MEASUREMENT OF WIDE-BANDGAP POWER DEVICES TIPS & GUIDELINES

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ROHDE&SCHWARZ

Make ideas real

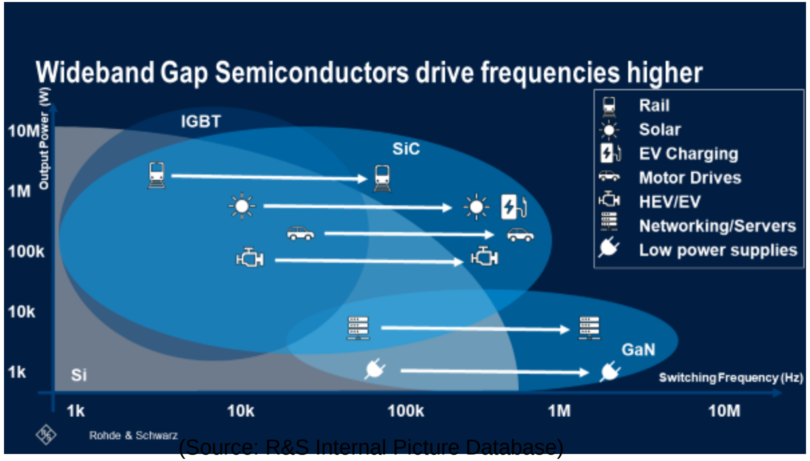
INTRODUCTION

- ► Overview of WBG Technology
- ► Challenges In Measuring WBG Power Devices
- ► Essential Measurement Tools And Equipment, Probing Solutions And Their Impact
- ► Advanced Measurement Techniques For Device Characterization
- ► Case Study Of Switching Converter
- ► Conclusion / Q&A

WHY NEW MEASUREMENT METHODS?

- ► Wideband Gap Technology
  - – Higher Switching Frequency
  - – Less Parasitic Components

Benefits Are Efficiency And Compact Designs!!!



(Source: R&S Internal Picture Database)

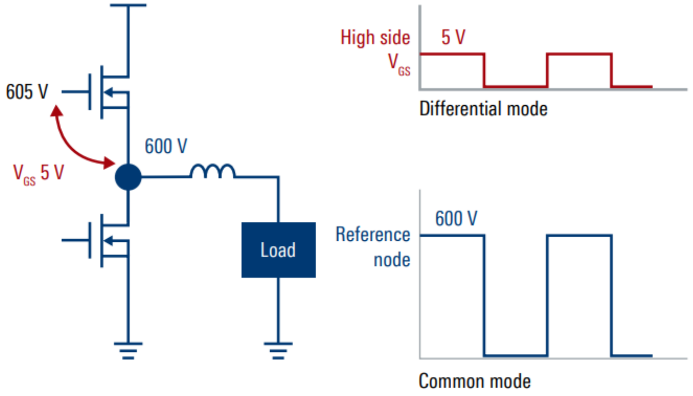
- ► Looking From A Measurement Perspective
  - – Higher Bandwidth
  - – Common Mode Noise (dv/dt)
  - – Probing Itself Becomes Critical
  - – Lower Gate Voltages
  - – Filtering of EMI Emissions

COMMON MODE NOISE

- What is CM Noise?
  - Appears In Any Half-Bridge Structure
  - Caused By Turn-On And Turn-Off Of Power Switches At Switch Node
  - It Degrades Signal Fidelity

- Why Is It More Challenging Using WBG Devices?
  - Faster Rising And Falling Edges (dv/dt)
  - Measurement Tools Need To Suppress This Noise

High-Side Gate Voltage & Current Shunt



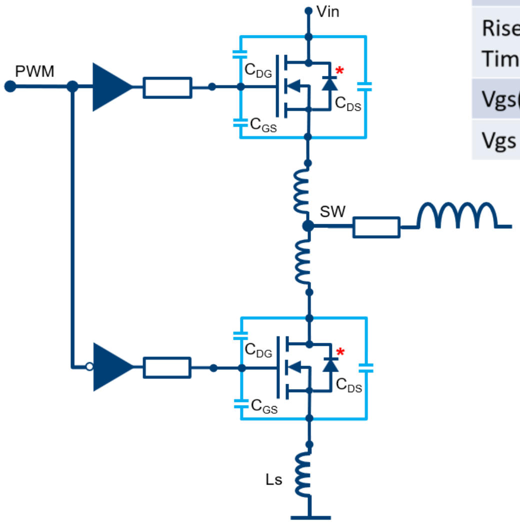
(Source: R&S RT-ZISO Brochure)

PARASITIC COMPONENTS OF WBG

- ▶ WBG Devices Provide Lowest Parasitic Components Cgs, Coss and Cdg Compare To Silicon Counterparts
- ▶ The Parasitic Elements Introduced By Probes Can Overlay The GaN Device Parameters And Lead To Erroneous Measurement Results
- ▶ More Critical Are The External Inductor Created By Loops in the PCB (di/dt)
  >> Impact On Probing

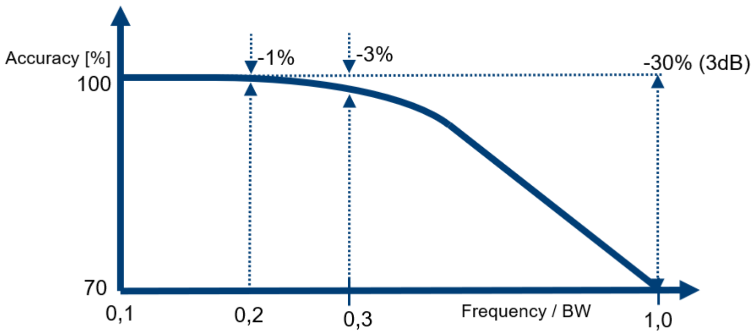
Parameter	GaN 100V/6mΩ	Silicon 100V/6mΩ
Ciss (Cgd+Cgs)	644pF	2025pF
Cgd	2,4pF	20pF
Cds	304pF	468pF
Rise Time/ Fall Time	1,4ns	22ns/8ns
Vgs(TH)	1V	3V
Vgs (on/off)	5V/0V	10V/0V

(Source: Datasheet GaN2204/FDPF085N10A)



BANDWIDTH & RISE TIME & ACCURACY

- Estimation Of System Bandwidth (f_{BW}) Is Determined By Rise Time (t_r)
  - t_r : Transition time for a signal to go from the 10% to the 90% level of the steady maximum value
  - f_{BW}: Frequency range over which the frequency response of a signal degrades by 3 dB



- Most Used Equation:

$$f_{BW} = 0.4\,/t_r$$

It is derived by considering a first-order passive filter and calculating its step-response in frequency and time domain.

- This Equation Would Be An Overestimation:

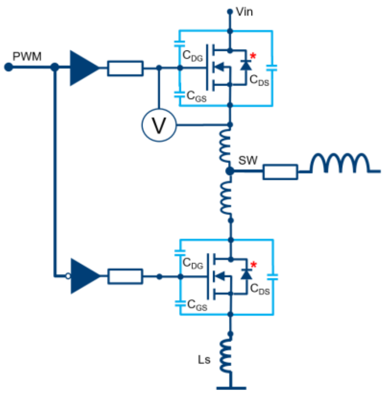
$$f_{max} = 1/t_r$$

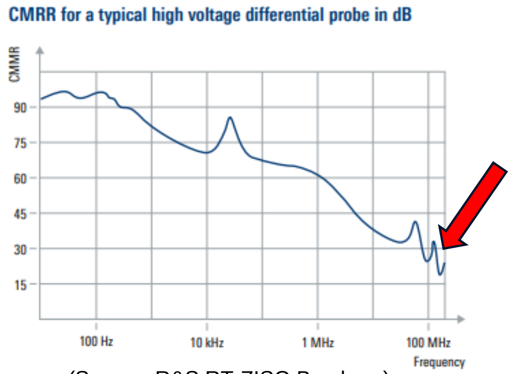
- System Bandwidth Is Defined By Scope AND Probe

$$BW_{system} = \frac{1}{\sqrt{\left(\frac{1}{BW_{probe}}\right)^2 + \left(\frac{1}{BW_{scope}}\right)^2}}$$

CMRR FOR STANDARD DIFFERENTIAL PROBES

- ► Determining CMRR Requirement
  - – High-Side Gate Measurement In the Presence Of High CM Noise
    >> dv/dt = 40V/2ns = 20V/ns
  - – Max. Failure < **2%** On HS-Gate
    - – Voltage Failure[V] < **100mV** @ 5V (On State of GaN Gate)
  - – CMMR = 20*log(0,1V/40V) = **52dB**
    - – Suppression Is Required At >200MHz





(Source: R&S RT-ZISO Brochure)

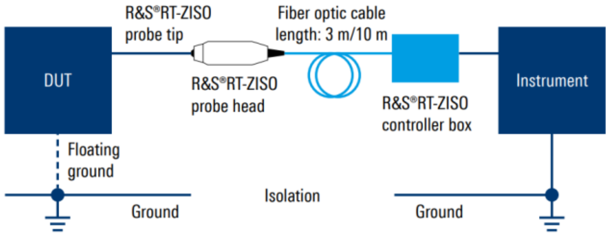
Traditional HV Differential Probes Will Fail Because Of Low CMMR (30dB >> 25%) And Bandwidth Limitation

OPTICAL ISOLATED MEASUREMENT SOLUTION

- ► Fully Optical Isolated Probing System
  - – CMMR Of Up to 80dB Is Possible
  - – Example:

    With 80dB (10000) CMMR @ 40V

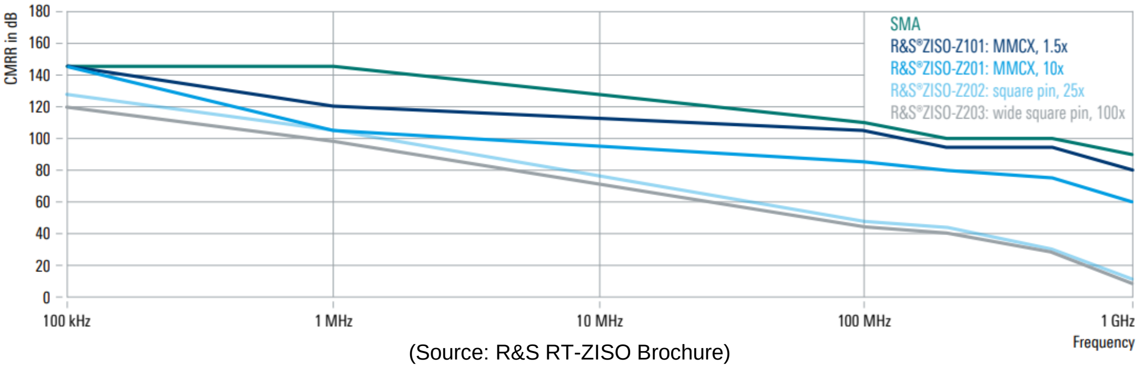
    Voltage Failure [V] **< 4mV**



(Source: R&S RT-ZISO Brochure)

- ► Max. Failure < 0,1% On HS-Gate of GaN Devices

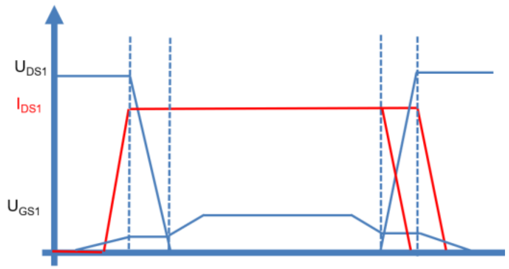
Coax System Is Part Of The Probing Solution



(Source: R&S RT-ZISO Brochure)

THE IMPORTANCE OF SKEW

- De-Skewing Is Required For Measuring Turn-On and Turn-Off Losses
  - Highly Recommended If Different Probe Types Are Being Used
  - High Impact On Accuracy For Measuring Turn-On and Turn-Off Losses



- Current Measurement Solutions:

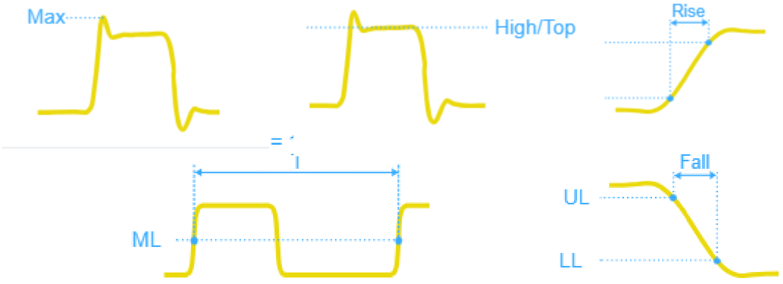
	Coax Current Shunt	Current Transformer	Rogowski Coil	Infinity
Pros	High Accuracy High Bandwidth	Isolation	• Low Insertion Inductance • Isolation	• Very Low Insertion Inductance
Cons	Large Size Practical Use	Large Size Loop Inductance Low Bandwidth	Low Bandwidth AC Current Only	Design-In Required AC Current Only
Best Use	Switching Losses Evaluation	Lower Bandwidth Applications	Very High Current (DPT) Low Bandwidth	Smaller Application

- How To De-Skew For GaN Applications?

1. Using Data Sheet Values / Values Are Not Accurate Enough To Provide Accurate Skew Figures (E.G < 5ns for A Passive Probe)
2. Using 2 Identical Optical Probes Would Be The Best >> Propagation Delay Is Provided By Probe
3. Perform Multiple Double Pulse Tests And Use Smart Post Processing To Align Voltage & Current (PE-System)

INHERENT MEASUREMENT FUNCTIONS

- How To Characterize Devices At Switch Node
  - Minimum and Maximum
    Drain-Source Voltage
  - Oscillations
  - Rising and Falling Edges
    (Impact On EMI)
- Automated Measurement Functions Are Useful



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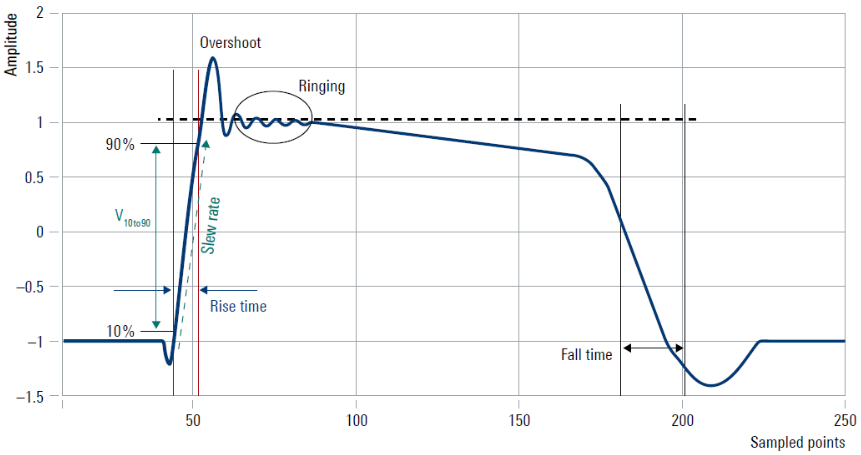
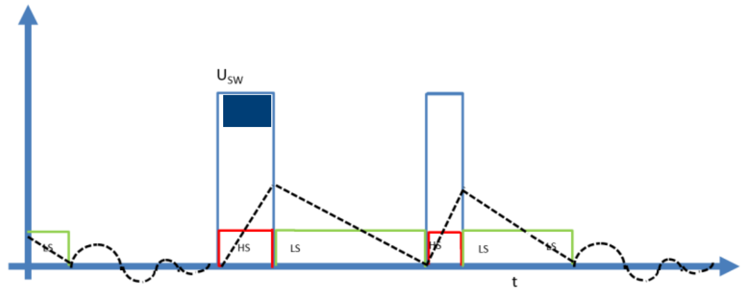


(Source: Marcus Sonst, R&S White Paper
"Switching Analysis")

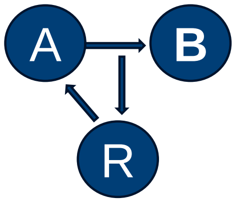
- Fast FFT Implementation

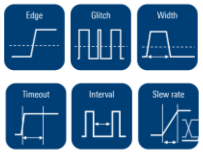
USE OF SMART TRIGGER FUNCTIONS

- ► Problem: Converter Changes Operating Mode
  - – PWM Frequency and On Time Is Not Stable
  - – Simple Edge Trigger Will Fail



- ► Solution: Sequence Trigger (A/B-R)
  - – Combination of 2 Different Trigger Type In A Sequence With Reset Condition
  - – Digital Trigger Implemented In Hardware





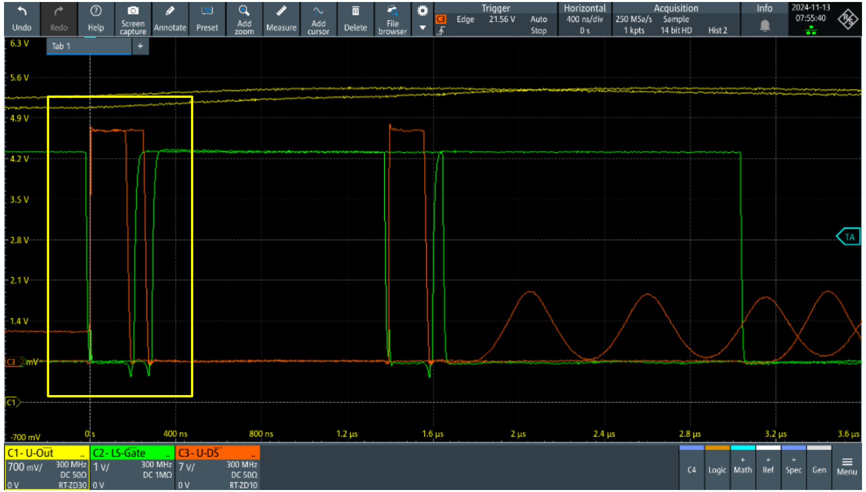
(Source: R&S Internal Picture Database)

- ► Alternative >> ZONETRIGGER
  - – The Zone trigger triggers on the intersection or non-intersection of the signal and one or more zones

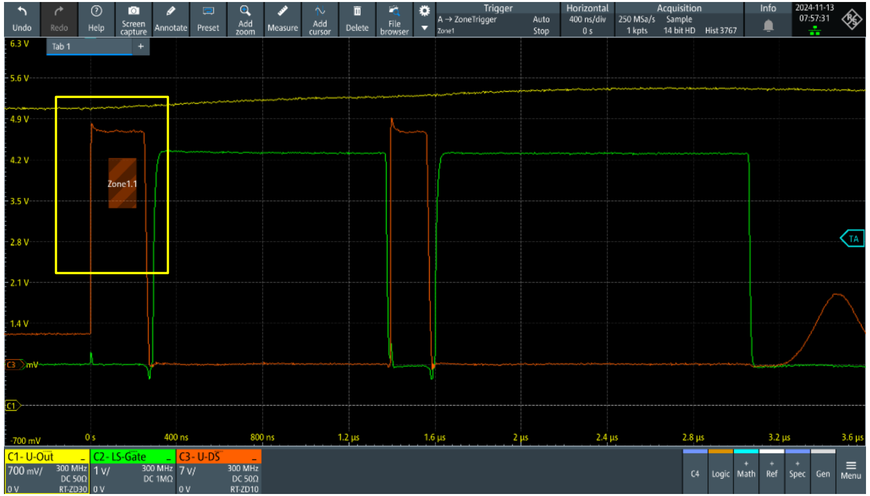
ZONE TRIGGER IN ACTION

- ► Problem: On-Time Of Duty Cycle Changes Due To Control Loop Of PWM Controller (CCM >> DCM)

Simple Edge Trigger Shows Unclear Result



Trigger With Area Works In Real Time



HOW TO PERFORM A CMRR MEASUREMENT

- How Can Be CMRR Being Measured In A Real Circuit?
  - Validation Of Measurement Equipment Is Performed

    A High Voltage Pulse Source (50 Ω System)

    (Step Response)

- In Your Circuit, A Pulse Is Generated By Your Circuit At The Switch Node

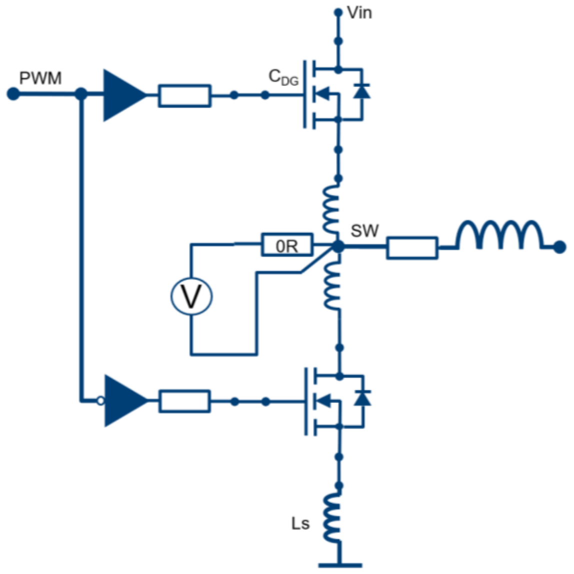
- All What Needs To Be Done Is To

  Connect The Probe (All MMCX Pins)

  To The Switch Node

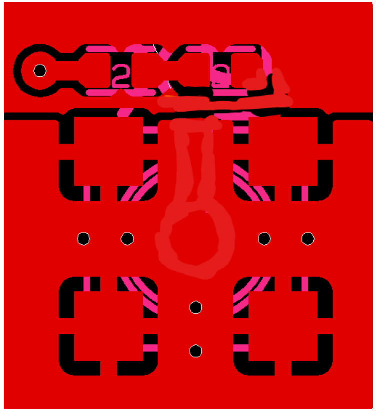
Common-mode rejection ratio

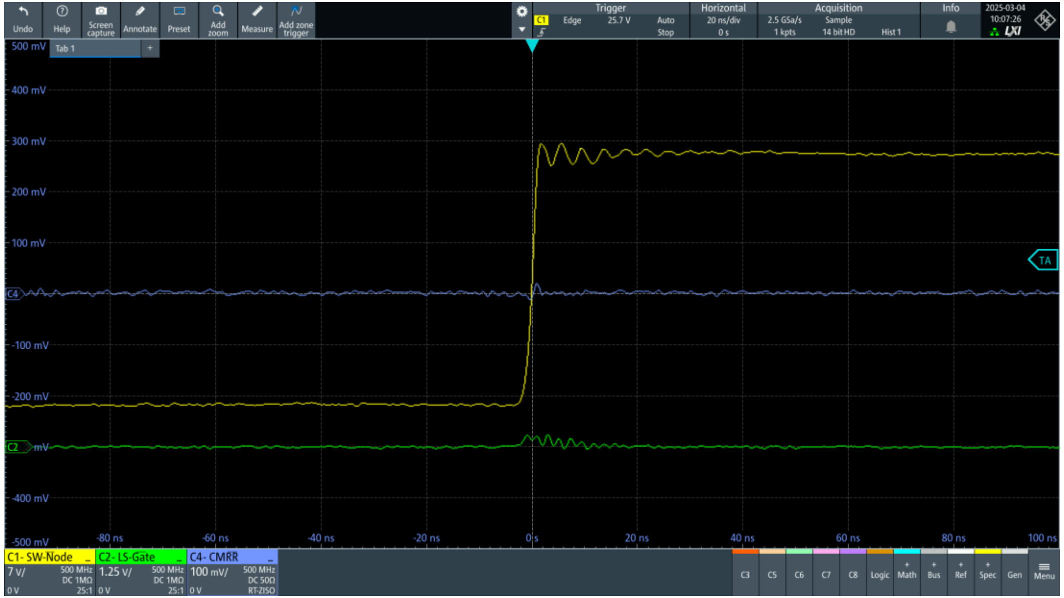
$$CMRR_{dB} = 20log_{10}\left(\frac{|A_d|}{|A_{cm}|}\right)$$



CMRR MEASUREMENT WITH REAL WORLD EXAMPLE)

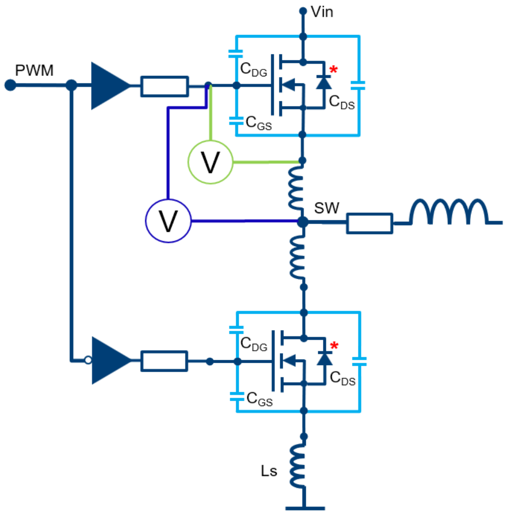
- The Configuration Resistor Has Almost 20dB Reduction On CMMR Of The Probe Datasheet
  - It Is Mandatory To Avoid Any Loop
  - Source Impedance Of The Circuit Is Unknown

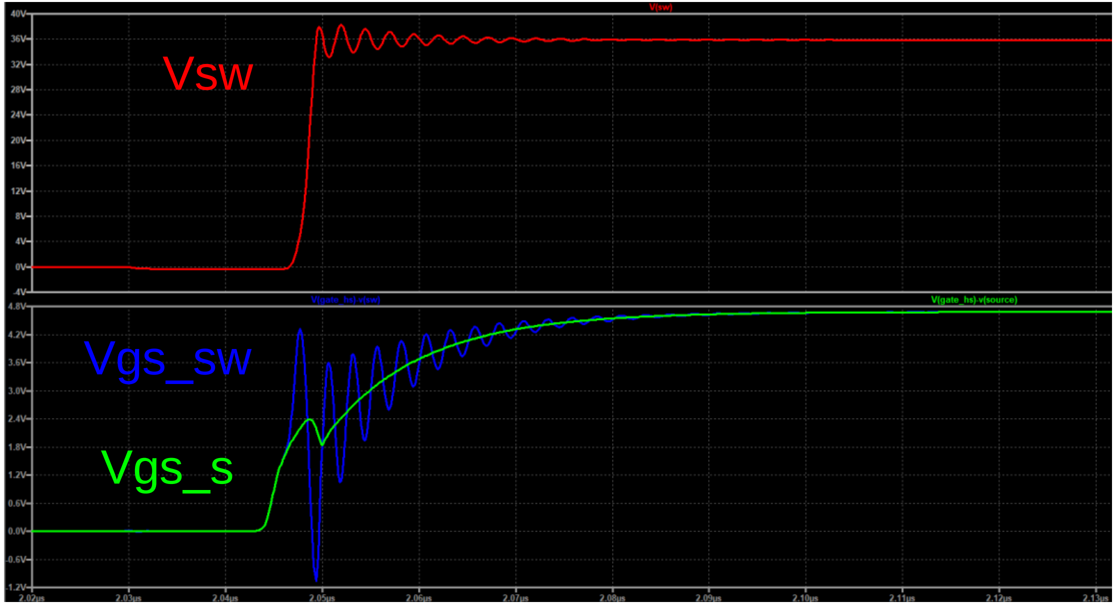




HOW TO CONNECT MMCX TO SWITCH NODE

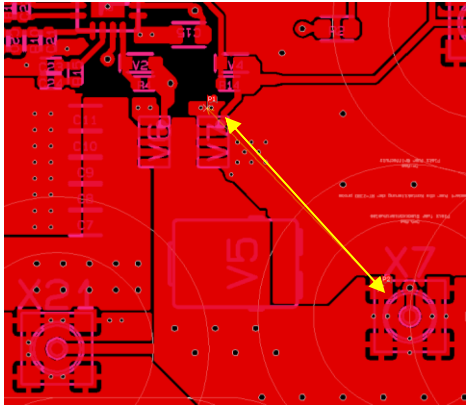
► Location And Connection Of MMCX Shield Is Critical





HS-GATE RESULT WITH STANDARD PCB LAYOUT

- MMCX Position Is Not Optimized
  - Track Between Source And MMCX Shield Must Be Of Very Low Impedance
- 15mm Distance + Vias



PROBE COMPARISON OF HS-GATE MEASUREMENT

High-Side Gate Voltage Measurement With Different Probes with Optimized Probe Location

- Traditional High Voltage Differential Probe (f_{BW}=200MHz / CMRR = 30dB)

- High Bandwidth / Low Voltage Differential Probe (f_{BW}=1GHz / CMRR = 30dB)

- Fully Isolated Probing System (f_{BW}=1GHz / CMRR =75dB)

.

CONCLUSION

► Wide Band Gap Technologies Requires New Measurement Tools And Methods

► WBG Technology Require Deeper Knowledge Where The Measurement Tools Have Their Limits

► Probing Technique Has Significant Impact On Signal Fidelity (E.g. Change From Twisted To Coax Cable)

► It Is Very Challenging To Achieve CMRR Datasheet Values In Real Circuits Because Of Implementation Limits

Find further information:

www.rohde-schwarz.com/oscilloscopes

THANK YOU