

APEC
2023


MARCH 19-23, 2023
ORANGE COUNTY CONVENTION CENTER | ORLANDO, FL

Using a High Bandwidth Loss Probe to Measure SiC and GaN FETs Losses with a Lower Bandwidth Oscilloscope

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cleverscope

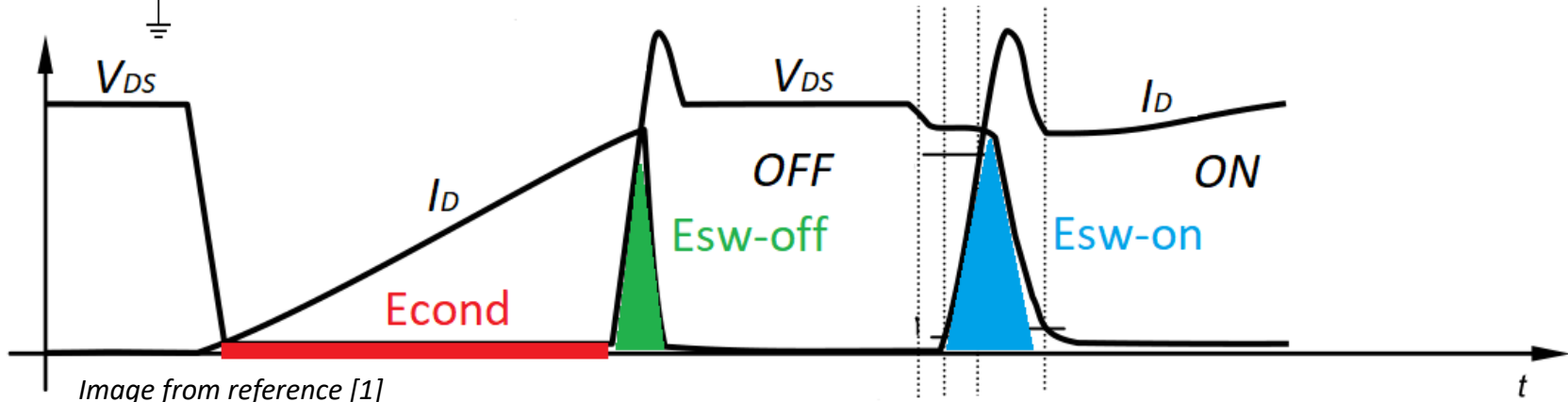
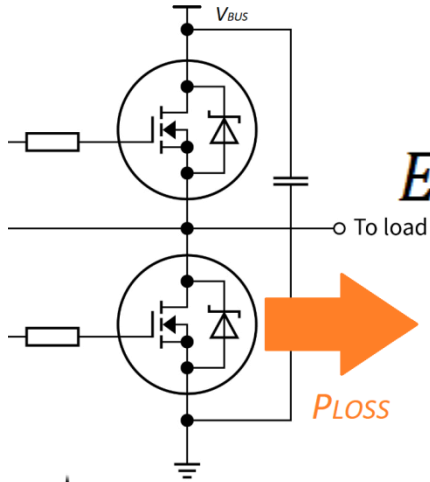
plug & play instruments
oscilloscopes

Power Converter Losses

$$P_{\text{Loss}} = f.(\text{Econd} + \text{Esw-off} + \text{Esw-on})$$

$$E_{\text{cond}} = \int V_{\text{DSsat}}.I_{\text{D}} dt \quad E_{\text{sw}} = \int V_{\text{DS}}.I_{\text{D}} dt$$

Need to measure V_{DS} & I_{D} accurately in both time and amplitude



The Measurement Challenge (1): Esw

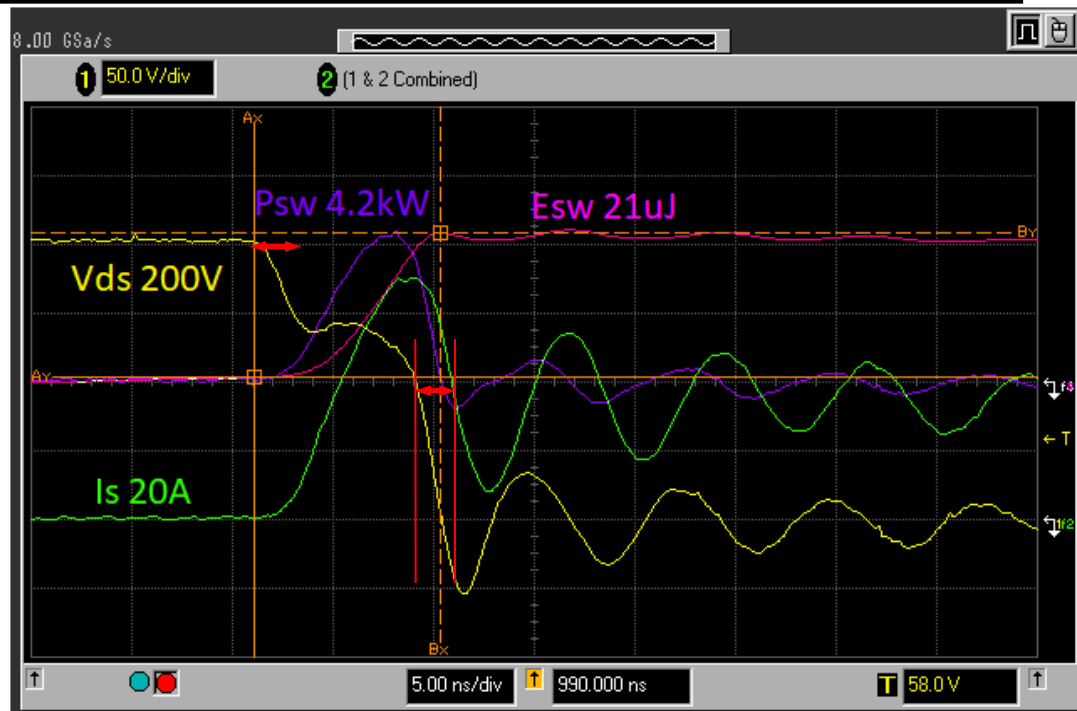
To calculate:

$$E_{sw} = \int V_{DS} \cdot I_S$$

for low error, need at least 10 samples on the fastest edge. The Vds edges \leftrightarrow have 10-90% fall times of 1.6ns. So:

$f_{\text{sample}} > 6.2 \text{ GSPS}$

$BW > 600 \text{ MHz}$.



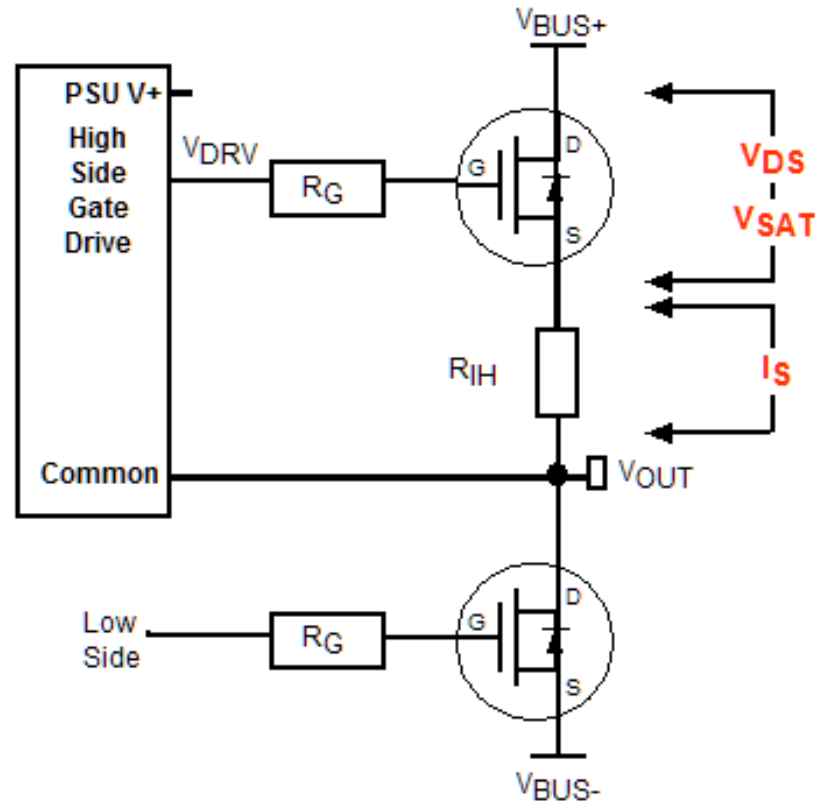
$$t_{r,\text{meas}} \approx \sqrt{t_{r,\text{sig}}^2 + t_{r,\text{probe}}^2 + t_{r,\text{osc}}^2} \quad BW \approx \frac{1}{\pi t_r}$$

The Measurement Challenge (2): Isolation

To measure V_{DS} , V_{SAT} and I_S we need isolation, high CMRR, and $BW > 600$ MHz.

The current shunt R_{IH} max dissipation = 1W. For $I_S = 20A$, $V_{RIH} = 50mV$. For $< 1\%$ error, $V_{noise} < 0.5mV$.

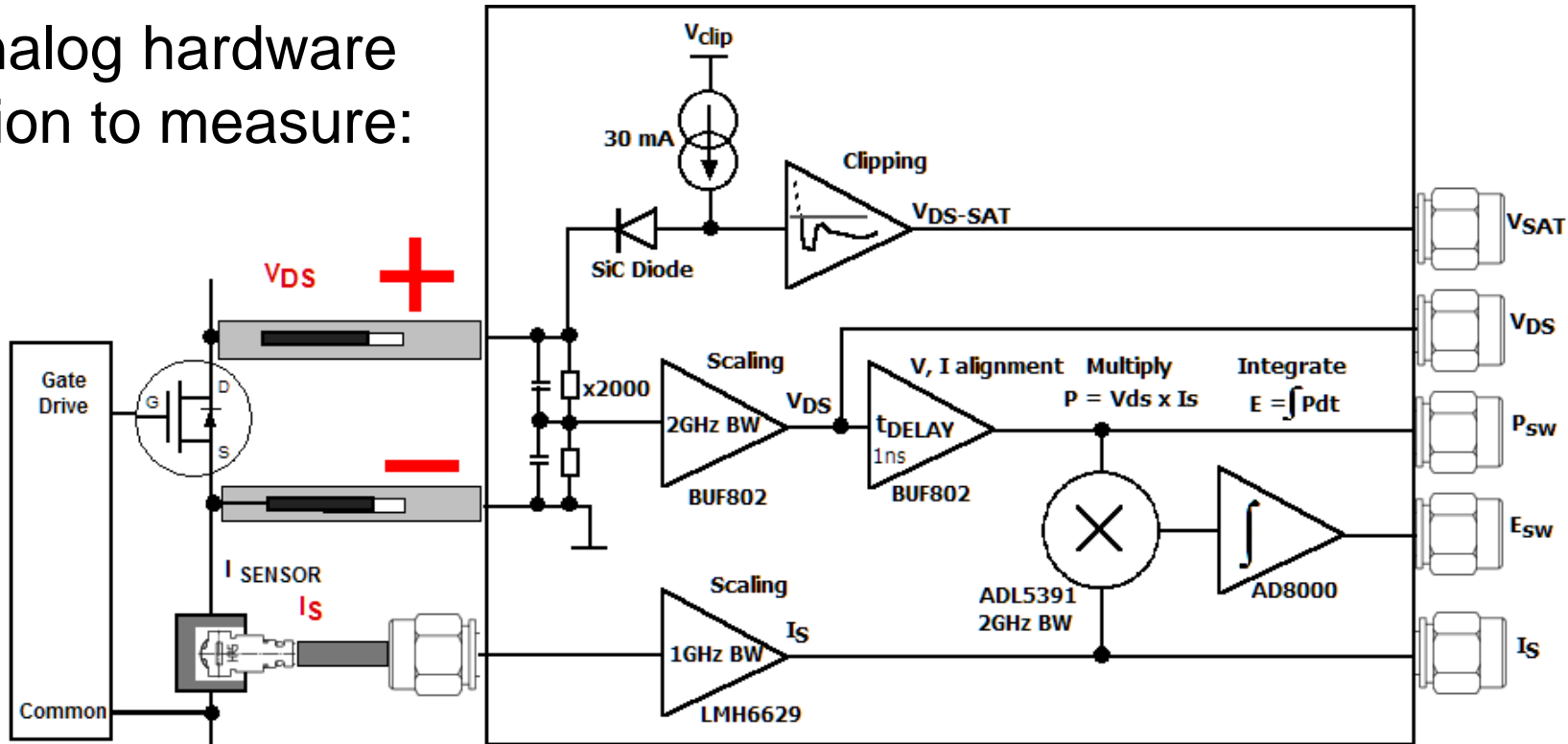
But 1 GHz BW isolated probes cost $> USD25k$, and at > 40 mVp-p noise, are too noisy!



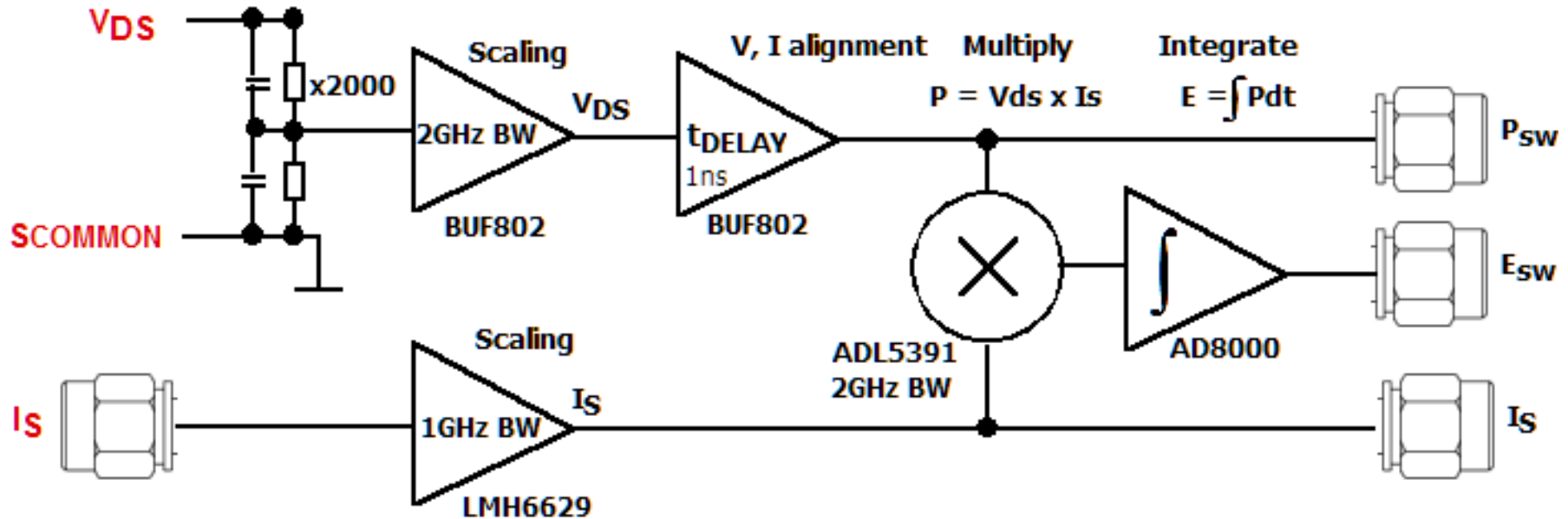
Another Way: The Analog Loss Probe

Uses analog hardware generation to measure:

- V_{DS}
- I_S
- V_{SAT}
- P_{SW}
- E_{SW}
- E_{COND}



Loss Probe: Esw Signal Path



V_{DS} ► De-skew ► $V_{DS} \cdot I_S$ ► Integrate ► E_{sw}

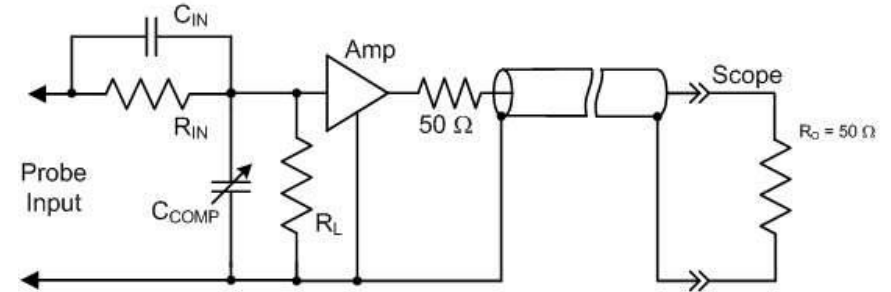
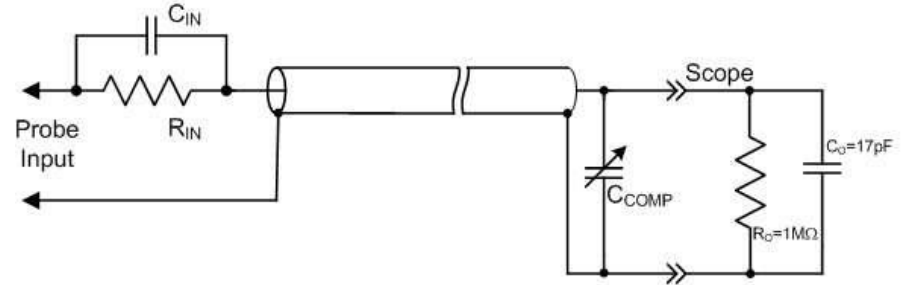
Probing Voltage

Oscilloscope probe C_{IN} limits BW
to $\approx 500\text{MHz}$

Cable + Scope $\approx 90\text{pF}$ so C_{IN} 9pF
 9pF @ $500\text{MHz} = 35\Omega$

Better to have divider close to
measurement, enables lower
 C_{IN} . Then amplifier to drive
cable to scope.

Active probe good for 2GHz .



Probing Current (1) Shunt Resistor

Shunt Resistors

Good DC accuracy, but no isolation.

Coaxial Shunt (e.g. SDN-414-10)

2 GHz for 100mΩ, high 2-5nH, high cost

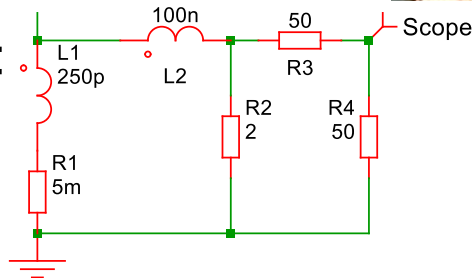
SMD Shunt

Low cost, small, low 0.1-0.5nH

100mΩ ≈ 100-500MHz

Low mΩs need L-R comp:

$$f_{BW(\text{Shunt})} = \frac{R_{\text{Shunt}}}{2 \cdot \pi \cdot L_{\text{Shunt}}}$$



Probing Current (2) Magnetic Sensing

Rogowski Coil

Simple addition to circuit

BW 50Hz-50MHz

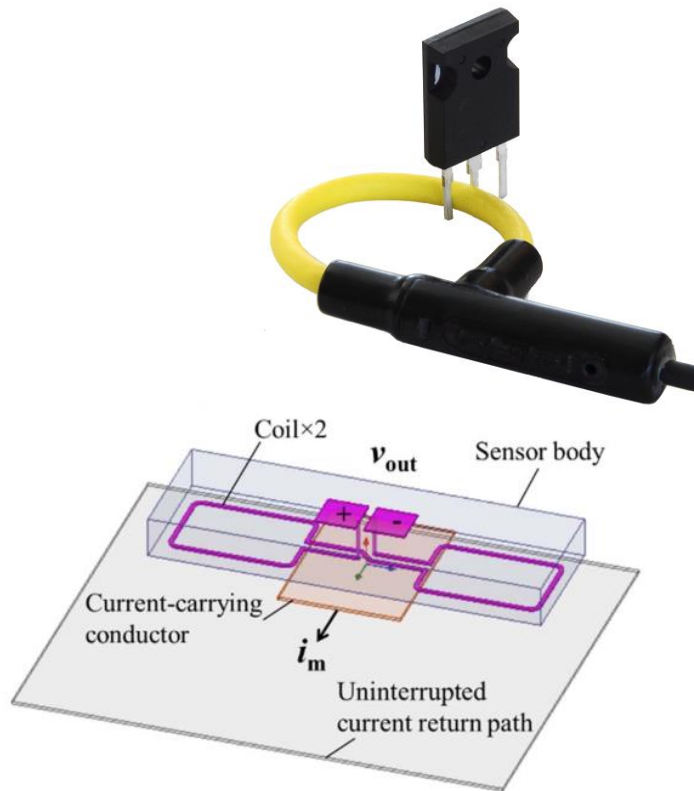
Infinity Sensor

Small 8x3.5mm

<200pH insertion

BW 1MHz-1GHz

Integrator Maths on Scope

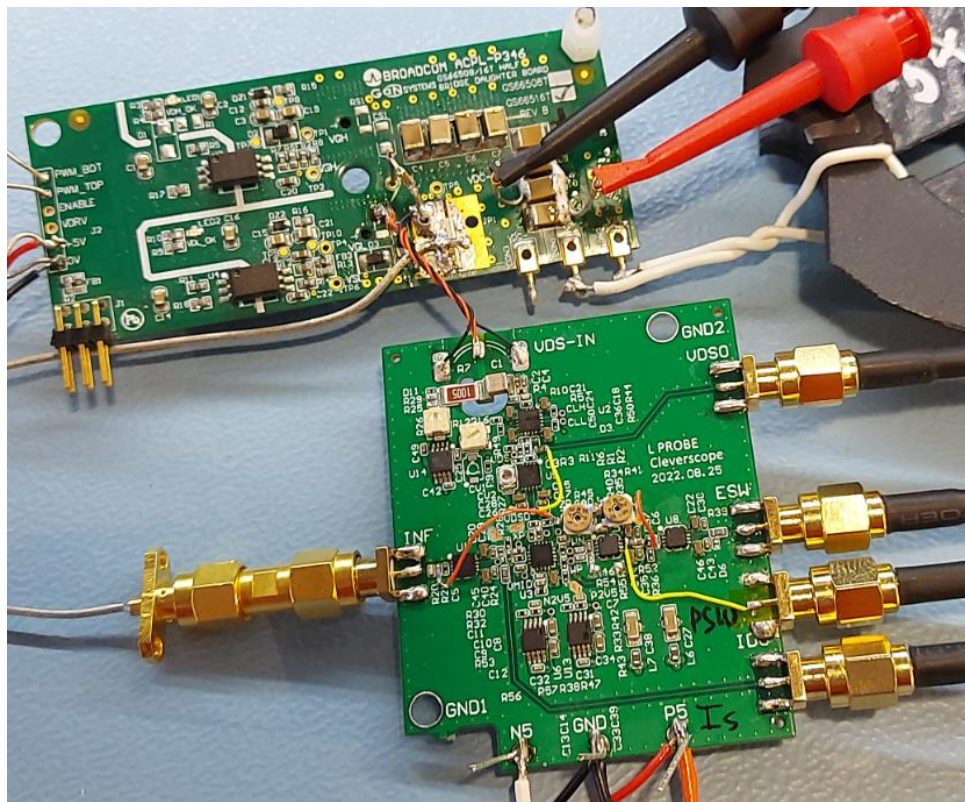


Loss Probe Esw Prototype

Test with GaN Systems
GS66508 Half Bridge at
200V 20A D.P.T.

Current sensing: 2x 0612
50mOhm SMD parallel
gives 25mV/A

Voltage sensing: twisted
pair to Vds and 100:1
scaling.



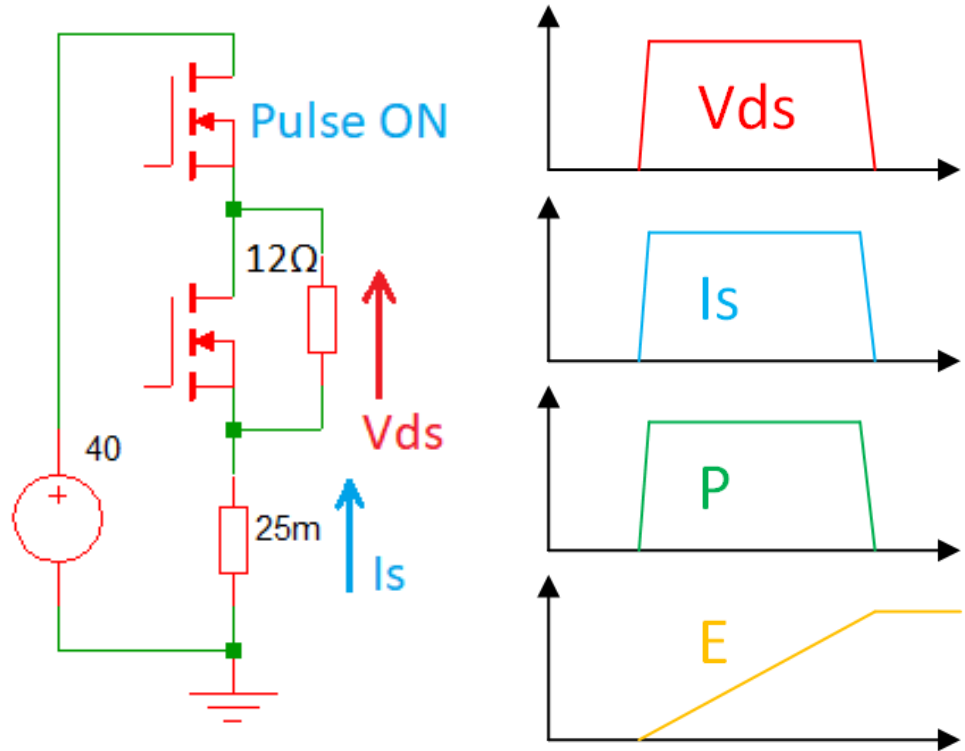
Loss Probe Calibration (1)

Use resistor load for pulsed constant current.

Flat current = Flat power so
Energy is a ramp.

$$E = \int P dt$$

Fast & straight edge allows
accurate de-skew.



Loss Probe Calibration (2)

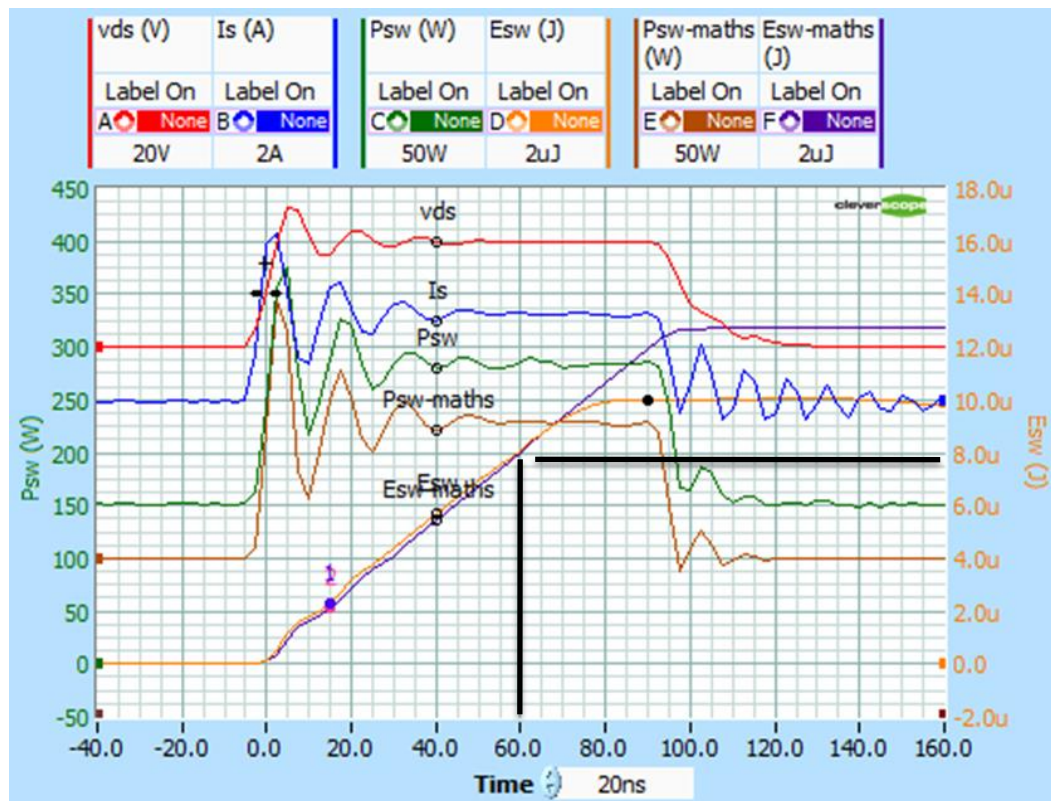
Compare Energy from
Loss Probe (Esw)

To Energy using Maths
(Esw-maths)

Check Energy is a ramp
and scaling is correct.

$$P = V^2/R = 40^2/12 = 133.3\text{W}$$

$$E = P \cdot t = 133.3\text{W} \cdot 60\text{ns} = 8\mu\text{J}$$



Measure Esw-off for 200V 20A DPT

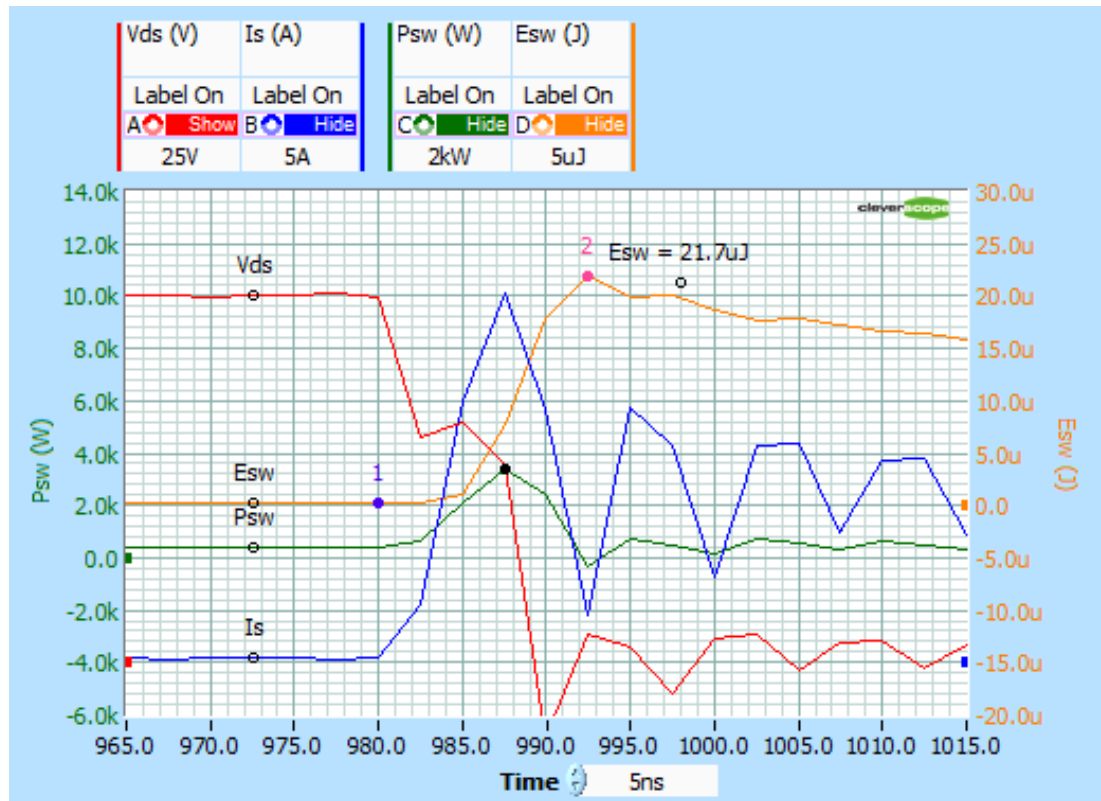
Use with CS548
200MHz 400Msps
oscilloscope.

Analog outputs from
Loss Probe:

Psw 12 kW/V

Esw 50 μ J/V

Get Esw = **21.7 μ J**



Compare with Fast Scope & Passive Probe

1.5GHz 8Gps Scope

500MHz 100:1 V_{DS}

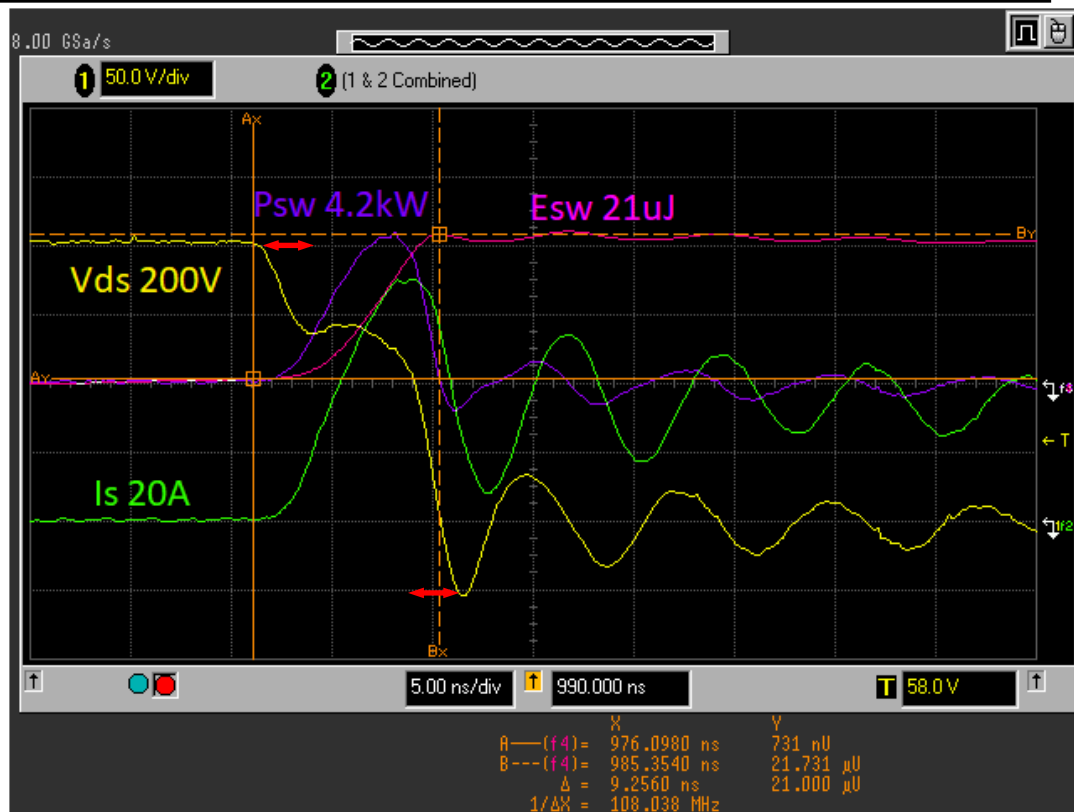
25mOhm SMD Shunt

Maths on scope:

$$P_{sw} = V_{DS} * I_S$$

$$E_{sw} = \text{integral}(P_{sw})$$

Calculated E_{sw} **21uJ**



The Measurement Challenge (3): V_{sat}

Difficult to measure V_{sat}

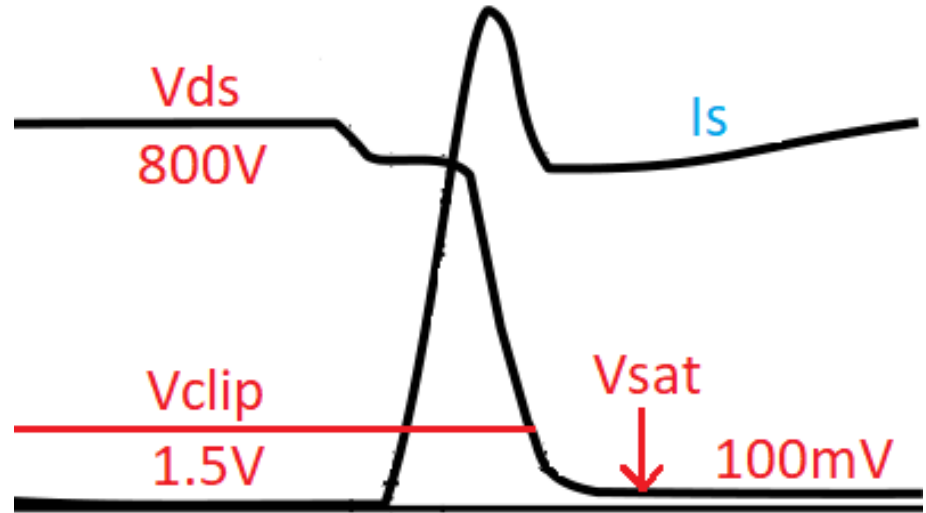
Large dynamic range

Probe linearity & flatness

Scope input saturation

Solution:

Clip off the high voltage to allow accurate measurement of V_{sat}

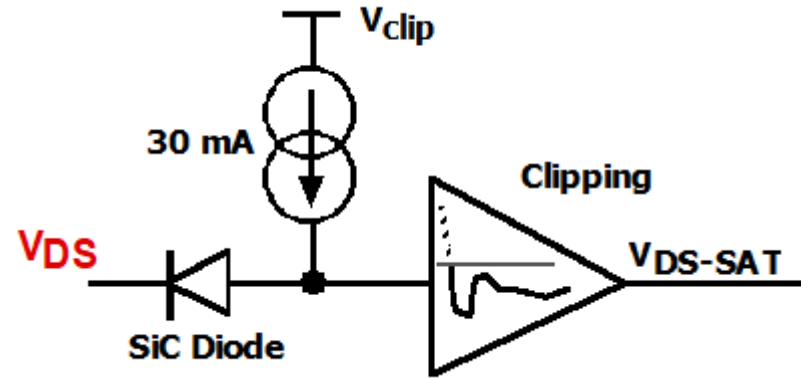


Existing solution for Vsat: CS1133

Clipping circuit with HV diode
and current source

V_{DS} High (FET off) diode blocks

V_{DS} Low (FET on) diode on



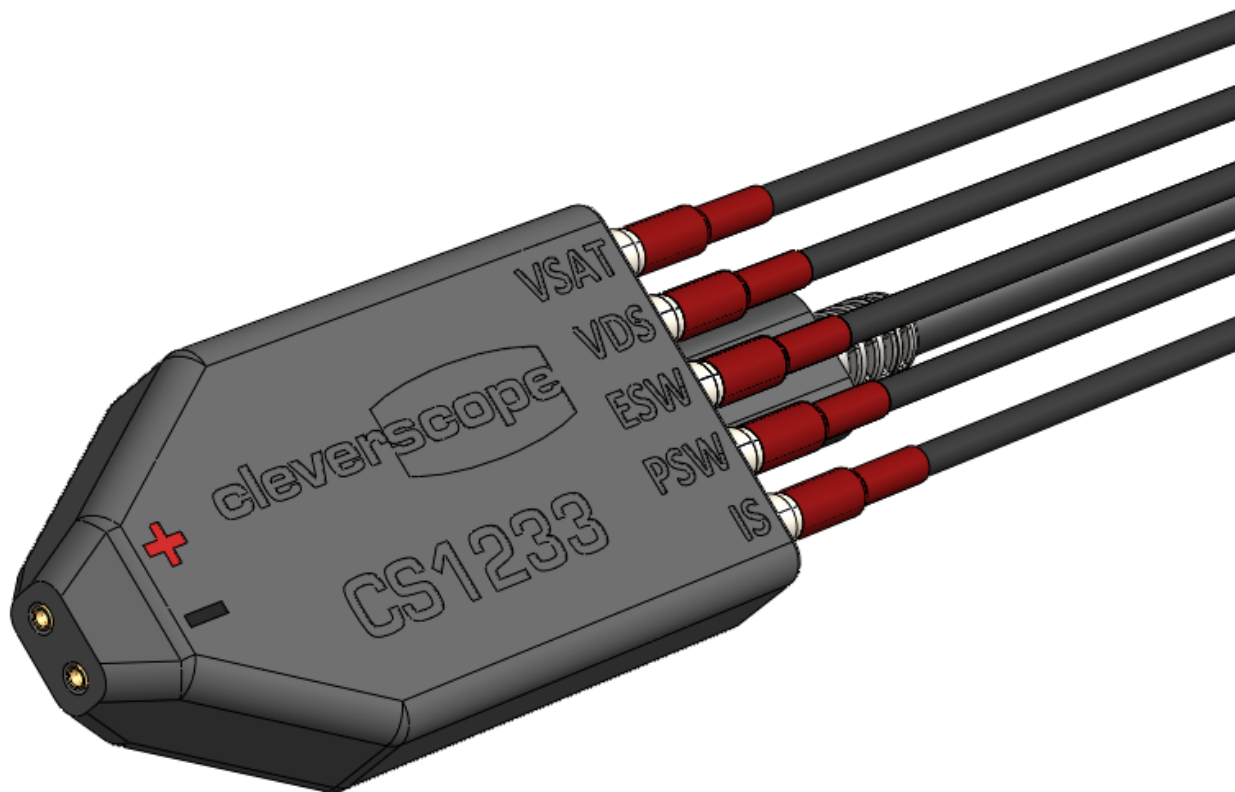
Esw & Vsat in One Probe: CS1233

Inputs

- Vds (2kV)
- Is (25mV/A)
- Power & Control

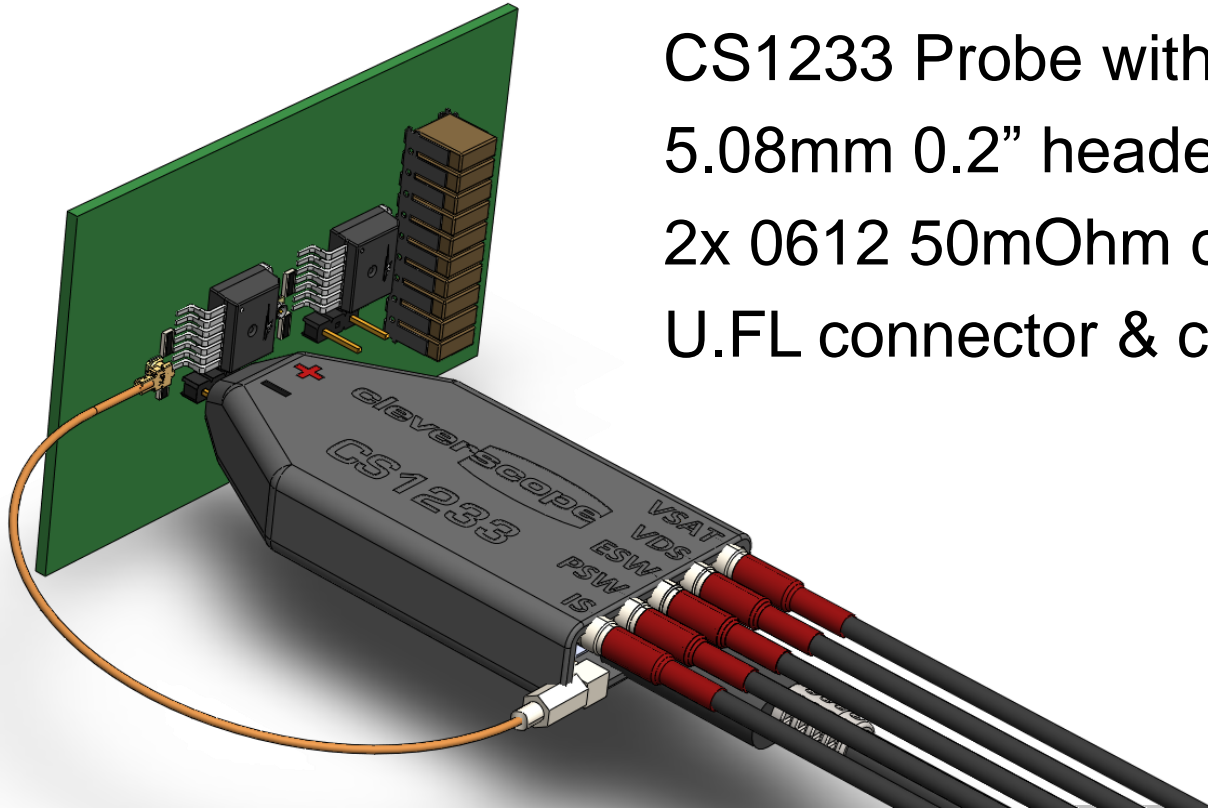
Outputs (50Ω)

- Vsat
- Vds
- Esw
- Psw
- Is



How to Connect Probe

CS1233 Probe with Half Bridge
5.08mm 0.2" header for V_{DS}
2x 0612 50mOhm current sense
U.FL connector & cable to I_S input.

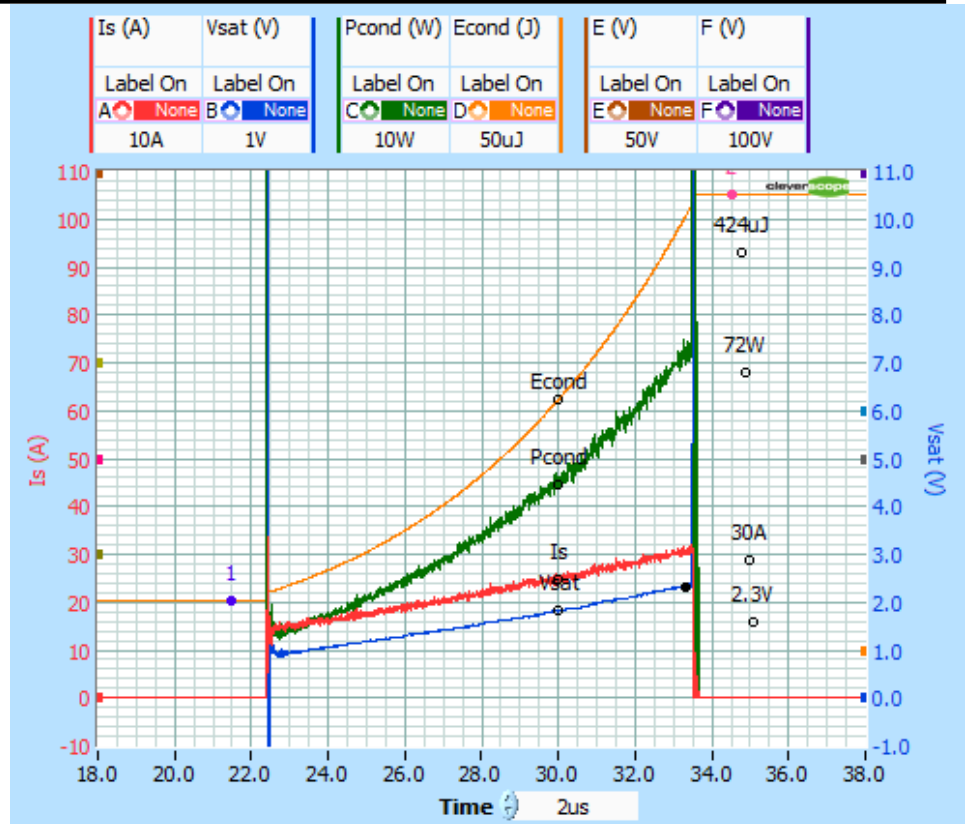


E_{COND} with Maths in Oscilloscope

Fast Analog Calculation of P_{SW} & E_{SW} are done inside the Loss Probe

Slower Calculation of E_{COND} is done using Maths in the Oscilloscope

$$E_{cond} = \int V_{sat}.I_s dt$$



Conclusions

- A hardware Loss Probe and lower BW isolated scope is much CHEAPER than high BW isolated probes and a high BW scope.
- It is BETTER, because it is more accurate:
 - Low noise current measurement is more accurate.
 - V_{sat} measurement accuracy \gg scope probe accuracy
 - Very short buffered V_{DS} connection = better accuracy because of lower capacitance, low series inductance, and low noise.
- It is BETTER, because it uses less space, and is easier to use.
- It is BETTER, because it can measure ALL the losses in a bridge.

Thank You!

Any Questions?

REFERENCES:

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- [2] <https://www.edn.com/why-are-oscilloscope-probe-amps-at-the-tip/> 08.2014
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- [6] Infinity Sensor: Temp Sensing in GaN Power Devices using Peak di/dt. Stark, B. ECCE 2018