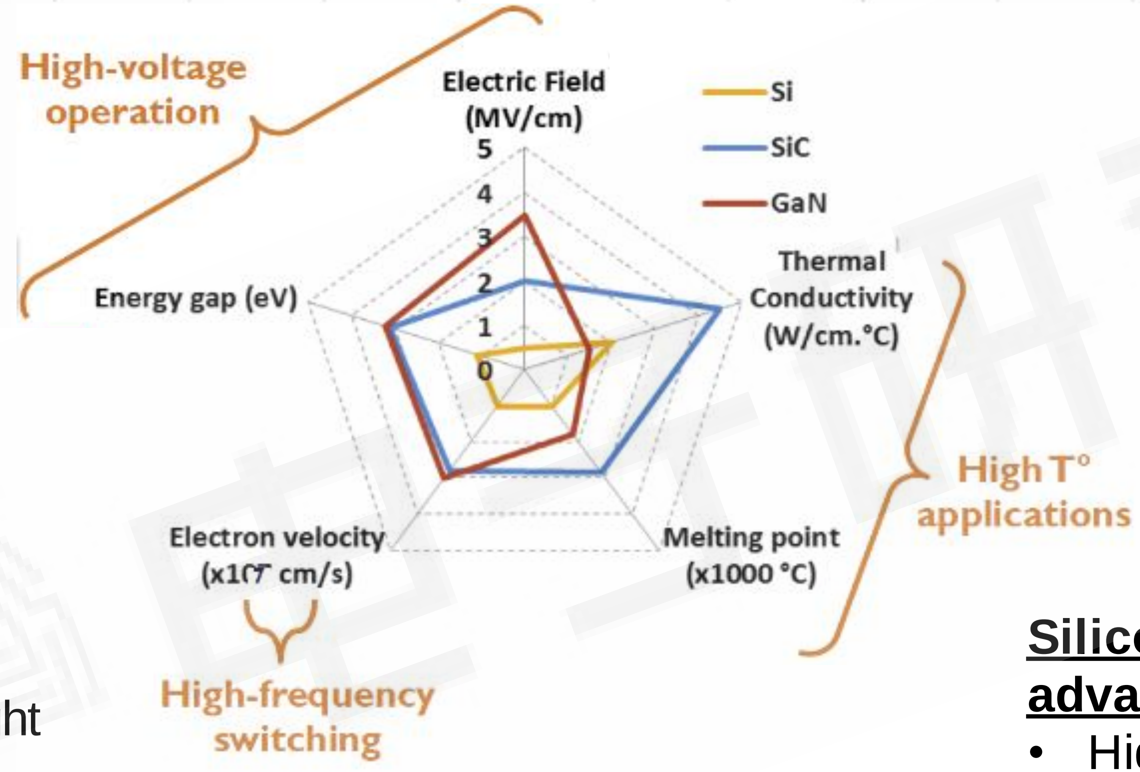
是德科技感恩月

有趣 有料 有惊喜

科技改变生活

New power semiconductor technology emerges

Wide Bandgap Devices (WBG) – Silicon Carbide (SiC) & Gallium Nitride (GaN)



<u>Galium Nitride (GaN) advantages over Si</u>

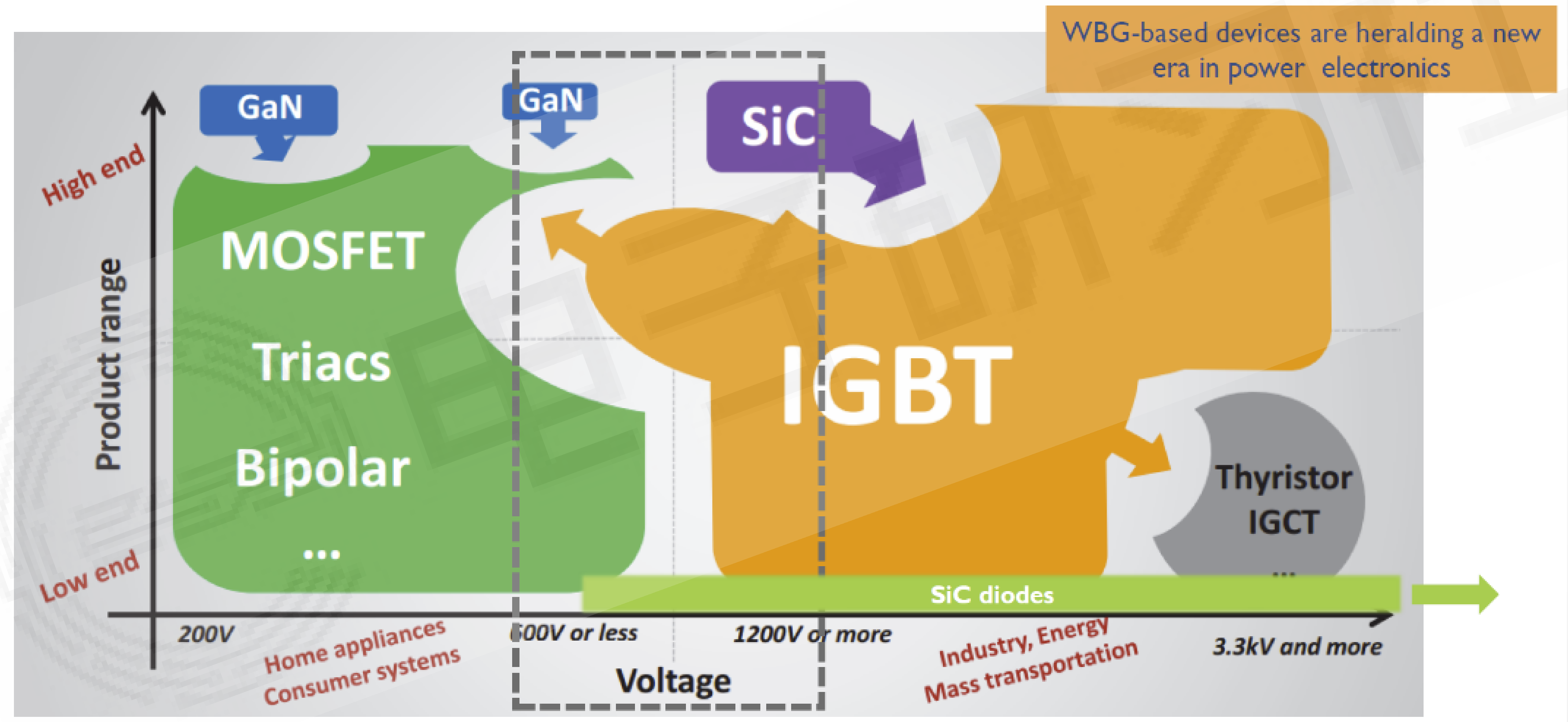
- Very fast switching frequency
- Compactness and weight reduction
- 3X higher bandgap of Si
- Reduction of conduction and switching loss
- Low $R_{ds(on)}$

<u>Silicon Carbide (SiC) advantages over Si</u>

- High Temperature Operation
- > 2X thermal conductivity of Si
- 3X higher bandgap of Si
- 10X higher breakdown field
- Up to 1000X lower $R_{ds(on)}$

Wide Band Gap Market

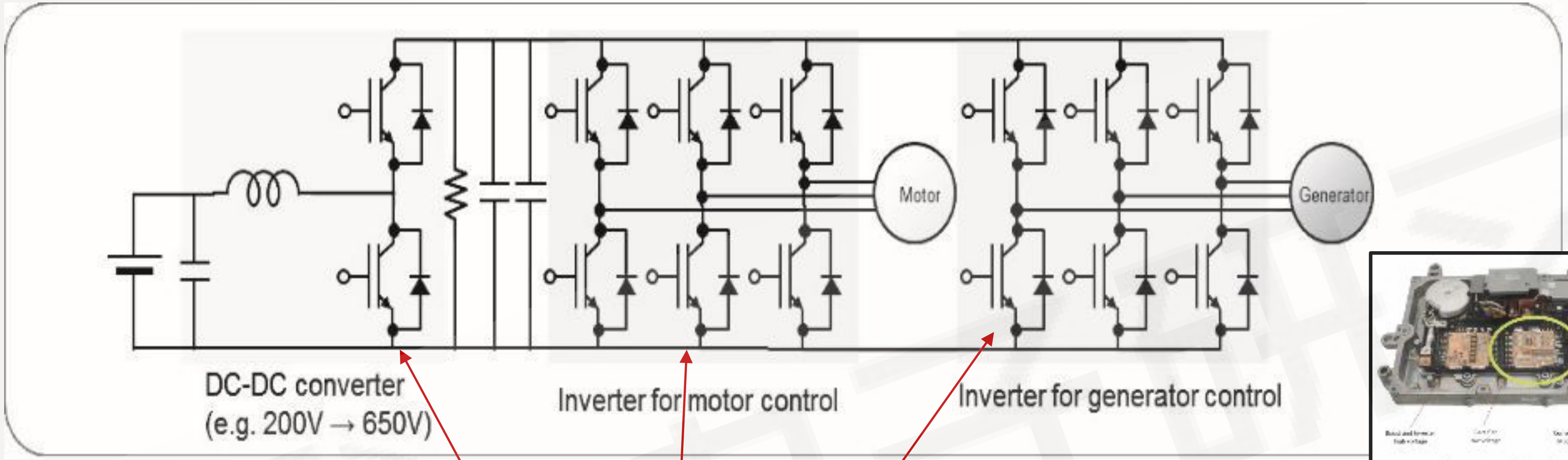
Power Device technology positioning by 2023

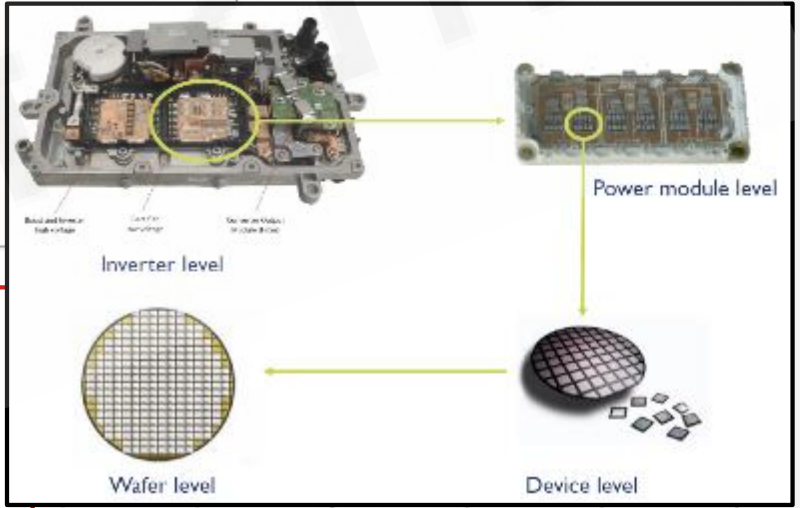


Source: Yole Developement

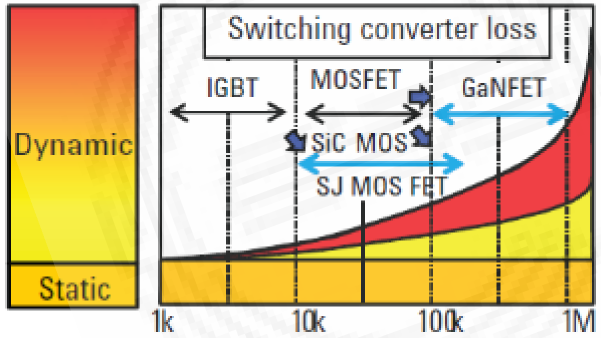
Power converter design

Switching power conversion





Power device loss vs Switching frequency



$$P(drive loss) = f * Qg * Vgs$$

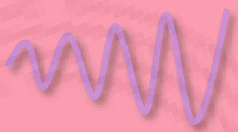
$$P(Switching\ loss) \propto f * (V * I * \Delta T),\quad \frac{1}{2} * Coss * V^2$$

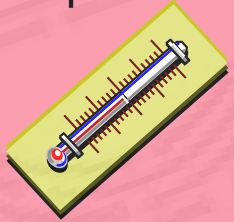
$\propto$ Rg , Crss ,

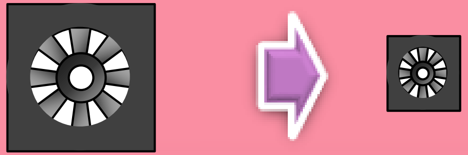
$$P(Conduction\ loss) = Ron * Irms^2$$

WBG device employment for power circuit

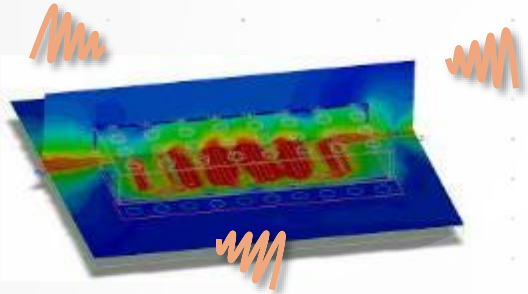
WBG properties	Benefits
Lower power loss	Better conversion efficiency = Smaller / Lighter cooling system
Higher frequency operation	Smaller passive circuit components
Higher temperature operation	Smaller / Lighter / Sealed cooling system for harsh environment use, (e.g. excavator use)



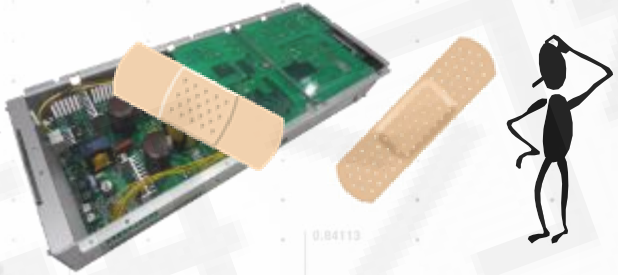




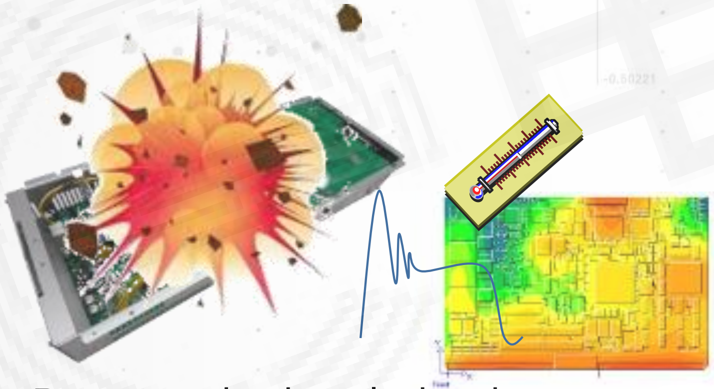
Challenges in power circuit design



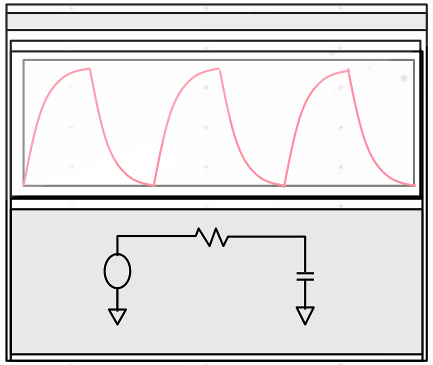
High switching frequency along with high frequency components in waveform causes unexpected EMI



High switching frequency and associated surge/ringing causes malfunction

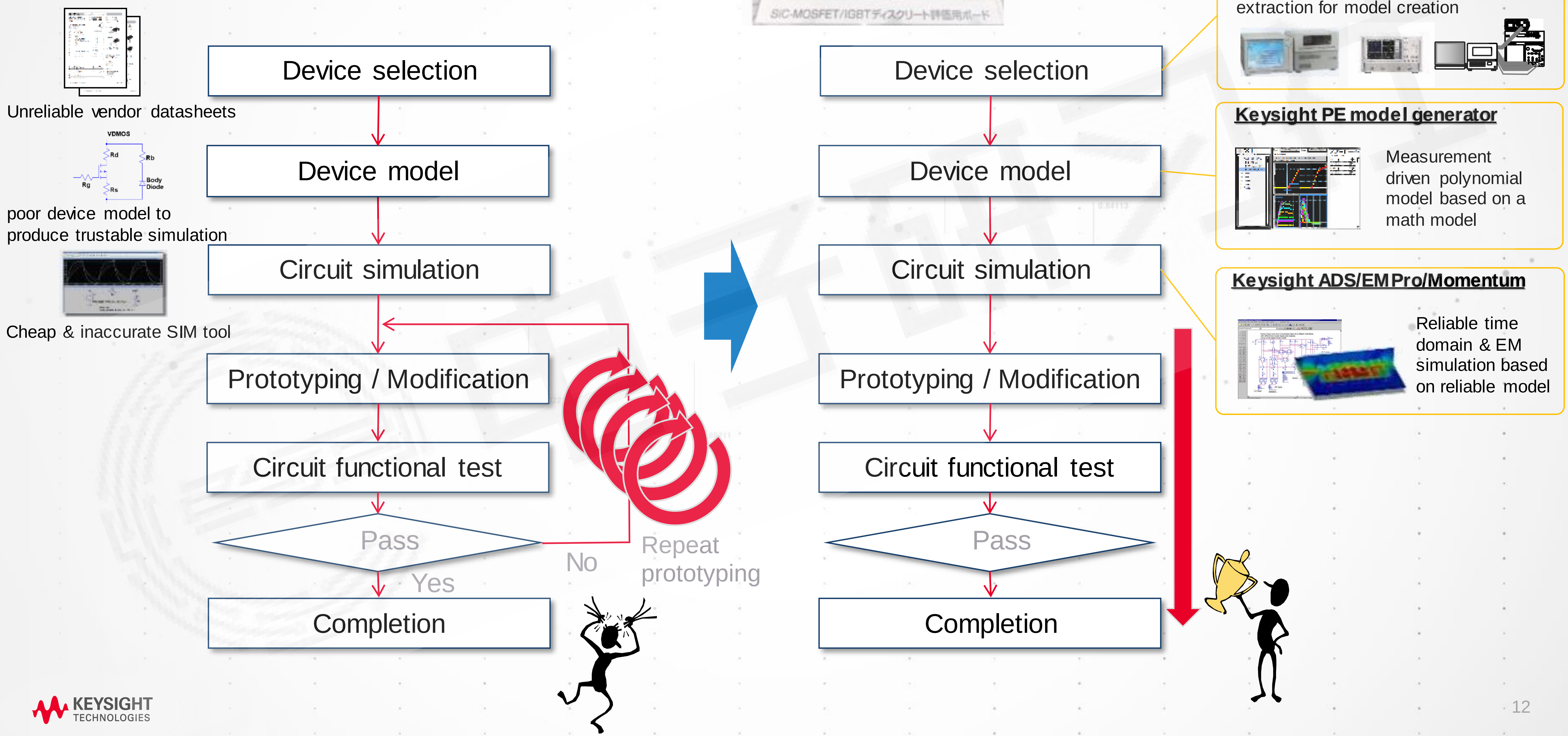


Prototype circuit explosion due to unexpected surge and heat generation



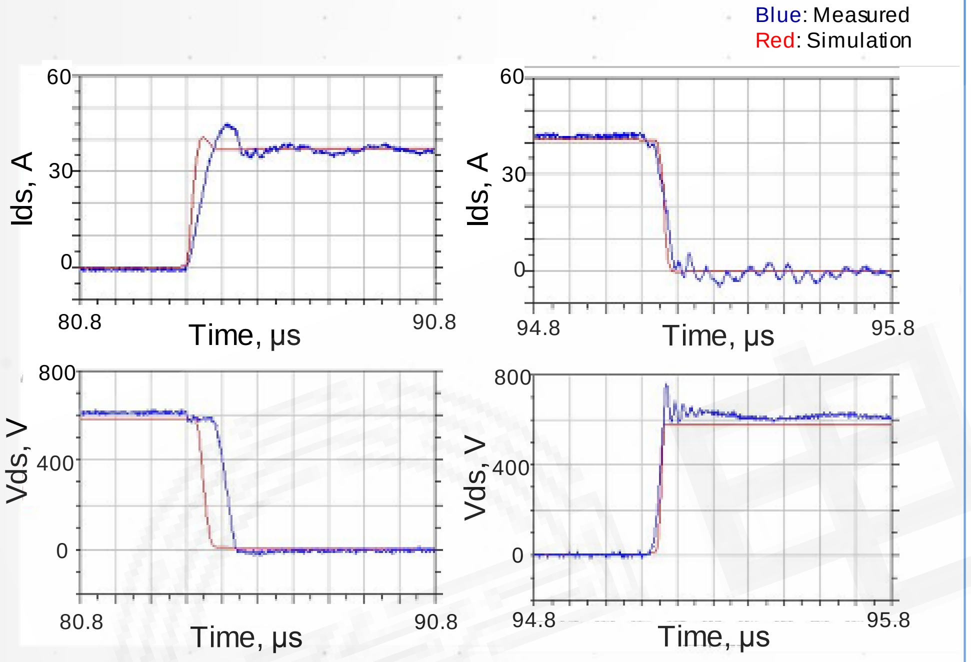
Lack of power circuit simulation tool. Conventional tool may work for low frequency circuit but not for WBG device circuit

Before & After Our Solution



Conventional simulation vs. New Keysight simulation method

Simulation with a conventional model

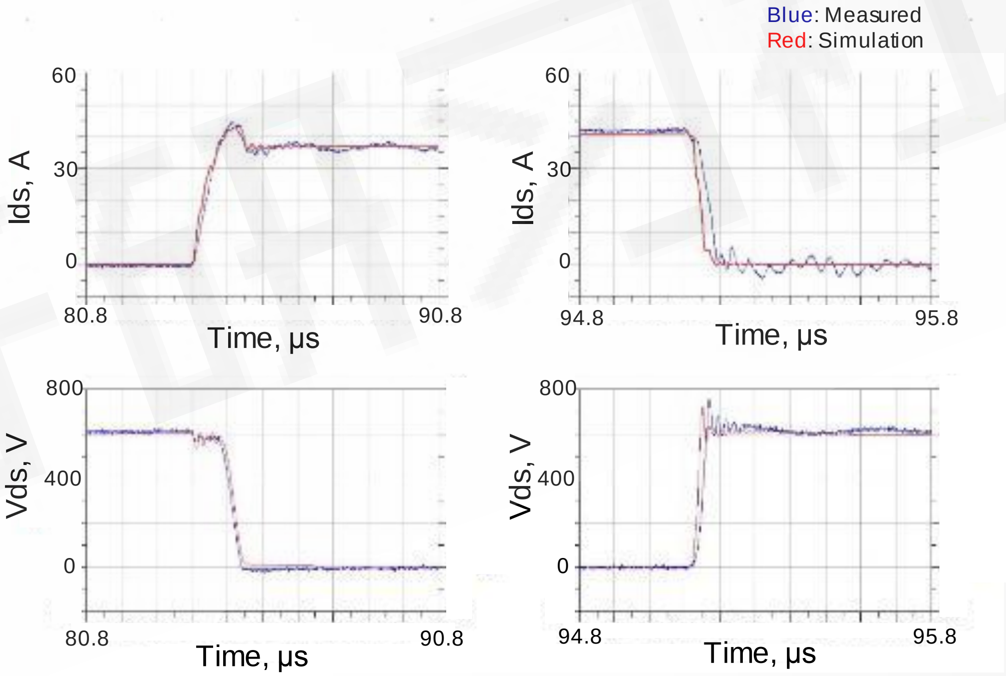


Waveforms don't match.

- Ringing/overshoot are not simulated (flat line)
- Timing deviation
- Slew rate deviation

Exact waveform match is critical for noise calculation as waveform contains high frequency components

Simulation with the Keysight math model



Excellent matching between simulation and measurement

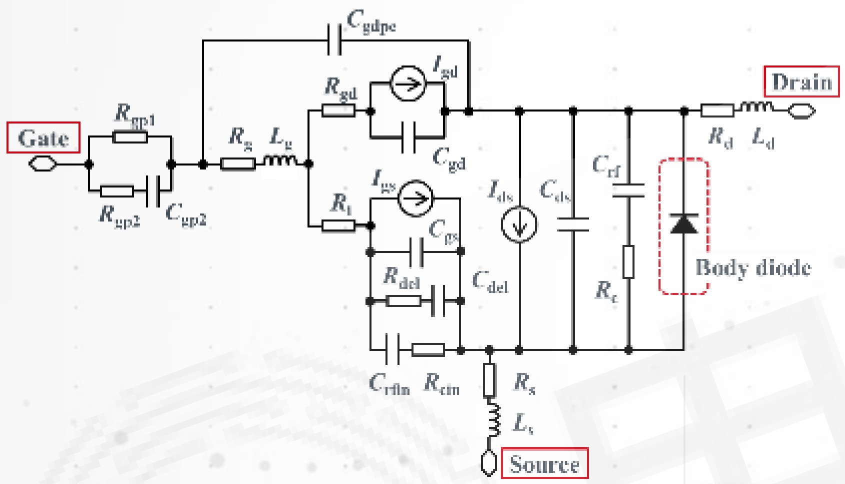
Source: "Measurement Methodology for Accurate Modeling of SiC MOSFET Switching Behavior over Wide Voltage and Current Ranges", H. Sakairi, et. al., IEEE Trans on Power Electronics early access,

What makes this improvement?

KEYSIGHT TECHNOLOGIES

What are different? (1)

DEVICE MODEL



Added body diode to better fit to SiC

$$\tanh\left(\left(\mathrm{Lambda1} \times \tanh\left(1 + \mathrm{Lambda2} \times V_{gs}\right)\right) \times V_{ds}\right)$$

Added Vgs, Vds dependent parameter to drain current equation to better represent unsaturated drain current

$$Q_{gs} = \left(C_{\mathrm{gspi}} + C_{\mathrm{gso}} \times \tanh 02\right) + \left(C_{\mathrm{gspi}} + \left(C_{\mathrm{gso}} \times \tanh 01 + C_{\mathrm{gs0i}} \times \tanh 1\mathrm{i}\right) \times \tanh 02\right)$$

$$\tanh XX(i) = 1 + \tanh\left(A + B \times V_{\mathrm{gs}} + C \times V_{\mathrm{ds}}\right)$$

Added tanhXX to express a positive bias dependence on charge equation

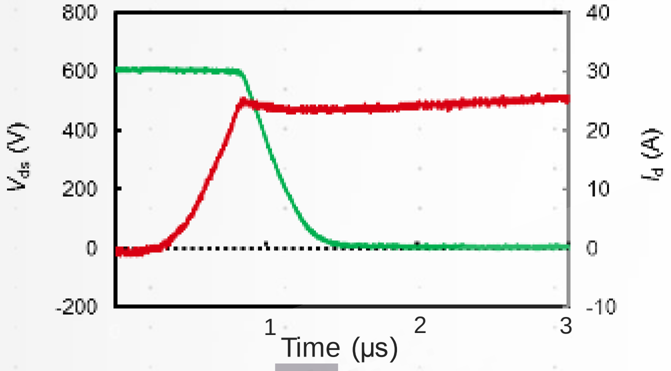
- Modified popular Angelov GaN
  - To represent SiC or GaN behavior better
  - Independent of device physics parameters (e.g. Tox) → Everyone (e.g. circuit designer) can use it

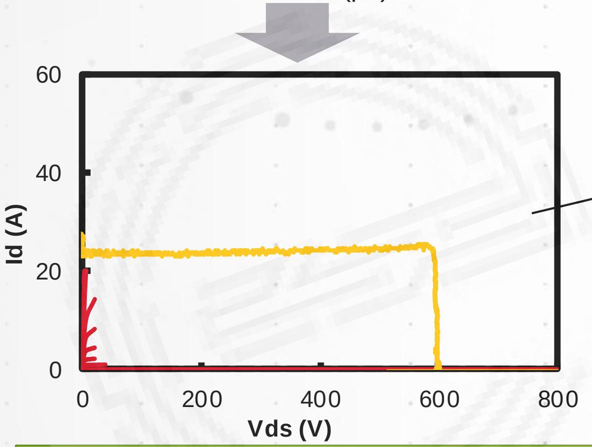
Source: "Measurement Methodology for Accurate Modeling of SiC MOSFET Switching Behavior over Wide Voltage and Current Ranges", H. Sakairi, et. al., IEEE Trans on Power Electronics early access,

What are different? (2)

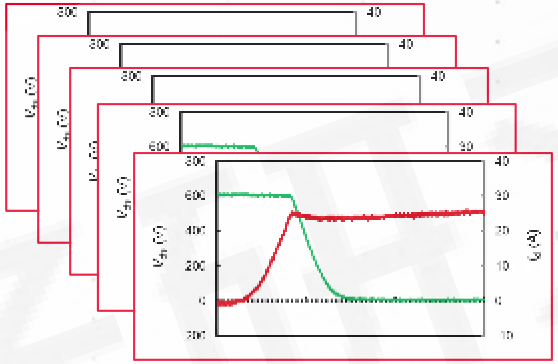
EXTENSIVE MEASUREMENT TO MAKE THE MODEL REPRESENTATION SIGNIFICANTLY BETTER

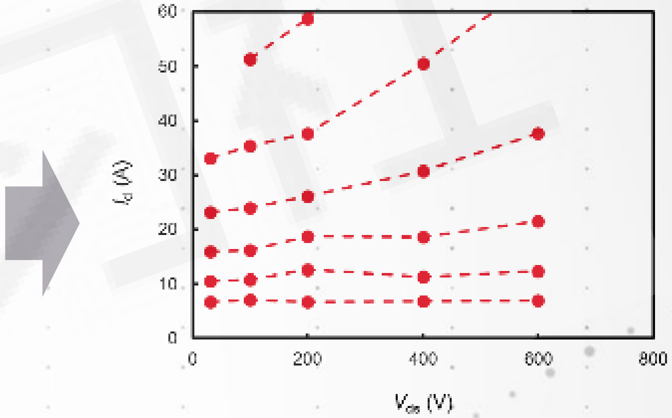
(A) Wide range IV using double pulse test

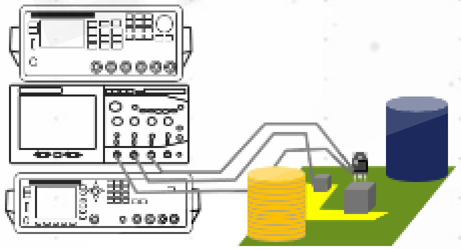




IV curve with conventional test equipment doesn't cover switching trajectory







Wide range IV curve

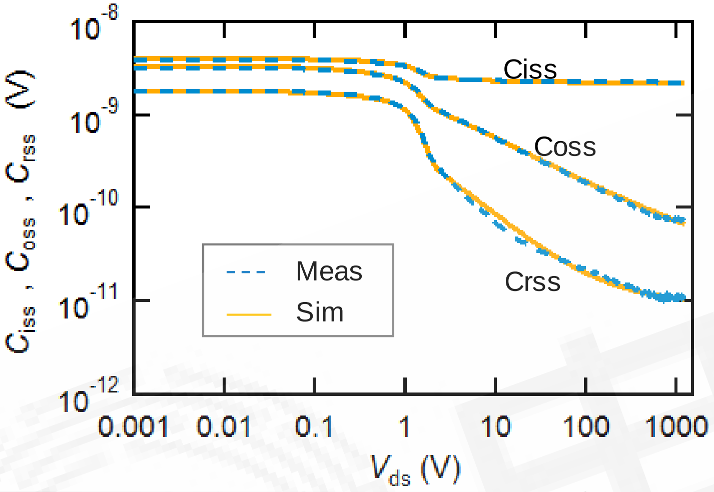
- Utilize double pulse test system to obtain wide enough IV curve to cover switching trajectory

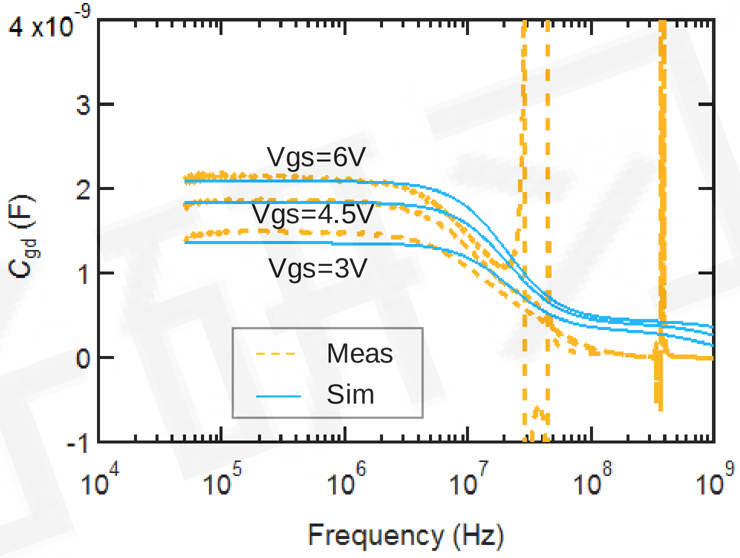
Source: "Measurement Methodology for Accurate Modeling of SiC MOSFET Switching Behavior over Wide Voltage and Current Ranges", H.Sakairi, et. al., IEEE Trans on Power Electronics early access,

What are different? (3)

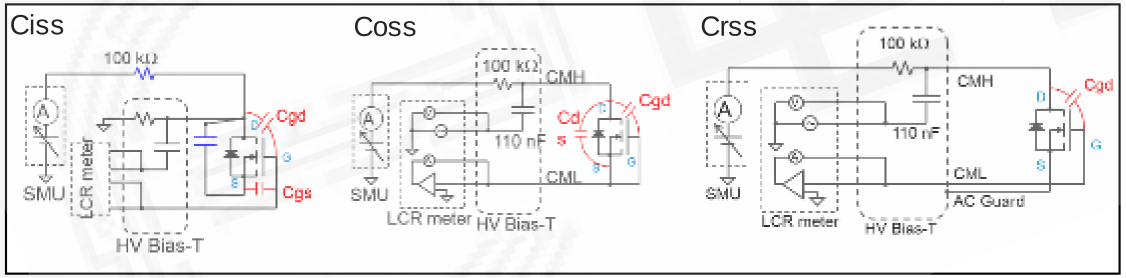
EXTENSIVE MEASUREMENT TO MAKE THE MODEL REPRESENTATION SIGNIFICANTLY BETTER

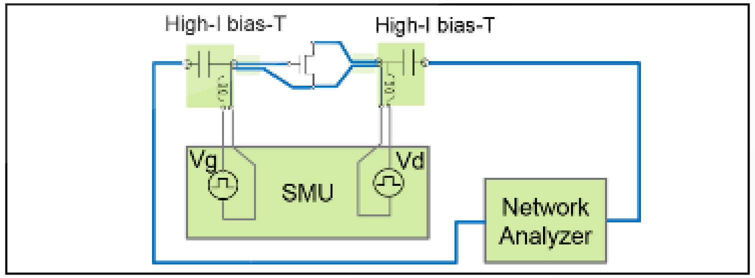
(B) Inclusion of CV (both off-state & on-state)





Discontinuous measurement points seen beyond 10MHz are considered to be caused by oscillation due to parasitic and stray inductance associated with measurement circuit. Therefore, simulation didn't include those points.





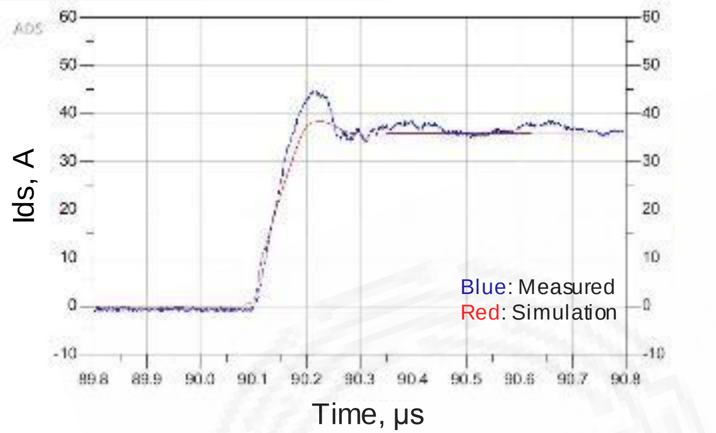
- Inclusion of non-linear characteristics is critical to represent device physical phenomena better

Source: "Measurement Methodology for Accurate Modeling of SiC MOSFET Switching Behavior over Wide Voltage and Current Ranges", H. Sakairi, et. al., IEEE Trans on Power Electronics early access,

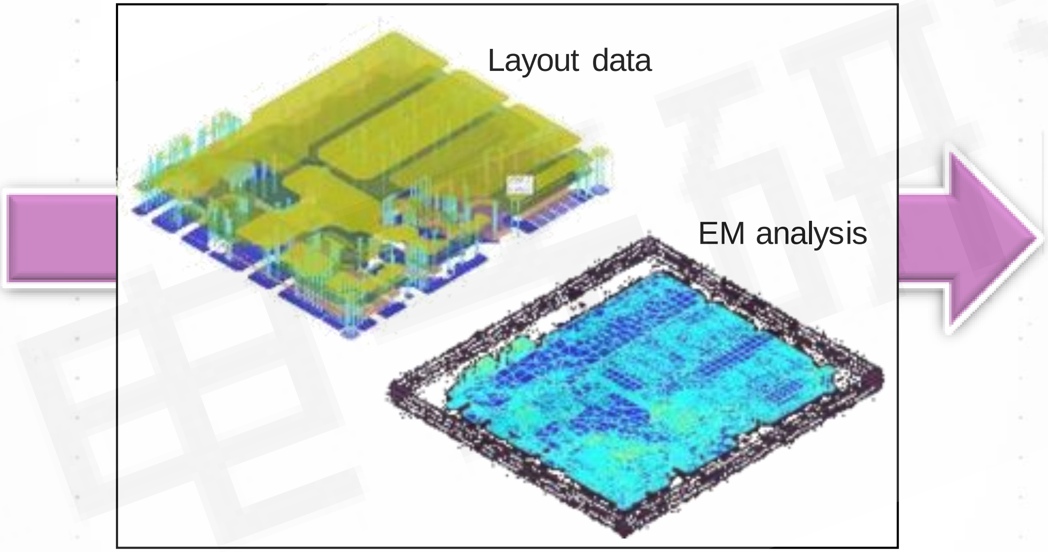
What are different? (4)

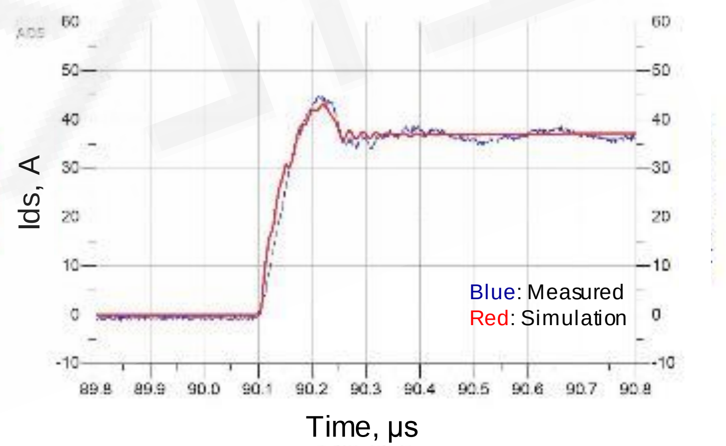
EMPLOYMENT OF ELECTROMAGNETIC ANALYSIS

To use simulation software that performs not only time domain analysis but also incorporate electro-thermal and layout distribution effects



Improved device model without extensive EM simulation





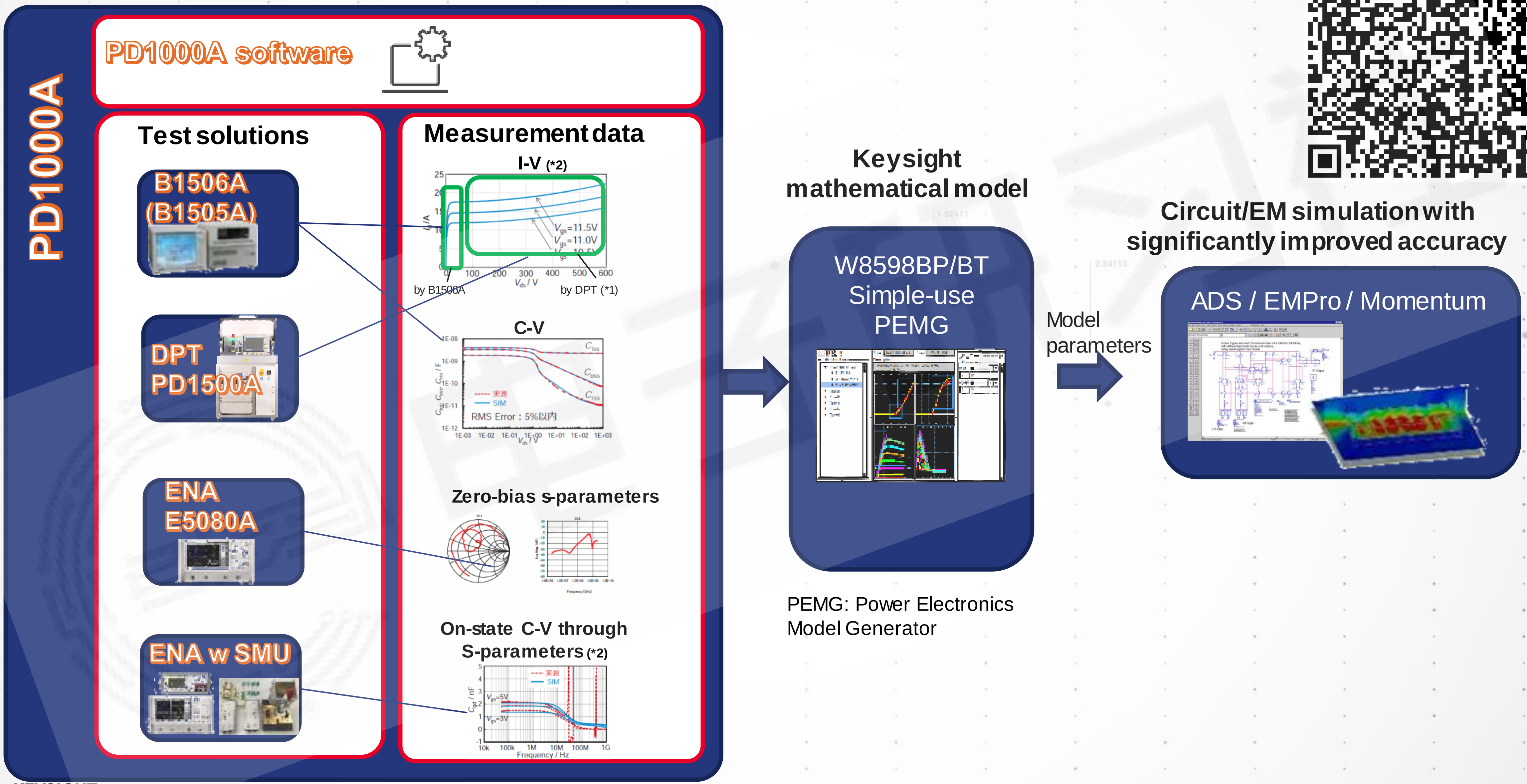
Improved device model with extensive EM simulation

Electromagnetic simulation using board layout information as well as inclusion of s-parameters measured on DUT, the simulation of circuit operation becomes significantly better.

Source: “Measurement Methodology for Accurate Modeling of SiC MOSFET Switching Behavior over Wide Voltage and Current Ranges”, H. Sakairi, et. al., IEEE Trans on Power Electronics early access,

KEYSIGHT TECHNOLOGIES

Solution to realize this vision



*1: DPT: Double Pulse Test System
*2) Source: "Measurement Methodology for Accurate Modeling of SiC MOSFET Switching Behavior over Wide Voltage and Current Ranges", H. Sakairi, et. al., IEEE Trans on Power Electronics early access,

元器件测试方案_B1506A功率器件分析仪

➢ **全面的测试参数**:

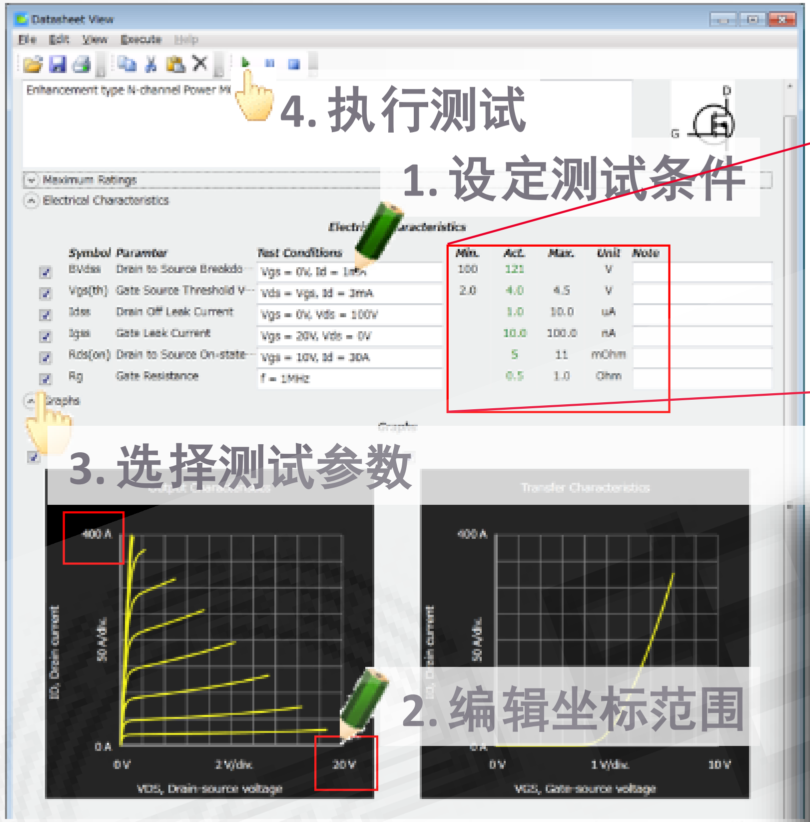
分类	参数
阈值电压	V(th)、Vge(th)
传输特征	Id-Vgs、Ic-Vge、 gfs
导通电阻	Rds-on、Vce(sat)
栅极泄漏电流	Igss、Iges
输出泄漏电流	Idss、Ices
输出特征	Id-Vds、Ic-Vce
击穿电压	BVds、BVces
栅极电荷	Qg、Qg(th)、Qgs、Qgd、Qsw、Qsync
栅极电阻	Rg
器件电容	Ciss、Coss、Coss_eff、Crss、Cgs、Cgd、Cies、Coes、Cres
切换参数	Td(通)、Td(断)、Tr、Tf;计算值。
切换损耗	特定频率上的驱动损耗/切换损耗 特定占空比下的传导损耗

➢ **宽广的测试范围**:

- 电流1500 A
- 电压 3 kV
- -50 ° C 至 +250 ° C 快速热测试

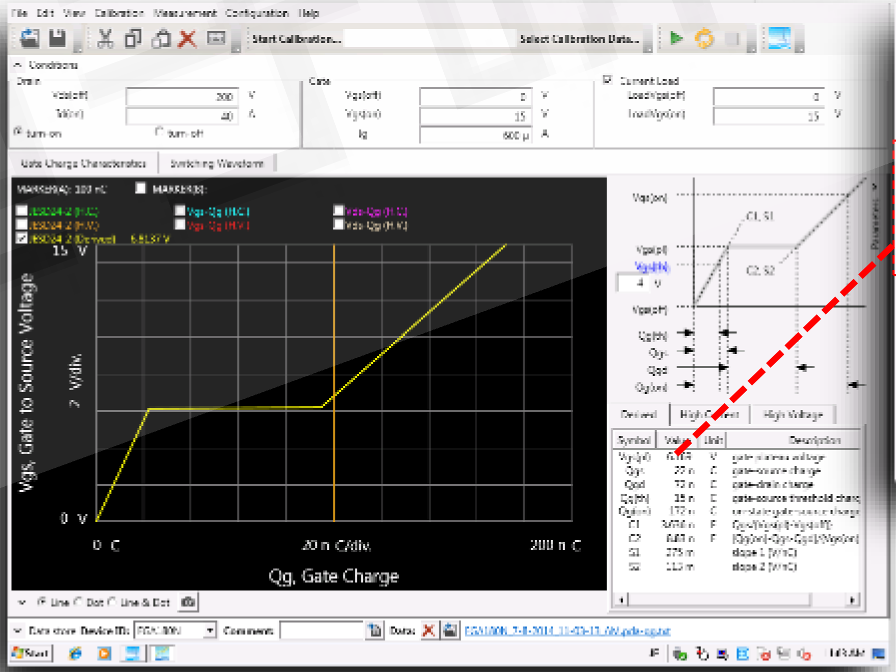
KEYSIGHT TECHNOLOGIES

元器件测试方案_B1506A功率器件分析仪



详细的测试参数

Min.	Act.	Max.	Unit	Note
100	121		V	
2.0	4.7	4.5	V	
	1.0	10.0	uA	
	10.0	100.0	nA	
	5	11	mOhm	
	0.5	1.0	Ohm	



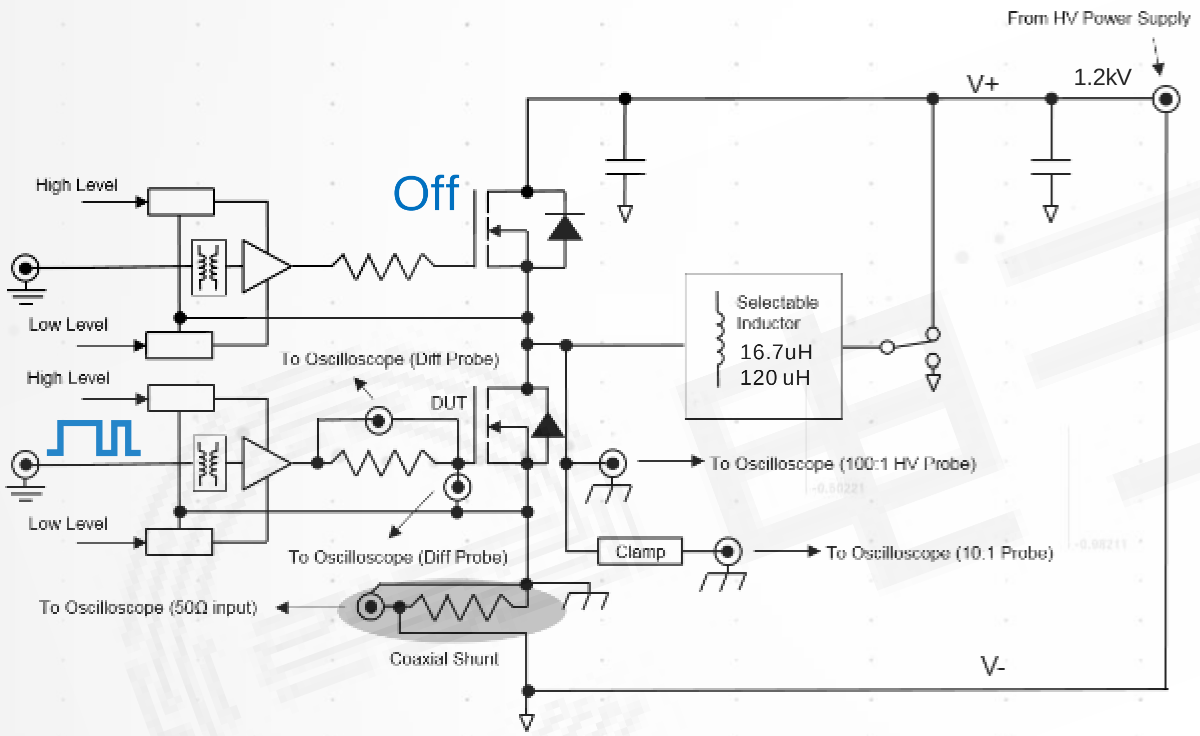
Derived | High Current | High Voltage

Symbol	Value	Unit	Description
Vgs(pl)	6.169	V	gate plateau voltage
Qgs	22 n	C	gate-source charge
Qgd	72 n	C	gate-drain charge
Qg(th)	15 n	C	gate-source threshold charg
Qg(on)	172 n	C	on-state gate-source charge
C1	3.636 n	F	Qgs/{Vgs(pl)-Vgs(off)}
C2	8.83 n	F	{Qg(on)-Qgs-Qgd}/{Vgs(on)
S1	275 m		slope 1 (V/nC)
S2	113 m		slope 2 (V/nC)

What is double pulse test?

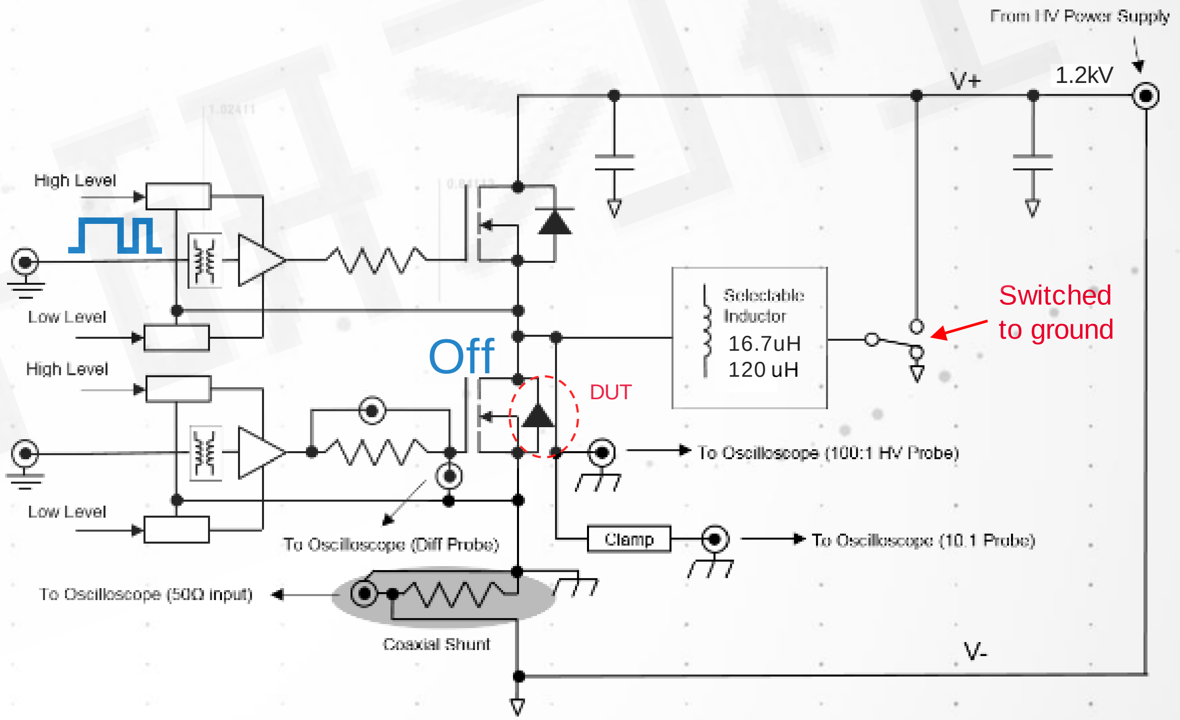
TO EVALUATE POWER DEVICE DYNAMIC BEHAVIOR

Switching characterization (*1)



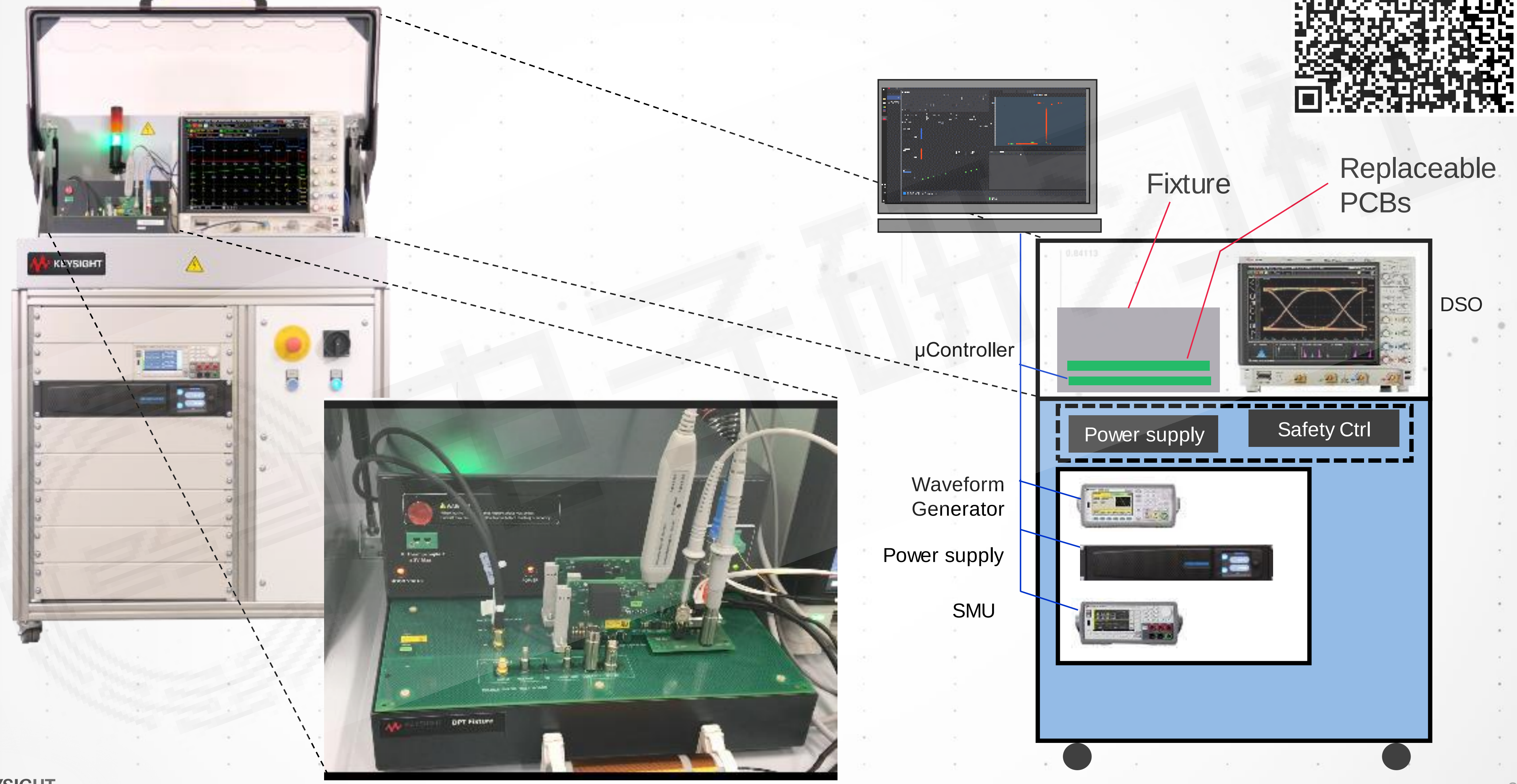
(*1) For gate charge measurement, the low side gate driver is exchanged to the one with high Rg.

Reverse recovery



Modular architecture concept

Adaptable, flexible, semi-automatic and safe test station



Fixture

Keysight PD1500A

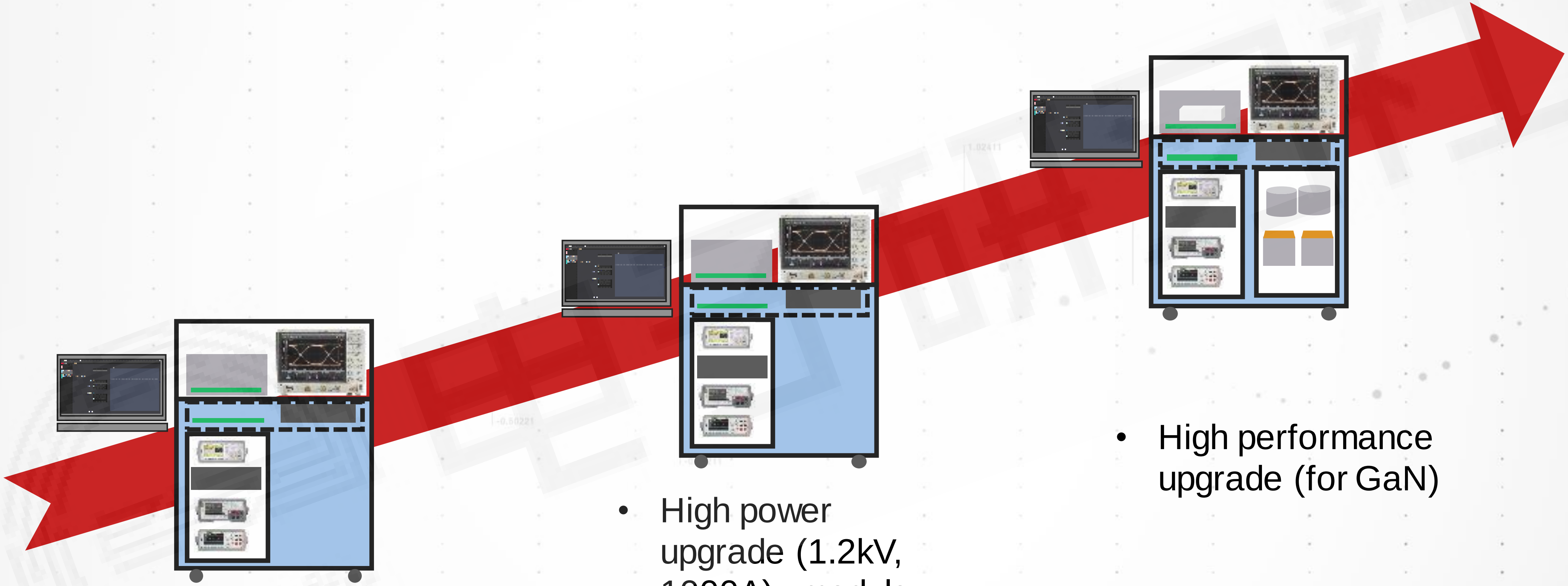
DYNAMIC POWER DEVICE ANALYZER/DOUBLE PULSE TESTER

- Clean & automated turn-key solution with safe test fixture
  - Covers various waveform characterization & parameter extraction with semi-automated operation
    - Switching / Reverse recovery / Gate charge / High power IV
    - (coming soon) Short circuit, UIS avalanche test
  - Automatic temperature control (room temperature to +150C)
  - Operator & resource safety (protection mechanism)
- Adaptable to various DUTs
  - Fast, low-parasitic, generic gate-driver with variable voltages (e.g. -10V to +29V, ns edge)
  - Modular architecture
  - Replaceable double pulse PCB for different apps.
  - Controllable capacitor bank & switchable inductor (16.7uH, 120uH)
- Repeatable, Reliable, Accurate measurement
  - Auto Calibration /De-skew / compensation for better accuracy
  - Shunt de-embedding

Applications

Parameter / Characteristics	Symbol	Basic	Clamp	Reverse recovery	Gate charge	DP	
Turn on delay time td(on)	td(on)	x	x				
Turn on rise time	tr	x	x				
Turn on time	ton	x	x				
Turn on energy	e(on)	x	x				
Turn off delay time td(off)	td(off)	x	x				
Turn off rise time	tf	x	x				
Turn off time	toff	x	x				
Turn off energy	e(off)	x	x				
di/dt	dv/dt	x	x				
dv/dt	di/dt	x	x				
On resistance	Rds(on)		x				
Switching characteristics	Id vs. t	x	x		x	x	x
Switching characteristics	Vds vs. t	x	x		x	x	x
Switching characteristics	Vgs vs. t	x	x		x	x	x
Switching characteristics	Ig vs. t	x			x	x	x
Switching characteristics	Clamped Vds vs. t		x				
Switching characteristics	e vs. t	x	x				
Switching locus	Id vs Vds	x	x				
Reverse recovery time	trr			X			
Reverse recovery charge	Qrr			X			
Reverse recovery energy	Err			X			
Maximum reverse recovery current	Irr			x			
Reverse recovery current characteristics	Id vs. t			x			
Total gate charge	Qg				X		
Threshold gate charge	Qgs(th)				X		
Plateau gate charge	Qgs(pl)				X		
Gate drain charge	Qgd				X		
Gate charge curve	Vgs vs. t				X		
Derived transfer characteristics	Id vs. Vg					x	
Derived output characteristics	Id vs. Vd					x	
Parasitic turn on Vgs	Vgs(para)						x
Parasitic turn on peak Id	Id(para)						x

Modularity allows for Upgradeability



Si, SiC (1.2kV, 200A)

- High power upgrade (1.2kV, 1000A) - module
- Avalanche Test
- Short Circuit Test

- High performance upgrade (for GaN)

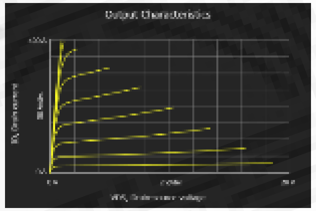
是德科技功率器件测试方案

2kV CAT1, 1kV
CAT III & 400 MHz

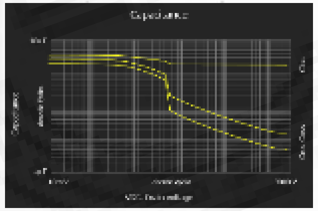
Keysight PD1000A Power Device Measurement System for Advanced Modeling

B1506A Power Device Analyzer

- I-V 3kV, 20A/500A/1500A models
- C-V up to 3kV (Ciss, Coss, Crss, Cox)
- Automated and easy to use operation
- Automated thermal up to +250°C
- Pulse width down to 10us



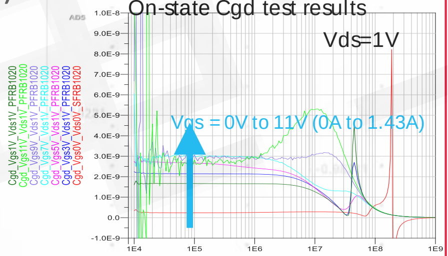
IV



CV up to 3kV

S-parameter measurement

- 9kHz – 4.5GHz
- High current bias-T (5A/42V)
- Automated and easy to use operation
- LCR extraction (Stray L, biased Crss, Rg, etc.)

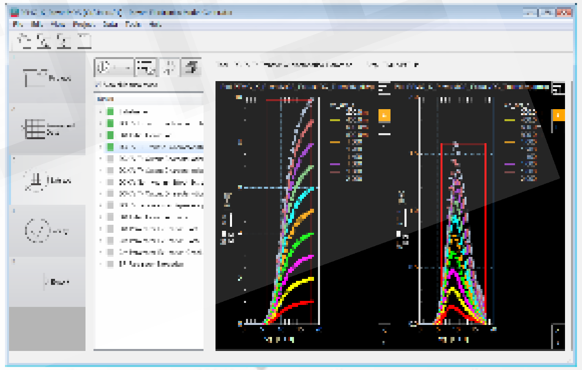


Extracted Crss from s-parameters

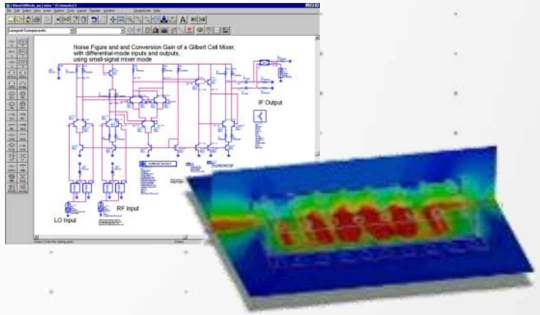
PD1500A Dynamic Power Device Analyzer/Double Pulse Tester

- 1.2kV/200A
- Switching parameters & high power IV derivation for modeling
- Automated and easy to use operation
- Automated thermal up to +150°C
- Modular architecture

Keysight W8598BP PEMG



Keysight ADS/EMPro



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仪器行业最大型的线上活动!!

Q&A

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