POWER ANALYSIS & EMI DEBUGGING WITH R&S OSCILLOSCOPE

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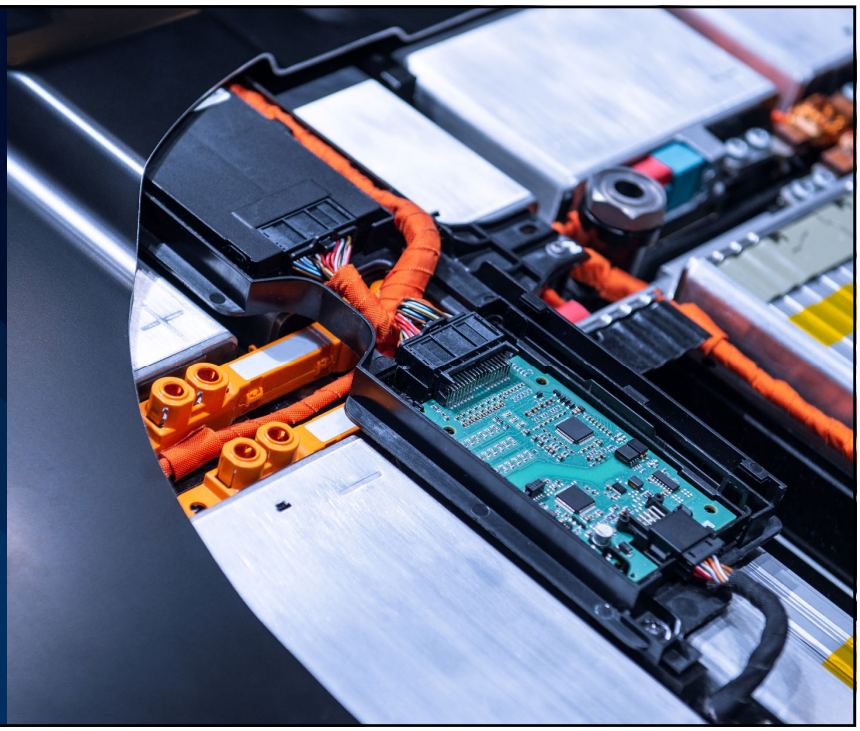
Application Engineer Oscilloscopes

90 YEARS OF ENSURING A SAFER AND CONNECTED WORLD

ROHDE&SCHWARZ
Make ideas real

CONTENT

1. Power Analysis
   - Choosing the right probes
   - Floating Measurement
   - Power rail probe
   - Current probe
2. EMI Debugging
3. R&S Oscilloscope Portfolio
4. Q&A

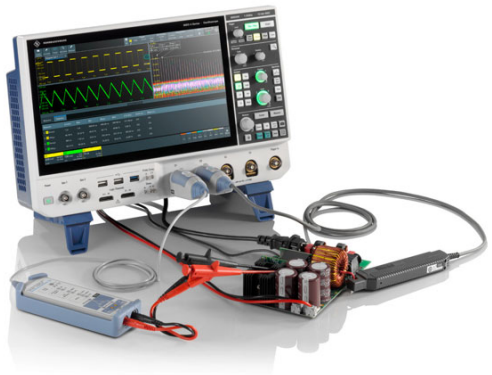


POWER INTEGRITY : PROBES

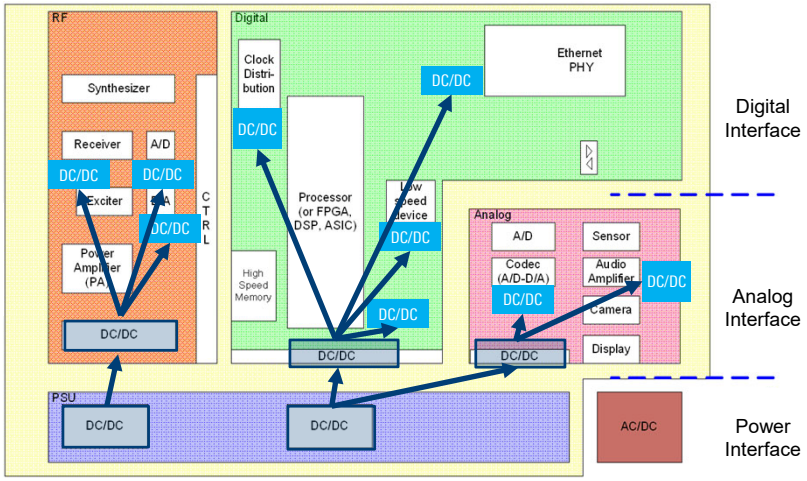
MEASURING SIGNALS IN THE CIRCUIT IS NOT EASY

- Signal is not easy to reach
- There is a lot of noise around
- Safety is a concern
- Current and voltage signals have different propagation delay

- **Voltage probing**
  - Floating measurements
  - Understanding common-mode rejection ratio
  - Other important probe parameters
- **Current probing options**
- **Other things to consider**

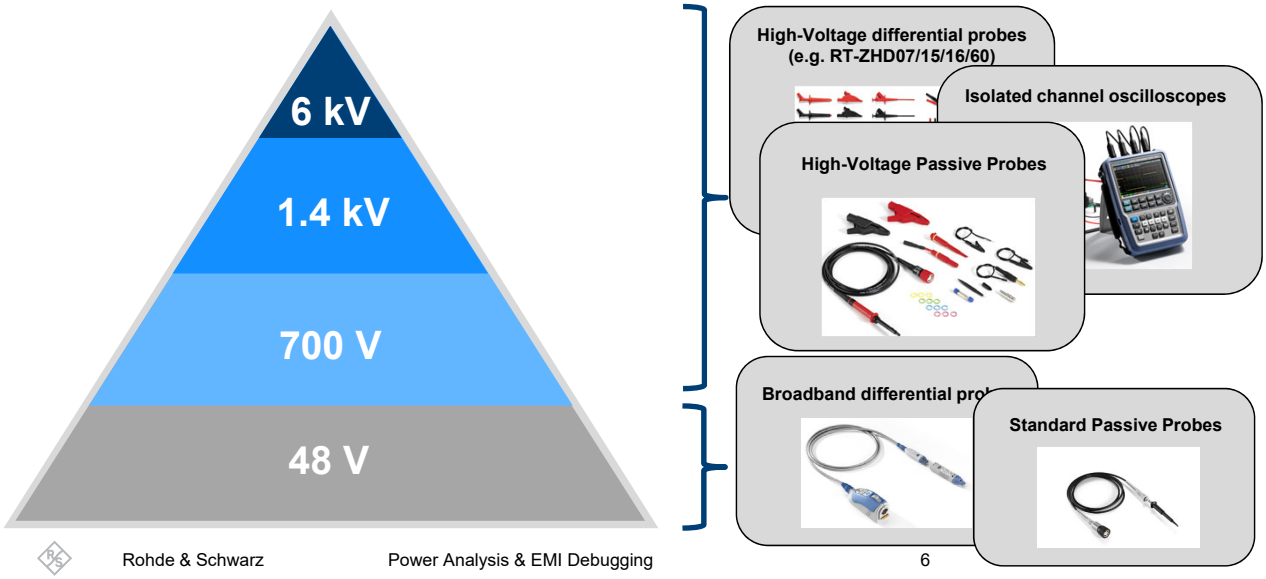


POWER INTEGRITY ACROSS ALL INTERFACES

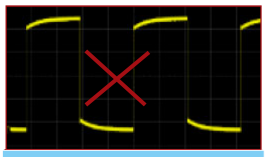


- Most circuit chipsets and design are based on DC supplies
- They rely on the source stability and expect them to be steady and quiet

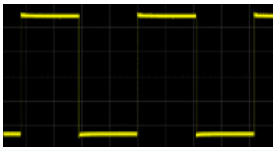
MEASURING VOLTAGE



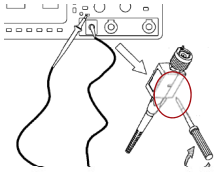
COMPENSATE YOUR PASSIVE PROBE BEFORE USE

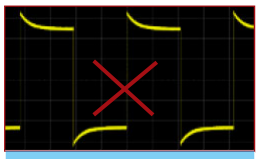


Under-Compensated Signal

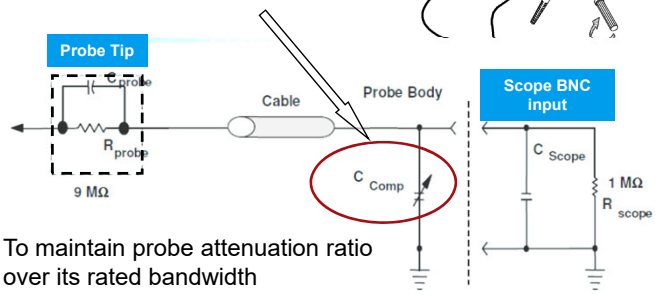


Properly Compensated Signal



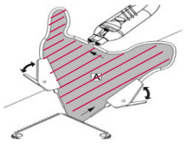


Over-Compensated Signal

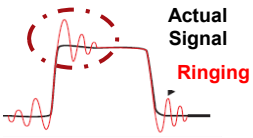


To maintain probe attenuation ratio over its rated bandwidth

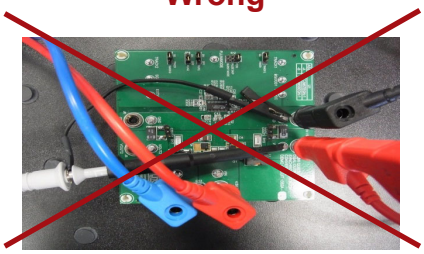
WHAT ELSE IS IMPORTANT



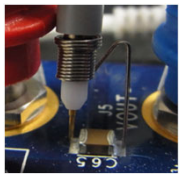
$$f_{Resonant} = \frac{1}{2\pi\sqrt{L \cdot C}}$$

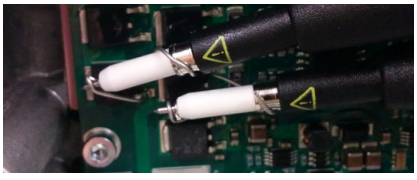


Wrong



Right

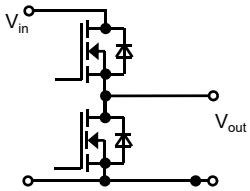




Keep Connections short

MEASURING VOLTAGE

- Basic sub-circuit for inverter, sync buck converter/resonant (LLC) converter, sync boost converter consists of a so called **high-side** and **low-side switch**

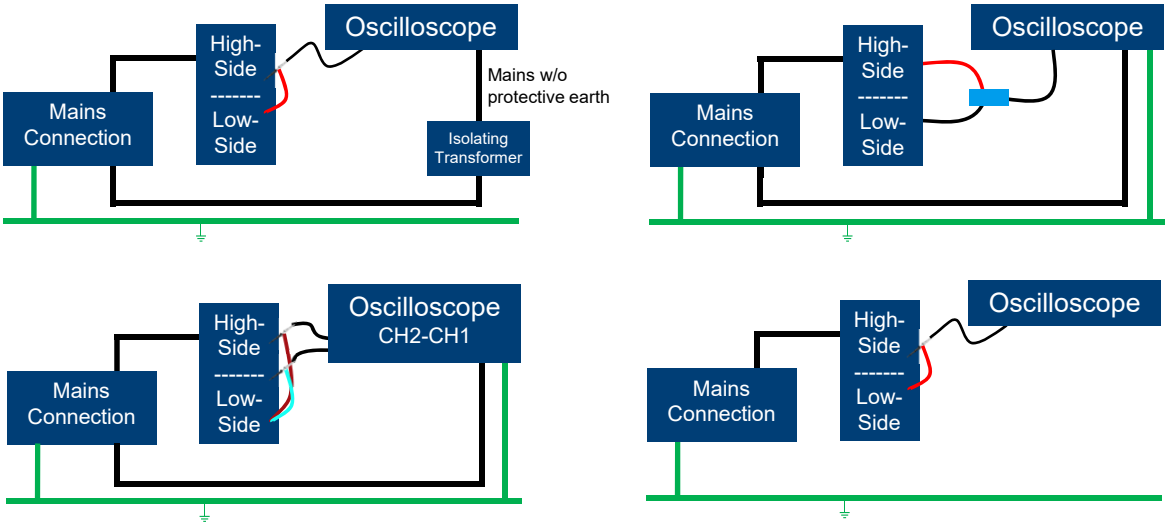


High-side switch: referenced to output voltage

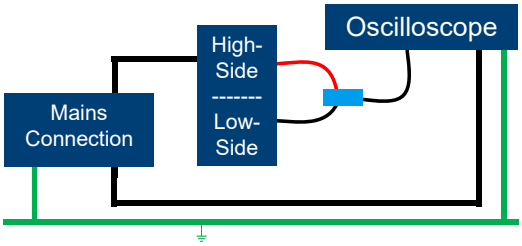
Low-side switch: ground referenced

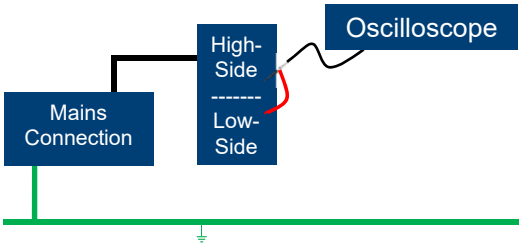
- DC-Offset of high-side switch has to be considered by design of measurement setup
- Floating measurement on high-side switch is necessary

FLOATING MEASUREMENT TECHNIQUES



FLOATING MEASUREMENT TECHNIQUES





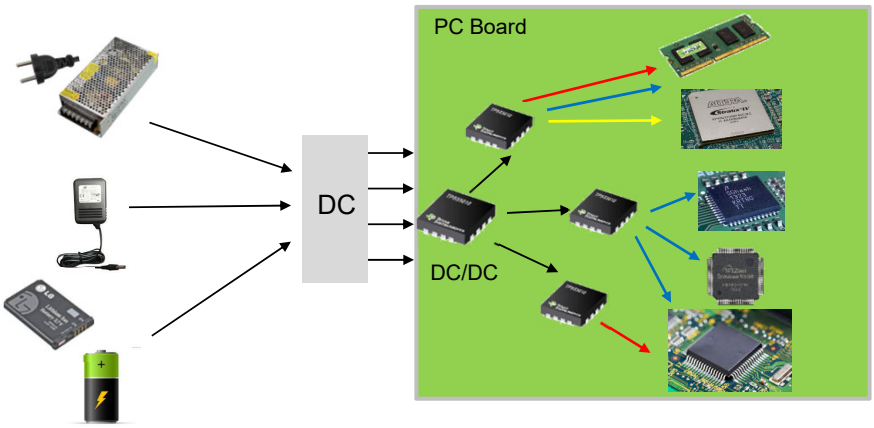
FLOATING MEASUREMENT TECHNIQUES

	Floating the Scope	A minus B	High-Voltage Differential Probes	Isolated Channel Oscilloscope
Safety	**Dangerous!**	Ok	**Very good**	**Very good**
Flexibility	Limited all channels have ground connected	Limited, needs two channels per signal	**Very good**	**Very good** (limited by max ground potential rating)
Sensitivity	**Very good**	**Very good**	Good (typ. 50:1 or 100:1)	**Very good** (10:1 attenuation)
Accuracy	**Very good**	**Not good**	**Very good**	**Very good**
Bandwidth	**Very good**	**Not good**	Good (typ. <=200 MHz)	**Very good** (up to 500 MHz)
CMRR	Not good	**Very bad**	**Very good**	Good
Conclusion	**Only recommended behind safety screen.**	**Not recommended!**	**Generally recommended**	**Recommended** (with limitations)

WHICH PROBE TO USE

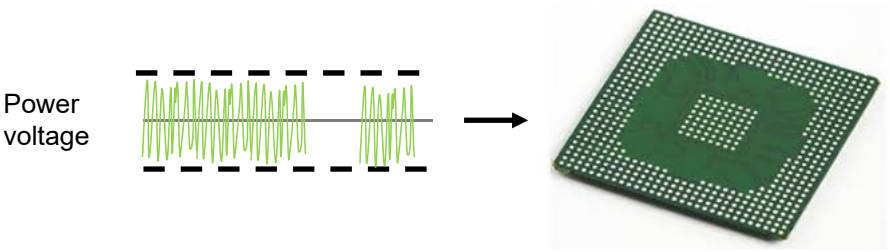
	RT-ZD10	RT-ZHD07/15/16/60	RT-ZH10/11	RT-ZI10/10C/11
				
Type / Interface	Active differential / **R&S**	Active differential / **R&S**	Passive / **BNC**	Passive / BNC only for R&S®Scope Rider
Bandwidth	1 GHz	100 MHz / 200 MHz	400 MHz	500 MHz
Max. Input Signal	5 V (without RT-ZA15) 60 V (with RT-ZA15)	750 Vpeak to 6000 Vpeak	1000 Vrms 6000 Vpeak	1000 Vrms 5000 Vpeak
CMRR	80 dB @ 10 Hz 40 dB @ 10 kHz to 1 MHz 30 dB @ 1 MHz to 100 MHz 20 dB @ 100 MHz to 1 GHz	80 dB @ DC – 60 Hz 60 dB @ 1 MHz 30 dB @ 100 MHz	N/A	Depends on measurement scenario
Offset	Up to 50 V	Up to 2000 VDC	N/A	N/A
DC Voltmeter	R&S Probemeter	R&S Probemeter	N/A	N/A

TYPICALLY LOTS OF POWER RAILS

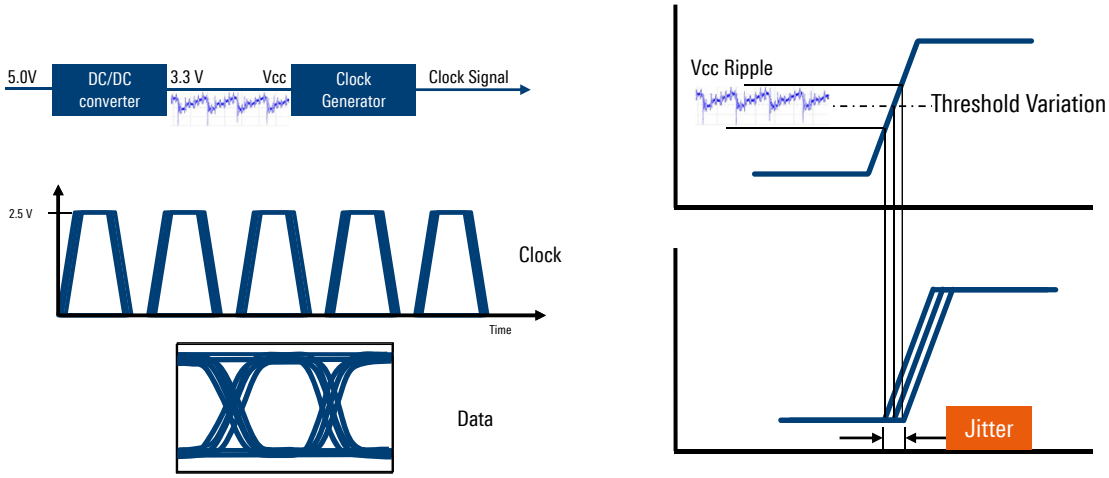


POWER RAIL TESTING

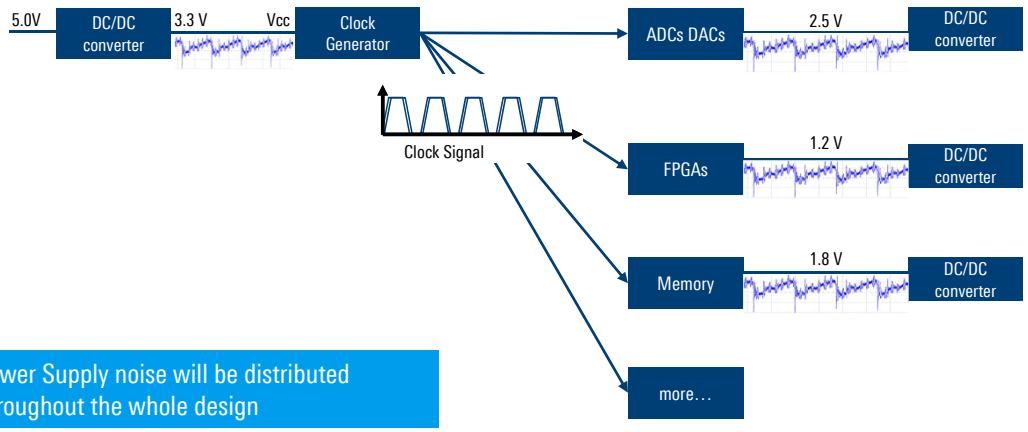
- IC suppliers specify # of power rails, voltage for each, and tolerance for each.
  - FPGAs, ASICs, CPUs, DDR memory…
- Measurements: sequencing, noise / ripple, drift, load/step response, EMI



NOISY POWER INFLUENCE SIGNAL INTEGRITY

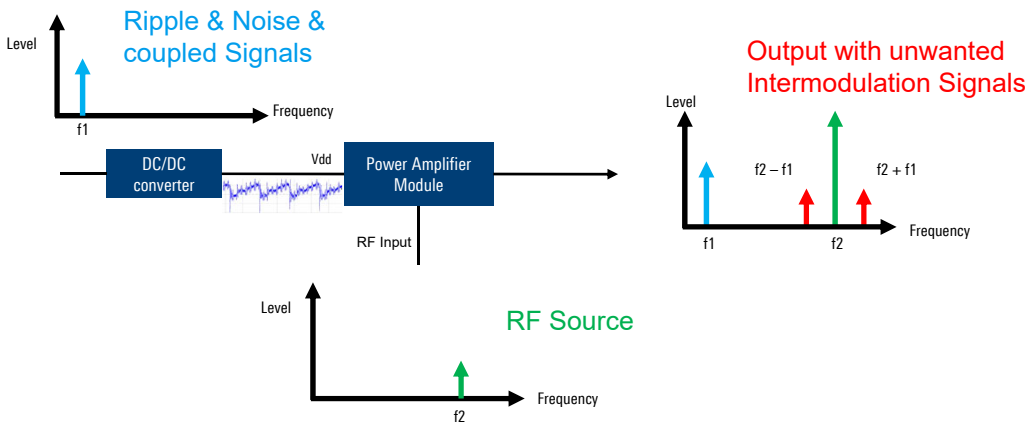


POWER NOISE PROPAGATE TO OTHER CIRCUITS



Power Supply noise will be distributed throughout the whole design

POWER NOISE AFFECTING RF PERFORMANCE

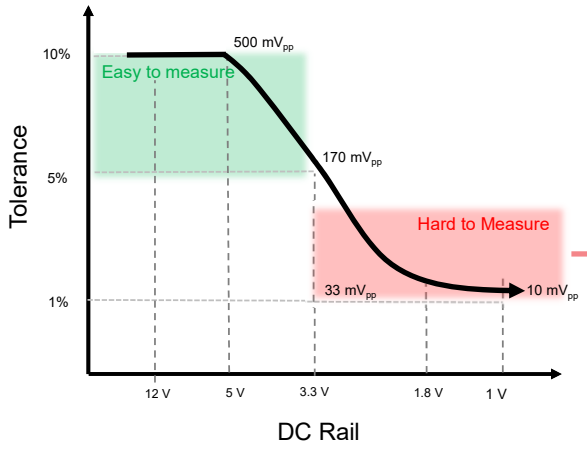


OSCILLOSCOPE :

PRIMARY TOOL FOR POWER RAIL ANALYSIS

POWER RAIL MEASUREMENT CHALLENGES

LOWER RAIL VOLTAGES AND SMALLER TOLERANCES



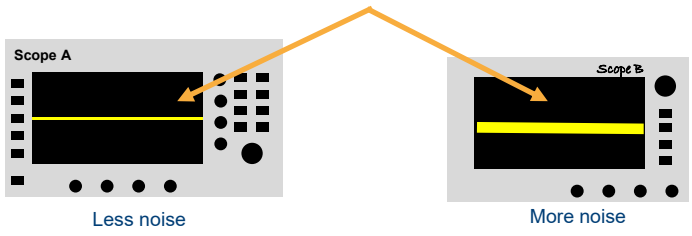
Examples

Rail Value	Tolerance	Need to measure
3.3 V	1%	33 mV_{pp}
1.8 V	2 %	36 mV_{pp}
1.2 V	2 %	24 mV_{pp}
1 V	1 %	10 mV_{pp}

Scope measurement noise can approach or exceed needed signal measurement values

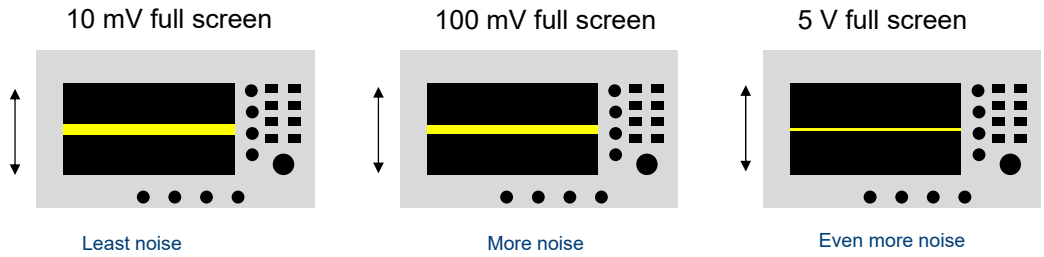
MEASUREMENT NOISE…
IS A FUNCTION OF WHAT SCOPE YOU USE

You will never be able to measure signal attributes smaller than the intrinsic noise of the scope.



Intrinsic measurement noise with all input signals disconnected.

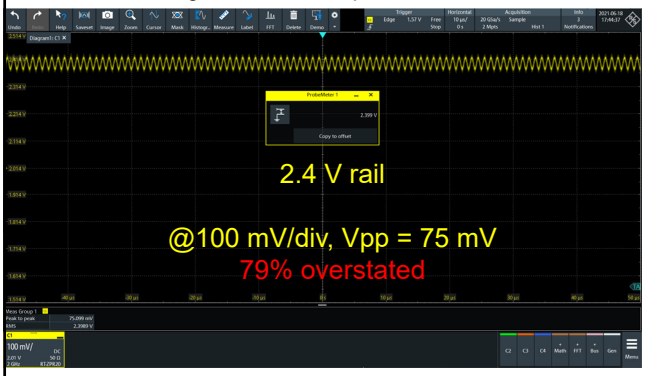
MEASUREMENT NOISE…
IS A FUNCTION OF FULL-SCALE VERTICAL SCALING (% OF FULL VERTICAL)



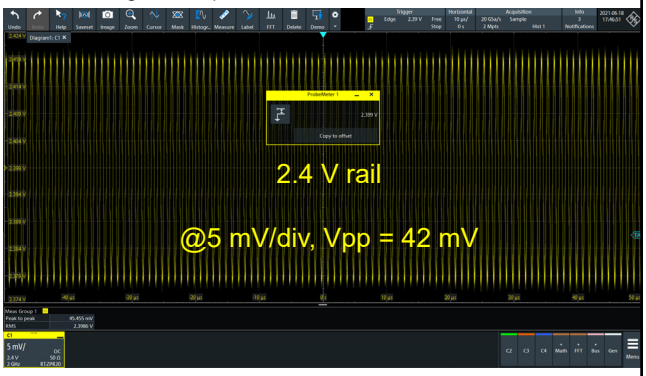
MEASUREMENT NOISE: INSUFFICIENT INTERNAL OFFSET IMPACTS

REQUIRES USING A HIGHER VERTICAL SENSITIVITY → MORE NOISE

Using max built-in scope offset



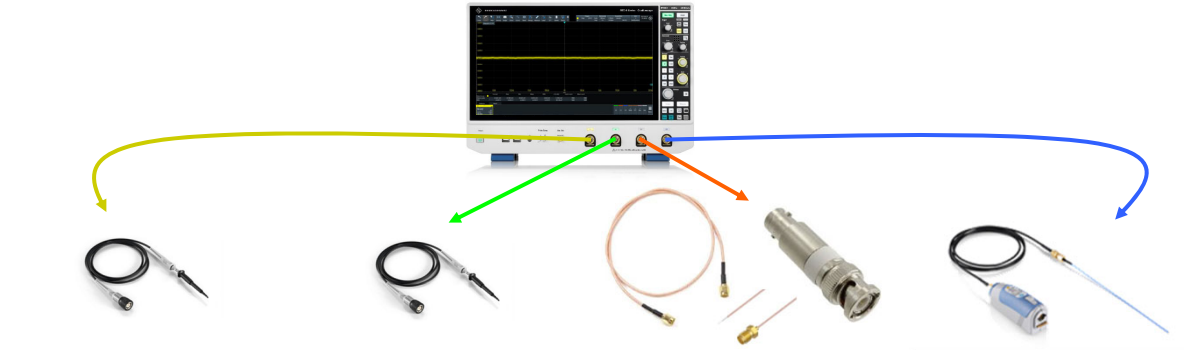
Using built-in probe offset



MEASUREMENT NOISE…

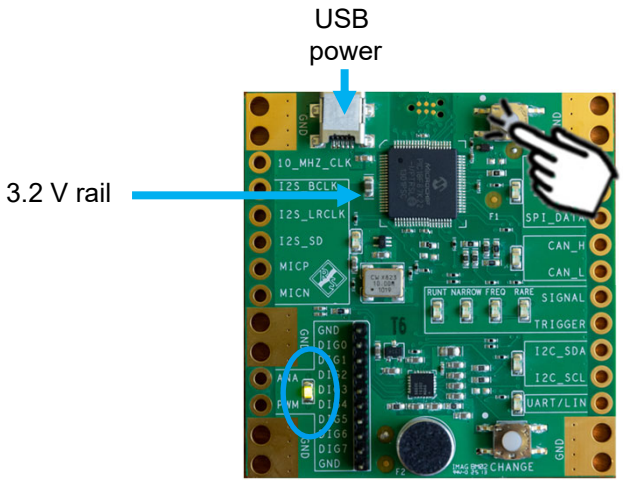
IS A FUNCTION OF MEASUREMENT SIGNAL PATH (50Ω / 1 MΩ) +PROBE + PROBE ACCESSORIES

FOUR MEASUREMENT APPROACHES



Standard **10:1** passive probe	Low BW **1:1** passive probe	50 Ω cable (with blocking cap)	Specialized **power rail** probe

DEVICE UNDER TEST – 3.2V POWER RAIL



10:1 PASSIVE PROBE

Standard **10:1** passive probe

Low BW **1:1** passive probe

50 Ω cable (with blocking cap)

Specialized **power rail** probe

10:1 PASSIVE PROBE

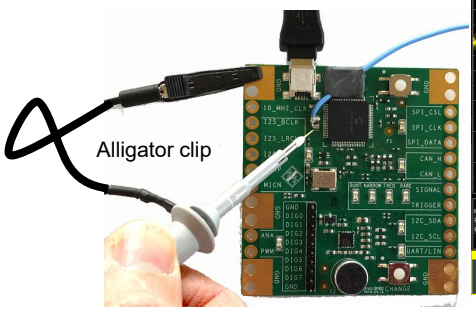
Advantages

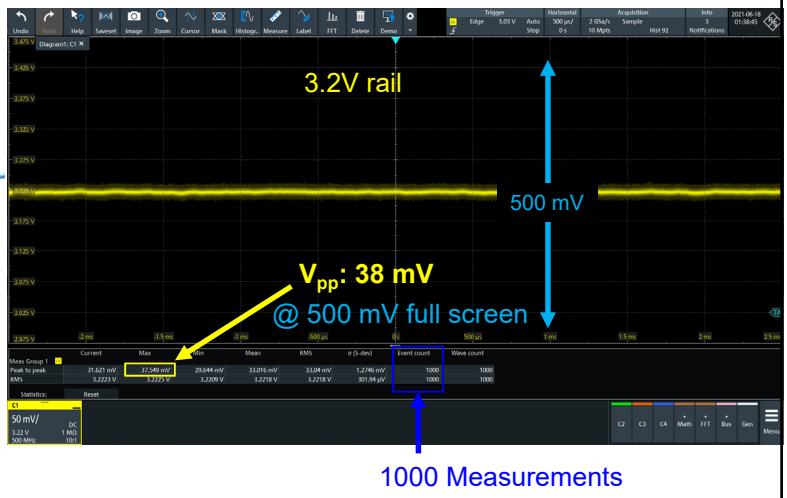
- Comes standard with most scopes
  - no extra expense
- 1 MΩ loading at DC
  - Preserves expected DC value
- Easy to connect using browser tip
  - Multiple ground alternatives

Disadvantages

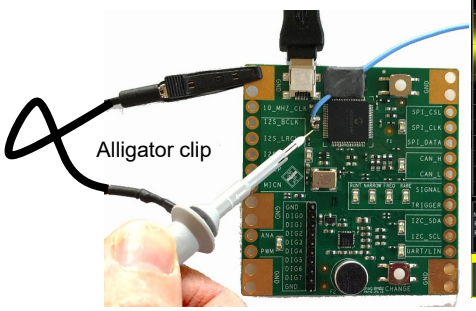
- Significant noise
  - 10:1 attenuation
  - Minimum vertical setting of 10 mV/div
- Long grounds
- BW limited (700 MHz for ZP-11)
- No solder-in alternative

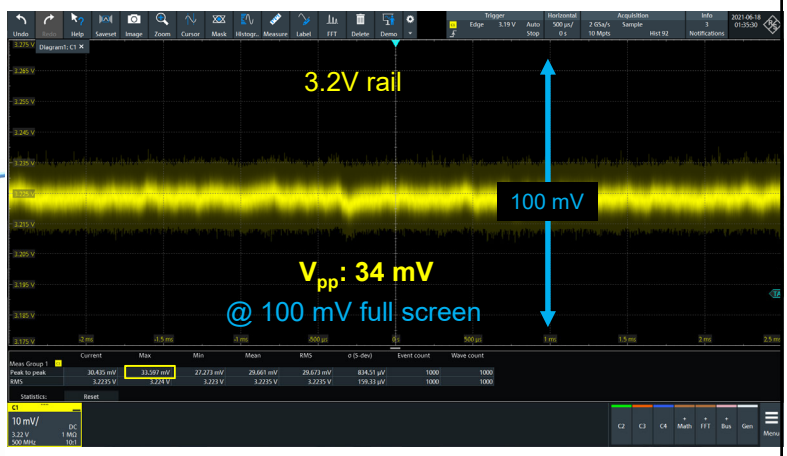
10:1 PASSIVE PROBE WITH ALLIGATOR CLIP





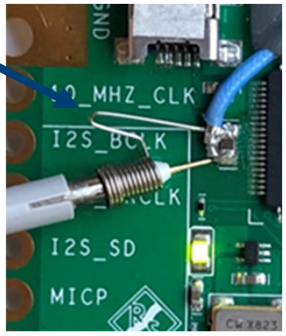
NOISE : FUNCTION OF VERTICAL FULL SCALE

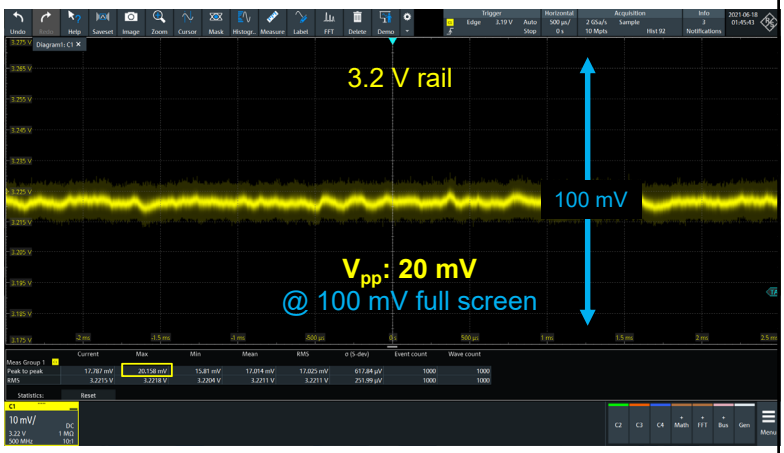




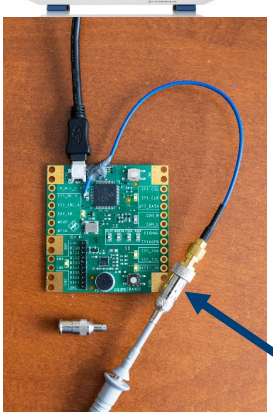
NOISE : FUNCTION OF PROBING ACCESSORIES

Ground spring

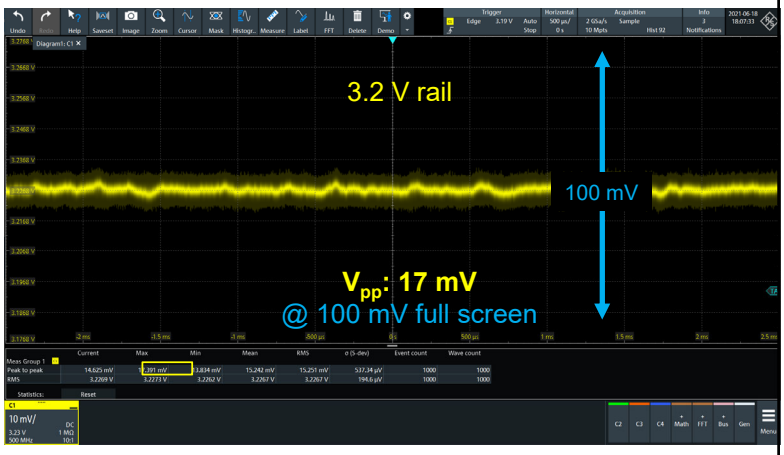




NOISE: FUNCTION OF PROBING ACCESSORIES



Passive probe to BNC adapter
(RT-ZA1 accessory)

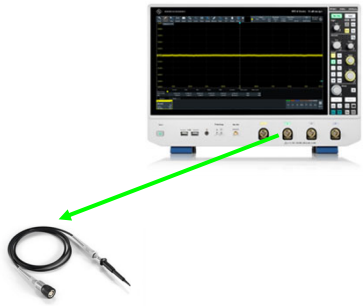


ADD AN EXTRA HAND

2D Probe Positioner

3D Probe Positioner (RT-ZAP)

1:1 PASSIVE PROBE



Standard **10:1** passive probe

Low BW **1:1** passive probe

50 Ω cable (with blocking cap)

Specialized **power rail** probe

1:1 PASSIVE PROBE

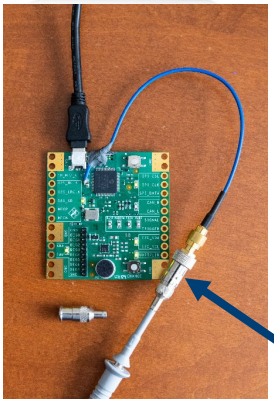
Advantages

- Low cost
- Excellent 1 MΩ loading at DC
  - preserves expected DC value
- Ability to scale to 1 mV/div
- Easy to connect using browser tip
  - Ground spring ground alternative

Disadvantages

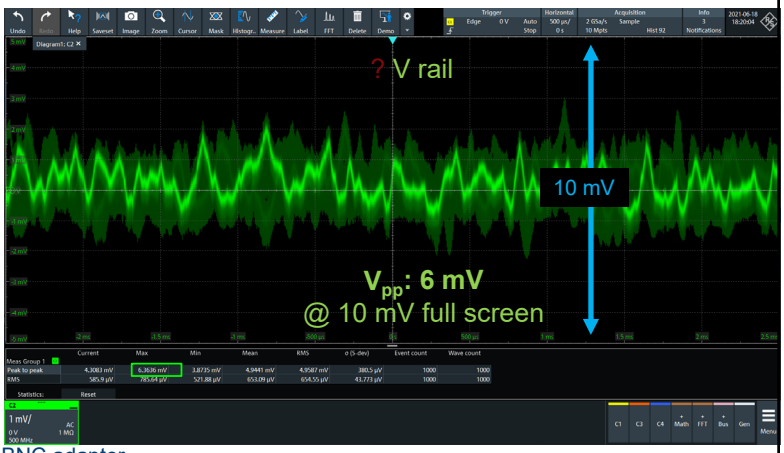
- Limited BW
  - 38 MHz for ZP-1X
  - under reports V_{pp} measurements
  - masks high freq signal coupling
- Limited offset – may require AC coupling
- No solder-in alternative

38 MHZ 1:1 PASSIVE PROBE WITH GROUND SPRING



Passive probe to BNC adapter
(RT-ZA1 accessory)

Not enough offset, required AC coupling



50Ω PATH

Standard **10:1** passive probe

Low BW **1:1** passive probe

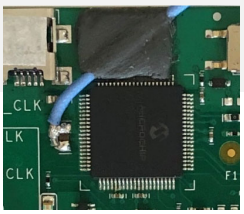
50 Ω cable (with blocking cap)

Specialized **power rail** probe

50Ω PATH

Advantages

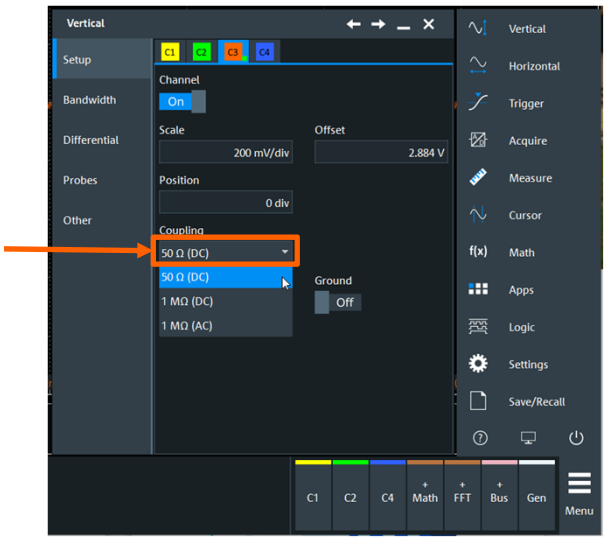
- 50 Ω scope path typically has less noise than 1M Ω scope path
- SMA connector or solder-in pigtail allows for measurement consistency and ease of access



Disadvantages

- 50 Ω loading at DC reduces power rail voltage
- Insufficient offset (requires blocking cap or AC coupling)
  - Masks DC drift
  - Eliminates ability to see true DC voltage

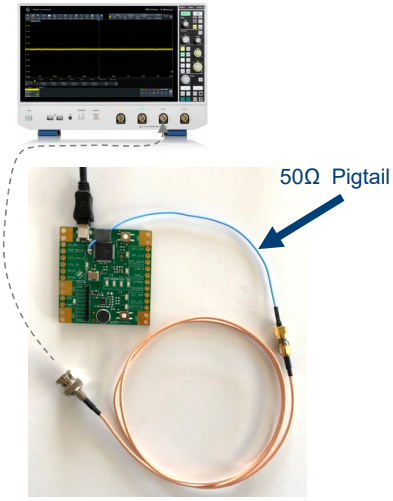
50Ω PATH : AC COUPLING

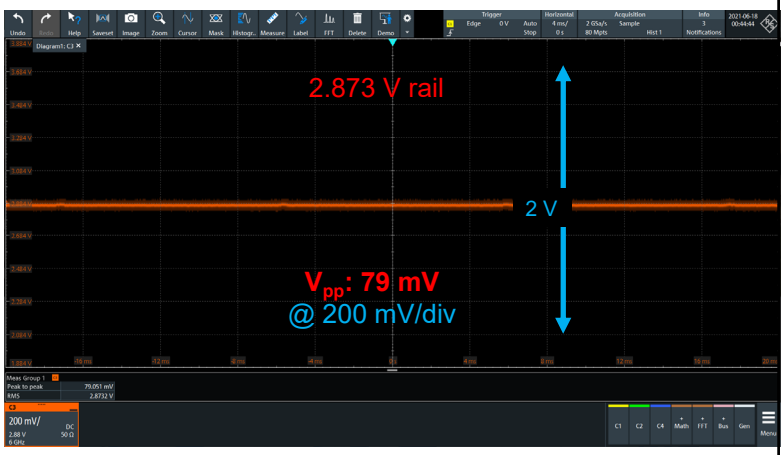


- Set to 50Ω path (channels setup)
- Attenuation to 1:1 (probe setup)
- 50Ω path (limited offset may require AC coupling)

50Ω PATH :

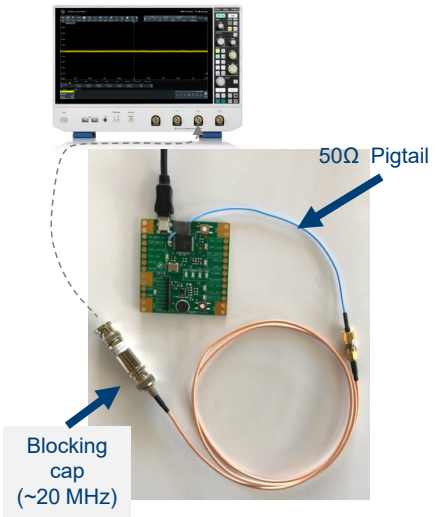
SUFFICIENT OFFSET NOT AVAILABLE: REQUIRES 200 MV/DIV SCALING

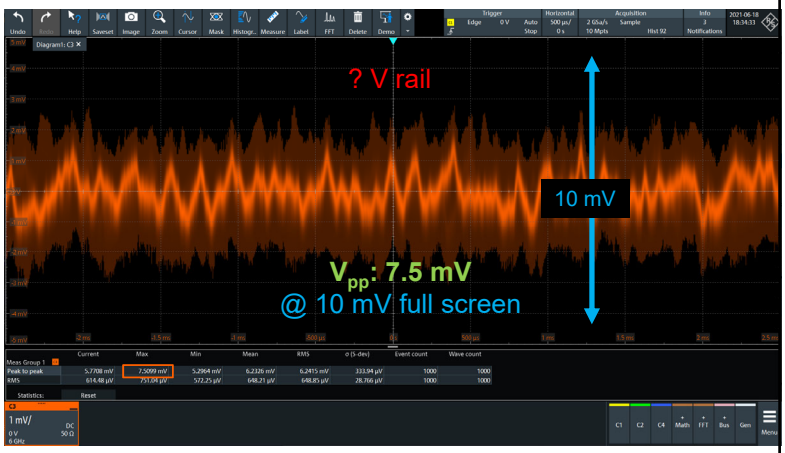




50Ω PATH WITH BLOCKING CAP (3DB BW = ~20 MHZ)

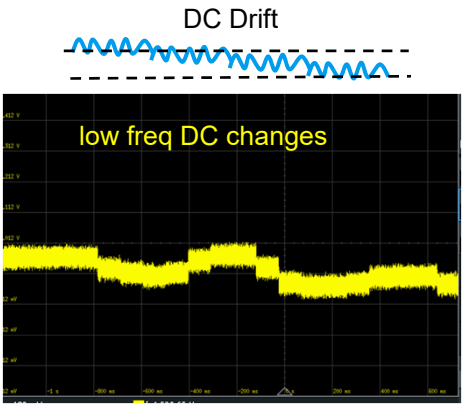
NO ABILITY TO MEASURE ABSOLUTE VERTICAL VALUES

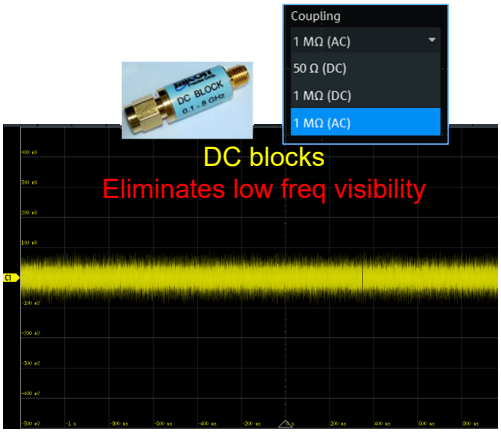




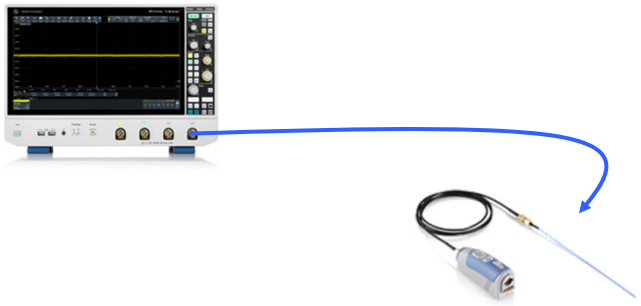
BLOCKING CAPS (AC COUPLING) CREATE MEASUREMENT PROBLEMS

AC COUPLING MODE AND BLOCKING CAPS ELIMINATE ABILITY TO SEE DC CHANGES





POWER RAIL PROBE



Standard **10:1** passive probe	Low BW **1:1** passive probe	50 Ω cable (with blocking cap)	Specialized **power rail** probe

POWER RAIL PROBE

Advantages

- Low noise (typically 1:1 attenuation ratio)
- Built-in offset (typically at least +/- 12V)
- Excelling loading at DC (typically 50 KOhms)
  - Power rail retains DC value
- Browser and solder-in connection

Disadvantages

- Initial investment expense
- Requires solder-in/SMA for full BW

LOW VOLTAGE RT-ZPR20/40 POWER RAIL PROBE

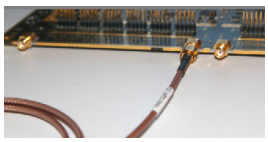
- Designed uniquely for measuring small perturbations on power rails
- Active, single-ended probe
- Low noise with 1:1 attenuation
- Offset compensation capability
- Built-in DC meter

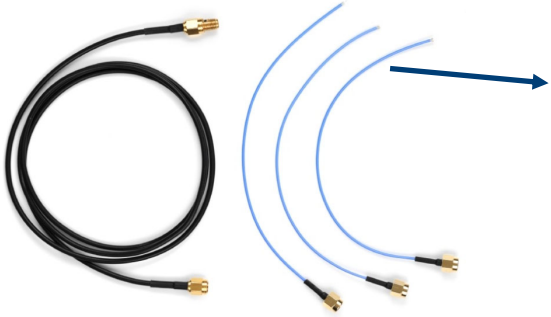
Key Specifications	
Attenuation	**1:1**
BW	**2 GHz / 4 GHz**
Browser BW	350 MHz
Dynamic Range	±850 mV
Offset Range	**> ±60 V**
Probe Noise Scope standalone Scope + Probe (at 1 GHz, 1mV/div)	 107 µV AC_{rms} **120 µV AC_{rms}**
Input Resistance	**50 kΩ** @ DC
R&S ProbeMeter	Integrated
Coupling	DC or AC

TYPICAL POWER RAIL PROBE SOLDER-IN TECHNIQUE

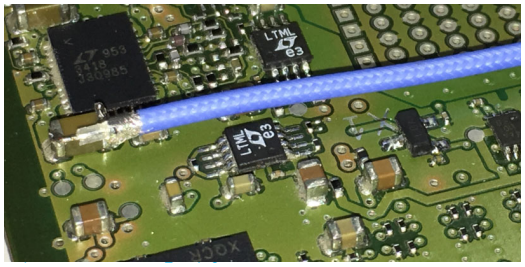
ACTIVE PROBE HEAD, MAIN CABLE AND SOLDER-IN CABLES

Direct connect to SMA



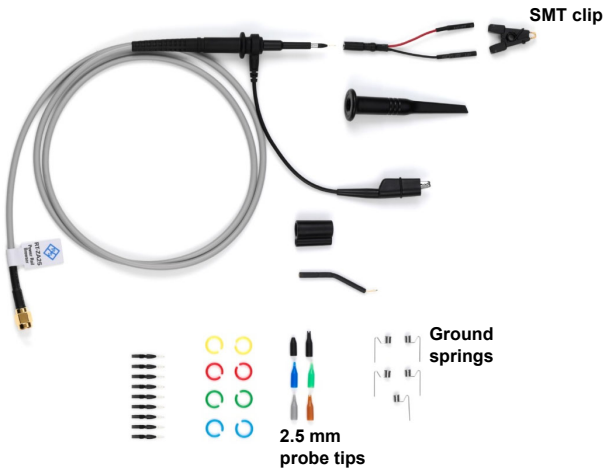


50 Ω SMA coaxial solder-in (2.5 GHz BW)

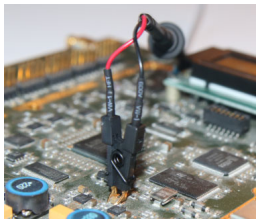


RT-ZPR POWER RAIL PROBE BROWSER

350 MHz BW, 1:1 ACTIVE PROBE, USES PASSIVE PROBE ACCESSORIES (Included standard)



Ground spring



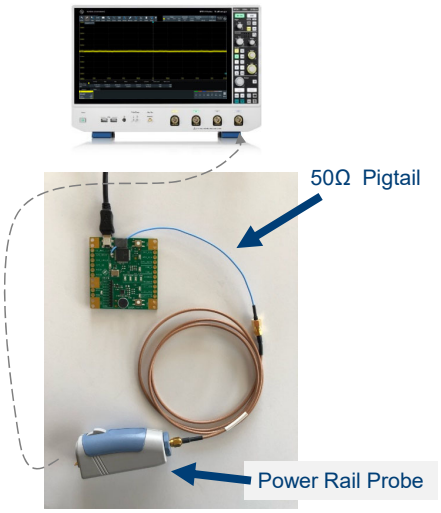
SMT clip

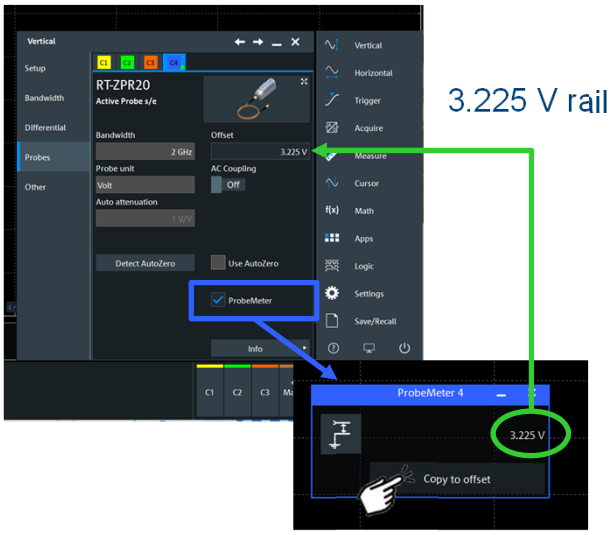
SOME POWER RAIL PROBES HAVE AN INTEGRATED VOLTMETER

R&S PROBES CALL THIS A "PROBEMETER"

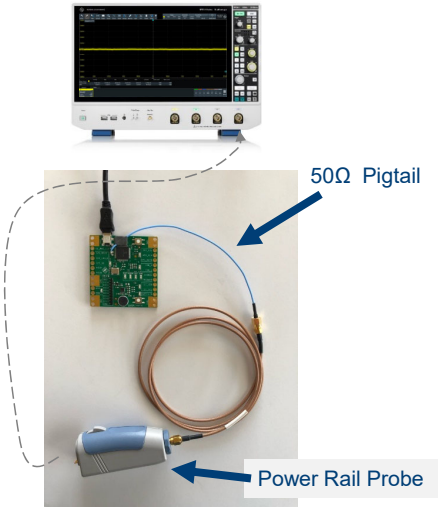
- Separate circuit with 18-bit ADC inside the probe
- Independent of scope ADC
- Measures DC value with 0.05% accuracy
  - > 10X more accurate than scope channel for DC measurement
- Eliminates need to attach a separate DVM in parallel to accurately measure DC

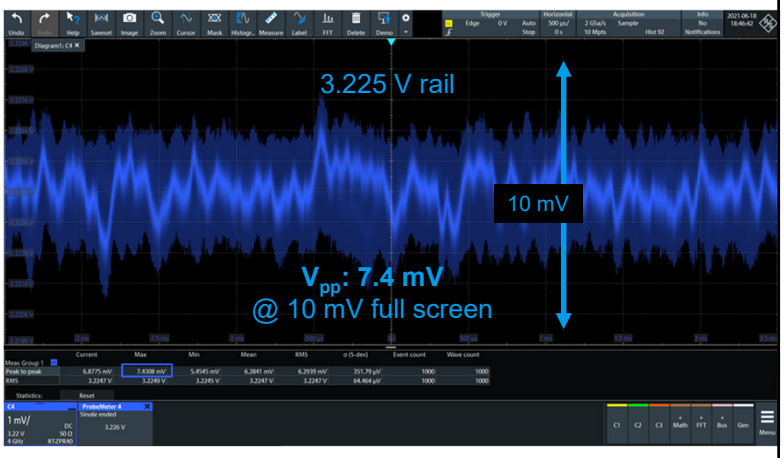
INTEGRATED VOLT METER
WITH CUT/PASTE DC OFFSET





POWER RAIL PROBE



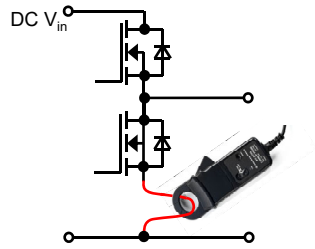


MEASUREMENT TECHNIQUE RESULTS COMPARISON

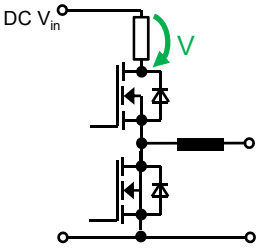
Noisy 10 MΩ DC loading Limited BW Limited scaling	Low noise 1MΩ DC loading Limited BW Limited offset	Low noise 50 Ω loading Inability to see drift Inability to see DC value	Low noise 50 KΩ loading High BW Built-in offset
Vpp: 17 mV	Vpp: 6 mV	Vpp: 7.5 mV	Vpp: 7.4 mV
			
Standard **10:1** passive probe	Low BW **1:1** passive probe	50 Ω cable (with blocking cap or AC coupling)	Specialized **power rail** probe

CURRENT MEASUREMENT

Clamp-on probes



Shunt resistors



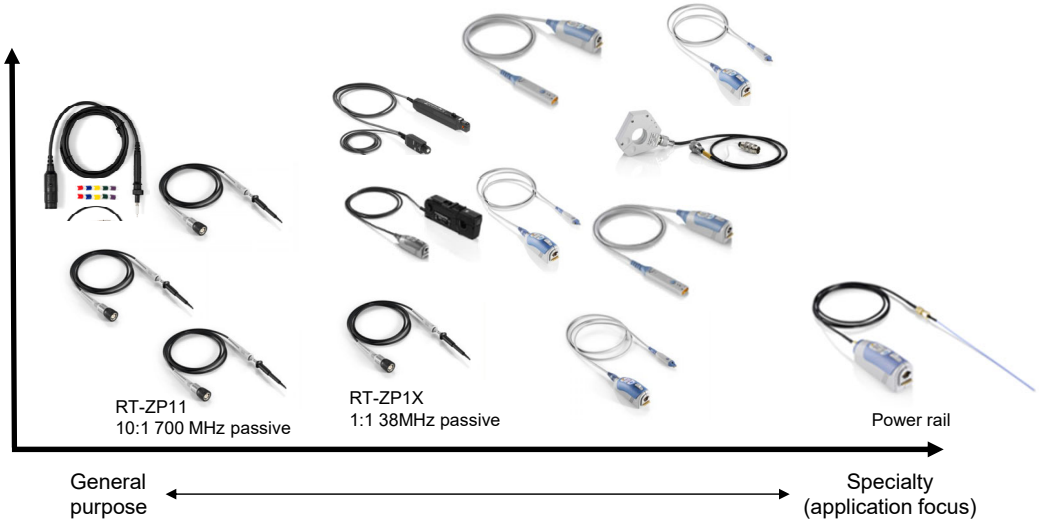
Rogowski probes

Photo: Curtesy PEM UK Ltd.

CURRENT MEASUREMENTS PROBE TYPES

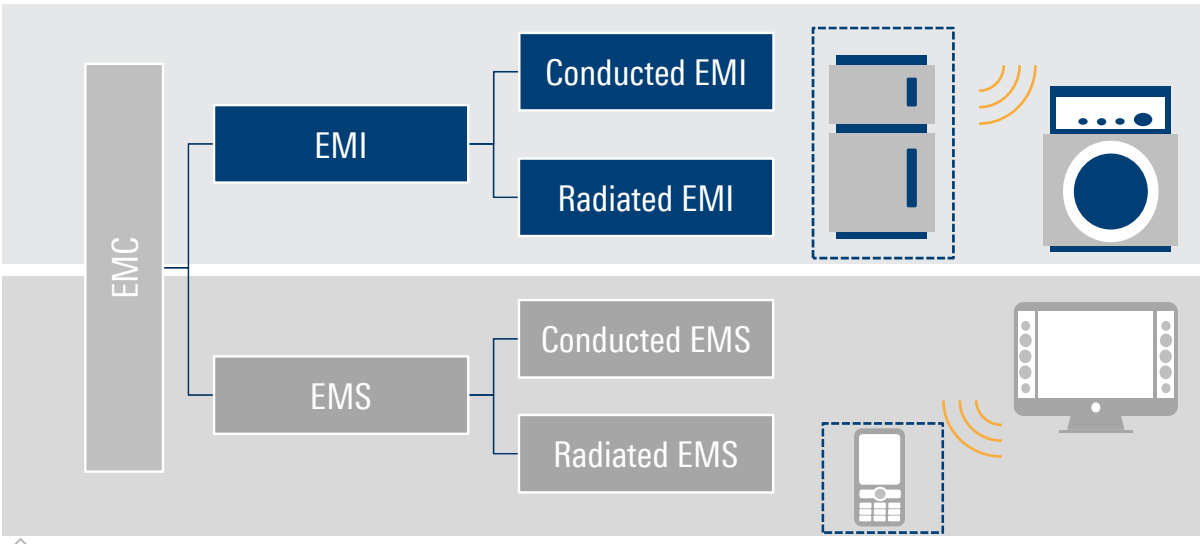
	Clamp-on probes	Shunt resistors	Rogowski Probes
Bandwidth	**~120 MHz** (5 A range) ... **~20 kHz** (~1000 A range) (depends on current range)	**Up to ~GHz**	**~50 MHz**
Current range	**~5 A** (120 MHz) ... **~1000 A** (20 kHz) (depends on bandwidth)	**Depends on shunt-value** (typically limited by max. Energy per current pulse)	**~A to ~kA**
DC measurement	**Yes**	**Yes**	**No**
Important advantages	• DC measurement capability • Easy "clamp-on" measurement	• Very high bandwidth	• High bandwidth at high current • Easy "wrap-around" measurement (little space needed)
Important drawbacks	• Extra space needed, adds loop-inductance • Derating of maximum current with measurement frequency	• Design-in needed • Fixed measurement range • Limited maximum thermal load	• No DC measurement • Noise sensitivity • Accuracy depends on position of conductor in loop
Typ. applications	• All kind of general purpose current measurement	• Switching analysis (double-pulse test)	• Switching analysis • Motor drives

LOTS OF PROBES FOR DIFFERENT APPLICATIONS



EMI DEBUGGING

WHAT IS EMC?

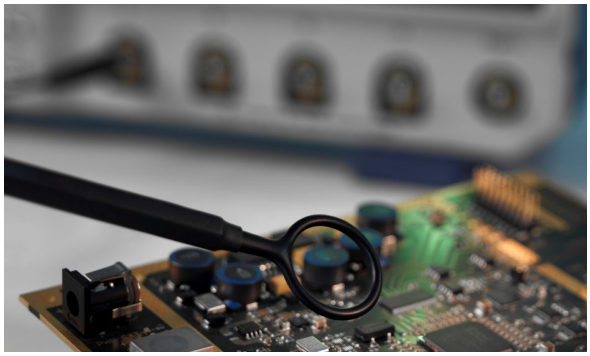


EMI TESTS IN SUMMARY

	CISPR 11 ISM	CISPR 14 HOUSEHOLD EQUIPMENT	CISPR 15 LIGHTINGS	CISPR 32 MUTLIMEDIA EMC
CONDUCTED EMI (MAINS PORTS)	✓	✓	✓	✓
CONDUCTED EMI (TELECOM PORTS)				✓
RADIATED EMI (MAGNETIC FIELD)	✓	✓	✓	
RADIATED EMI (ELECTRIC FIELD)	✓	✓	✓	✓
POWER DISTURBANCE		✓		

EMI DEBUGGING

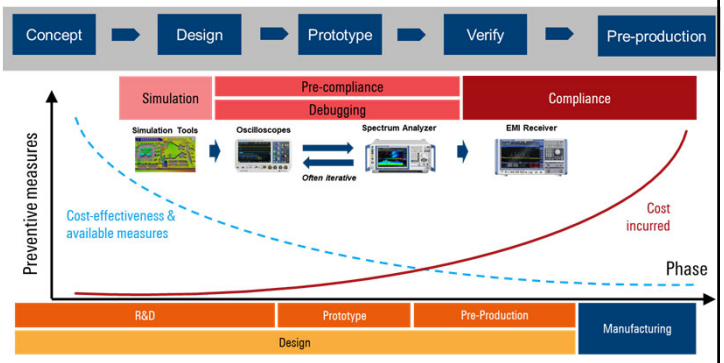
PREVENTION IS BETTER THAN CURE



Similar to medical check-up for preventive health care, we diagnose early on circuit to avoid future issues

EMI DEBUGGING WITH OSCILLOSCOPES?

- Available on every R&D engineers desk
- Oscilloscopes show both time and frequency domain
- Today's oscilloscopes provide excellent sensitivity and usability



TEST RECEIVER VS OSCILLOSCOPE

Scan spectral energy for fixed duration

Using different band-limited detectors

Log scale display with limit lines

Right tool and compliant to standard

Time domain captured calculated FFT spectrum

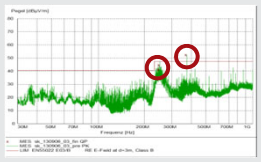
Wideband capture with limited ADC sensitivity

Typically linear spectrum display

Companion for early debug testing

COMMON EMI DEBUGGING PROCEDURE : ANALYSIS STEPS

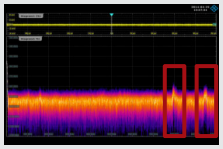
A) Far-field measurement



B) "Know your DUT":
List of potential interferer sources

Source	Frequency
Clock frequency	e.g. 25 MHz + Multiples
Ethernet PHY	e.g. 125 MHz + Multiples
Voltage converter / power adapter	broadband
…	

C) Reference measurement without DUT

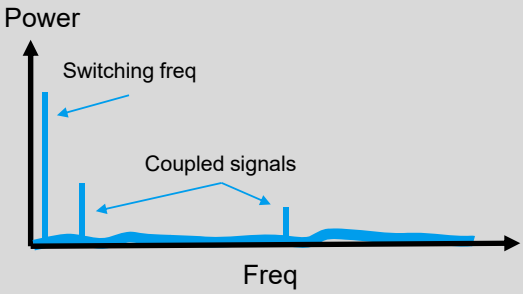


D) Interferer current measurement to find out the coupling type

E) Nearfield probe to localize the interferer source

F) Applying counter-measures and validation

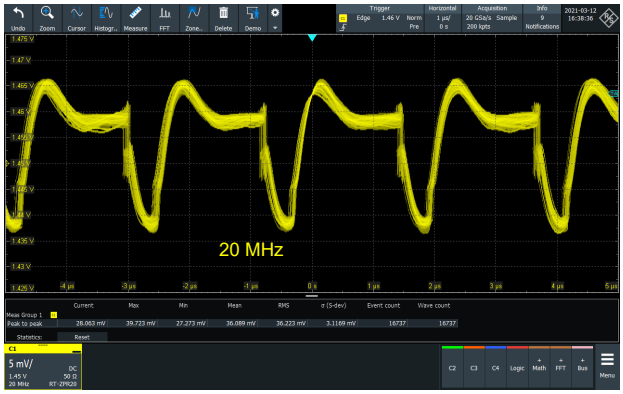
HOW MUCH BANDWIDTH OR PI MEASUREMENTS?



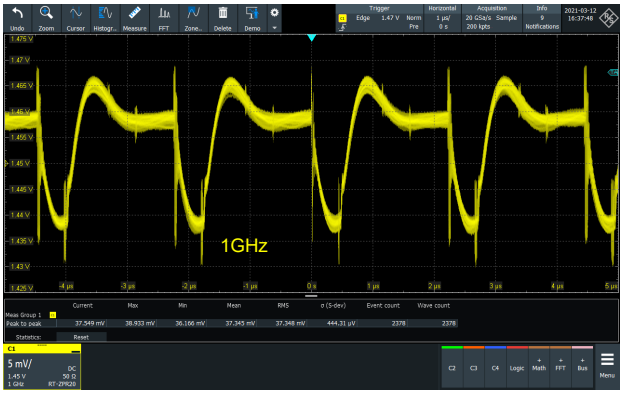
HOW MUCH BANDWIDTH DO YOU NEED?

START HIGH AND REDUCE. USE FFT TO HELP DETERMINE HOW MUCH

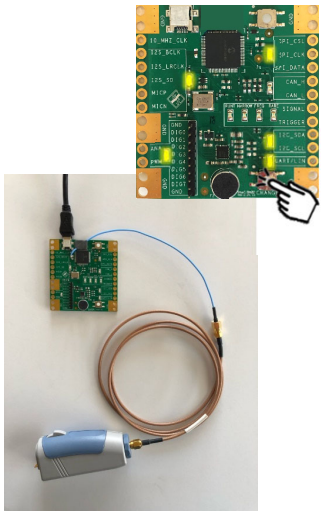
20 MHz



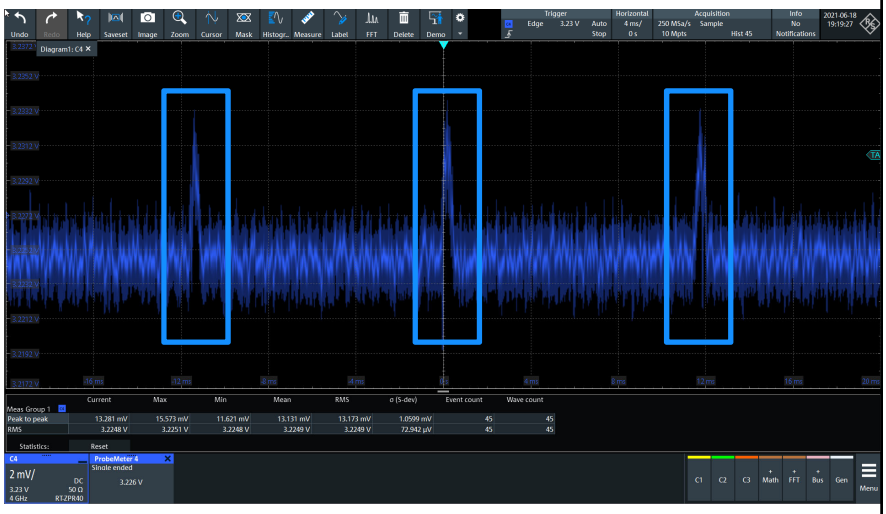
1 GHz



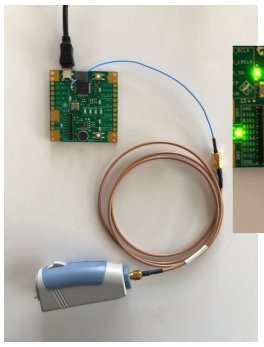
EXTRA CREDIT: WHAT'S CAUSING PERIODIC RAIL SPIKES?



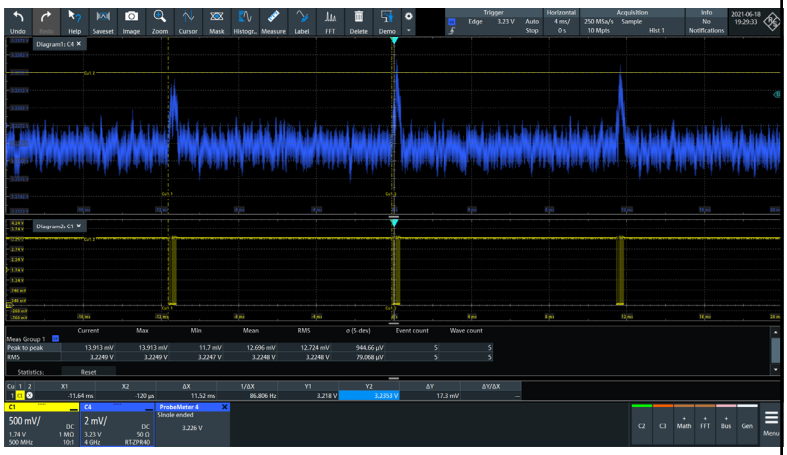
Timebase at 4 ms / div



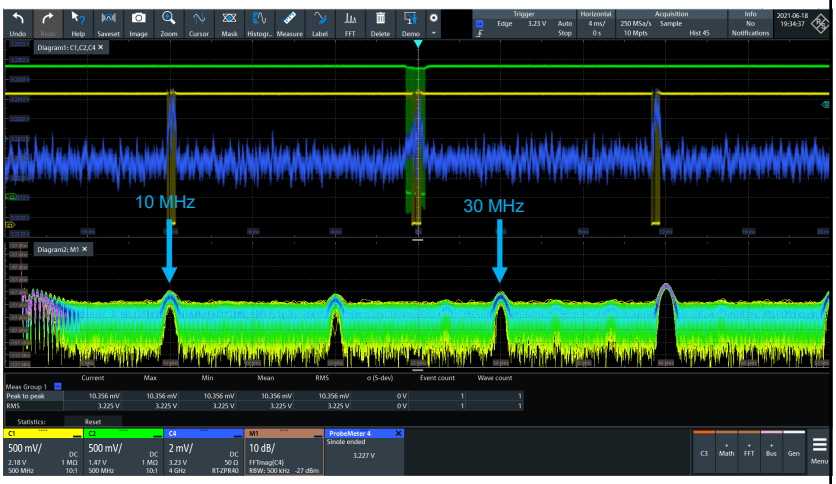
POWER RAIL PEAKING CORRESPONDS TO I²C PACKETS



Attach to I²C signals

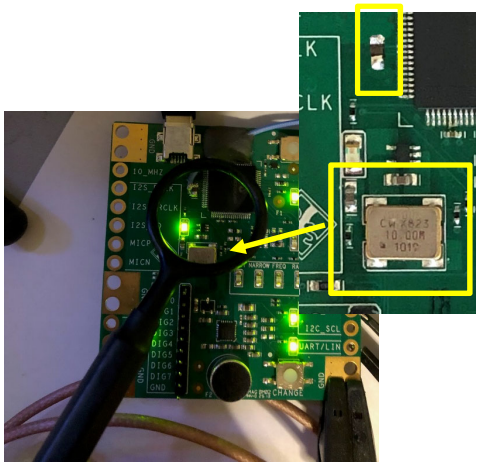


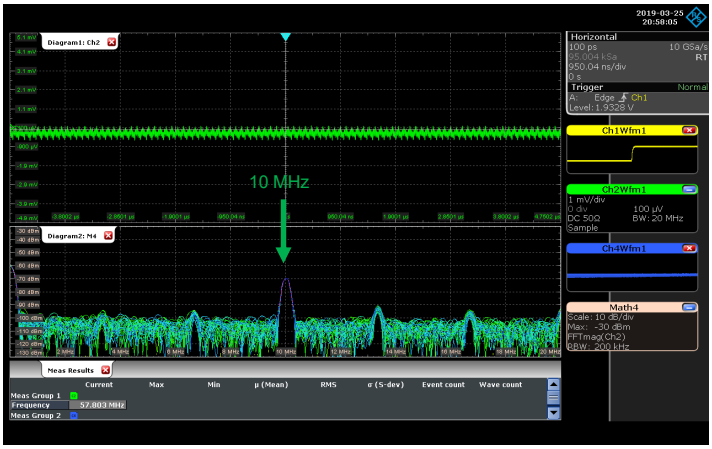
FFT ON POWER RAIL SHOW 10 MHZ AND HARMONIC TONES



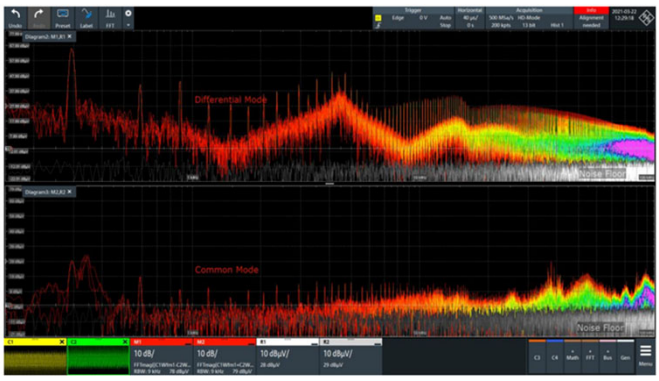
NEAR FIELD PROBE

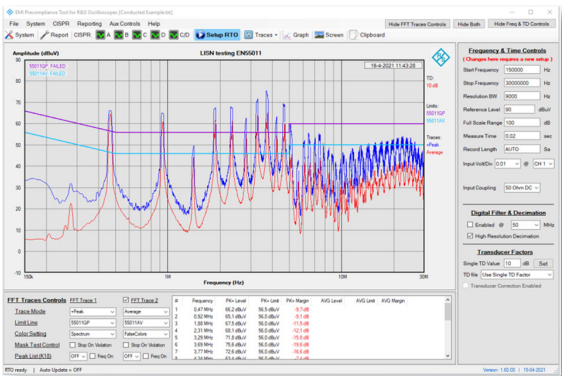
10 MHZ EMI…. COMING FROM 10 MHZ OSCILLATOR





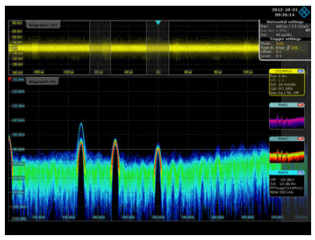
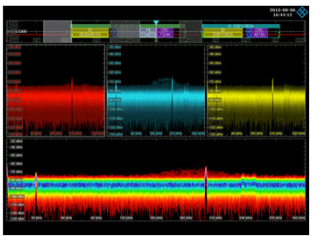
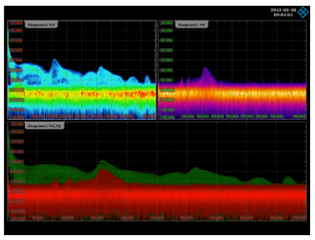
EMI PRECOMPLIANCE APPLICATION :





R&S OSCILLOSCOPE USP ON EMI DEBUGGING TECHNIQUES

Hardware Specifications	DDC, HW-based FFT, 1 mV/div at full BW, high ENOB, Acquisition bandwidth

Locate	Capture	Analyze
		
High speed FFT Multi-channels FFT (Overlay of multi-channels FFT) Overlapped FFT Real time FFT Intensity grading display	**Time domain** Digital trigger system Serial and parallel bus trigger Mask violation **Frequency domain** Mask violation	Multi-traces Gated FFT Correlated time and freq. domain Sampled memory (Post analysis) History mode

R&S OSCILLOSCOPE PORTFOLIO