Tektronix

와이드밴드갭 디바이스의 테스트 도전과제 및 솔루션

25 AUG. 2020

이기응 이사

Agenda

- Introduction : WBG device, Application, Market
- Critical challenge for measurement
- Solution : Tektronix IsoVu probe, Property and Advantage
- Technical view for CMRR and ideal probe
- Detailed probe spec for WBG device

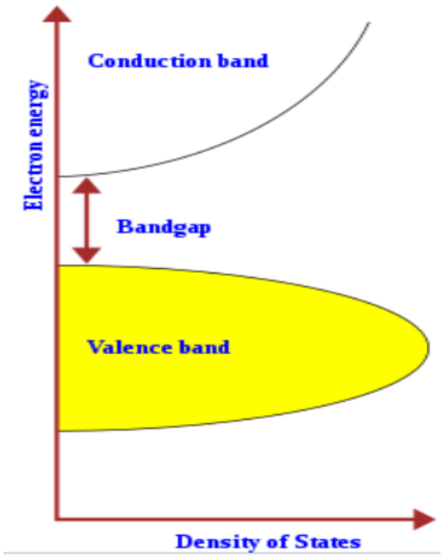
Wide-bandgap semiconductors

- A relatively large band gab compared to typical semiconductors

  -Silicon : 1 - 1.5 electronVolt(eV),

  -Wide-bandgap : 2 - 4eV.

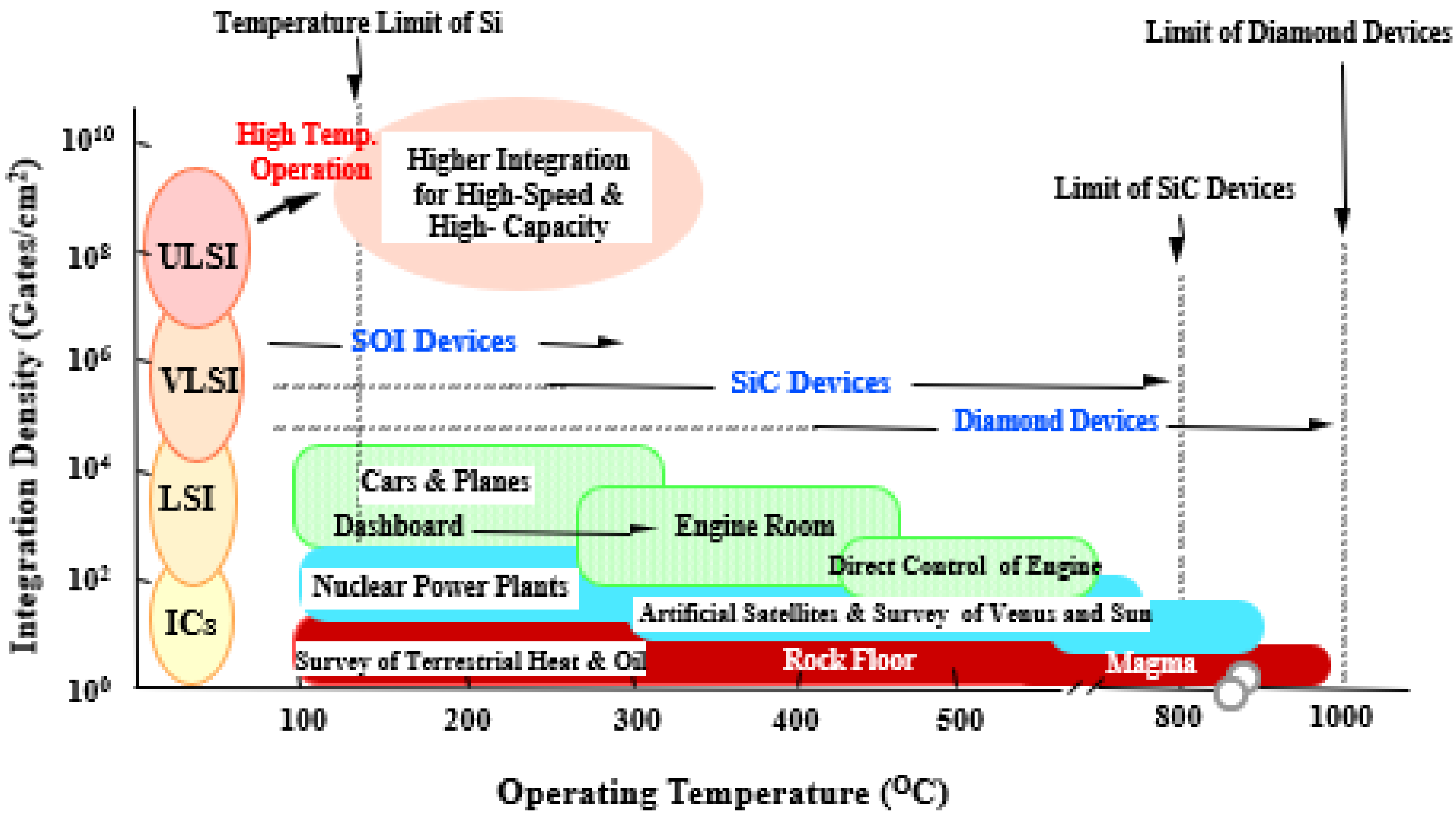
  Electronic properties between semiconductors and insulators.



- Operate at much higher voltages, frequencies and temperatures compared to Silicon and GaAS: at over 300°C

- Switching speed is higher than typical semiconductor.

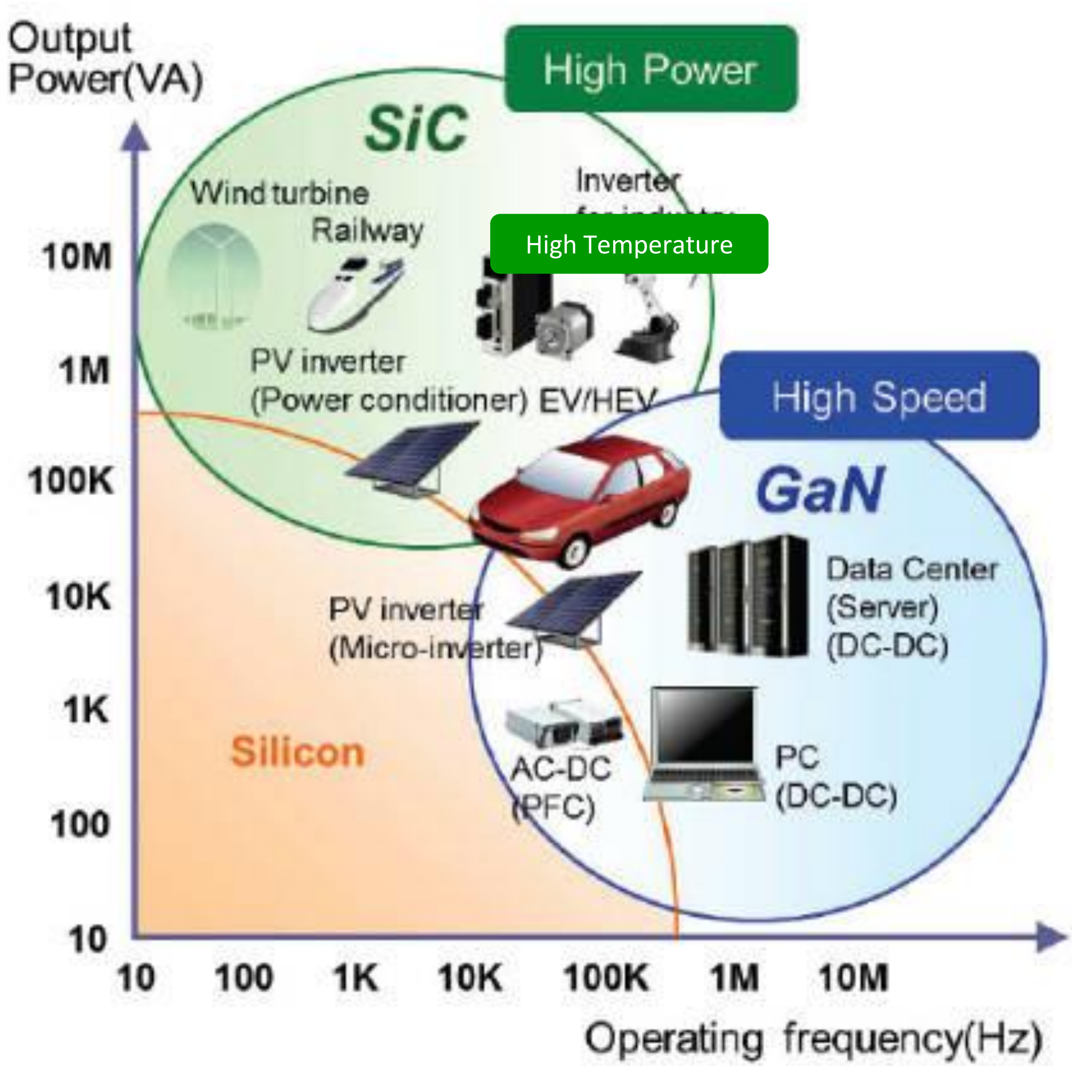
Applications of High Temperature Devices



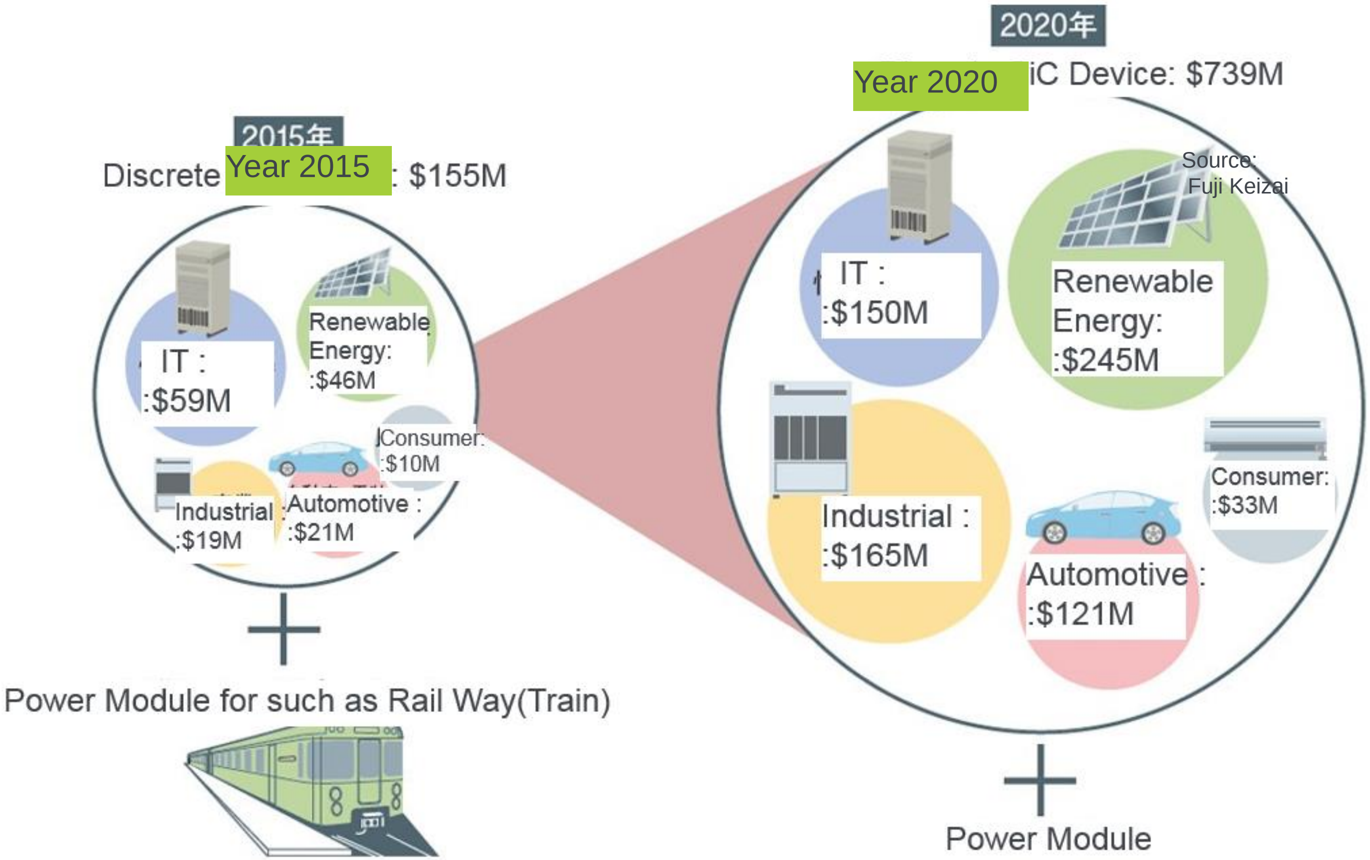
Why you need WBG devices?

- Wish List for power switch designers
  - ➢ Lower on resistance
  - ➢ Faster
  - ➢ Less capacitance
  - ➢ Smaller
  - ✓ **Lower RDS(on) and Faster**…It starts with a superior conduction mechanism: Superior conduction starts with the confinement of electrons into a two dimension electron gas (2DEG) leads to high conductivity and high velocity. This is a property of eGaN FETs.
  - ✓ **Less Capacitance…Superior Figures of Merit give unprecedented**: performance: eGaN FETs offer designers best in class Figures of Merit versus MOSFET in both hard switching and soft switching applications.
  - ✓ **Smaller Size…Think Big – Buy Small!**: Board space is very expensive real estate. eGaN FETs are provided in a low inductance, low resistance, small, low cost LGA package.

Why Wide Bandgap (WBG)? application



Market of Wide Band Gap Power Device



What are the critical challenges

CRITICAL PARAMETERS FOR GaN & SiC DESIGN

- **Miller Charge Qg much lower, which allows fast switching speeds**
- Requires significantly less parasitic capacitance, resistance and inductance.

→

- **Ability to measure extremely fast dv/dt, di/dt and high frequency and reduce loading, Inductance and capacitance.**

- **GaN - Max Vgs and max Vth is much lower**
- **SiC - Requires high Vgs and negative bias on turn-off**
- Requires tight regulation of Vgs and Vth voltage

→

- **Ability to accurately measure Vgs on all gate nodes in the circuit on high-side and low-side.**

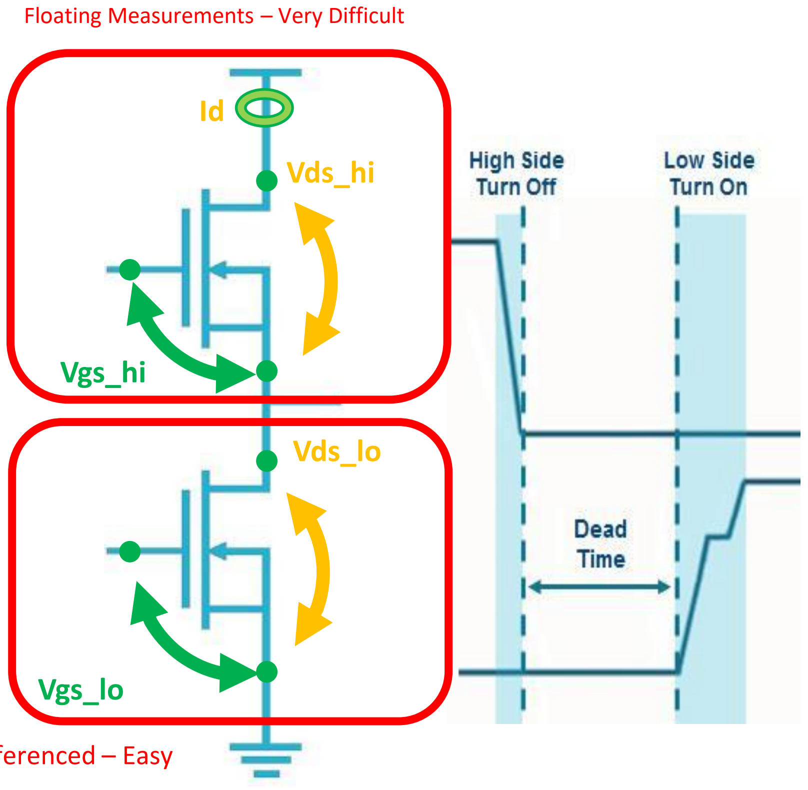
- **Body Diode voltage drop is higher**
- Requires tight control of dead time to minimize losses.

→

- **Ability to accurately measure turn-on, turn-offs, dead-time and eliminate measurement effects of phantom ringing on high side and low side switches.**

What are the critical challenges

- **Gate-Source voltage (Vgs) characterization :** Gate-Source (Vgs) measurements on Low-Side and High-Side.
- **Dead-time optimization-** Vgs and Vds measurement on low-side and high side simultaneously.
- **Efficiency and loss analysis:** Vds and Id measurements on low-side and high side simultaneously.
- **Other losses:** Magnetic loss measurements



Why the solution SHOULD BE IsoVu?

- Why are Wide Band Gap devices(GaN & SiC) getting popular against MOSFET?
- What are the critical challenges for GaN measurement?
- How does IsoVu technologies solve the challenges?
- How was the measurement comparison?

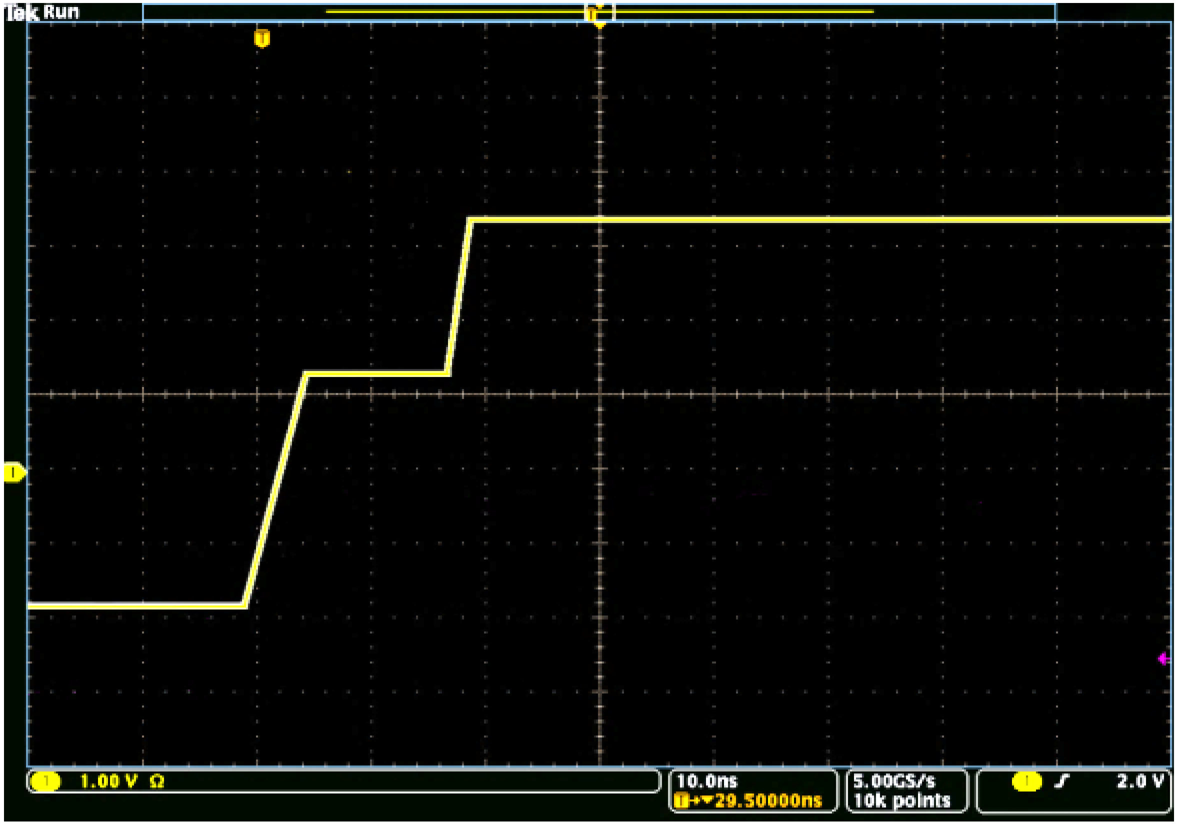
How IsoVu technology helps

IsoVu™ technology is a radically new high voltage isolated differential probing solution that gives **Accurate** and **Repeatable** results

- Galvanically isolates the device-under-test from a Tektronix oscilloscope.
- **1 GHz** bandwidth (risetime <350ps)
- World's best Common Mode Rejection
  - Up to **160 dB** (100 Million to 1)
- **2500 V differential** voltage range
- **60 kV** common Mode voltage range
- Up to **40 MΩ** input resistance

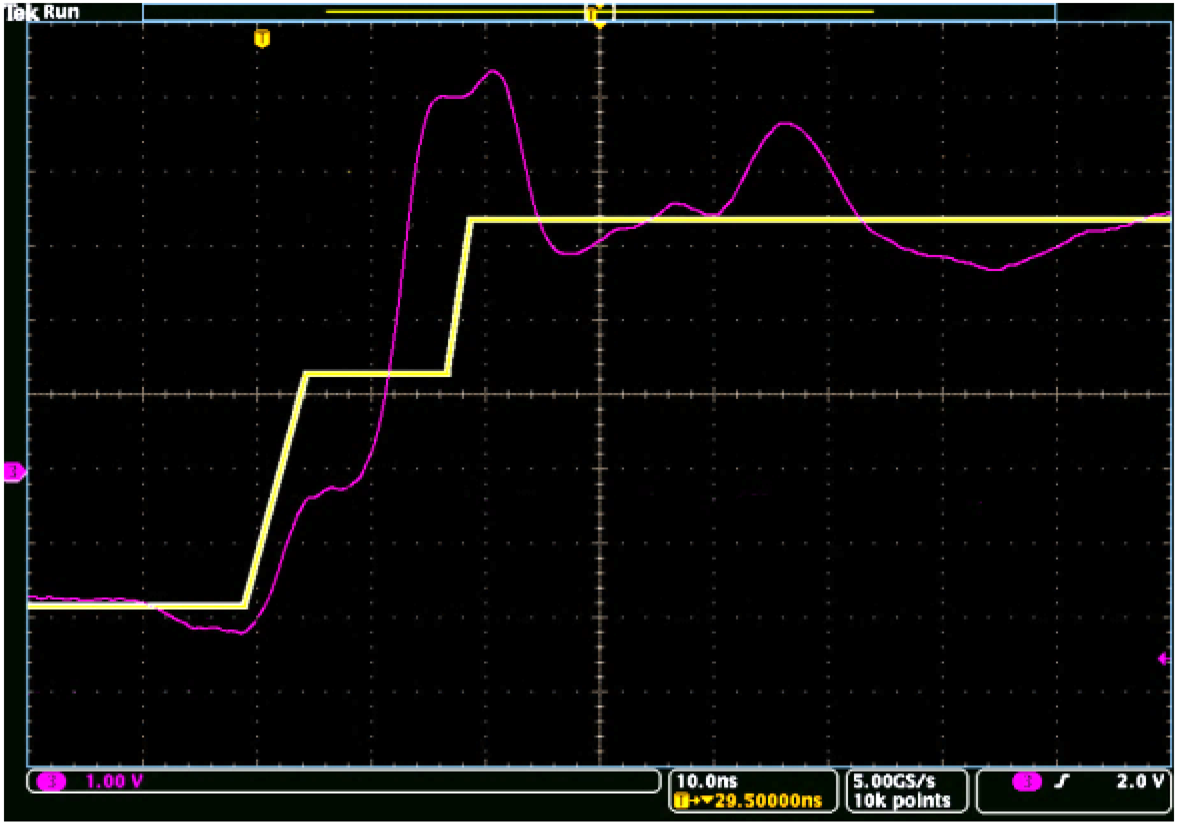
Do Your Measurements Match Your Expected Results?

- You run your simulations and this is the waveform you expect



Do Your Measurements Match Your Expected Results?

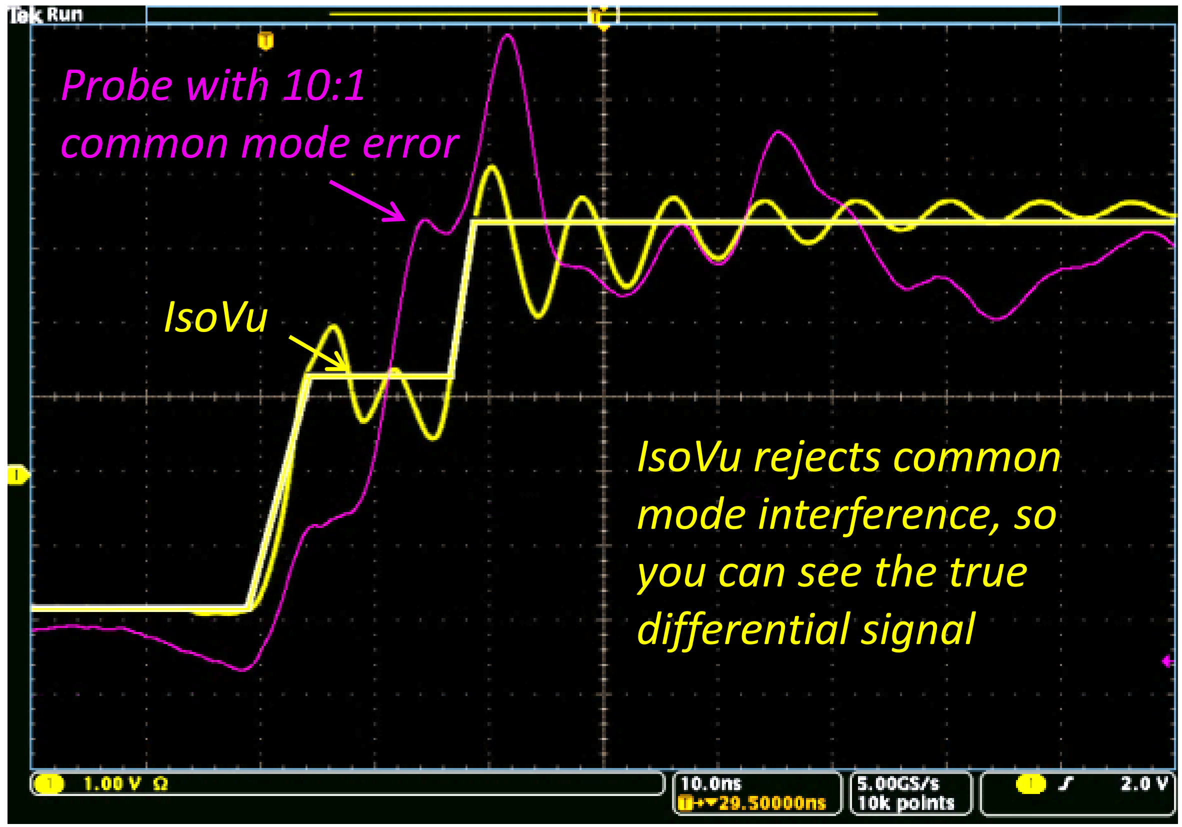
- But when the measurement doesn't match your simulation, is it your design or is it measurement error?



Do Your Measurements Match Your Expected Results?

- IsoVu gives you an accurate, repeatable measurement providing meaningful correlation with expected performance

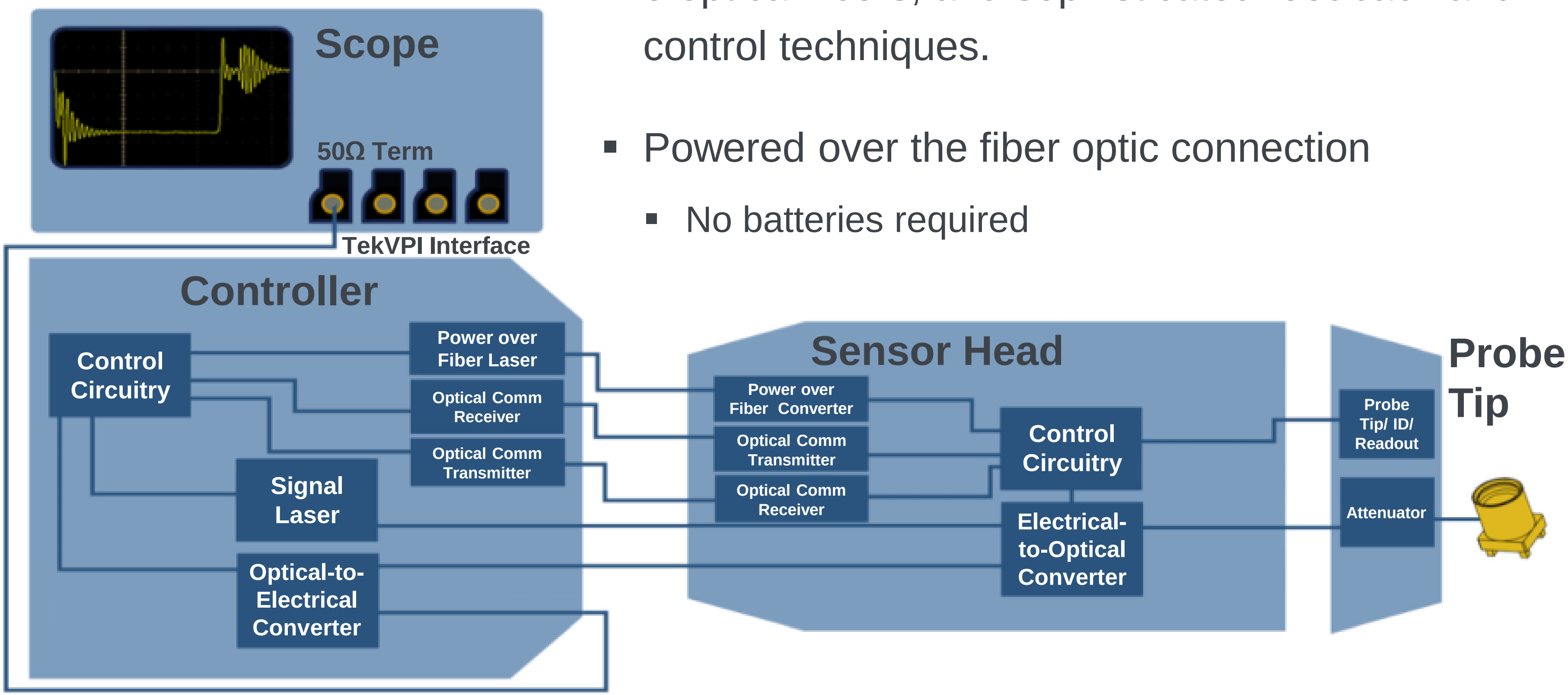
Expected Simulation Results



What is IsoVu Technology?

IsoVu™ utilizes an electro-optic sensor to convert the input signal to **optical modulation**

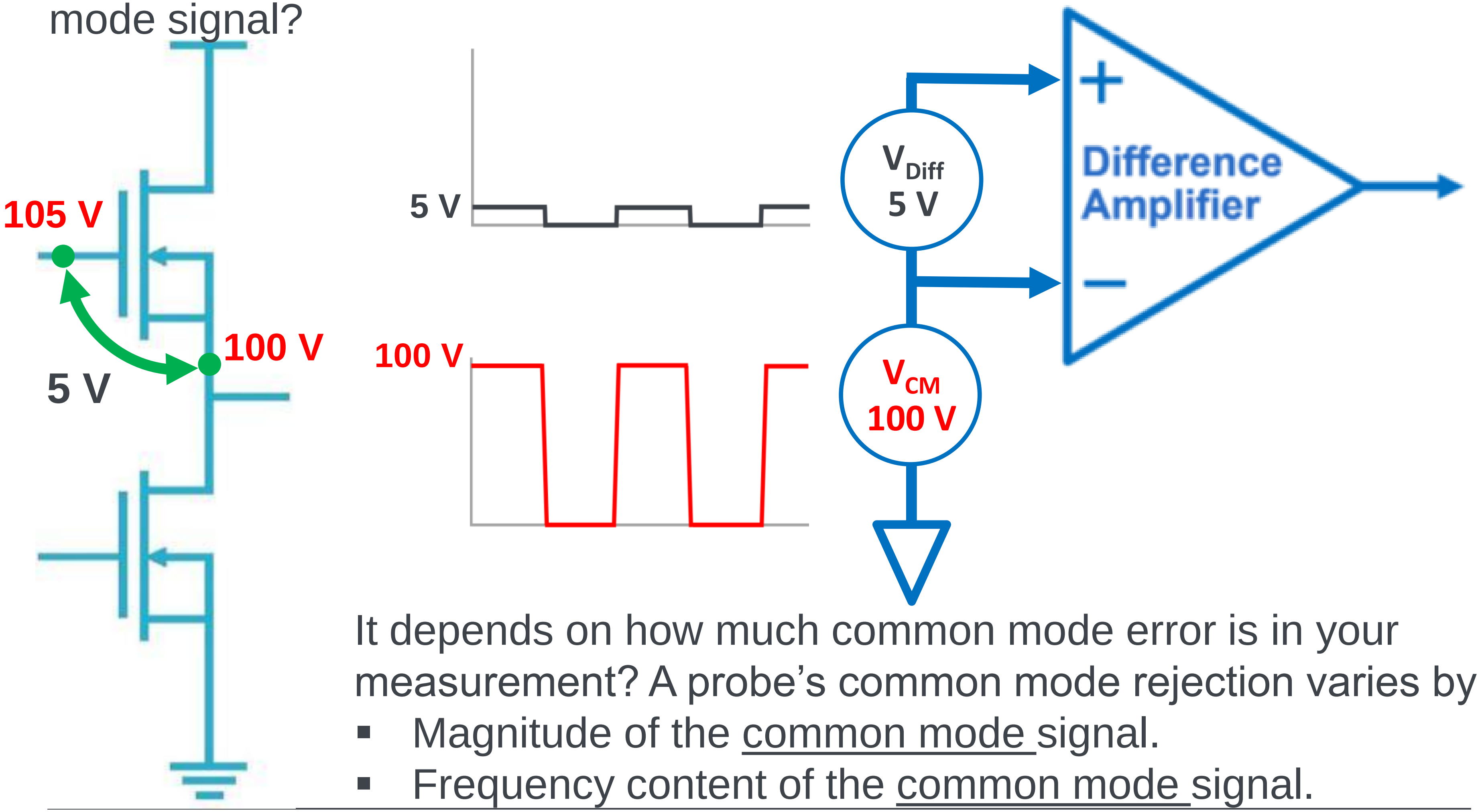
- Incorporates 4 separate lasers, an optical sensor, 5 optical fibers, and sophisticated feedback and control techniques.
- Powered over the fiber optic connection
  - No batteries required



The Measurement Problem

CMRR IS A CRITICAL BUT OFTEN OVERLOOKED SPECIFICATION

Can a 5V differential signal be measured in the presence of 100V common mode signal?

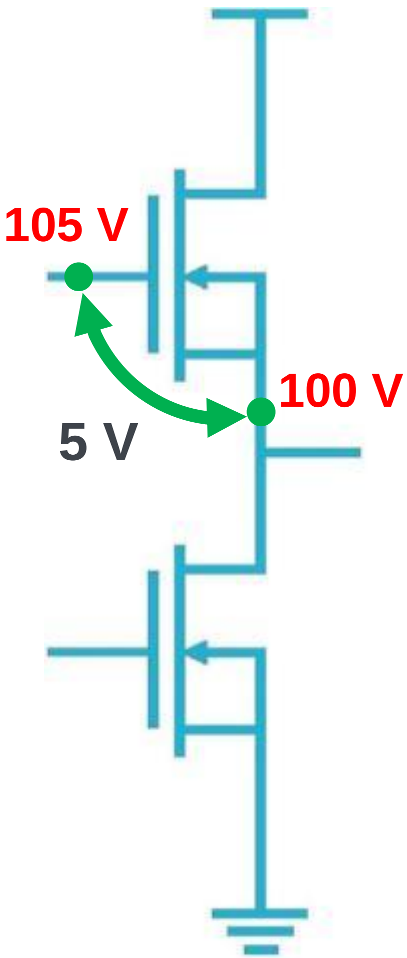


It depends on how much common mode error is in your measurement? A probe's common mode rejection varies by:

- Magnitude of the common mode signal.
- Frequency content of the common mode signal.

IsoVu Solves the Common Mode Problem

MOST PROBES HAVE VERY POOR CMRR ABOVE A FEW MHZ



At 100 MHz, most probes have 20 dB or less common mode rejection. This is 10:1 common mode rejection.

- With 100 V common mode voltage, 20 dB or (10:1) common mode rejection is:
  100 V divided by **10** → **10 V error**

You can't resolve 5V with 10V of error

IsoVu has 120 dB or 1 Million to 1 common mode rejection at 100 MHz

100 V divided by **1 Million** → **100 µV error**

How is Common Mode Rejection Specified?

Typically Only Specified at DC and Low Frequencies

This probe specifies a bandwidth of ≥100 MHz

Performance characteristics

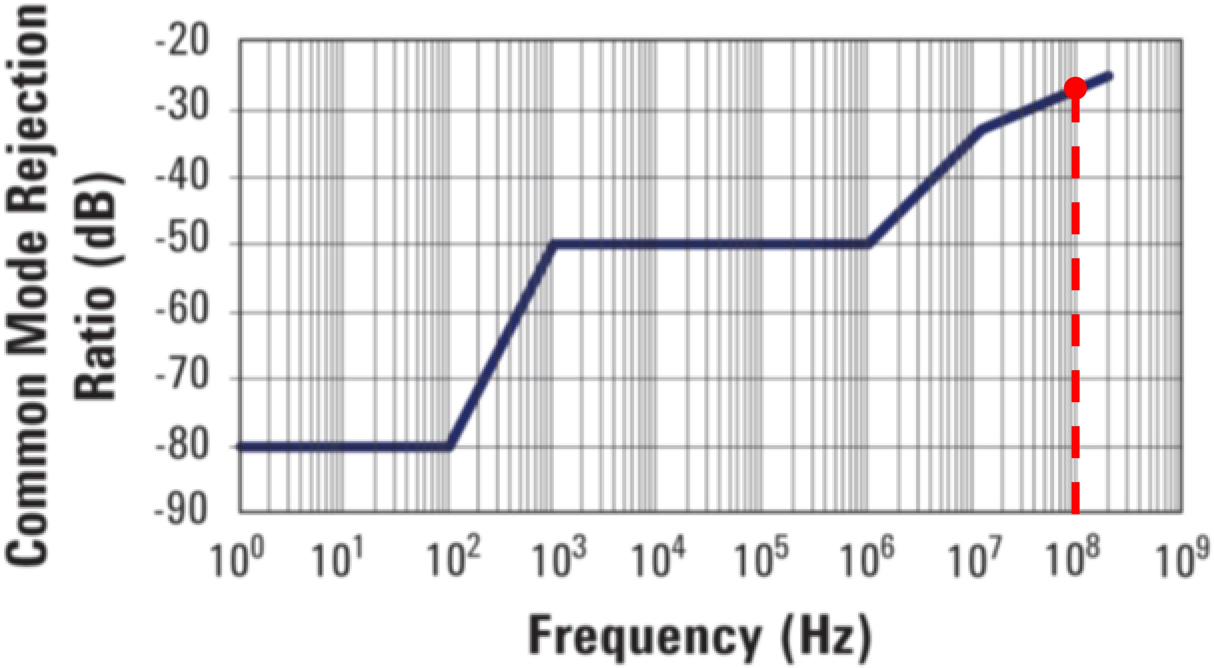
Product number	
Bandwidth (-3dB)	≥100 MHz probe bandwidth
DC CMRR	–70 dB at 500 VDC
AC CMRR	–80 dB at 50/60 Hz –50 dB at 1 kHz –50 dB at 1 MHz

but the data sheet only specifies CMRR to 1 MHz

WHY?

How is Common Mode Rejection Specified?

Only at DC and Low Frequencies



At 100 MHz, this probe has -27 dB CMRR

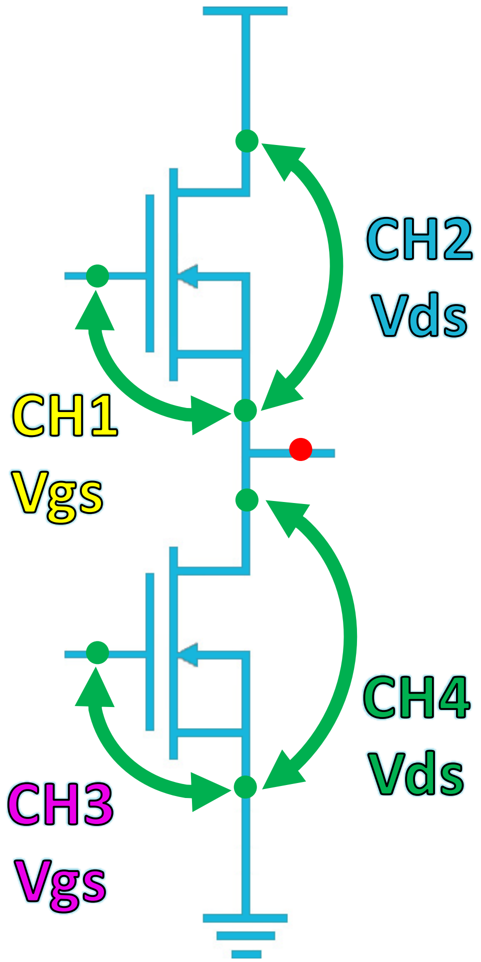
-27 dB CMRR? That's 22:1.

For 100 V Common Mode, Divide by 22

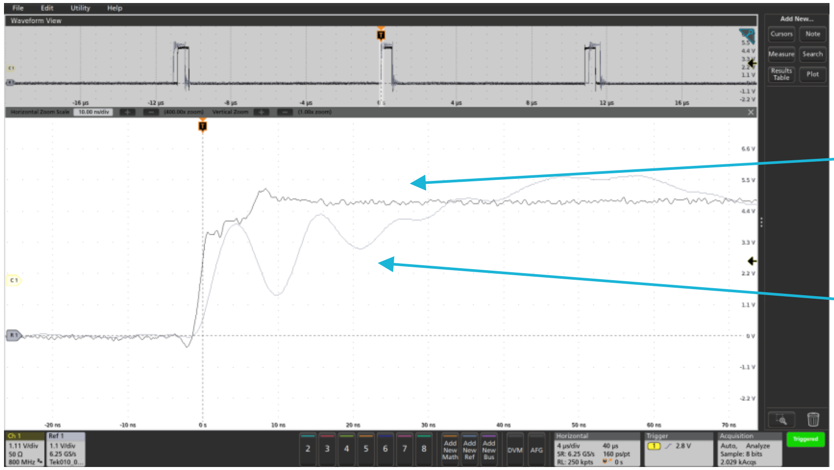
→ ~5 V Common Mode Error

Characterize the Entire Switching Circuit

ISOVU MAKES THE HIDDEN VISIBLE



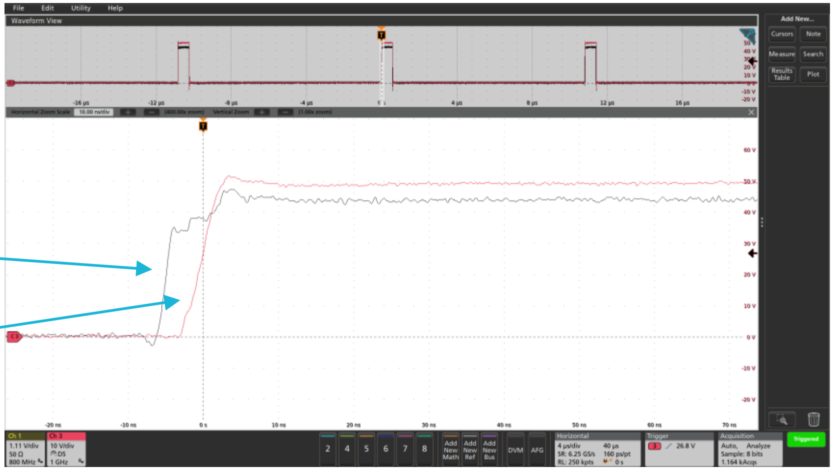
General probe vs IsoVu probe



TIVH08

THDP0200

<HV Diff. vs IsoVu>



TIVH08

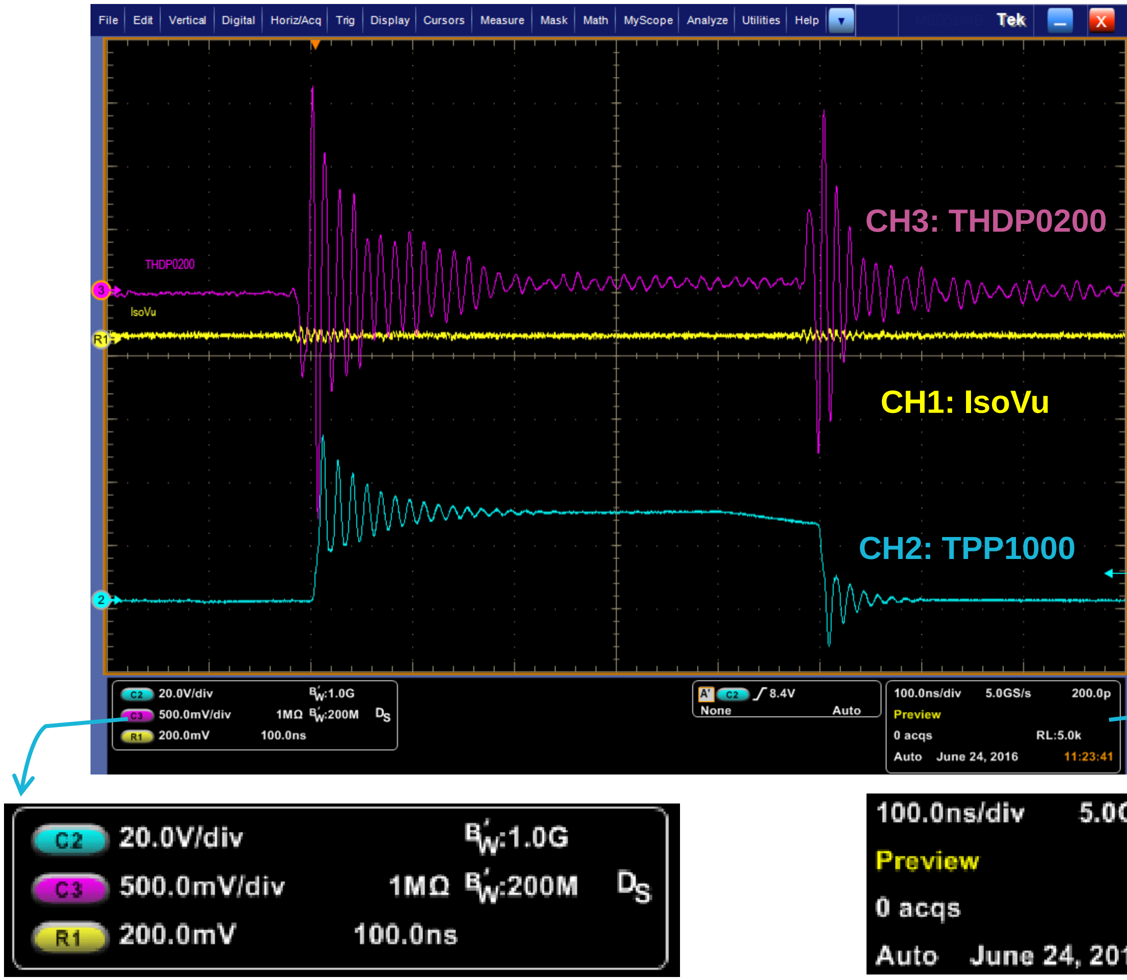
TPP1000

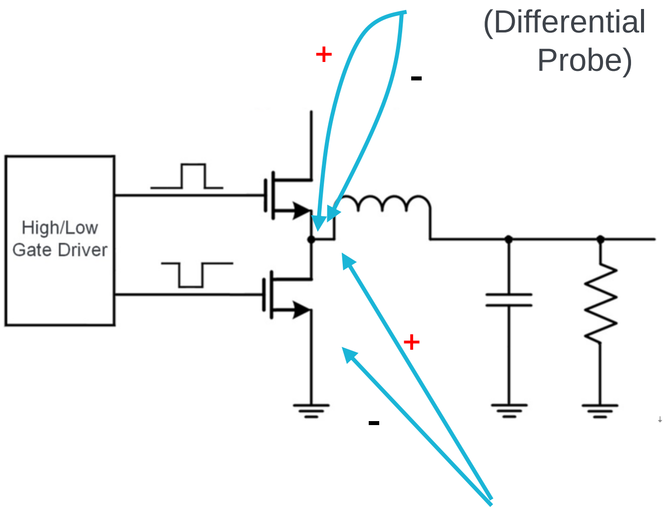
<Passive probe vs IsoVu skew adjust>

Influence of CMRR

High CMRR and Low Input Capacitance of IsoVu（TIVM1）

- Probing to floating point with shorted differential probe

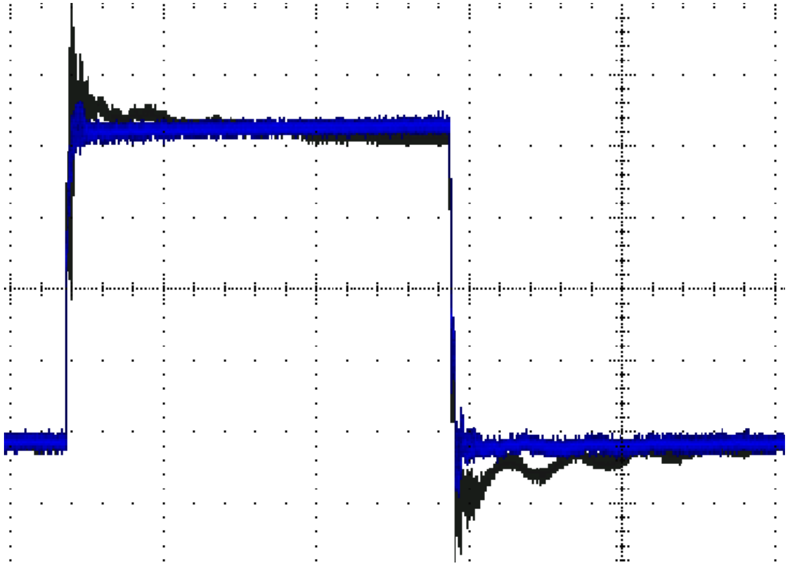




Influence of CMRR

BAD CMRR DISTORTS WAVEFORMS.

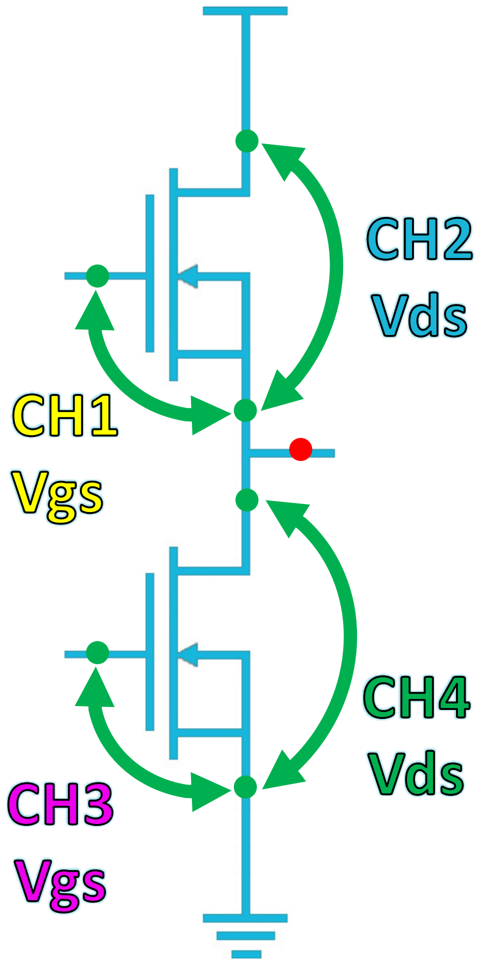
- Example of high-side gate measurement of SiC



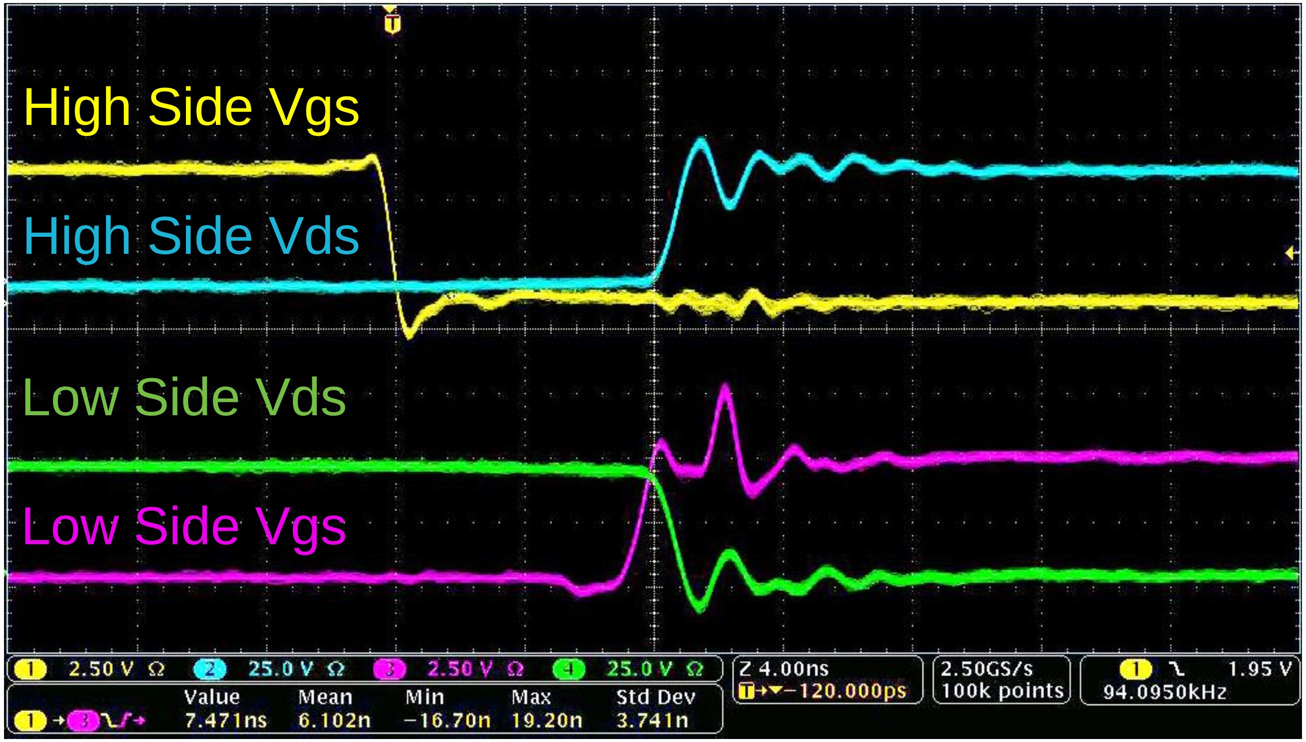
Black: Measured by differential probe which the customer had.
Blue: Measured by IsoVu

Characterize the Entire Switching Circuit

BUT ISOVU MAKES THE HIDDEN VISIBLE



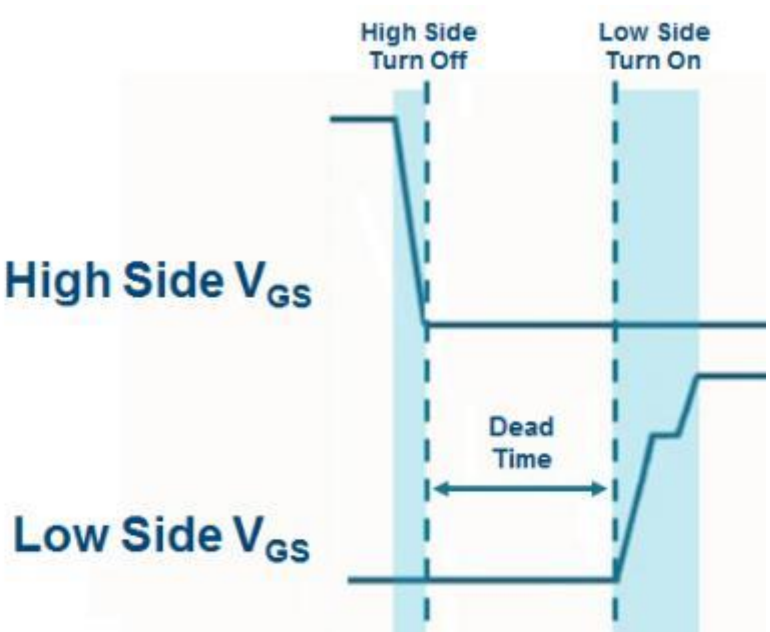
- Characterize the gate voltages, Vds, and Is
- Characterize the time alignment of high and low side events
- Optimize and tune switching characteristics (edge rates, overshoot, ringing and dead time)

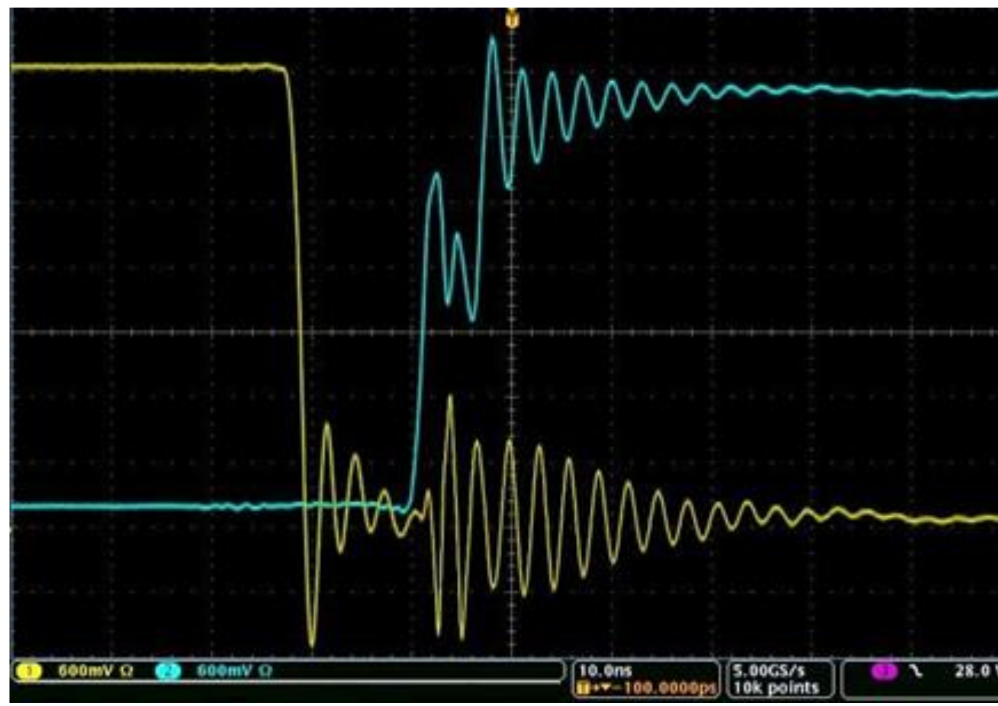


High-Side Gate Measurements

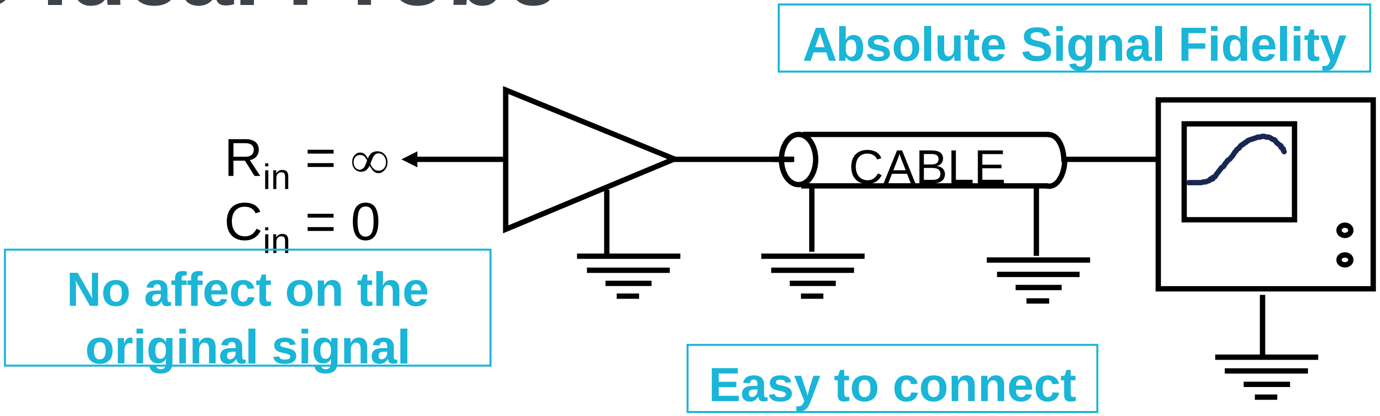
INTERACTION BETWEEN THE HIGH AND LOW SIDE

- Violation of specifications can lead to simultaneous conduction (it blows up), switch loss, loss of efficiency, and device degradation
- Parasitic coupling between switch node and both FETs





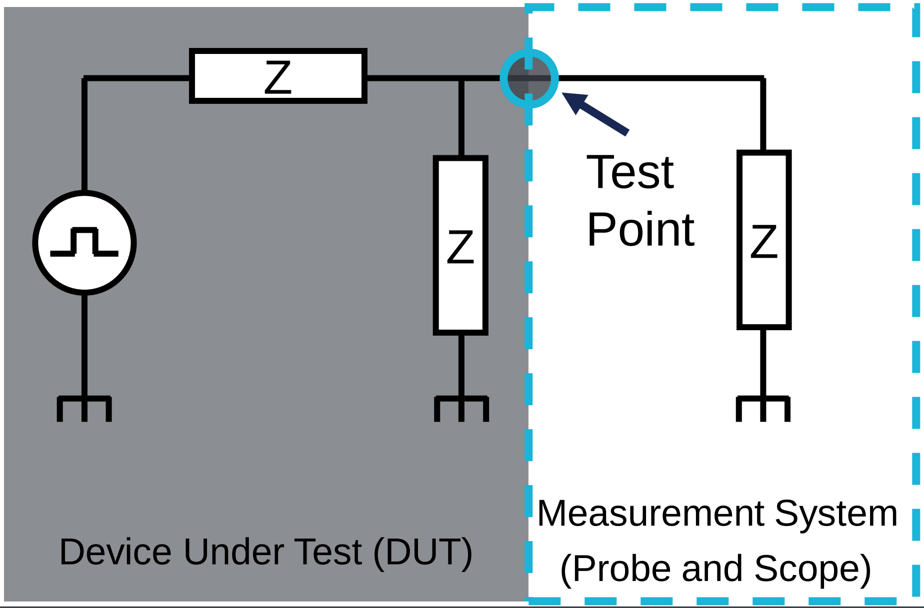
The Ideal Probe



- **No affect on the original signal – *No signal source loading!***
  - Zero Input Capacitance
  - Infinite Input Resistance
- **Absolute Signal Fidelity**
  - Unlimited bandwidth
  - Unlimited rise time
  - Zero attenuation
  - Linear phase across all frequencies
- **A convenient and easy way to connect to the device-under-test**
  - Mechanically well suited to application

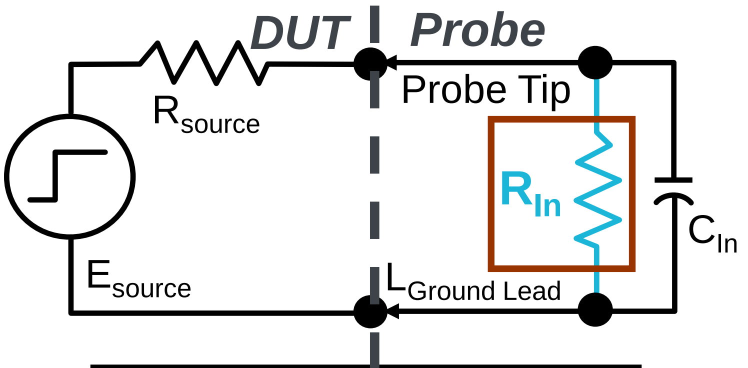
Signal Source Loading

- When the probe is connected to the DUT, the probe will draw some current.
- The impedance values of the probe and scope will affect the measured signal.
- The Measurement System impedance **(Z)** consists of:
  - Resistive Elements (Resistance, R)
  - Reactive Elements (Capacitance, C and Inductance, L) which vary over frequency
- Good probe design uses R, L, and C elements to influence signal fidelity, attenuation, and source loading over specified frequency ranges.



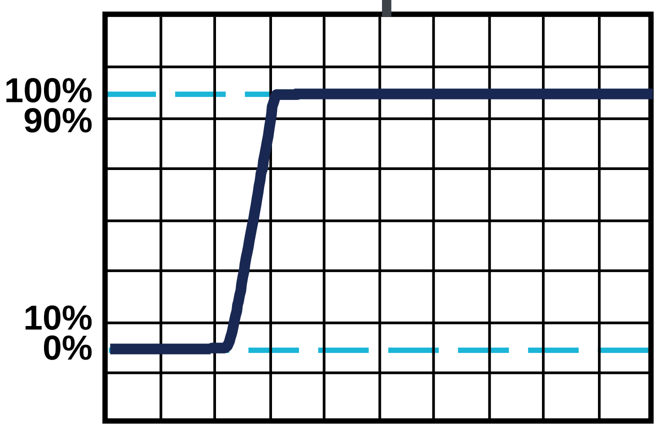
Source Loading – Input Resistance

- R_{in} acts like a voltage divider
- Higher input resistance – less loading
- Lower source resistance – less loading

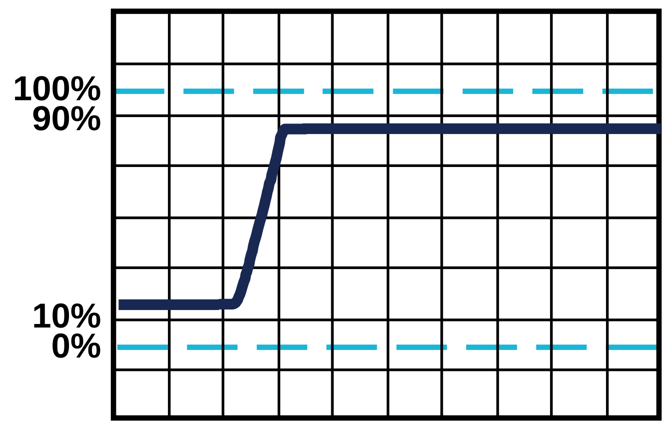


Decreased Signal Amplitude

$$V_{meas} = V_{source} \frac{R_{in}}{R_{in} + R_{source}}$$



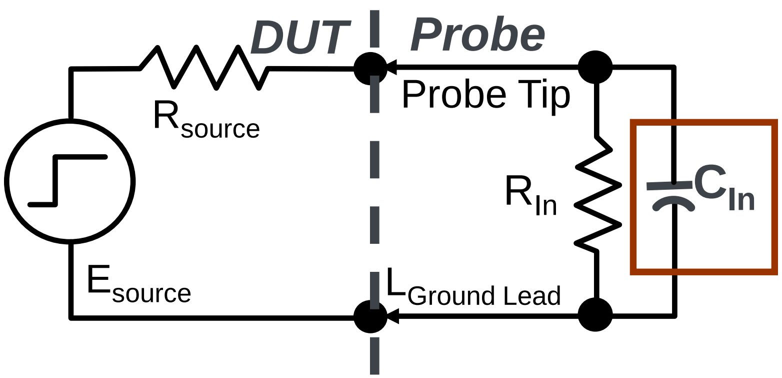
Source Signal



Effects of Input Resistance

Source Loading – Input Capacitance

- Smaller input capacitance - higher probe impedance, less loading
- As signal frequency increases, capacitance increases and loading increases



- **Decreased Amplitude**
- **Phase Change**
- **Slower Rise Time**

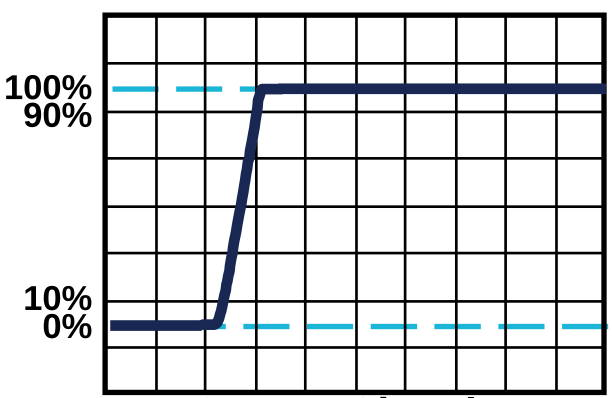
$t_r \cong 2.2(R_{source} \times C_{in})$

<u>Example:</u>

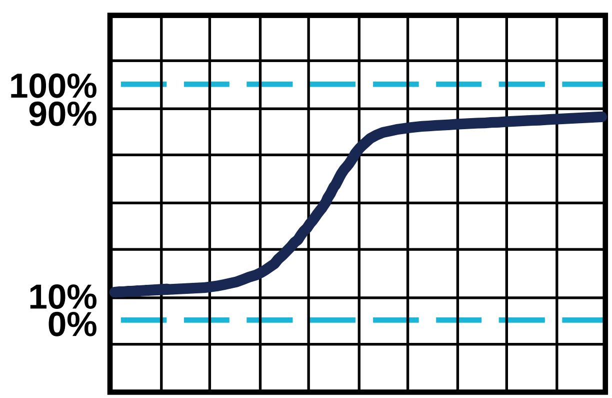
C_{in} = 100 pF
t_r ~ 220 nsec

C_{in} = 10pF
t_r ~ 22 nsec

If R_{source} = 1 kΩ



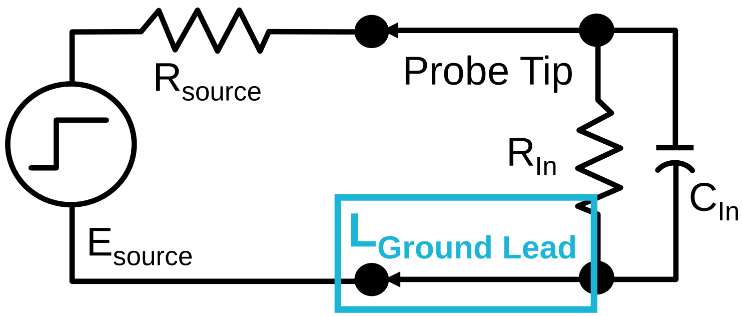
Source Signal



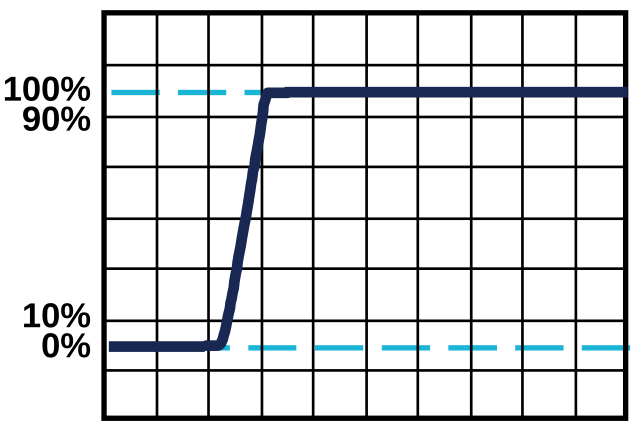
Effects of Input Capacitance

Source Loading - Inductance

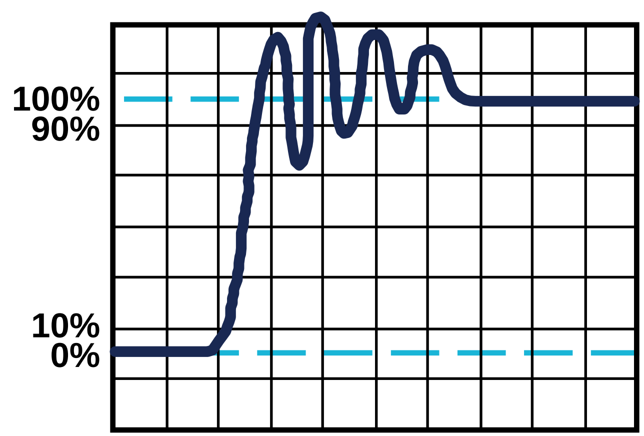
- The longer the ground lead, the higher the probe inductance.
- Keep ground leads as short as possible to avoid ringing!



Resonance (Ringing)



Source Signal



Effects of Inductance

IsoVu Technology Delivers

CHARACTERIZE THE ENTIRE CIRCUIT

- Simultaneously measure high-side V_{GS}, V_{DS}, and I_S
- Optimize and tune switching characteristics (edge rates, overshoot, ringing, dead time)
- Characterize time alignment of high and low side events

	ISOVU TIVM SERIES	ISOVU TIVH SERIES
Bandwidth	Up to 1 GHz	Up to 800 MHz
Rise Time	Down to 350 ps	Down to 450 ps
Differential Voltage Range	±5mV up to ± 50 V	±5mV up to ± 2.5 kV
Common Mode Voltage Range	60 kV	60 kV
Common Mode Rejection Ratio	DC – 1 MHz: 160 dB (100 Million to 1) 1 MHz – 100 MHz: 120 dB (1 Million to 1) 1 GHz: 80 dB (10,000 to 1)	DC – 1 MHz: 160 dB (100 Million to 1) 1 MHz – 100 MHz: 120 dB (1 Million to 1) 800 MHz: 80 dB (10,000 to 1)
Input Impedance	Up to 2.5 kΩ < 1 pF	Up to 40 MΩ As low as 2 pF
Fiber Cable Length	3 meters or 10 meters	3 meters or 10 meters
Power Over Fiber	Powered over the fiber connection – no batteries required	Powered over the fiber connection – no batteries required
Input Offset	Up to ± 100 V	Up to ± 1000 V
Input Coupling	DC	DC or AC

Note: Specifications are dependent on the probe tip cable

TIVH series: Sensor Head SMA Input Up to 25V

DESIGNED FOR INCREASED SENSITIVITY AND CONVENIENCE

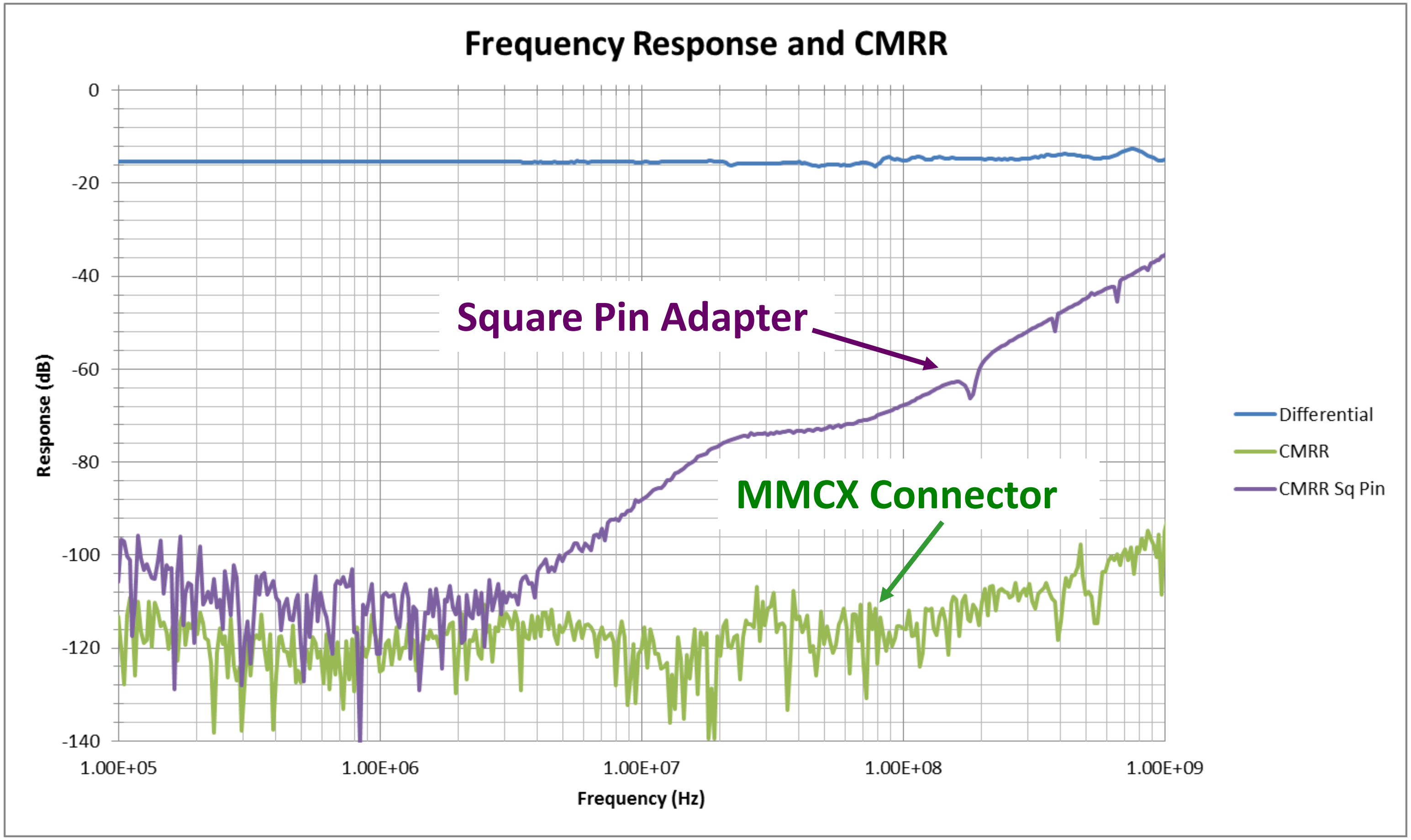
- The Sensor Head SMA input provides a high impedance input with increased sensitivity for measuring small differential signals.

MMCX Tip Cable (TIVH series: Up to 250V)

DESIGNED FOR OPTIMAL PERFORMANCE AND CONVENIENCE

- Planned test points (MMCX Connectors) → Best Performance
  - MMCX connectors are small, inexpensive (typically <$2) and come in a variety of packages that can be purchased from Digi-key or other vendors. They can be soldered onto unplanned test points.
  - https://www.digikey.com/products/en/connectors-interconnects/coaxial-connectors-rf/437?k=&pkeyword=&pv801=27&FV=ffe001b5&mnonly=0&newproducts=0&ColumnSort=0&page=1&quantity=0&ptm=0&fid=0&pageSize=25

Common Mode Rejection over Frequency

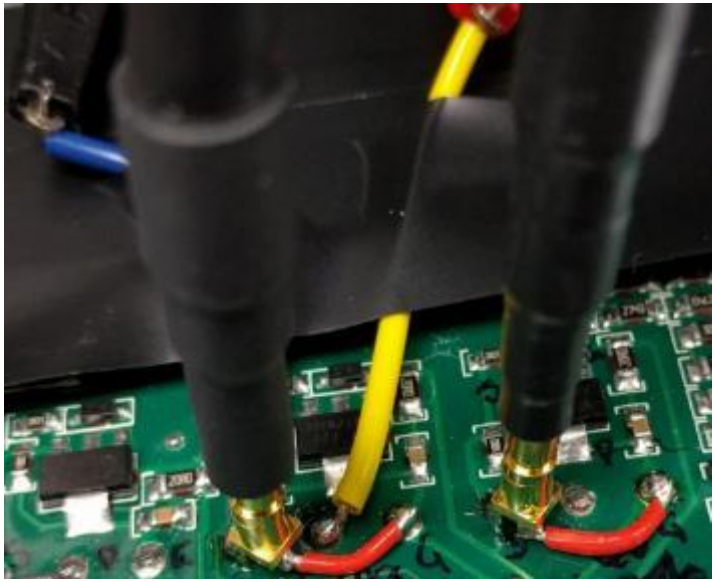


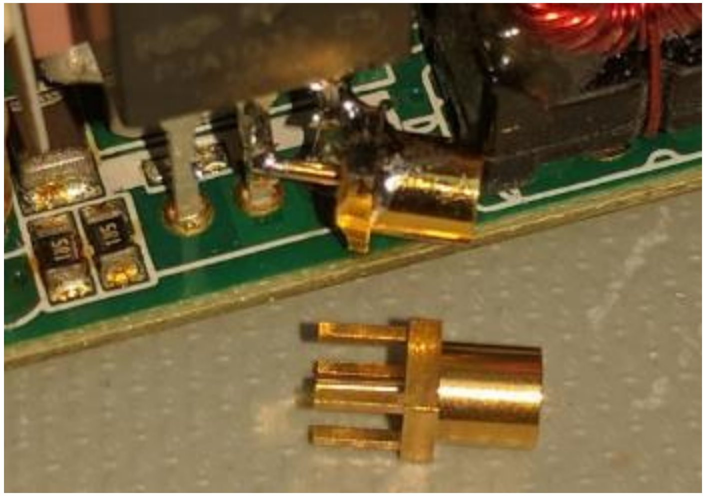
Note: Measurement above, from DC - ~100MHz, is limited by the VNA noise floor

MMCX Tip Cable (TIVH series: Up to 250V)

DESIGNED FOR OPTIMAL PERFORMANCE AND CONVENIENCE

- Using an MMCX on unplanned test points

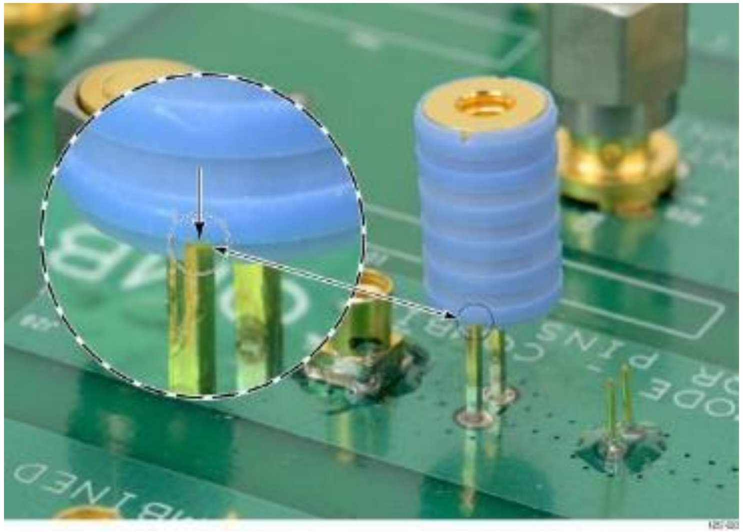


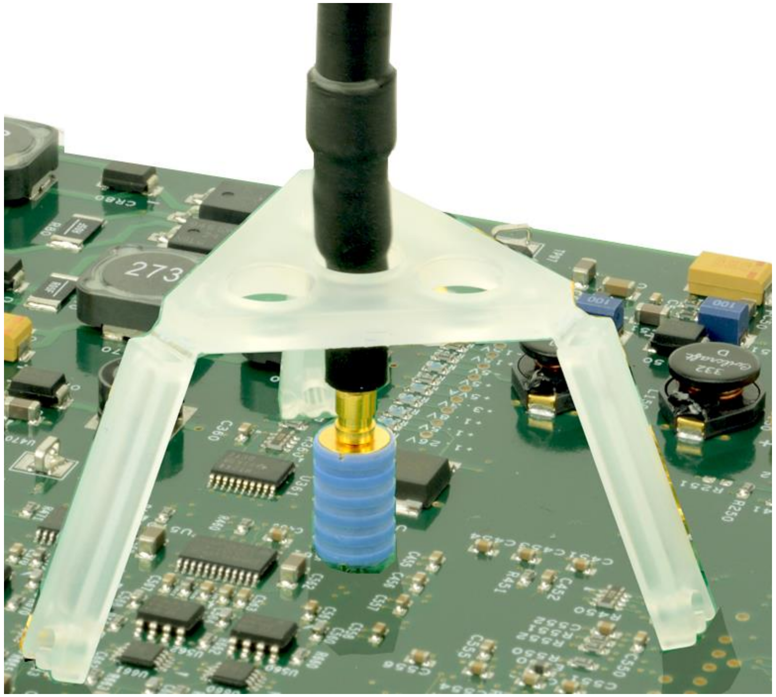


Square Pin to MMCX Adapter

UNPLANNED TEST POINTS

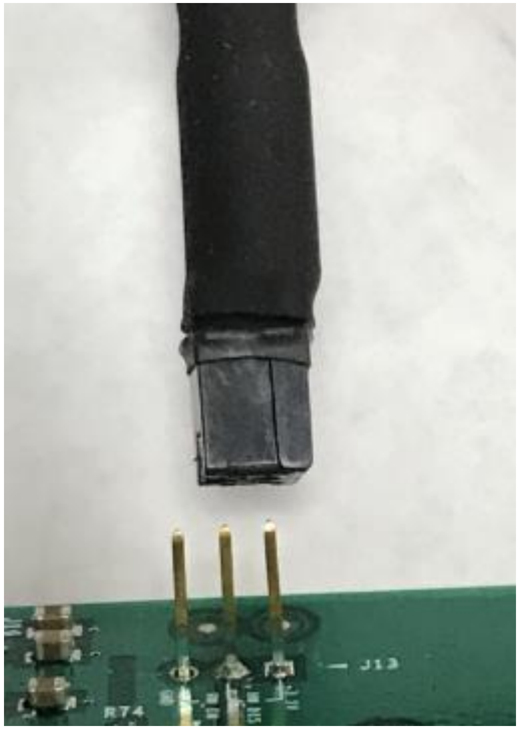
- 0.100” (2.54mm) and 0.062” (1.57mm) Square Pin to MMCX Adapter
  - High performance square pin adapter designed to minimize the performance impact of the square pins
  - Not your usual Tek differential probe square pin adapter

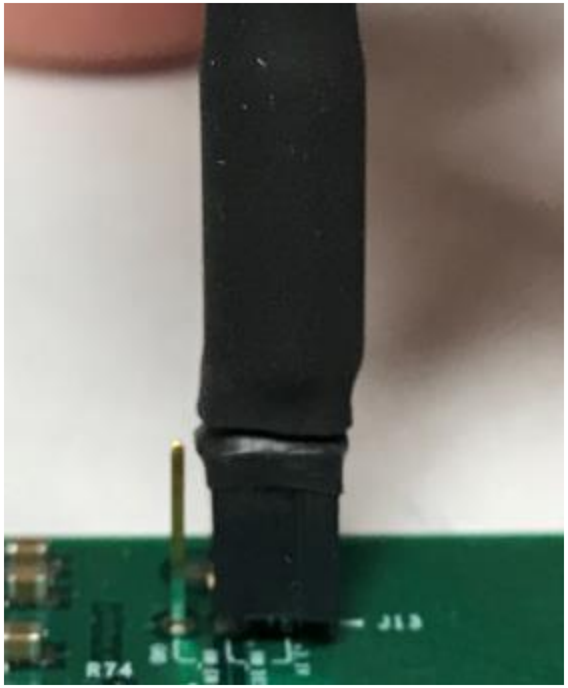




TIVH series: 0.1” (2.54mm) Square Pin Tip Cable Up to 600V

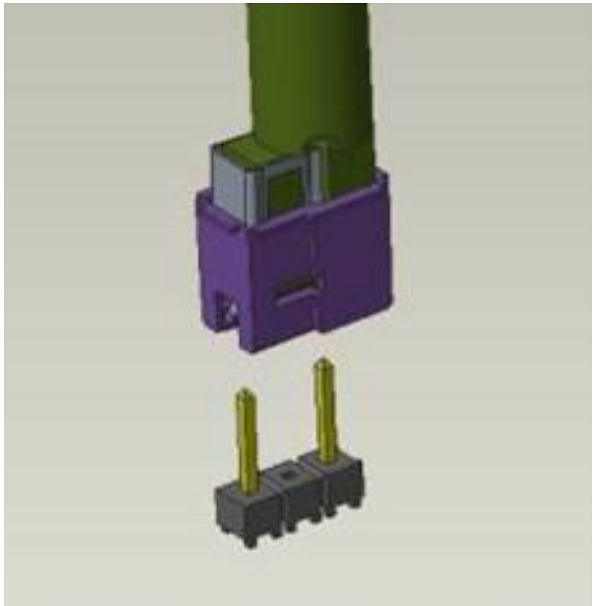
- Square Pin Probe Tip Cable
  - 0.1” (2.54 mm) pitch





TIVH series: 0.2” (5.08mm) Square Pin Tip Cable Up to 2500V

- Square Pin Probe Tip Cable
  - 0.2” (5.08 mm) pitch



IsoVu TIVH-Series Detailed Specifications

	ISOVU TIVH SERIES				
Bandwidth and Rise Time	TIVH08: 800 MHz / 450 ps TIVH05: 500 MHz / 700 ps TIVH02: 200 MHz / 1.8 ns				
Common Mode Voltage Range	60 kV (UL safety limitation)				
Common Mode Rejection Ratio	DC – 1 MHz: 160 dB (100 Million to 1) 1 MHz – 100 MHz: 120 dB (1 Million to 1) 800 MHz: 80 dB (10,000 to 1)				
Attenuation Differential Voltage Range Offset Range Input Impedance	Sensor Tip Cable	Attenuation	Differential Voltage Range	Offset Range	Input Impedance
	Direct Connection into SMA Input of the Sensor Head				
	SMA Input	1X	± 1 V	± 25 V	1 MΩ // 20 pF
	MMCX Style Sensor Tip Cables				
	MMCX10X	10X	± 10 V	± 250 V	10 MΩ // 6 pF
	MMCX50X	50X	± 50 V	± 250 V	10 MΩ // 3 pF
	MMCX250X	250X	± 250 V	± 250 V	10 MΩ // 2 pF
	0.100" Pitch (2.54 mm) Square Pin Style Sensor Tip Cables				
	SQPIN100X	100X	± 100 V	± 600 V	10 MΩ // 3.5 pF
	SQPIN500X	500X	± 500 V	± 600 V	10 MΩ // 3.5 pF
	0.200" Pitch (5.08 mm) Square Pin Style Sensor Tip Cables				
	WSQPIN1000X	1000X	± 1000 V	± 1000 V	40 MΩ // 3 pF
	WSQPIN2500X	2500X	± 2500 V	± 1000 V	40 MΩ // 3 pF
Noise (Input Referred) – SMA Input 1X Range (Scales with Tip Cable Attenuation)	TIVH08/08L: 1.2mV$_{RMS}$ TIVH05/05L: 0.72mV$_{RMS}$ TIVH02/02L: 0.61mV$_{RMS}$				
Power Over Fiber	Powered over the fiber connection – no batteries required				
Input Coupling	DC or AC				

Note: Specifications are dependent on the probe tip cable

IsoVu TIVM-Series Detailed Specifications

	IsoVu TIVM1				
Bandwidth and Rise Time	TIVHM1: 1 GHz / 350 ps				
Common Mode Voltage Range	60 kV (UL safety limitation)				
Common Mode Rejection Ratio	DC – 1 MHz: 160 dB (100 Million to 1) 1 MHz – 100 MHz: 120 dB (1 Million to 1) 1 GHz: 80 dB (10,000 to 1)				
Attenuation **Differential Voltage Range** **Offset Range** **Input Impedance**	Sensor Tip Cable	Attenuation	Differential Voltage Range	Offset Range	Input Impedance
	Direct Connection into SMA Input of the Sensor Head				
	SMA Input	1X	± 1 V	± 25 V	50 Ω
	MMCX Style Sensor Tip Cables				
	IVTIP1X	1X	± 1 V	± 2 V	50Ω
	IVTIP5X	5X	± 5 V	± 10 V	250Ω // <1 pF
	IVTIP10X	10X	± 10 V	± 20 V	500Ω // <1 pF
	IVTIP25X	25X	± 25 V	± 50 V	1.25 kΩ // <1 pF
	IVTIP50X	50X	± 50 V	± 100 V	2.5 kΩ // <1 pF
Noise (Input Referred) – SMA Input 1X Range (Scales with Tip Cable Attenuation)	TIVM1/1L: 0.8mV$_{RMS}$				
Input Coupling	DC only				

Note: Specifications are dependent on the probe tip cable

Will release a new probe soon

- Small form factor
- Various BW
- Low price
- Ease of use

Thank you!