How to Correctly Select an Oscilloscope Probe for Testing SiC and GaN Power Devices

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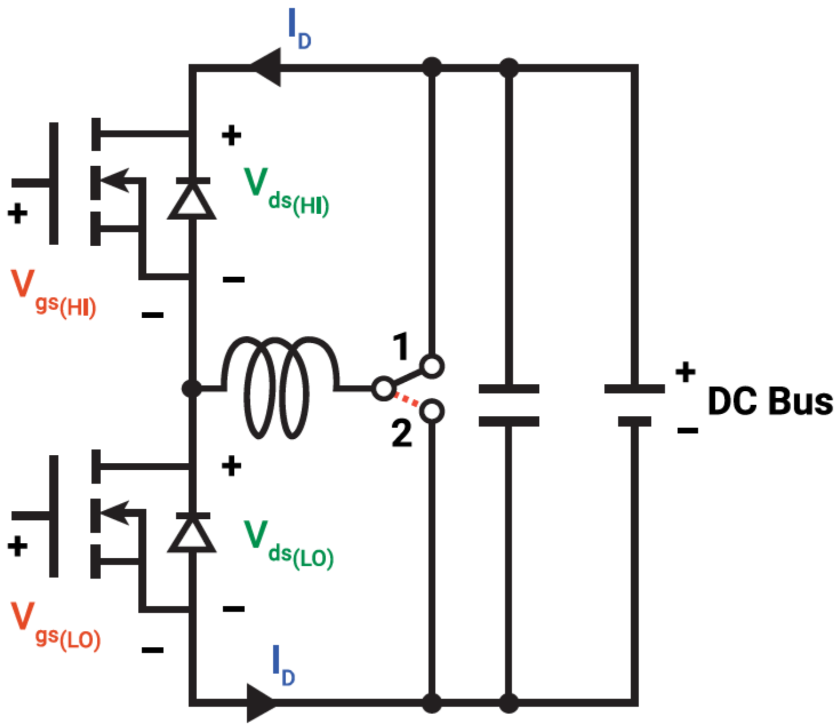
Gate Measurements on SiC and GaN - probing challenges

- **High-side** floating voltages are not simple to measure
  - $V_{gs(HI)}$ is a floating voltage, at high voltage from GND
  - You generally need a probe that can measure a very small voltage at significant voltage from ground
  - Differential probes are the first possible solution, but have some important limitations to consider
    - Max Voltage between D+ and D- (diff. Voltage)
    - Max Voltage between each pin and GND (CM Voltage)
    - To meet both specs a high attenuation is required, limiting the actual differential voltage resolution and accuracy
    - Fast switching time, BW of 1 GHz and more may be required

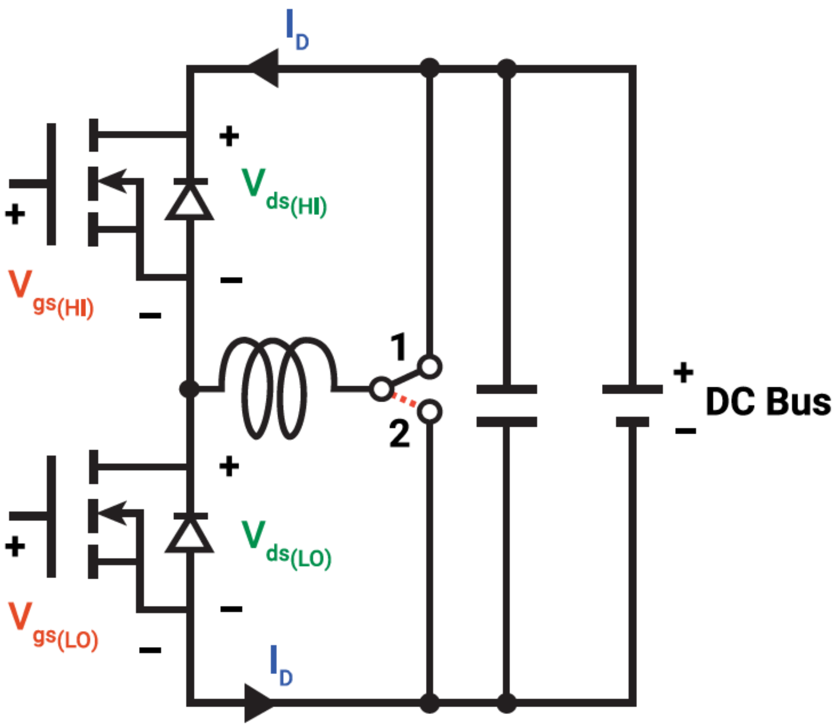


Gate Measurements for SiC and GaN probing challenges

- **Low gate side** is simpler to measure
  - $V_{gs(LO)}$ measurement is referenced to GND
  - Passive probes can be used but are BW limited and noisier. Be aware of loading and BW derating curve.
  - Compensate a passive probe with Cal. out before using it.
  - High common mode Differential probes are a better choice, more expensive but can go up to 1 GHz BW

One aspect for both low and high side

  - Probing (tip connection) is not simple, especially with power switching and is not a secondary aspect.
  - Passive probe's GND lead captures signals coming from the other side of the switching gate
  - Probe Tip inductance may not be negligible (Hook tip)
  - Loading, BW and isolation derating curves are always to be taken into consideration



Oscilloscope probe landscape: Many probes for different applications

Low Voltage

1. Passive, Single-ended
2. Active, Single-ended “FET”
3. Active, Single-ended “Rail”
4. Active Differential
5. Low voltage High CMRR

High Voltage

6. Passive, Single-ended
7. Fiber-optic isolated low BW
8. Active, Differential (conventional high Differential probes)
9. Fiber-optic isolated High BW

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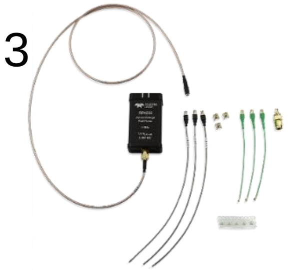
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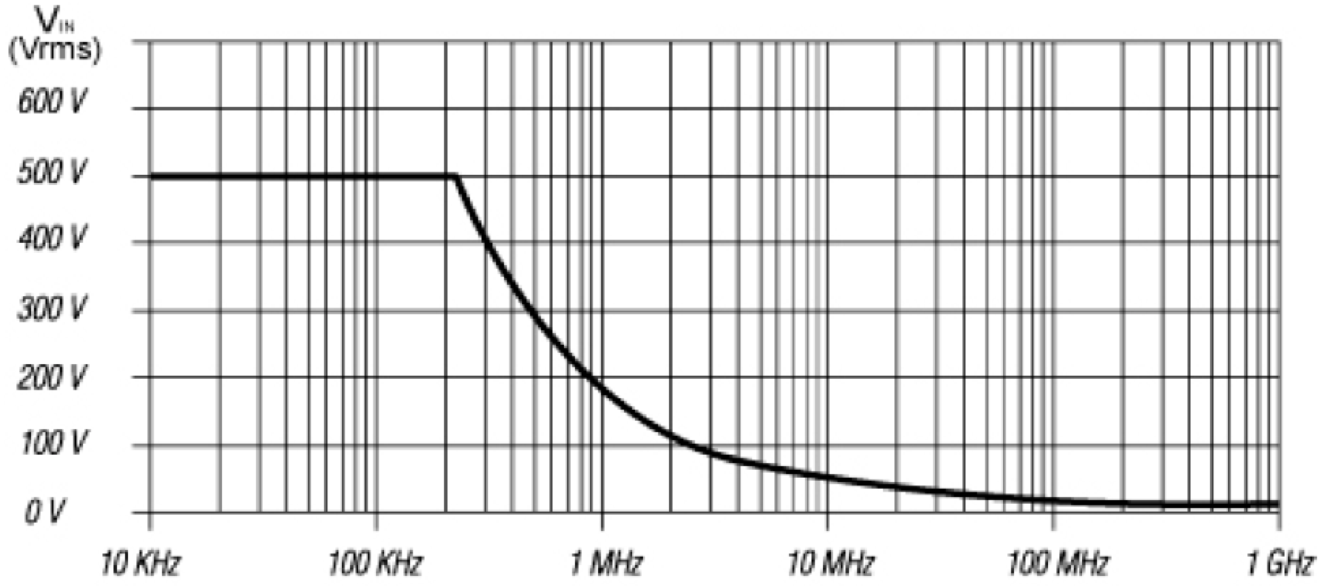
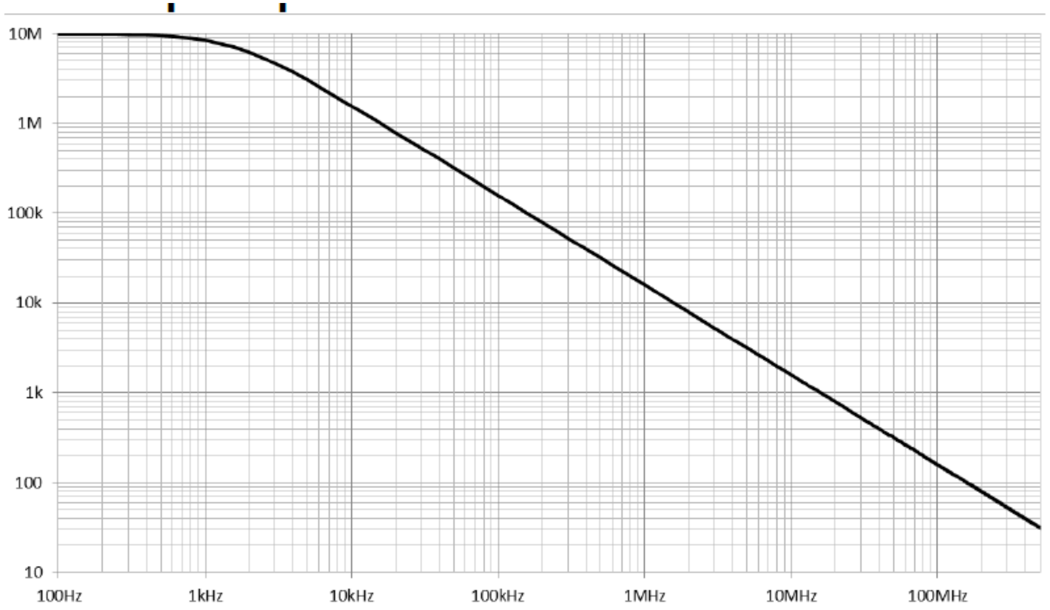
Which one is the best for my application?
Technical and economical aspects to be considered

Typical Derating curves of passive probes

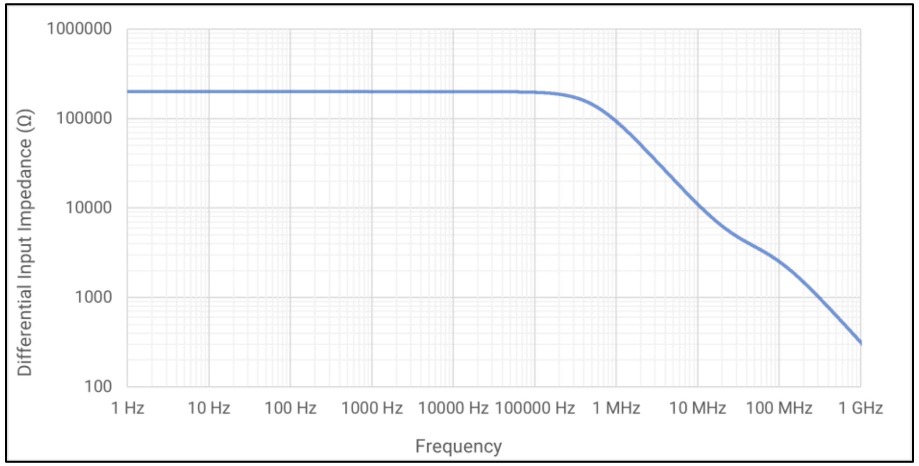
Voltage vs. Frequency Derating Curve



Probe loading profile

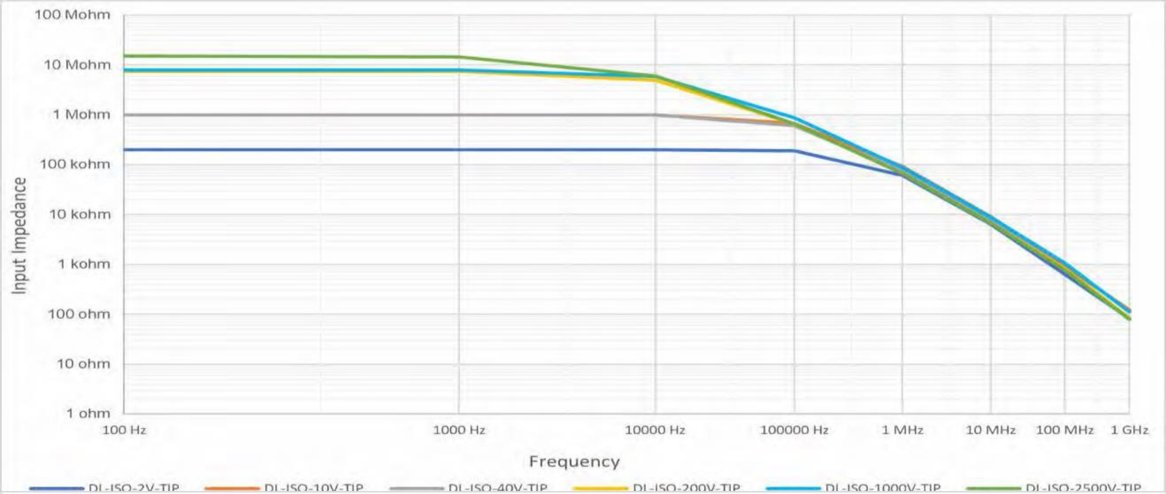


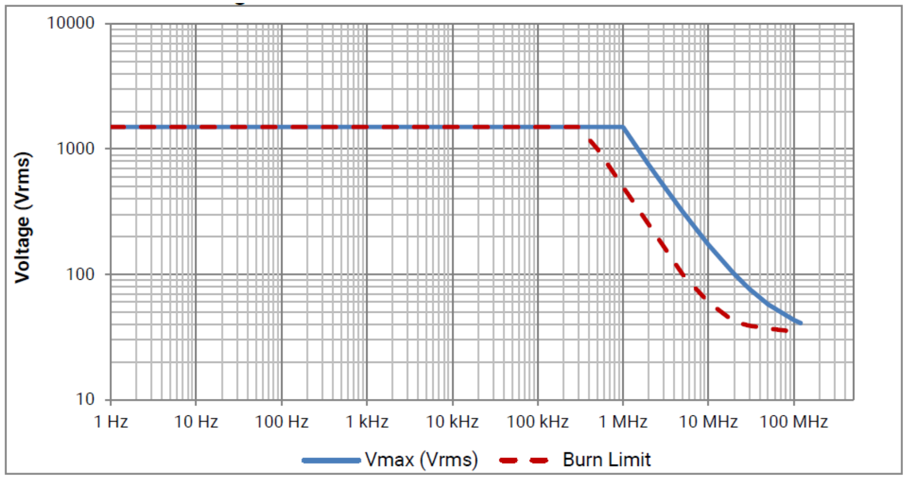
All probes have a variable AC behavior (from User manuals)



Low Voltage Active Diff. Probe

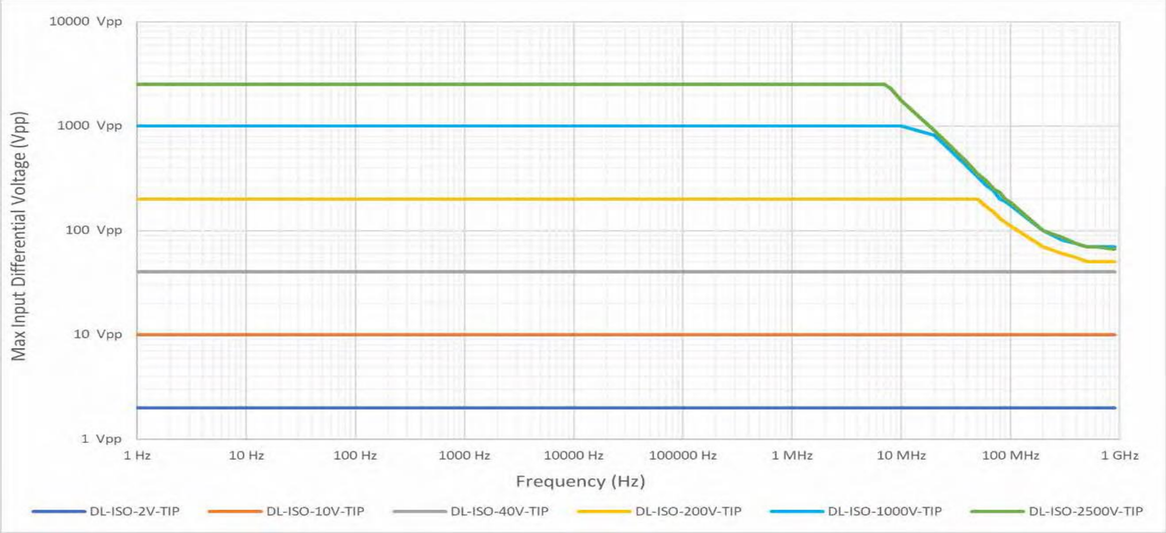
BW response





2KV - HVD probe

isolation derating curve



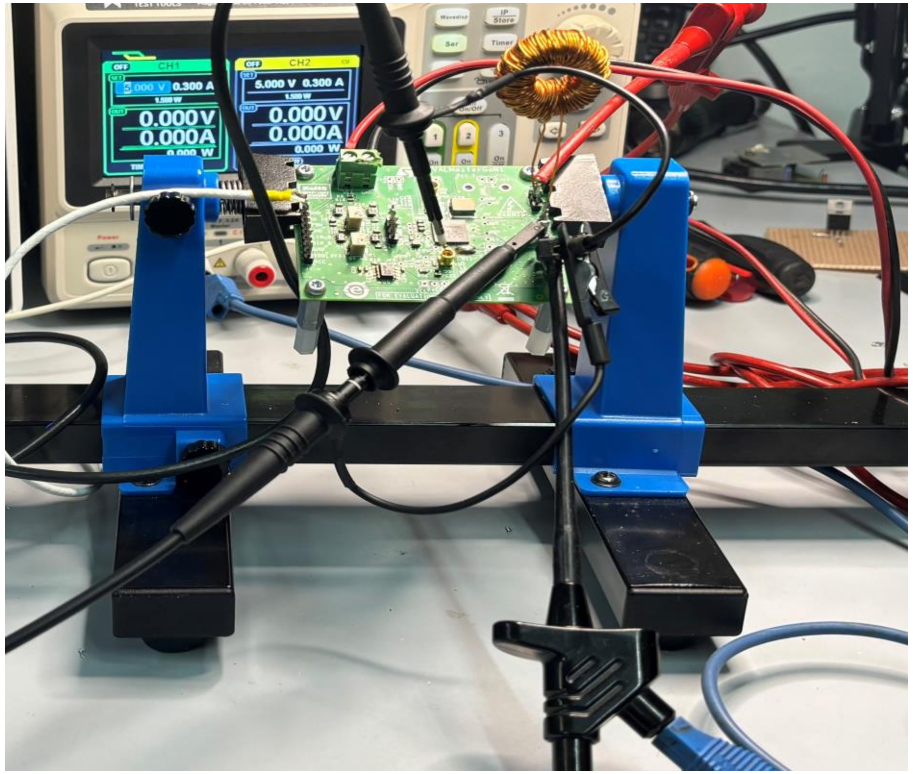
Optically Isolated High BW probe - different attenuation tips

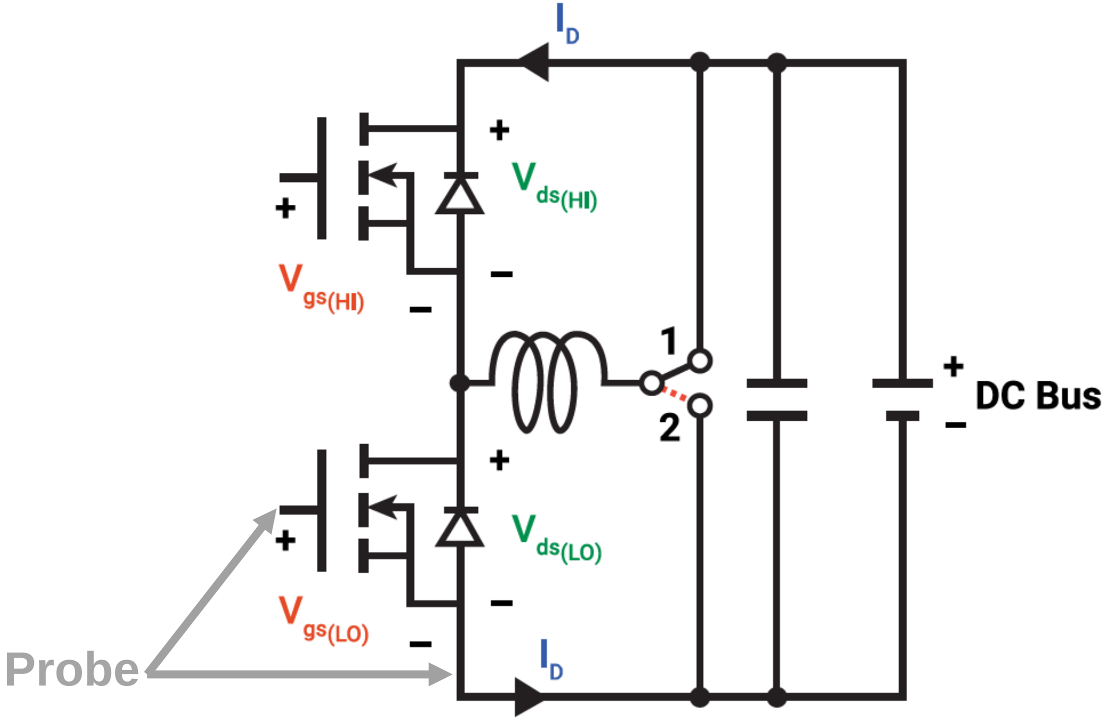
Possible measurement approaches

- Make measurements only on low side
  - Assume that the high-side will work just like the low-side because the design has been replicated on both devices
    - You won’t know if there’s a problem specific to high-side device
- Use High Voltage Differential probe on both High and Low side
  - As mentioned in the previous slide HVD probes are often used even if not ideal for small voltages.
  - Lower S/N ratio because of typical high attenuation (100x to 500x)
  - Acceptable cost in most cases
- **Use different probes according to test point and specific requirements**
  - Save time, get best results, may be more expensive

Low-side gate

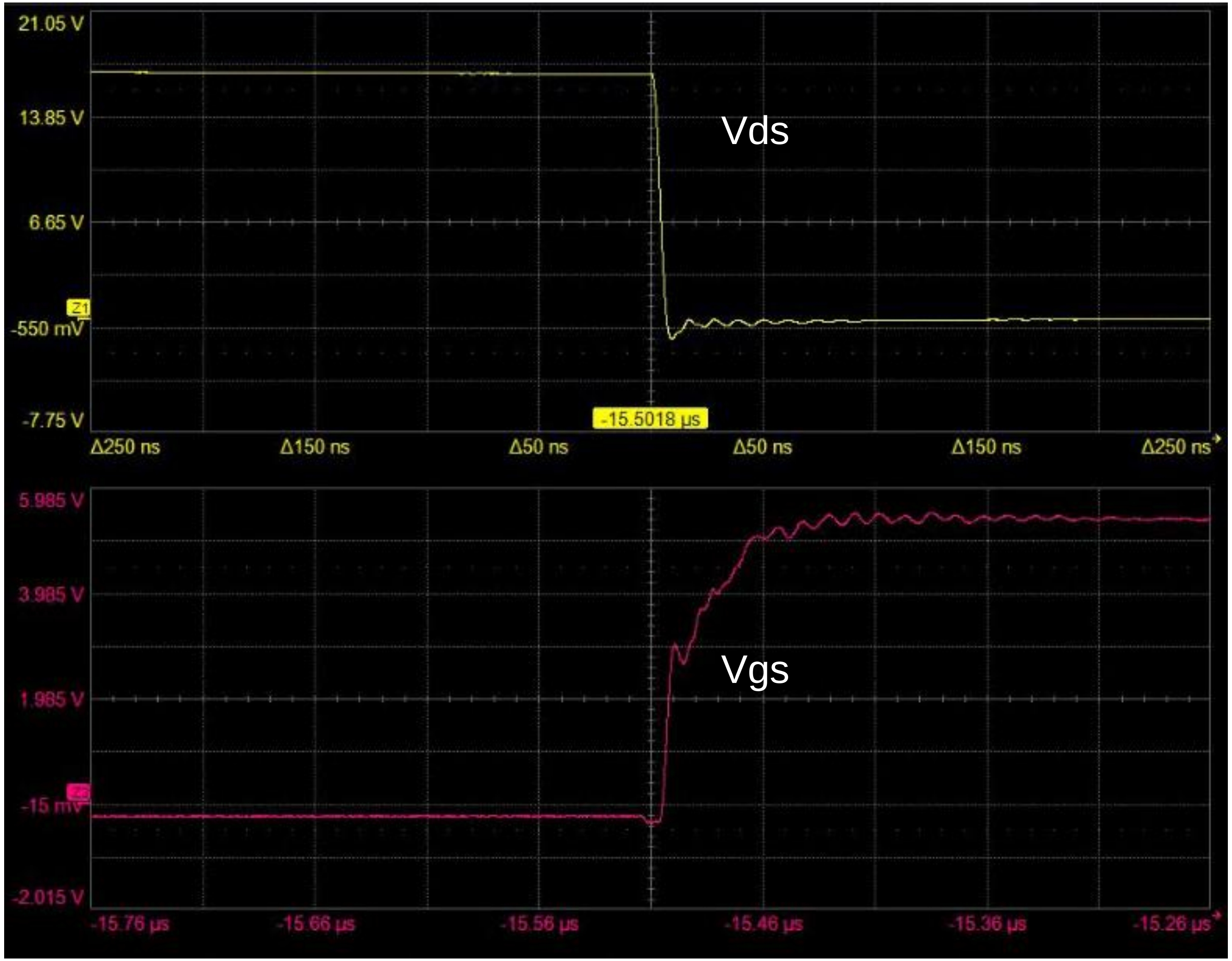
- About $V_{gs(LO)}$:
  - Low V signal
  - Low-side device is referenced to ground
  - Will passive probe work well?





GND leads have an impact on the signal?

Passive probe Vgs-low: results

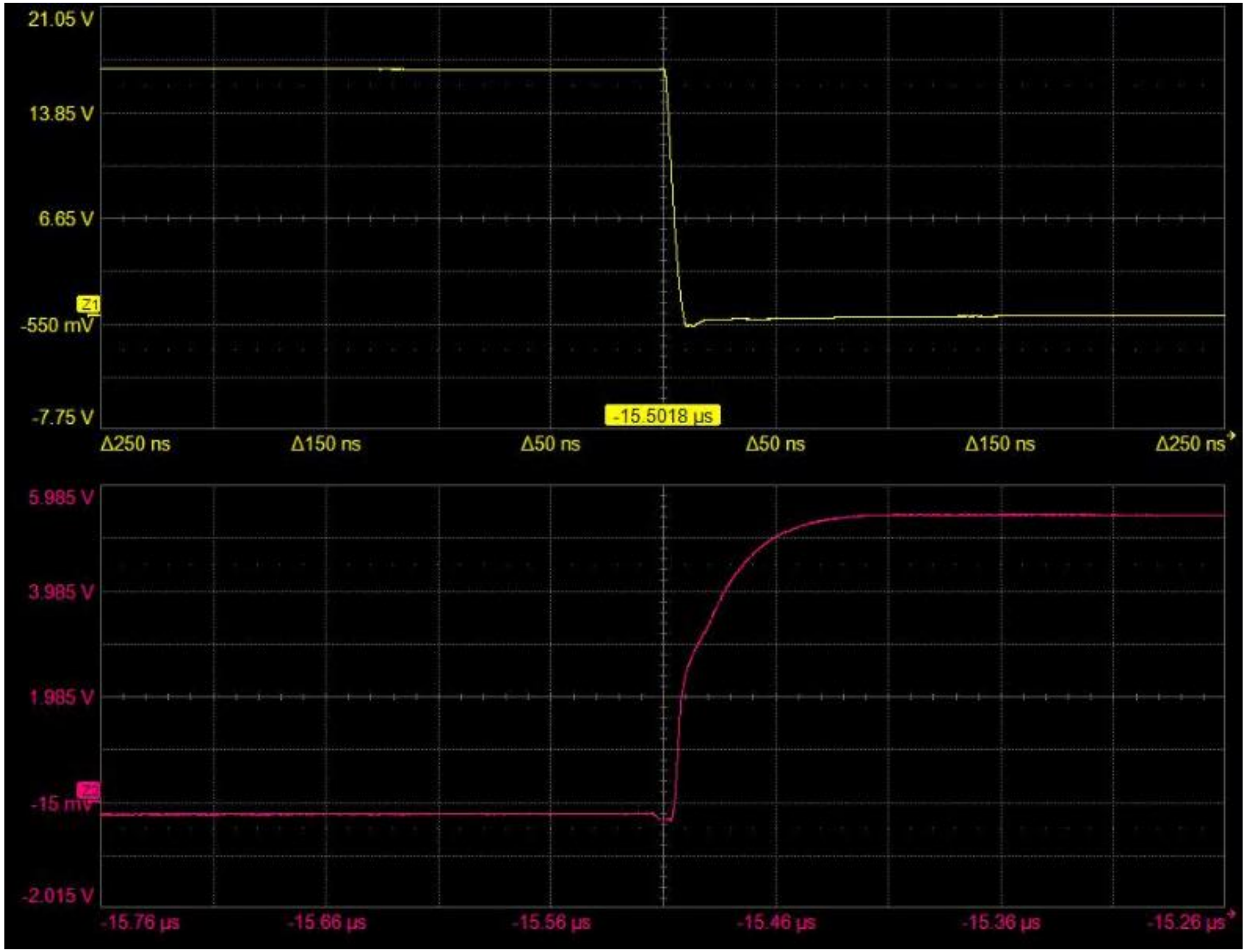


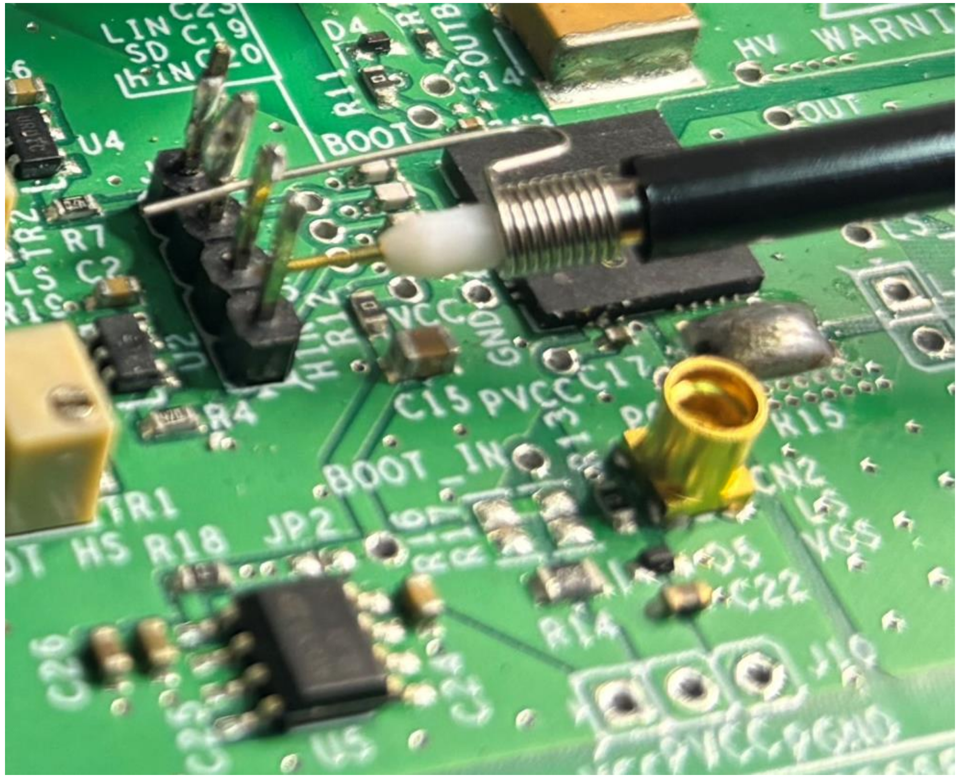
Results are not too bad, but with a small effort we can do much better.

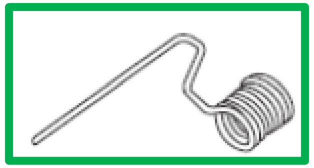
Remove GND leads
Use available probe tip adapters
Some adapters can be soldered directly on board

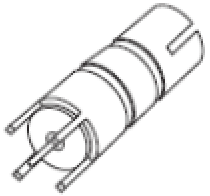
Passive probes typically have 500V max input voltage, but this is true only <200KHz high switching frequency may reduce dramatically the probe loading and BW is limited as well

Make GND as short as possible



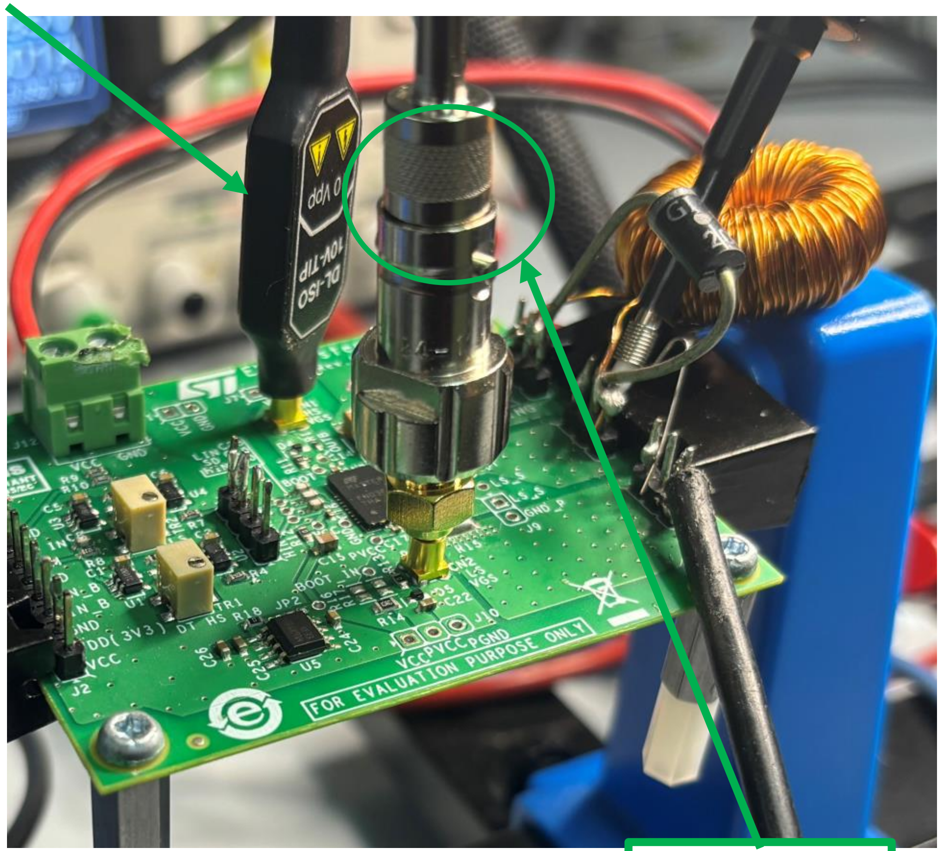




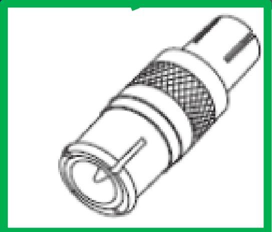


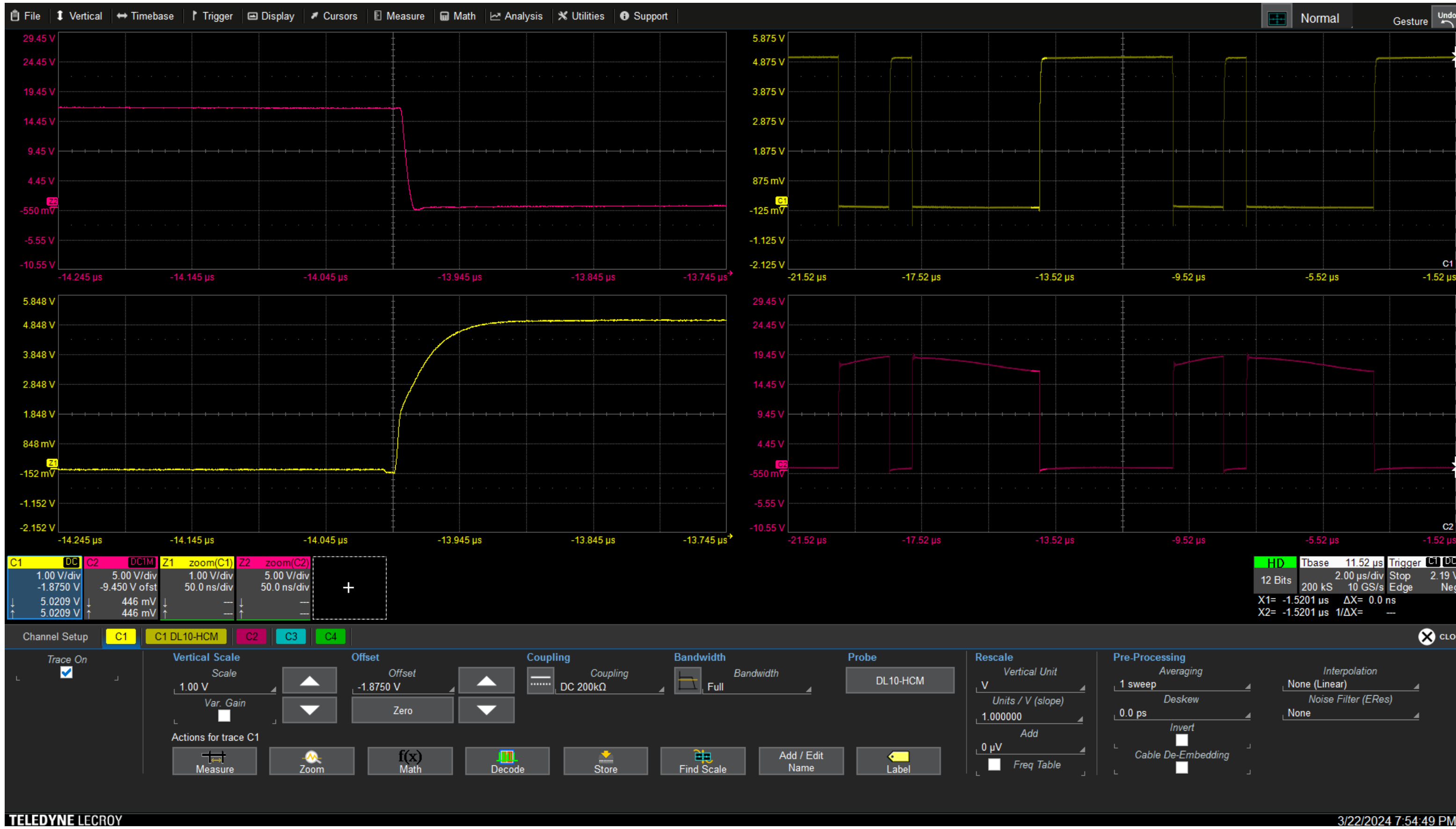
Differential and passive probe with MMCX adapter

Optically isolated probe



Another useful passive probe accessory



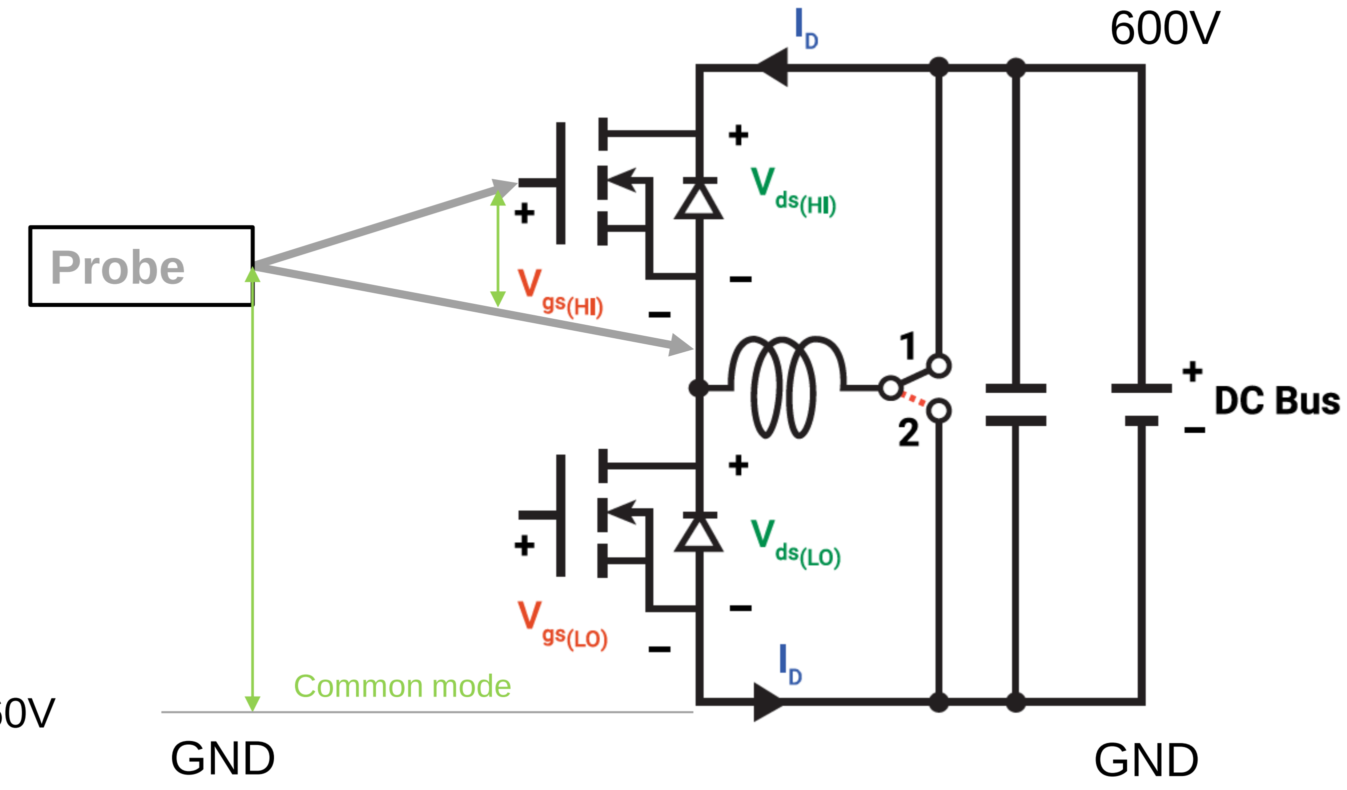


GaN Low-side Gate Drive Comparing four different probes

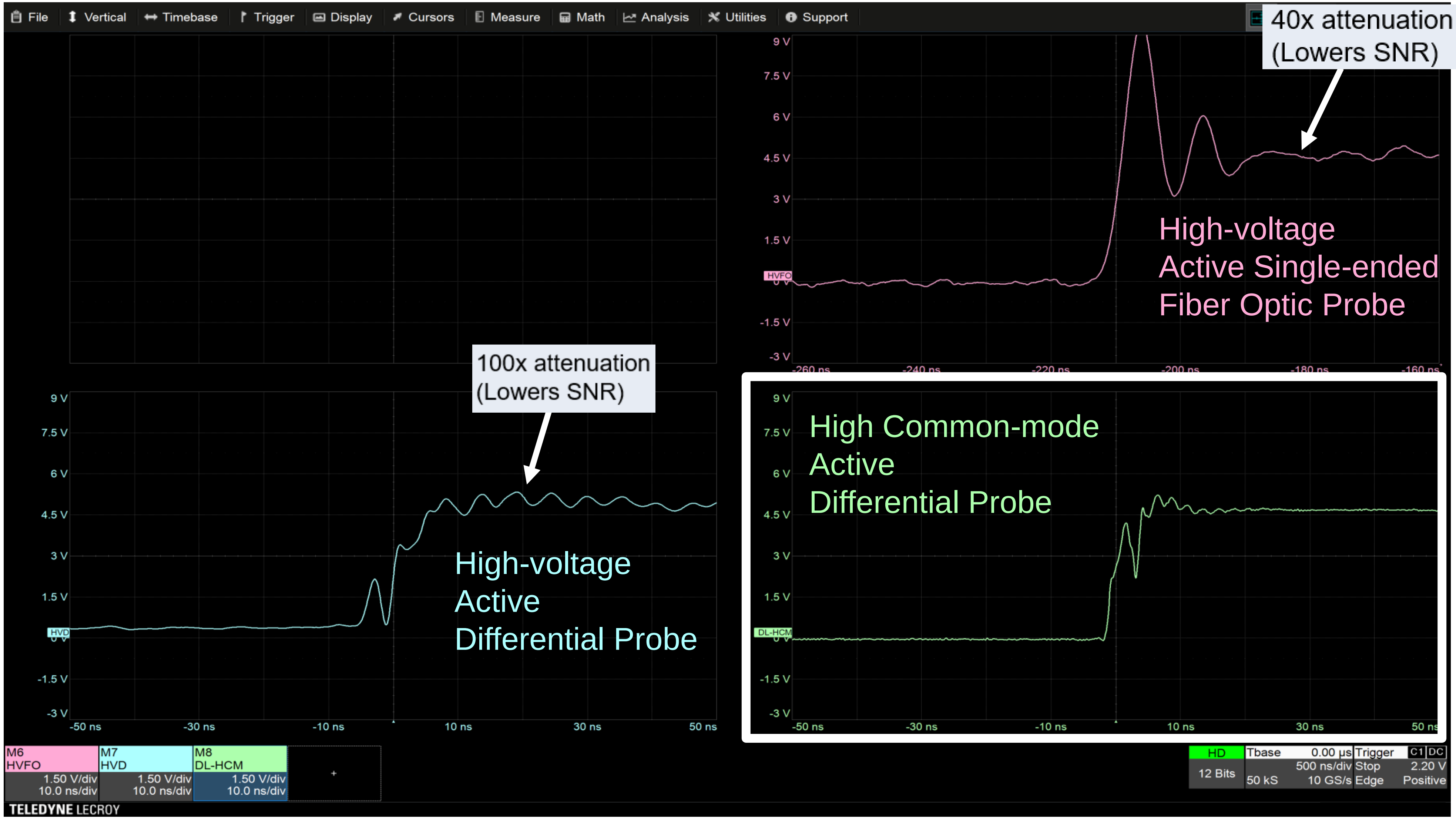
Takeaway: Passive probe suffices for low-side gate measurement

High-side gate

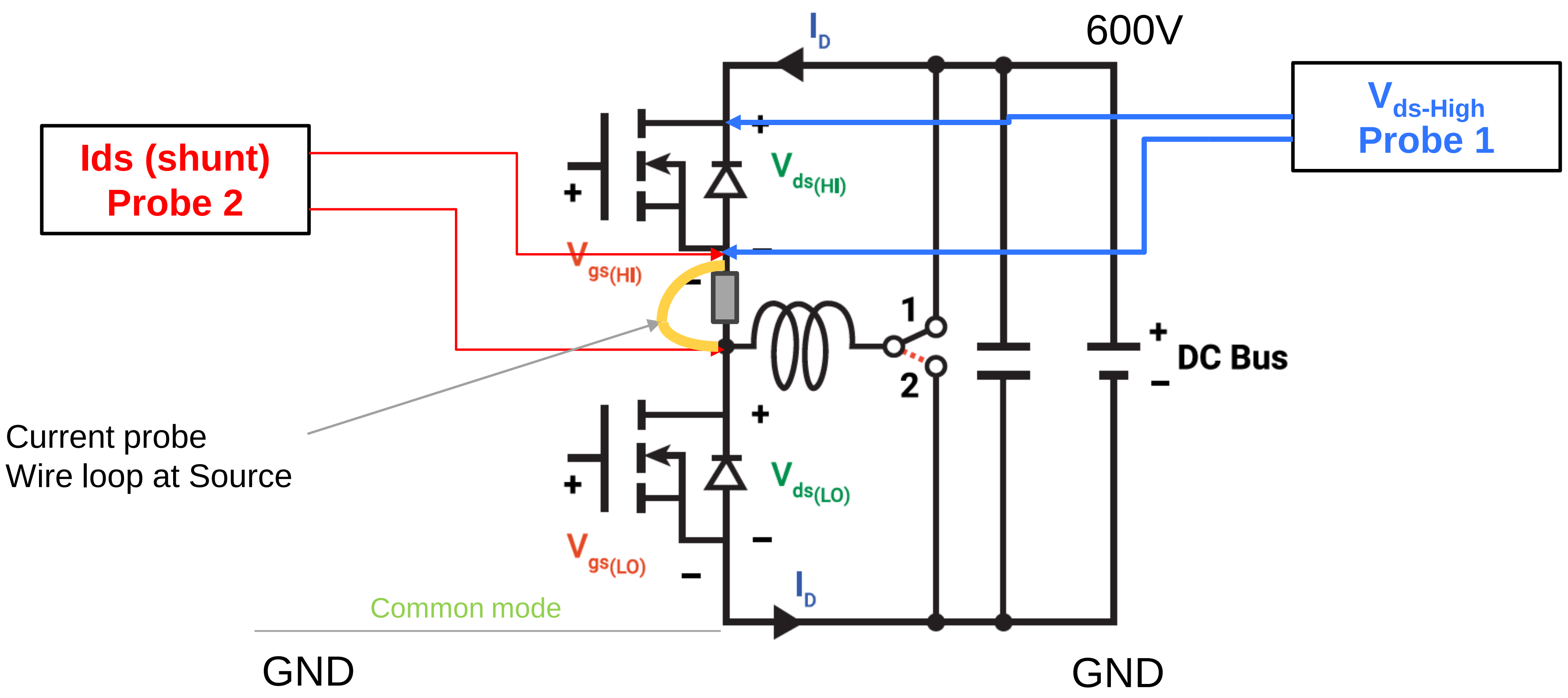
- About $V_{gs(HI)}$:
  - -5 to 15 V signal
  - High common-mode voltage
  - Passive probes can't be used
  - HVD must be used with high attenuation because of the high common mode voltage
  - 2 possible options
    - Optically Isolated probes with low attenuation probe pin
    - Differential probe if CM voltage <60V



High-side Gate Drive Measurements
Comparing three different probes (passive probes are excluded)



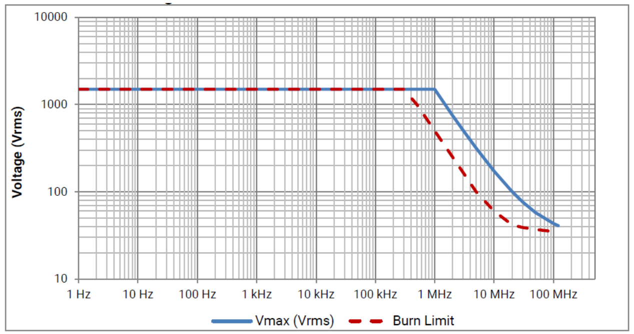
Other signals we need to capture (on both high and low side)



V_{ds} which probe to use?

Can be several hundred volts (Pk-Pk)
High voltage differential (HVD) probes are typically used for V_{ds} measurements, even if not ideal for $V_{ds\text{-}ON}$ because $R_{ds\text{-}on}$ can be few tens of milliohm and even with high currents the voltage drop is small.
Typical attenuation of an HVD ranges from 100x to 500x depending on actual rail voltage.
Remember differential probe specs:

- Pin to pin differential probe and pin to ground common mode Voltage
- High voltage specs drops at higher frequency
- BW is often not a big issue (100 to 400 MHz)



Differential Voltage Range	1500 V (DC + peak AC)
Common Mode Voltage Range	±2000 V (DC + peak AC)
Maximum Input Voltage to Earth	±2000 Vpk (nominal, either input to ground)

I_{ds} can be measured using a current probe or sense resistors or shunt

Current probes can be used if a wire loop can be added on source (major concern is the loop inductance) and have limited BW ≤ 100MHz; <5MHz for currents >300A.
This limitation can be problematic when measuring switching losses, where edges are important.

Often a shunt is used for currents >50A
Sense resistors may be present on test PCB for low currents
HVD are still not ideal because of high attenuation, both probe tips still at high voltage on high side

Optically Isolated probes are often a better choice

- small attenuation tip can be used
- much higher BW than current probes (1GHz)
- floating voltage is not a concern (can be >60KV)
- shunt can be very accurate (0.01% and lower)
- cost may be a limiting factor.

What about $R_{ds\text{-}ON}$

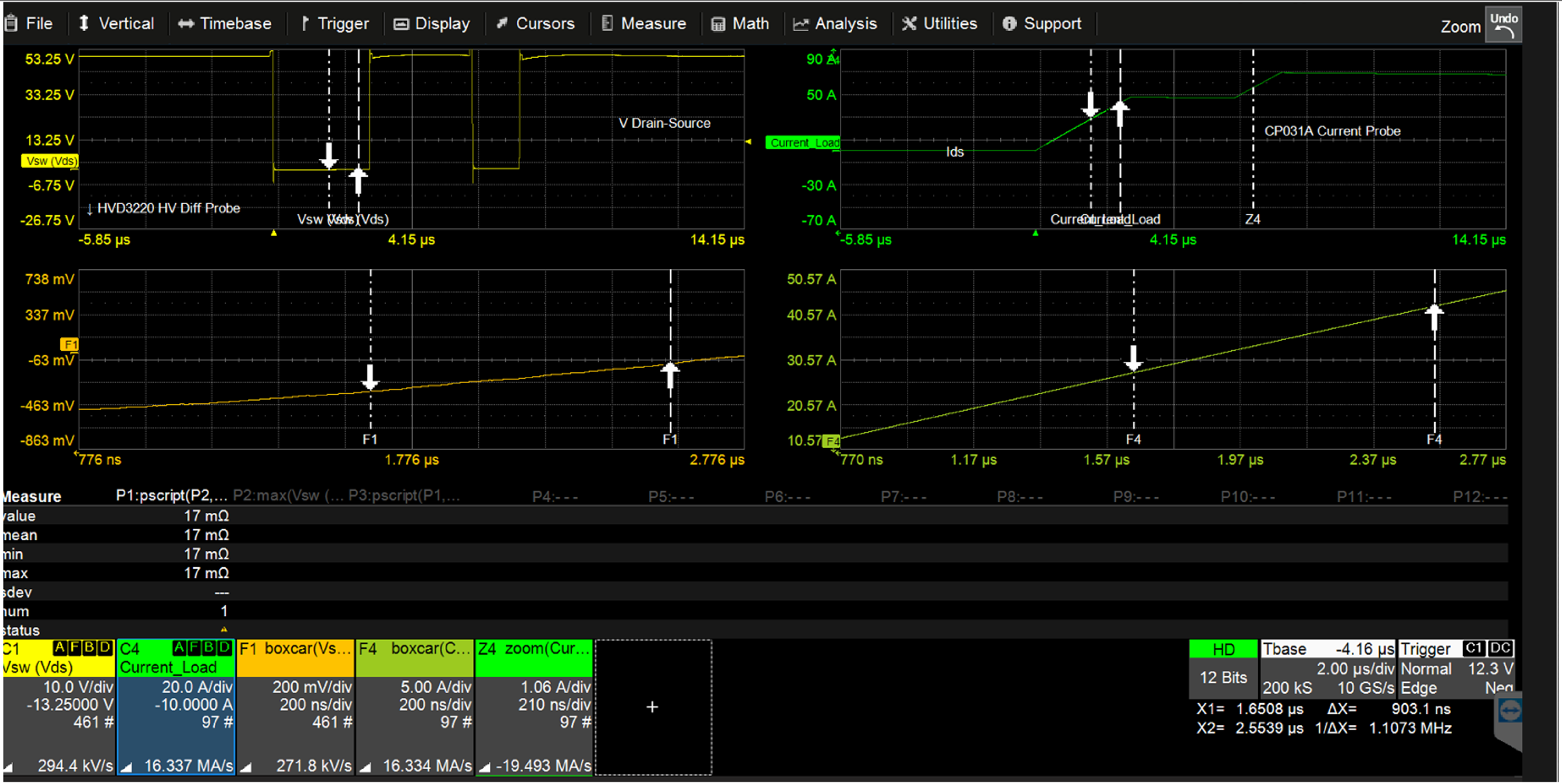
Aspects to consider:

- Attenuation limits vertical dynamic range of DSO
- Noisy environment
- Nonlinear effects (ringing) at turn on do not allow to show real shape of $V_{ds\text{-}ON}$
- Vds id high, then DSO must be set at high Volt/div reducing vertical dynamic range at $V_{ds\text{-}ON}$
- Calculation errors
- Probes accuracy (typically 1%)
- DC Gain accuracy of scopes

What can we do about this?

- Both Vds and Ids during ON period have low frequency content, filtering can be used (box car for example). An oscilloscope with high vertical dynamic range (12 Bit ADC) is important
- Increase verticals bits with ERES filter (80MHZ filter with 10Gs/s sample rate adds 3 vertical bits)
- Double pulse allows a good trigger pointaver, aging is possible.
- Considering R constant use $\delta V / \delta I$ (Vds and Ids slopes) to calculate R across a cursor selectable linear Vds and Ids area

$R_{ds\text{-}on}$ result



There is much more to say, but time is up….If you have any questions please do not hesitate stopping by at our booth?

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