HIGH-EFFICIENCY TESTING TECHNOLOGIES FOR SERVER POWER IN THE AI ERA

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ROHDE & SCHWARZ

Make ideas real

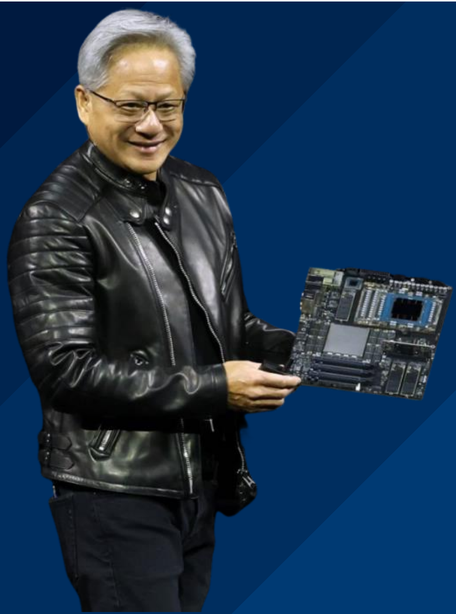
AGENDA

- ► Market & Technology Trends
- ► Optimize your power supply
  - – Input analysis
  - – Wide-bandgap Testing
  - – Digital Power Measurement
  - – EMI Debugging
- ► Conclusion

300W / GPU

700W / GPU

1200W / GPU



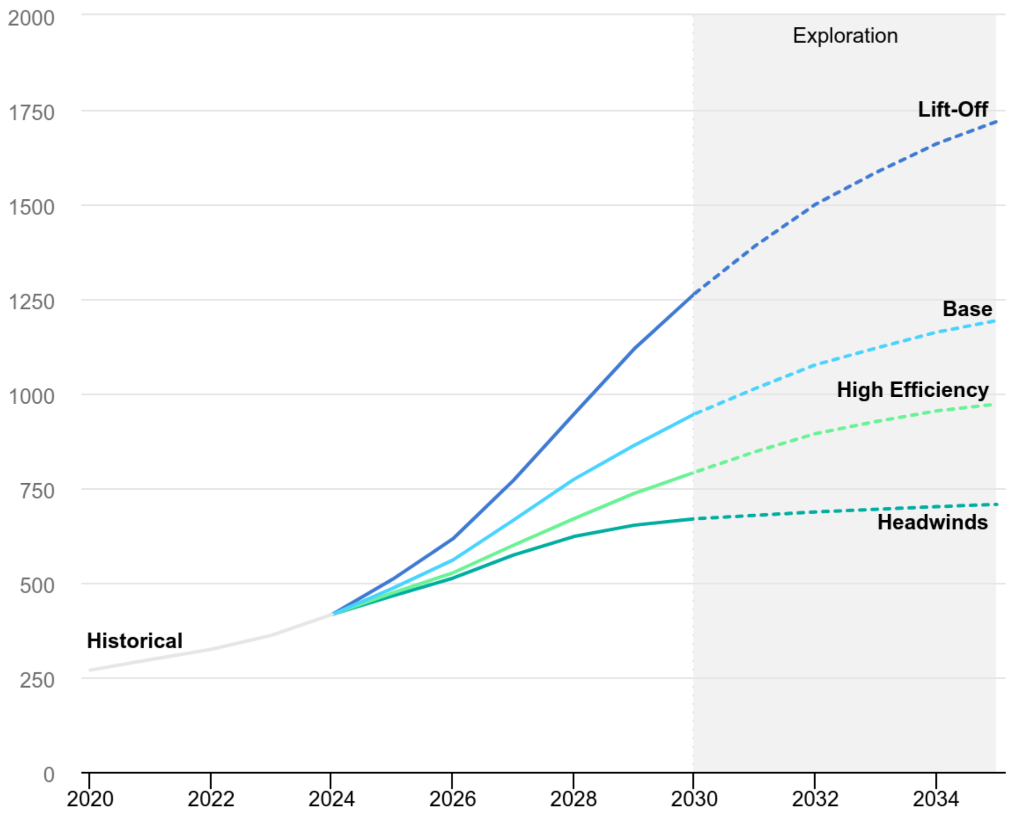
1800W / GPU

MARKET & TECHNOLOGY TRENDS

As computing power grows, so does its power consumption

Computing power and power saving are equally important

We need to focus on improving energy efficiency from the start



資料來源：IEA、高盛研究、美國能源部 、台達電子

MARKET & TECHNOLOGY TRENDS

Before 2020

Traditional 48V System Dominance

Data centers primarily used 48V DC distribution, an upgrade from 12V systems

2021-2022

Initial 380V HVDC Adoption

Some large data centers began piloting 380V HVDC systems

2023-2024

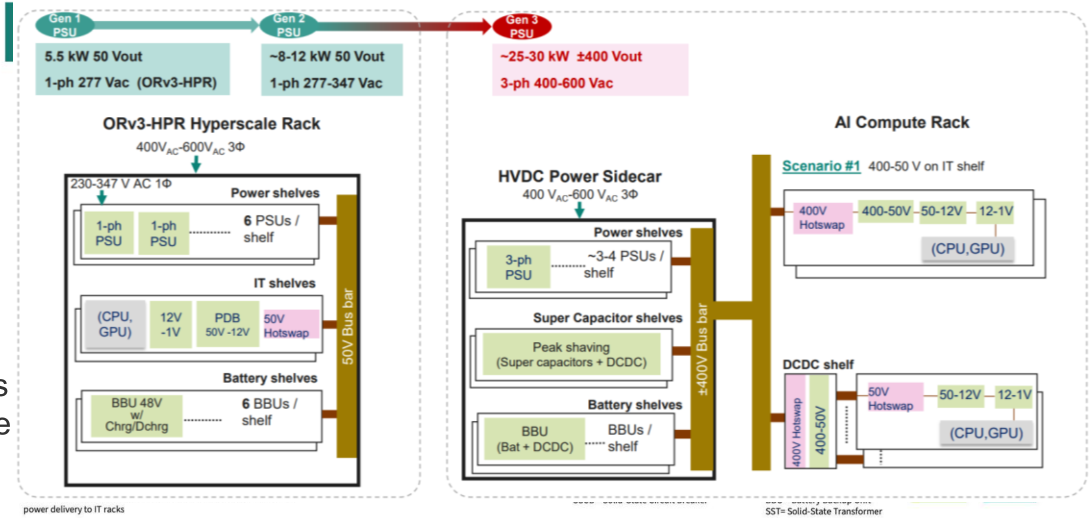
NVIDIA Introduces 800V HVDC

To address high power demands of AI servers NVIDIA proposed an 800V HVDC architecture

2025-2027

Industry Collaboration & Standardization

NVIDIA collaborates with power supply manufacturers to promote 800V HVDC standardization



Source: NVIDIA Developer, Electronic Design, Navitas Semiconductor

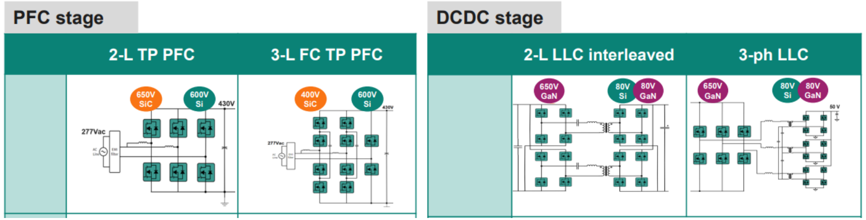
MARKET & TECHNOLOGY TRENDS

With the growth of AI computing power demand, the power density of single servers and racks has experienced explosive growth, escalating from kW to MW.

Si SiC GaN

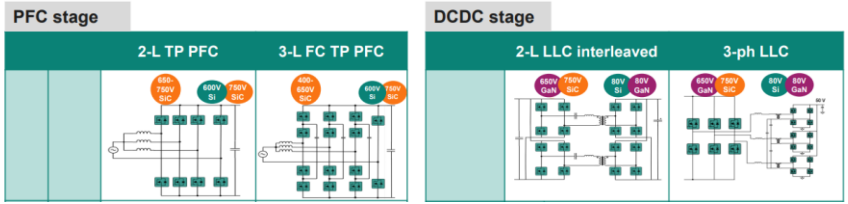
Traditional Servers (2015-2020)

Single server power consumption:**200-500W**
Rack power density:**5-8kW**



AI Servers (2020-2025)

Single server power consumption:**1-8kW**
Rack power density:**<100kW**

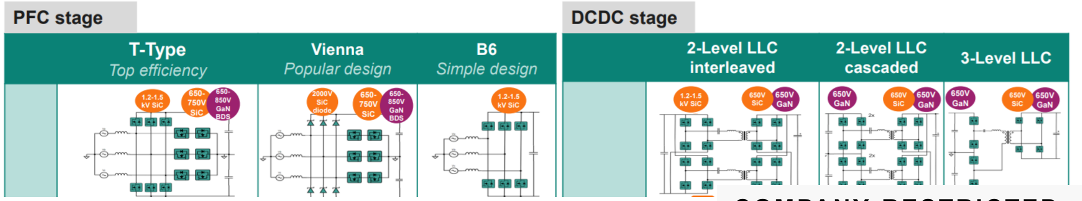


High-Performance AI Servers (2023-2027)

Single server power consumption:**>10kW**
Rack power density:**>100kW**

Future AI Factories (2027+)

Single server power consumption:**>20kW**
Rack power density:**>1MW**



Source: AFCOM, Enconnex, Ramboll, NVIDIA, Infineon

MARKET & TECHNOLOGY TRENDS

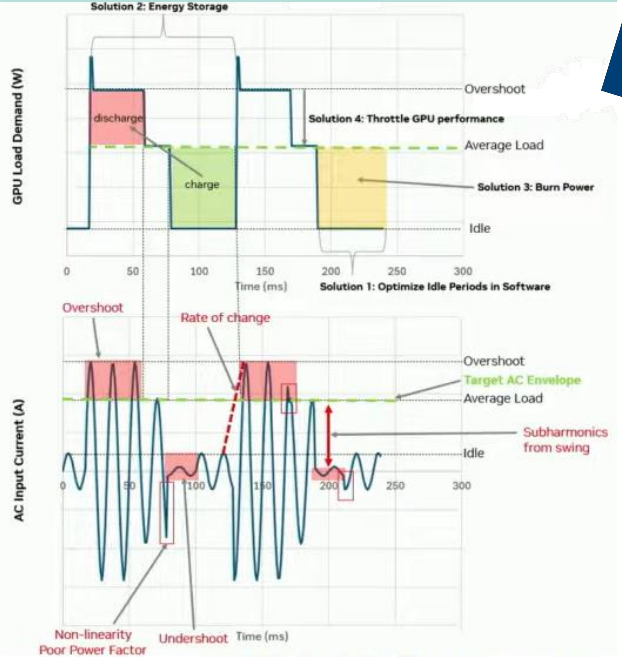
80 PLUS Certification	277V / 480V Internal Redundant					380V DC Internal Redundant				
% of Rated Load	5%	10%	20%	50%	100%	5%	10%	20%	50%	100%
80 PLUS										
80 PLUS Bronze		80%	82%	85% PFC ≥ 0.90	82%		80%	82%	85%	82%
80 PLUS Silver		82%	85%	89% PFC ≥ 0.90	85%		82%	85%	89%	85%
80 PLUS Gold		85%	88%	92% PFC ≥ 0.90	88%		85%	88%	92%	88%
80 PLUS Platinum		88%	90%	94% PFC ≥ 0.95	91%		88%	90%	94%	91%
80 PLUS Titanium		90%	94% PFC ≥ 0.95	96%	91%		90%	94%	96%	91%
80 PLUS Ruby	90% PFC ≥ 0.90	91% PFC ≥ 0.90	95% PFC ≥ 0.96	96.5% PFC ≥ 0.96	92% PFC ≥ 0.96	90%	91%	95%	96.5%	92%

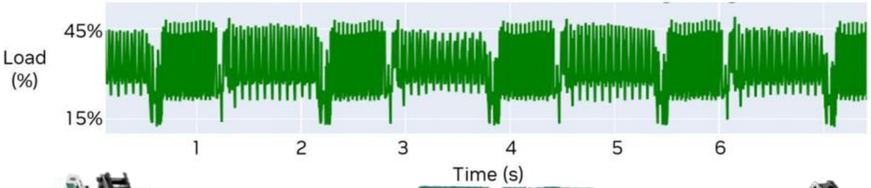
HIGHER PEAK POWER AND TRANSIENT DYNAMICS

GPU draws high peak power and high load transient

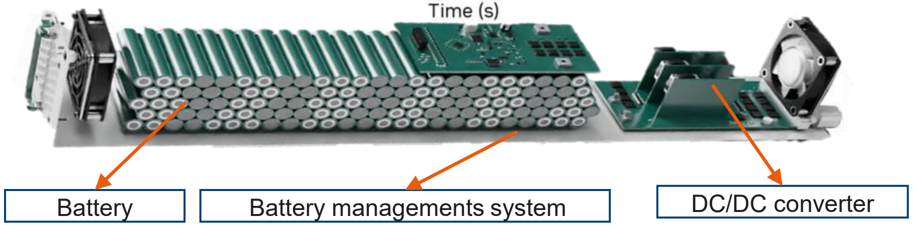
-Higher switching frequency is needed to increase the control loop bandwidth

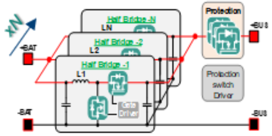
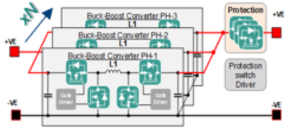
Load for AC/DC AI power





BBU



State of art solutions for 48 V bus architecture		
Topology	Multiphase buck or boost	Multiphase buck boost
		
Limited to	$<44\ V_{BAT\_MAX}$	$<60\ V_{BAT\_MAX}$
	≤ 4.4 kW	

Source: NVIDIA Develop, Infineonr

MARKET & TECHNOLOGY TRENDS
- DATA CENTER CHALLENGES

Increasing requirements regarding

- ► I/O data rates
- ► Processing power
- ► Power density

Power delivery solutions need to provide

- ► Low ripple / noise
- ► Precise sequencing
- ► Fast response on load transients

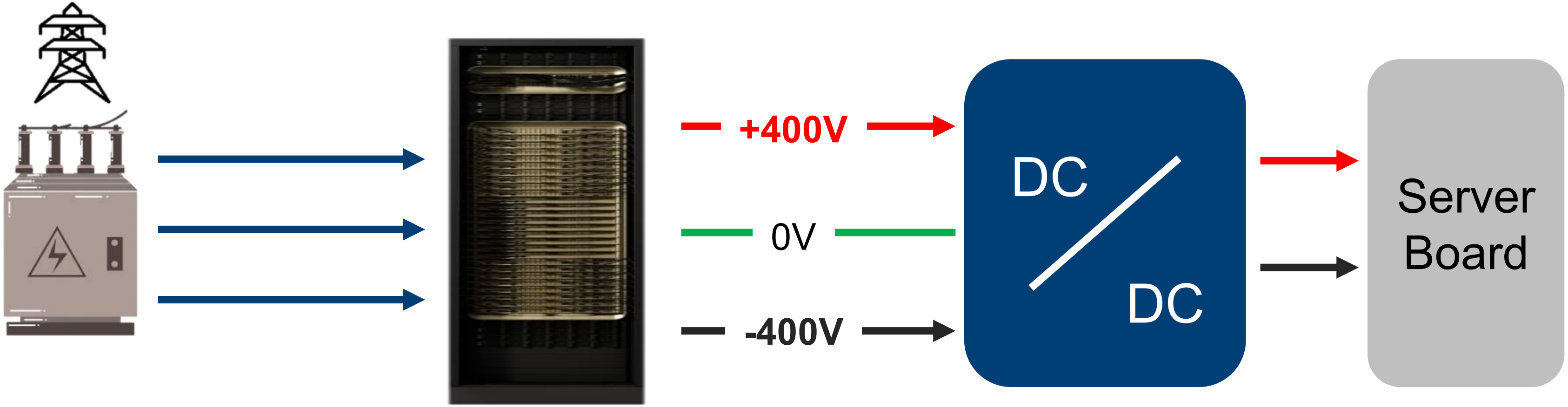
CHALLENGES FOR HIGH-PERFORMANCE POWER

Input analysis

- Frequency
- Duty Cycle
- Apparent Power (VA)
- Active Power (P)

Digital Power Measurement

- Timing and PWM Observation
- Output voltage & Regulation



Wide-bandgap Semiconductor

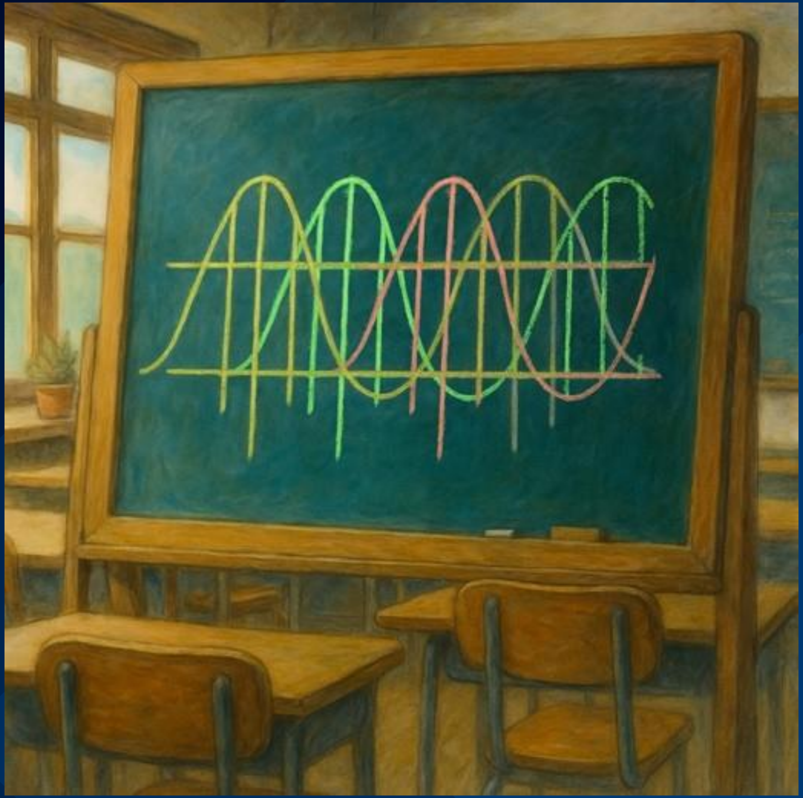
Double Pulse Testing

- Switching Loss
- Reverse Recovery loss
- Semiconductor Parameters

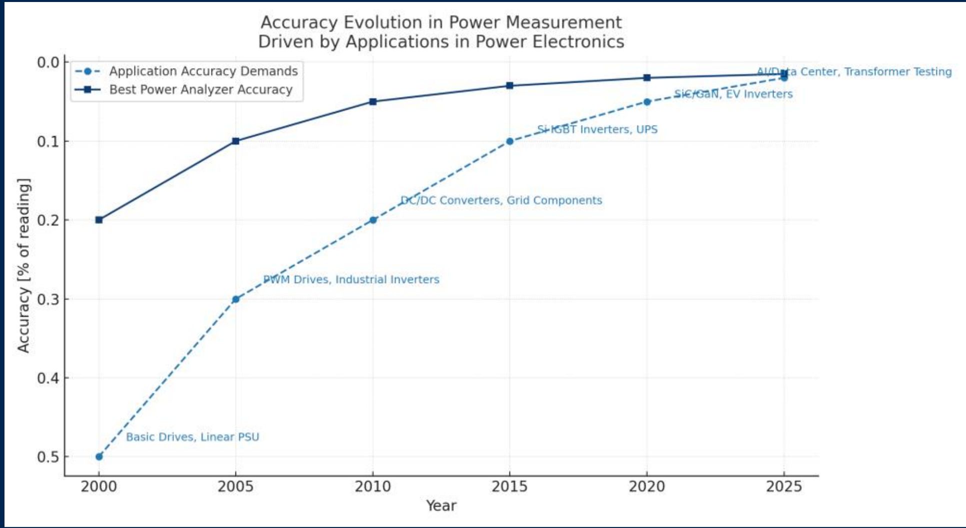
EMI Debugging

- Conduction Debug
- Radiation Debug
- Application

INPUT ANALYSIS



HIGH MEASUREMENT PRECISION



- ► Precision Enables Correct Device Specification
- ► Inaccuracy Risks Non-Compliance and Failed Conformity
- ► Reproducible & Comparable Measurement Series

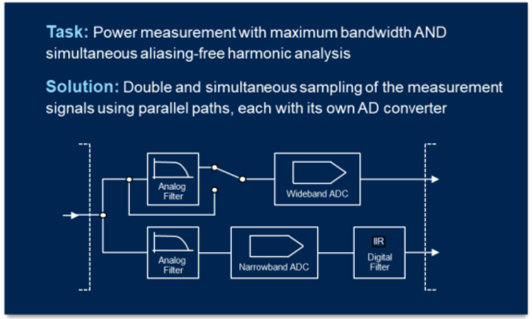
Example: 99.5% efficiency

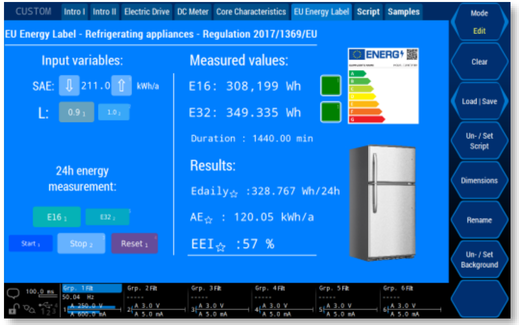
Measuring error ±1%: 98.5% … **100.5%**

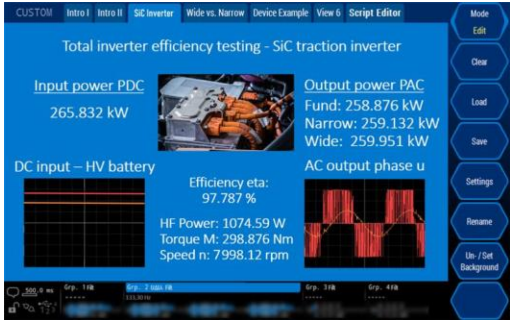
Measuring error ± 0.1%: 99.4% … 99.6%

ZIMMER ANALYZER

- ▶ EU Energy Label
- ▶ Custom Menu
- ▶ DualPath-Architecture
- ▶ Integrated Custom Script Editor

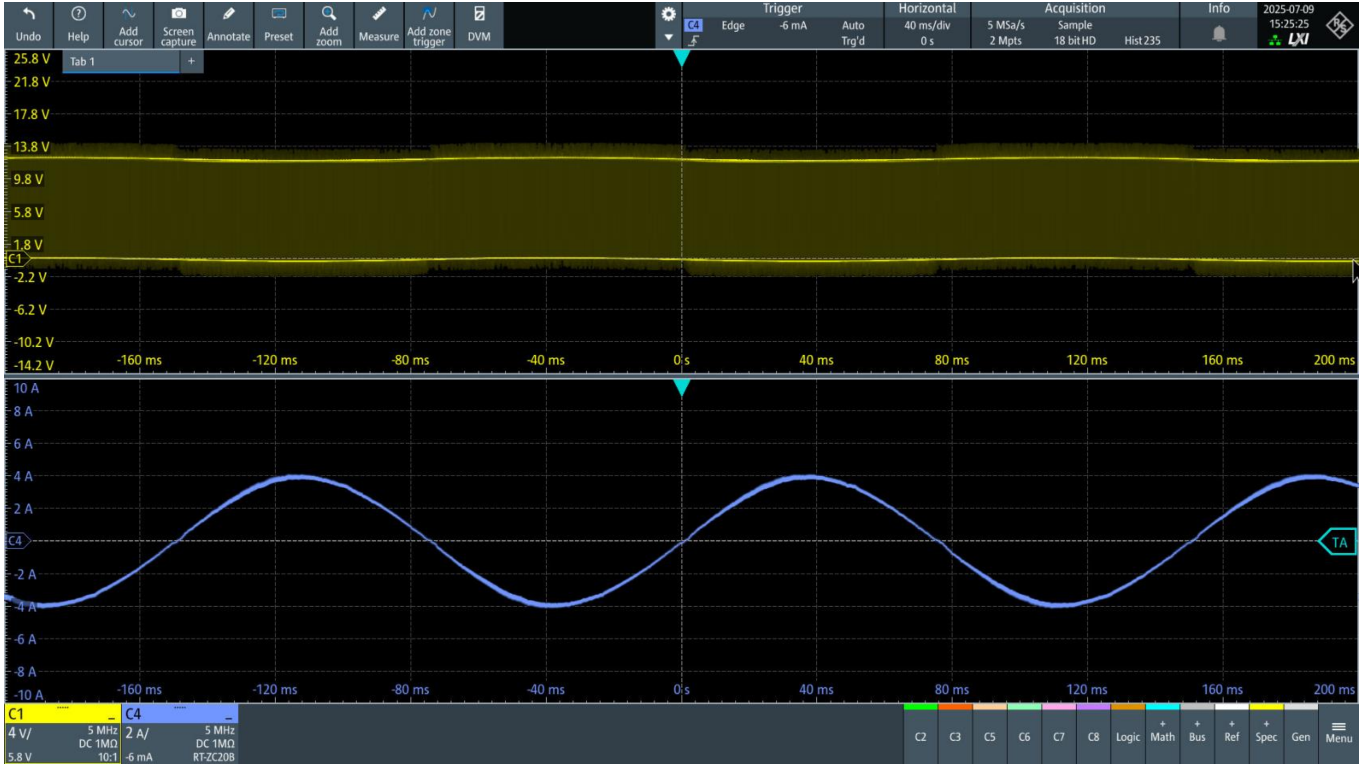




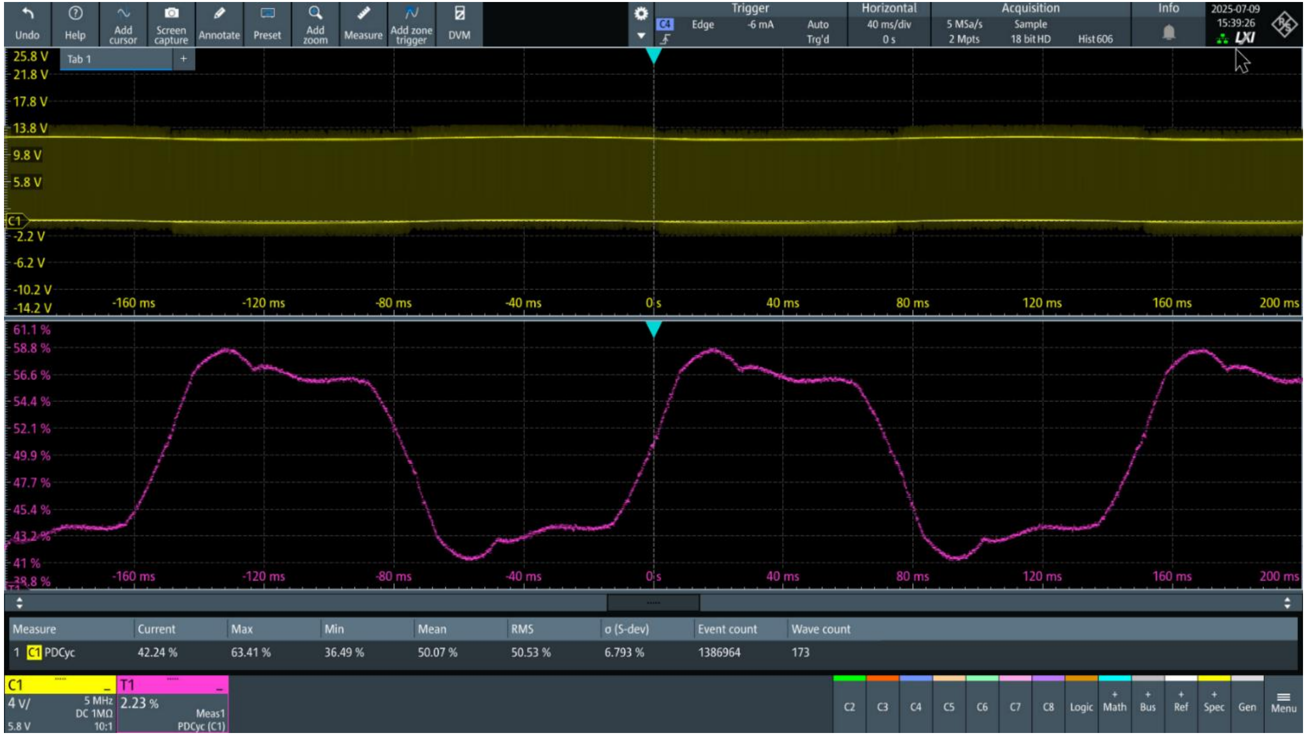


INPUT ANALYSIS: WHAT CAN WE MEASURE?

- Frequency
- Duty Cycle
- Voltage RMS (V rms)
- Current RMS (I rms)
- Apparent Power (VA)
- Active Power (P)



INPUT ANALYSIS
-FREQUENCY & DUTY CYCLE



Pulse-width modulation (PWM) control of sinusoids

Track shows the variation of a parameter for each cycle of the waveform

Pulse duration of PWM react as load changes

INPUT ANALYSIS
-VOLTAGE RMS & CURRENT RMS

Two Ways to Measure RMS

- **Cycle RMS :** Gate one full cycle
- **Using DVM**

V_{rms}

I_{rms}

INPUT ANALYSIS
-APPARENT POWER MEASUREMENT

Apparent Power = $V_{rms} \times I_{rms}$

Apparent power is the total power required to drive the circuit

Measurement Method Comparison

Oscilloscope Measurement

Calculate V_{rms} and I_{rms} directly from waveforms, then multiply

DVM Measurement

Uses digital voltmeter for continuous measurement
(Without occupying waveform acquisition memory)

INPUT ANALYSIS
-APPARENT POWER MEASUREMENT

Active Power = V× I (Cycle Mean.)

Active power is power actually consumed in a circuit

Measurement Method

Cycle Challenges

Same as with Voltage measurements, requires precise gate settings to cover complete electrical cycles

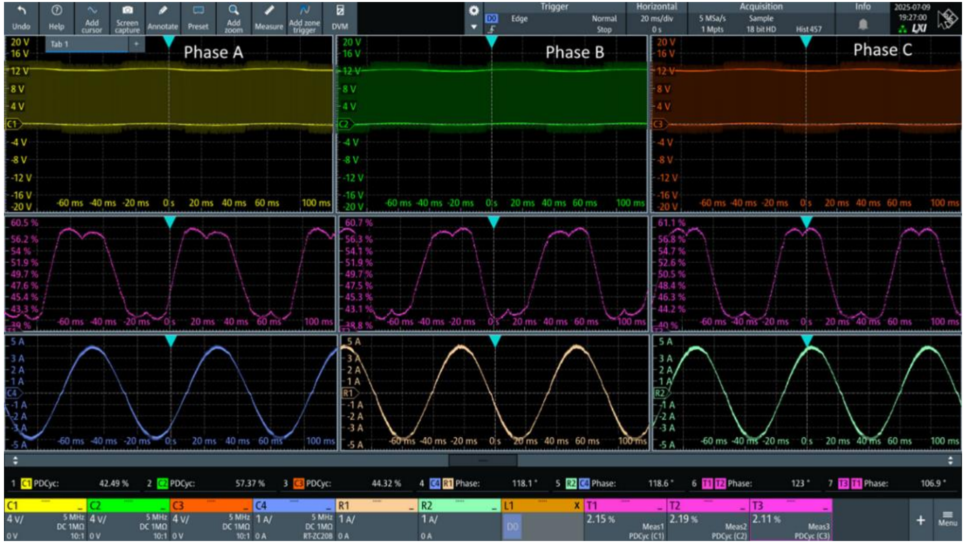
Solution

Use Gates and Mean Measurement to ensure accurate cycle measurement

INPUT ANALYSIS
-THREE-PHASE SYSTEM PHASE ANALYSIS

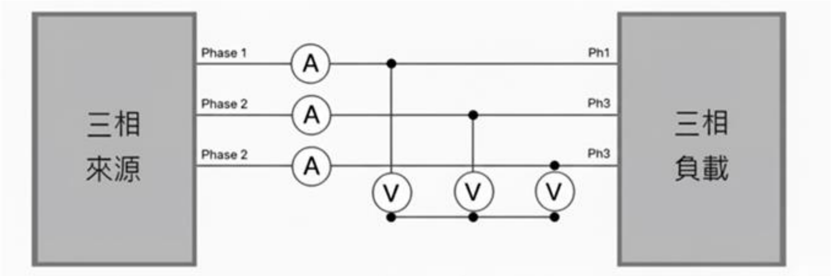
In three-phase systems, comparing duty cycle tracks and current waveforms across phases is essential for evaluating system balance.

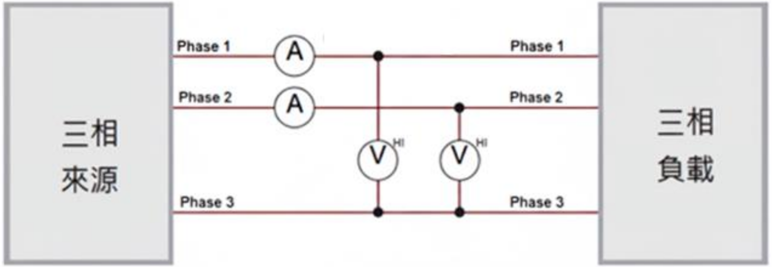
- In an ideal balanced three-phase system, phases should be **120° apart**
- Oscilloscope makes three-phase differences easy to see



Measurement results show phase differences close to ideal values, confirming balanced system operation

INPUT ANALYSIS
-THREE-PHASE TOTAL POWER MEASUREMENT





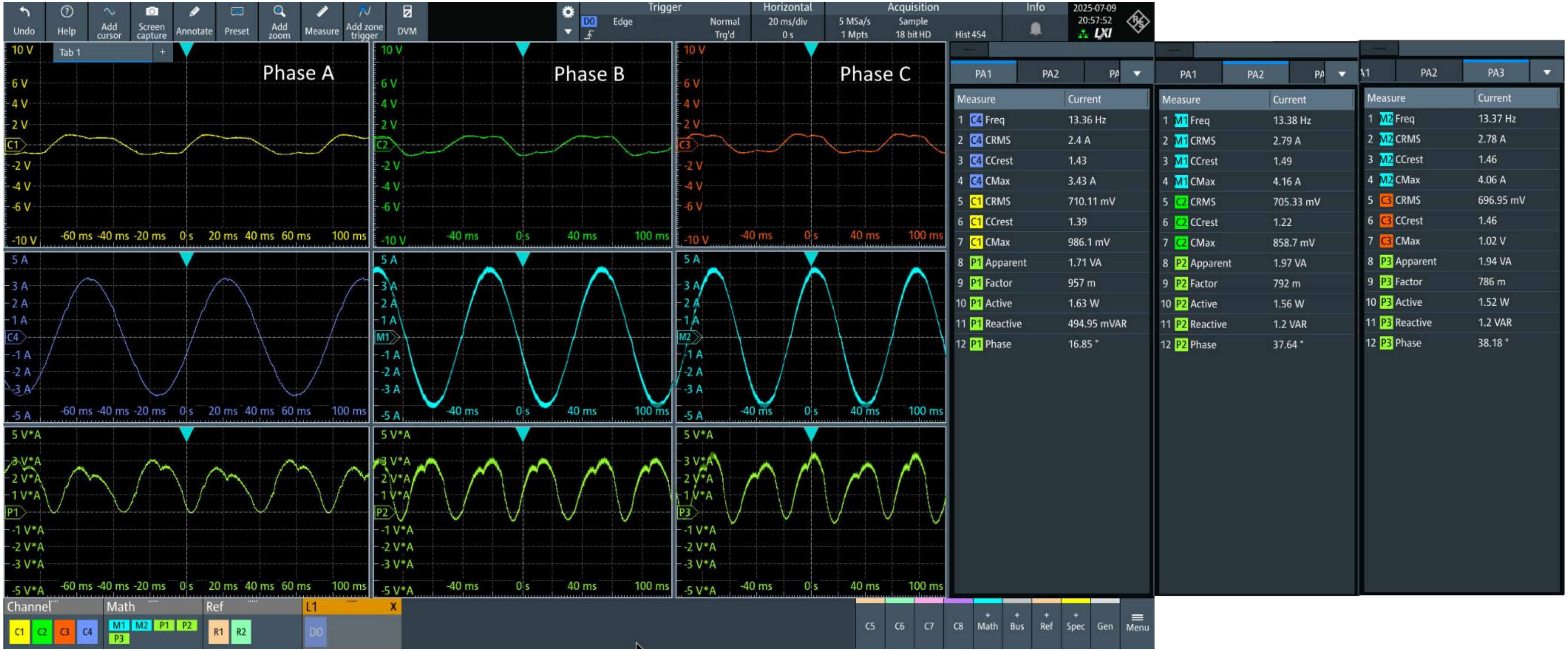
Three-Wattmeter Method

- Total system power (P, S, Q) is the sum of all three phases
- In balanced systems, total power can be considered as 3× any individual phase measurement
- Requires measuring voltage from each phase to neutral point

Two-Wattmeter Method

- Suitable for systems where phase-to-neutral voltages cannot be measured
- Measures line-to-line voltages instead of phase-to-neutral voltages
- Requires only two wattmeters to calculate total power in a three-phase system

THREE-PHASE TOTAL POWER MEASUREMENT
-THREE WATTMETER METHOD



THREE-PHASE TOTAL POWER MEASUREMENT
-TWO WATTMETER METHOD

Complementary Solution for Complete Testing

Basic Specifications

Specification	Power Analyzer i.e. LMG671	Oscilloscope i.e. MXO5
Bandwidth	10 MHz	350 MHz – 2 GHz
Accuracy	± 0,015% of rdg.	± 5% full scale
Sampling Rate	1.21 MS/s	5 GS/s
Resolution	18 Bit ADC	12-bit ADC
Channels	Up to 14 (7 power channels)	4, 8
Direct Inputs	1000Vrms / 32Arms	5Vrms / 50Ohm 300Vrms / 1MOhm

Power Analyzer **Oscilloscope**

Complementary Solution for Complete Power Electronics Testing

Precise Power Analysis

Ultra-fast Signal Analysis

WIDE-BANDGAP SEMICONDUCTOR TESTING

WIDE-BANDGAP SEMICONDUCTOR TESTING
-WIDE-BANDGAP APPLICATION

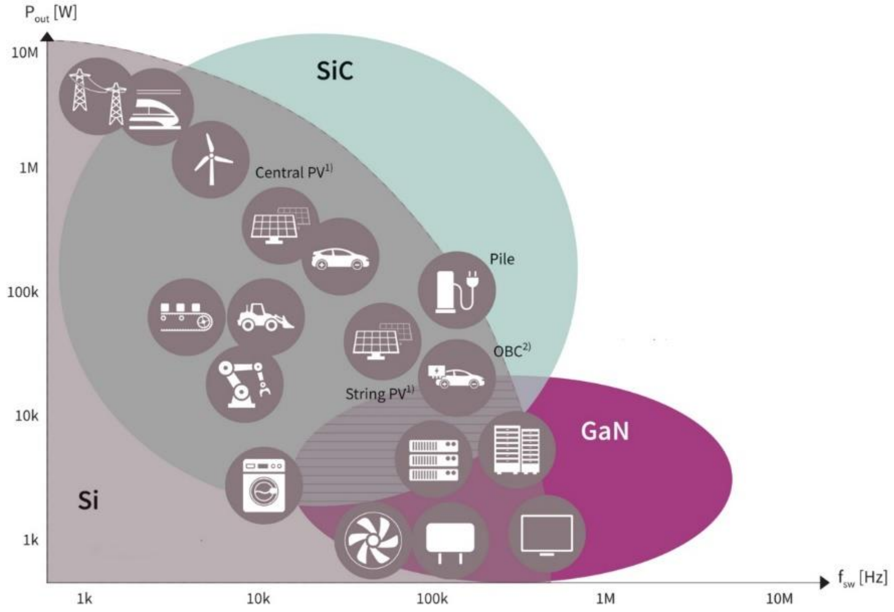
Higher Efficiency
Lower Rds(on), less conduction loss

Reduced System Size
High frequency enables smaller magnetics

High Voltage & Temperature Capability
Tolerates higher voltages and temperatures

Fast Switching Speed
Improves dynamic response

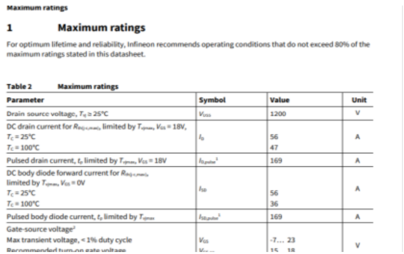
System Cost Optimization
Efficiency cuts cooling and passive costs



1) PV = photovoltaic inverter
2) OBC = on-board charger

WIDE-BANDGAP SEMICONDUCTOR TESTING
- DOUBLE-PULSE USE CASES

Datasheet generation



Maximum ratings

1 **Maximum ratings**

For optimum lifetime and reliability, Infineon recommends operating conditions that do not exceed 80% of the maximum ratings stated in this datasheet.

Table 2 Maximum ratings

Parameter	Symbol	Value	Unit
Drain source voltage, $T_{vj} \geq 25°C$	V_{DSS}	1200	V
DC drain current for $R_{th(j-c,max)}$, limited by T_{vjmax}, V_{GS} = 18V, T_C = 25°C T_C = 100°C	I_D	 56 47	A
Pulsed drain current, t_p limited by T_{vjmax}, V_{GS} = 18V	$I_{D,pulse}$[1]	169	A
DC body diode forward current for $R_{th(j-c,max)}$, limited by T_{vjmax}, V_{GS} = 0V T_C = 25°C T_C = 100°C	I_{SD}	 56 36	A
Pulsed body diode current, t_p limited by T_{vjmax}	$I_{SD,pulse}$[1]	169	A
Gate-source voltage[2] Max transient voltage, < 1% duty cycle Recommended turn-on gate voltage	 V_{GS}	 -7… 23 15 … 18	V

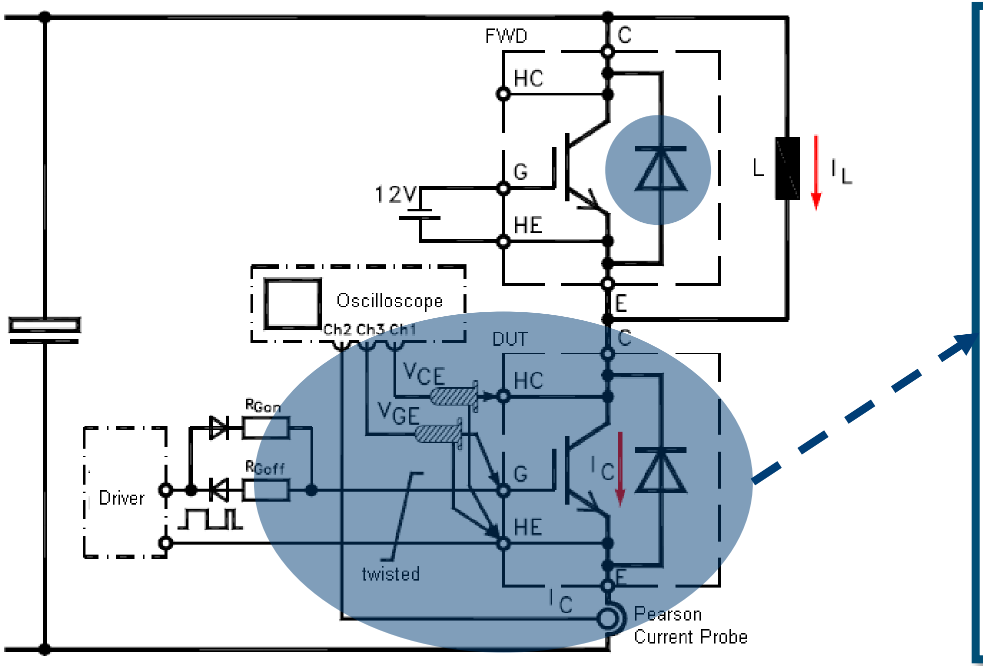
Converter Design

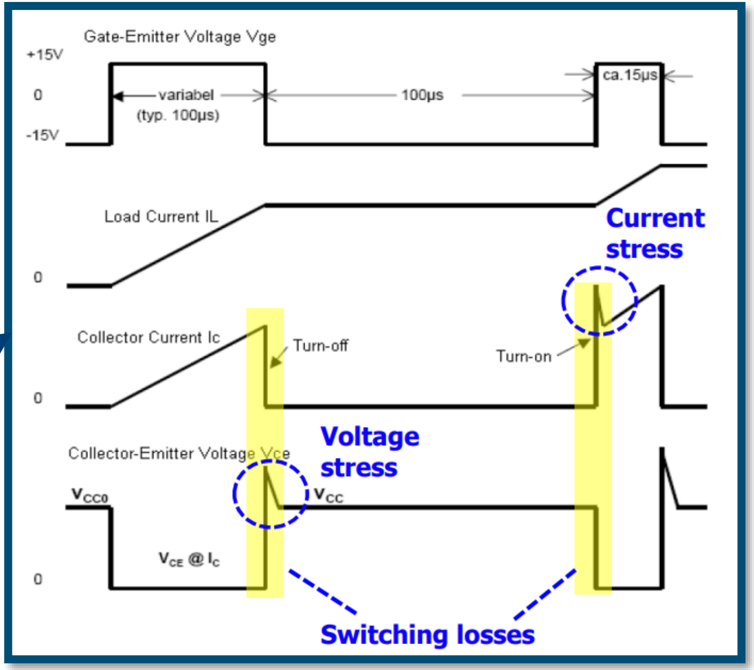
Module selection

- Double-pulse test allows to cover all four basic operation modes

- **All main parameters can be measured**
  - Switching losses
  - Reverse recovery losses
  - Switching times
    - Turn-on and turn-off delay time
    - Rise and fall times

WIDE-BANDGAP SEMICONDUCTOR TESTING
-DOUBLE-PULSE TESTING



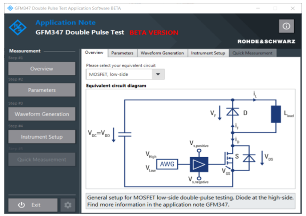


DOUBLE-PULSE TESTING
-TYPICAL SETUP

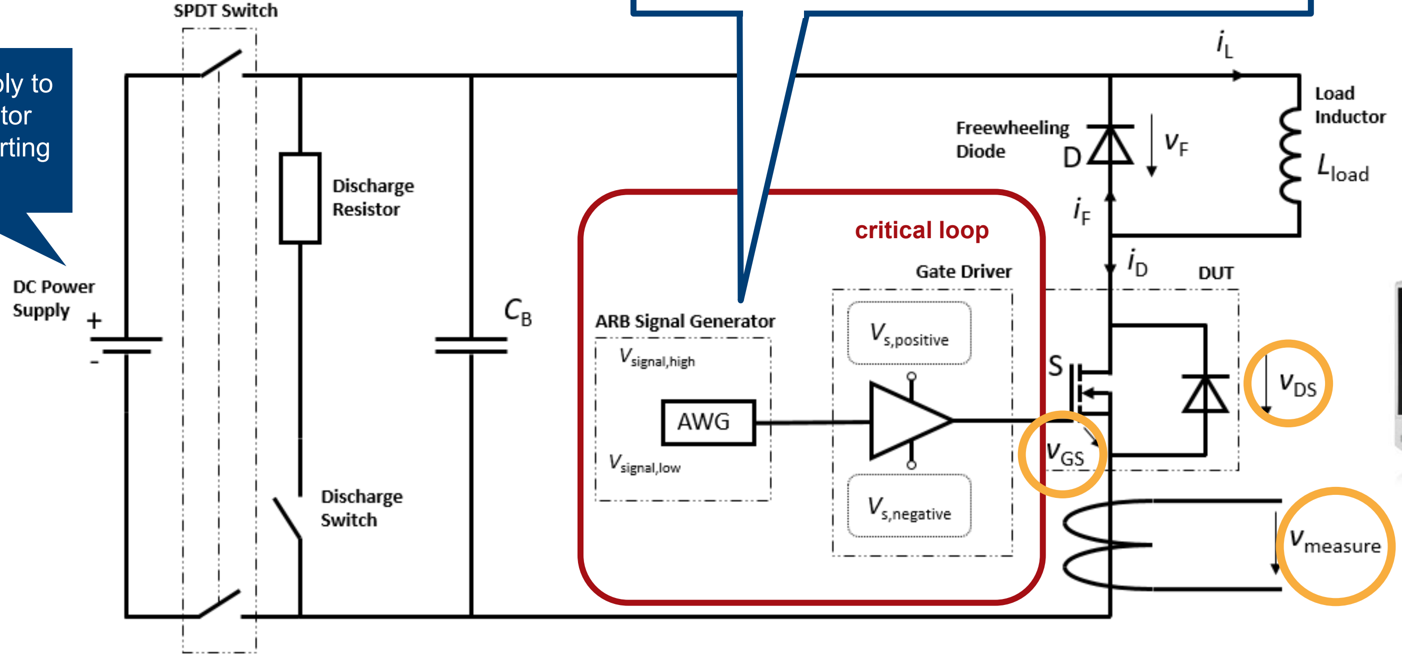
HMF2550 ARB Generator

RTM3000 Oscilloscope

DBT SW



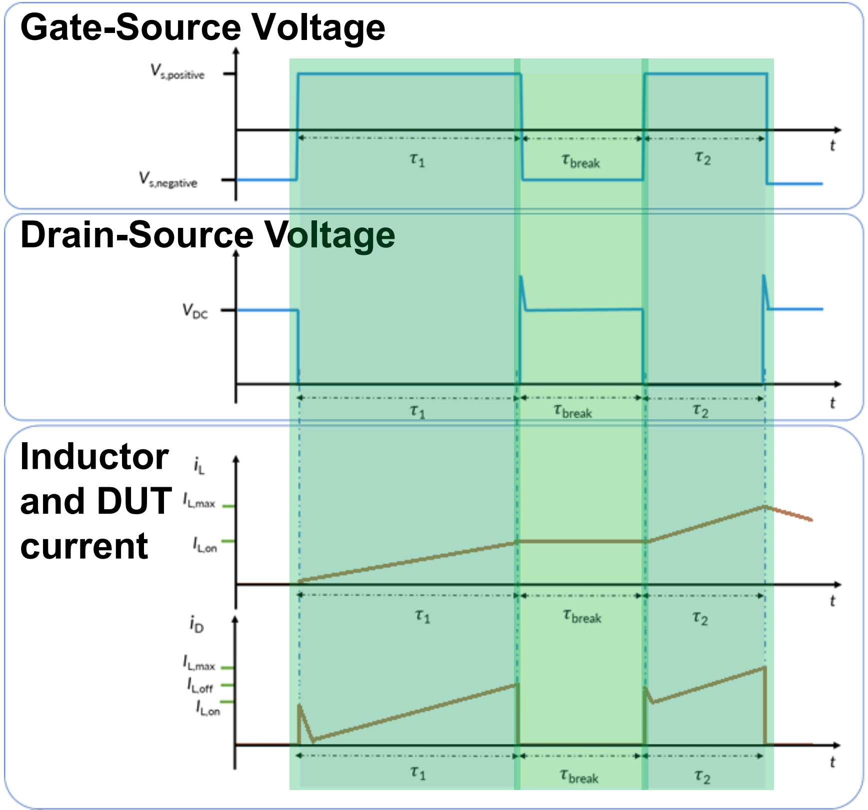
DC Power Supply to charge capacitor bank before starting the test

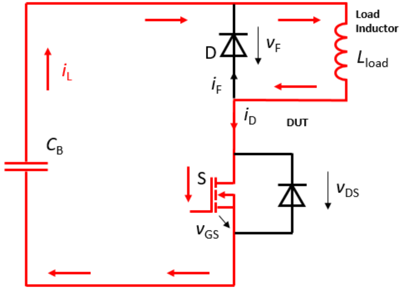


MXO 4 Oscilloscope

RTM3000 Oscilloscope

DOUBLE-PULSE TESTING
-THEORY AND TEST PROCEDURE



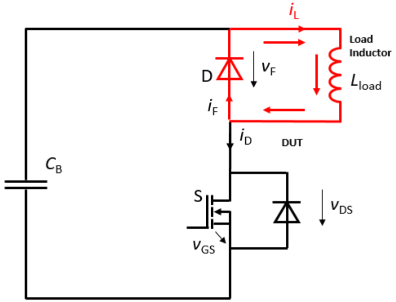


Interval τ_1

Low-side switch turn on

Voltage is applied to the inductor

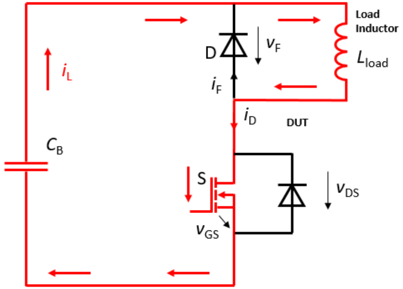
Inductor current rises linearly



Interval τ_{break}

Low-side switch turn off

Inductor current freewheels through the diode

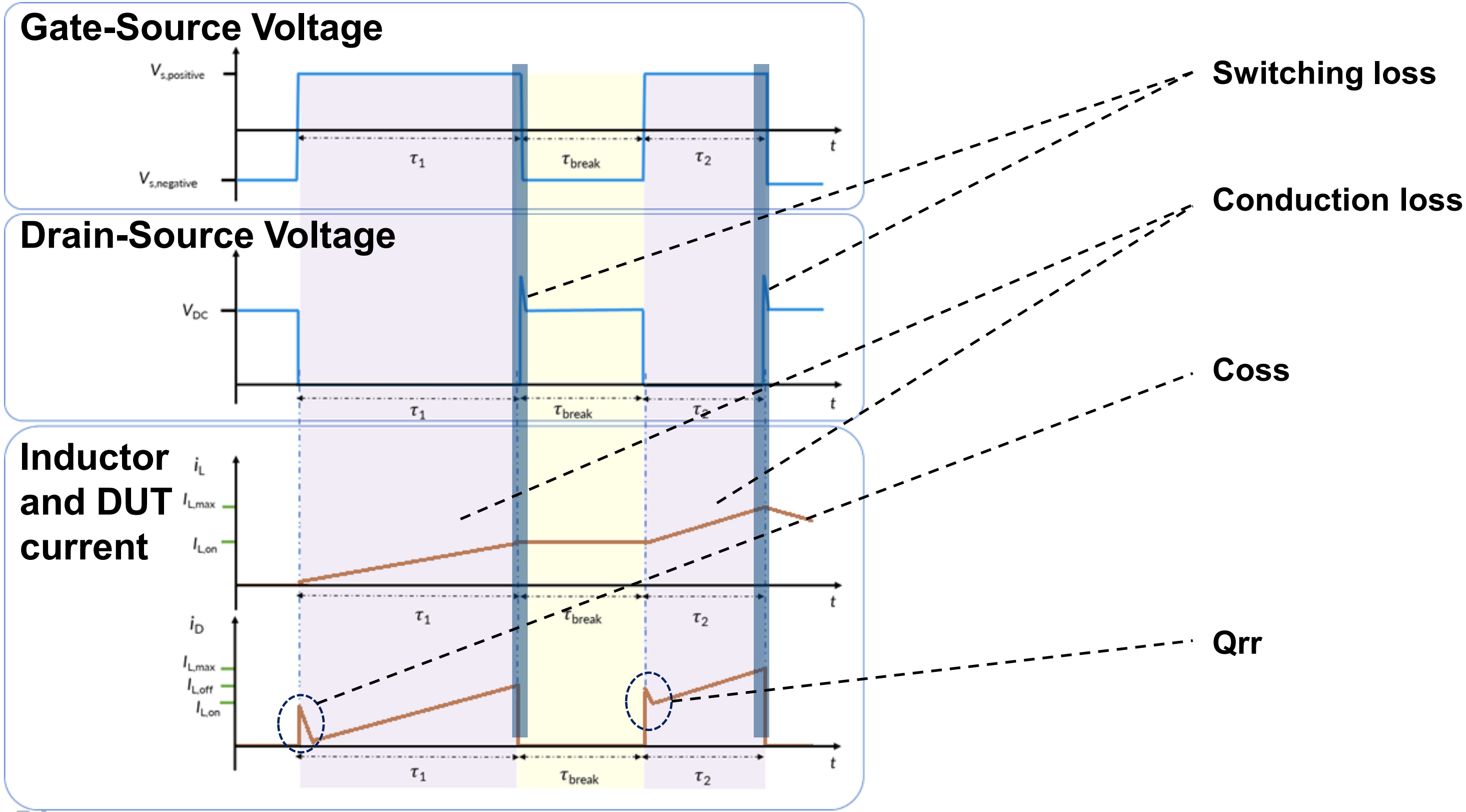


Interval τ_2

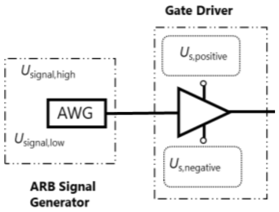
Low-side switch turn on again

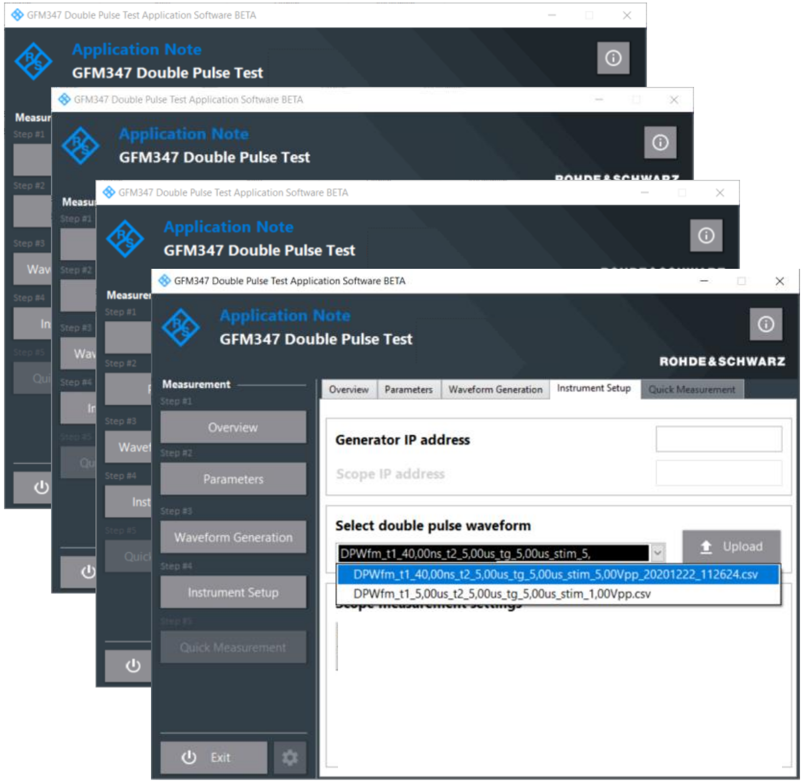
Reverse recovery current can be captured on the probe

DOUBLE-PULSE TESTING
-THEORY AND TEST PROCEDURE



SETTING UP THE MEASUREMENT
-R&S DOUBLE PULSE TEST TOOL

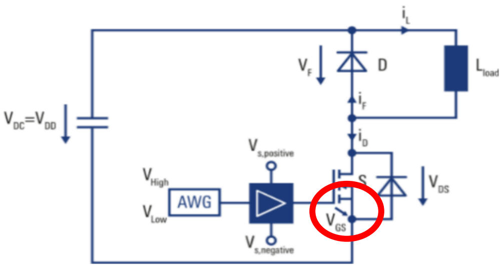
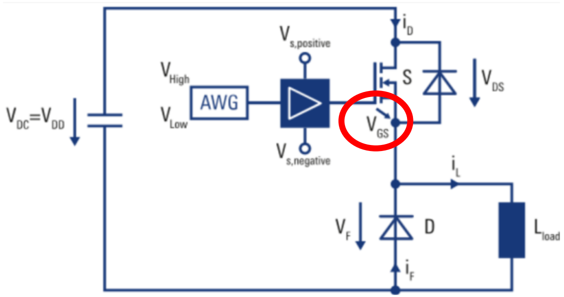




- **Important considerations**
  - Right signal levels
  - Correct pulse width setting

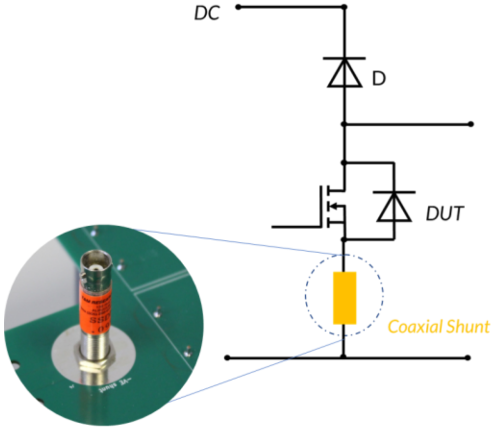
- **Tipp:** Always check ARB signal when creating new setup

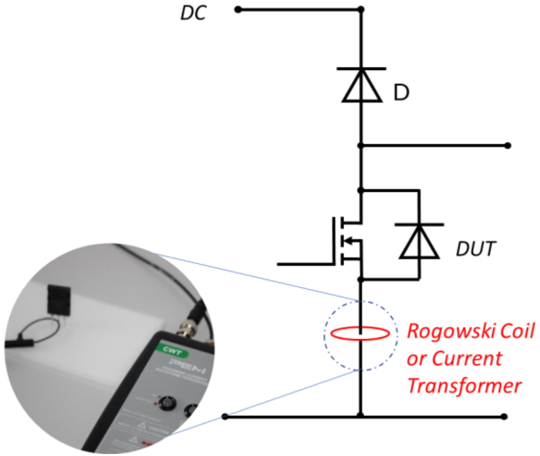
SETTING UP THE MEASUREMENT
-VOLTAGE PROBING

Low side gate driver measurement	High side gate driver measurement
  	 
► Very high bandwidth ► Input voltage range of +/-50V Tips: Avoid long ground leads	► Measurements with highest precision ► High CMRR to suppress switch-node signal
Probe:**RT-ZP11 / RT-ZS10**	Probe:**RT-ZISO**

SETTING UP THE MEASUREMENT
-CURRENT PROBING

- **Basic requirements**
  - High measurement bandwidth
  - Sensor as small as possible
  - Low insertion inductance

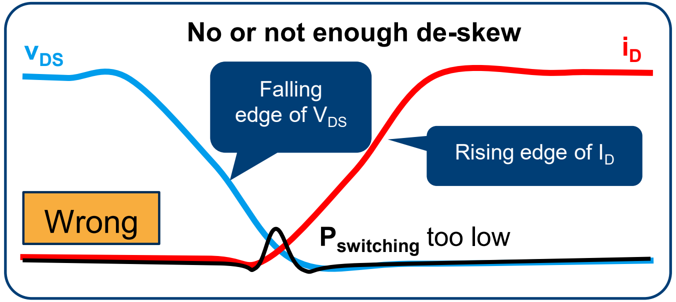


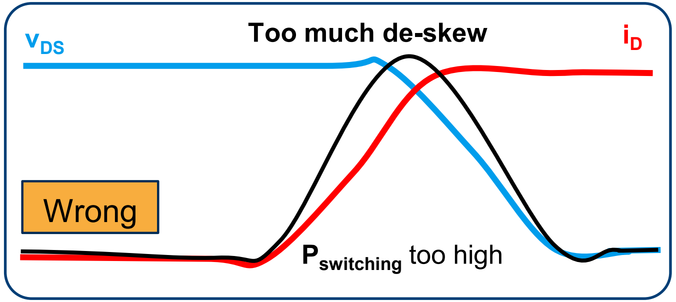


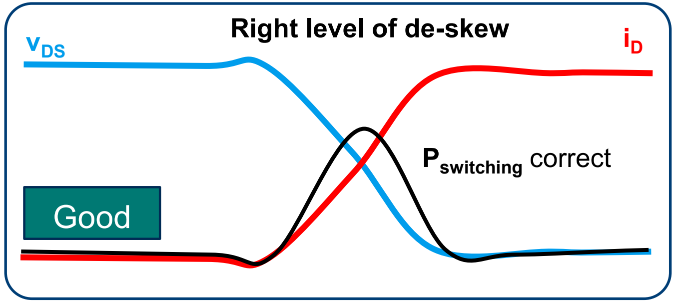
	Coaxial shunt	Rogowski probe	Current transformer
Pro's	• Very high bandwidth (2 GHz) • DC-measurement capability • Very low insertion inductance	• Physically small, no "design-in" of sensor necessary	• High bandwidth (~200 MHz) • High current possible
Con's	• Limited maximum current • Design-in of sensor necessary	• Limited bandwidth (typically **30-50 MHz** but recently also higher bandwidth up to 100 MHz available) • Limited accuracy	• Large sensor with core, limits the possibility to have low-insertion inductance designs

SETTING UP THE MEASUREMENT
-DE-SKEW BASICS

- **Voltage and current probes have different group delay**
- **Examples**
  - High voltage differential probe: ~8 ns group delay
  - Clamp-on current probe: ~15 ns
  - Small loop Rogowski probes: ~12 – 20 ns
- **For accurate switching loss measurements the delay has to be compensated (De-skew)**

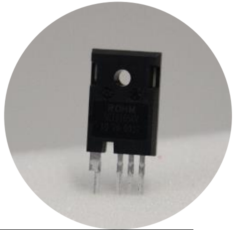


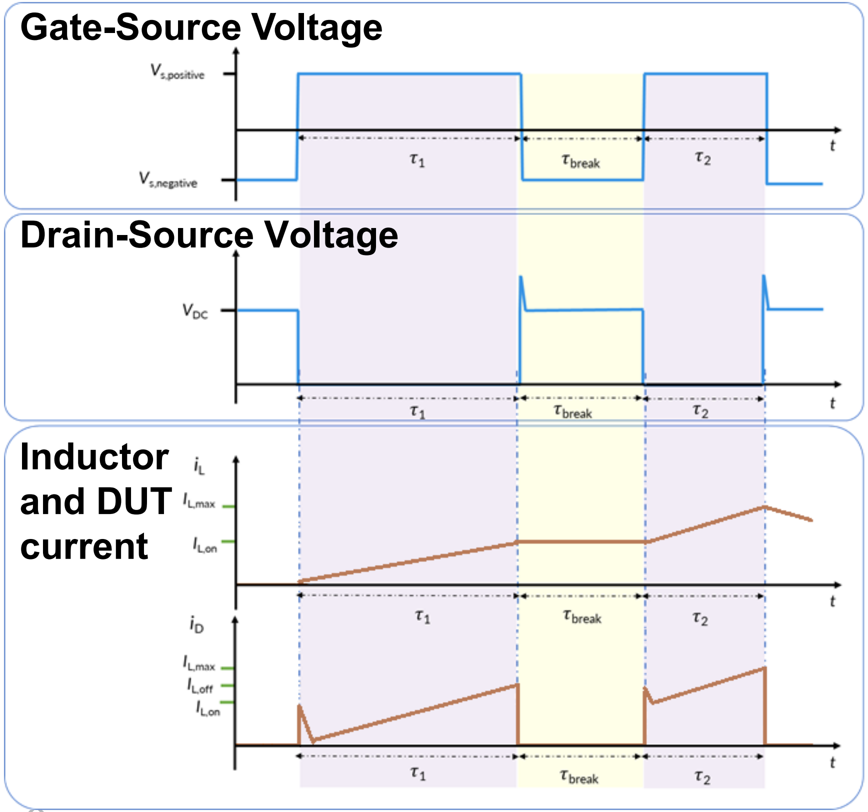


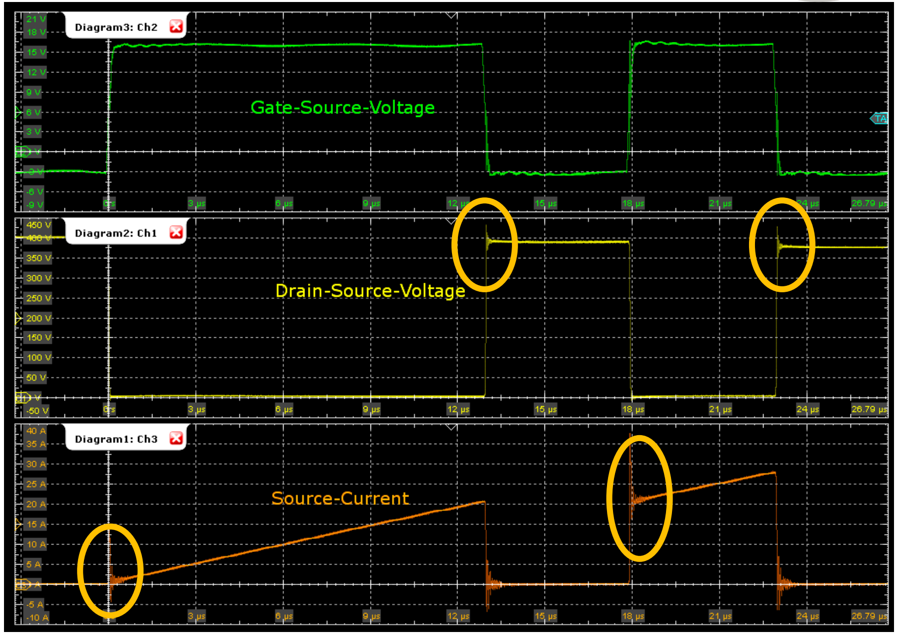


RT-ZF20 Power De-skew Fixture

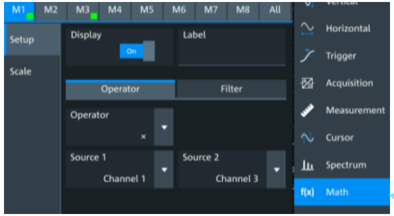
A PRACTICAL EXAMPLE



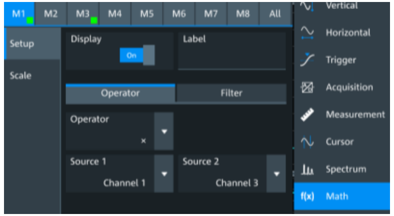




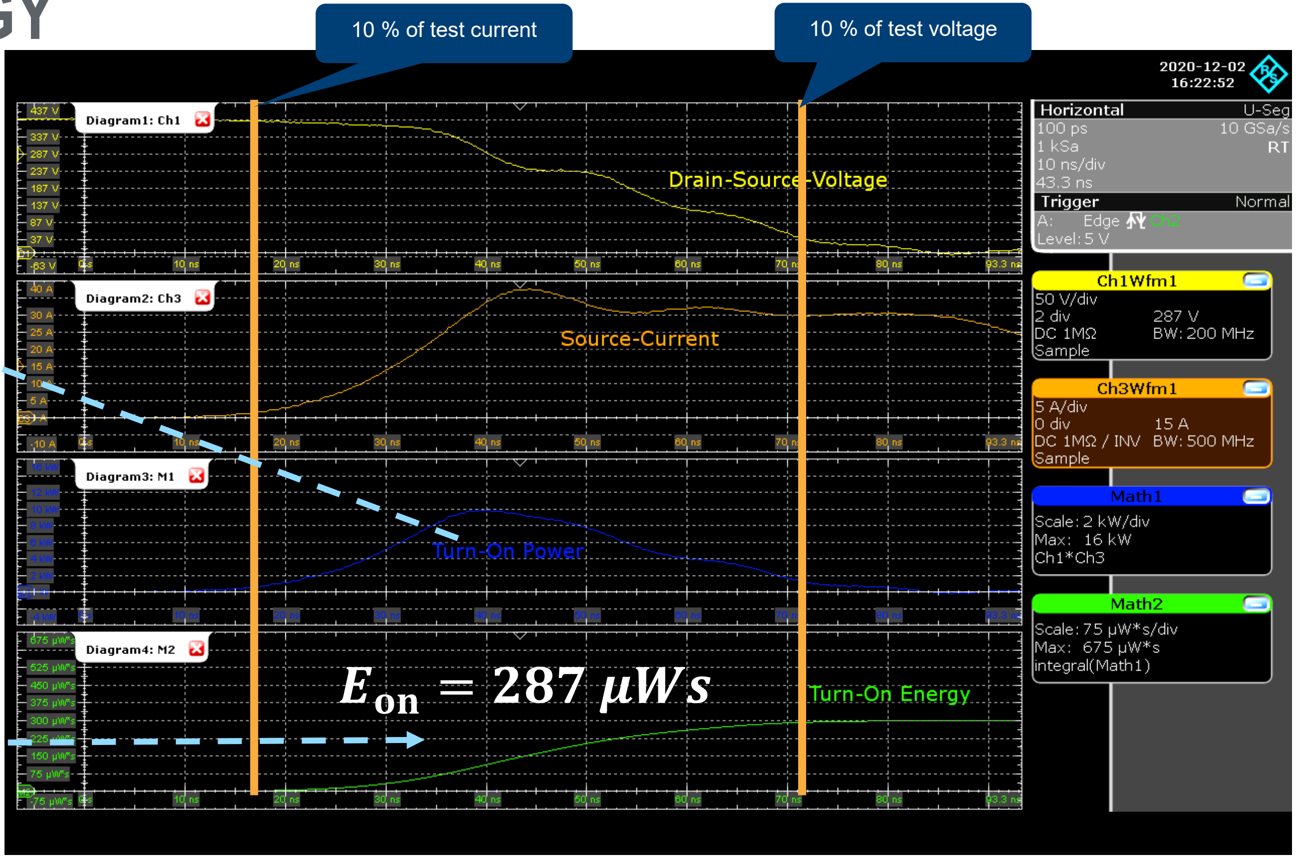
A PRACTICAL EXAMPLE
-TURN-ON ENERGY



$$P_{\text{turn-on}} = v_{\text{DS}}(t) \cdot i_{\text{D}}(t)$$

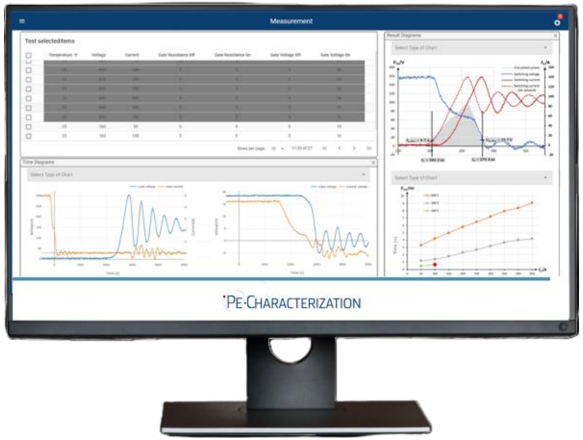


$$E_{\text{on}} = \int_{t_{I_{\text{test10}}}}^{t_{V_{\text{DC10}}}} P_{\text{turn-on}}\ dt$$

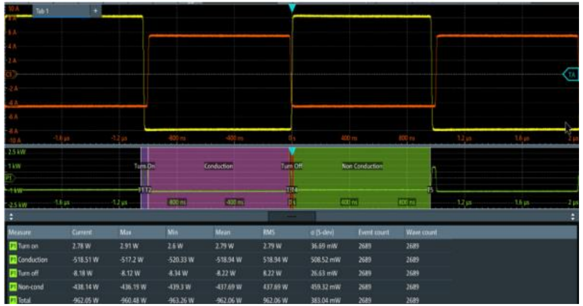


SOFTWARE SOLUTION

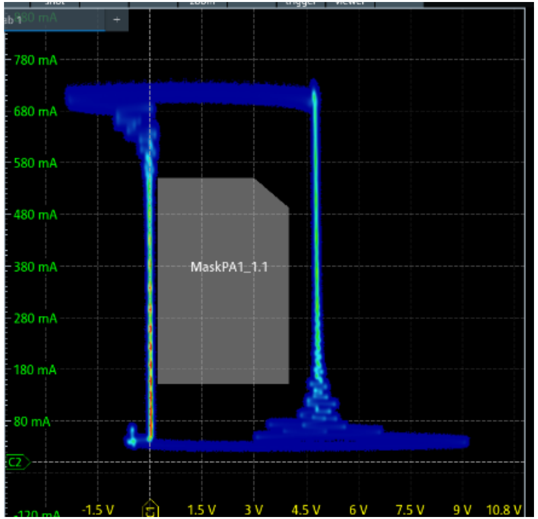
DPT Software

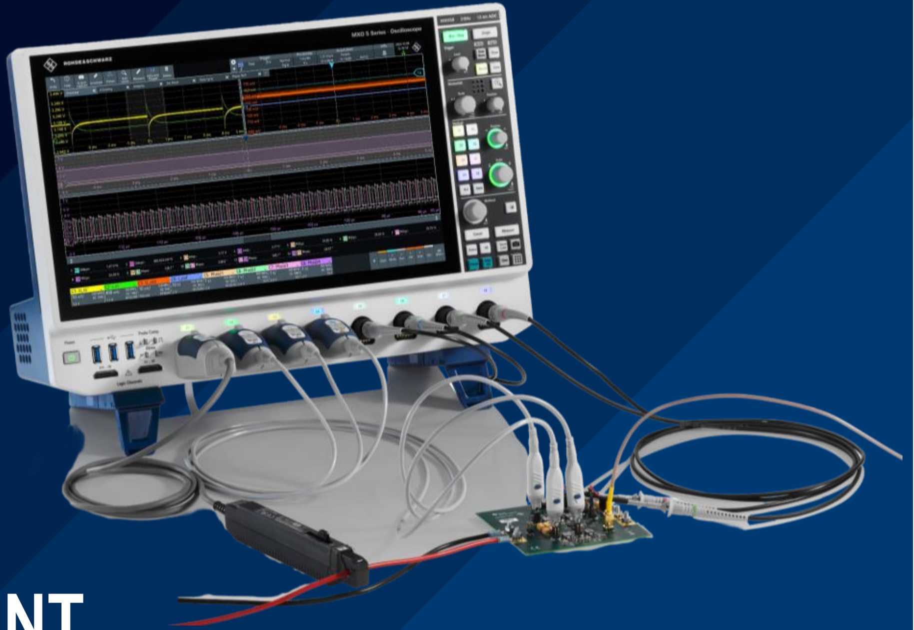


Switching Loss



SOA Measurement





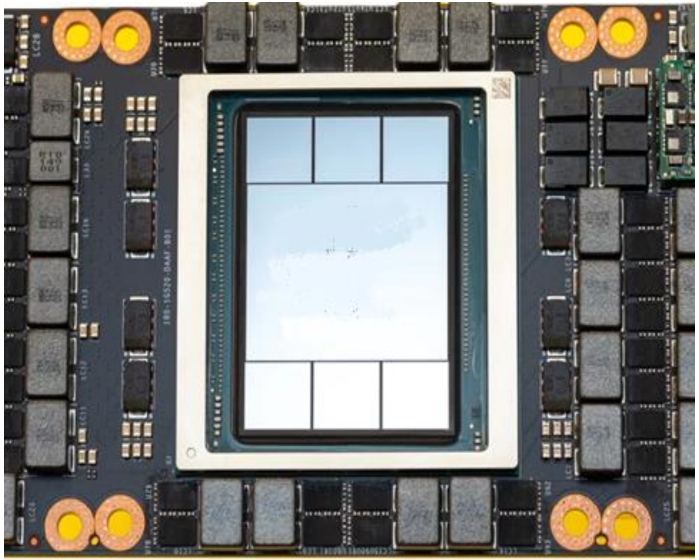
DIGITAL POWER MEASUREMENT

DIGITAL POWER MEASUREMENT CHALLENGES

High current
low voltage

High bandwidth
transient response

Advance control and
telemetry decoding



Probing challenges in
high-density design

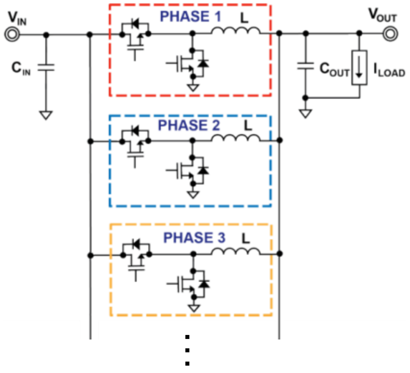
Power integrity and
noise

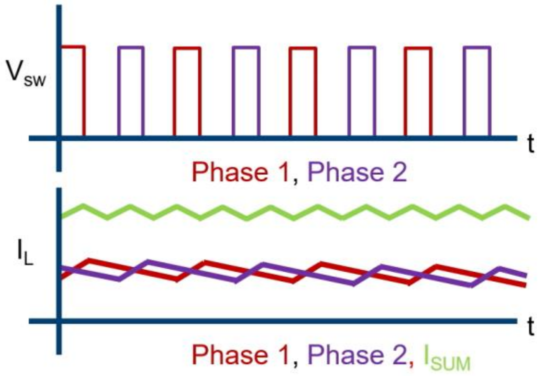
Power loss and
efficiency measurement

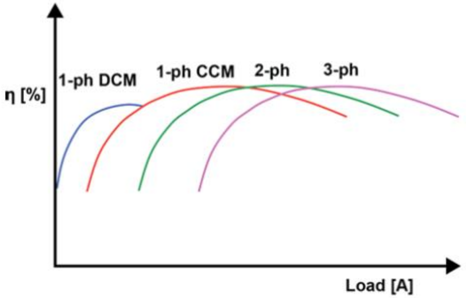
MULTIPHASE-PHASE BUCK CONVERTER

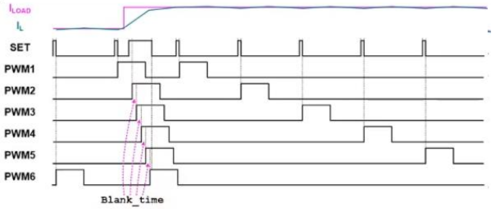
Benefits:

- ► Reduced voltage ripple
  → Reduce capacitor usage
- ► Phase management optimizes efficiency across loads
- ► Reduced thermal for high currents
- ► Improved load transient response time

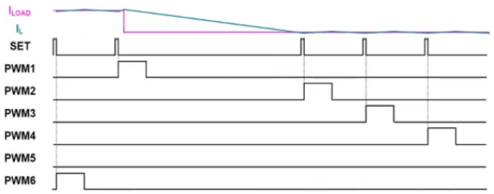








Load step up

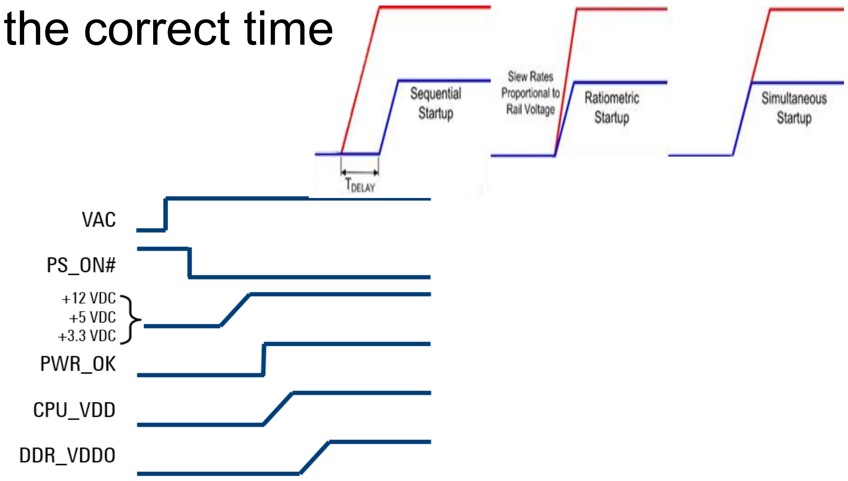


Load step down

MEASUREMENT CHALLENGES
- MULTI-PHASE CONTROL & POWER SEQUENCING

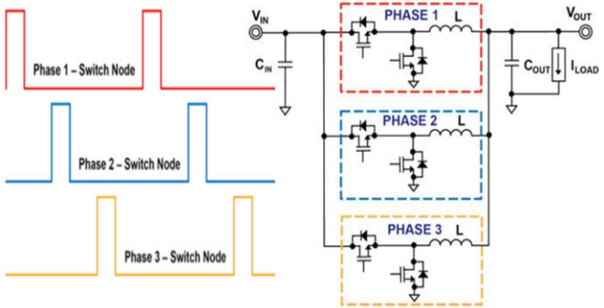
Timing Measurement

Ensure each component is turned on at the correct time



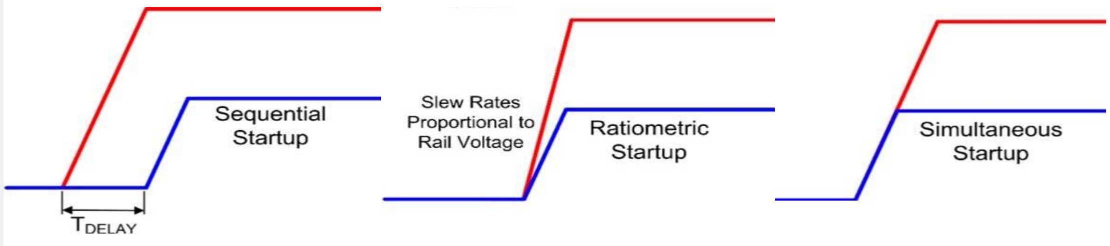
PWM Monitoring

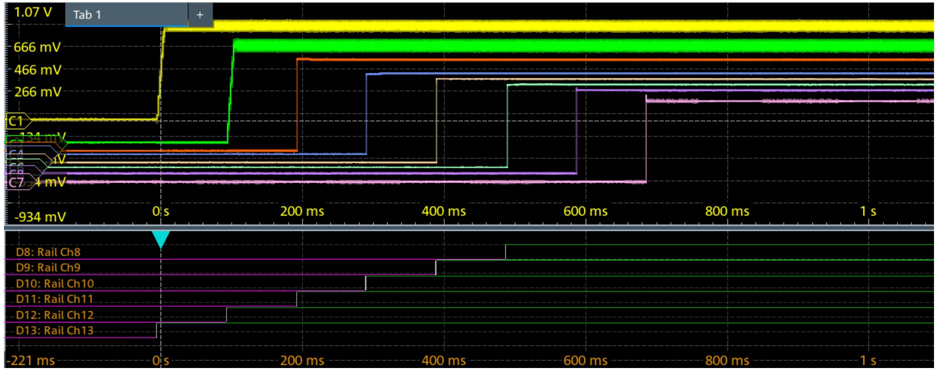
Analyze switching frequency, duty cycle, and phase to optimize efficiency & stability

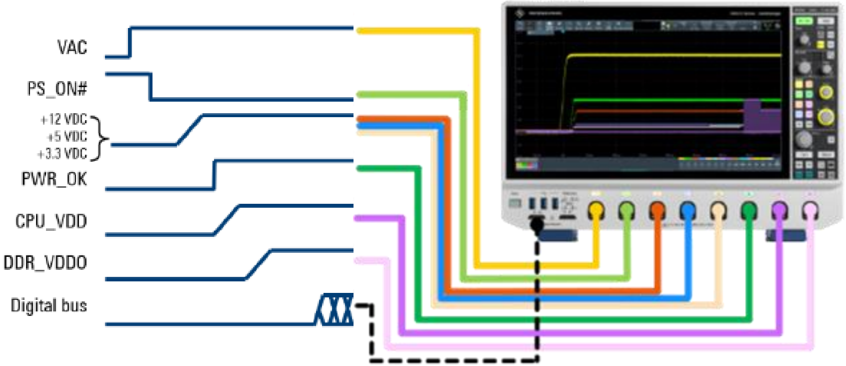


POWER SEQUENCING CHALLENGES & MEASUREMENT

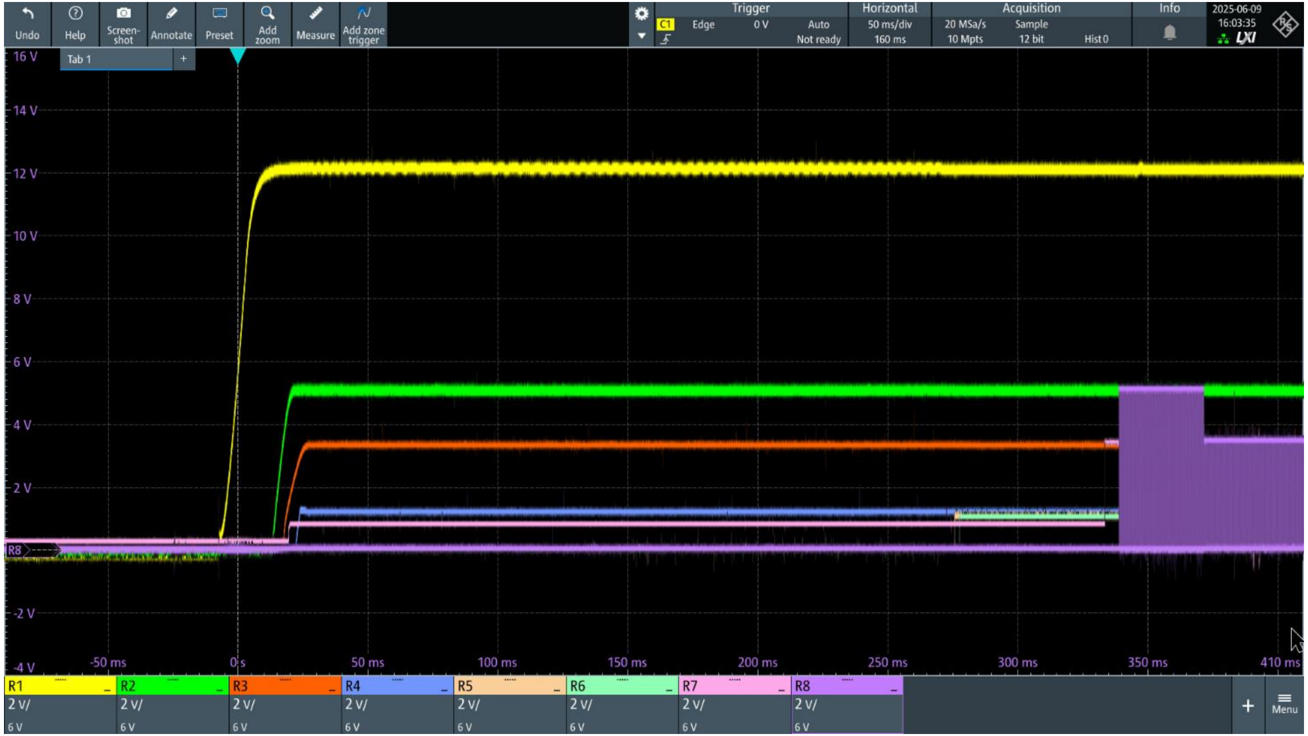
- Steeper slew rates
- Higher currents & lower voltage
- Multiple power rails
- Power supply noise and ripple





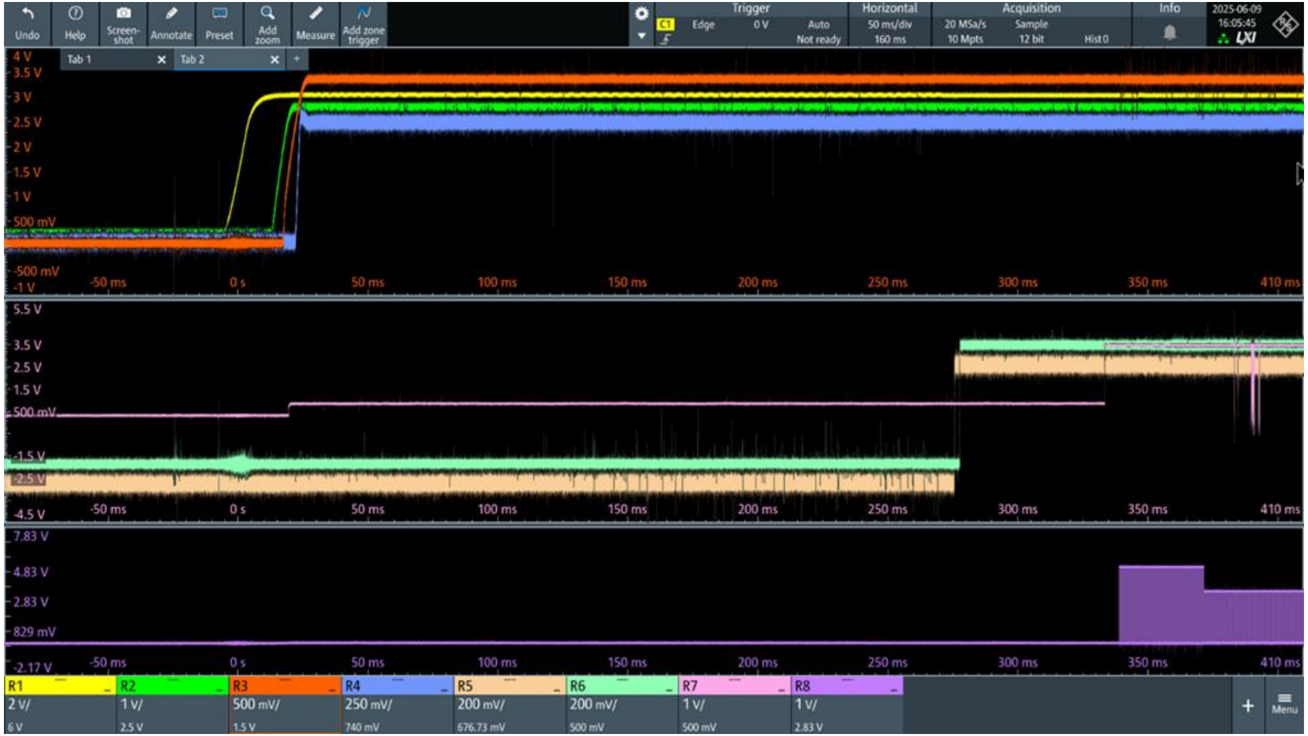


MULTI-PHASE CONTROL & POWER SEQUENCING -TIMING MEASUREMENT



Multi-channel for multi-rails measurement

MULTI-PHASE CONTROL & POWER SEQUENCING
-TIMING MEASUREMENT



Multi-channel for multi-rails measurement

Flexible UI settings for convenient signal observation

MULTI-PHASE CONTROL & POWER SEQUENCING -TIMING MEASUREMENT

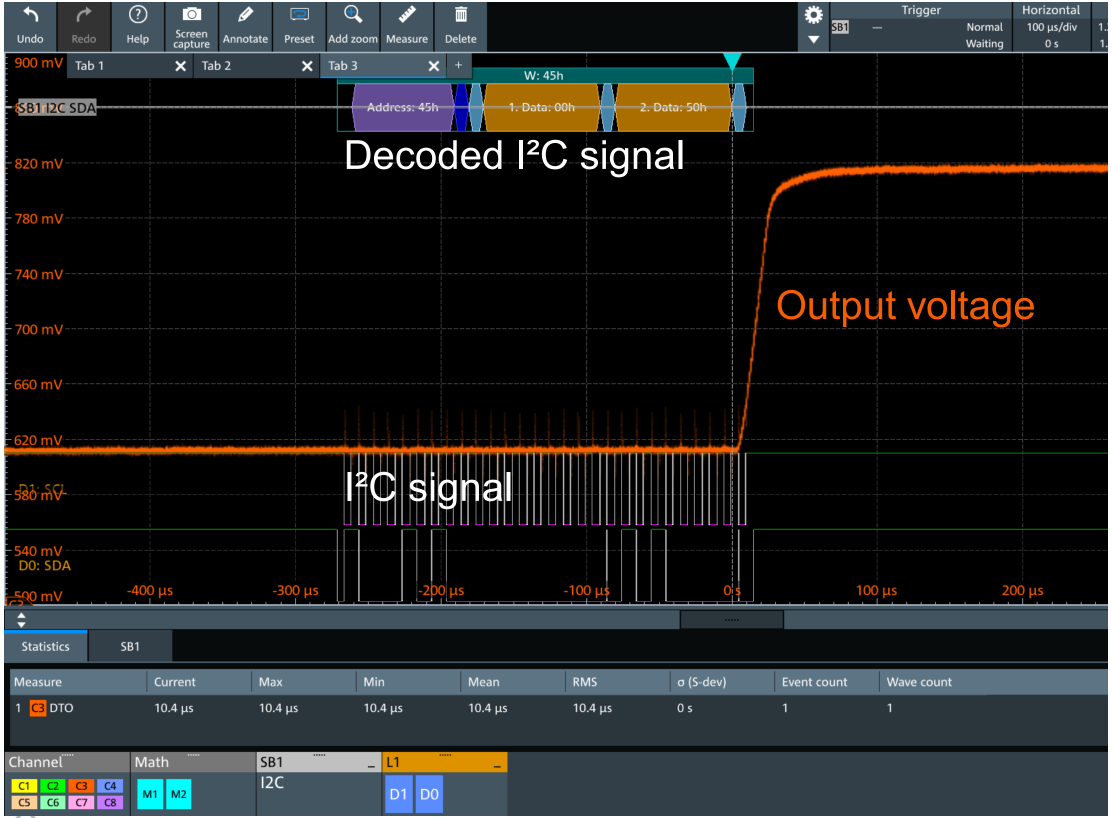
Multi-channel for multi-rails measurement

Flexible UI settings for convenient signal observation

Automated timing measurement

Custom level settings

MULTI-PHASE CONTROL & POWER SEQUENCING
-TIMING MEASUREMENT



Dynamic voltage and frequency scaling for control and monitoring

CPU controls voltage regulator

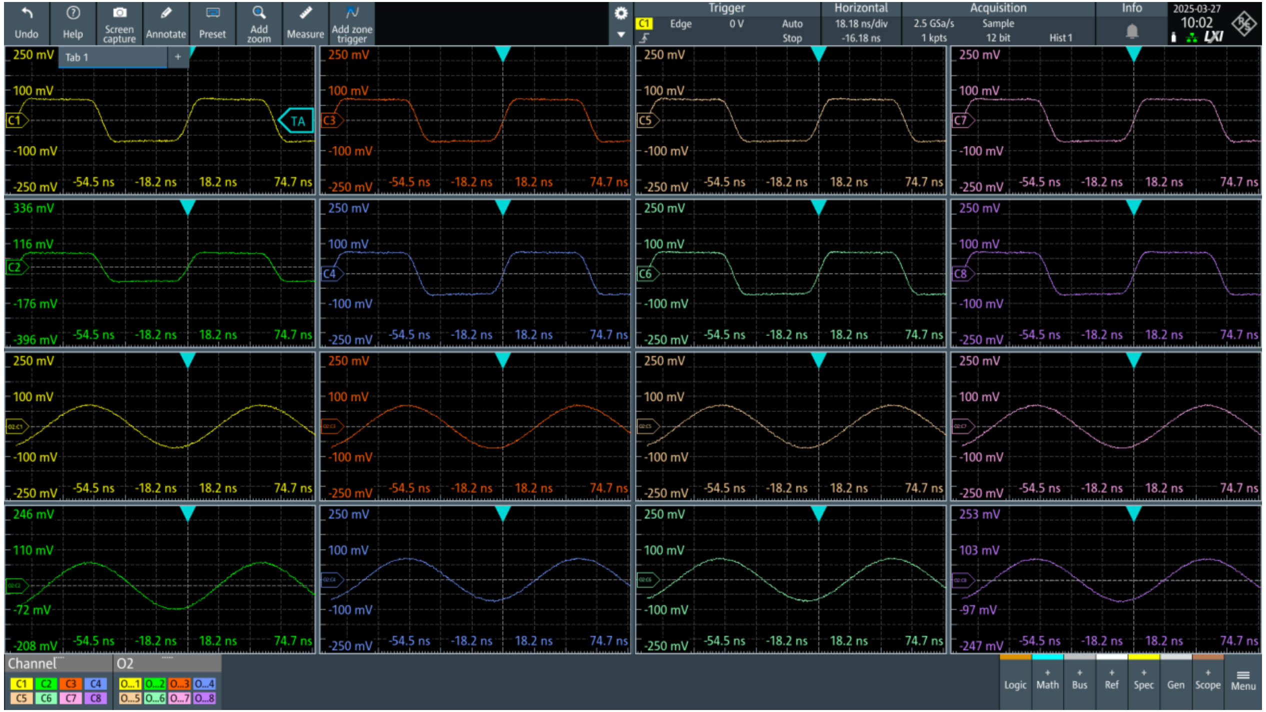
Adjust voltage based on processor load

- **High Load:** Increase voltage for performance.
- **Low Load:** Decrease voltage to save power.

Typical control interfaces:

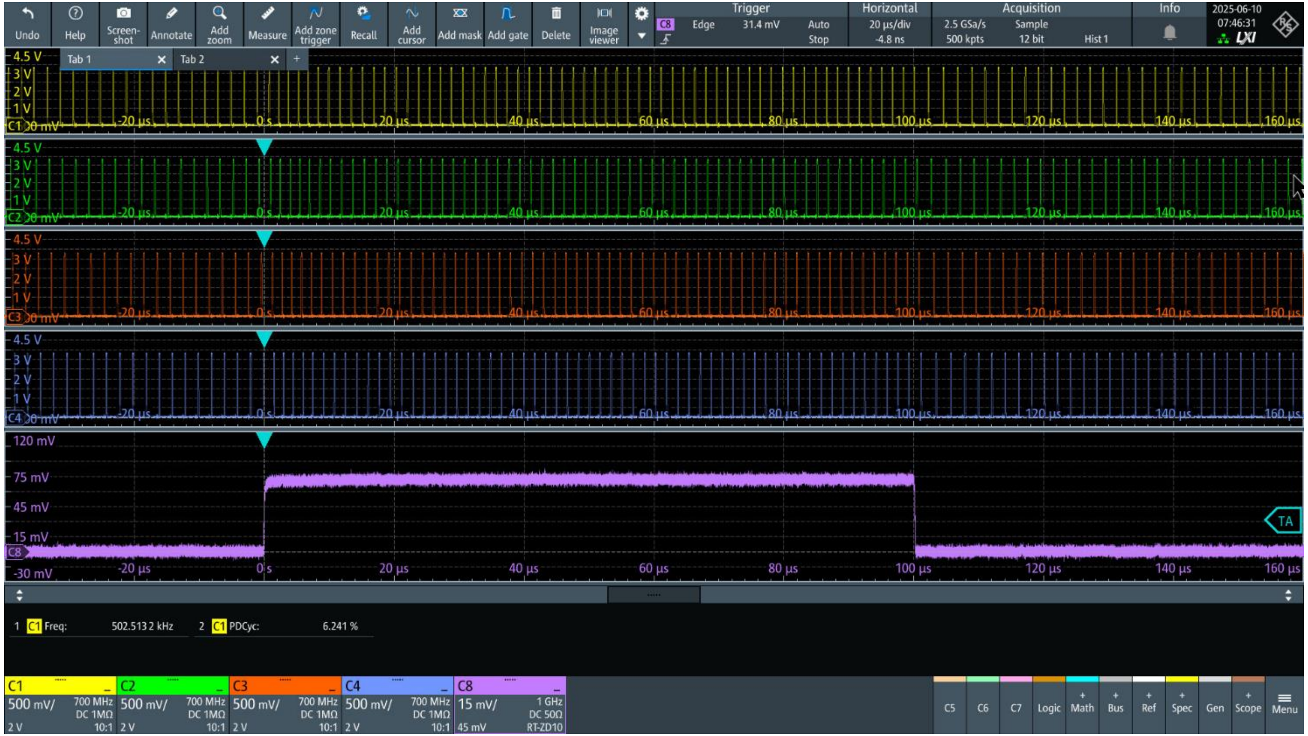
- I2C, SPI, SPMI, PMBus

MULTI-PHASE CONTROL & POWER SEQUENCING
-TIMING MEASUREMENT



ScopeSync displays waveforms from two oscilloscopes on one screen

MULTI-PHASE CONTROL & POWER SEQUENCING
-PWM MONITORING



Pulse-width modulation (PWM) control of sinusoids

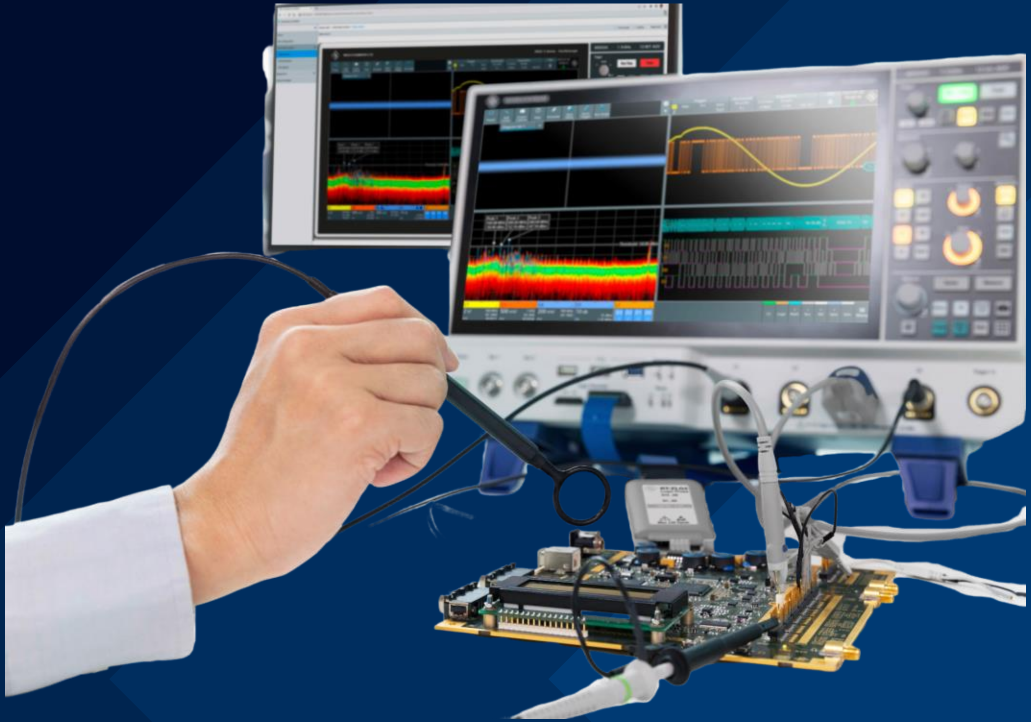
MULTI-PHASE CONTROL & POWER SEQUENCING
-PWM MONITORING

Pulse-width modulation (PWM) control of sinusoids

Track shows the variation of a parameter for each cycle of the waveform

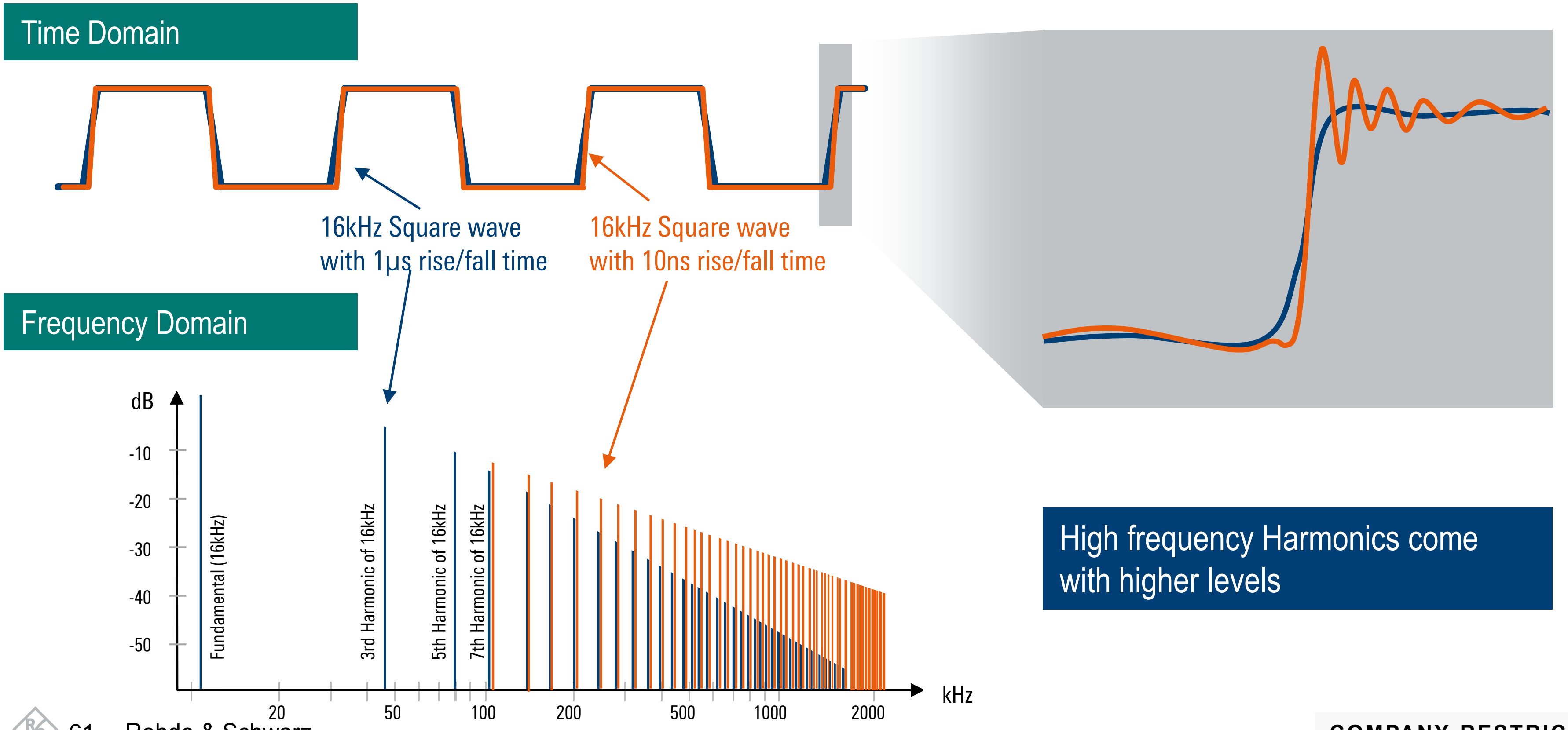
Pulse duration of PWM react as load changes

AI-powered automatic verification software



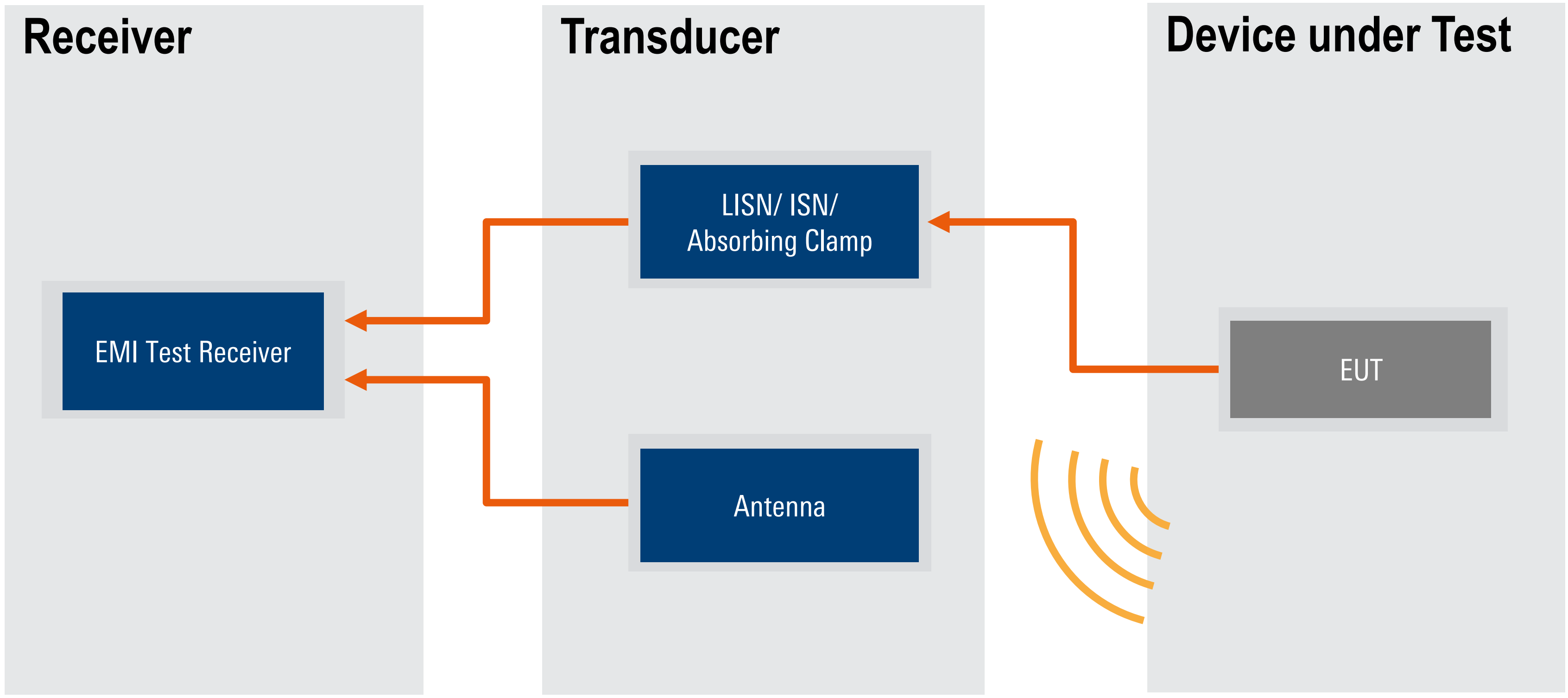
EMI DEBUGGING

IMPACT OF FASTER SWITCHING AND STEEP EDGES ON EMI

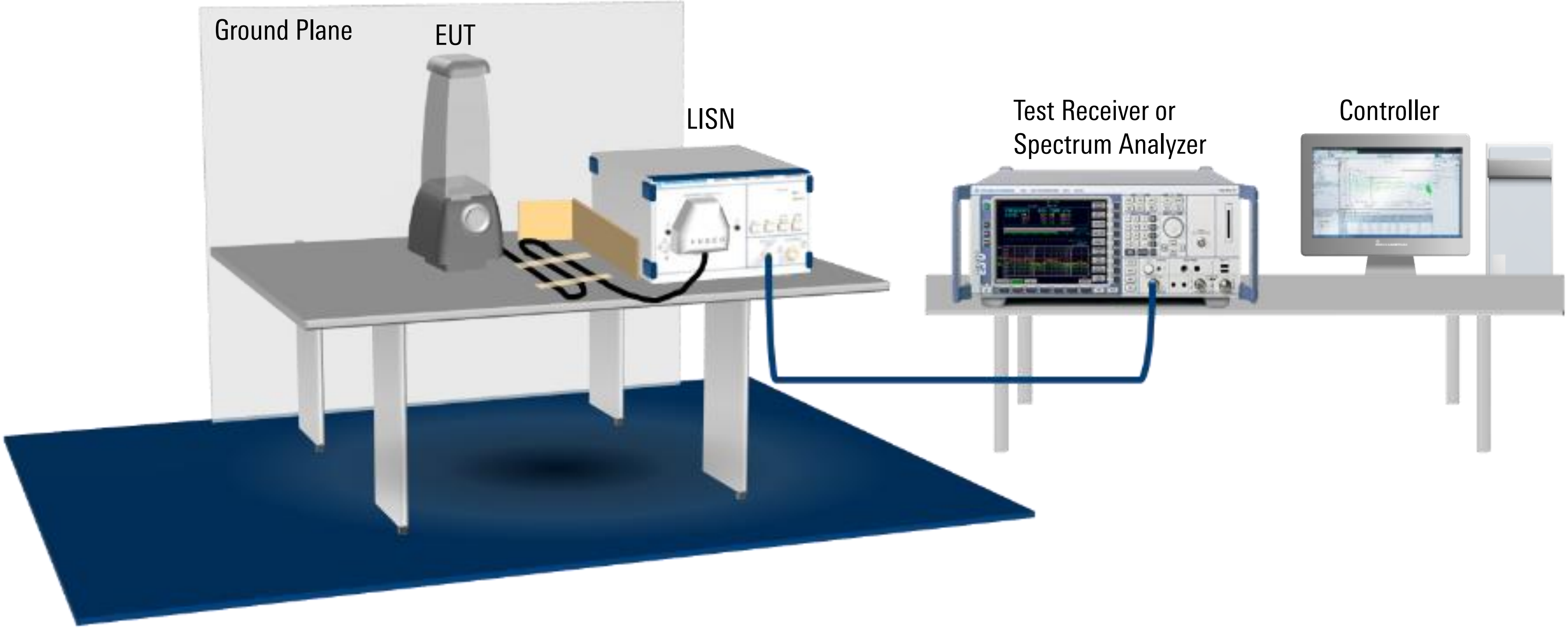


High frequency Harmonics come with higher levels

SYSTEM CONFIGURATION
EMI COMPLIANCE

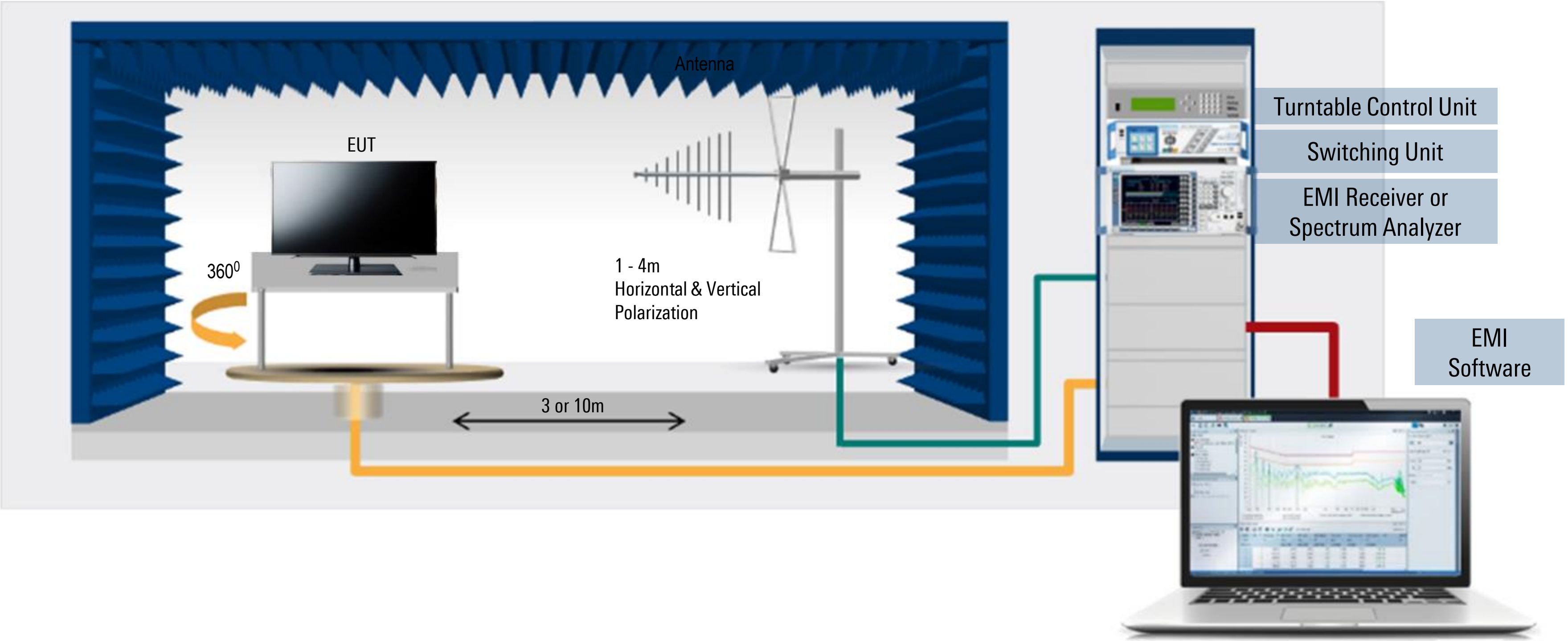


SYSTEM CONFIGURATION
CONDUCTED EMISSIONS TEST

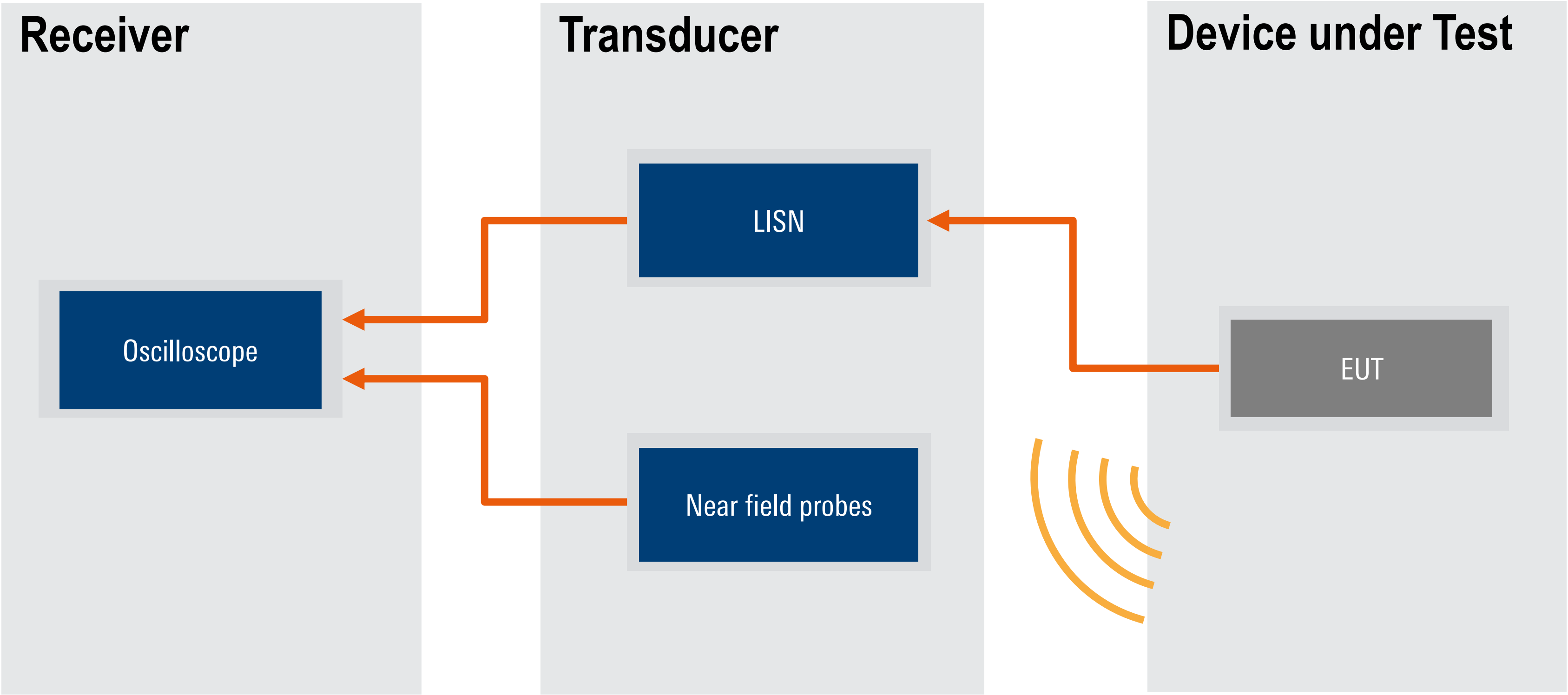


COMPANY RESTRICTED

SYSTEM CONFIGURATION
RADIATED EMISSIONS TEST

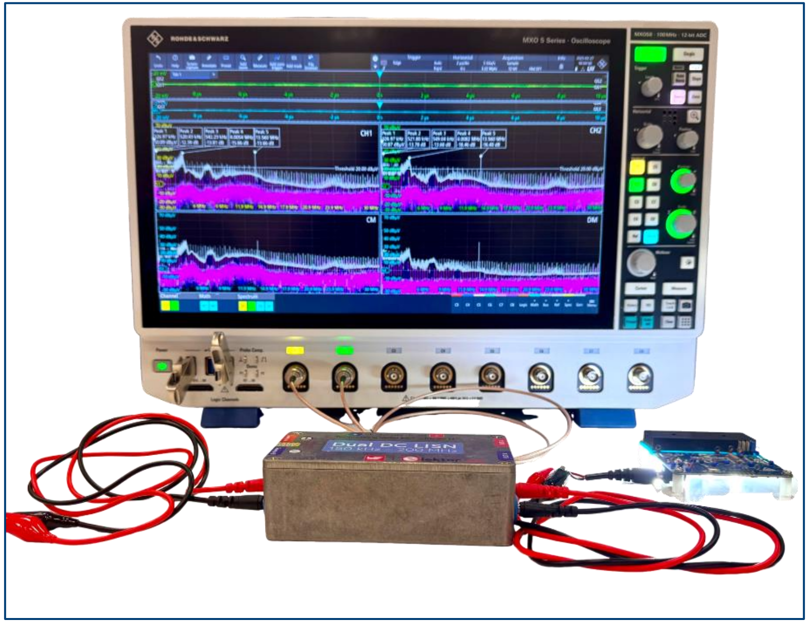


SYSTEM CONFIGURATION
EMI DEBUGGING



SYSTEM CONFIGURATION
EMI DEBUGGING

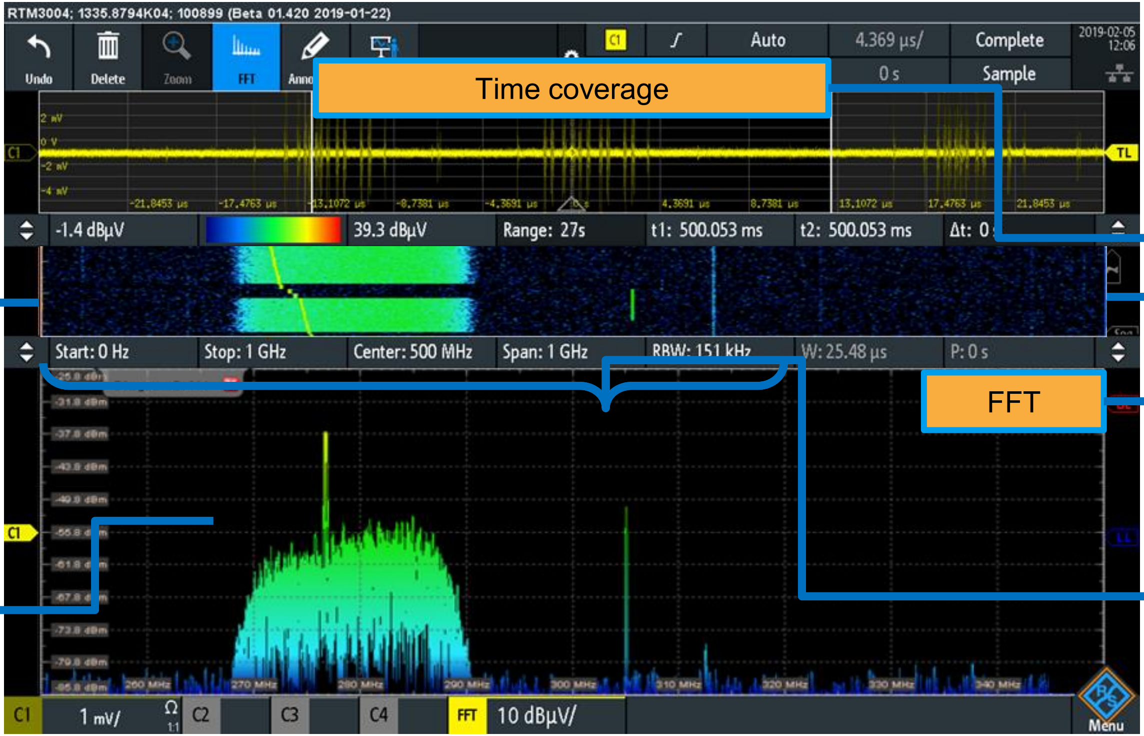
Radiated Emission	Conducted Emission



MODERN SCOPE FFT CAPABILITIES
CORRELATION OF TIME AND FREQUENCY INFORMATION

Waterfall diagram helps to show short emissions

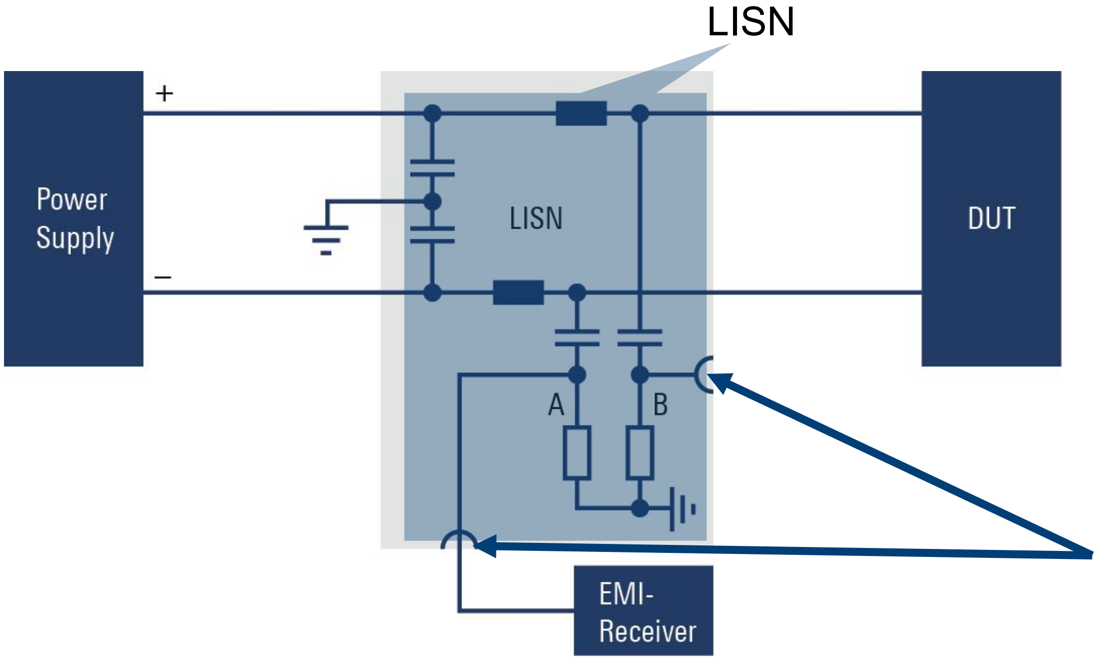
Color coding display for better visibility



Time-frequency correlation of emissions

Directly set start, stop and resolution bandwidth

CONDUCTED EMISSION DEBUGGING
CONDUCTED EMISSION SETUP



Measurement is required on both power lines

CONDUCTED EMISSION DEBUGGING
TRANSMISSION MODES

Common Mode

Noise on all lines propagating in the **same direction with respect to earth**

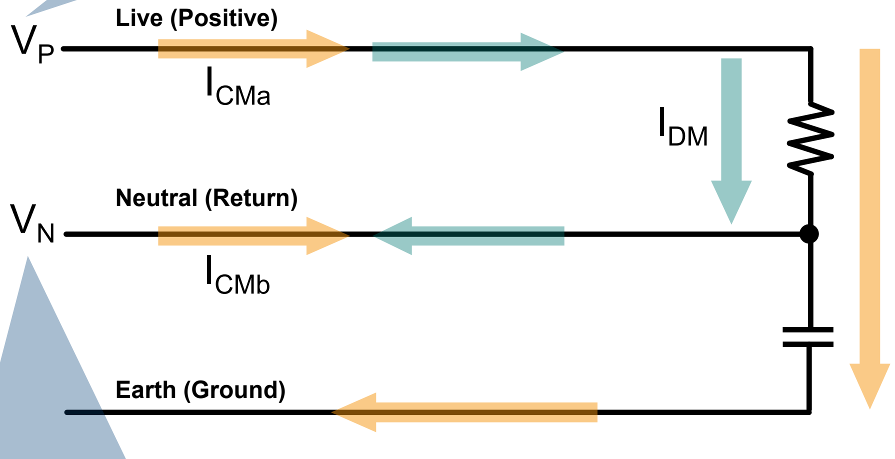
$$V_{CM} = V_P + V_N$$

Differential Mode

Noise or signals on a **line(s) with a return path**

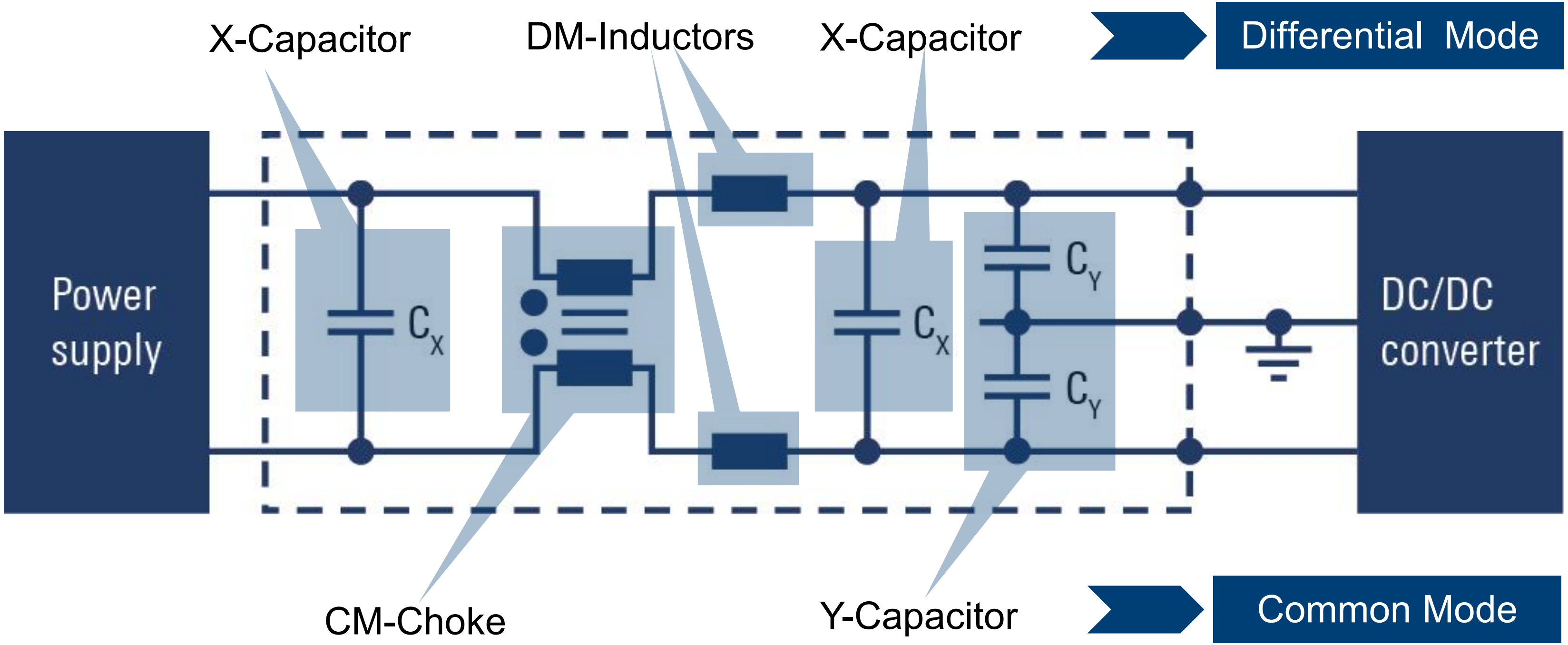
$$V_{DM} = \frac{V_P + (-V_N)}{2}$$

$$V_P = (I_{CM_a} + I_{DM}) * Z_{LISN}$$



$$V_N = (I_{CM_b} - I_{DM}) * Z_{LISN}$$

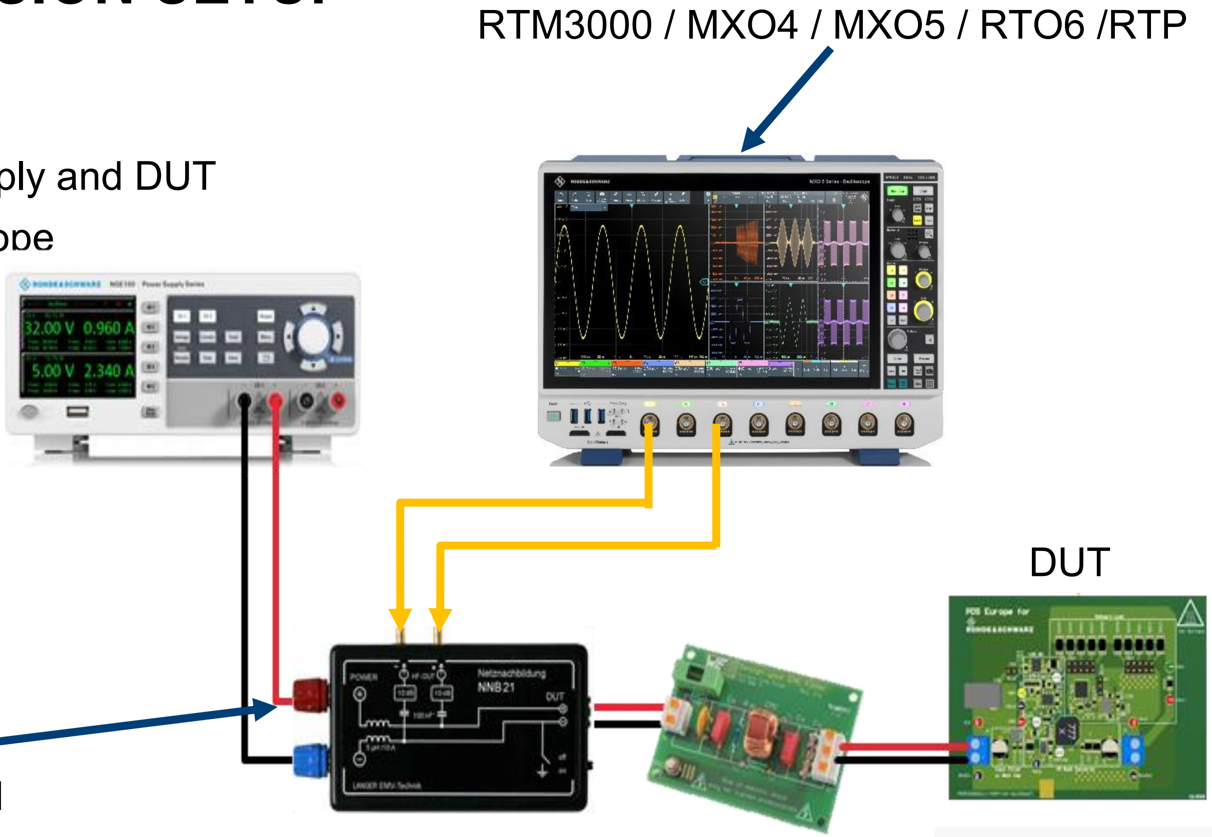
CONDUCTED EMISSION DEBUGGING
EMI INPUT FILTER STRUCTURE



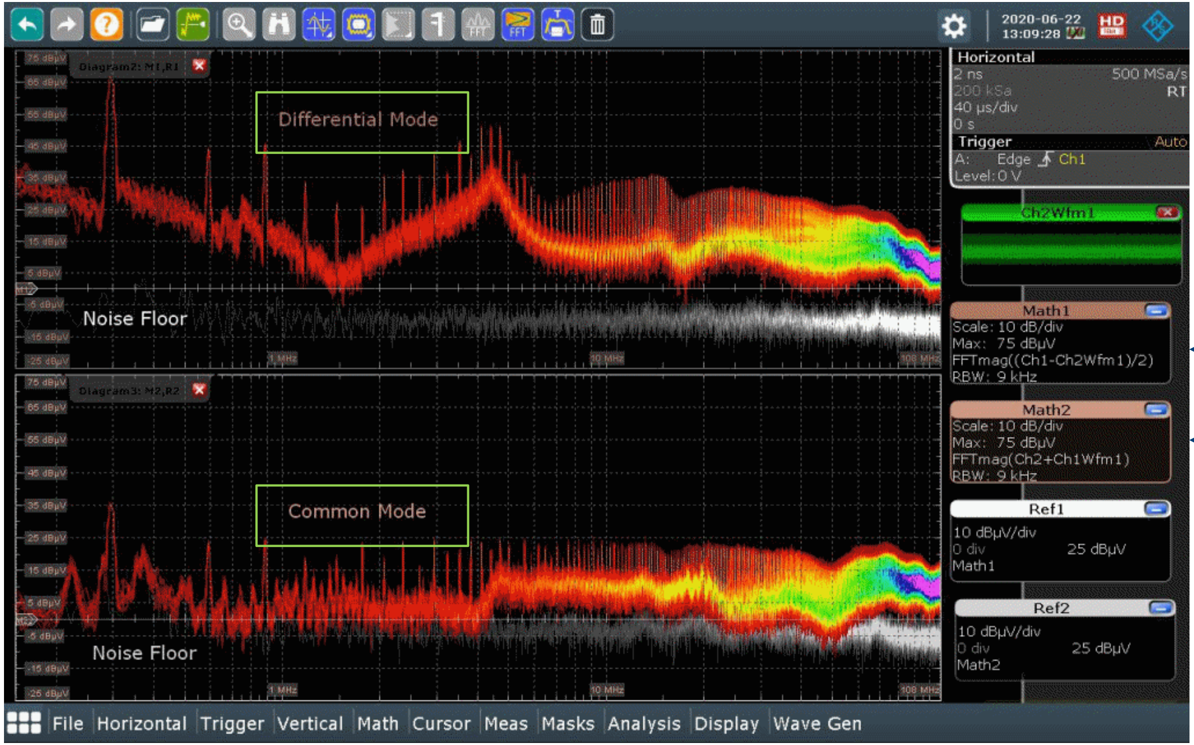
CONDUCTED EMISSION DEBUGGING
CONDUCTED EMISSION SETUP

Oscilloscope

- 50 Ohm connection to LISN
- Connect LISN between supply and DUT
- Use Spectrum on Oscilloscope



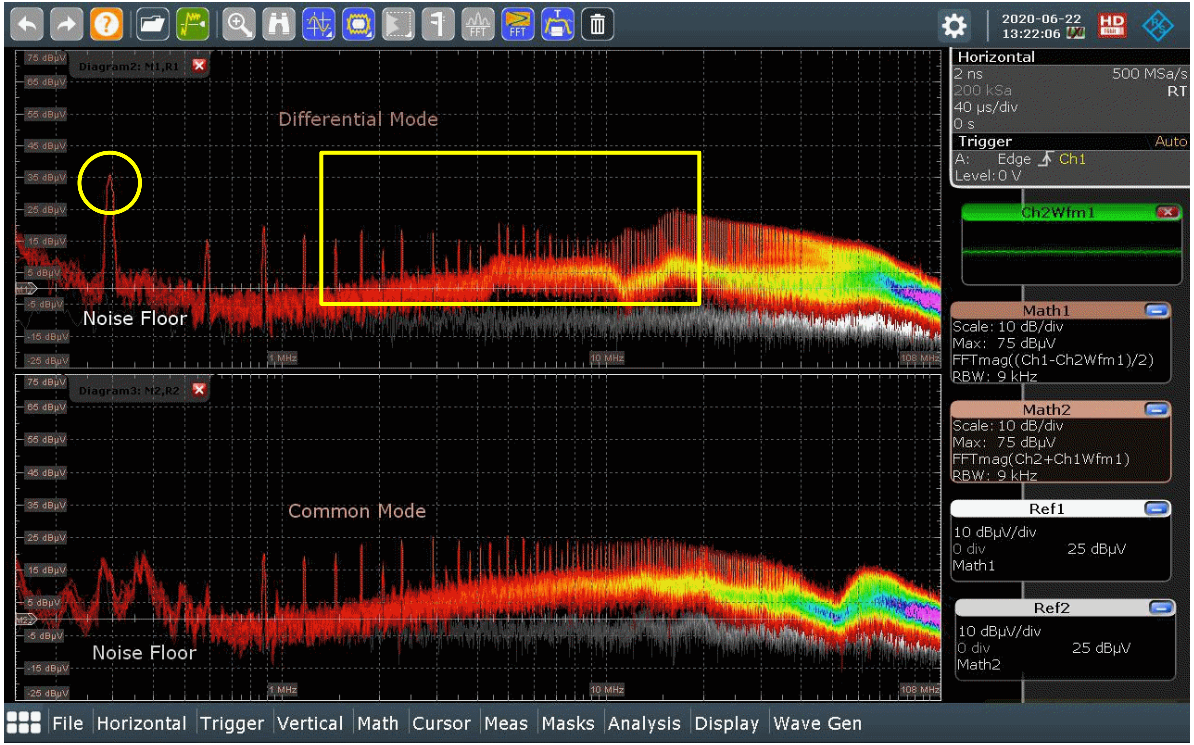
CONDUCTED EMISSION DEBUGGING CASE STUDY
NO FILTERING



$$V_{DM} = \frac{V_P + (-V_N)}{2}$$

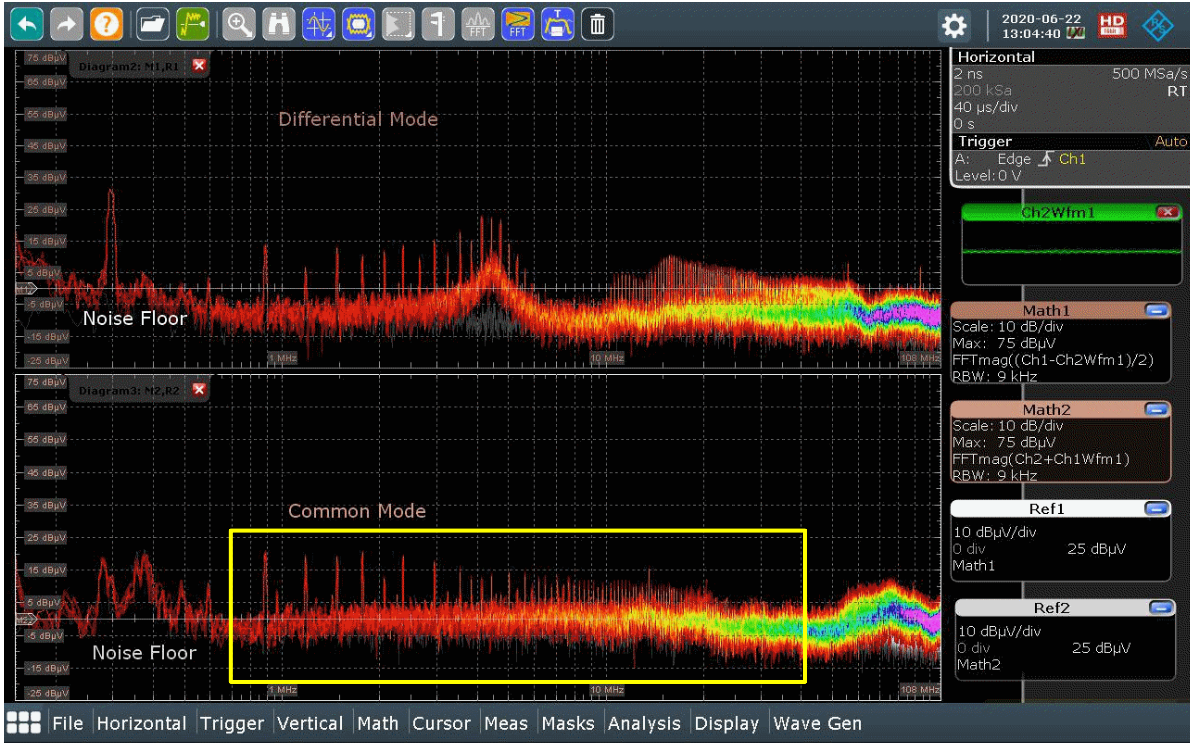
$$V_{CM} = V_P + V_N$$

CONDUCTED EMISSION DEBUGGING CASE STUDY
DM FILTER APPLIED



DM solution
DM Choke
2 x X-Cap

CONDUCTED EMISSION DEBUGGING CASE STUDY
DM FILTER APPLIED & CM FILTER APPLIED



DM solution
DM Choke
2 x X-Cap

CM solution
CM Choke

RADIATED EMISSION DEBUGGING

- Compliance is tested in the **far field**
  - Tells us that a **problem exists**
- Debugging is done in the **near field**
  - Shows us the **source (location) of the problem**
- Steps in the EMI debugging process:
  - **Detect** and characterize emissions
  - **Locate** the physical source of the emission
  - Remediate to **reduce or eliminate** the emission
- Oscilloscopes and near field probes are the most common tools used in radiated emission debugging

RADIATED EMISSION DEBUGGING
RADIATED EMISSION SETUP

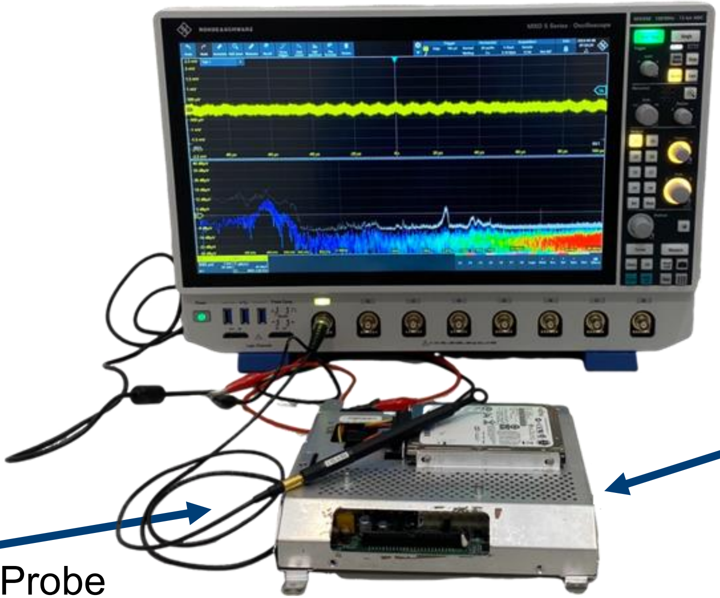
Oscilloscope

► 50 Ohm connection to **near field probe**

► Use Spectrum on Oscilloscope

Magnetic (H)   Electric (E)

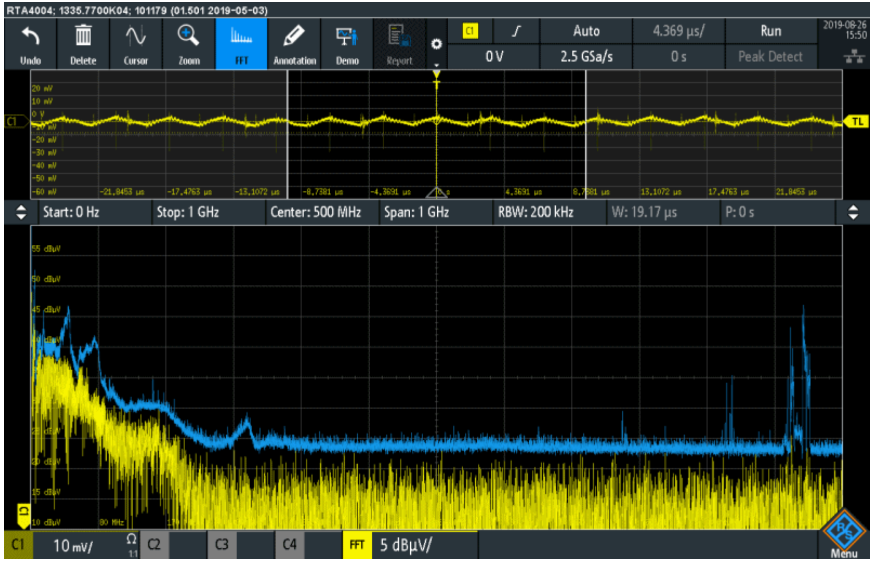
RTM3000 / MXO4 / MXO5 / RTO6 /RTP

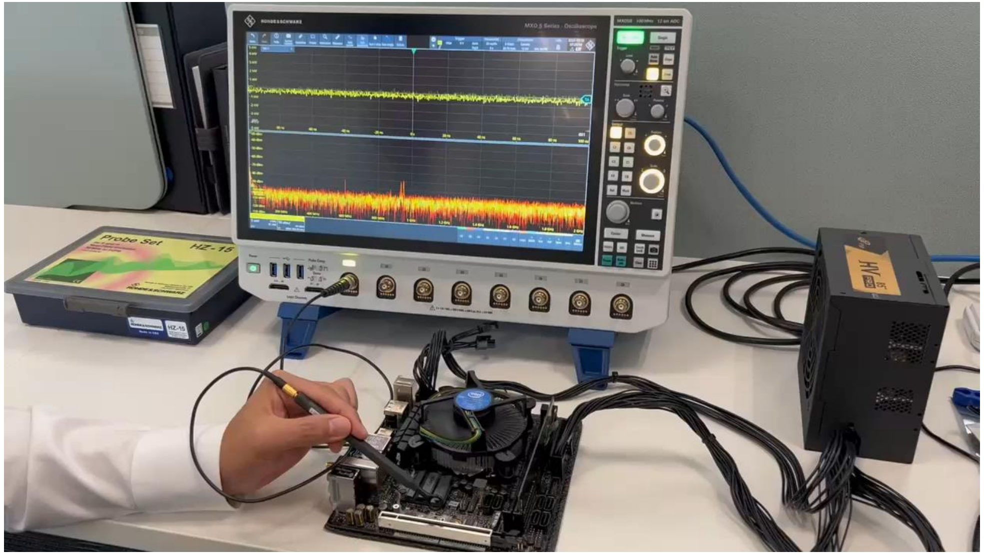


DUT

Near Field Probe

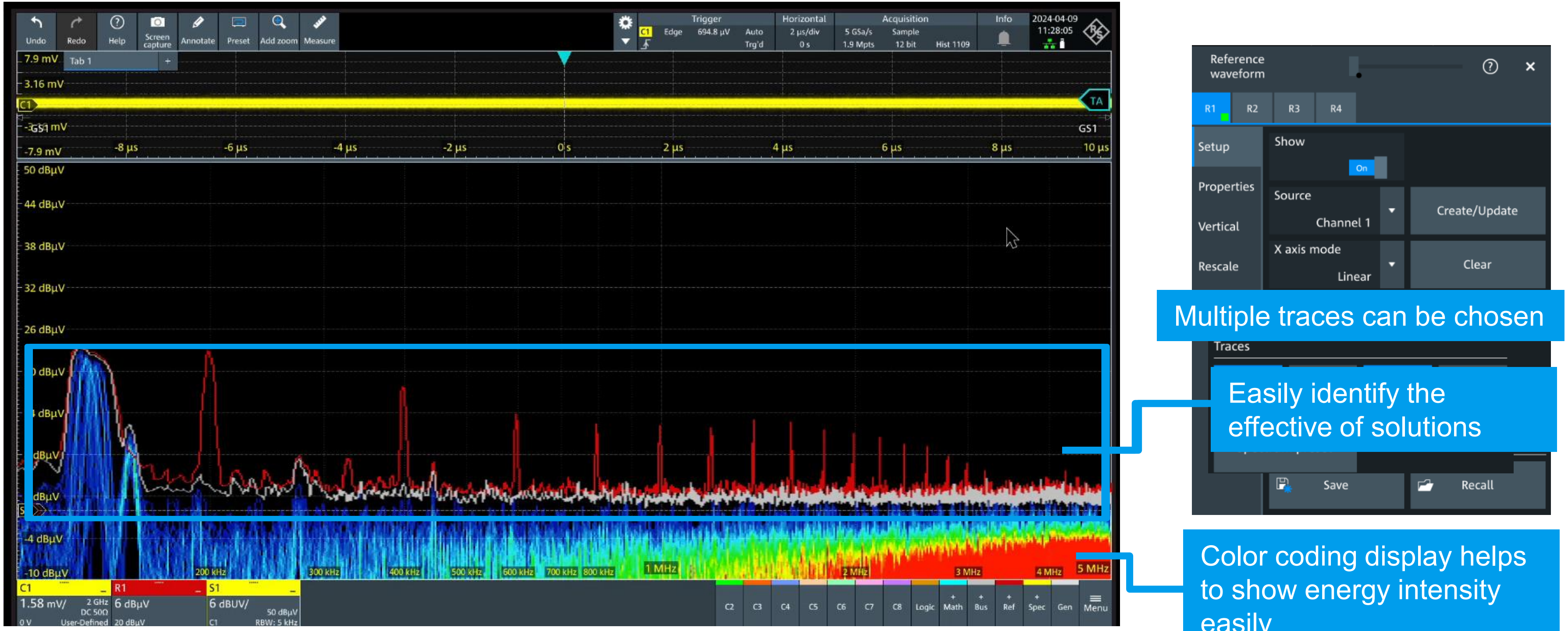
RADIATED EMISSION DEBUGGING
NEAR-FIELD PROBE WITH AN OSCILLOSCOPE





COMPANY RESTRICTED

RADIATED EMISSION DEBUGGING
NEAR-FIELD PROBE WITH AN OSCILLOSCOPE



Multiple traces can be chosen

Easily identify the effective of solutions

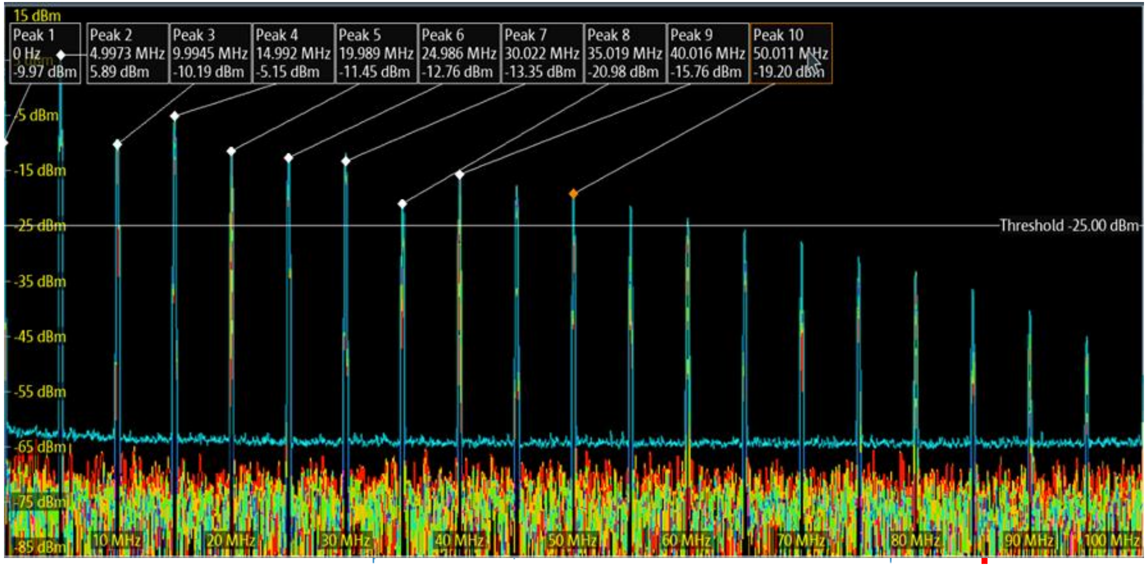
Color coding display helps to show energy intensity easily

OSCILLOSCOPE EMI DEBUGGING APPLICATIONS
FREQUENCY ZONE TRIGGER

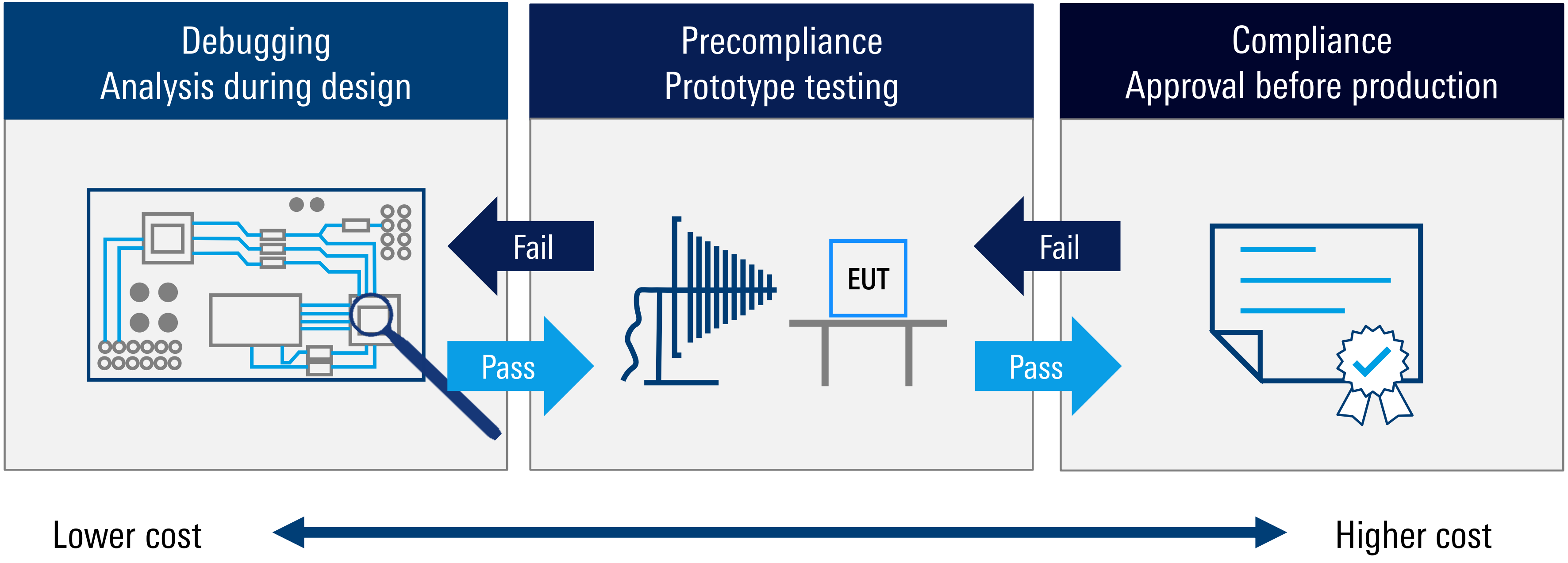
- Difficult to detect and analyze intermittent events
  - Need to **trigger on power exceeding** a threshold at given frequencies
- Achieve this with a **frequency zone trigger**
- When the mask is **violated**, the acquisition **stops and captured** data can be analyzed in detail

OSCILLOSCOPE EMI DEBUGGING APPLICATIONS
PEAK LIST

- In EMI debug, **peak levels** are often the most interesting / important
- Peaks can be found using:
  - Eyeballs
  - Cursors
  - Peak search / list
- Peak list gives the **highest amplitude signals** and their frequencies



FROM DESIGN TO COMPLIANCE
SAVE YOUR TIME AND COST



SUMMARY

- Rising compute and I/O demands are driving higher power requirements in data centers
- Key challenge is rising processor power and increasing power density
  - ⚡ Power Density Surge: 1–10 kW → >10 kW
  - 🔌 Voltage Evolution: 48 V → 380 V → 800 V HVDC
- Oscilloscope is a powerful tool for design

Input Analysis:

- Measurement tracking for frequency & duty cycle
- Multi-channel & Smart-Grid for three-phase observation

Wide-Bandgap Testing:

Double-pulse testing reveals switching losses and parasitic parameters

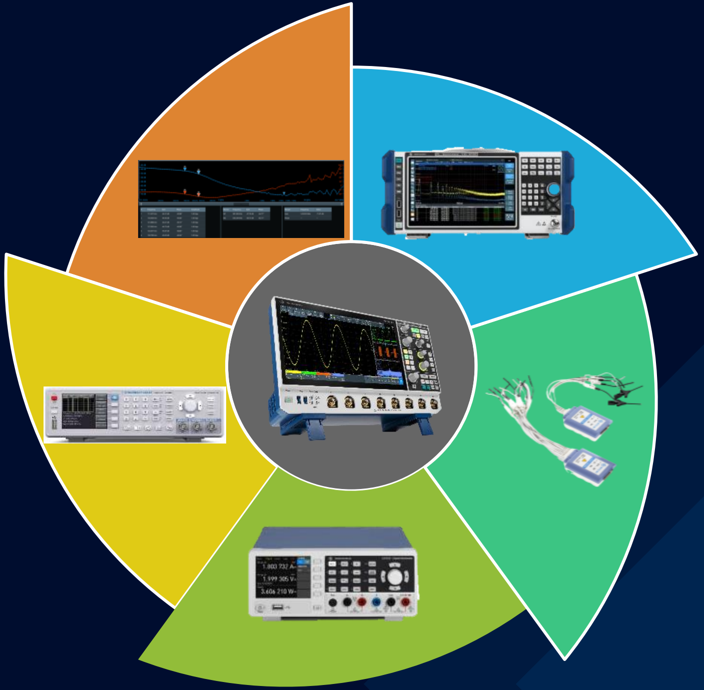
Digital Power Measurement :

- Mask testing quickly shows pass/fail output
- Use measurement tracking to easily verify PWM / Frequency changes

EMI Debugging: :

- Observing both time domain and frequency, can debug in different dimensions
- Use near-field probe & Dual LISN to quality debug

NEW! MXO3 SERIES



MORE resolution on all sample rate

Instantly see MORE infrequent event

Capture even MORE time

THANKS FOR YOUR ATTENDANCE