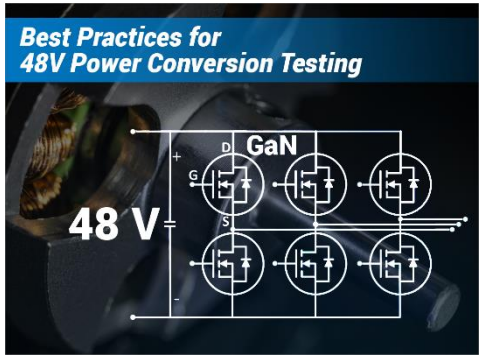
Probe challenges when using an oscilloscope for power electronics measurements

Measurements on power Conversion electronic circuits

Probing challenges electronic engineer may face making measurement on power conversion circuits, particularly at Power MOS Gate, where higher BW is needed.



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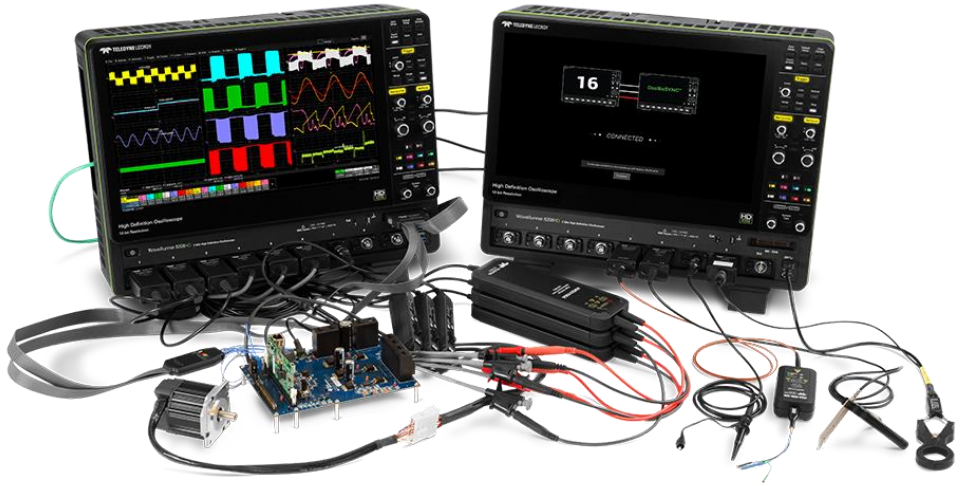
Teledyne LeCroy offers a broad range of oscilloscopes, protocol analyzers and more.



Teledyne LeCroy is distributed in the Benelux by AR Benelux.

General application areas

GaN is displacing Silicon in many applications with benefits to designers and consumers . Thanks to the faster switching time of this active components, we can reach much higher efficiency as well more complexity in the measurements

Types of Voltage Probes Commonly Used in Power Electronics

- Low Voltage
  1. Passive, Single-ended
  2. Active, Single-ended “FET”
  3. Active, Single-ended “Rail”
  4. Active Differential
  5. Active Differential, 60 V Common-mode
- High Voltage “Isolated”
  6. Passive, Single-ended
  7. Active, Single-ended (fiber-optic isolated)
  8. Active, Differential (conventional high attenuation)
  9. Active, Differential Amplifier with matched probe pair (conventional high attenuation)

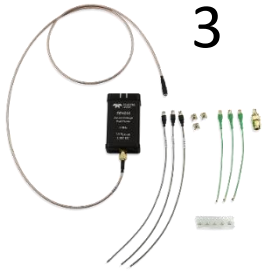
1

PP Series

2

ZS Series

3



RP4030

4

ZD Series

DL-HCM Series ($60\ V_{CM}$)

5

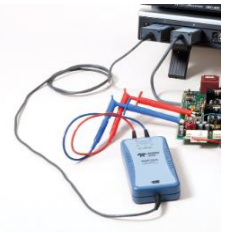
PPE or HVP Series

6

7

HVFO108

8



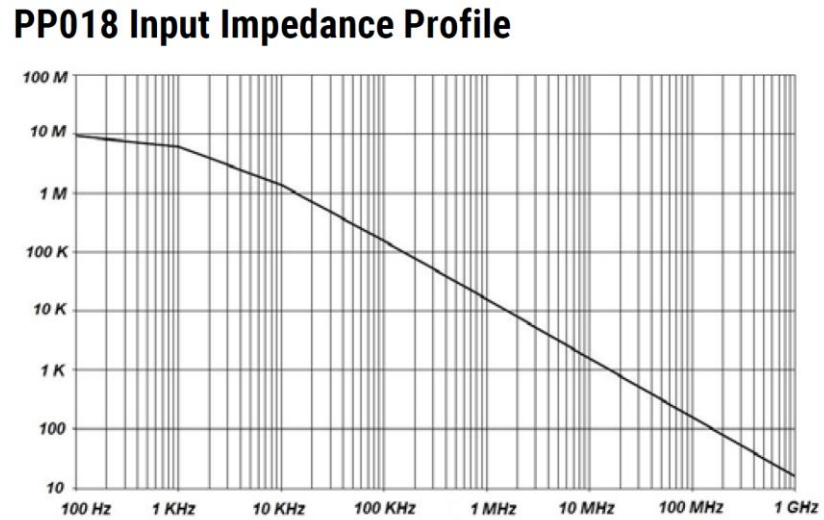
HVD or ADP Series (1-6 kV_{CM})

9

DA1855A + DXC100A

Low Voltage Passive Single-ended Probes

Parameter	Value
Bandwidth	500 MHz
Voltage Range (SE) Voltage Range (DM) Voltage Range (CM)	~400Vpk N/A N/A
Voltage Offset	N/A
Loading	10MΩ || 10pF Z_{IN}=30Ω@500 MHz
Attenuation	10x
CMRR	N/A



- Rugged, reliable, inexpensive
- General purpose use

7 - High Voltage Active Single-ended (Fiber Optic) Probes

Parameter	Value
Bandwidth	150 MHz
Voltage Range (SE) Voltage Range (DM) Voltage Range (CM)	2 to 80V N/A Virtually Unlimited
Voltage Offset	N/A
Loading	1-10MΩ || 34-22pF Z_{IN}=50kΩ@100 kHz
Attenuation	1x to 40x
CMRR	140 dB

- A new topology specifically for measuring small signals floating on a HV DC bus

8 - High Voltage Active Differential Probes

Parameter	Value
Bandwidth	~100 MHz
Voltage Range (SE) Voltage Range (DM) Voltage Range (CM)	N/A 2kV to 8kV 1kV to 6kV
Voltage Offset	1kV to 6kV
Loading	10MΩ || 2.5pF Z_{IN}=1kΩ@100 MHz
Attenuation	50-2000x
CMRR	85 dB @ 60 Hz 65 dB @ 1 MHz

- Excellent all around choice for many applications, but has its limitations
- Some models/brands perform better than others

Gate-drive Measurement Results

Some probes perform better than others in this application, and it is important to understand what impact the probe might be having on your measurement and why.

Low-side Gate Drive Measurements - Comparing four different probes

Low Voltage 10:1 Passive Single-ended Probe

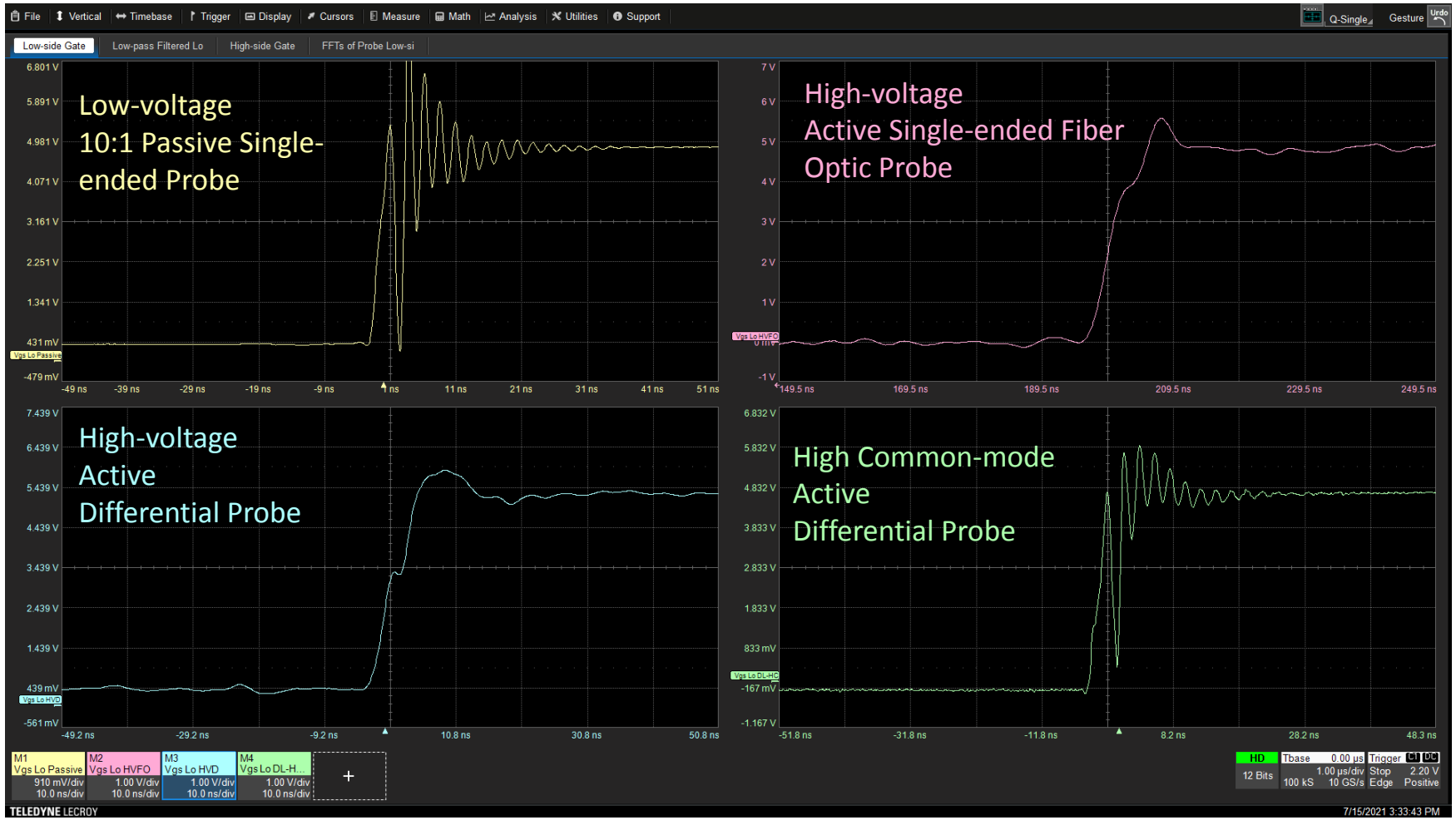
Note: this probe can be safely used to probe the low-side gate signal provided the board reference can be tied to oscilloscope ground, BUT this type of probe may be prohibited in your company's power electronics lab or your circuit might not want board reference connected to ground.

High Voltage Active Single-ended Fiber Optic Probe

High Voltage Active Differential Probe

High Common-mode Active Differential Probe

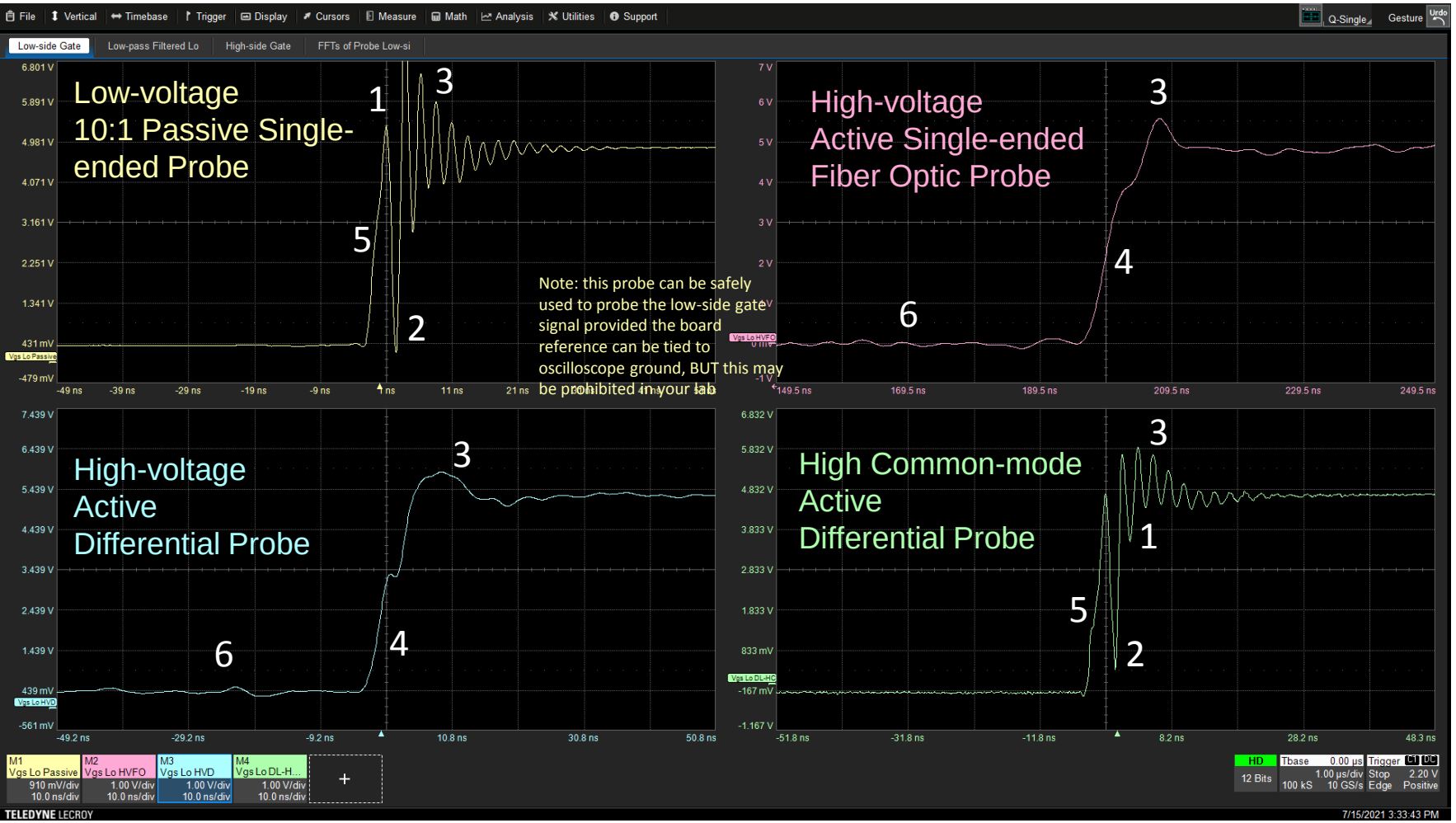
Low-side Gate Drive Measurements - Comparing four different probes



Low-side Gate Drive Measurements - Questions You May Have

1. Why is their so much ringing?
2. Why is their such a pronounced dip?
3. Why is their overshoot on the rising edge of the signal?
4. Why some probes show better signal fidelity?
5. Why do 2 of those probes have the fastest rise times?
6. Why 2 of those have a not flat top and base?
7. How does probe loading factor impact the measurements?

Low-side Gate Drive Measurements – related displayed signals



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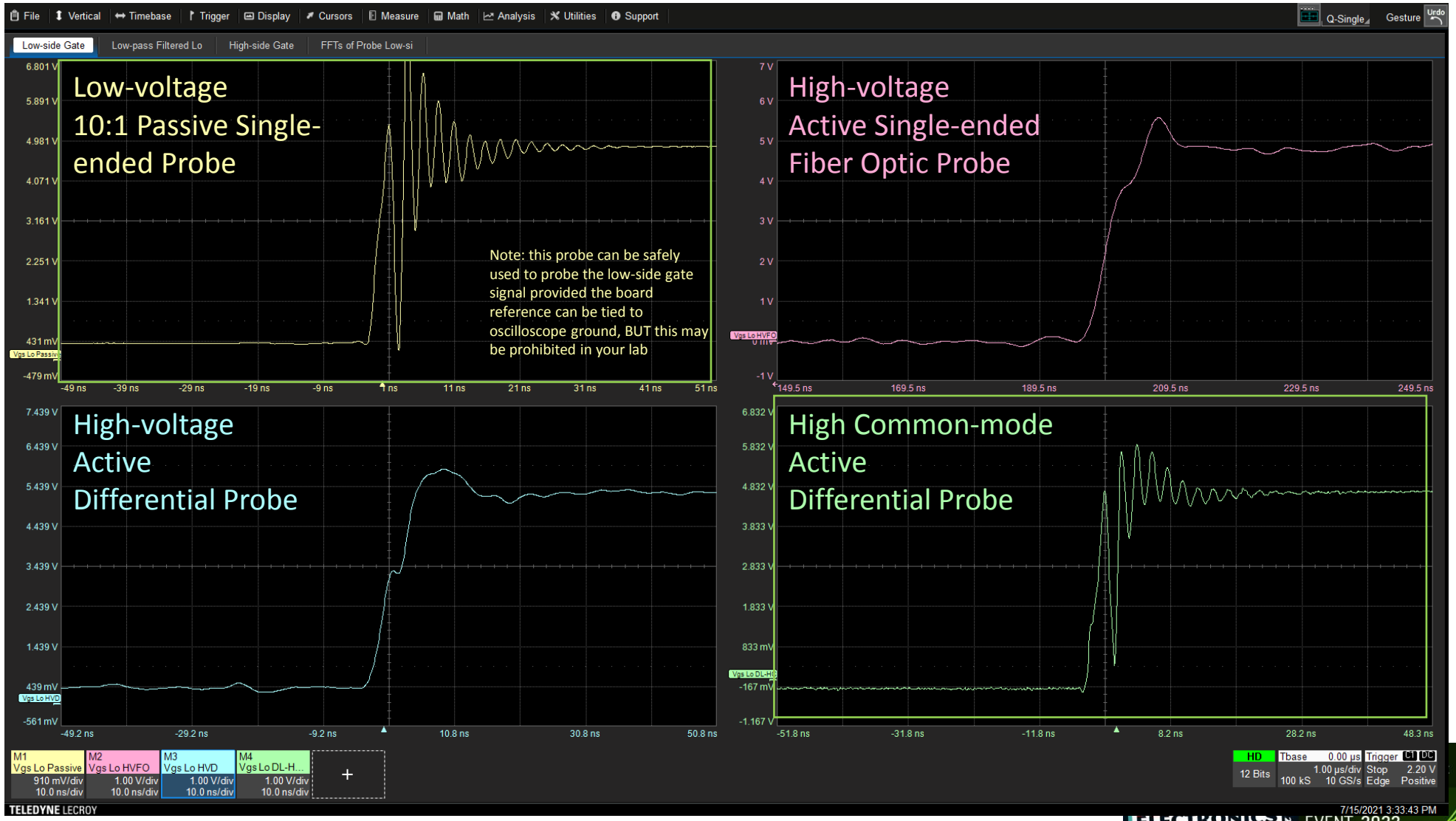
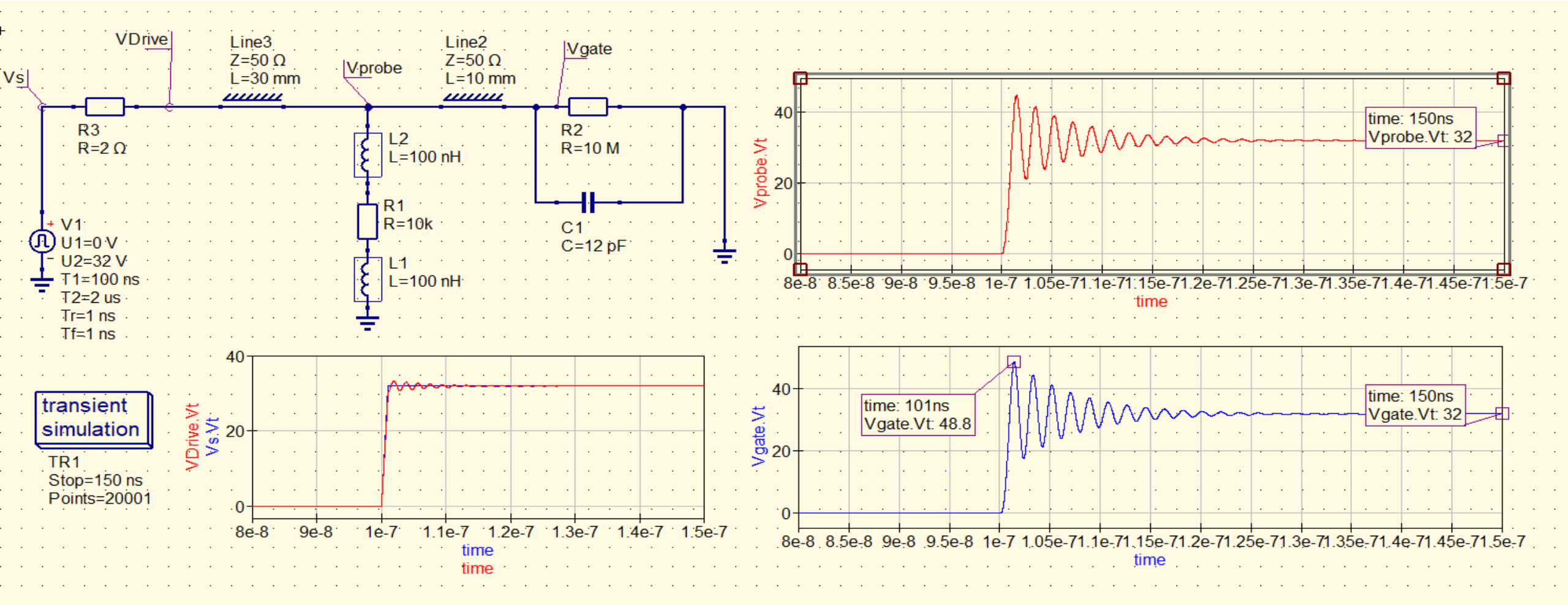
Low-side Gate Drive Measurements - Ringing

Question: Why is their so much ringing when using the Passive and High Common-mode probe?



Impedance mismatch reflections: low Z source – high Z load Circuit Simulation

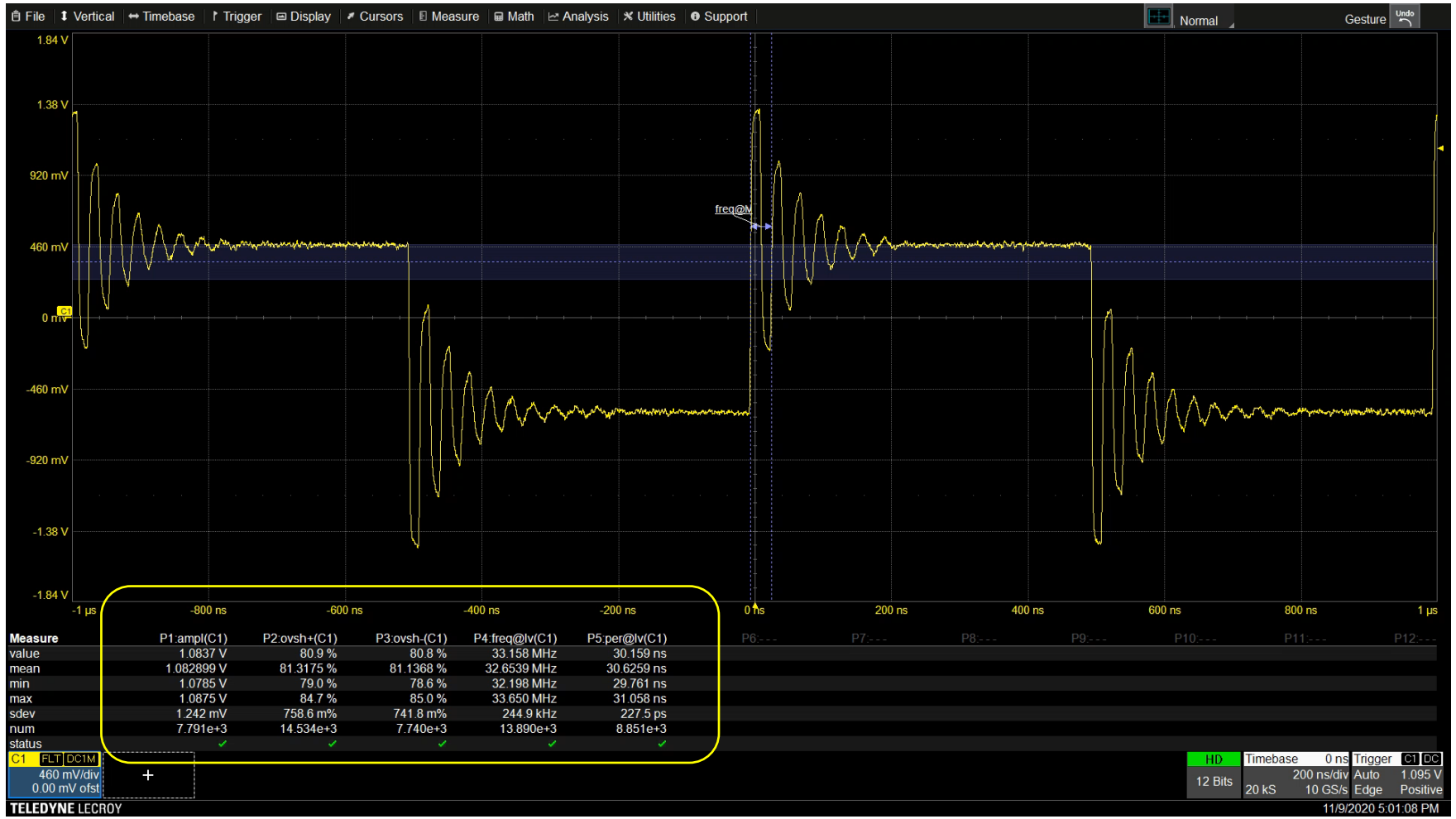


The signal path and local impedance.

When a signal, traveling on a interconnection, sees an instantaneous impedance change, a fraction of the signal will be reflected back and the rest will continue down the interconnection.

This physical effect is the source of most signal-quality problems on high-speed signals and is now happening in power conversion circuits using fast switching circuits (GaN Power mos)

The signal path. Impedance simulation on DSO (5-50-1M)



Source: 5ohm AFG

Path: 50ohm coax cable

Load: 1Mohm DSO

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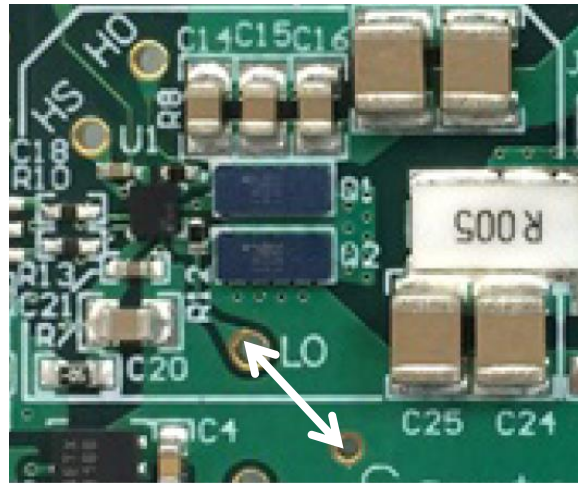
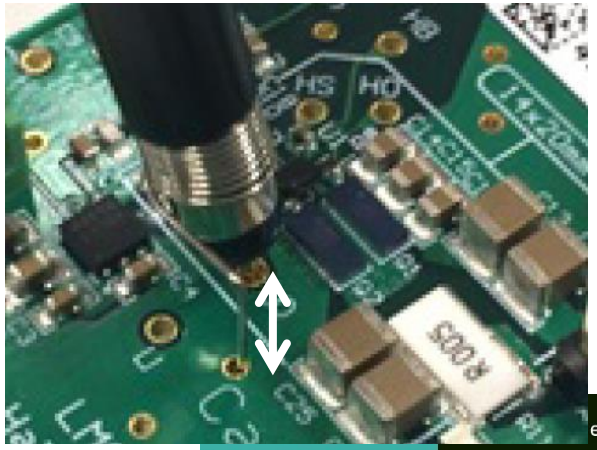
Ringing

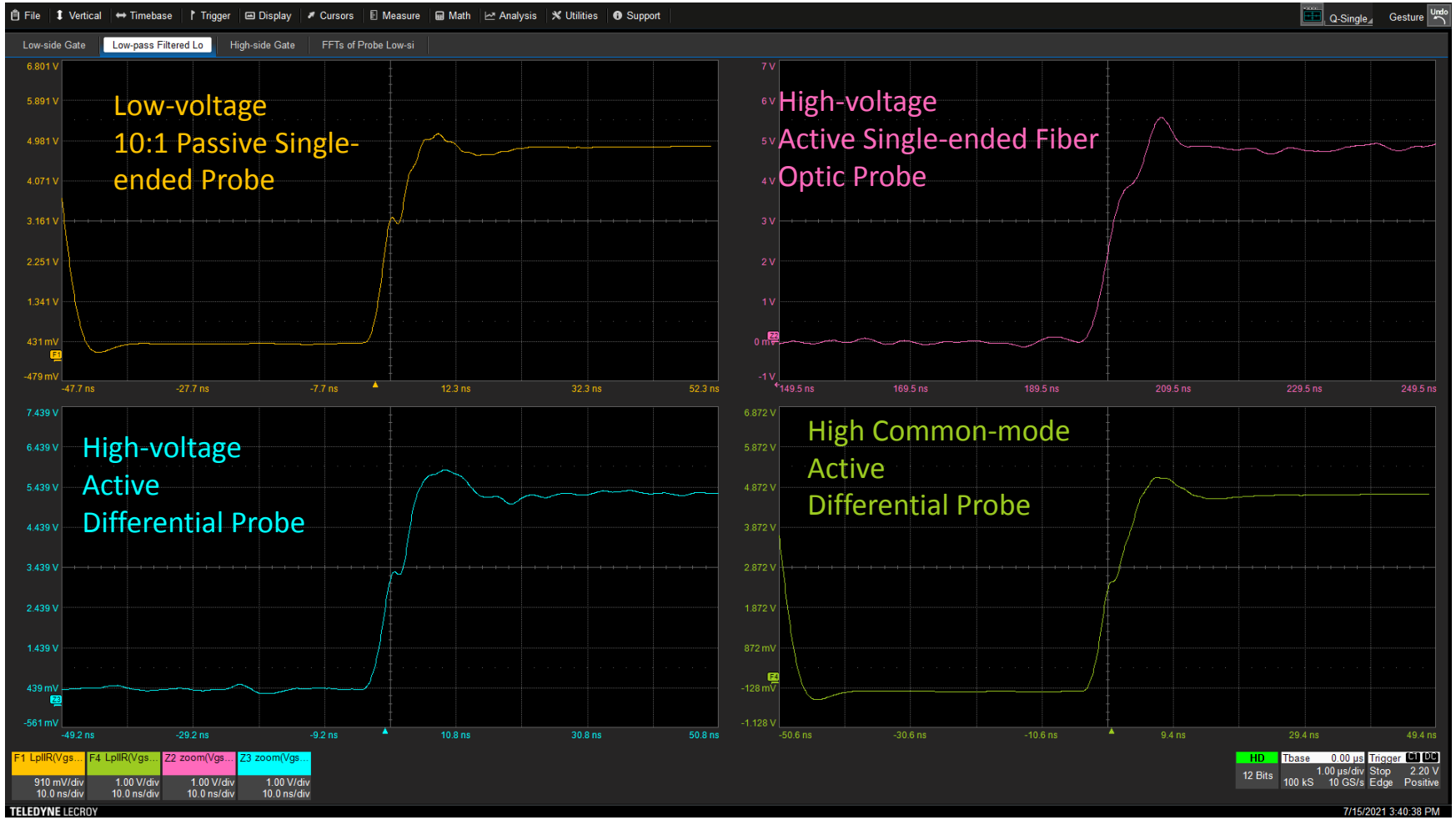
- Question: Why is there so much ringing when using the Passive Probe and High Common-mode probe?





- High BW probes may not filter the ringing
  - passive probe: 500MHz
  - DL-HCM: 1GHz
  - HVD and HVO probes < 150 MHz
  - The ring frequency is ~350 MHz (~3 ns period, proportional to Gate driver to Gate-probing point distance)
- Probing Point
  - test point to ground reference distance should be as short as possible
  - There is a loop formed by the ground connection and signal connection
- **The signal also have native ringing (path impedance change)**

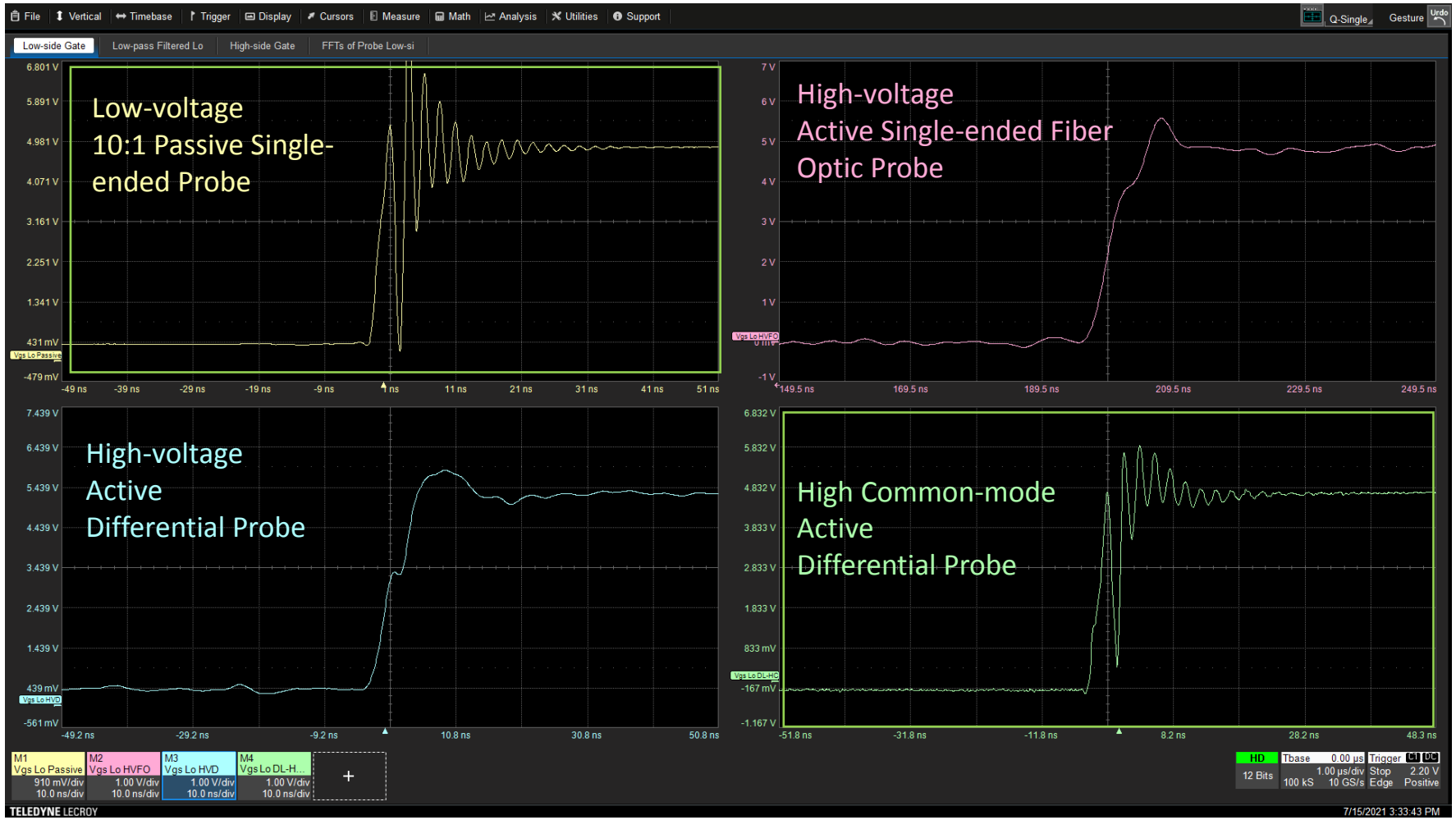
Results with 150 MHz Bandwidth filter



Ringing is no longer visible when BW filter is applied

Pronounced Dip in Rising Edge

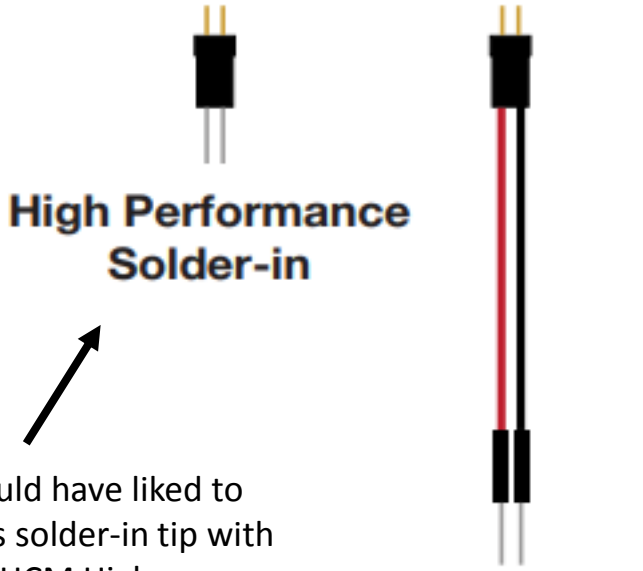
Why is their such a pronounced dip in the rising edge on the Passive Probe and High Common-mode probe?



Pronounced Dip in Rising Edge

- Why is their such a pronounced dip in the rising edge on the Passive Probe and High Common-mode probe?

- Transient pickup from the high-side device switching moments after the low-side device switches
- Limited probe CMRR of probes
  - CMRR typically drops with frequency
  - Better results can be achieved NEW DL-ISO probe (HBW optical isolated)
- Well designed test point will minimize this effect
  - minimize “antennas” created by the probe signal and board reference test point probe connections.
  - Coaxial and/or short distance connections are best

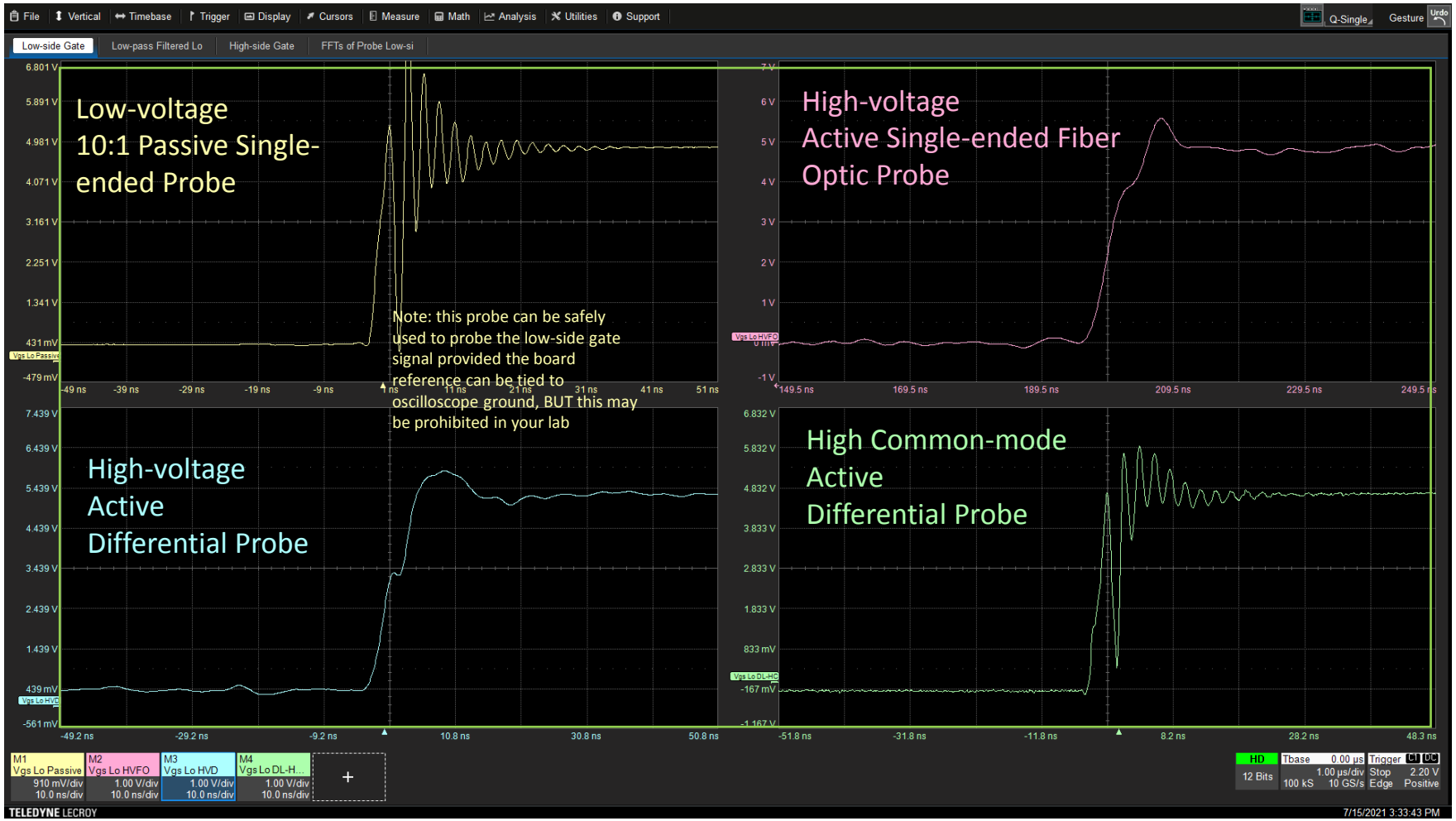


We would have liked to use this solder-in tip with the DL-HCM High Common-mode probe

But we had to use this tip instead due to geometry of test points

Overshoot

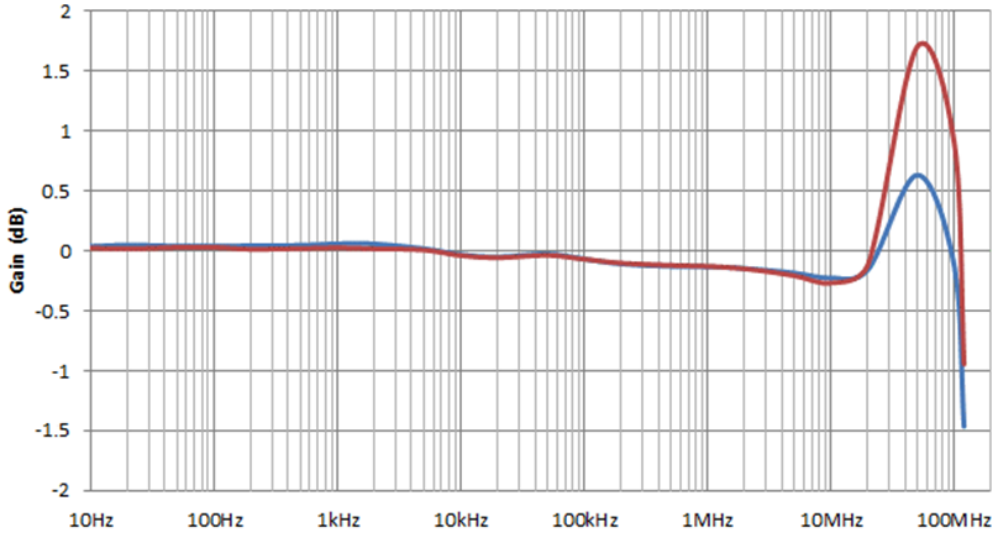
Why is there overshoot on the rising edge of the signal?



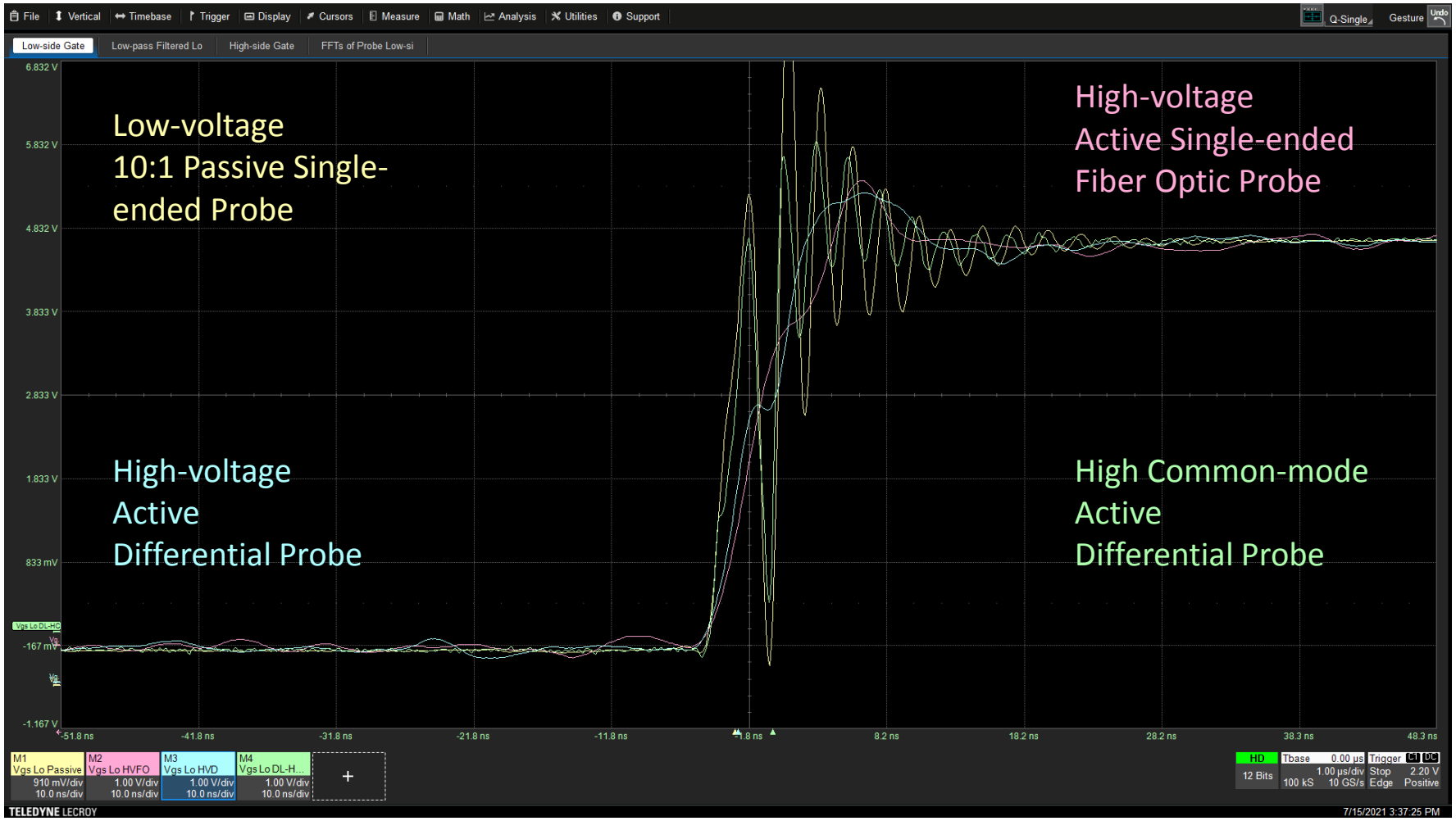
Overshoot

- Why is there overshoot on the rising edge of the signal?

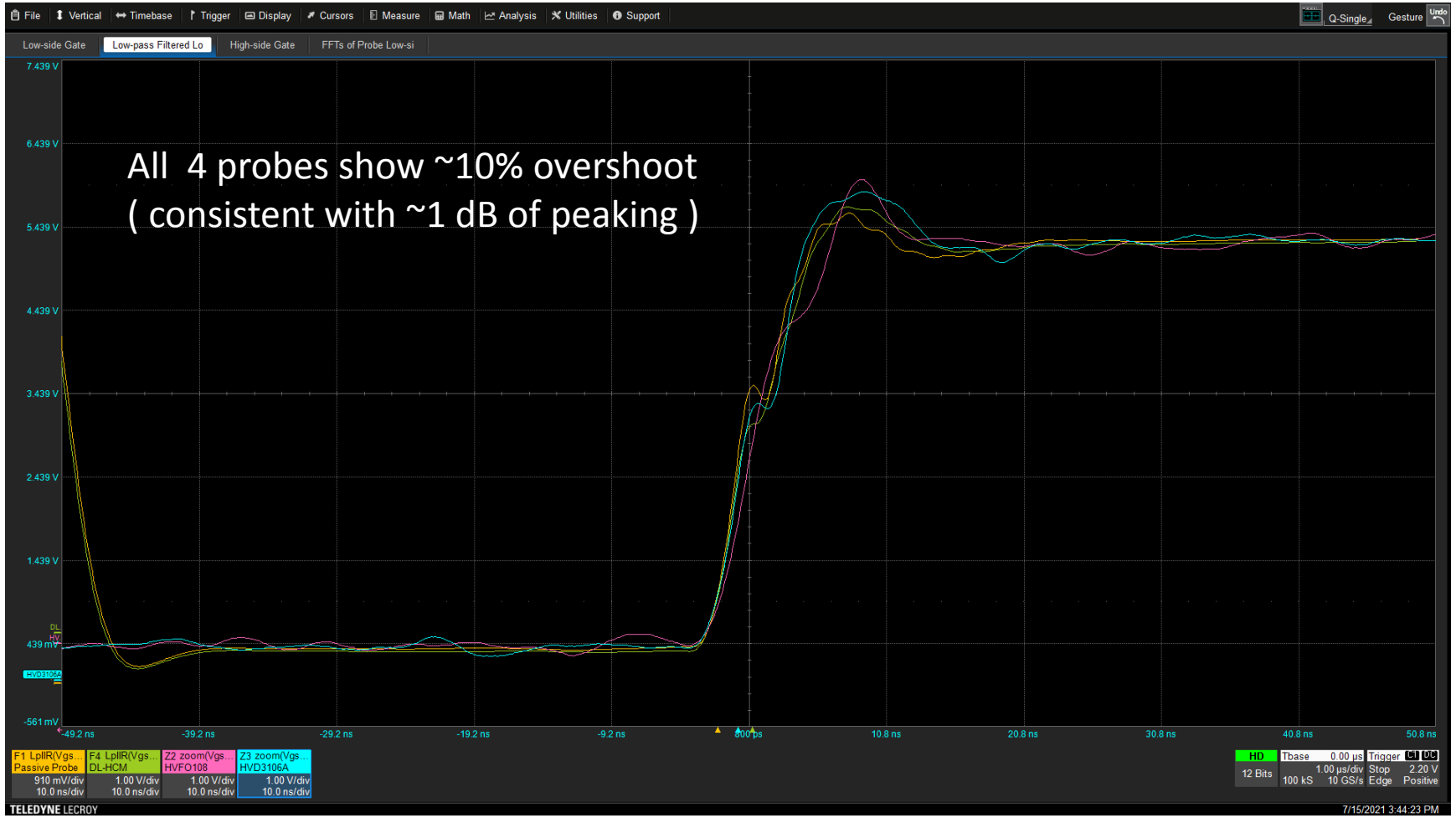
- Probes intrinsic peaking
  - All probes show a Typical “peaking” effect near the probe’s BW limit
  - 1 dB = 10% overshoot
- Can happen that signal has intrinsic overshoot, not in this case



This is the same set of signals as before, now overlaid



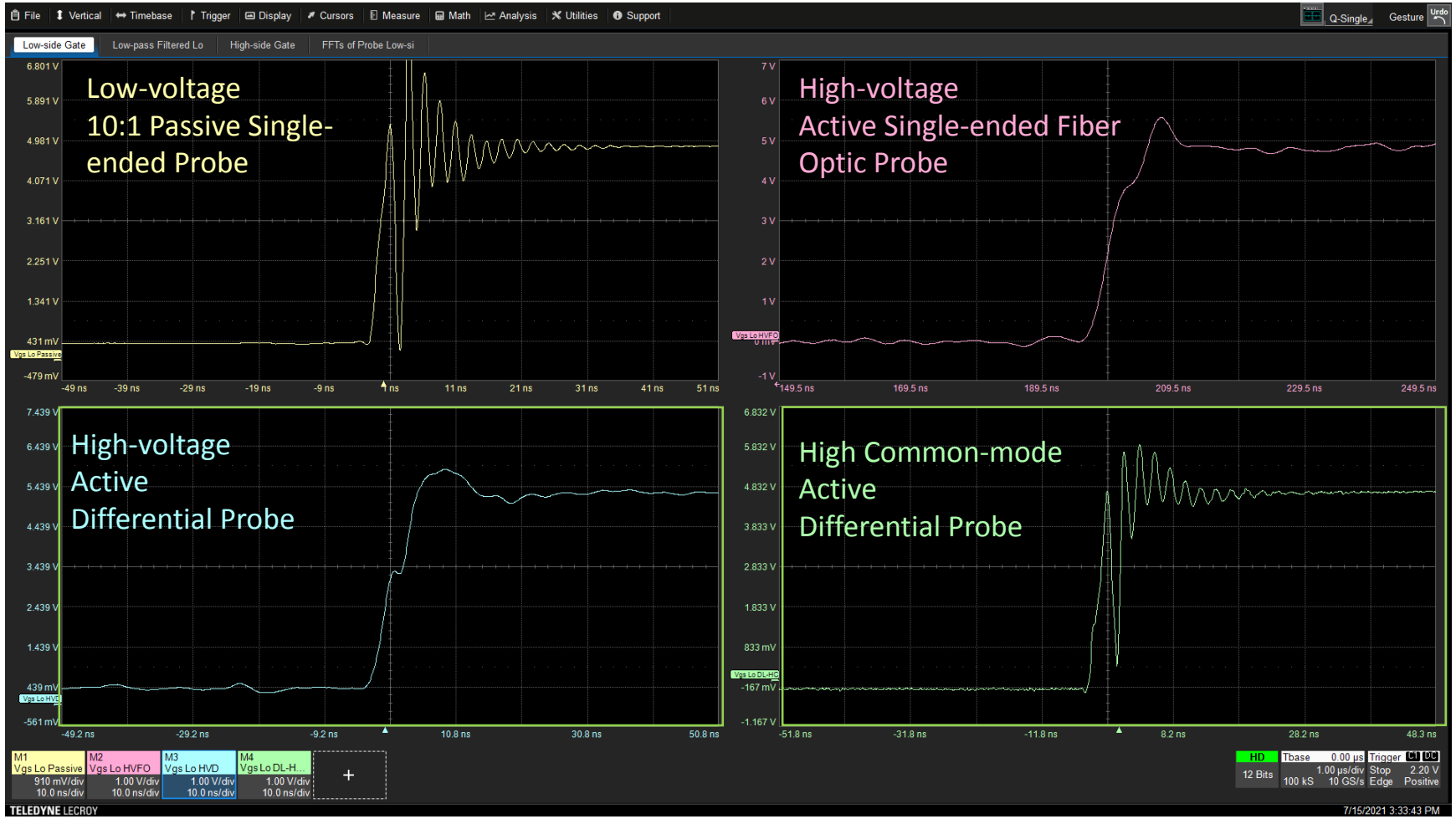
150 MHz filter applied



Low-side Gate Drive Measurements - Rise Time and Signal Fidelity

HVD and HVO probes seem to have the best signal fidelity on the rising edge, and have the fastest rise times, why?

Because the lower bandwidth probes filter out signal content and higher-bandwidth probes, by design, have faster rise times.



Top and Base Flatness

Why HVD and HVO probes do not have a very flat top and base?

Top and Base Flatness

Why do the High Voltage (Active, Single-ended) Fiber Optic Probe and the High Voltage Active Differential Probe have a not very flat top and base?

- Noise performance of the probes
  - Passive (10x attenuation) probes in general have relative lower noise
  - HV Probes have high attenuation, then more noise
    - High Voltage Differential Probe – 50x attenuation (in this case)
    - High Voltage Fiber Optic (HVFO) Probe – 20x attenuation (in this case)
    - DL-HCM – 7.8x attenuation (in this case)
  - HVFO Probe has higher inherent noise floor
  - DL-HCM probe has very inherent noise floor

- CMRR performance of some probes
  - HVD Probes have good CMRR, not as good as the DL-HCM at higher frequencies
  - HVFO probe worse noise dominates its low CMRR benefits.

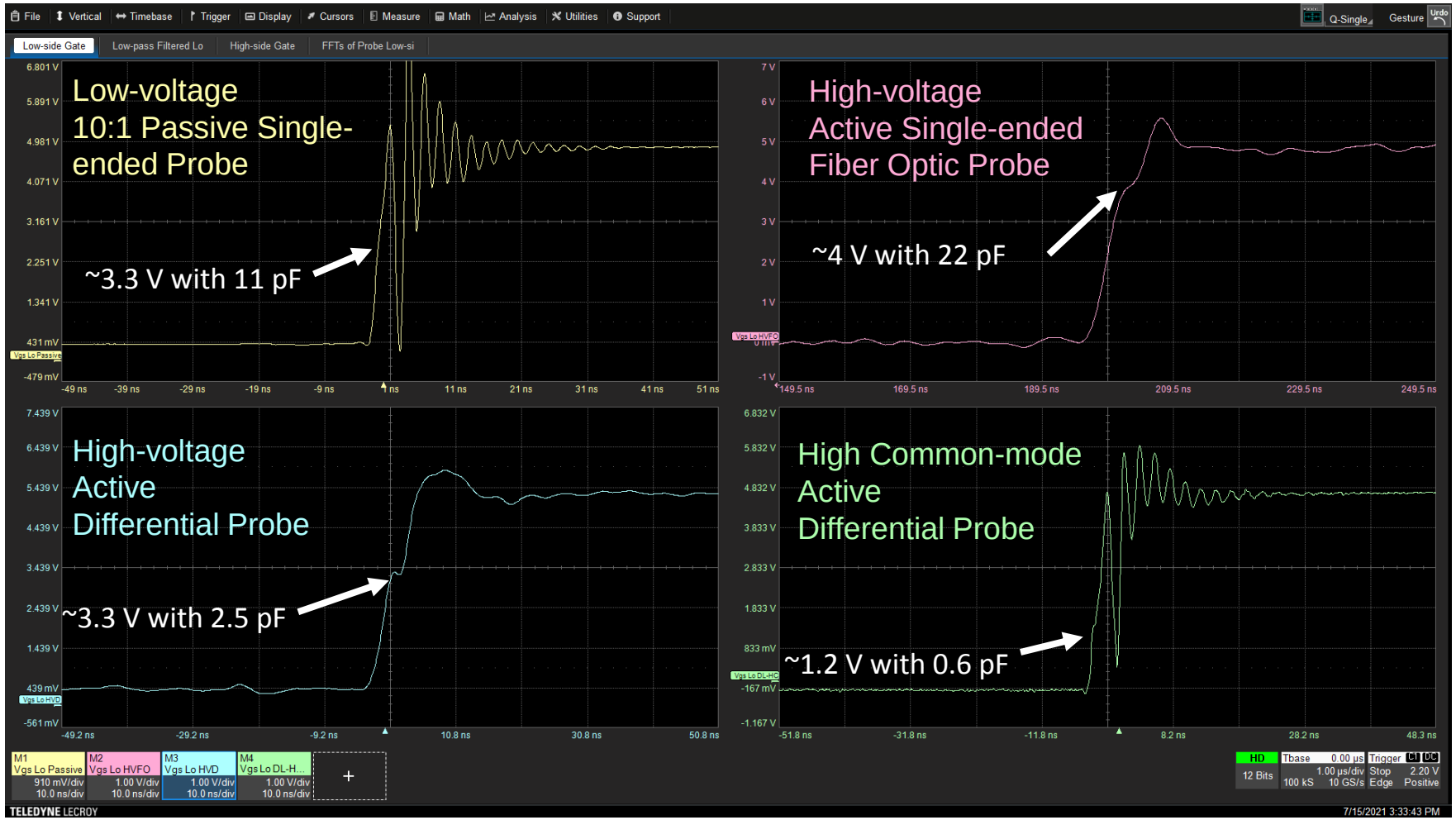
Loading

- How does probe loading factor into the measurements?
- We do not see a visible loading effect on this circuit, mainly because of the low source impendence

We see instead an effect on Miller plateau caused by probe capacitance

- Low Voltage 10:1 Passive Probe (10 MΩ // 11 pF)
- High Voltage Fiber Optic Probe (10 MΩ // 22 pF for 20x tip)
- High Voltage Differential Probe (10 MΩ // 2.5 pF)
- High Common-mode Differential Probe (200 kΩ // 0.6 pF)

Miller plateau correlation to probe tip capacitance



High-side Gate Drive Measurements

You must not use these probes on the high-side – damage to yourself, the probe, the DUT, and the oscilloscope is possible. Also, don't "float the scope" – it's not safe and measurement quality will likely degrade.

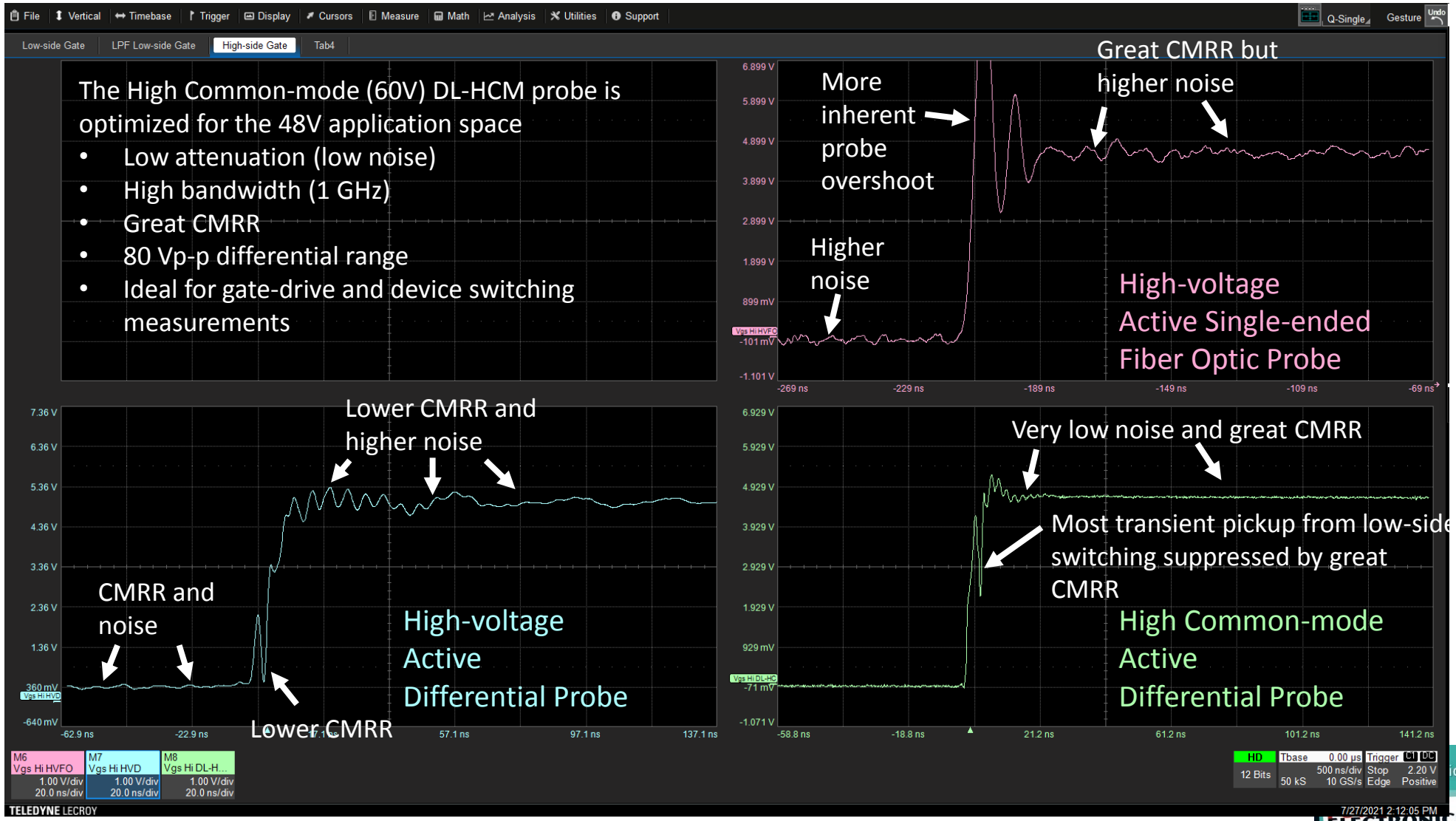
Low Voltage
10:1 Passive Single-ended Probe

High Voltage
Active Single-ended
Fiber Optic Probe

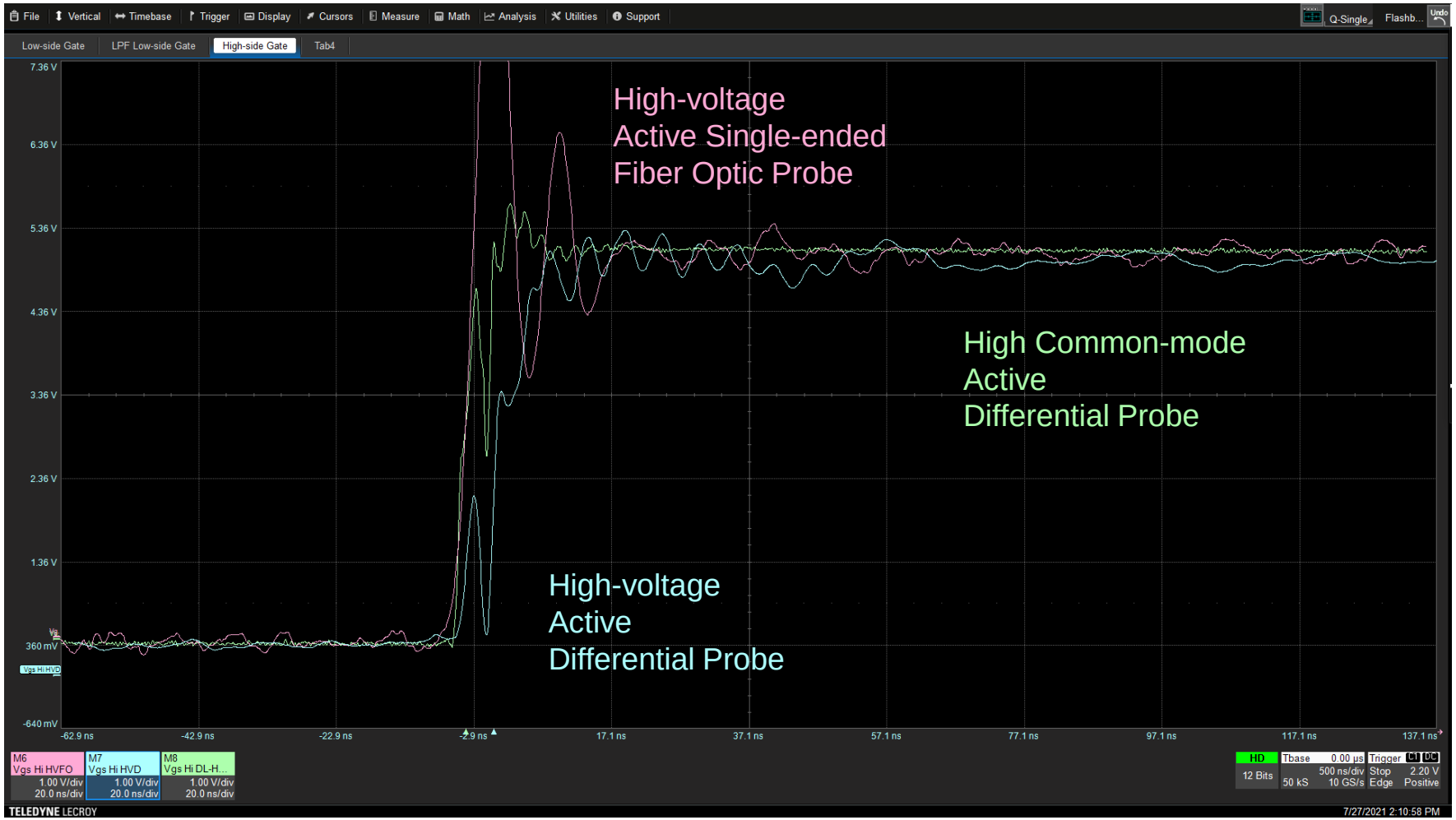
High Voltage
Active
Differential Probe

High Common-mode
Active
Differential Probe

High-side Gate Drive Measurements: same as lower side, but Passive probe can't be used



High-side Gate Drive Measurements – Overlaid traces



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Conclusions

- An ideal probe does not exist
  - All probes have a BW limit, loading capacitance, connection leads
  - Use the one best suited for your circuits and application
  - What you see on DSO display is always the signal present on your circuit, but modified by probe's BW, input capacitance and loading
  - Peaking is an intrinsic effect of any probe, just verify is not > 1dB
- Ringing is often caused by impedance mismatch between Gate driver and Gate high impedance
- While ringing frequency is proportional to the driver to MOS-Gate distance

Thanks for your attention

Find us at booth 30

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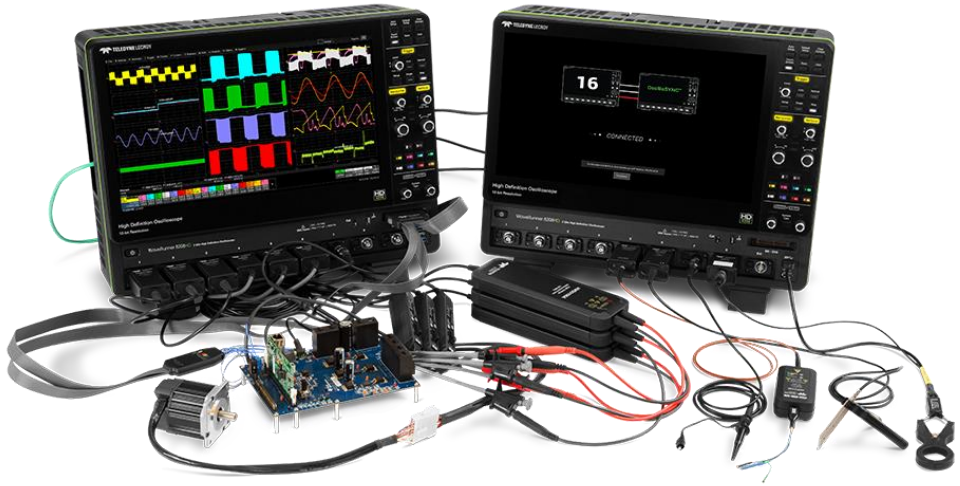

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