

Tektronix®



Automated Measurement on Double Pulse Testing

Sharon Lau

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KEITHLEY
A Tektronix Company





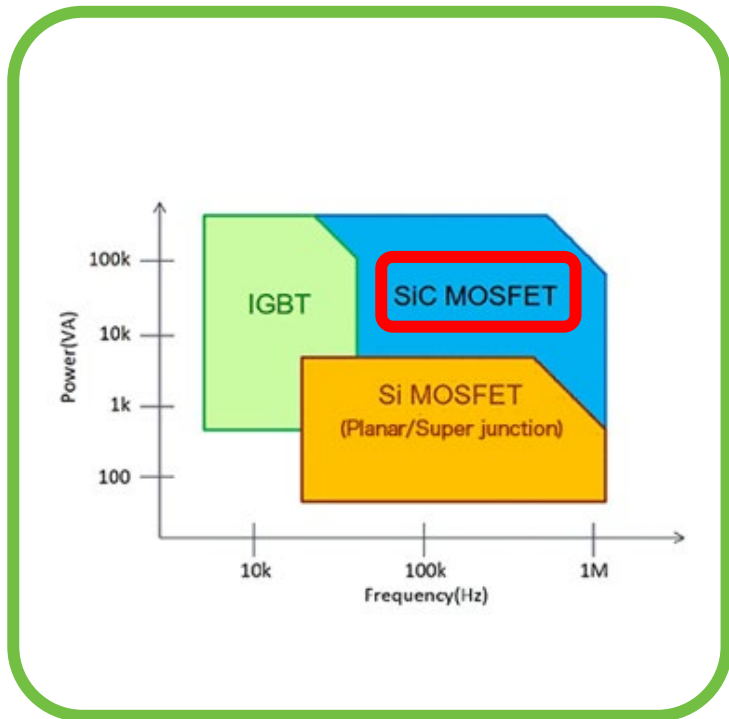
Agenda

- Switching Losses in Semiconductor Devices
- Double Pulse Test (DPT)
 - What is DPT?
 - Importance of DPT
 - Challenges on DPT
 - Automated Measurements on DPT
- Summary



Wide Bandgap (WBG)

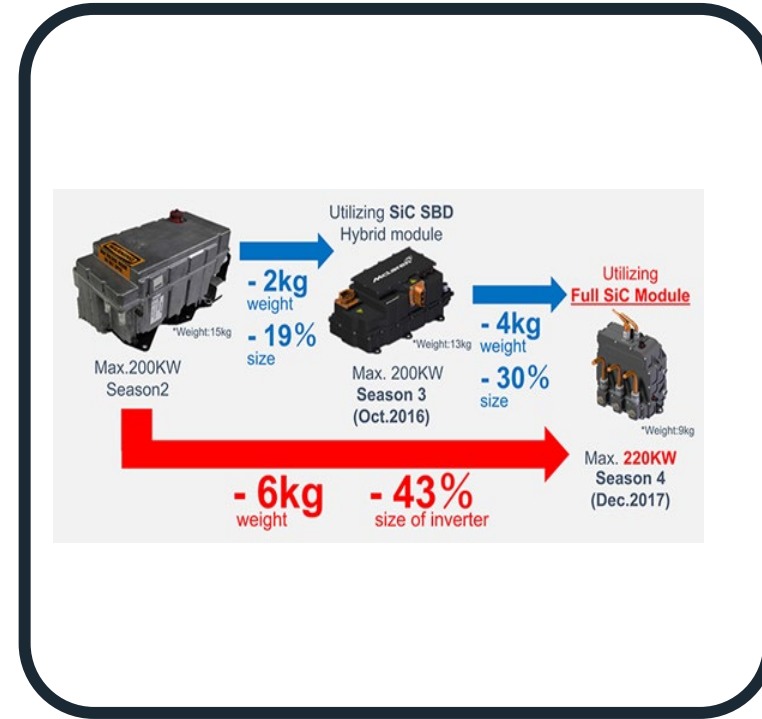
INTRODUCTION



**Higher Power Levels
Faster Switching speeds**



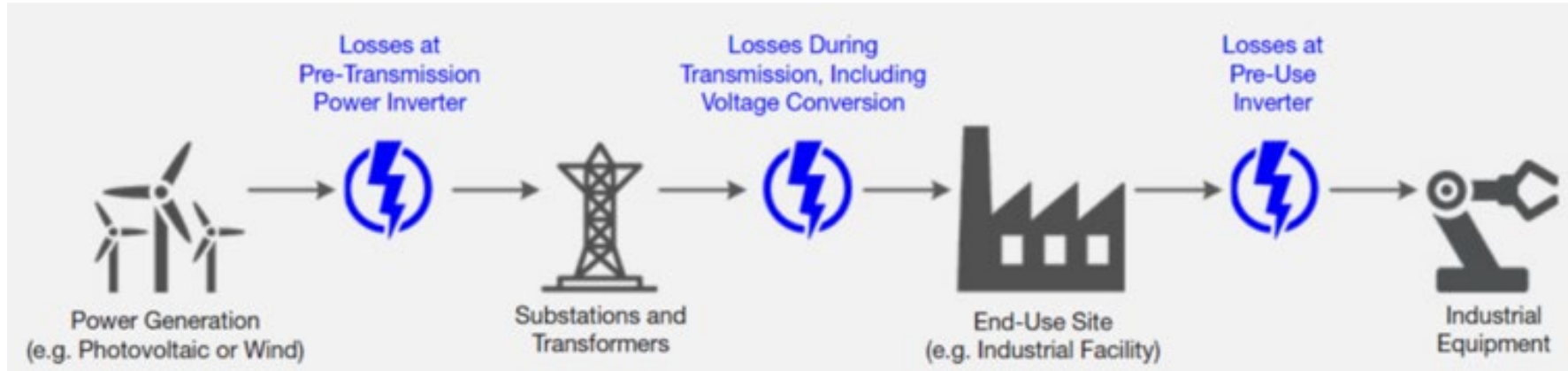
Lower Switching Losses



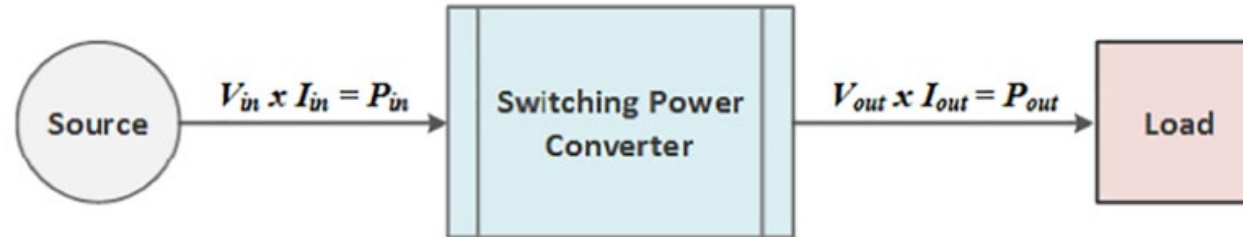
Smaller Form Factor

Power Conversion

INTRODUCTION



Power losses at the points of generation, transmission, and consumption

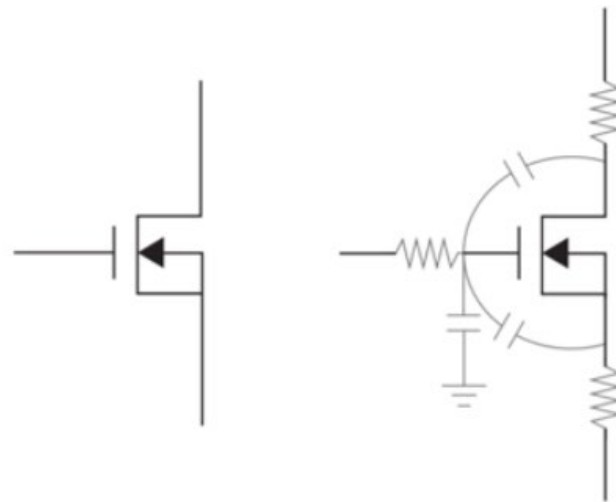
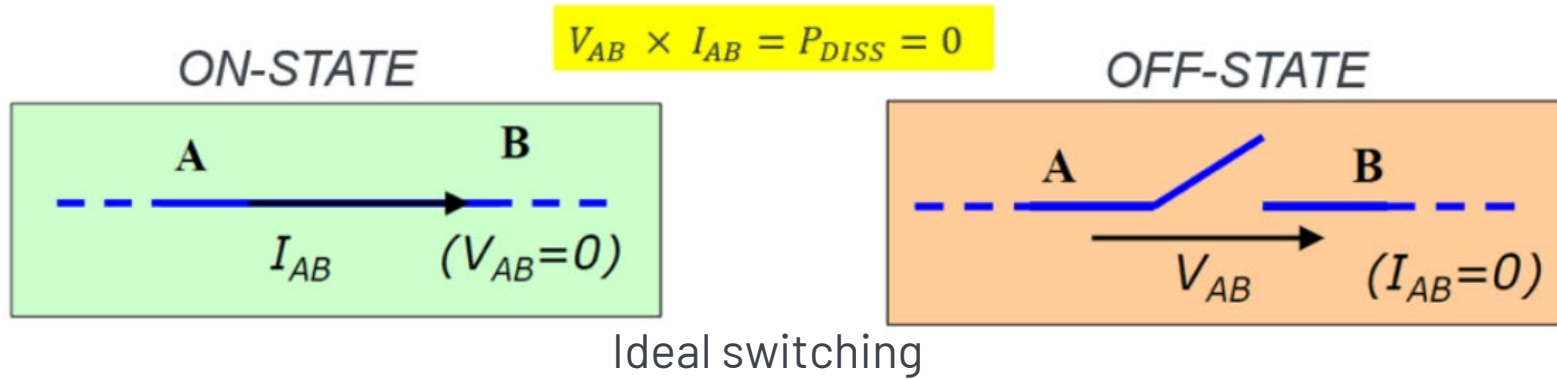


In ideal (100% efficient) power conversion, $P_{in} = P_{out}$

Ideal power conversion efficiency

Switching Losses

IDEAL SWITCHING AND PRACTICAL SWITCHING



A.
How switch
appears on
schematic

B.
How the
circuit sees
the switch

Practical switching



What is Double Pulse Test (DPT)?

EVALUATE SWITCHING BEHAVIOR ON MOSFETS AND IGBTs

- **Turn-on Parameters:** turn-on delay ($t_{d(\text{on})}$), rise time (t_r), turn-on time (t_{on}), On Energy (E_{on}), dv/dt and di/dt
- **Turn-off Parameters:** turn-off delay ($t_{d(\text{off})}$), fall time (t_f), turn-off time (t_{off}), Off Energy (E_{off}), dv/dt and di/dt
- **Reverse Recovery Parameters:** reverse recovery time (t_{rr}), reverse recovery current (I_{rr}), reverse recovery charge (Q_{rr}), reverse recovery energy (E_{rr}), di/dt and forward on voltage (V_{sd})



<https://u.dianyuan.com/upload/space/2011/07/29/1311925659-501009.pdf>

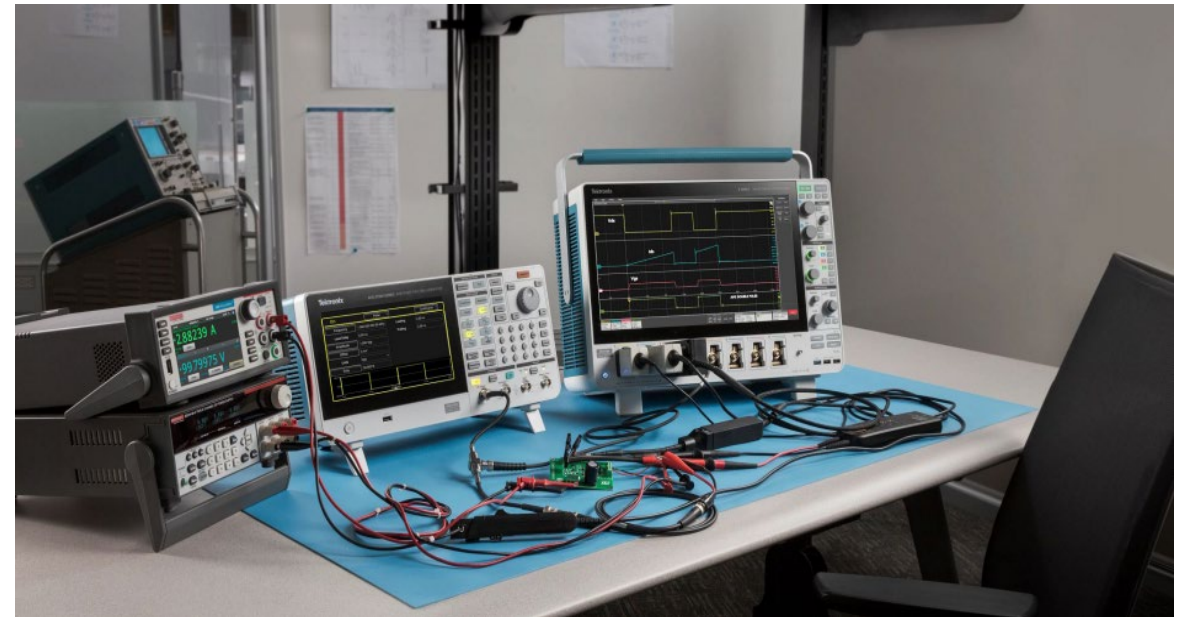
<https://training.ti.com/understanding-mosfet-datasheets-switching-parameters>



Importance of Double Pulse Test

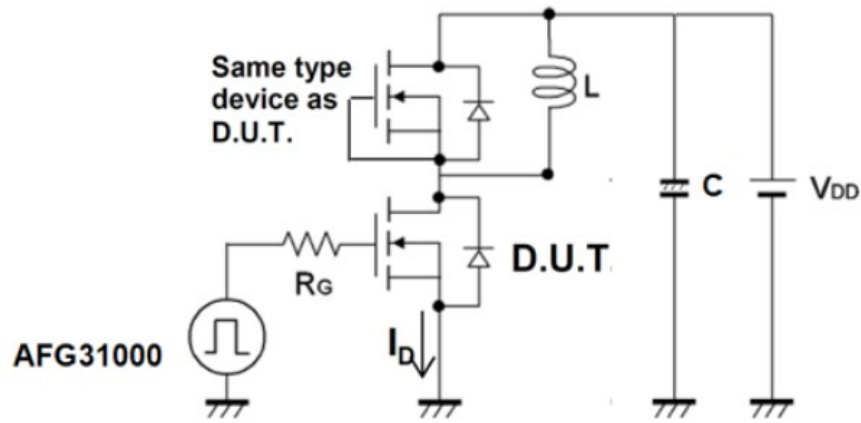
EVALUATE THE DYNAMIC SWITCHING BEHAVIOR OF SEMICONDUCTOR

- Guarantee specifications of power devices like MOSFETs and IGBTs.
- Confirm actual value or deviation of the power devices or power modules.
- Measure these switching parameters under various load conditions and validate performance across many devices.

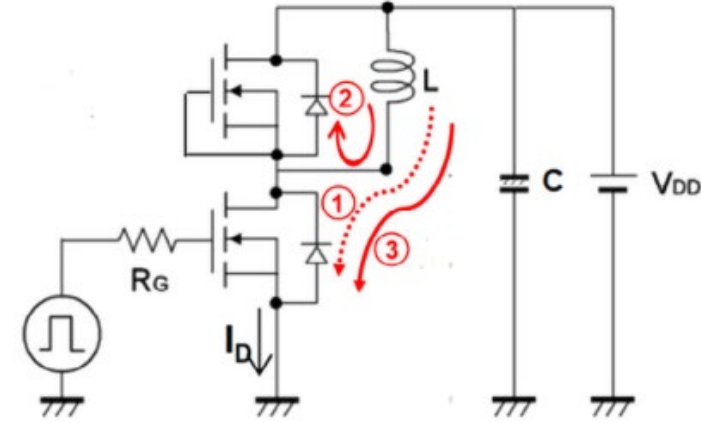


Double Pulse Test Circuit

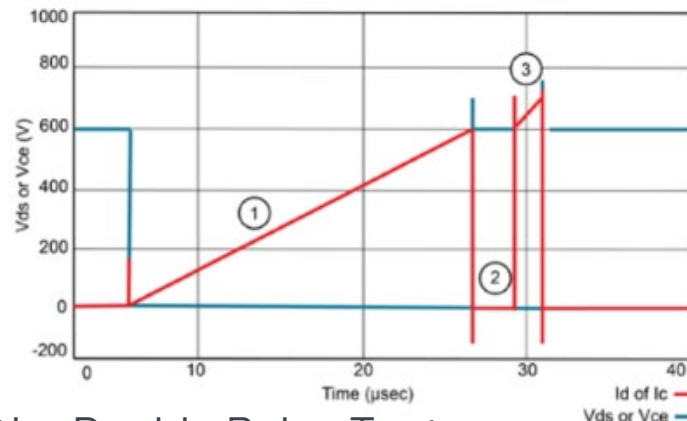
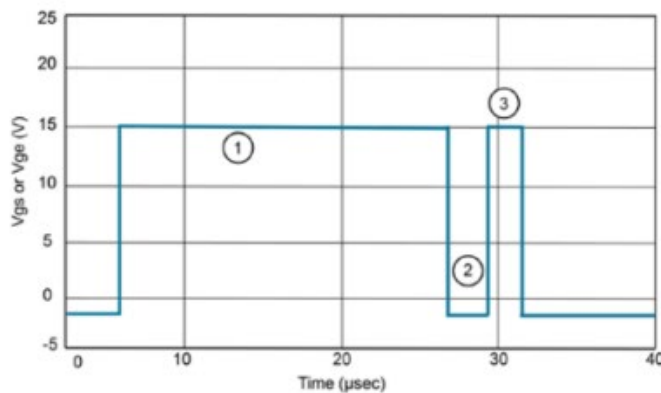
OPERATION OF DOUBLE PULSE TESTING



Typical Double Pulse Test circuit



Current Flow

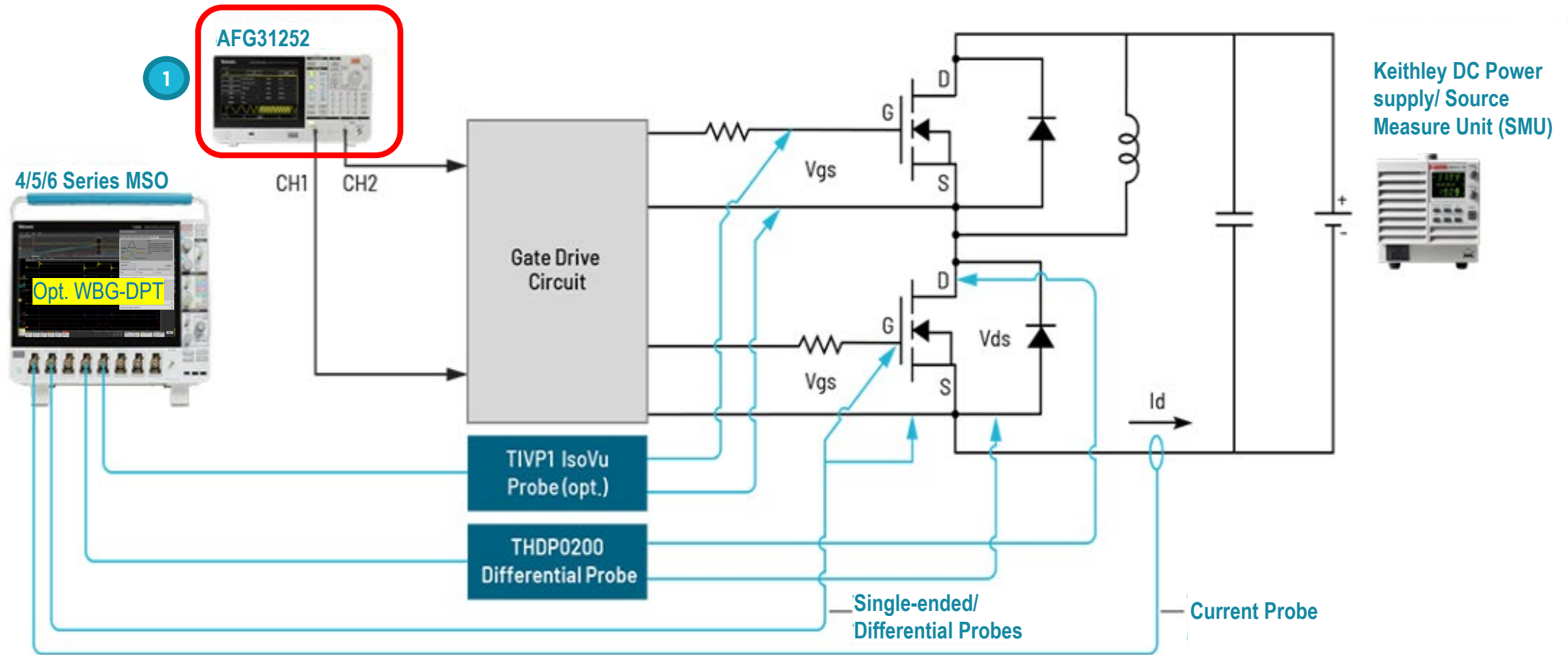


Typical Waveforms of the Double Pulse Test

- 1 **Pulse 1 (Turn on):** Long pulse to reach rated current and charge the inductor
- 2 **Pulse 1 (Turn off):** Creates current in free-wheeling diode
- 3 **Pulse 2 (Turn on):** Short pulse to capture turn-on measurements and not overheat the device

Double Pulse Test Setup

MEASURE SWITCHING LOSSES ON MOSFETS





Challenges

HOW TO DRIVE THE GATE

- Traditional **function generator** cannot control each pulse width individually
- Using PC to create arbitrary waveforms and load them onto the AFG is **cumbersome** and **time consuming**
- Using microcontrollers require a lot of **effort and time** to program

AFG or Scope Built-In AFG

LEVERAGE THE AFG AS A GATE DRIVER



AFG 31000

Double Pulse

Number of Pulses: 2

High: 1.2500 V

Low: -1.2500 V

Trigger Delay: 10.0000 u s

Trigger Source: Manual

Load: 50 Ω

N	Width (s)	Gap (s)
1	2.000u	10.000u
2	2.000u	10.000u

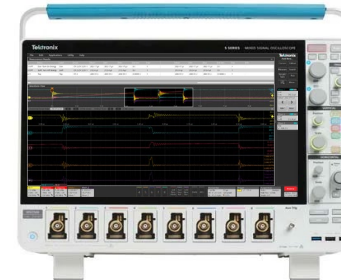
High

Low

Trig

Open Close Save As Default Help Run

Double Pulse Test application on the AFG31000



Scope Built-in AFG

WBG-DPT MEAS 1

EON

Max Voltage (Vds): 25 V

Max Current (Id): 1 A

Max Gate Voltage (Vgs): 10 V

Pulse Width: 15 μs

Generator Setup

Power Preset

Power Preset uses the inputs above and generator settings to preset the oscilloscope and generator for optimal Vertical, Horizontal, Trigger and Acquisition settings. Before Power Preset, turn OFF power supply and configure AFG31000 series. After performing Power Preset, turn on power supply with lower Vcc. WBG devices can operate at higher voltage and power ratings, handle with care.

GENERATOR SETUP

AFG IP address

Test Connection: Not Connected

Run

AFG Source

Ch1 - Low Side

High: 4.975 V

Low: 0 V

Load: 50 Ω High Z

Trigger Interval: 1 ms

Number of Pulses: 2

Pulse	Width	Gap
1	3 μs	5 μs
2	2 μs	5 μs

WBG-DPT MEAS 1

EON

CONFIGURE

Pulse Region: Second Pulse

Label: Eon

Voltage Source (Vds): Ch 1

Current Source (Id): Ch 2

Gate Source (Vgs): Ch 3

Levels

Auto Custom

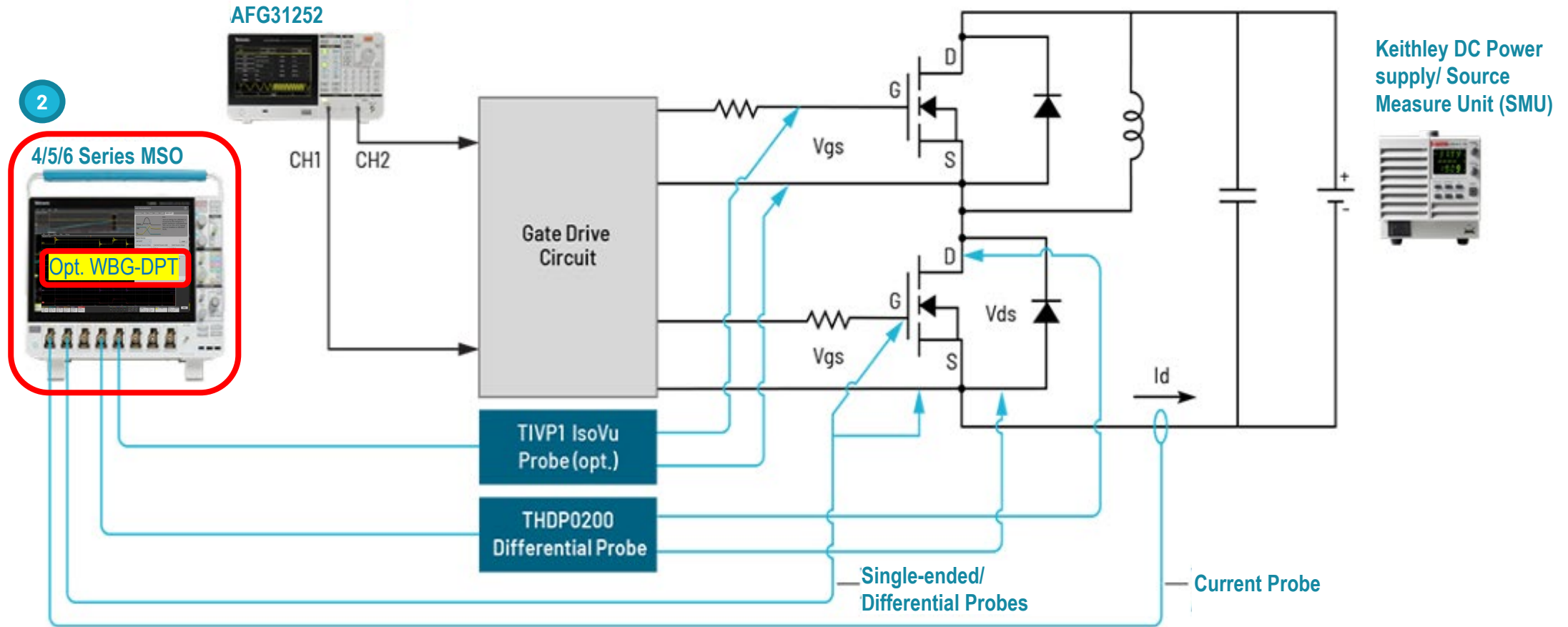
Refine Edge

Start Level Id

Stop Level Vds

Double Pulse Test Setup

MEASURE SWITCHING LOSSES ON MOSFETS





Challenges

ANALYSING SWITCHING BEHAVIOURS

- Core Measurements are centric around **Timing** and **Switching**
- To analyze these losses, we need to **gate the right regions of interest**
- It takes expertise to **capture the right signals** and **manually add cursors**
- **Manually document the results** - save the waveforms, reports, session files



Automated Measurements (Opt. WBG-DPT)

TEST GROUPS AND MEASUREMENTS

ADD MEASUREMENTS

Standard Jitter Power IMDA DPM WBG-DPT

Eon
Turn-on energy for a MOSFET, is measured as the integral of a power waveform computed from 10% of I_d to 10% of V_{ds} , during turn-on condition or specified levels.

Power Device: MOSFET

Voltage Source (Vds): Ch 1, Current Source (Id): Ch 2, Gate Source (Vgs): Ch 3

SWITCHING PARAMETER ANALYSIS: Eon, Eoff, Vpeak, Ipeak, d/dt

SWITCHING TIMING ANALYSIS

DIODE RECOVERY ANALYSIS

Switching Parameter Analysis

ADD MEASUREMENTS

Standard Power IMDA DPM WBG-DPT

Td(on)
Turn-on delay time for a MOSFET, is the time interval between 10% of increasing V_{gs} to 90% of decreasing V_{ds} , during turn-on condition or specified levels.

Power Device: MOSFET

Voltage Source (Vds): Ch 1, Current Source (Id): Ch 2, Gate Source (Vgs): Ch 3

SWITCHING PARAMETER ANALYSIS

SWITCHING TIMING ANALYSIS: Td(on), Td(off), Tr, Tf, Ton, Toff, d/dt

DIODE RECOVERY ANALYSIS

Switching Timing Analysis

ADD MEASUREMENTS

Standard Power IMDA DPM WBG-DPT

Trr
Reverse recovery time is time interval between the instant when the current passes through zero when changing from the forward direction to the reverse direction and the instant when extrapolated reverse current between A and B points reaches zero.

Power Device: MOSFET

Current Source (Id): Ch 1, Gate Source (Vgs): Ch 2

SWITCHING PARAMETER ANALYSIS

SWITCHING TIMING ANALYSIS

DIODE RECOVERY ANALYSIS: Trr, Qrr, Err, Irrm, Diode d/dt

CAPACITANCE ANALYSIS

Diode Recovery Analysis

ADD MEASUREMENTS

Standard Jitter Power IMDA DPM WBG-DPT

Qoss
Qoss is the charge that must be supplied to the output capacitance of the power device during a specified time interval, that is determined from voltage reaching a threshold level which is a percentage of peak V_{ds} .

$Q_{oss} = -\int_{t_1}^{t_2} I_d(t) dt$

Power Device: MOSFET

Voltage Source (Vds): Ref 1, Current Source (Id): Ref 2, Gate Source (Vgs): Ref 3

SWITCHING PARAMETER ANALYSIS

SWITCHING TIMING ANALYSIS

DIODE RECOVERY ANALYSIS

CAPACITANCE ANALYSIS: Qoss

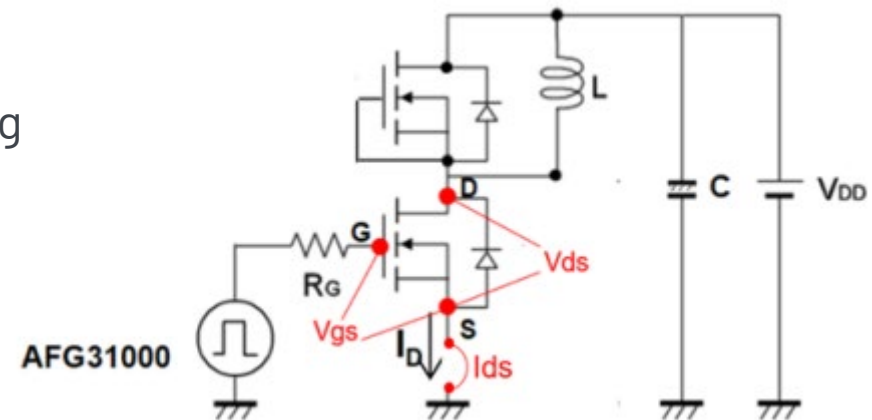
Capacitance Analysis

Turn-on and Turn-off Parameters

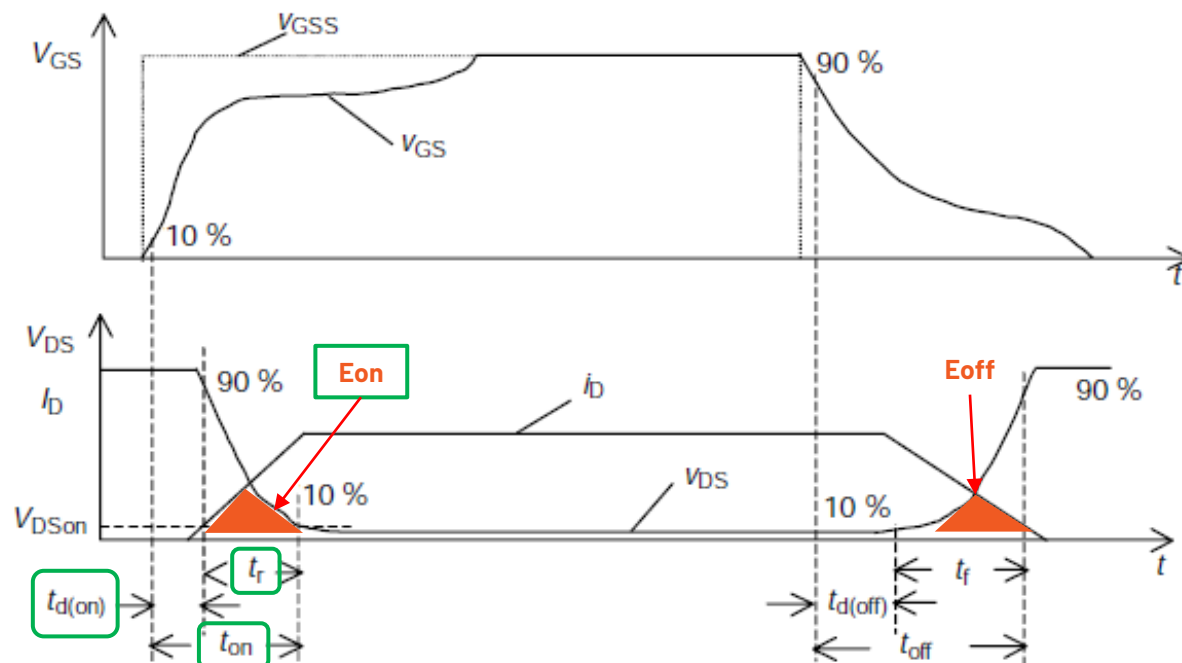
ENERGY LOSSES

The following equation is then used to calculate the energy losses during the turn-on and turn-off transition:

$$E_{on} = \int_0^t V_{DS} I_{DS} dt \quad E_{off} = \int_0^t V_{DS} I_{DS} dt$$



Scope measurements test points



$t_{d(on)}$: Time interval between 10% of the peak of VGS and 90% of the peak of VDS

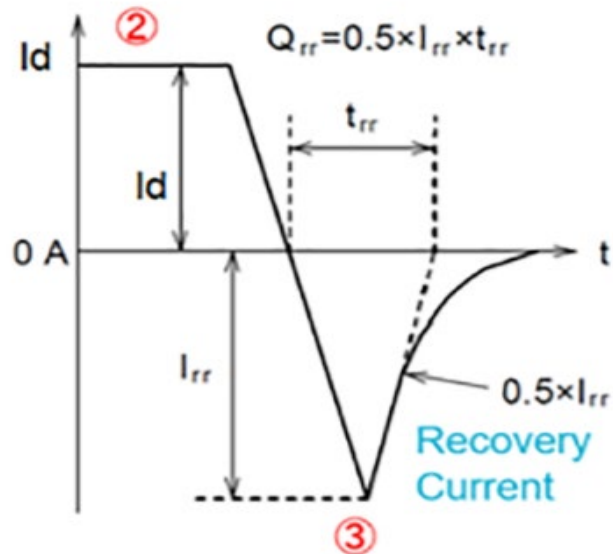
t_r : Time interval between 10% and 90% of the peak of VDS

Diode Reverse Recovery

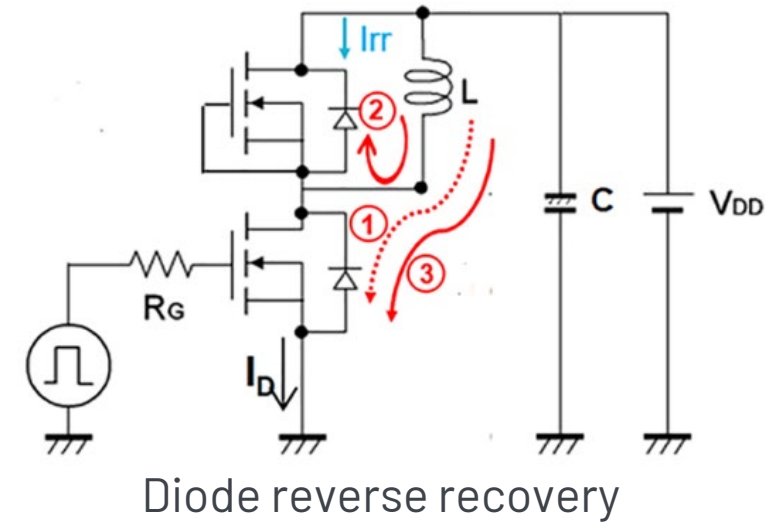
ENERGY LOSSES

The following equation is then used to calculate the energy losses during the transition:

$$E_{rr} = \int_0^t V_{sd} I_{rr,max} dt$$



Diode reverse recovery waveform



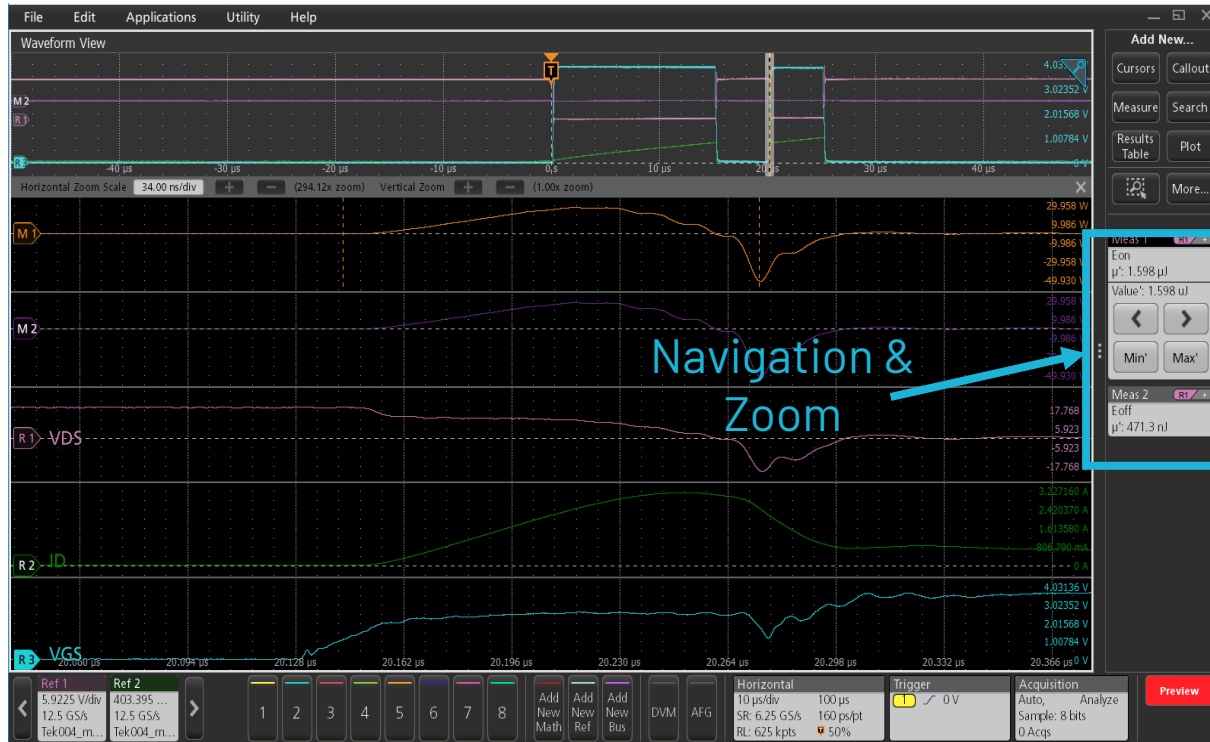
Diode reverse recovery

t_{rr} : Time interval between the zero crossing of the diode current I_d and the point in time the current has decayed to 25 % of I_{rr}

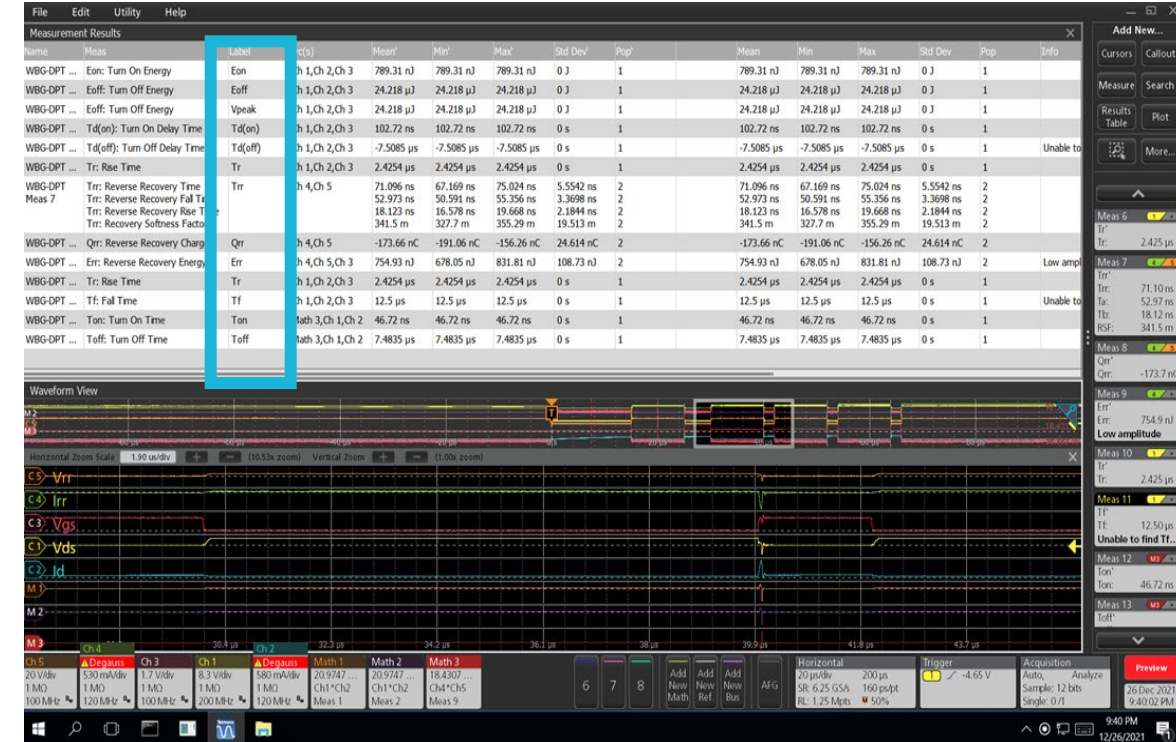
Q_{rr} : Amount of charge that flow through the diode when diode changes its state from forward conduction mode to reverse blocking mode

Powerful Features

NAVIGATION, ZOOM, DETAILED SUMMARY



Understanding region of interest

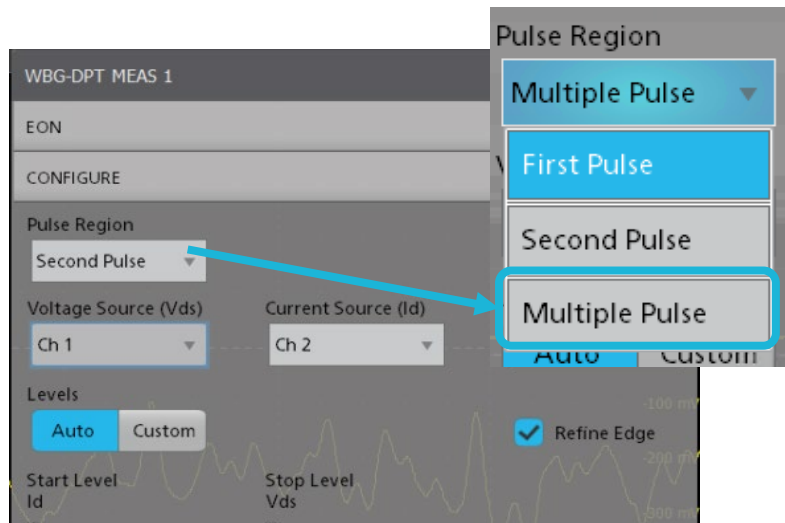


Detailed measurement summary

Powerful Features

TESTING WITH MULTIPLE PULSES

- **Understand the device behavior** at increasing drain currents
- Testing the device for increasing levels of drain current is **time consuming** as it involves several test cases
- Ability to program and **automate the gate driver** is critical



Powerful Feature

REAL WORLD WAVEFORMS HAVE GLITCHES AND RINGING

WBG-DPT MEAS 1

EON

CONFIGURE

Pulse Region: Second Pulse

Voltage Source (Vds): Ch 1

Current Source (Id): Ch 2

Gate Source (Vgs): Ch 3

Levels: Auto Custom

Set Levels In: % Absolute **Refine Edge**

Start Level: Vds Id

Stop Level: Vds Id

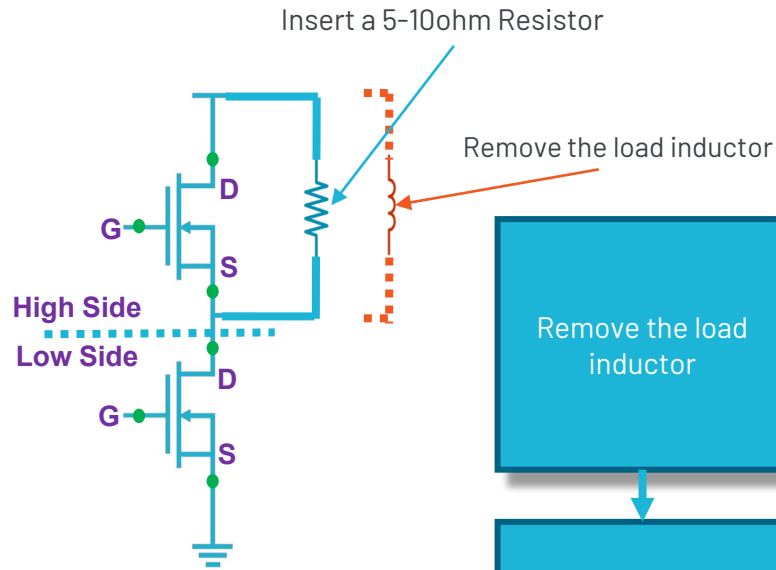
1 A 5 V





Challenges

CONVENTIONAL DESKEW METHOD



Remove the load inductor

Connect a low inductance resistor (~10 Ohm) across the device

Apply DC bus voltage

Measure V_{gs} , V_{ds} and I_{ds} across lower device

Save the waveforms

Align the V and I waveforms based on their vertical scales

Zoom to the turn on/off regions

Manually measure the delay between the waveforms and apply deskew on one of the channel until the two traces are perfectly aligned

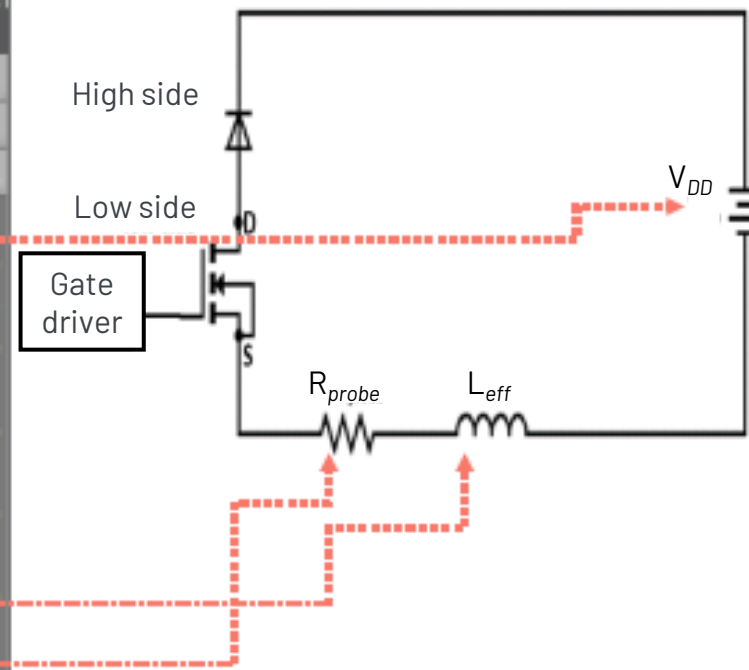
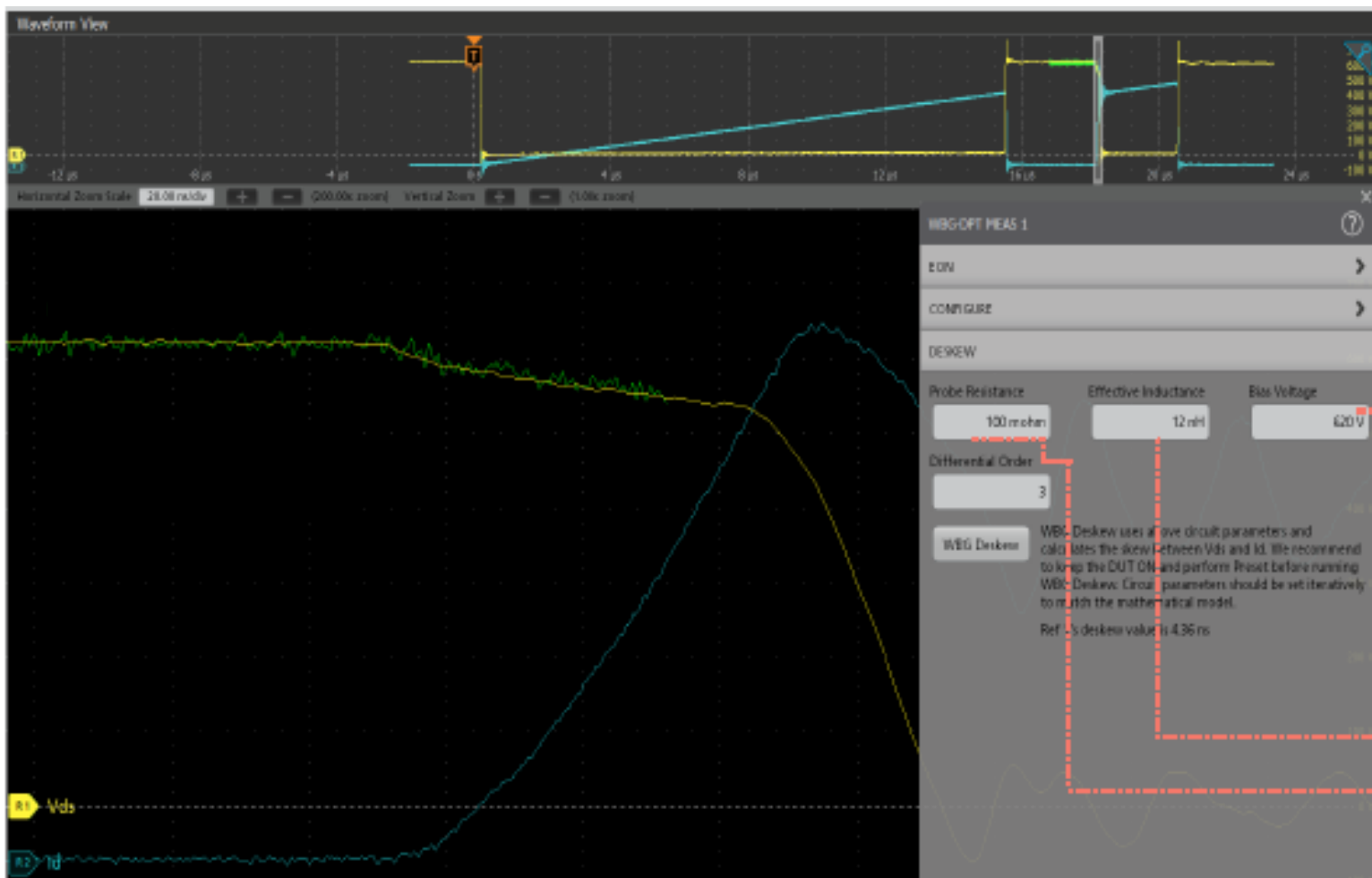
Remove the resistor and reconnect the load inductor

Start testing; Repeat procedure if setup changes

+60 Minutes per deskew cycle

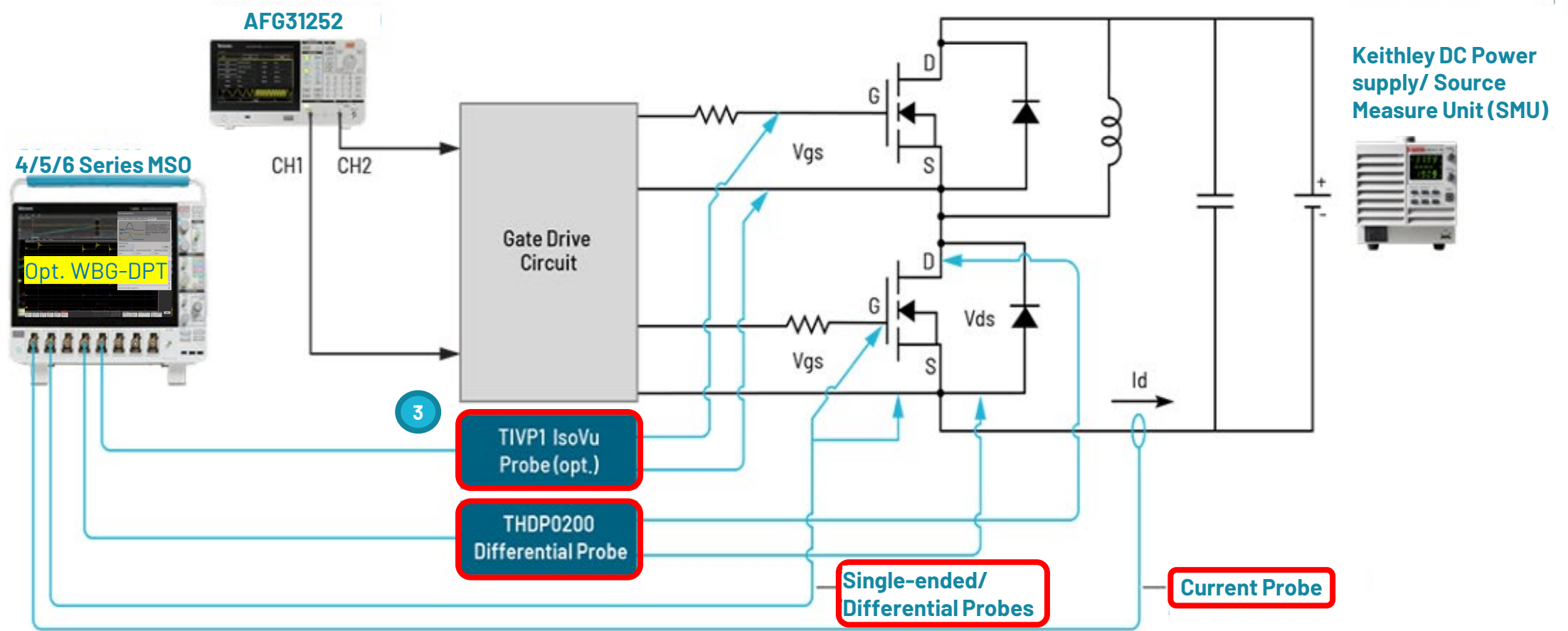
Powerful Feature

AUTOMATED DESKEW



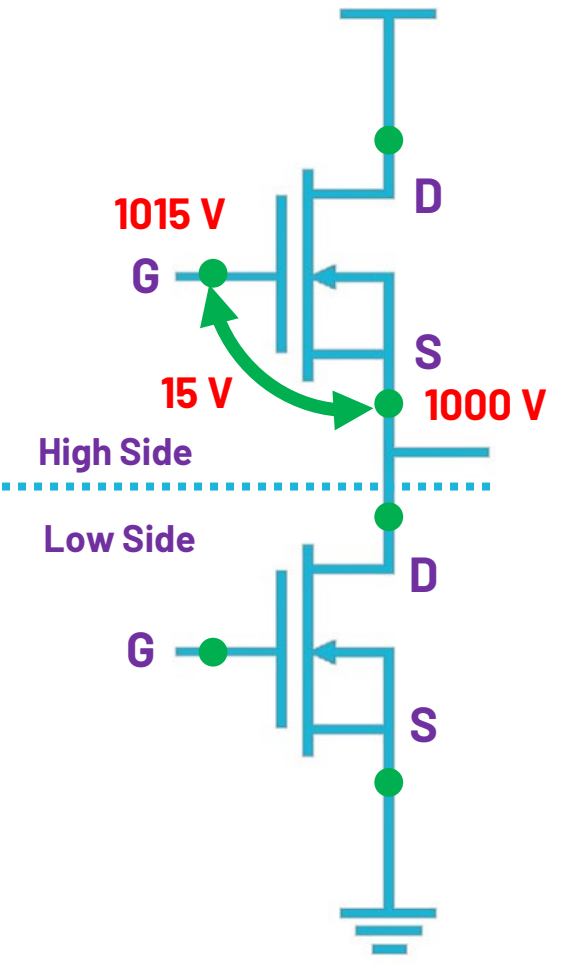
Double Pulse Test Setup

MEASURE SWITCHING LOSSES ON MOSFETS



High Side Vgs

PROBE SPECIFICATIONS COMPARISON



	Single Ended	Differential Probe	Isolated Probe (IsoVu)
	TPP0850 / TPP1000	THDP0200	TIVP1
Bandwidth	800 MHz / 1 GHz	DC to 200 MHz	DC to 1 GHz
Maximum Measurement Voltage	2.5kVpk, 1kV CAT II / 300V CAT II	±1.5kV differential	±1.5kV differential
Common Mode Voltage	N/A	±1,500 V	60,000 V
Loading (Input + to ground)	50 MΩ <1.8 pF / 10 MΩ <4 pF	5 MΩ <4 pF	None
Loading (Input - to ground)	N/A	5 MΩ <4 pF	<5 pF
Loading (input + to -)	N/A	10 MΩ <2 pF	40 MΩ <2.4 pF (tip dependent)
Aberrations	Best	Better	Good
Isolation	None	None	Optical
Common Mode Voltage	2,500 Vpeak	±2,300 V	±60,000
Common Mode Rejection Ratio	N/A	>-80 dB (10k:1)	-160 dB (100M:1)
CM Error (1kV) @ DC	N/A	0.1 V	1 mV
CM (1kV) @1 MHz	N/A	3.2 V	1 mV
CM Error (1kV) @100 MHz	N/A	45.2 V	1 mV
CM Error (1kV) @ Full BW	N/A	178.6 V	0.1 V



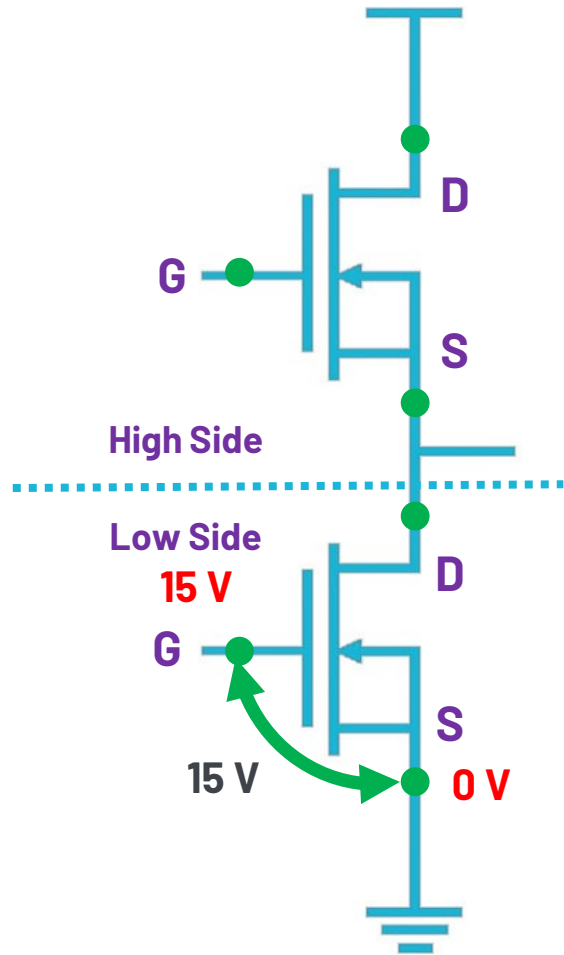
High Side Vgs Comparison

WAVEFORM COMPARISON



Low Side Vgs

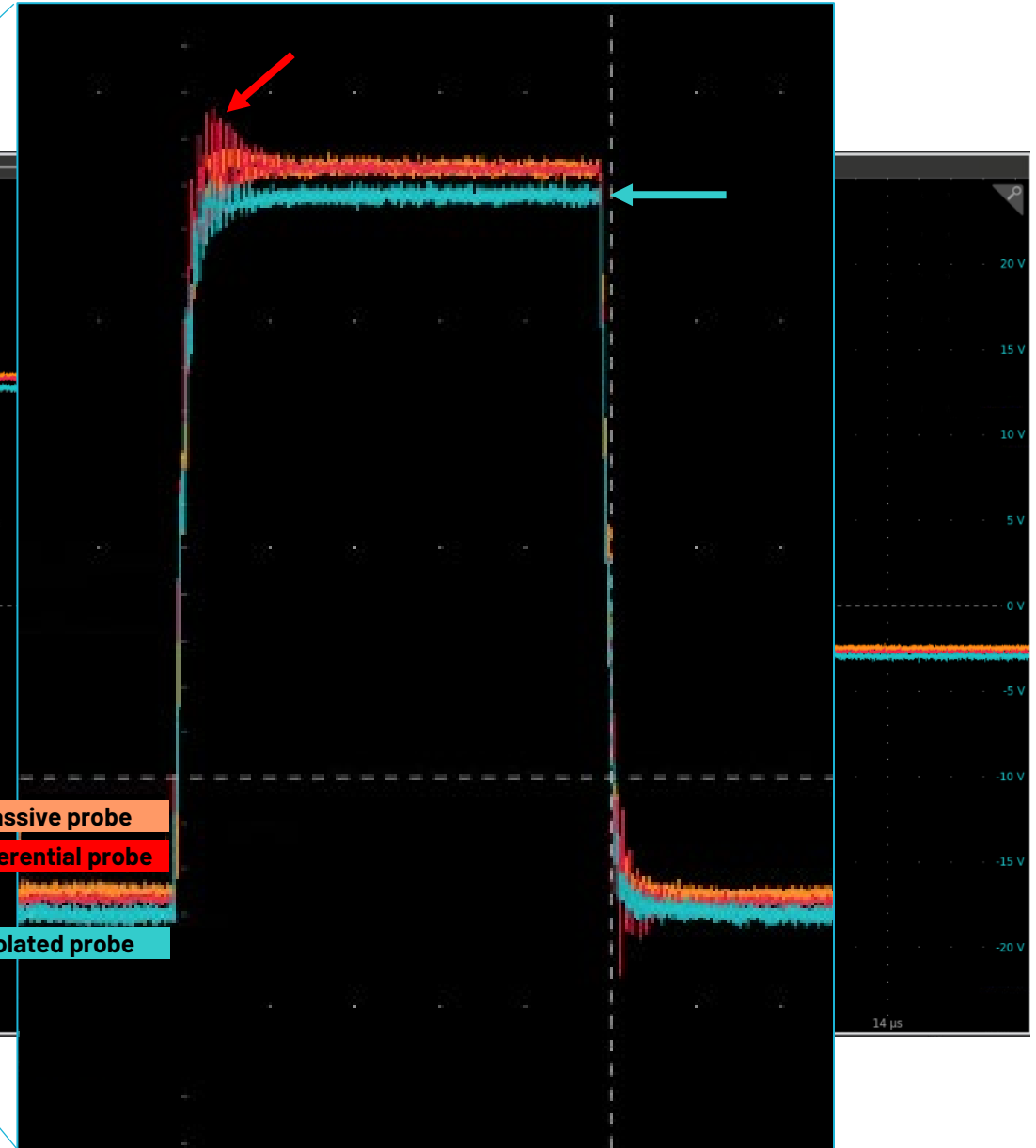
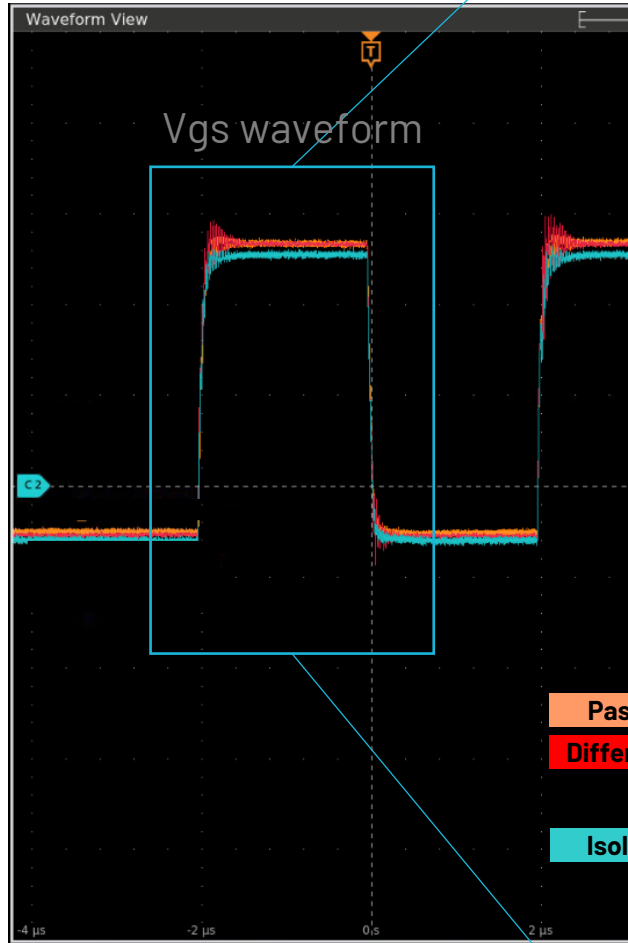
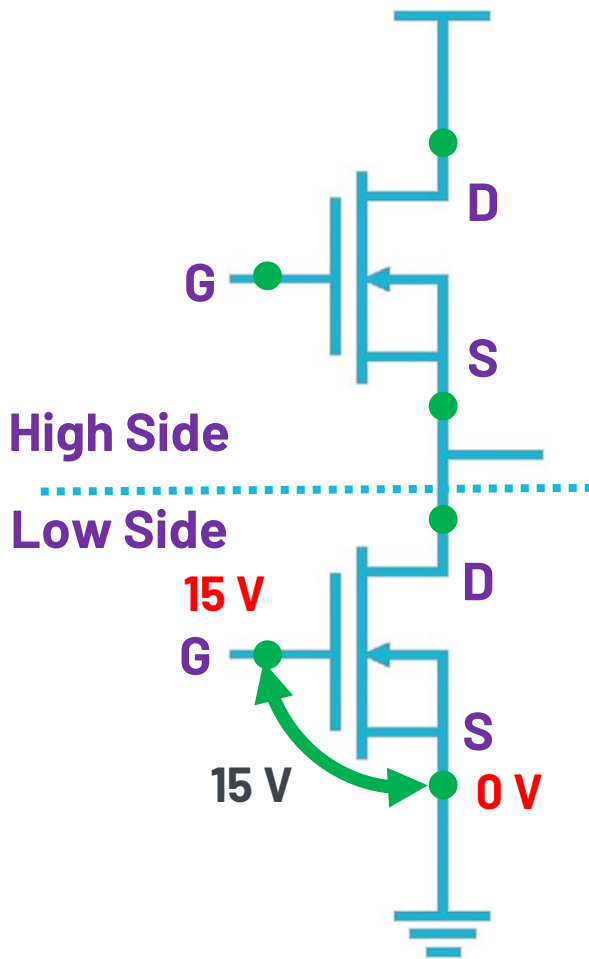
PROBE SPECIFICATIONS COMPARISON



	Single Ended	High Voltage Differential	Isolated
Bandwidth	TPP0850 / TPP1000	THDP0200	TIVP1
Maximum Measurement Voltage	800 MHz / 1 GHz	DC to 200 MHz	DC to 1 GHz
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Common Mode Voltage	None	None	Optical
Common Mode Rejection Ratio	2,500 Vpeak	±2,300 V	±60,000
	N/A	>-80 dB (10k:1)	-160 dB (100M:1)

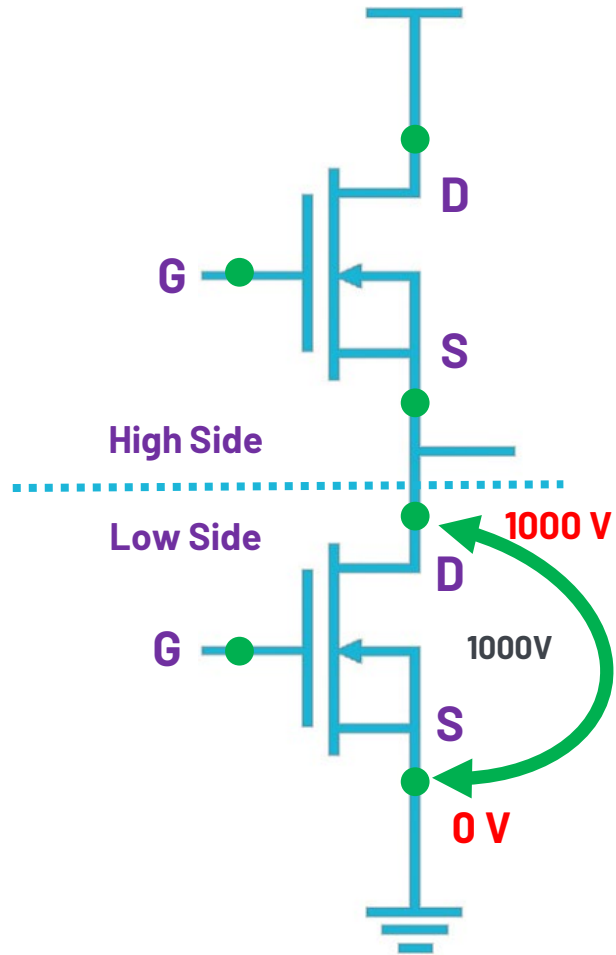
Low Side Vgs Comparison

WAVEFORM COMPARISON



Low Side Vds

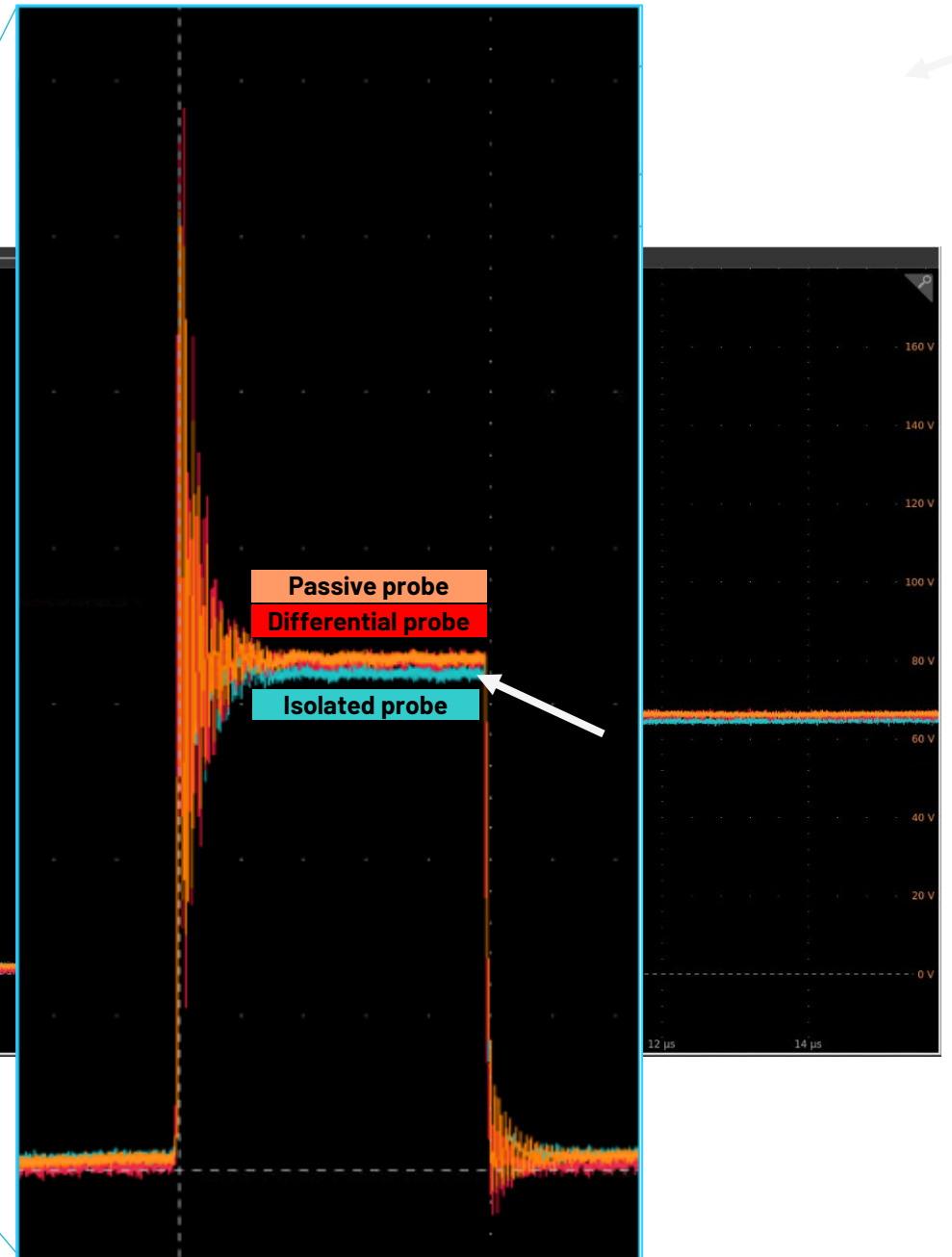
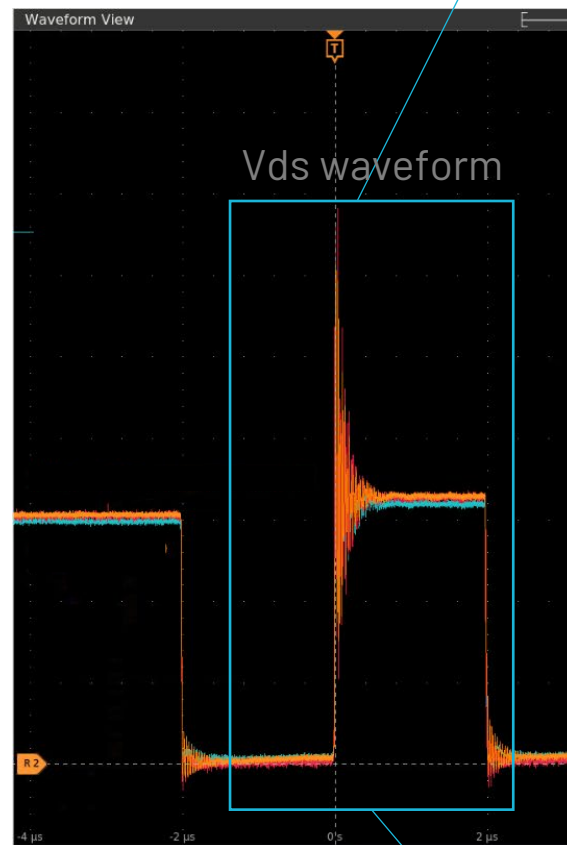
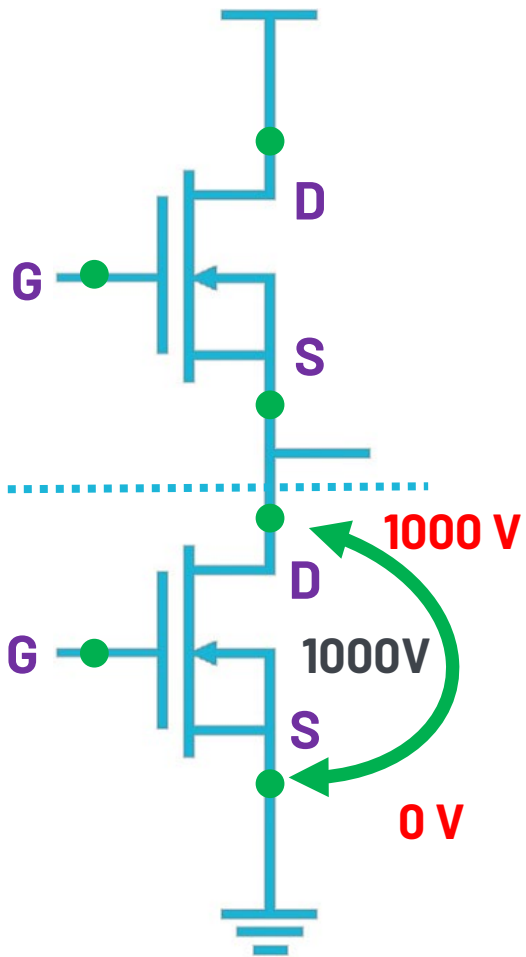
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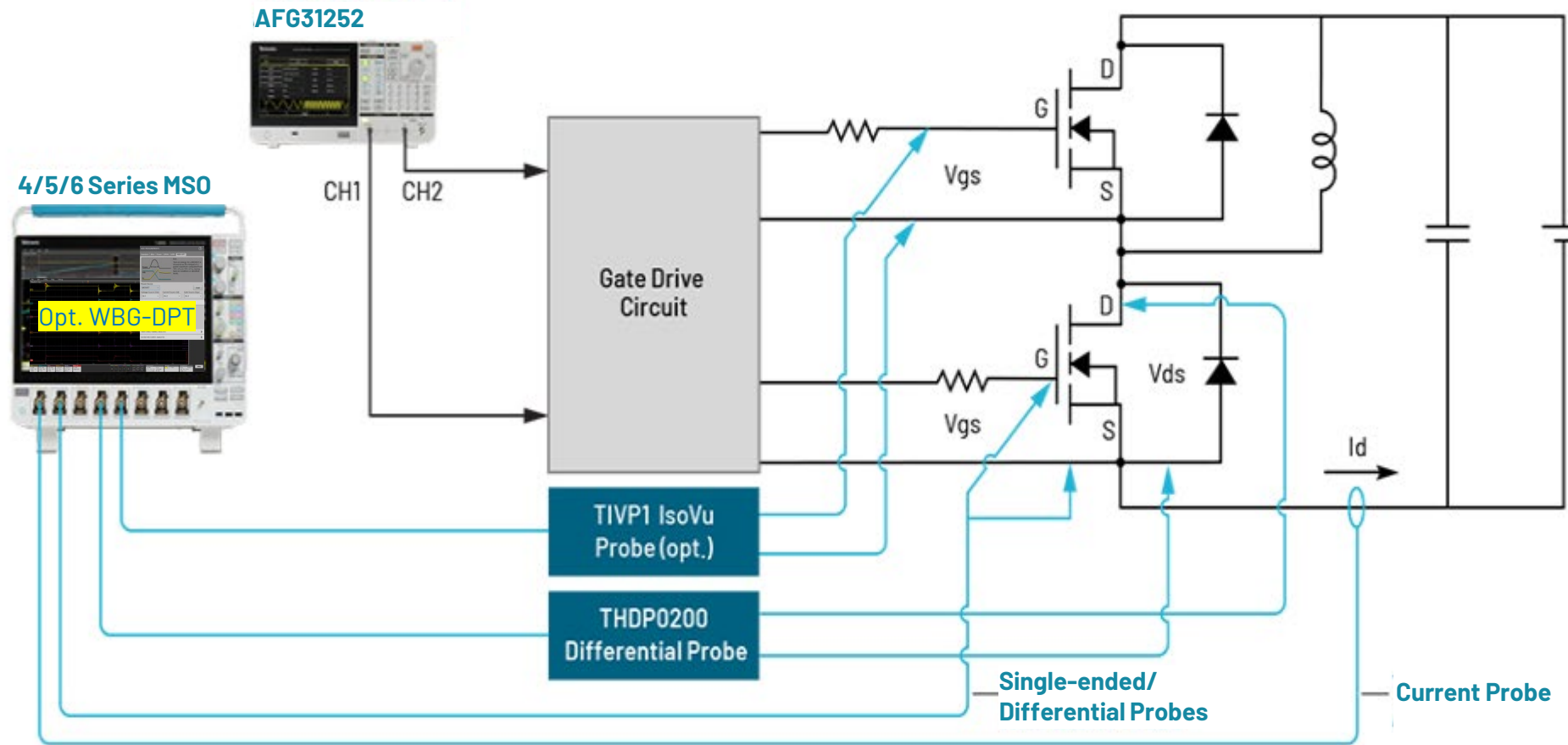
Low Side Vds Comparison

WAVEFORM COMPARISON



Double Pulse Test Setup

MEASURE SWITCHING LOSSES ON MOSFETS



4

Keithley DC Power supply/ Source Measure Unit (SMU)





Power Supplies/SMU (Keithley)

Model	Rated voltage range	Rated current	Rated output power
2470 SMU	1000V Max	Up to 1A	20W
2260B-800-2	0-800V	0 - 2.88A	720W
2657A	3000V Max	120mA Max	180W



Series 2220/2230/2231 Multiple Output DC Power Supplies

- Two or three independent outputs
- All outputs displayed simultaneously
- Remote sensing on all channels
- Low noise
- Programmable



Series 2260B 360W/720W/1080 DC Power Supplies

- Power up to 1080W
- Outputs up to 800V and 100A
- Analog input
- Single channel
- Wide range
- Programmable
- Used in automated test equipment



Series 2300 Battery Simulating DC Power Supplies

- Single and dual output models
- Each output can source or sink
- Programmable output resistance
- Low noise



Series 2230 High Power 3 Output DC Power Supplies

- 195 W and 375 W versions
- 6 A or 60 V per output
- Remote sensing on all outputs
- Three-channel models
- Low noise
- Programmable



Series 2280 Precision Measurement Variable Bench Power Supply

- 192W with up to 6A
- 6 ½-digit, 10nA current measurement resolution
- Displays plots of voltage and current
- Programmable
- Designed for benchtop and automated testing of power conversion devices and IoT devices
- TFT LCD display to monitor current and voltages



Keithley 2400 Graphical Touchscreen Series SMU

- Nanostructured Materials Research
- Power Semiconductor GaN, SiC
- Biosensor Development
- Semiconductor Device Design
- Automotive Sensor Design

[View Product](#)



SMU 2600B: Single or Dual Channel Systems

- Semiconductor Production Test
- Semiconductor Device Design
- Transistor Characterization
- IDDQ Testing and Standby Current Testing
- Multi-Pin Device Test

[View Product](#)



2601B-PULSE System SourceMeter® 10 µs Pulser/SMU Instrument

- VCSEL Test for LIDAR
- High Brightness LED Test
- Laser Diode Production Test
- Semiconductor Device Design

[View Product](#)



Keithley 2400 Standard Series SMU

- Resistor/Resistor Network Production Test
- Connector, Relay, Switch Test
- Accelerated Stress Testing
- Circuit Protection Device Test
- Materials Research

[View Product](#)



SMU 2650 Series for High Power

- Power Semiconductor GaN, SiC
- Solar Panel Test
- Electromigration studies
- Semiconductor junction temperature characterization

[View Product](#)



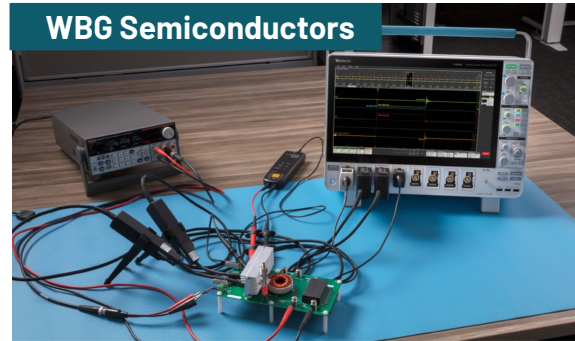
SMU 2606B: High Density SMU

- VCSEL, Laser Diode Production Test
- LED Production Test
- Transistor Characterization

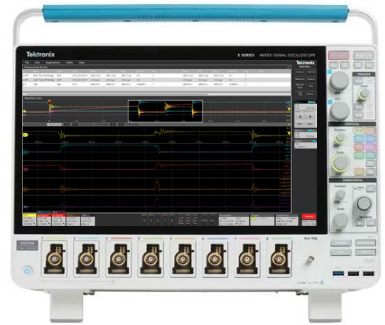
[View Product](#)



The Complete Solution!



SCOPE



4/5/6 SERIES MSO

PROBES



TCPx, TPPx, IsoVu

DC POWER GATE DRIVE



SMU, AFG

SOFTWARE



Opt. WBG-DPT

SERVICES

Total protection service options to protect your investment over the lifetime of the solution

SOFTWARE
BUNDLES

Tektronix[®]



**THANK
YOU**

Contact Information



Get in touch with us @

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