Measurements of GaN Application to Avoid Influences of Parasitic Components

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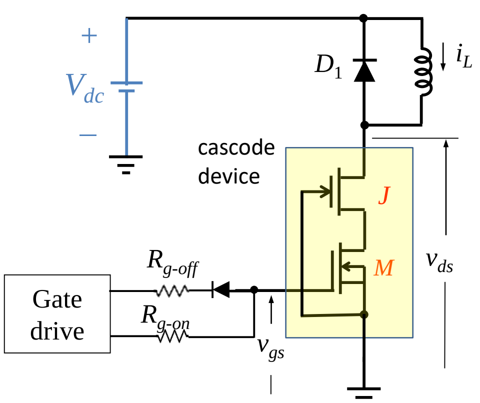
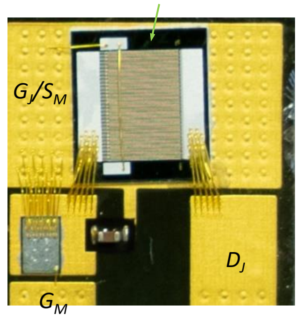
Test Circuit with d-mode GaN and Si MOSFET Cascode

FEEC



- *J* is 120mm NYCU d-mode GaN
- *M* is a low-voltage Si MOSFET in the package
- V_{gs} is a double-pulse gate-source voltage applied to Si MOSFET with $R_{g\text{-}on}$ = 10 Ω, $R_{g\text{-}off}$ = 4.7 Ω.
- Scope bandwidth is 1 GHz

120mm d-mode GaN



Si MOSFET

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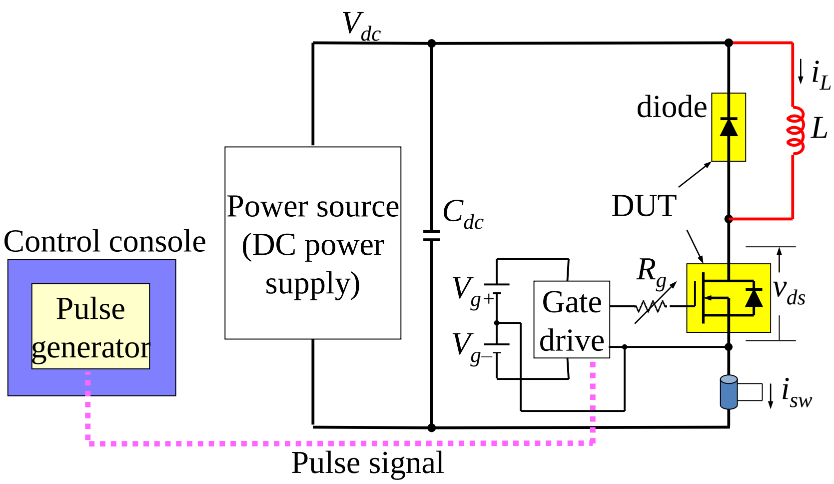
Double Pulse Tester for Device Characterization



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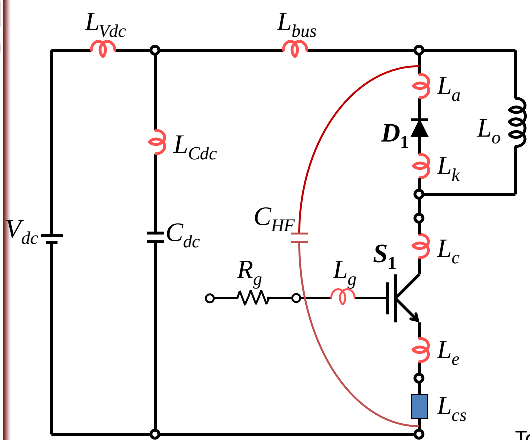
Minimize Loop Inductance with a High-Frequency Low-Inductance Bypass Capacitor



$$L_{loop} = L_a + L_k + L_c + L_e + L_{cs}$$

To minimize loop inductance, the layout parasitic needs to be nearly zero. A high-frequency low-inductance is normally added to bypass bulk capacitor and bus bar inductances. In this case

Current Sensing

- Response time needs to match with the voltage probe
- More accurate current sensors tend to add more loop inductance
- DC type is better than AC type, which does not reset to zero in the next cycle
- Typical current sensors in device characterization are found
  - Rogowski coil – AC type, minimum parasitic inductance, slow response
  - Pearson CT – AC type, inject significant parasitic inductance, fast response
  - Non-inductive current viewer (T&M current shunt) – DC type, inject some parasitic inductance, fast response

Rogowski Coil Specs and Features

Model	Output (mV/A)	Time Domain Parameter		Frequency Domain Parameter	
		Peak Current (A)	**Peak di/dt** (kA/µs.)	**3dB Low Freq.** (Hz)	**3dB High Freq.** (MHz)
CWT015	200.0	30	2.0	116.0	30
CWT03	100.0	60	4.0	66.5	30
CWT06	50.0	120	8.0	32.0	30
CWT1	20.0	300	20.0	9.0	30
CWT3	10.0	600	40.0	6.2	30

Power Electronics Measurements (PEM), www.pemuk.com

Features:
- Ease of installation and inserting into any terminal without introducing much parasitic inductance
- Good linearity (±0.05%)
- Reasonably wide bandwidth, but not fast enough for WBG device switching characterization

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Pearson Current Transducer

Model	Output (V/A)	Time Domain Parameter			Frequency Domain Parameter			
		Max. Peak Current (A)	**Droop** (%/msec.)	**Rise Time** (nsec.)	**Max. RMS Current** (A)	**3dB Low Freq.** (Hz)	**3dB High Freq.** (MHz)	**I/f** peak amps (/Hz)
2877	1.0	100	200	2	2.5	300	200	0.0025
6585	1.0	500	300	1.5	10	400	250	0.008
150	0.5	1,000	20	20	15	40	20	0.07
6595	0.5	1,000	100	2.5	20	100	200	0.03
410	0.1	5,000	60	20	50	120	20	1.7

Features:
- Wide bandwidth
- Fast rise time
- Double EMI shielding
- High peak current
- Problem with the size (thickness), which creates significant parasitic inductance

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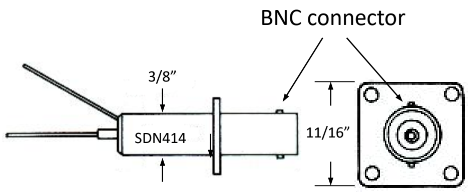
Non-inductive T&M Current Viewing Resistors

2W SDN-Series

Model	*R* (Ω)	Pass band (MHz)	Rise time (ns)	E_{max} (J)
SDN-414-01	.01	400	1	6
SDN-414-025	.025	1200	0.3	3
SDN-414-10	.1	2000	0.18	1



Note:

1. The CVR is non-inductive, and the bandwidth is superior, even better than the scope probes
2. Pass band is limited by the skin effect in resistive element

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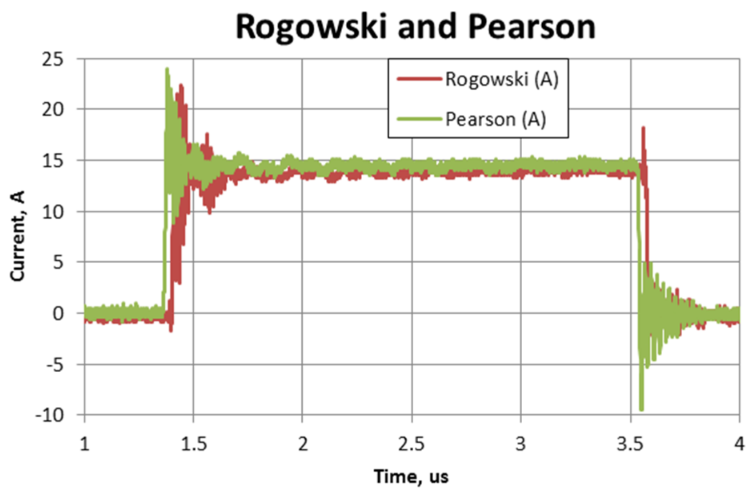
Measurement Results Comparison Between Rogowski Coil and Pearson CT



Note: Visible delay response with Rogowski coil

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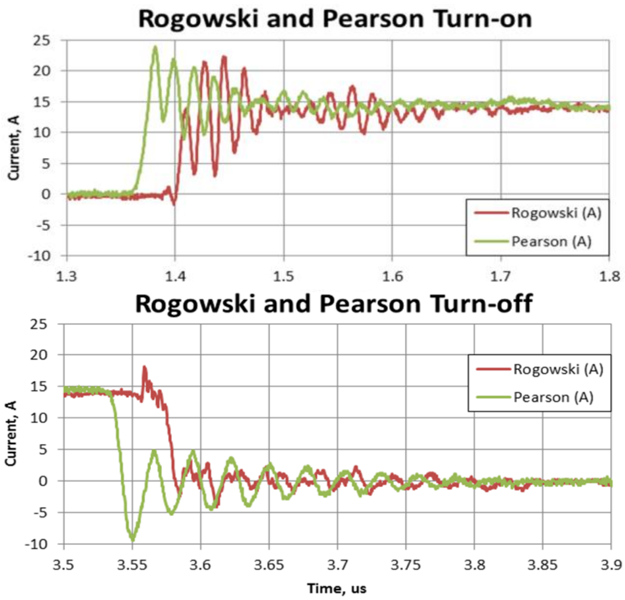
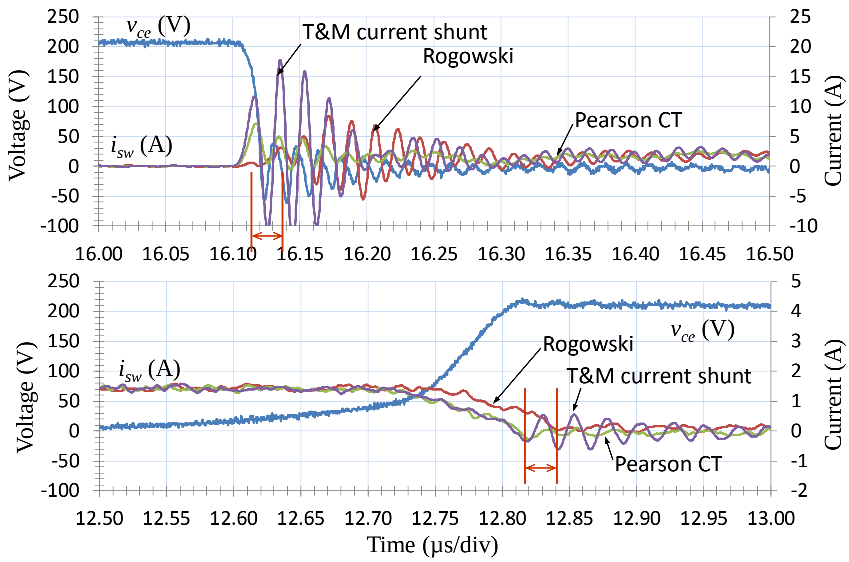
Comparison Between Rogowski Coil and Pearson CT



- Approximately 30ns delay with Rogowski coil during current rise and fall conditions.
- Significantly smaller first peak with Rogowski coil

Comparison Between Three Different Current Sensors

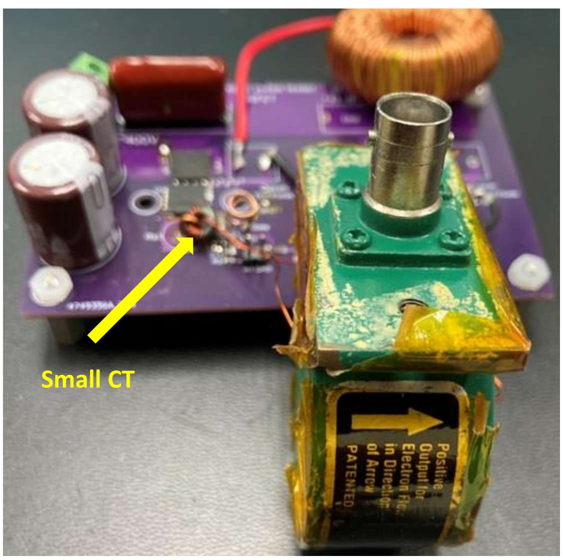


- T&M CVR shows fastest response
- Rogowski delay is >20ns, and the first peak magnitude is significantly lower, not good for WBG devices.
- Pearson CT response agrees with T&M CVR but with a slightly lower magnitude.

Summary of Current Sensing Devices

- **T&M current shunt is most preferred, but layout is quite challenging. Once it's mounted, it's difficult to change the setup.**
- **Rogowski is most convenient, but its measurement results are not always trustable due to delay response and noise coupling.**
- **Pearson CT is good enough for most devices, but its mounting is very challenging. Use of another coupling methods is needed to avoid introducing loop inductance.**
- **The standard way of using Pearson CT is to add a small ferrite ring core and make it the first-stage CT, then couple its output to the Pearson CT**

Adding a Small CT to Extract Current While Avoiding a Large Parasitic Inductance



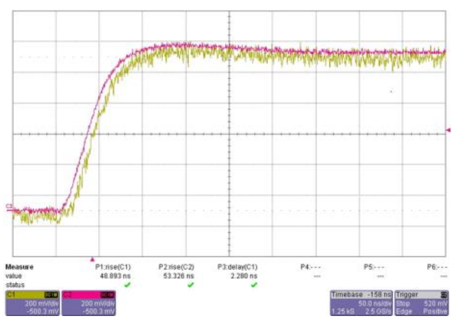
- **Make a small CT with 1:10 ratio**
- **Depending on the current magnitude, make sure the CT is not saturated**
- **Shorting the secondary of CT through a Pearson CT, typically 1A:0.1V**
- **The overall current transfer ratio will be 100A:1V**

Non-Isolated Voltage Probe

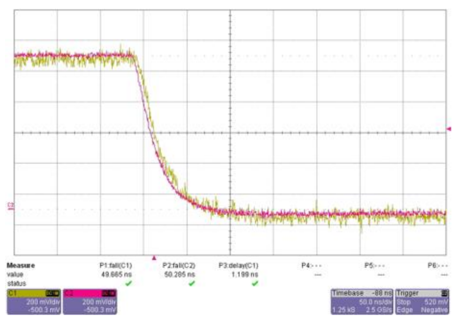
- **PP005A**
  - Ratio: 10:1
  - Bandwidth: 500 MHz
  - Input impedance: 10MΩ
  - Input capacitance: 11pF
  - Maximum input voltage: 600V
- **PPE5kV**
  - Ratio: 100:1
  - Bandwidth: 400 MHz
  - Input impedance: 50MΩ
  - Input capacitance: <6pF
  - Maximum input voltage: 5kV

Both are reasonably fast response for device characterization

Voltage Probe Response Comparison



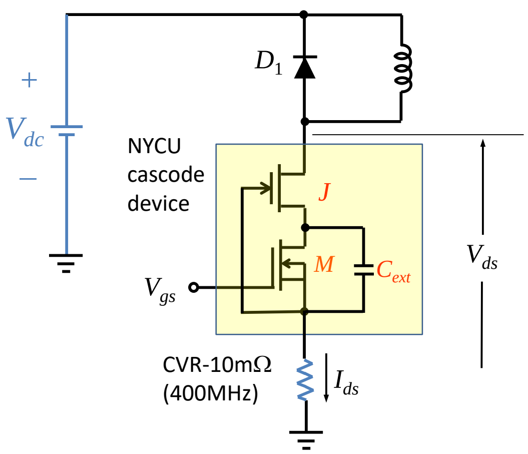
Rise time comparison between 5-kV probe (magenta) and 600-V probe (yellow)



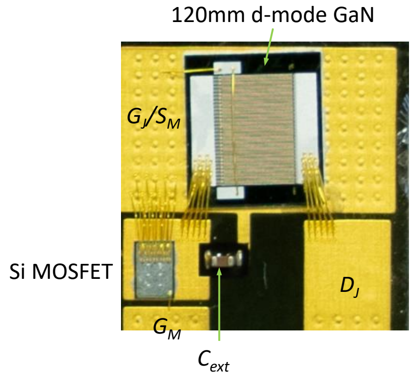
Fall time comparison between 5-kV probe (magenta) and 600-V probe (yellow)

Make sure probe responses are consistent between v_{gs} and v_{ds} measurements

Test Circuit with NYCU d-mode GaN and Si MOSFET Cascode



- J is 120mm NYCU d-mode GaN
- M is a low-voltage Si MOSFET in the package
- C_{ext} is a 0.1 µF externally added capacitor
- V_{gs} is a double-pulse gate-source voltage applied to Si MOSFET with $R_{g\text{-}on}$ = 51 Ω, $R_{g\text{-}off}$ = 0.
- CVR-10mΩ resistor is a non-inductive current viewing resistor with 400-MHz bandwidth



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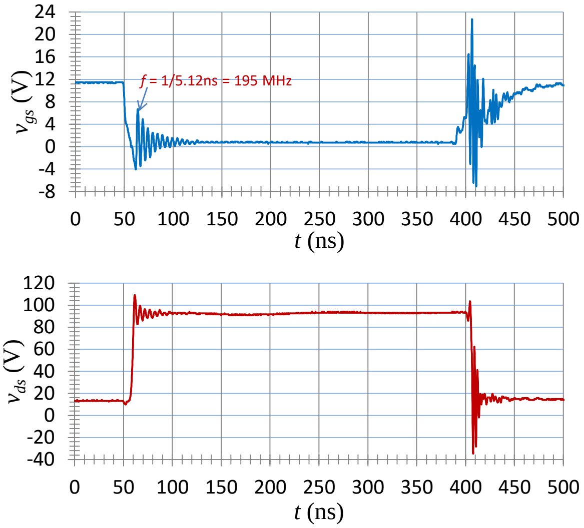
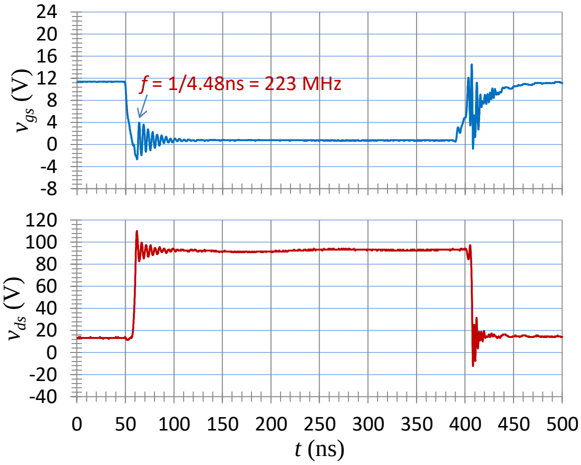
Transphorm Cascode GaN



With parasitic L_s (~15nH)



Without parasitic L_s

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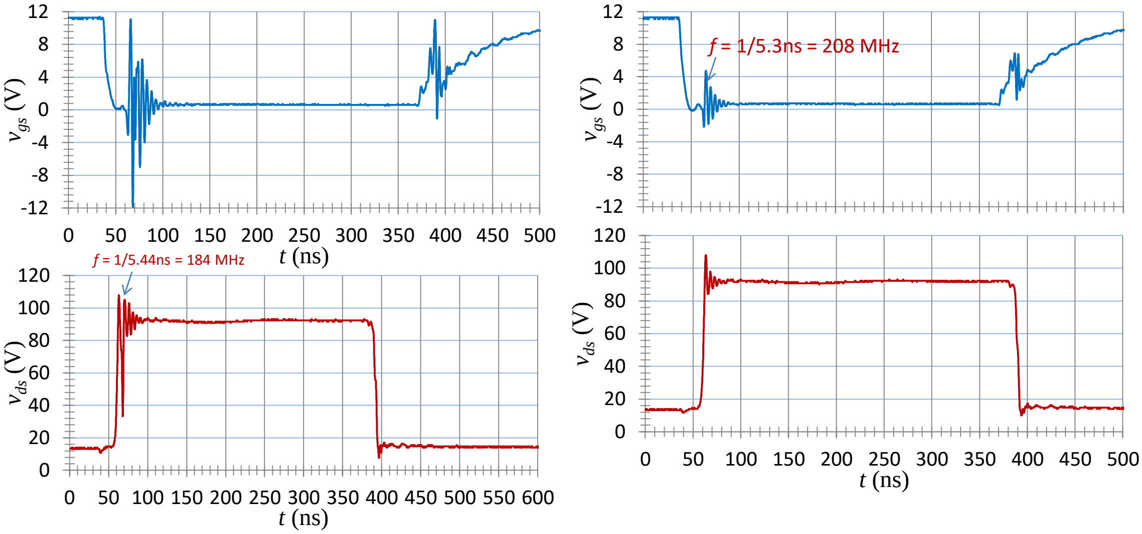
NYCU Cascode GaN

➔ much cleaner as compared with Transphorm GaN



With package lead parasitic (~15nH)

Without package lead parasitic

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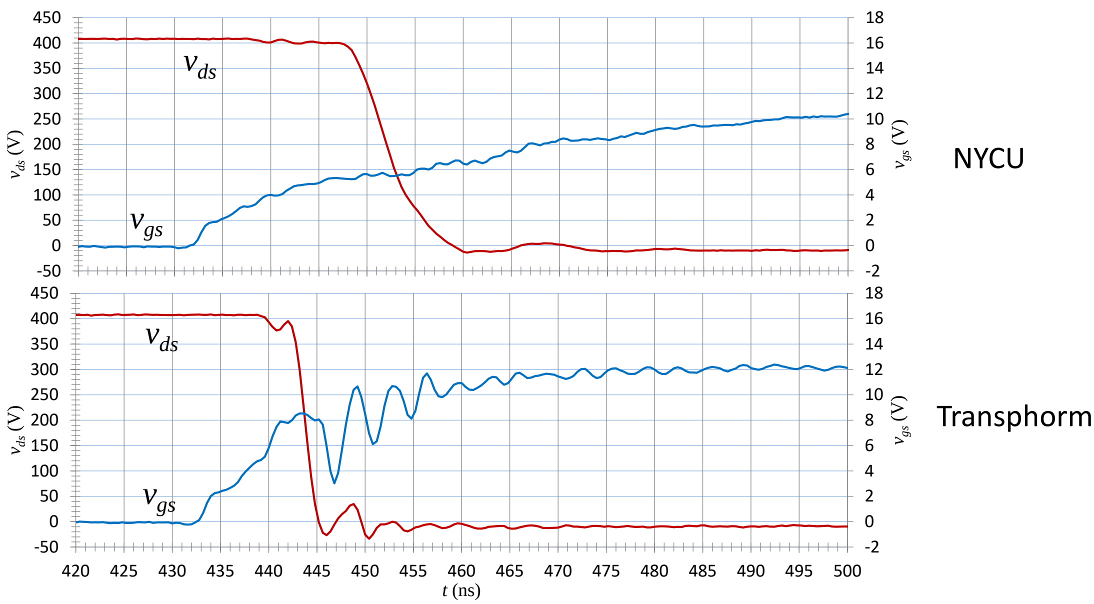
Turn-on Waveform Comparison



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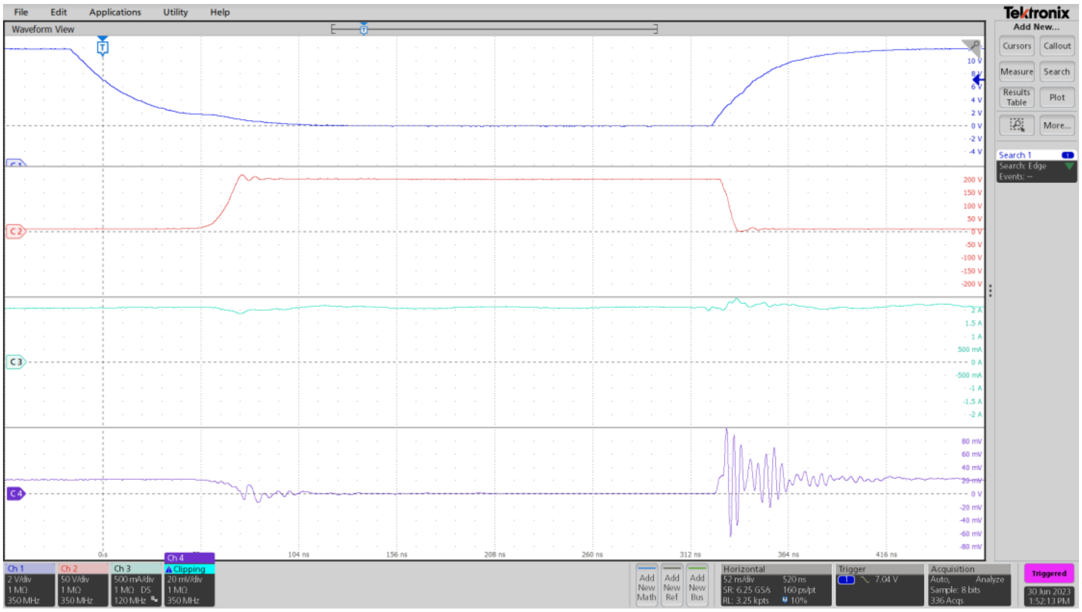
NYCU Cascode Device Test with I_{ds} Monitored at 200V



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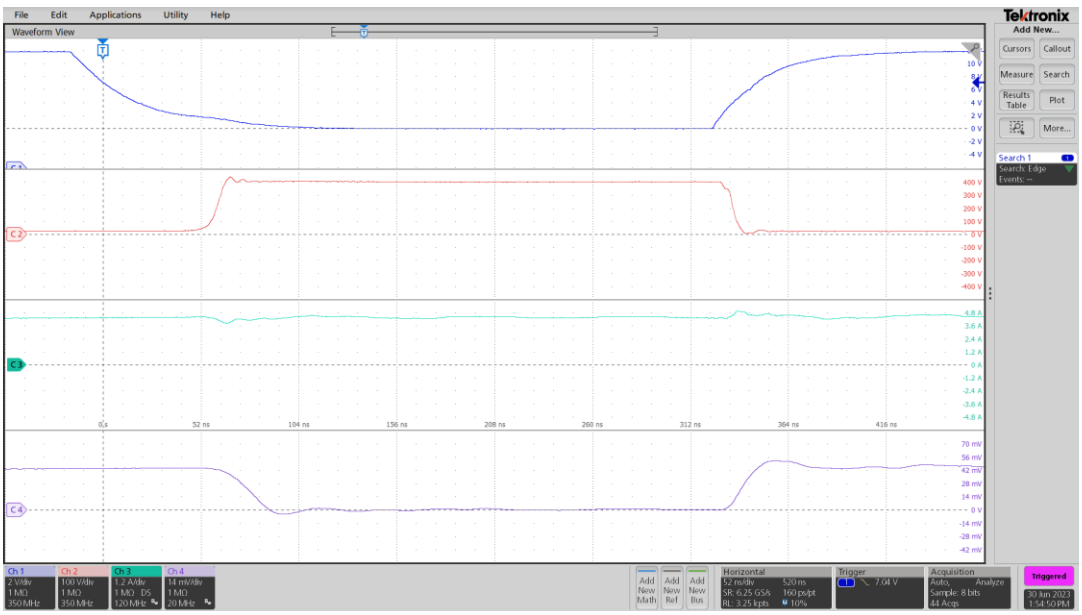
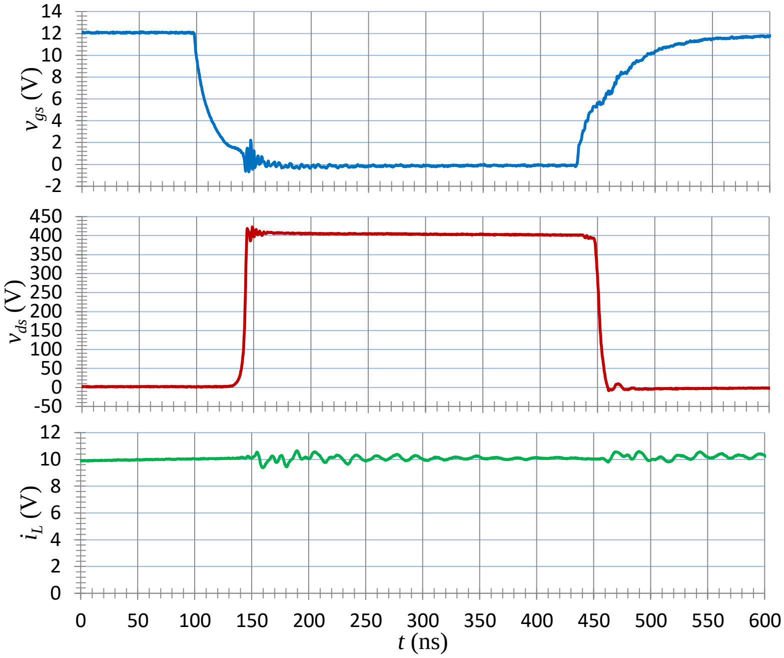
NYCU Device Test with Low Bandwidth I_{ds} Monitored at 400V



Experimental NYCU Cascode Device Switching Waveforms



- **Test at 400 V, 10 A**
- **No current monitoring**

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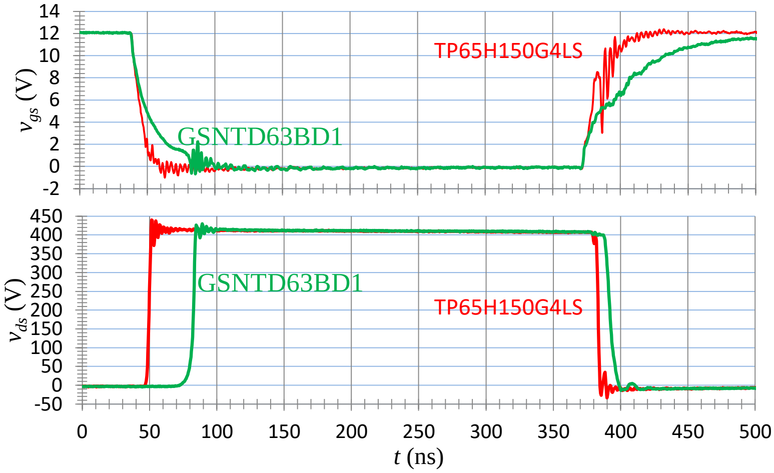
Experimental Results Comparison Between Two Cascode Devices



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Summary

- GaN device characteristics differ between different company products. Noise can be from device itself.
- Parasitic inductance can be largely avoided by removing the current sensing
- Bypass capacitor is crucial to cutting down the loop inductance.
- Different current sensing methods show significant differences in responses. T&M CVR is non-inductive and has highest bandwidth, but the inserting parasitic in measurement setup is unavoidable
- Frequency response of voltage and current probes need to match well for accurate characterization results

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