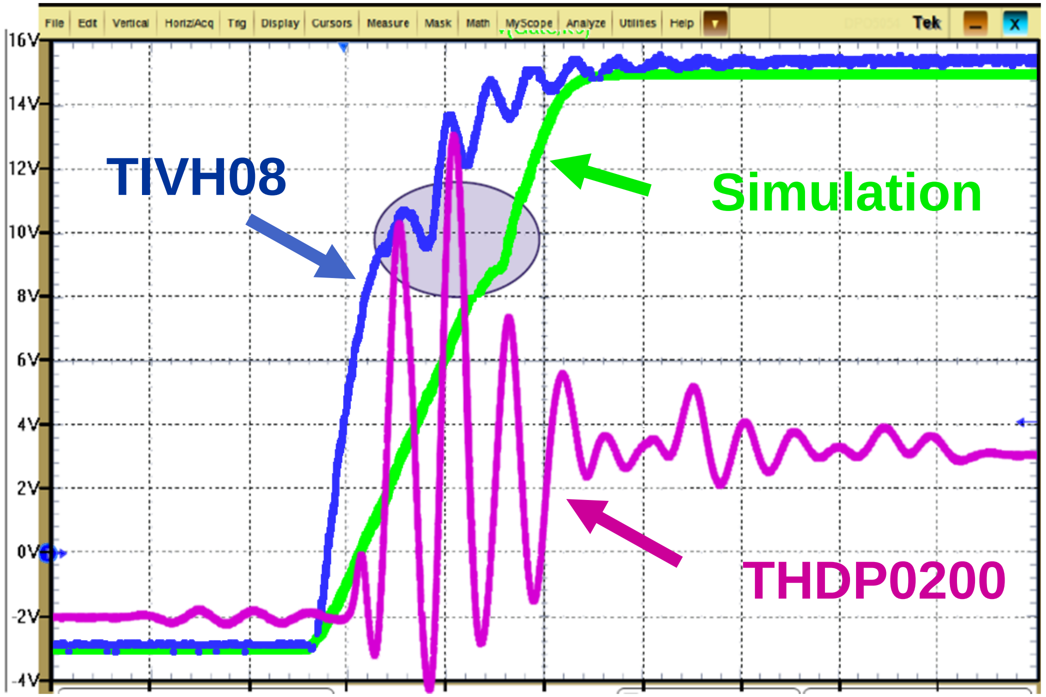


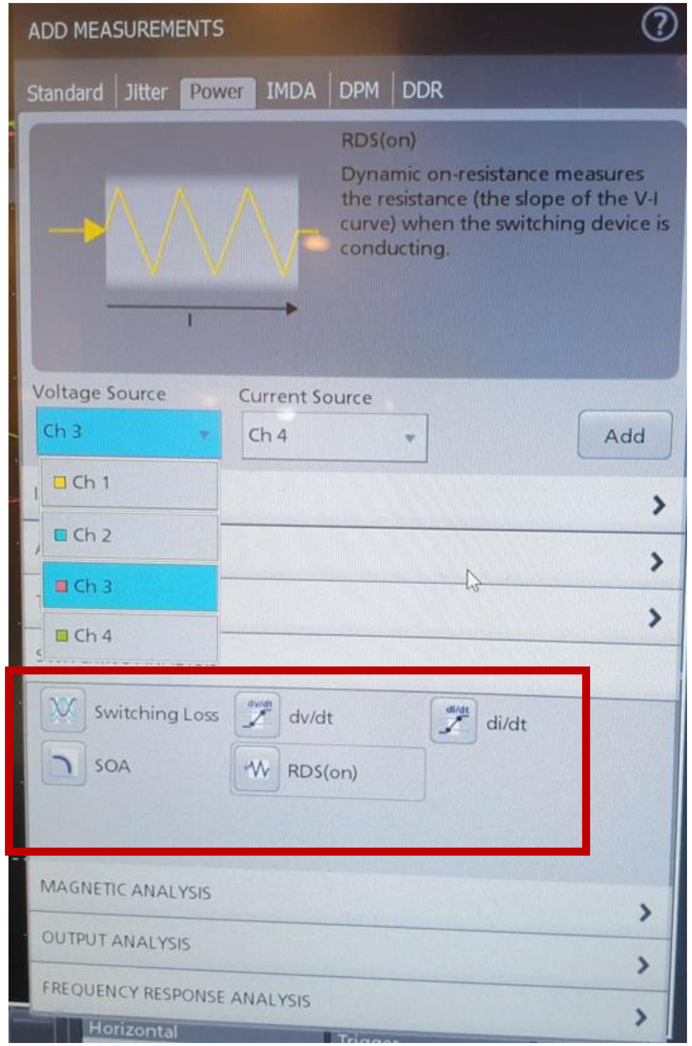
Tektronix Suggestion

3. Keithley Parametric test system for measuring various parameters

Tektronix Suggestion

4. Scope + IsoVu for measuring various parameters





Summary

- Wide Bandgap Semiconductors will play a big role of power devices.
- They are smaller, faster and more efficient than Silicon Counterpart.
- For meeting this, the characterizations involve measurements for materials is needed such as conduction loss, switching loss and many other parameters.
- Tektronix/Keithley can suggest 2600-PCT, 4200A and Oscilloscope with IsoVu for test.

Thank you !