Tektronix

Automated Measurement on Double Pulse Testing

Sharon Lau

November 15, 2023

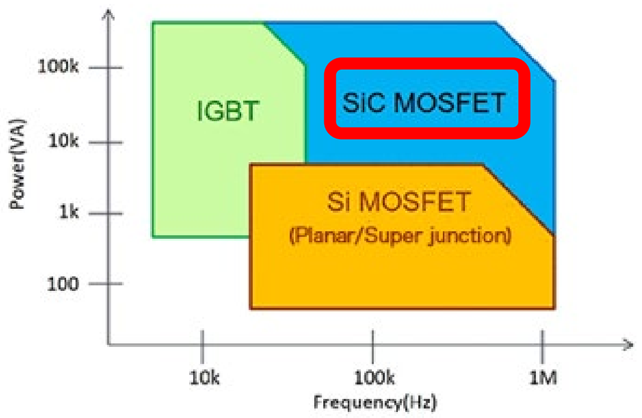
KEITHLEY
A Tektronix Company

Agenda

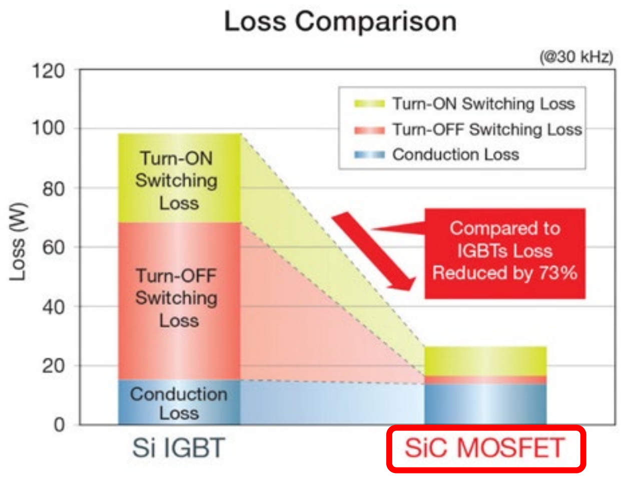
- Switching Losses in Semiconductor Devices
- Double Pulse Test (DPT)
  - What is DPT?
  - Importance of DPT
  - Challenges on DPT
  - Automated Measurements on DPT
- Summary

Wide Bandgap (WBG)

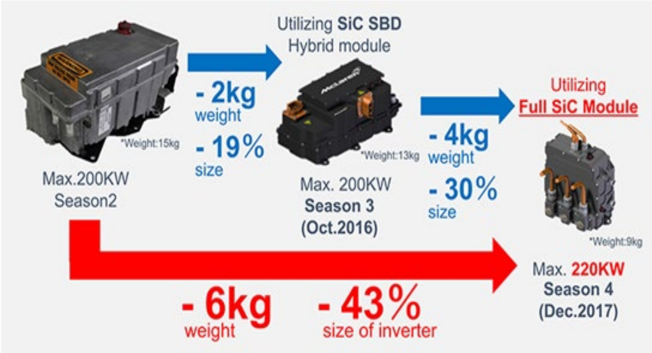
INTRODUCTION



Higher Power Levels
Faster Switching speeds



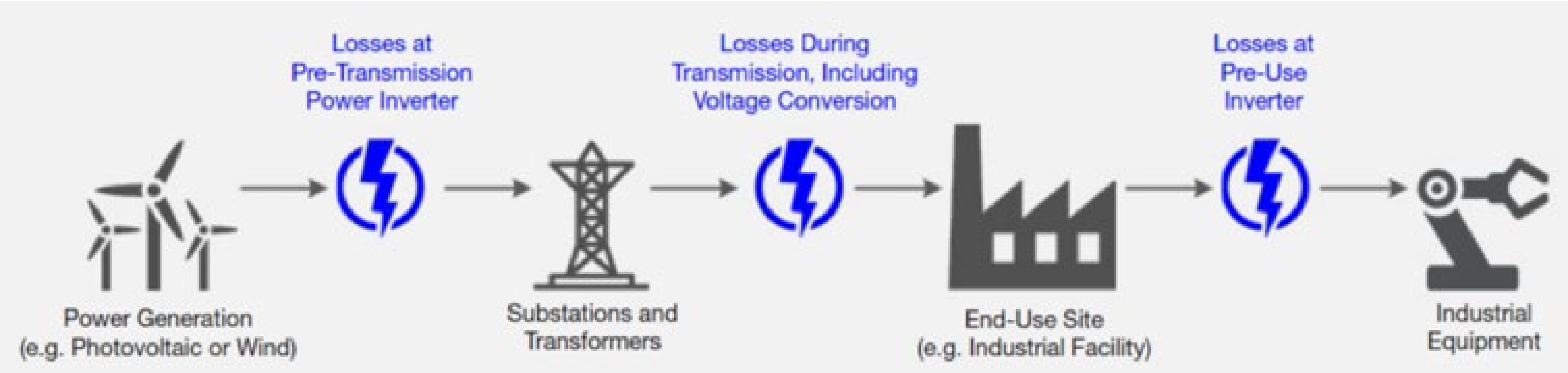
Lower Switching Losses



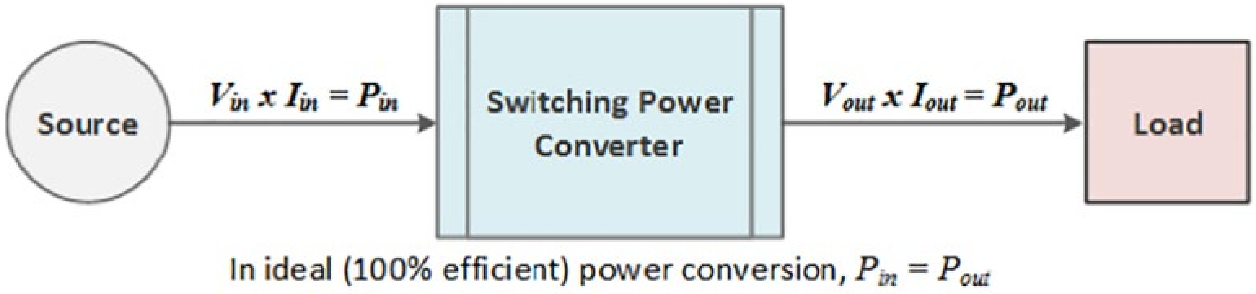
Smaller Form Factor

Power Conversion

INTRODUCTION



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



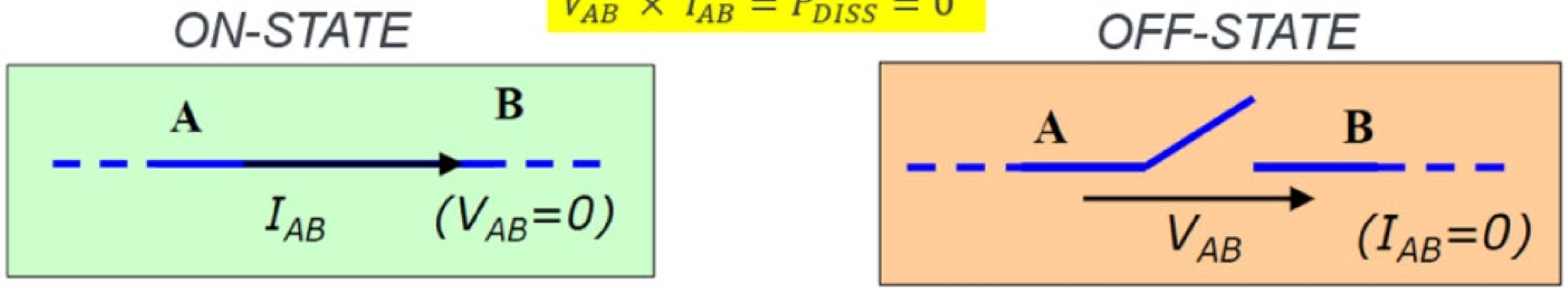
Ideal power conversion efficiency

https://www.tek.com/document/technical-brief/evolving-materials-and-testing-emerging-generations-power-electronics

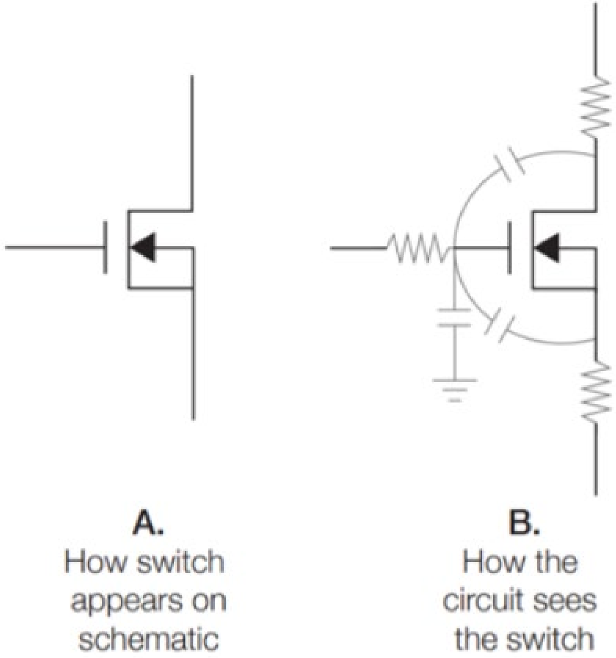
Switching Losses

IDEAL SWITCHING AND PRACTICAL SWITCHING

$V_{AB} \times I_{AB} = P_{DISS} = 0$



Ideal switching



Practical switching

What is Double Pulse Test (DPT)?

EVALUATE SWITCHING BEHAVIOR ON MOSFETS AND IGBTS

- **Turn-on Parameters:** turn-on delay ($t_{d(on)}$), rise time (t_r), turn-on time (t_{on}), On Energy (E_{on}), *dv/dt* and *di/dt*

- **Turn-off Parameters:** turn-off delay ($t_{d(off)}$), 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

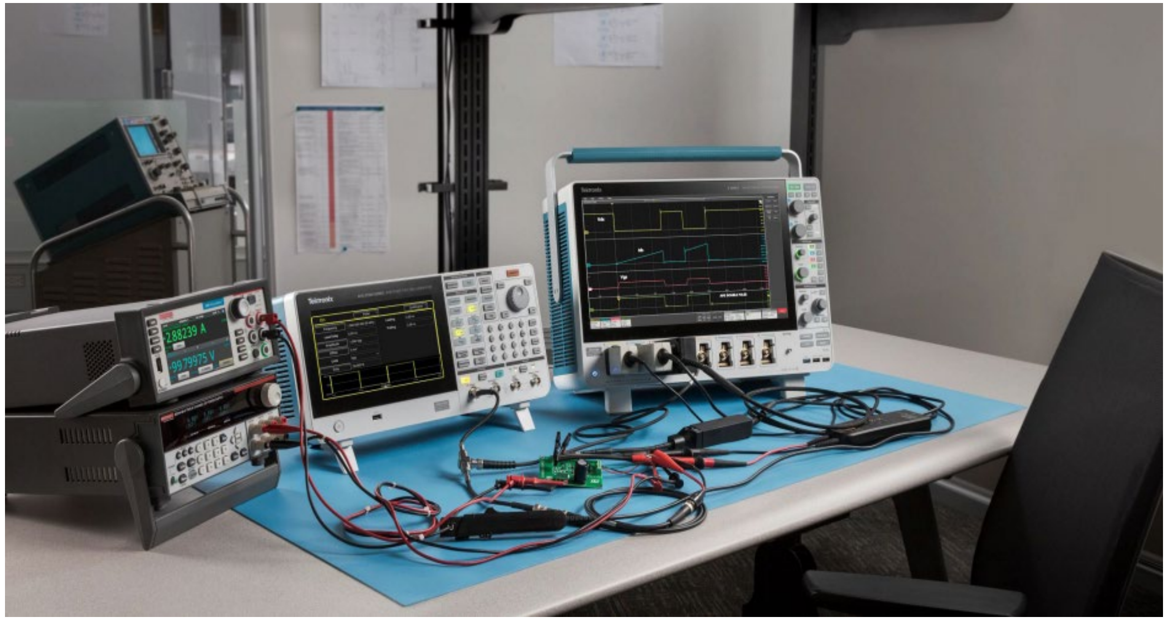
Importance of Double Pulse Test

EVALUATE THE DYNAMIC SWITCHING BEHAVIOR OF SEMICONDUCTOR

- Guarantee specifications of power devices like MOSFETs and IGBTs.

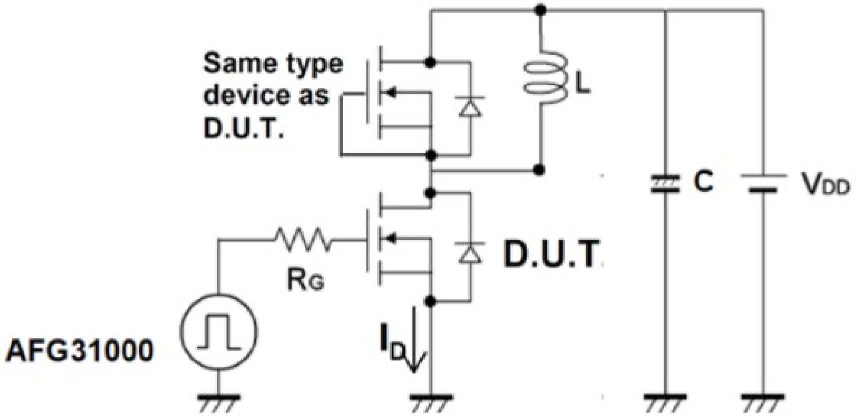
- Confirm actual value or deviation of the power devices or power modules.

- Measure these switching parameters under various load conditions and validate performance across many devices.

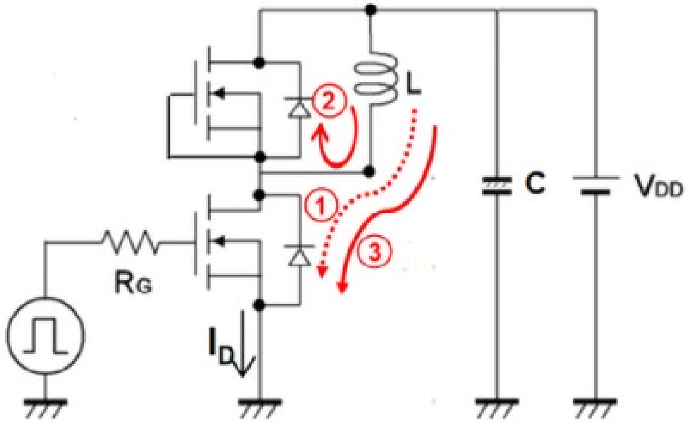


Double Pulse Test Circuit

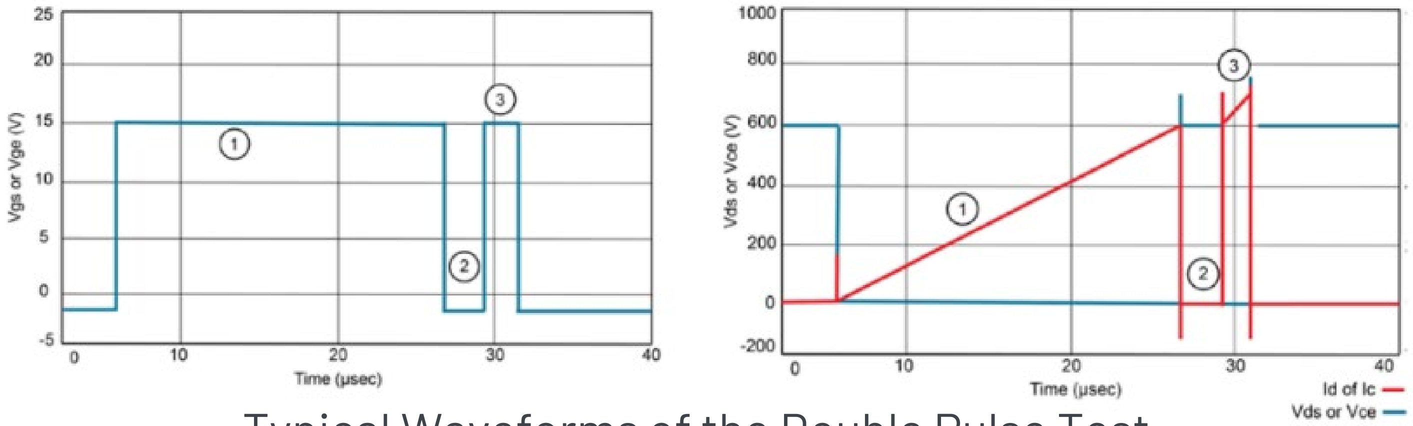
OPERATION OF DOUBLE PULSE TESTING



Typical Double Pulse Test circuit



Current Flow

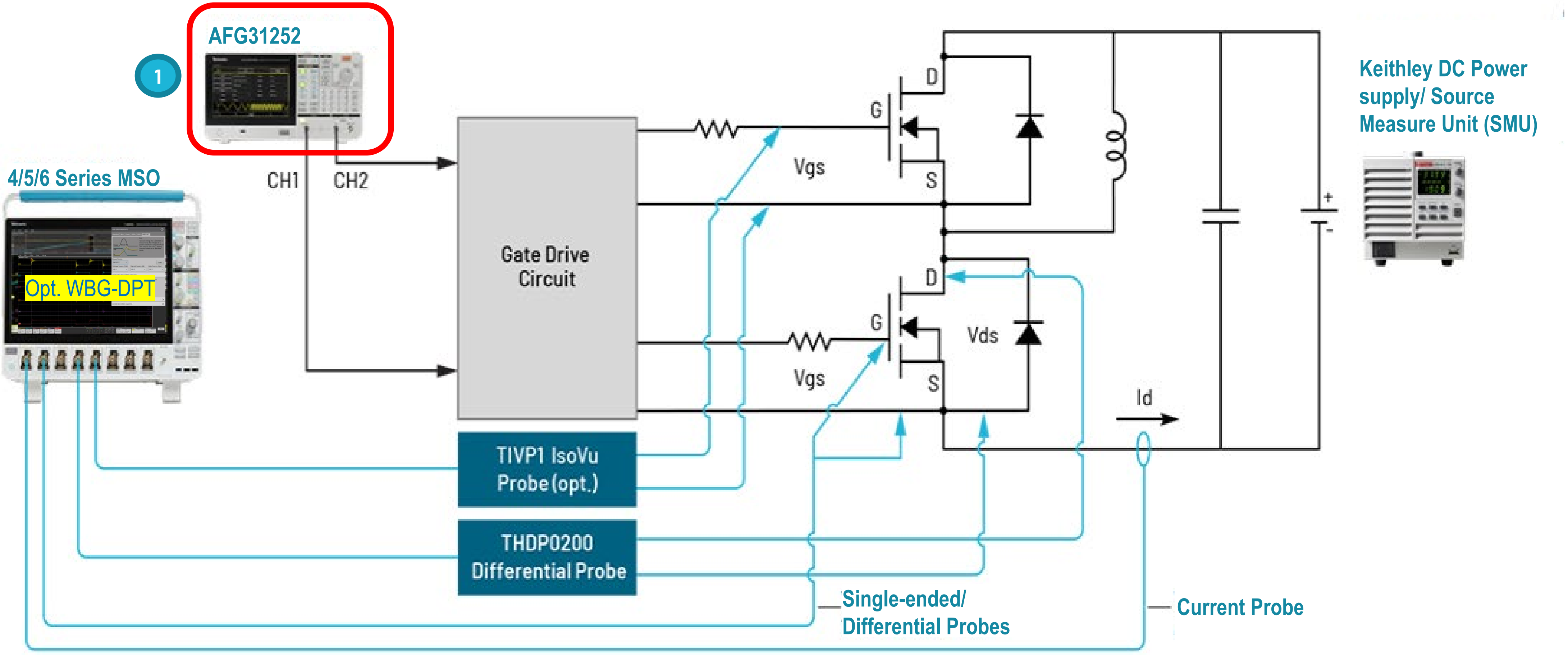


Typical Waveforms of the Double Pulse Test

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

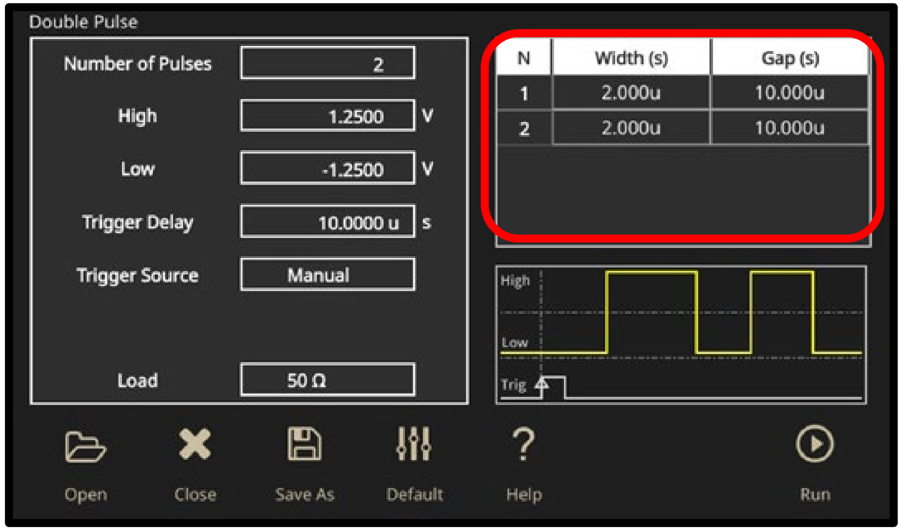
- Using PC to create arbitrary waveforms and load them onto the AFG is **cumbersome** and **time consuming**

- Using microcontrollers require a lot of **effort and time** to program

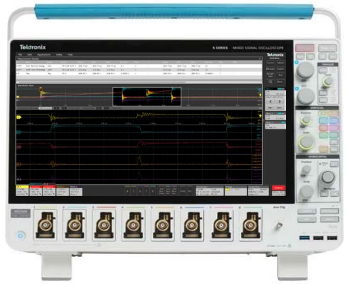
AFG or Scope Built-In AFG

LEVERAGE THE AFG AS A GATE DRIVER

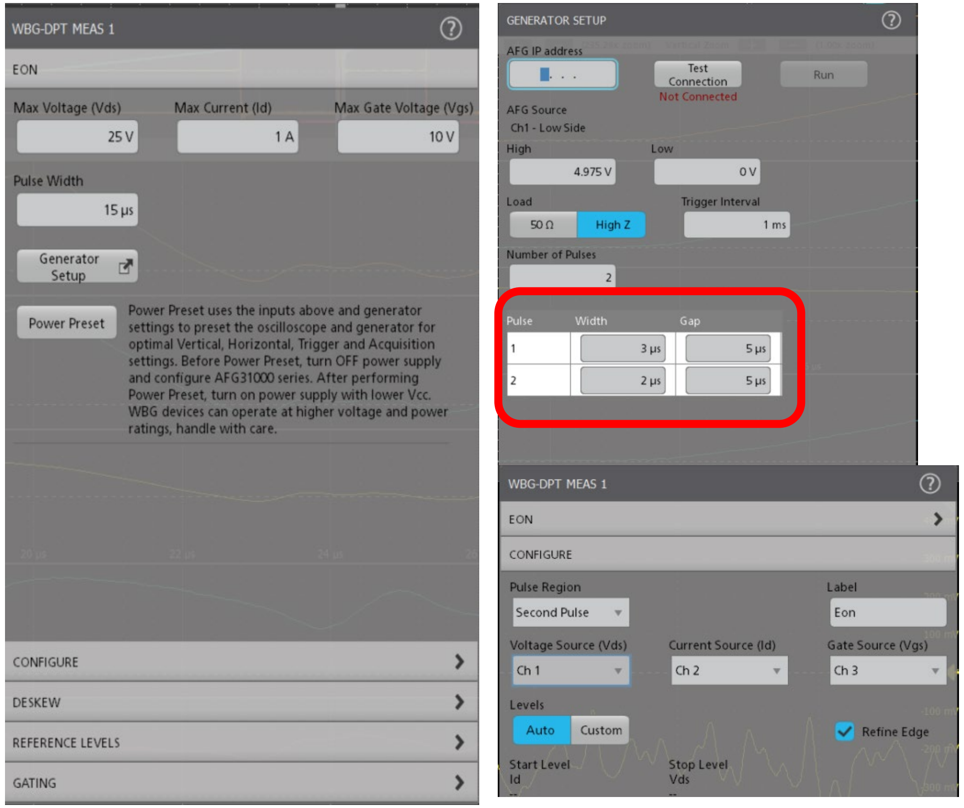
AFG 31000



Double Pulse Test application on the AFG31000

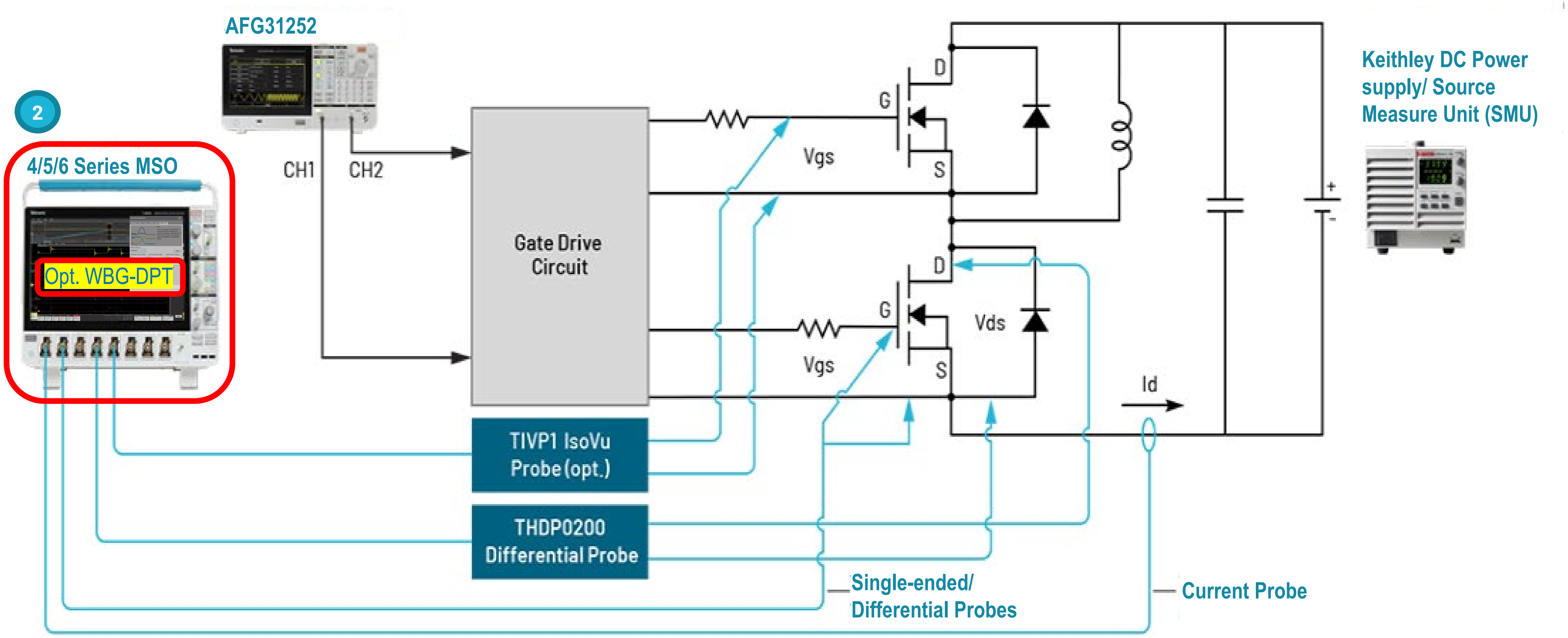


Scope Built-in AFG



Double Pulse Test Setup

MEASURE SWITCHING LOSSES ON MOSFETS



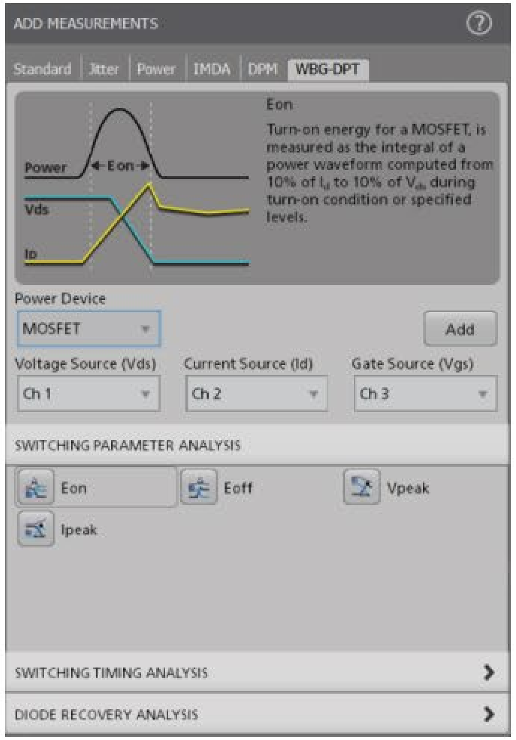
Challenges

ANALYSING SWITCHING BEHAVIOURS

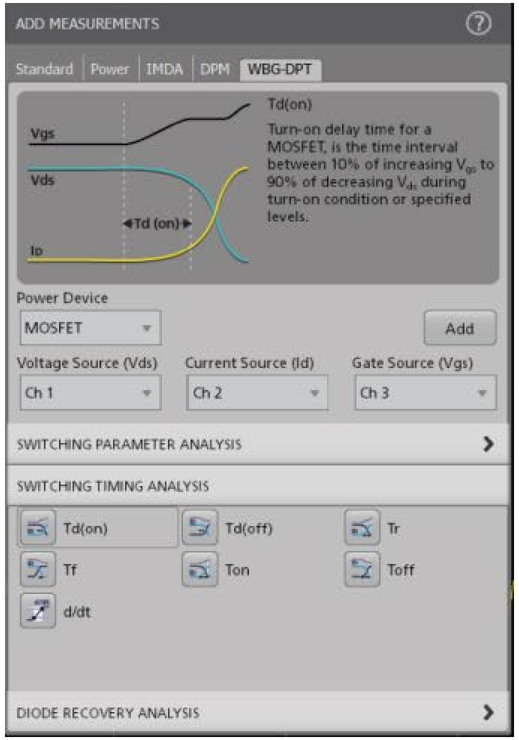
- Core Measurements are centric around **Timing** and **Switching**
- To analyze these losses, we need to **gate the right regions of interest**
- It takes expertise to **capture the right signals** and **manually add cursors**
- **Manually document the results** - save the waveforms, reports, session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

Automated Measurements (Opt. WBG-DPT)

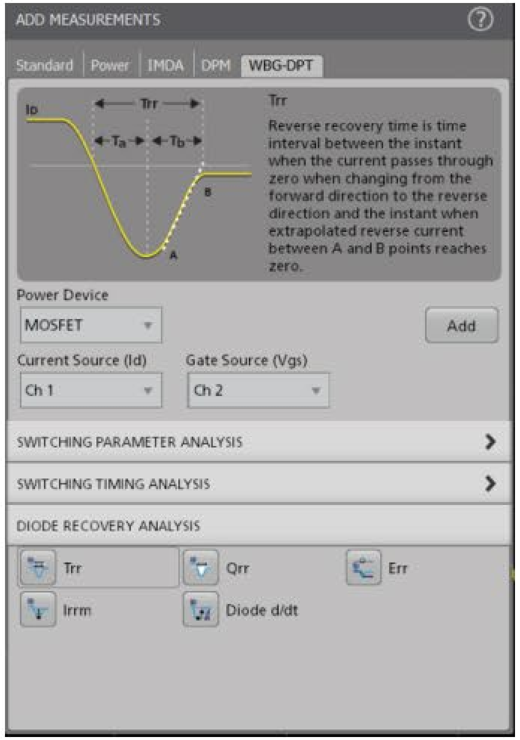
TEST GROUPS AND MEASUREMENTS



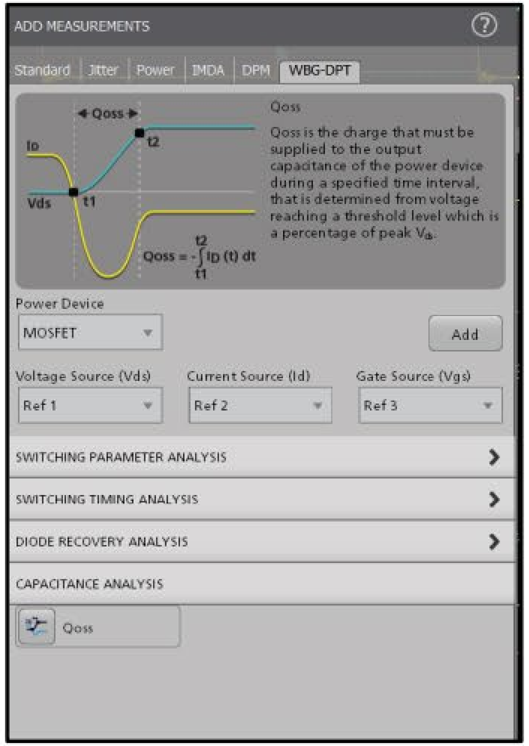
Switching Parameter Analysis



Switching Timing Analysis



Diode Recovery Analysis



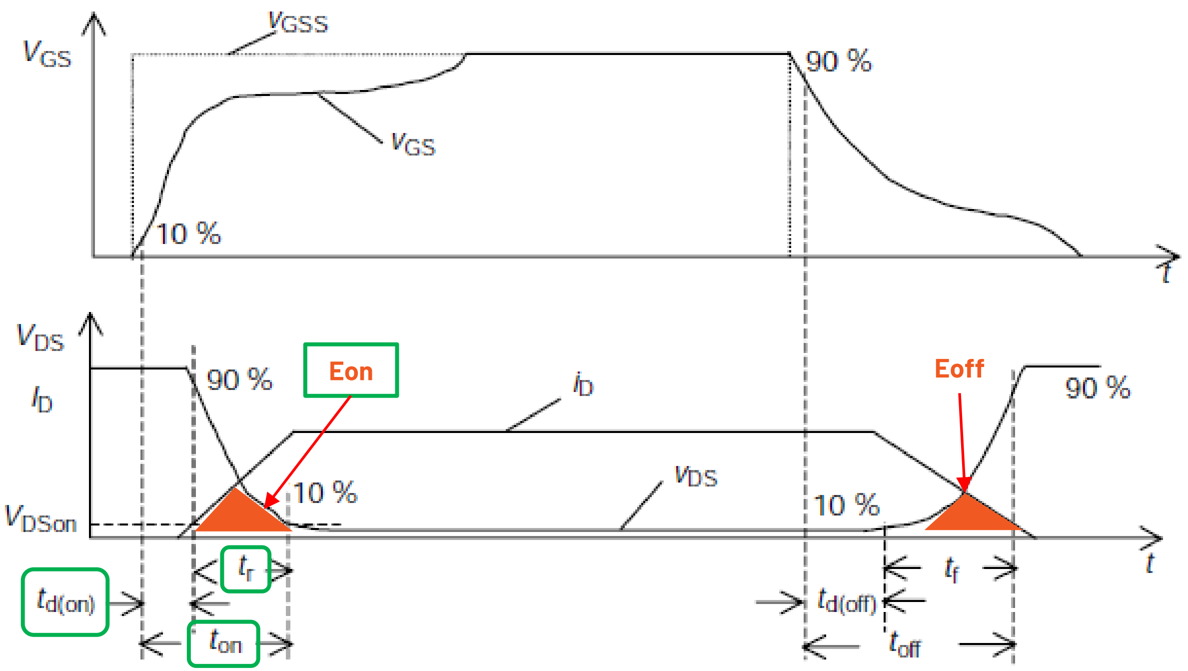
Capacitance Analysis

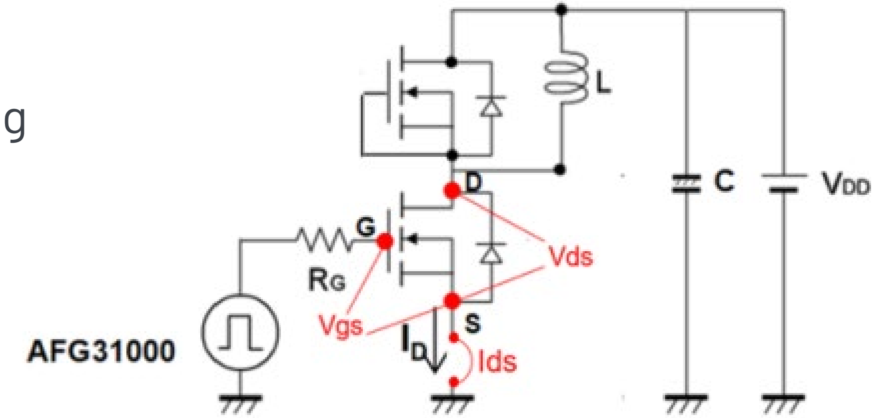
Turn-on and Turn-off Parameters

ENERGY LOSSES

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

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





Scope measurements test points

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

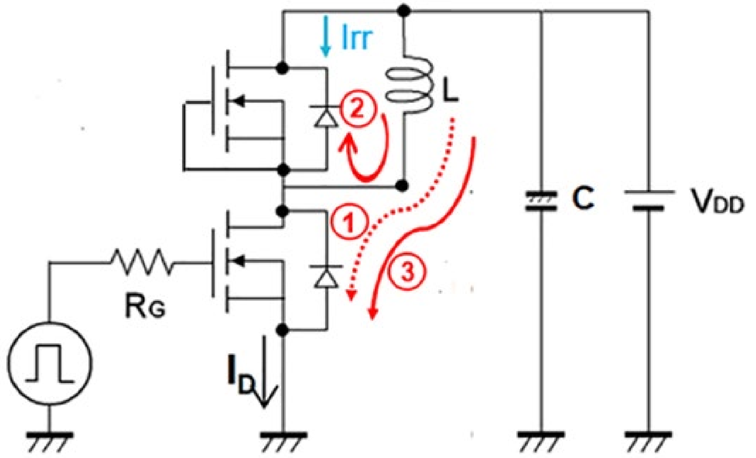
t_r: Time interval between 10% and 90% of the peak of VDS

Diode Reverse Recovery

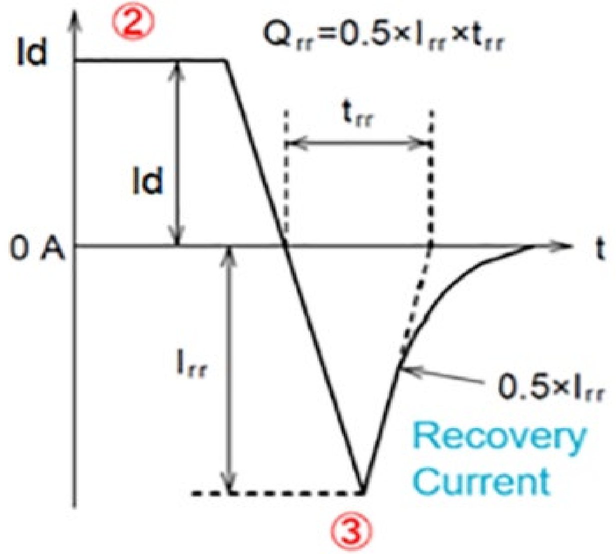
ENERGY LOSSES

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



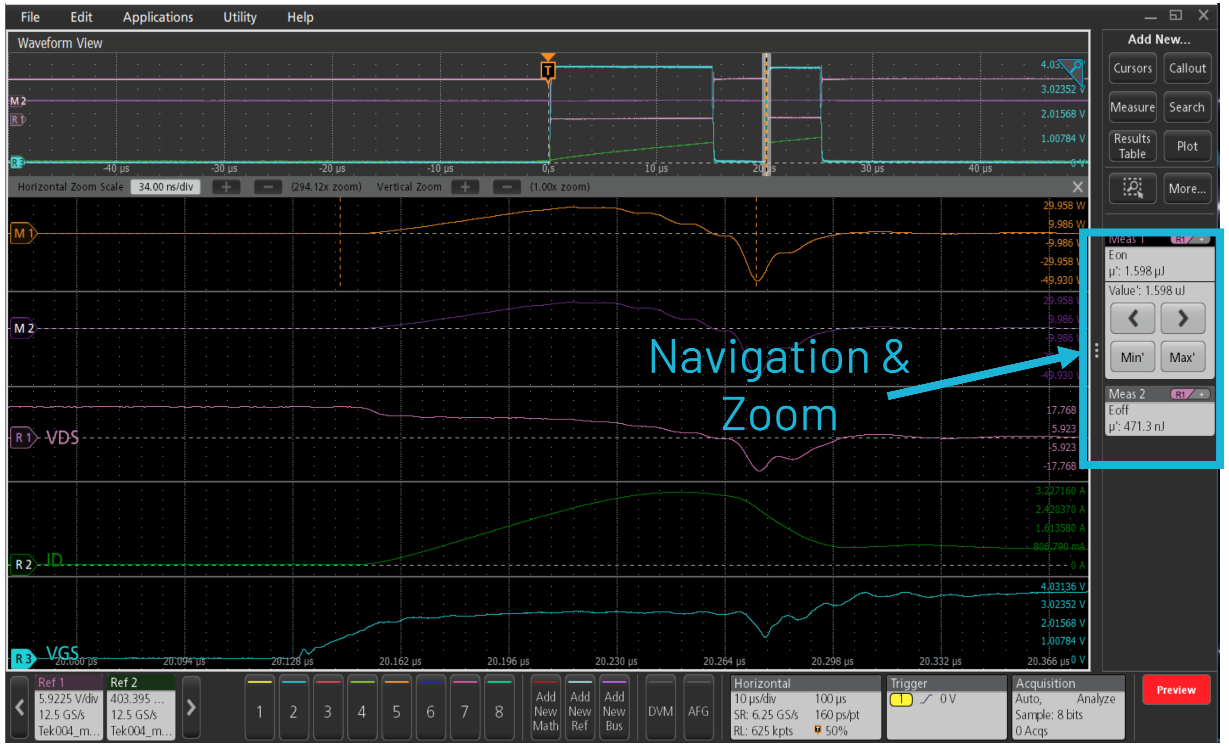
Diode reverse recovery waveform

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

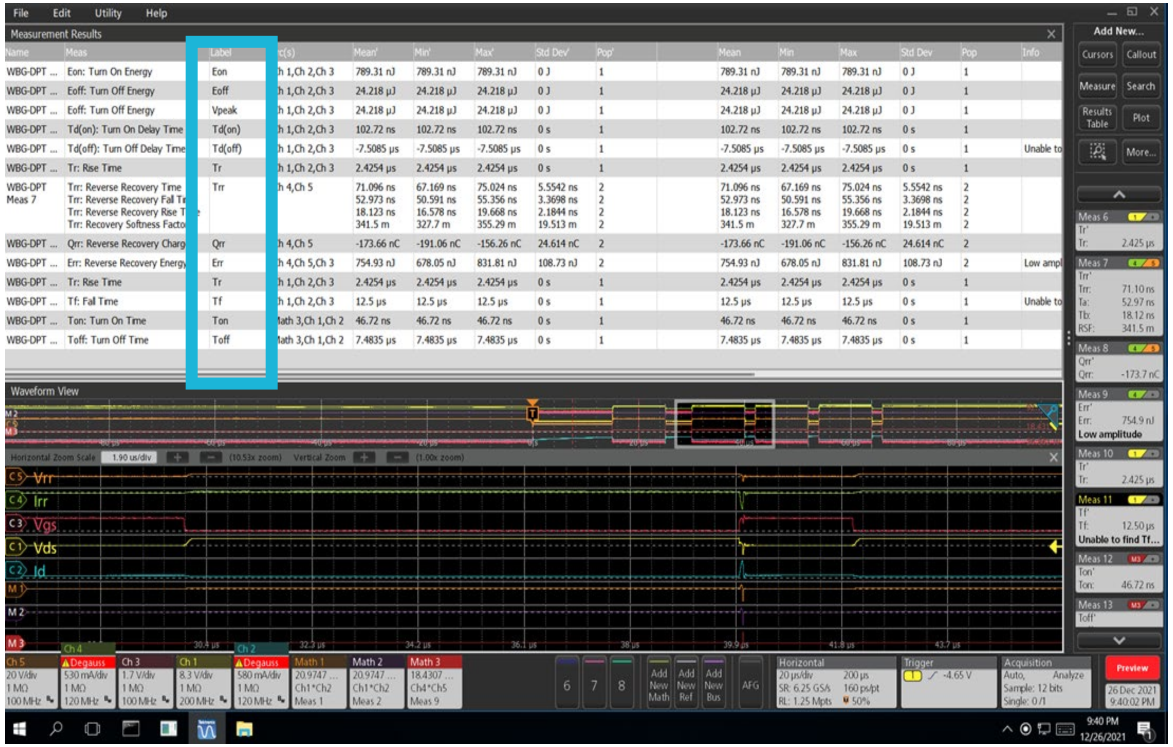
Q_{rr}: Amount of charge that flow through the diode when diode changes its state from forward conduction mode to reverse blocking mode

Powerful Features

NAVIGATION, ZOOM, DETAILED SUMMARY



Understanding region of interest

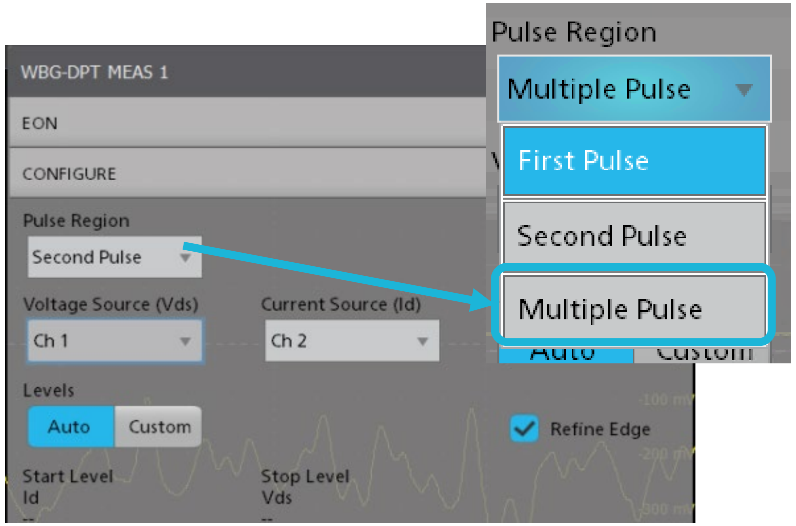


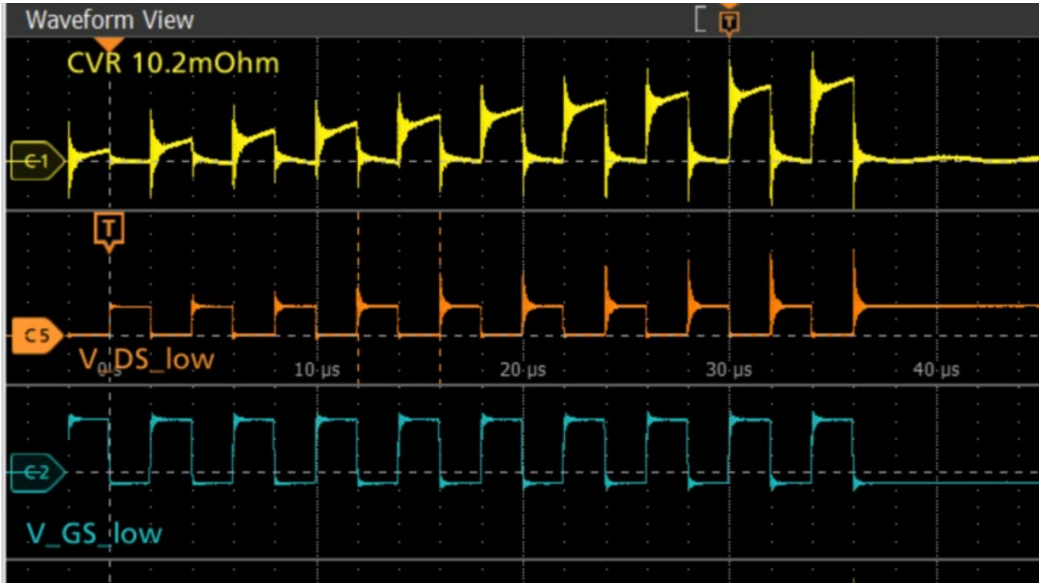
Detailed measurement summary

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



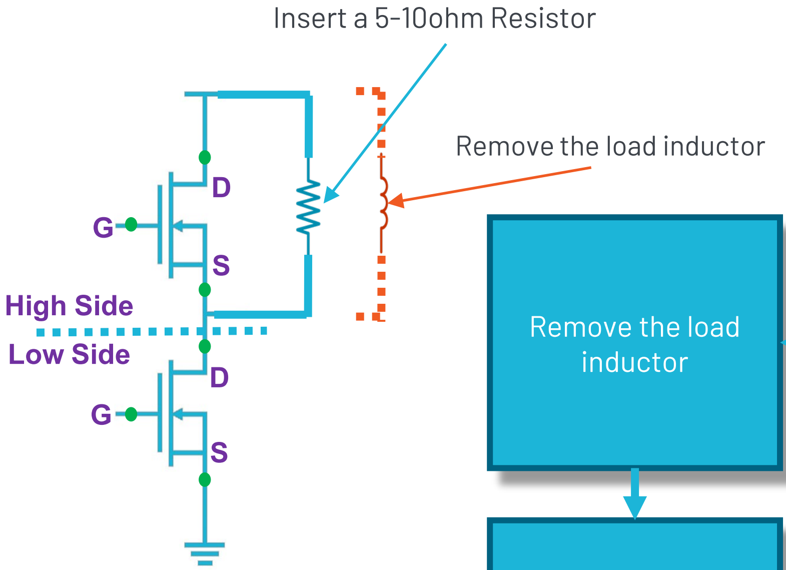


Powerful Feature

REAL WORLD WAVEFORMS HAVE GLITCHES AND RINGING

Challenges

CONVENTIONAL DESKEW METHOD



Remove the load inductor

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

Apply DC bus voltage

Measure Vgs, Vds and Ids 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

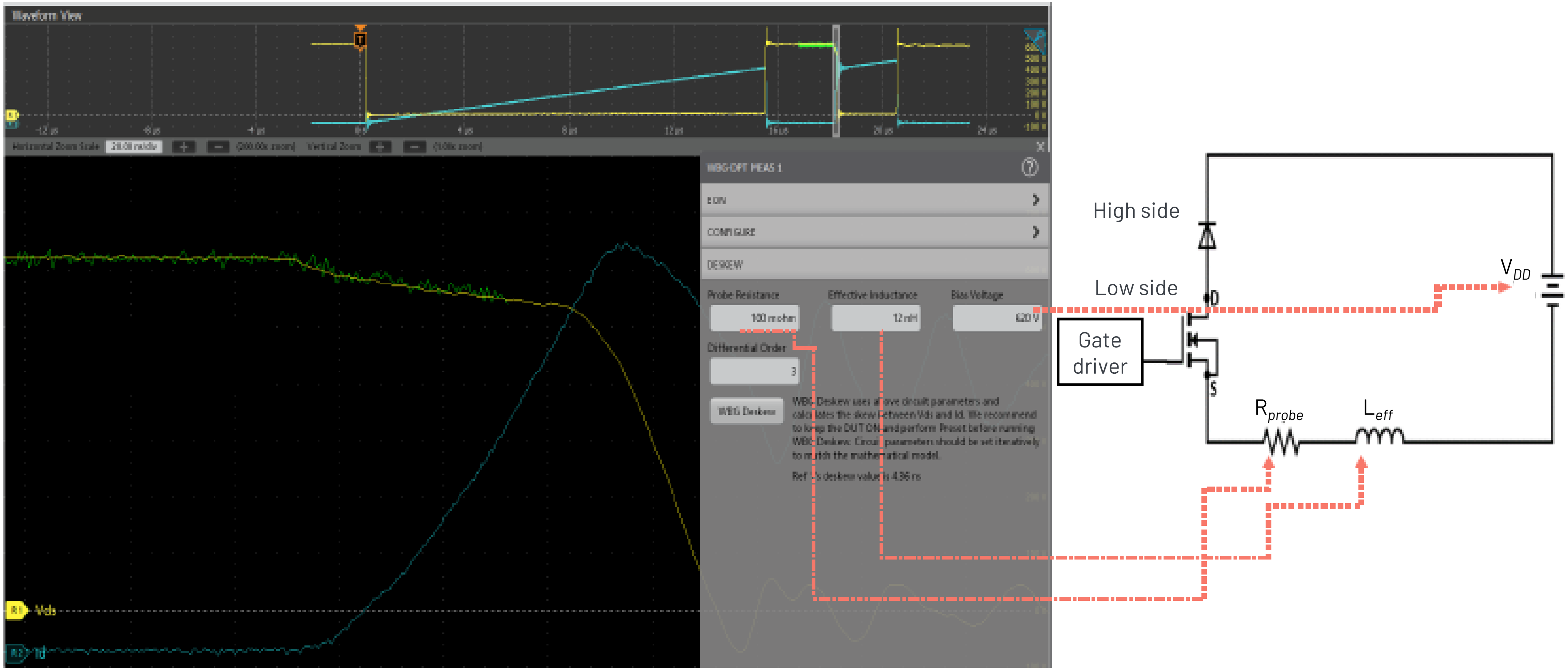
Remove the resistor and reconnect the load inductor

Start testing; Repeat procedure if setup changes

+60 Minutes per deskew cycle

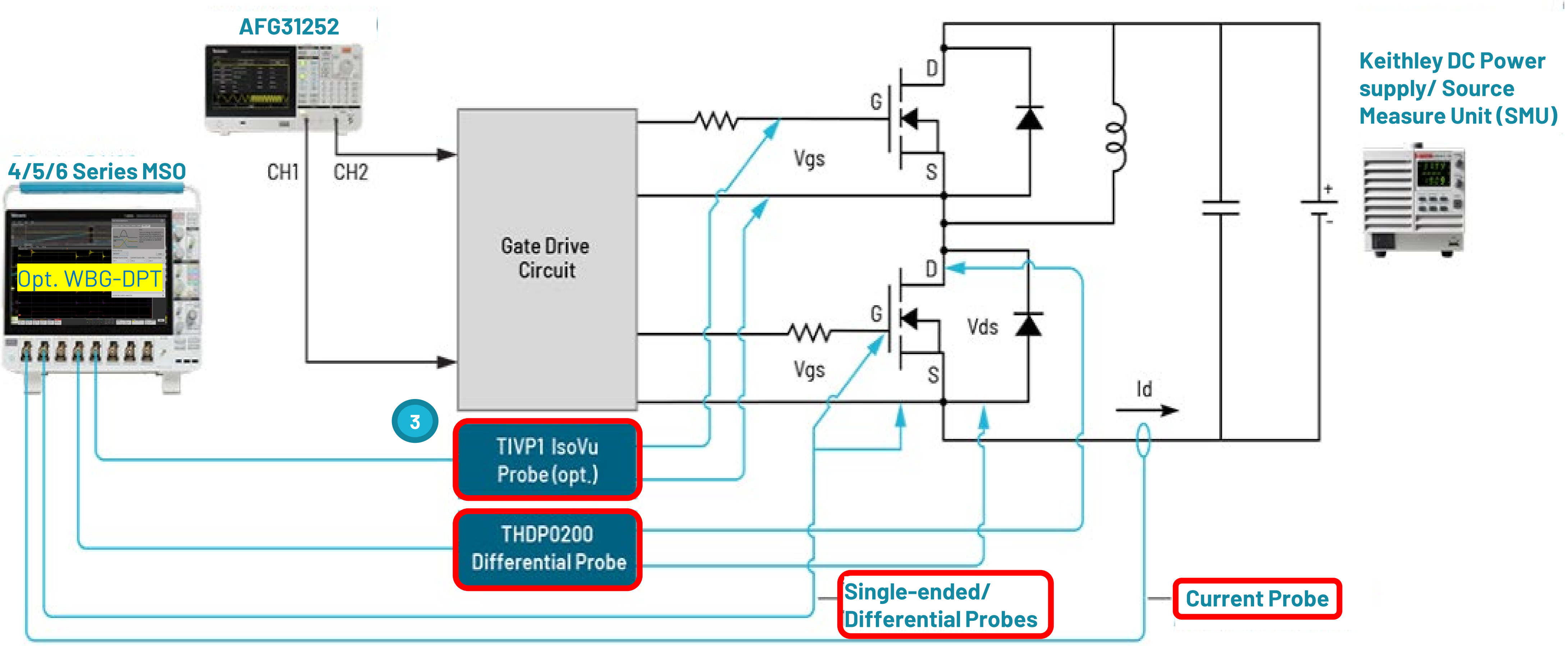
Powerful Feature

AUTOMATED DESKEW



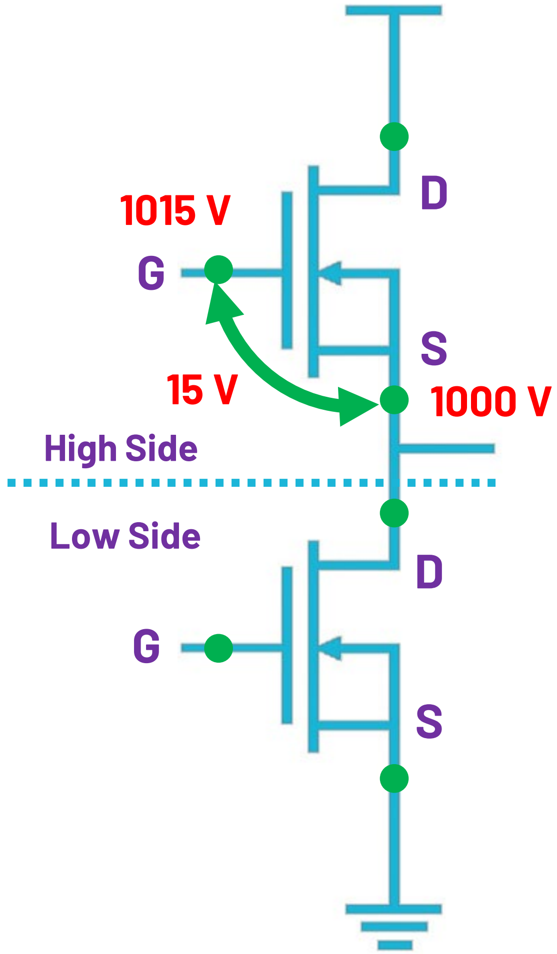
Double Pulse Test Setup

MEASURE SWITCHING LOSSES ON MOSFETS



High Side Vgs

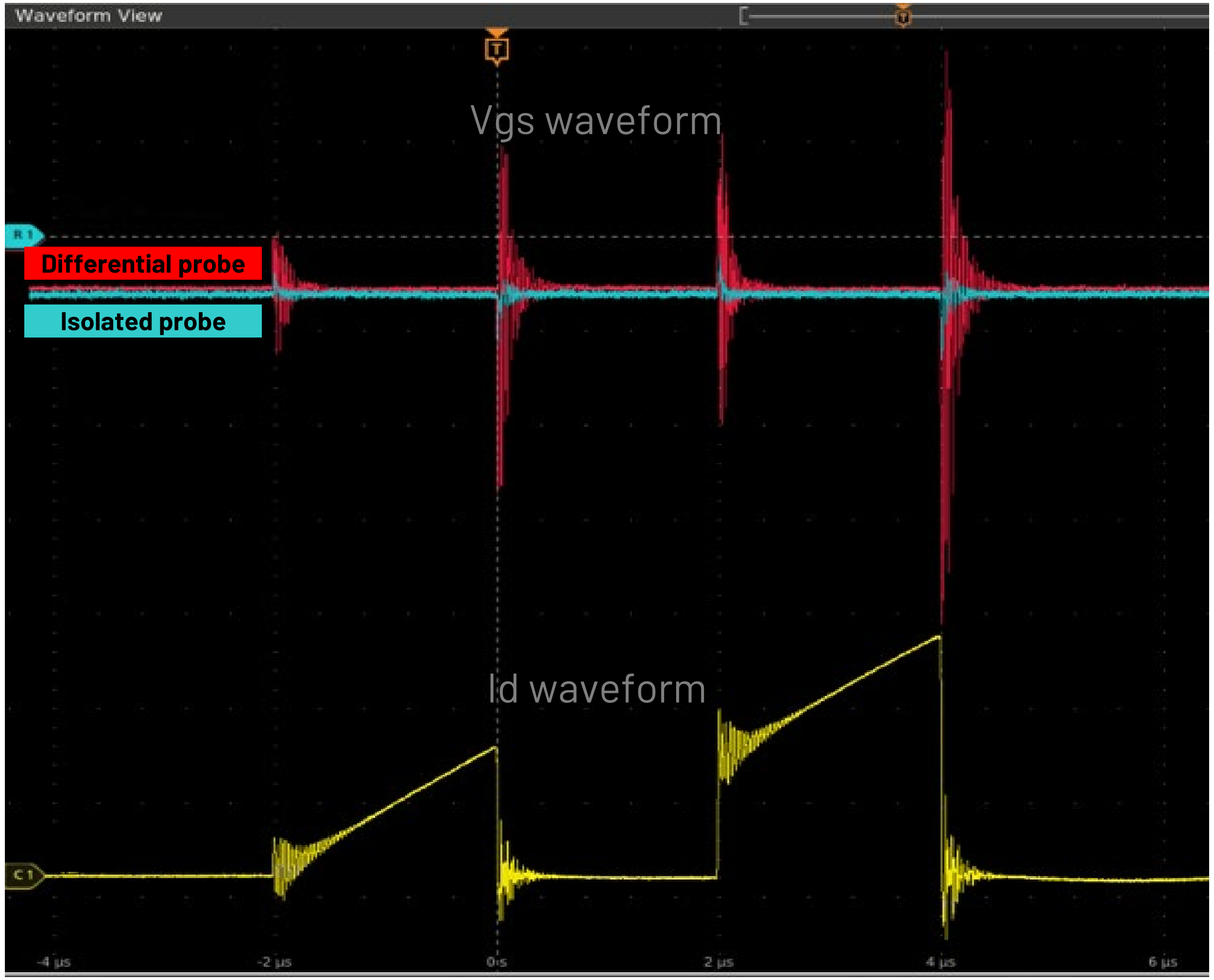
PROBE SPECIFICATIONS COMPARISON



	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 ll <1.8 pF / 10 MΩ ll <4 pF	5 MΩ ll <4 pF	None
Loading (Input – to ground)	N/A	5 MΩ ll <4 pF	<5 pF
Loading (input + to -)	N/A	10 MΩ ll <2 pF	40 MΩ ll <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

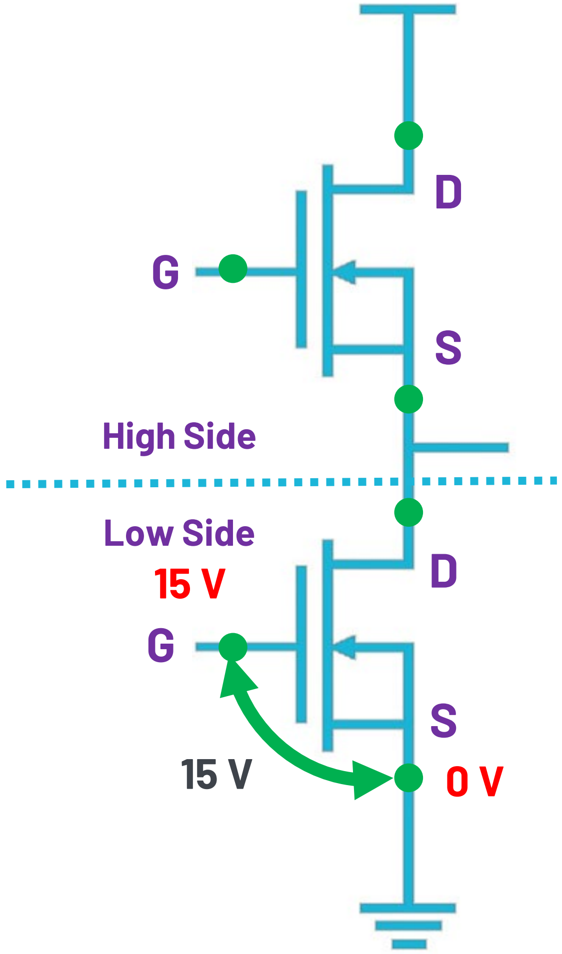
High Side Vgs Comparison

WAVEFORM COMPARISON



Low Side Vgs

PROBE SPECIFICATIONS COMPARISON



	Single Ended	High Voltage Differential	Isolated
	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
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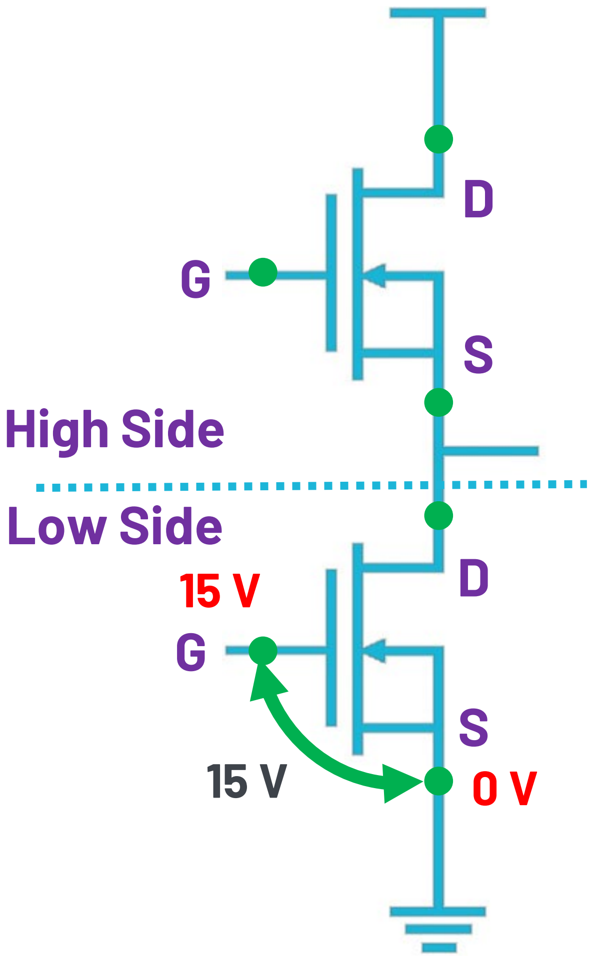
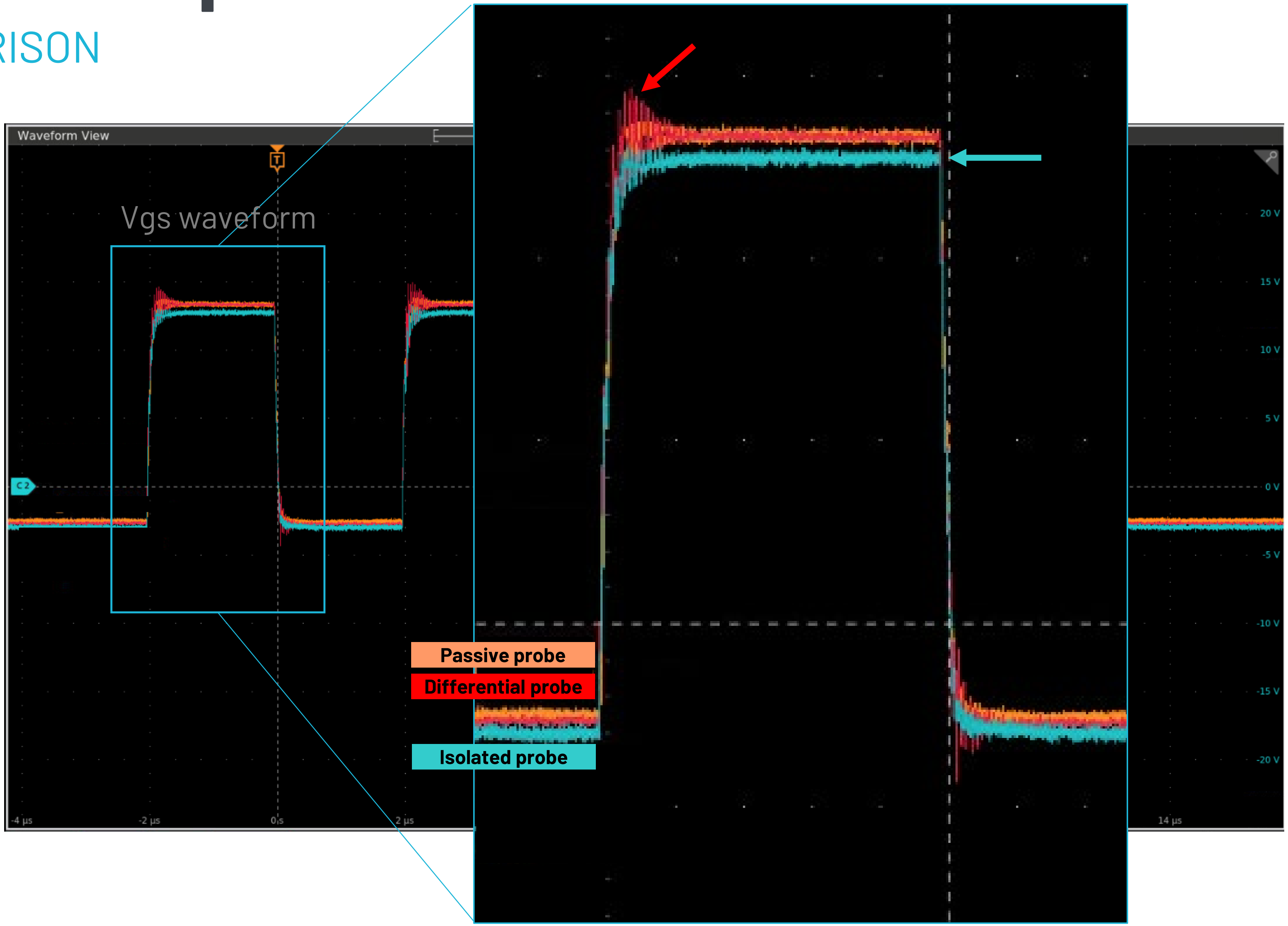
Common Mode Rejection Ratio	N/A	>-80 dB (10k:1)	-160 dB (100M:1)

Low Side Vgs Comparison

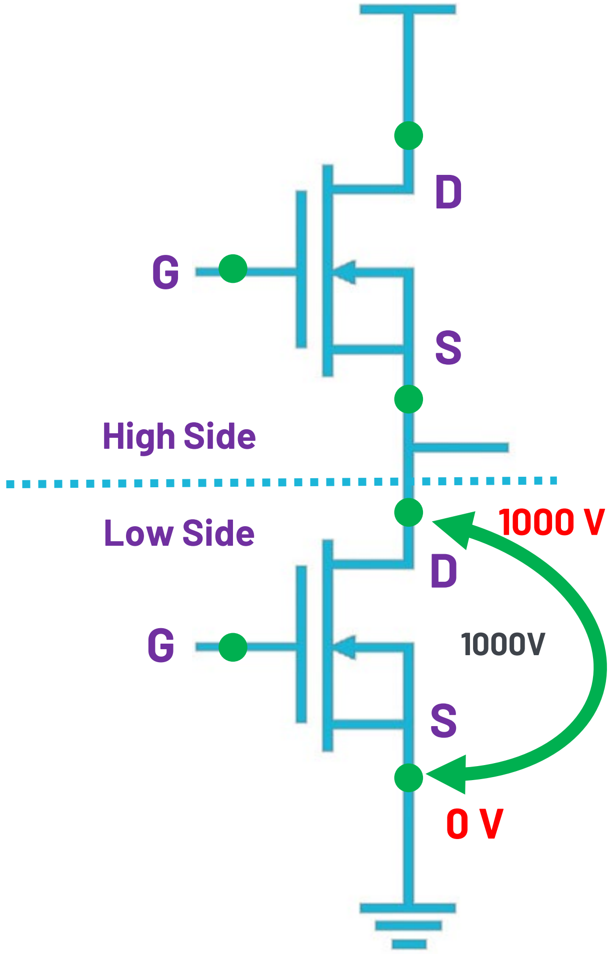
WAVEFORM COMPARISON





Low Side Vds

PROBE SPECIFICATIONS COMPARISON



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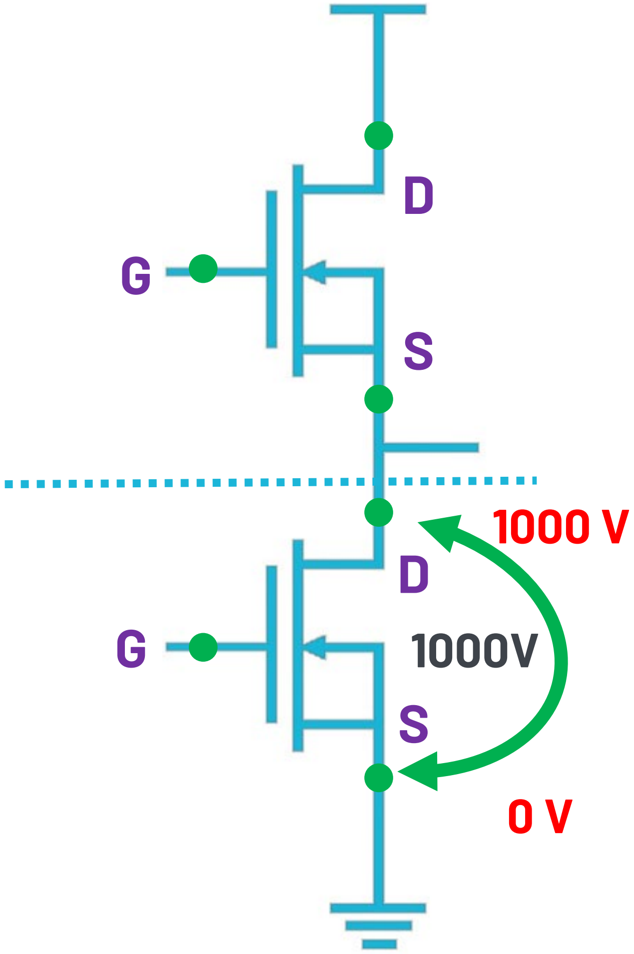
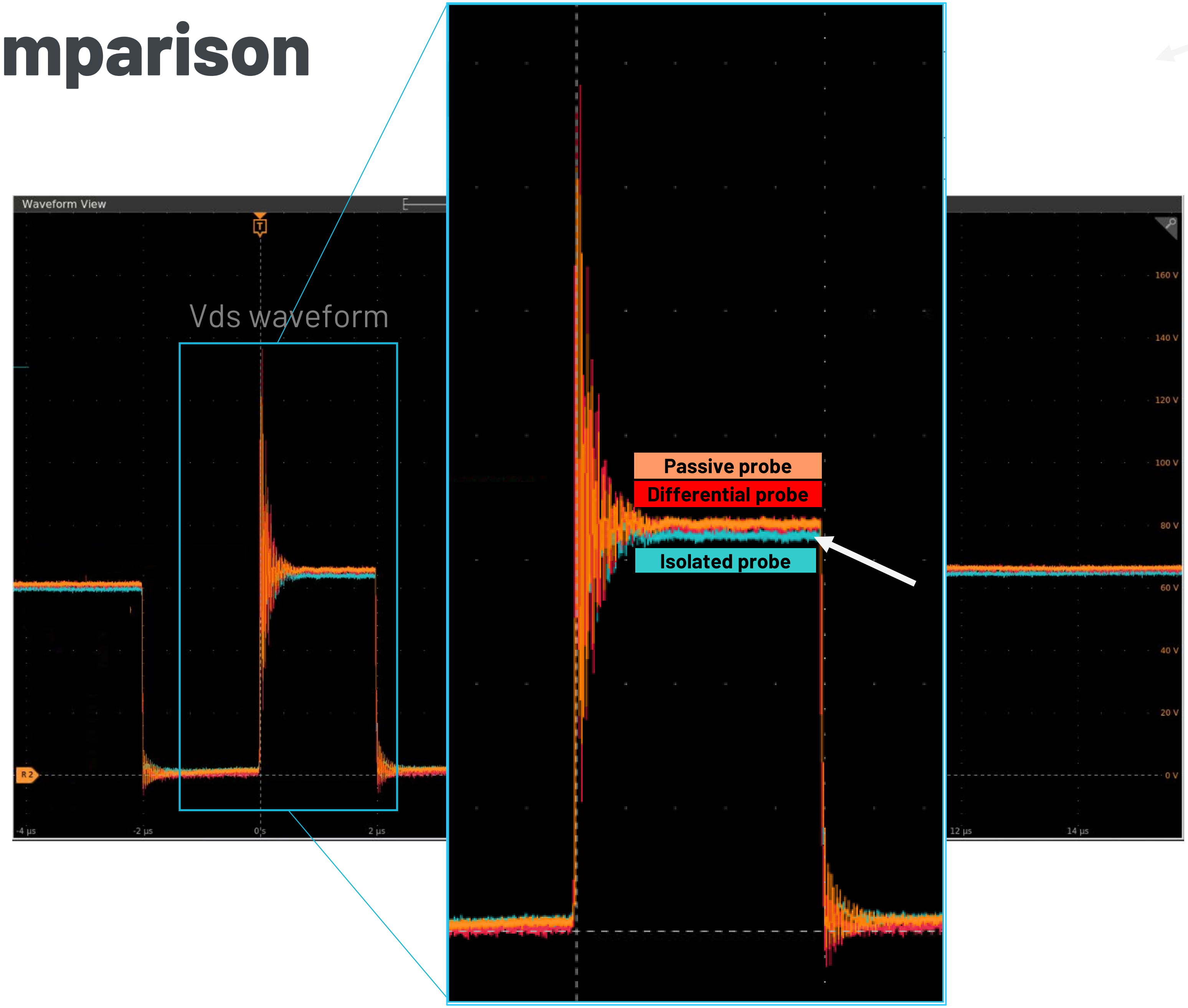
Low Side Vds Comparison

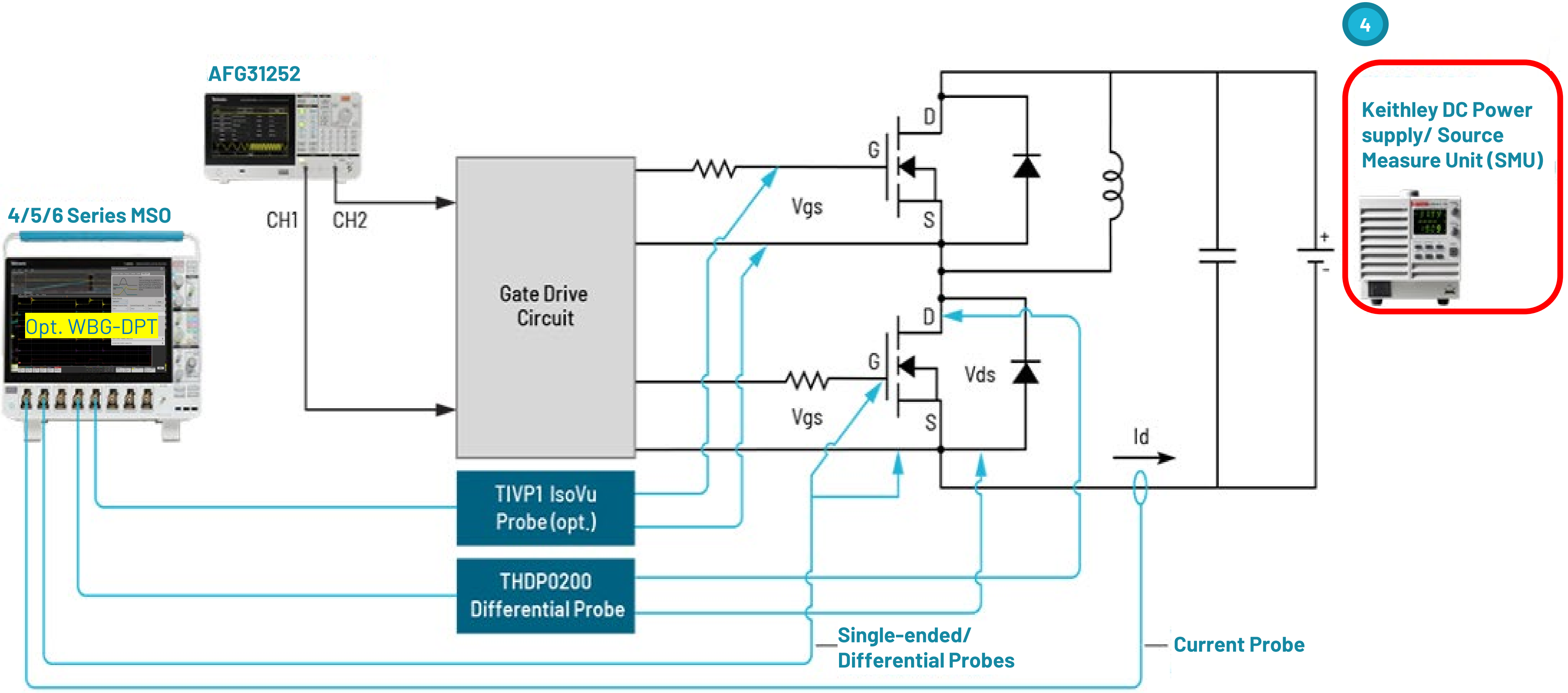
WAVEFORM COMPARISON





Double Pulse Test Setup

MEASURE SWITCHING LOSSES ON MOSFETS



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

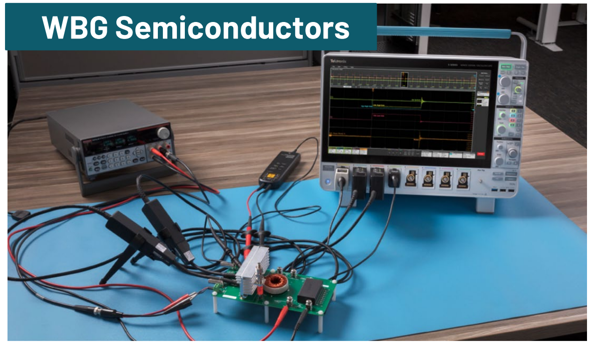
View Product

SMU 2606B: High Density SMU

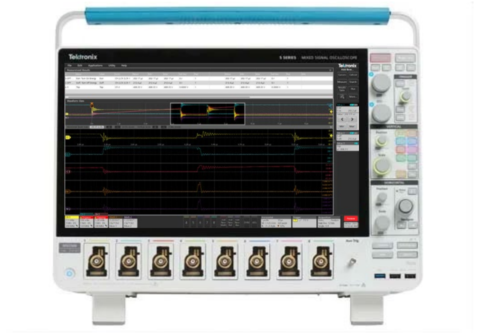
- VCSEL, Laser Diode Production Test
- LED Production Test
- Transistor Characterization

View Product

The Complete Solution!



SCOPE



4/5/6 SERIES MSO

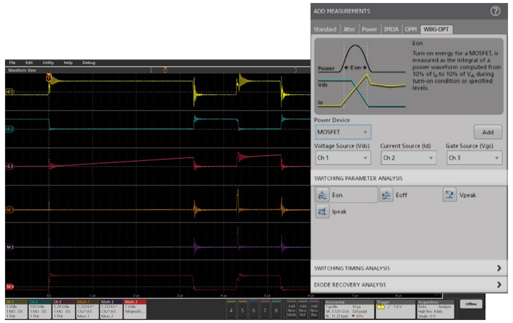
PROBES

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

THANK YOU

Contact Information

Get in touch with us @

asean.mktg@tektronix.com