Debugging of Embedded IoT Systems with a Multi-Domain Oscilloscope

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Feng Xie, Market Segment Manager - IoT

Webinar – January, 8th 2017

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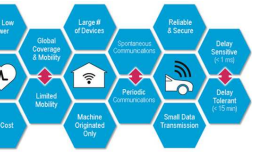
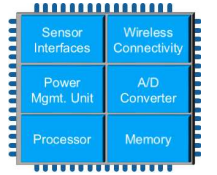
Outline

- Introduction of Rohde & Schwarz
- Introduction to Internet of Things and R&S Portfolio
- Challenges for Design and Test of Embedded Wireless Devices
- The R&S®RTO Oscilloscopes for Testing Multi-Domain Applications
- Test Examples with M2M IoT module





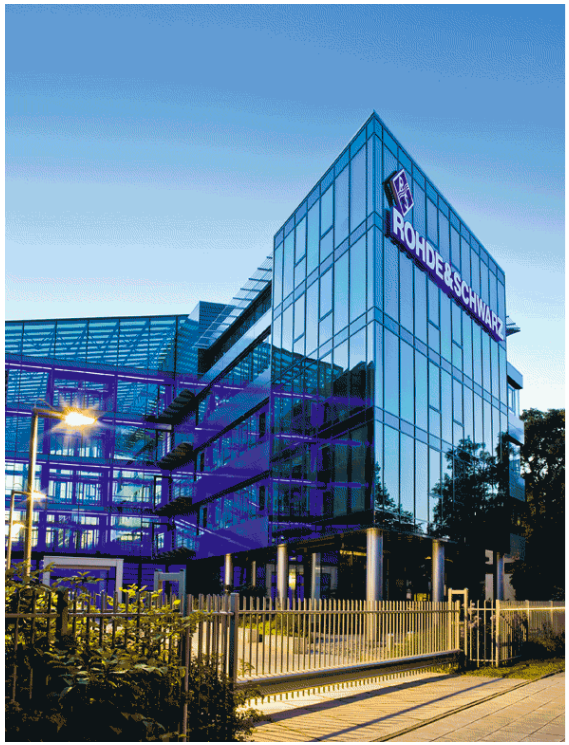
Rohde & Schwarz - The Expert in

Test & measurement
Broadcast and media
Secure communications
Cybersecurity
Radiomonitoring and radiolocation

ROHDE&SCHWARZ

The company group at a glance

- **History**
  Established 1933 in Munich, Germany
- **Type of enterprise**
  Independent family-owned company
- **Global presence**
  In over 70 countries, approx. 60 subsidiaries
- **Net revenue**
  EUR 1.92 billion (FY 15/16, July through June)
- **Export share**
  85 percent
- **Employees**
  10000 worldwide, with approx. 6000 in Germany
- **Success**
  A leading international supplier in all of its fields of business



Business fields

Test and Measurement	Broadcast and Media	Secure Communications	Cybersecurity	Radiomonitoring & Radiolocation
T&M instruments and systems for ▪ Wireless communications ▪ General purpose electronics ▪ Aerospace & defense applications	**Broadcast, T&M and studio equipment** for ▪ Network operators ▪ Broadcasters ▪ Studios ▪ Film industry ▪ Manufacturers of entertainment equipment	**Communications systems** for ▪ Air traffic control ▪ Armed forces **Encryption technology** for ▪ Armed forces ▪ Government authorities ▪ Critical infrastructures	**IT security products** for ▪ Economy ▪ Authorities	**Radiomonitoring equipment** for ▪ Regulatory authorities ▪ Homeland and external security ▪ Network operators **Radar intelligence systems**
Service				

Customers and markets

Manufacturers of mobile radio and other wireless terminal equipment

Operators of wireless communications and broadcast networks

Electronics manufacturers

Electronics service providers

Aerospace and defense

Studios and broadcasters

Government authorities and other public sector customers

Companies of all types and sizes

Leading-edge solutions

R&S®CMW500
Universal test platform for all common mobile radio and wireless technologies

R&S®RTO
Fastest oscilloscope on the market with the world's first digital trigger

R&S®FSW
Signal and spectrum analyzer with outstanding performance

R&S®QPS200
Latest generation millimeter wave security scanner for airports

R&S®ESMD
Compact high-end receiver for all radiomonitoring tasks

R&S®SDTR
Military radio based on state-of-the-art software defined radio (SDR) technology

R&S®SITLine ETH40G
Fastest Ethernet encryptor (40 GBit/s)

Rohde & Schwarz around the world

Beijing


Singapore


Madrid


London


Kuala Lumpur


São Paulo


Paris


Vienna

Production plants with high manufacturing depth

- **Quality made by Rohde & Schwarz**
  Most products are manufactured in Germany;
  additional plants in the Czech Republic, Singapore and Malaysia
- **High manufacturing depth**
  To maintain independence, flexibility and quality
- **Maximum production flexibility**
  To handle a wide variety of products and changing batch sizes and to quickly respond to changing market requirements
- **Short delivery times**
  Maximum of four weeks for off-the-shelf products
- **Development and production hand in hand**
  Short paths and close collaboration between production sites and development centers

Introduction to Internet of Things and Overview to R&S solution portfolio

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Internet of things becomes reality in vertical industries

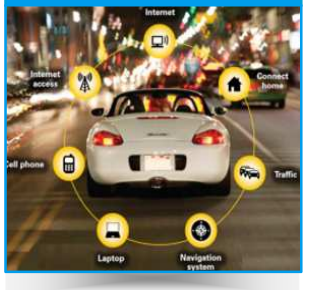
Wearables

Smart Homes

Smart Cities

Healthcare

Automotive



Smart Buildings

Asset Tracking

Retail

Agriculture

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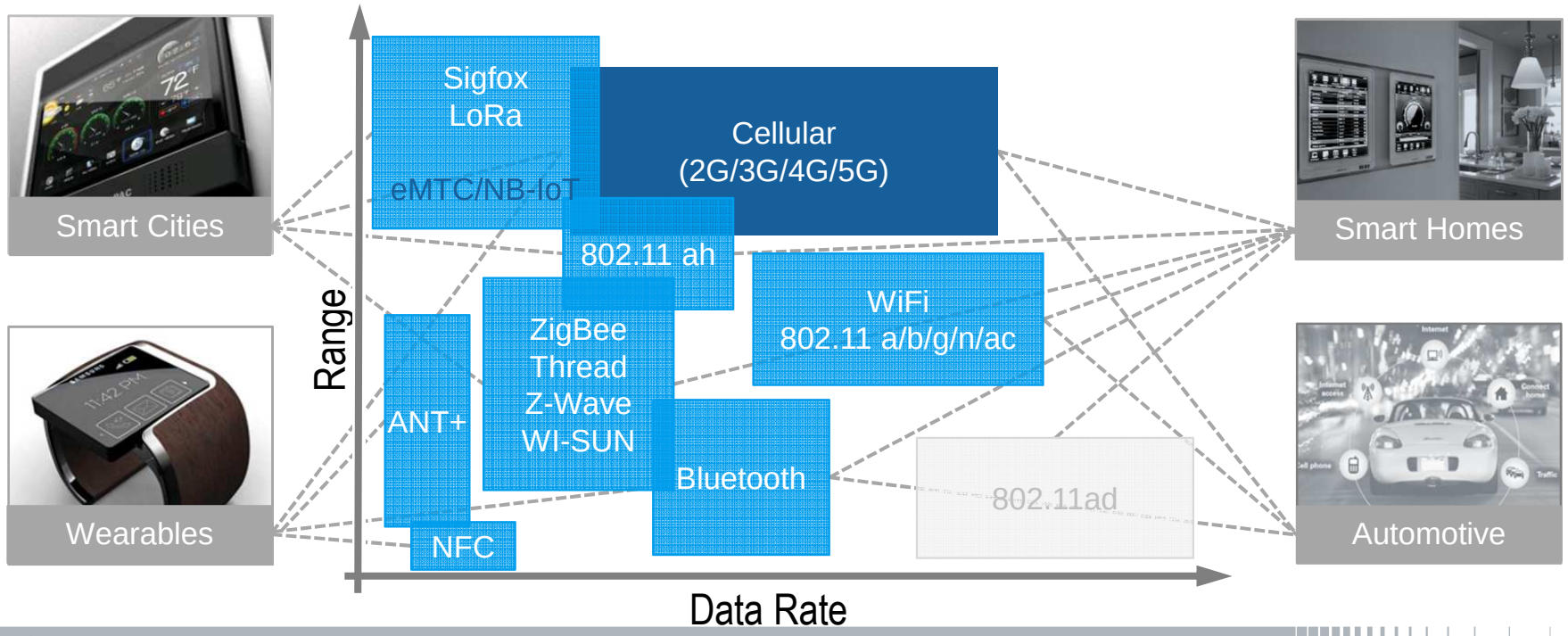
Wireless technologies enabling the Internet of Things



Embedded Wireless Devices

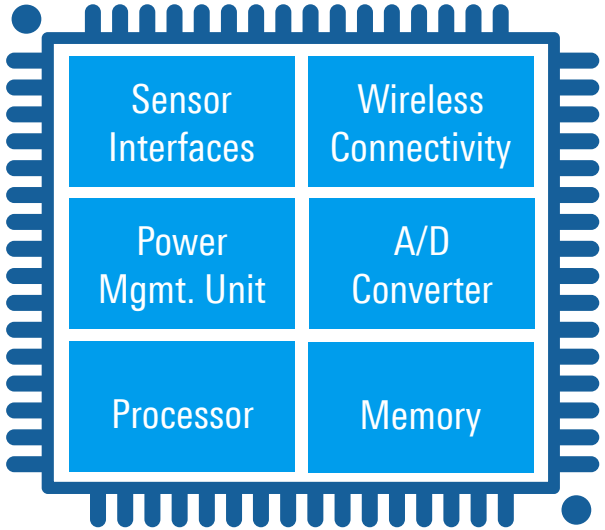
Key Components and Interfaces

Low Speed I/O
UART, I2C, SPI, GPIO, etc.

High Speed I/O
USB, PCIe, MIPI, SerDes, etc.

Power Supply
LDO, SMPS, etc.

Processor I/O
MCU, ARM, FPGA, etc.



Connectivity
LAN, WiFi, LTE, etc.

Analog Converter
A/D, D/A

Memory Interface I/O
eMMC, SD, LP DRAM, etc.

Testing in all phases of life cycle of IoT devices and networks

Research & Development	Design & Validation	Pre-Compliance & Compliance	Manufacturing	Deployment & Operation	Service & Repair
▌Digital and analog interface debug ▌Clock Analysis ▌EMI debug ▌Power Analysis	▌RF Parametrics ▌Co-existence ▌Functionality ▌Performance ▌Power analysis	▌Standard compliance ▌Regulator compliance ▌Carrier Acceptance	▌Calibration ▌Verification ▌Go / NoGo	▌Installation ▌Monitoring ▌Optimization	▌Fault Finding ▌Calibration ▌Verification
					

R&S Test solutions is ready for all IoT technologies

RF Development

R&S®SMW

R&S®SMBV

R&S®SGT

R&S®FSW

R&S®FSV

R&S®FPS

RF Layer Test

R&S®SMW & R&S®FSW

R&S®SGT & R&S®FPS

R&S®CMW500

Signaling and e2e

R&S®CMW500/290

Prot. Conformance

R&S®CMW500

RF Conformance

R&S®TS8980

MNO acceptance

R&S®PQA
R&S®TS-290

Production Testing

R&S®CMW100

R&S®CMW500

R&S®SGT/FPS/OSP

R&S®NRP

Switching Unit R&S®OSP

Install.& Mtc.

R&S®FSH

R&S®ZVH

Time domain

R&S®RTO

OTA

Additional portfolio

CMW the unique test solution platform for cellular and connectivity

The all-in-one platform

Support of all major cellular and non cellular wireless technologies for non-signaling, signaling and protocol testing

Parametric RF tests

RF Transmitter / Receiver validation test in real-time base station emulation mode incl. channel impairments

Protocol tests

Protocol testing including IMS (VoLTE), MTC features (NIMTC, SIMTC, Cat 0, Cat M1), or LTE-U and operator acceptance tests

Wideband Radio Communication Tester R&S®CMW

GSM HSPA LTE LTE Advanced Bluetooth WiFi WiMAX TD-SCDMA

Location based services

Possibility to test location based services for satellite based (GNSS) and networks based positioning

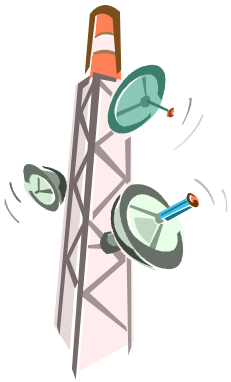
Application Performance

Data application unit and advanced IP analysis as well as impairment features allow comprehensive e2e testing

GUI and Automation

CMWcards for easy test of complex scenarios and CMWrun for test automation from R&D to production

One Example with Base Station Simulation: Transmission Power Control



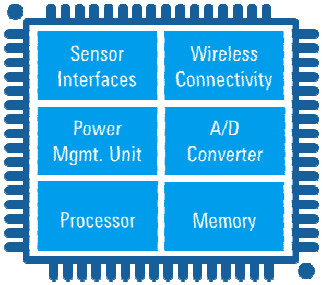
PUSCH max power: + 23dBm

PUSCH min power: - 40dBm

50Ω

3.2V

0.00225V



Challenges for Design and Test of Embedded Wireless Devices

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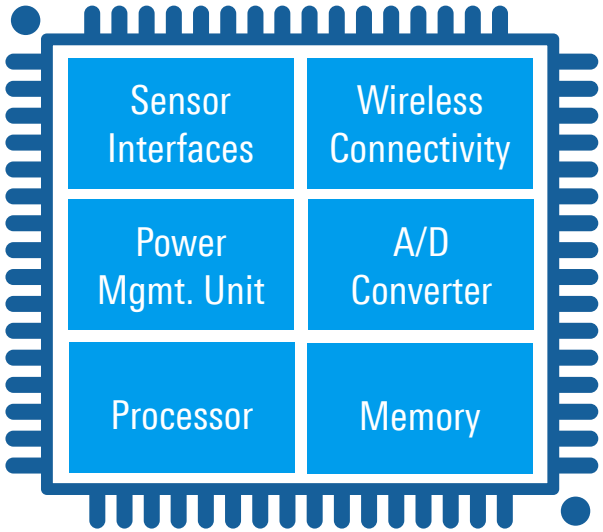


Connectivity
LAN, WiFi, LTE, etc.

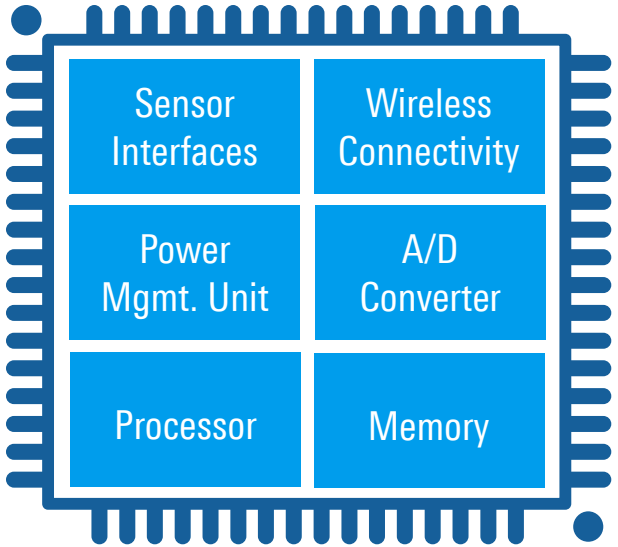
Analog Converter
A/D, D/A

Memory Interface I/O
eMMC, SD, LP DRAM, etc.

Embedded IoT Devices
Design Challenges

IoT devices combine resources for sensor data collection, computing and connectivity, as well as infrastructure for power management and storage.

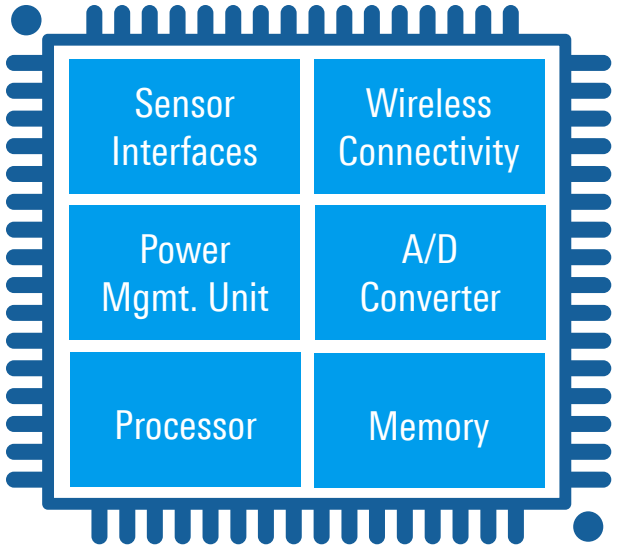
- High integration level of different technologies
- Low cost
- “10 years” battery life time
- Reliability & Security



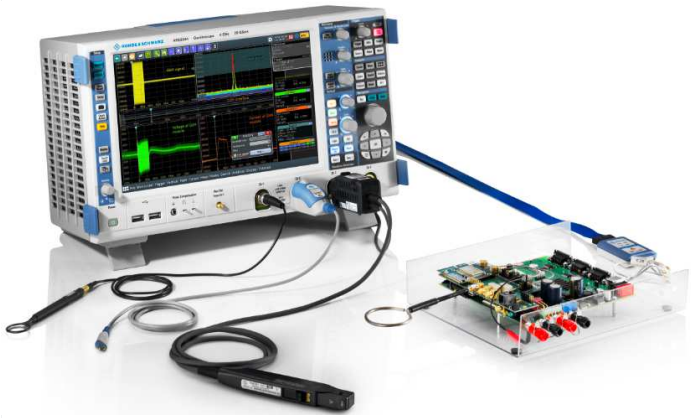
Embedded Wireless Devices
Test Challenges

During the design, the debug and the evaluation phase there are several key test challenges:

1. Power: Current consumption / Power integrity
2. Digital: Signal integrity
3. RF: Wireless interface testing
4. Debugging of overall system



R&S Debug Solution: the R&S®RTO Oscilloscope



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R&S®RTO Oscilloscope for Multi-Domain Applications

Time domain analysis

General debugging,
Signal integrity,
Power analysis

Acquisition rate,
trigger capabilities

Consistent interface

Trigger & Decode

Serial bus debugging
(e.g. I2C, SPI, UART)

Protocol analysis

Multi Domain

600 MHz .. 6 GHz models

Logic analysis

Parallel and serial busses,
ADC testing

MSO
upgradability,

Time aligned

Multiple FFT´s,
Speed

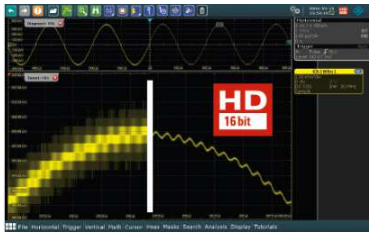
RF analysis,
EMI debugging

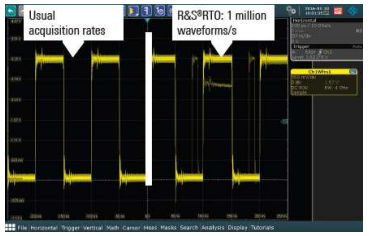
Frequency analysis

R&S®RTO Key Performance Parameters

Best performance

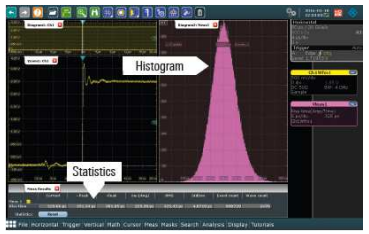
- **I6 GHz**, 20 Gsample/s, **2 Gsample** deep memory
- Low noise, high dynamic, up to **16-bit** res.
- Finding signal faults quickly - **1 million** wfms/s
- Trigger on any signal details - digital trigger system





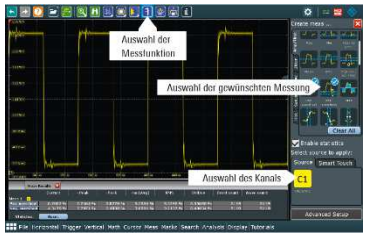
Wide range of capabilities

- QuickMeas: key results at the push of a button
- Integrated **spectrum analysis**
- History: analyze previous acquisitions
- Mask: settings in only seconds
- First **Zone trigger** in time and **freq. domain**



Powerful user interfaces

- High-resolution **12.1" capacitive** touch screen
- Easy **customizable** waveform displays
- Fast access to important tools
- Undo/redo forgives your mistakes



Test Challenge #1a
Current Consumption

Current Measurements

Unique R&S®RTO solution: Best Capabilities and Performance

RTO key capabilities for high-sensitivity measurements

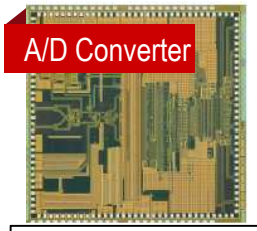
- Low noise, >7 bit ENOB ADC, high sensitivity FE
- 16 bit High Definition mode

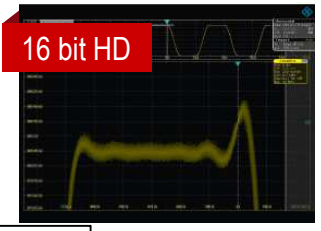
Current probes for small currents and high bandwidth

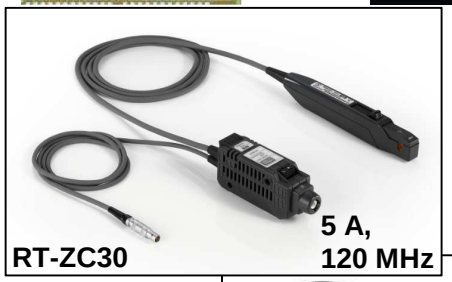
- R&S®RT-ZC30 High-sensitivity current probe
  (120 MHz, 5 A (RMS), 60 uA noise, 1 V/A)
- R&S®RT-ZC20B
  (100 MHz, 30 A (RMS), 1 mA noise, 10 V/A)

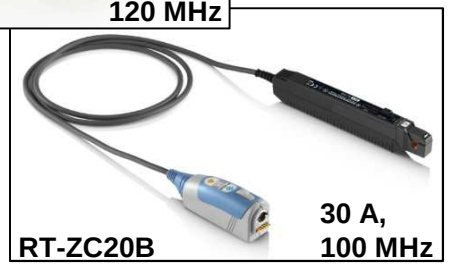
Your benefits:

- Measure small dynamic currents with high Bandwidth









Current Measurements with R&S®RTO

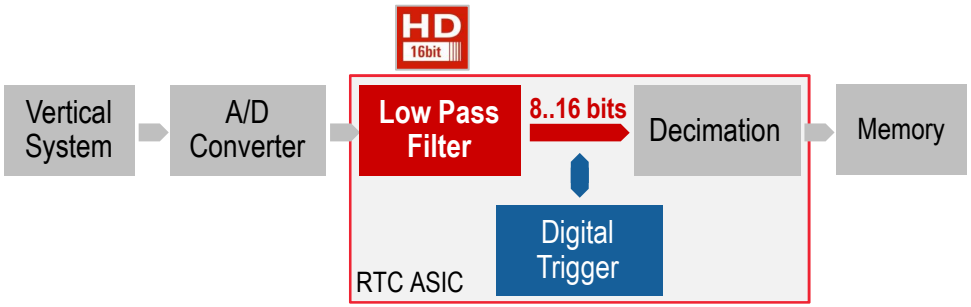
16 bit High Definition Mode

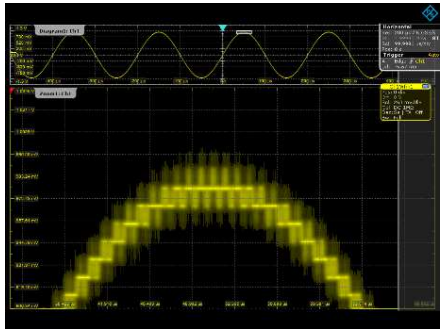
High Definition mode - system design

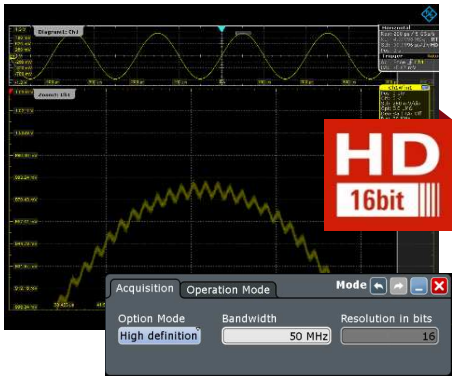
- Single-core monolithic ADC (10 Gsample/s, > 7 ENOBs)
- 16 bit wide processing architecture

High Definition mode (R&S®RTO-K17)

- Up to 16 bit vertical resolution
- More signal details and more precise analysis results
- Real-time triggering on smallest signal details
- No aliasing, no decimation
- High acquisition rate and signal processing
- All in one box!



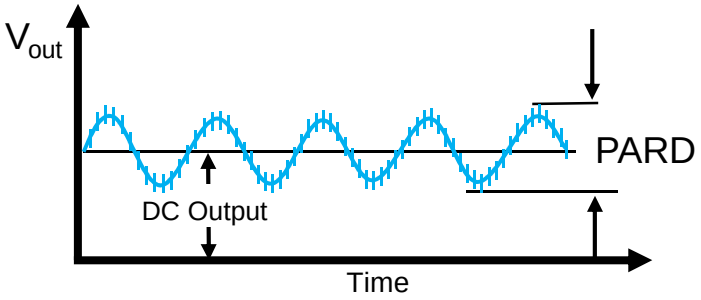


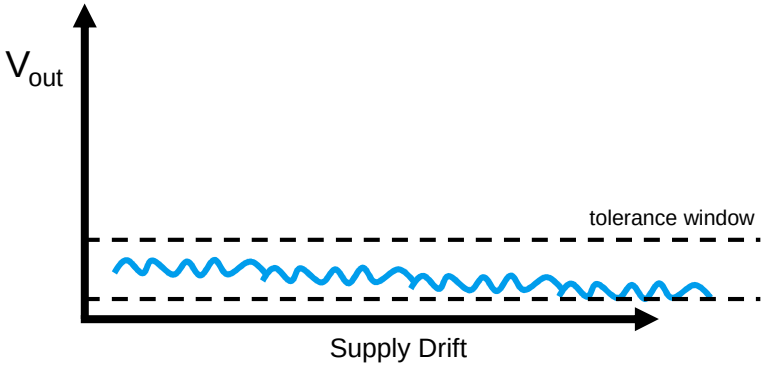


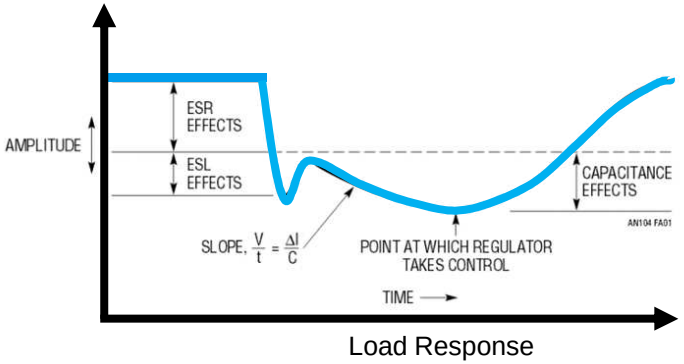
Power Integrity

Common Measurements

- PARD (Periodic and Random Disturbances): noise, ripple (V_{pp}), transients
- Static and dynamic load response
- Supply drift



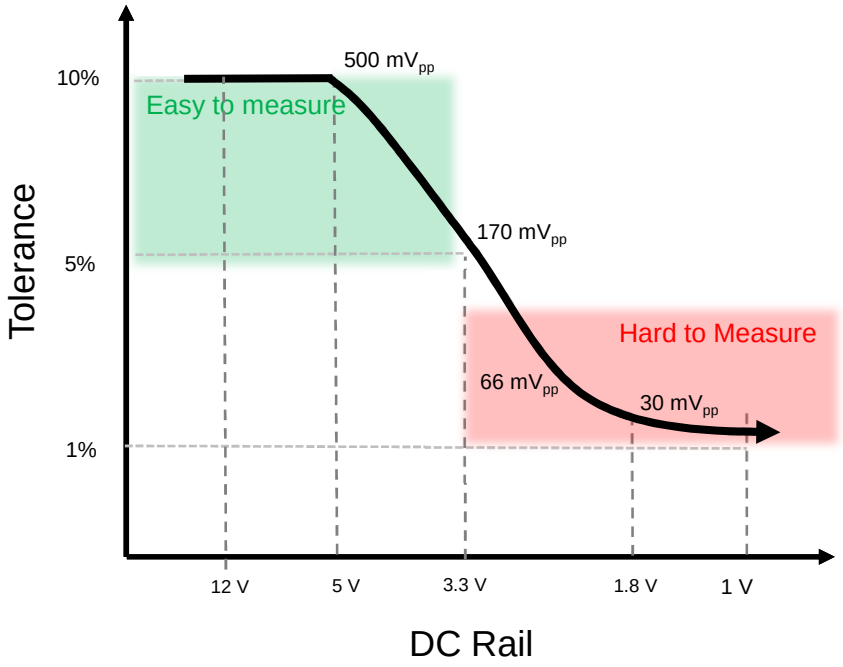




Test Challenge #1b

Power Rail Measurement Challenges

Lower rail voltages and smaller tolerances



Examples

Rail Value	Tolerance	Need to measure
3.3 V	2%	66 mV_{pp}
1.8 V	3 %	30 mV_{pp}
1.2 V	2.5 %	30 mV_{pp}
1 V	3 %	30 mV_{pp}

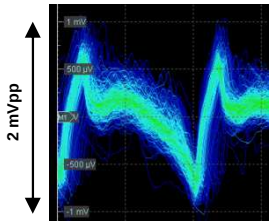
Test Challenge #1b

Power Rail Probing

Top Concerns For Power Rail Measurements

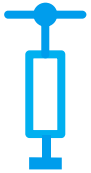
A) Low Noise:

Measure ripple
down in the mV range



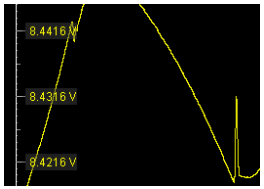
D) Low loading:

Tight power supply tolerances require low loading for low influence



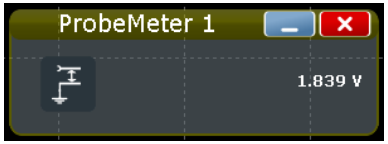
B) Sufficient Offset at high vertical sensitivity

Zoom into higher voltage
DC rails



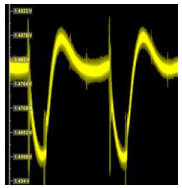
E) Accurate DC meas.

Verify tight supply
voltage tolerances and
observe drift



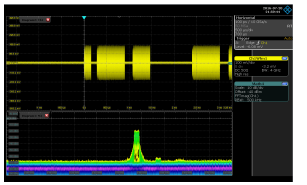
C) High bandwidth

Capture periodic and random disturbances as well as high-frequency transients



F) Ability to see coupled signals

Uncover unwanted RF noise
on the power rail



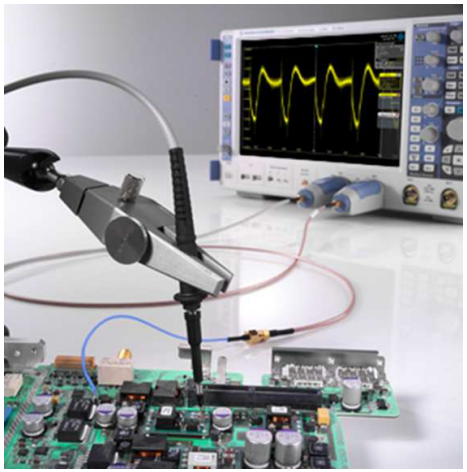
Test Challenge #1b

RT-ZPR20 Power Rail Probe

Designed for power integrity measurement

- High bandwidth
- Low noise, 1:1 active single-ended probe
- Best in class offset compensation capability
- R&S®Probe Meter integrated
- Perfect fit to RTE and RTO oscilloscopes

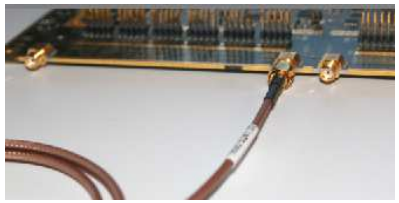
Target Specifications	
Attenuation	**1:1**
Probe BW	**2.0 GHz**
Browser BW	350 MHz
Dynamic Range	±850 mV
Offset Range	**±60 V**
Display Noise	**120 μV_{rms}** (with RTO @ 1 mV/div, 1 GHz BW)
Input Resistance	**50 kΩ** @ DC
R&S ProbeMeter	Integrated
Coupling	DC or 10 Hz AC



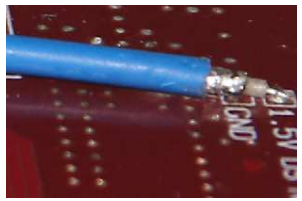
RT-ZPR20 Power Rail Probe

Active probe head, main cable and solder-in cables

Direct connect to SMA



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



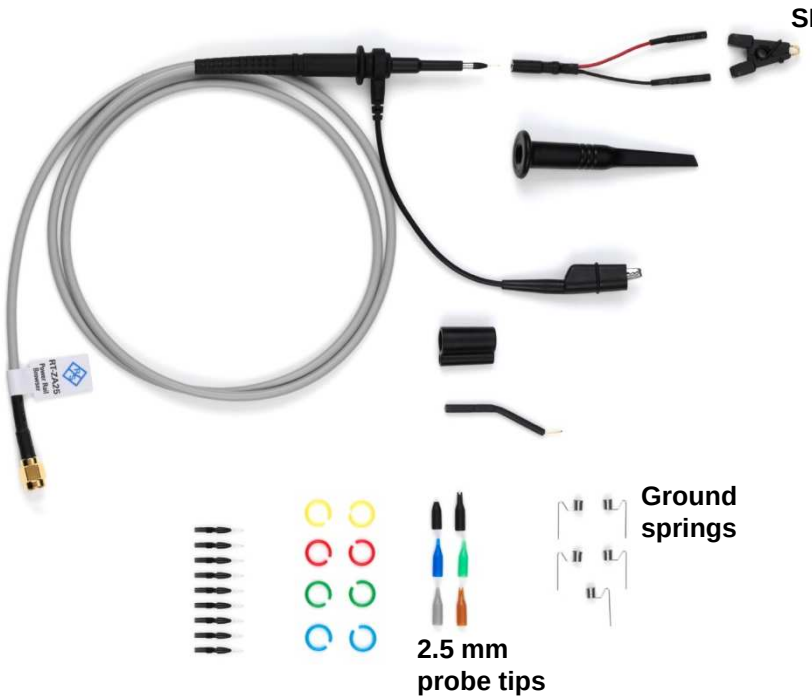
SMA to 2-pin Socket

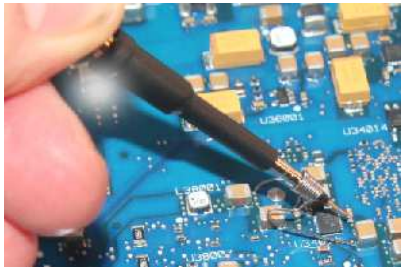
ZBX00SAMS-P (reference sell)

http://www.zebax.com/index_files/page1044.htm

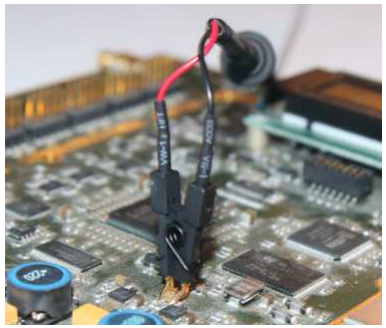
RT-ZPR20 Power Rail Probe

350 MHz browser and accessory





Ground spring



SMT clip

Test Challenge #1b

Power Integrity

RTO Oscilloscopes + Power Rail Probe

Fast 1 MWfs/s update rate finds worst case tolerances quickly

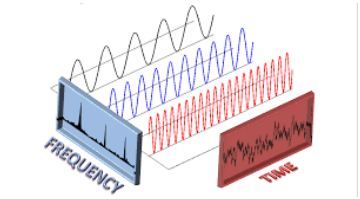
High BW shows coupled sources

Built in R&S 16-bit ProbeMeter shows DC voltage

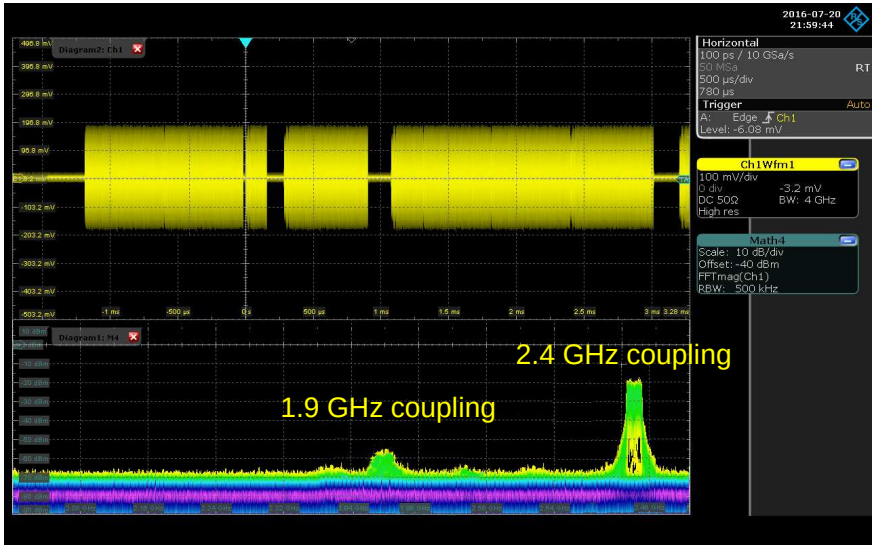
Vpp with statistics

Power Integrity
Finding Coupled Signals

Test Challenge #1b



Switching (low freq FFT)



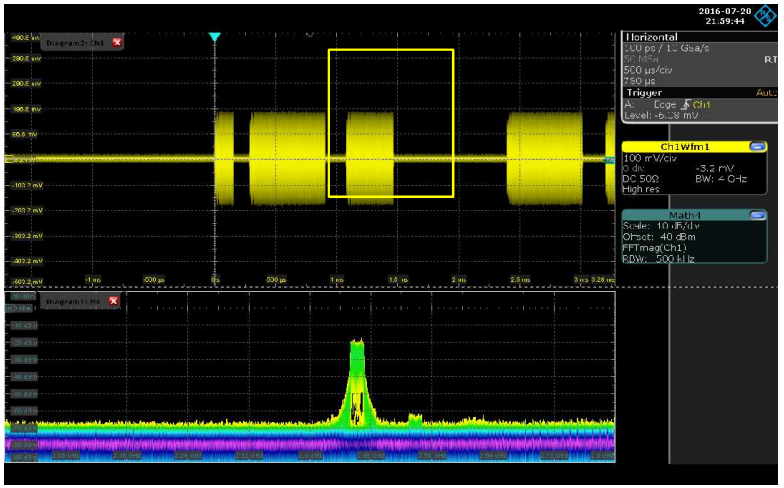
EMI/coupling (high freq FFT)
(Cross-coupling from the rf path into the PDN)

Test Challenge #1b

RT-ZPR20 Power Rail Probe – Typical Applications

IoT Devices: Verify Power Integrity and Debug EMI Issues

- **Measurement Challenge**
  - Low power design of IoT devices require to check for tight DC supply voltage tolerances
  - Wireless connectivity can cause unwanted coupling into power distribution network (PDN)
  - Unwanted ripple, noise and interference on the power distribution network can cause performance degradation and malfunction
- **Solution**
  - Low-noise probing with RT-ZPR20 and RTO oscilloscope
  - Leading-industry FFT analysis with RTO
  - Mask test to capture erratic interference



Correlation between time-and frequency-domain unveils the source of the problem: Cross-coupling from the rf path into the PDN

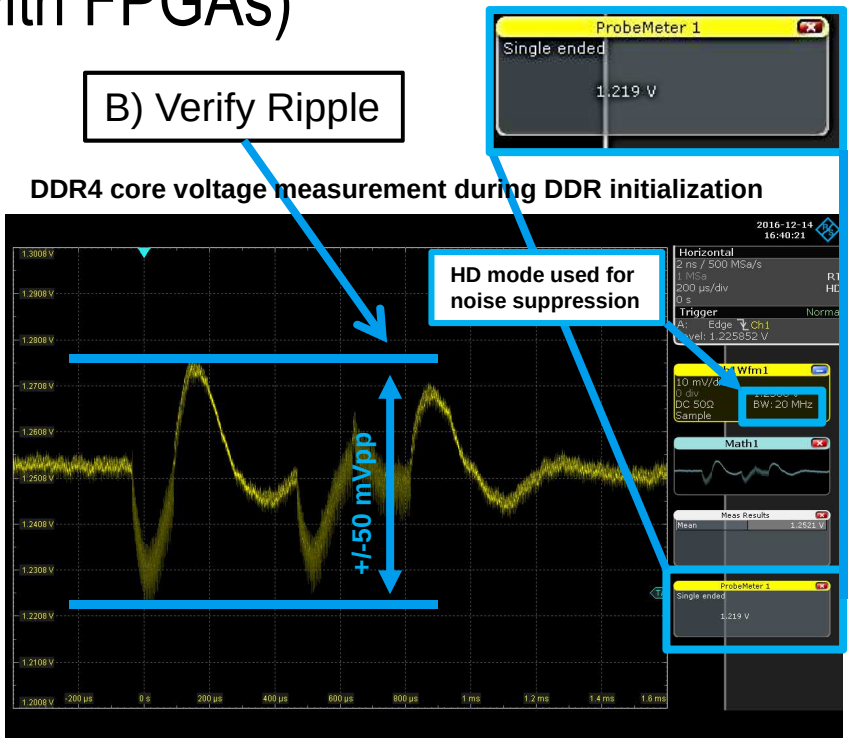
RT-ZPR20 Power Rail Probe – Typical Application

DDR4 Power Supply Qualification (with FPGAs)

- **Measurement Challenge**
  - DDR4 memories have tight supply voltage requirements
  - Large ripple or short voltage dips in I/O lines can cause data loss / malfunction
  - Probing on I/O pins for supply voltage measurement is not possible
- **Solution**
  - Use additional FPGA IO pin to route out DDR4 core power supply
  - Adjust offset of RT-ZPR20 to DDR4 core voltage (1.2 V)
  - Verify DC voltage and ripple

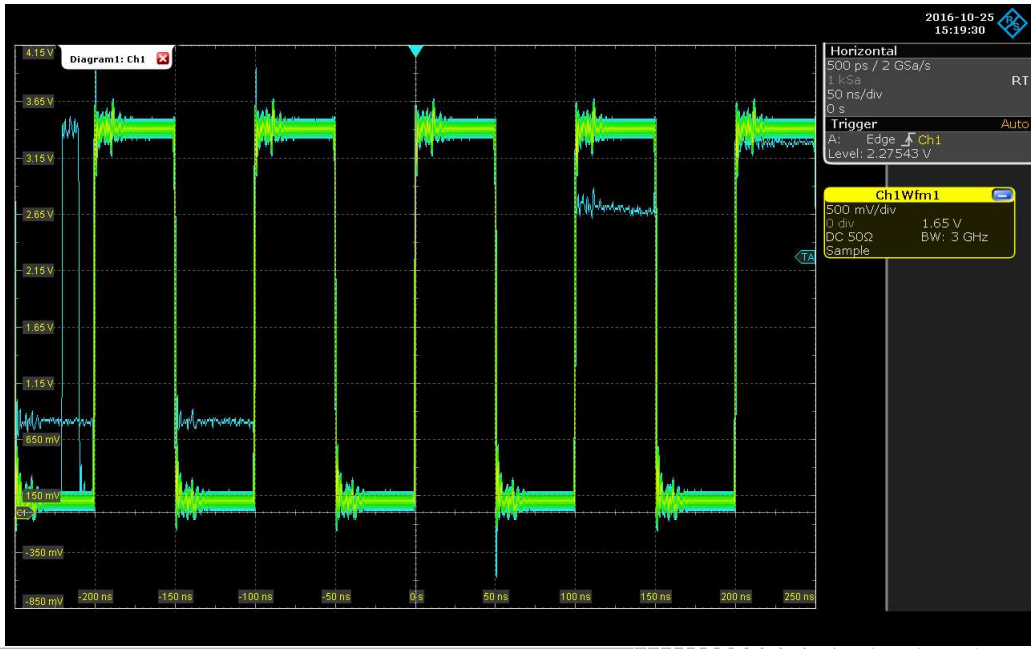
A) Verify exact DC voltage with R&S®Probe Meter

B) Verify Ripple



Signal Integrity

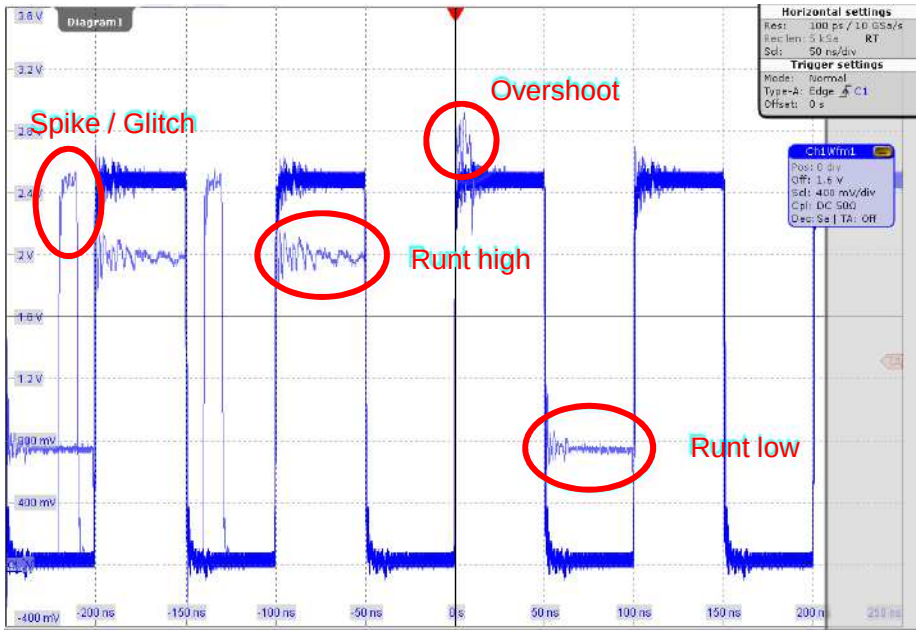
- By definition, integrity means *“complete and unimpaired”*
- Likewise, a signal with good integrity has
  - Clean, fast transitions
  - Stable and valid logic levels
  - Accurate placement in time
  - Would be free of any transients
- Evolving technology makes it increasingly difficult to produce and maintain complete, unimpaired signals in highly integrated embedded designs



Test Challenge #2

Signal Integrity
Debug Checklist

- Check digital signals for common symptoms of signal integrity problems:
  - Runts
  - Glitches
  - Slow rise time
  - Setup and hold violations
- Analyse signals for:
  - Overshoot, Undershoot
  - Droop
  - Non monotonic edges
  - Amplitude problems
  - Pulse width
  - Noise

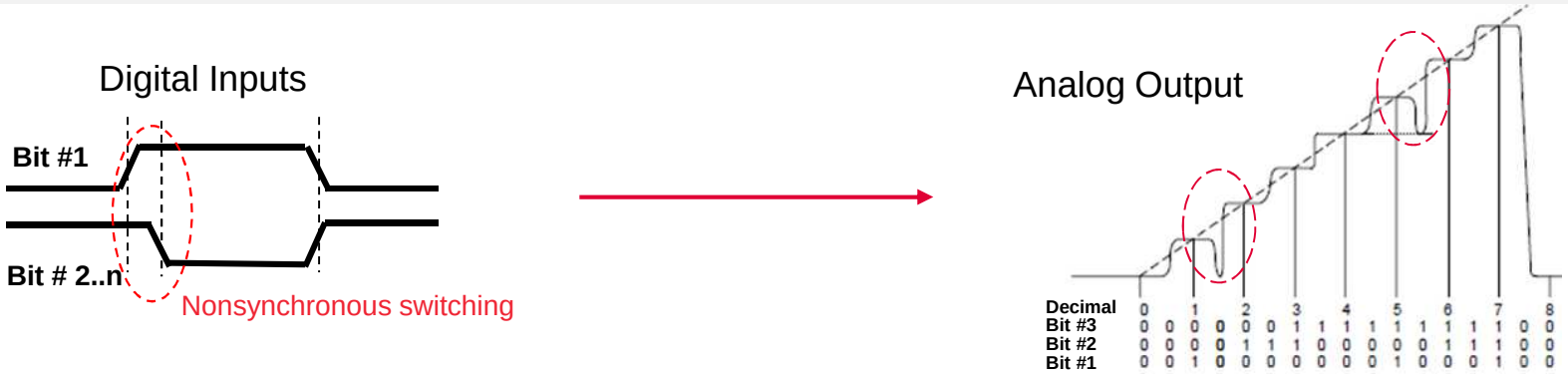


With what confidence are we able to capture these effects - quickly?

Signal Integrity

Common Circuit faults – DAC Glitches

- Glitches in D/A converters can occur with any change of the input code at the output of a DAC
- Common error sources:
  - **Nonsynchronous switching times.**
  - **Different switching speed** of the logic parts in dependency of the slope direction.
  - **Interference** over parasitic capacitance into the signalling paths.



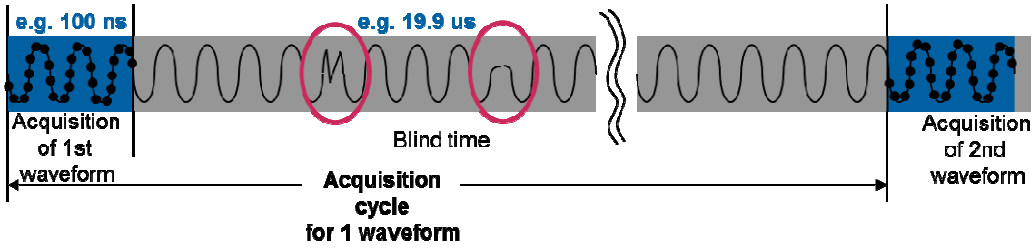
Need for high timing resolution across analog and digital channels.

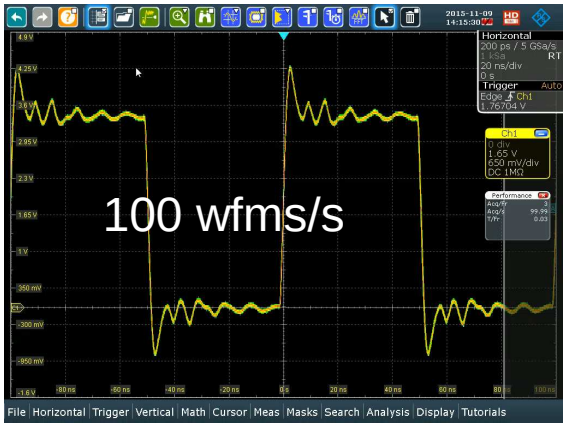
Test Challenge #2

Signal Integrity

Unique R&S®RTO solution: Fastest Acquisition

- The R&S®RTO has minimized blind times due to an dedicated acquisition ASIC:
  - high integration level (14 million gates)
  - massive parallel high-speed paths





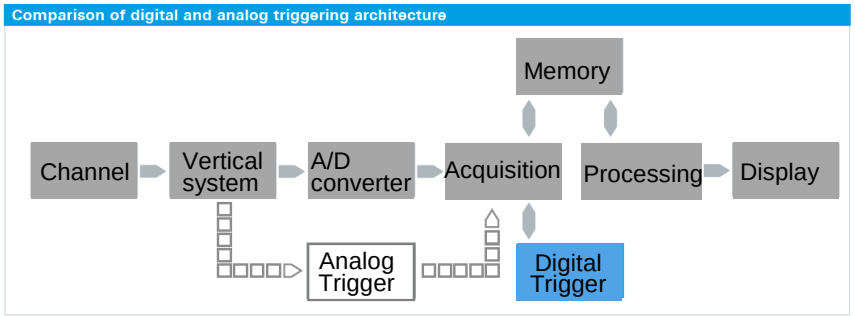
Your benefits:

- Sees more than traditional oscilloscopes with 1 Mio wfms/s
- Detects rare signal faults reliable and very fast

Signal Integrity

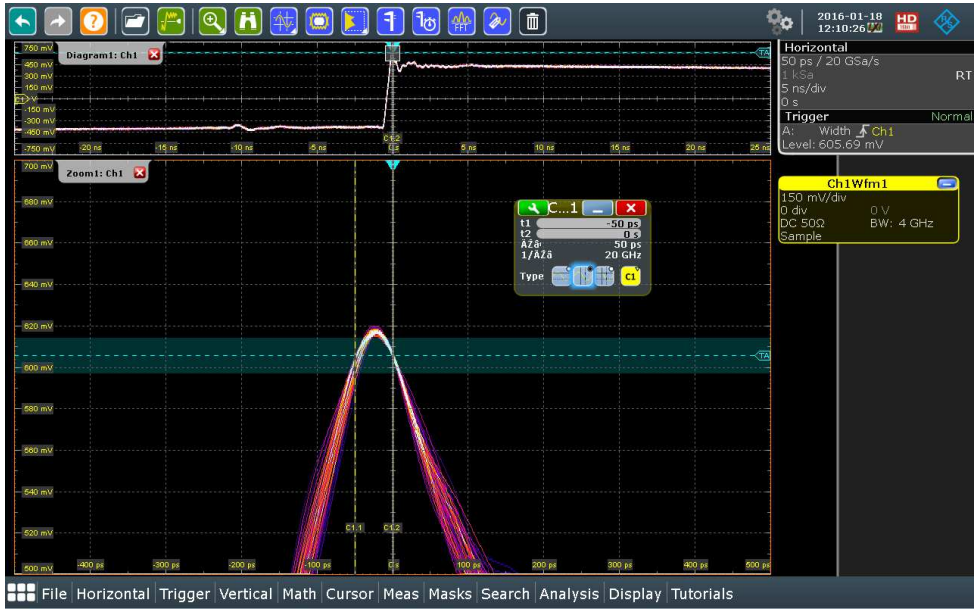
Unique R&S®RTO solution: Digital Trigger

- Digital trigger system uses data of 10 GHz A/D converter



Your benefits:

- Trigger on any detail you see
- Minimum trigger jitter
- Very high sensitivity



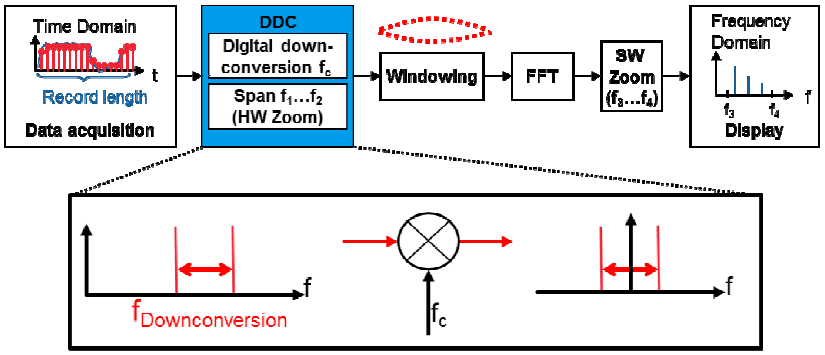
Stable trigger on ≤ 50 ps pulse width of an overshoot

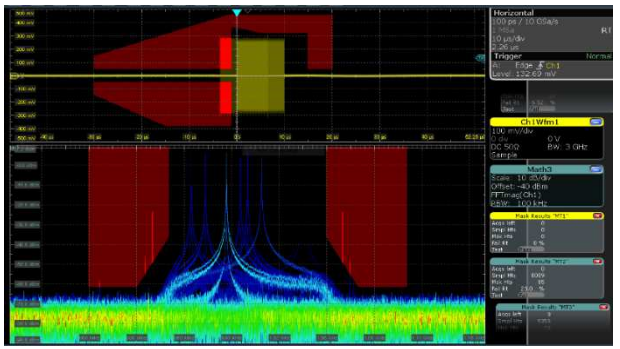
Test Challenge #3
RF Signal Analysis

RF Signal Analysis

Unique R&S®RTO solution: Integrated FFT-based Spectrum Analysis

- **Spectrum analyzer like operation**
  - Set START, STOP, SPAN and RBW
- **Overlapping FFT**
  - Fast and accurate detection of rare events
- **Digital down-conversion (DDC)**
  - FFT done on the selected frequency range
  - Higher resolution compared to conventional FFT
- **Zone Trigger in Frequency Domain**
- **… and additionally**
  - Up to 4 channels in parallel
  - Correlated analysis of signals in time- & and frequency domain



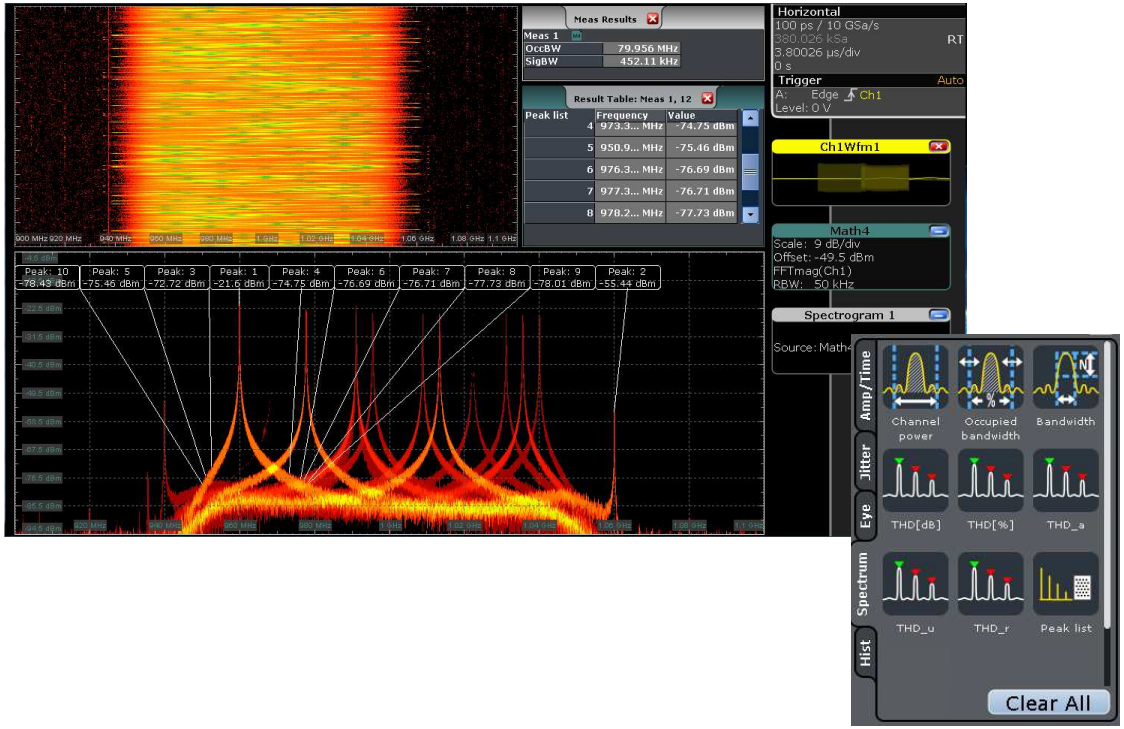


Test Challenge #3

R&S®RTO RF Signal Analysis

Advanced Spectrum Analysis with RTO-K18

- **Spectrogram - visualization of changes vs. time:**
  - Power vs. time
  - Frequency vs. time
- **Peak list - visualization in frequency domain**
  - Automatic labeling
  - Threshold level for peak detection
- **Log-Log scaling**



Test Challenge #3

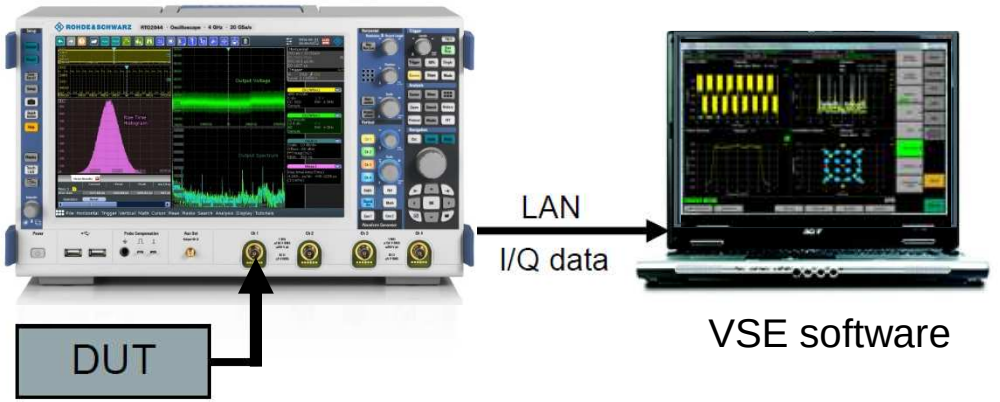
R&S®RTO RF Signal Analysis

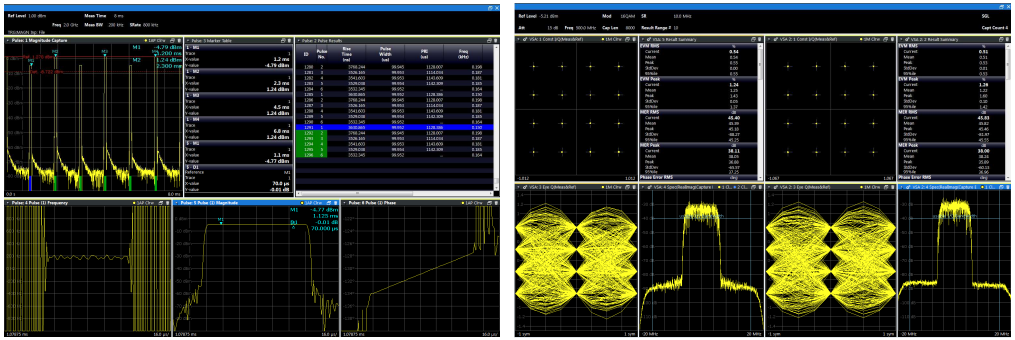
Signal Processing

Vector Signal Explorer SW:

- I/Q Analyzer
- Analog Demodulation
- Vector Signal Analysis (VSA)
- 3G FDD
- GSM
- WLAN
- LTE
- etc.

- *Universal SW tool for R&S oscilloscope and spectrum analyzers*



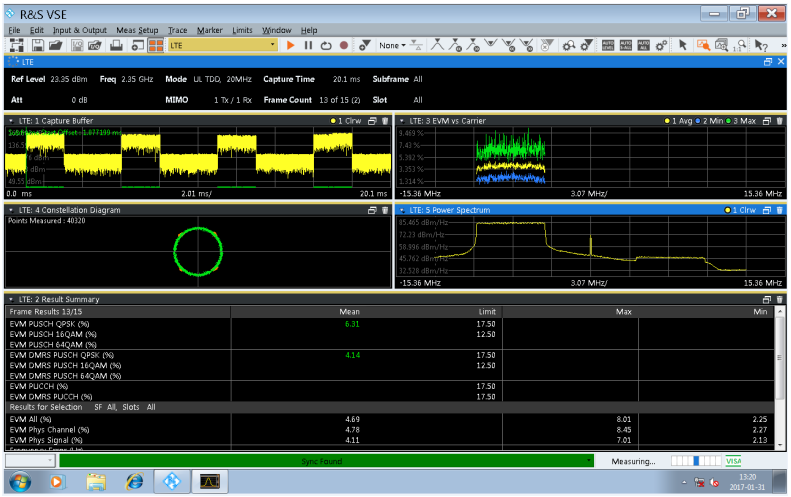


Test Challenge #3

RF Signal analysis with R&S®RTO Oscilloscope

Vector Signal Explorer Software

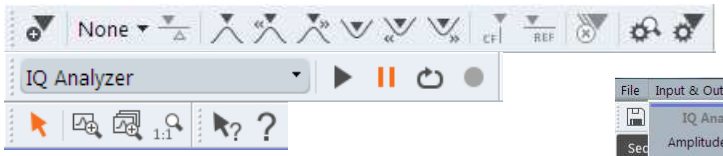
- **Base Capabilities**
  - Control instruments and capture IQ Data,
  - Read and write IQ Files
  - Basic IQ data analysis (Magnitude/ Spectrum/ Statistics/ IQ Vector/..)
- **Additional Analysis Options**
  - Pulses
  - Analog Demodulator (FM, AM, PM)
  - GSM
  - Generic VSA
  - 3GPP
  - WLAN
  - LTE FDD /TDD

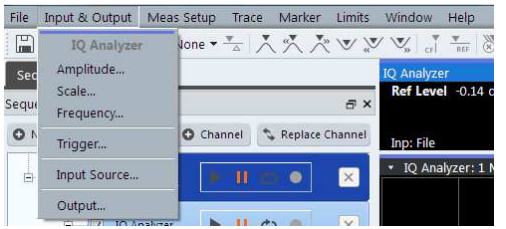


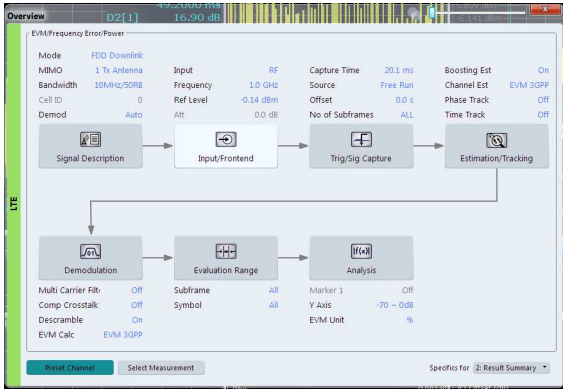
- **Operating system**
  - 64 Bit software / Windows 7 /10
- **Remote system**
  - Control instruments via VISA / SCPI

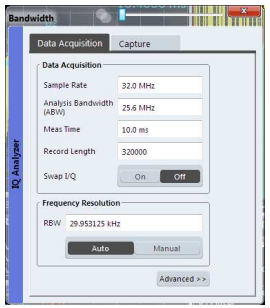
VSE User Interface

- User interface based on FSW, but adapted to PC usage
  - Menus
  - Toolbars
  - Context help
  - Similar Dialogs
  - Similar Diagrams
- Hides instrument specific details as much as possible









Test Challenge #3

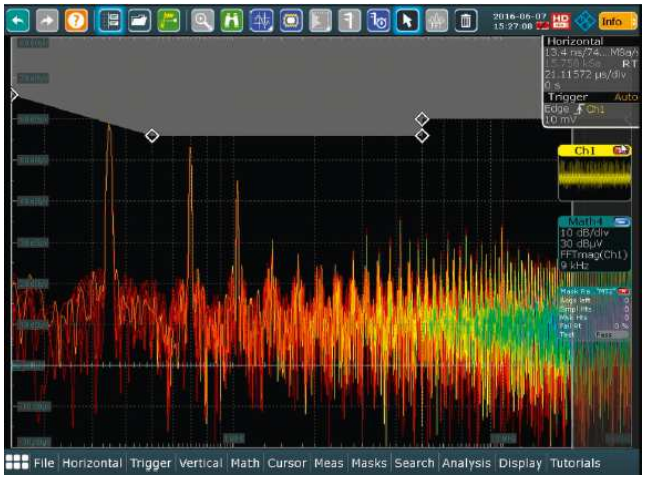
EMI debugging

With the R&S®HZ-15 Probe set

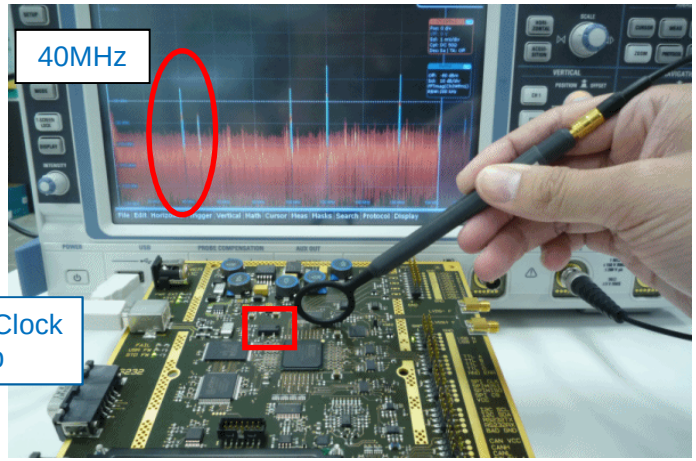
Detection of EMI sources with the R&S®RTO Oscilloscope

- Fast and accurate measurements
- Multiple FFT traces
- Easy configuration of masks for EMC limit testing

R&S®HZ-15 Probe set for E and H near-field emission measurements. 30 MHz to 3 GHz



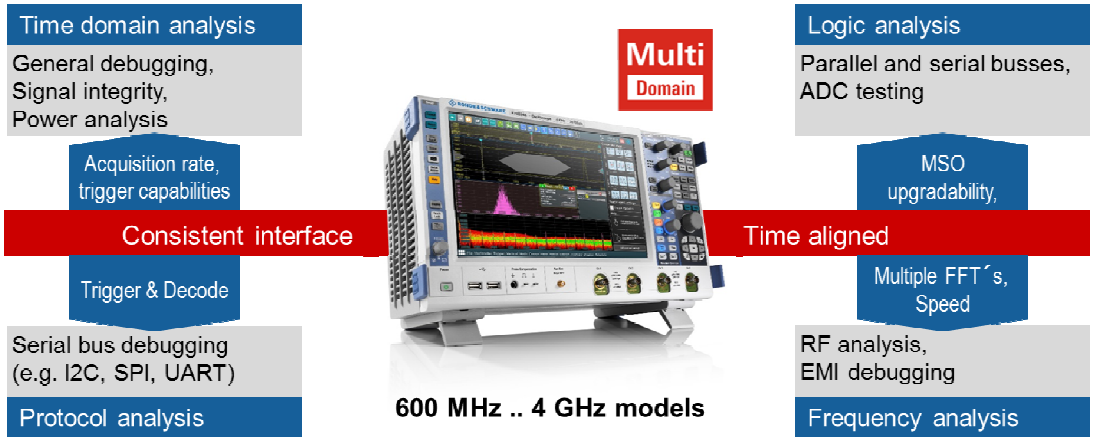
Conducted emission test with a mask defined in the spectrum.

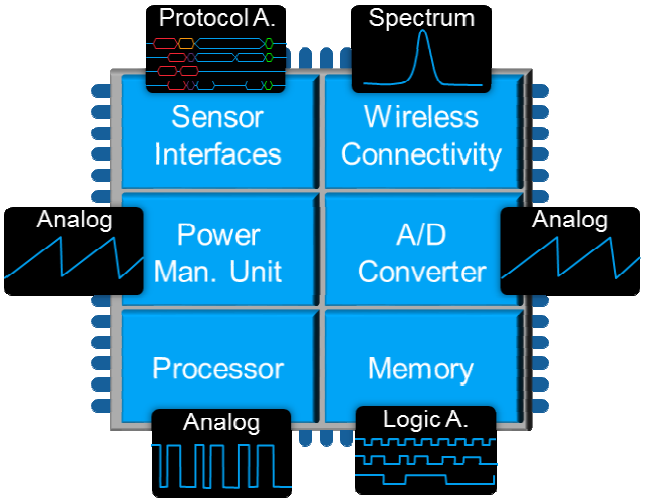


Test Challenge #4
Overall System Debugging

Debugging overall system functionality
R&S®RTO Multidomain Capabilities

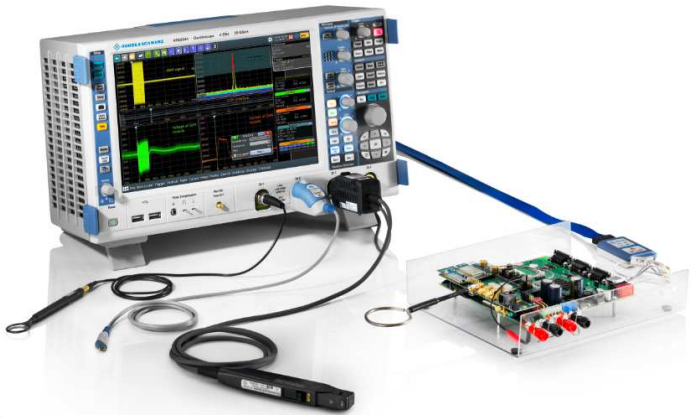
Time correlated analysis for the various device signals.





Measurement Examples:

M2M IoT module



ROHDE&SCHWARZ

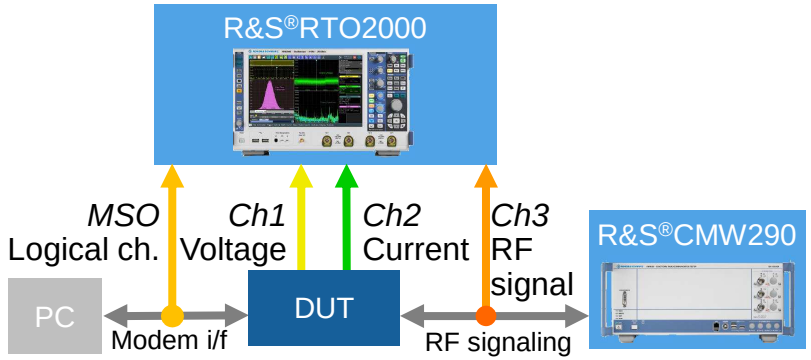
Setup with IoT Device

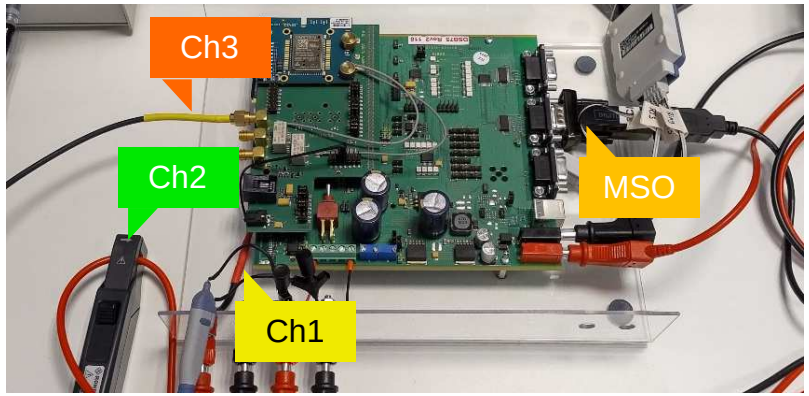
LTE Cat 1 IoT module

- LTE / GSM RF Tranceiver and processor
- USB 2.0 / GPIO / I^2C interfaces; Serial modem interface
- Internal flash, LPDDR2 memory interface
- Power management unit

Test Equipment

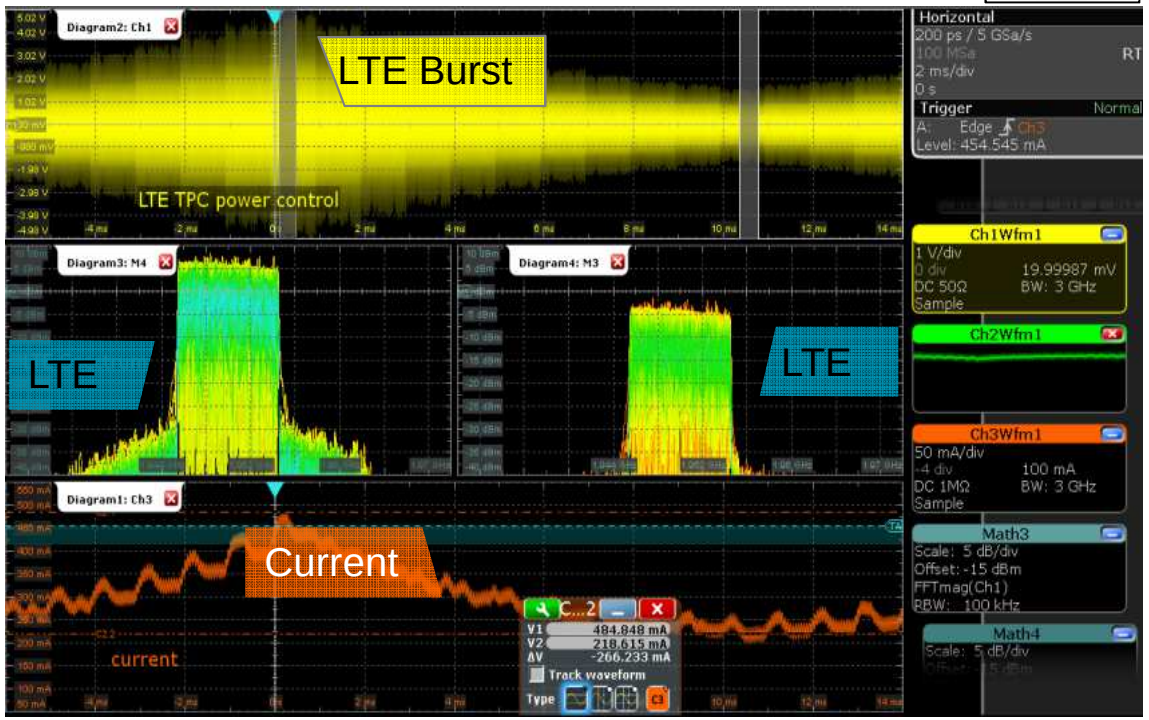
- RTO oscilloscope
  (current, voltage, RF, MSO: UART T&D)
- Communication tester (R&S CMW290)
- Power supply HMP4040
- PC (PuTTY)





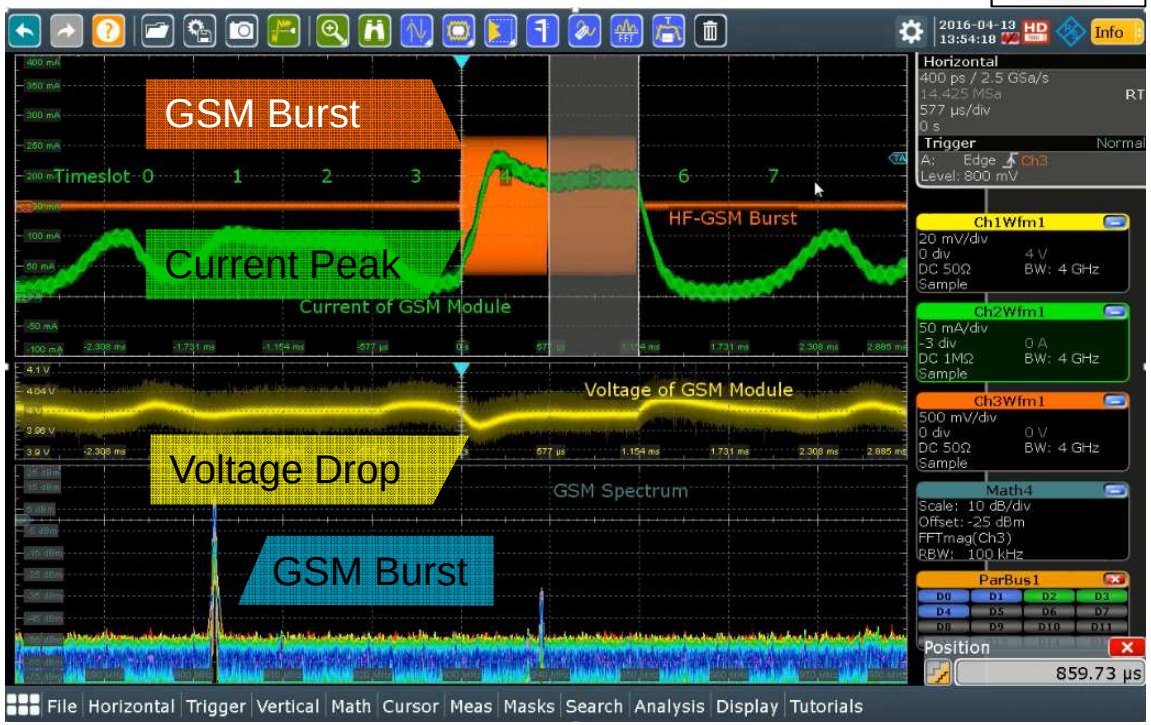
Example 1a: Correlation of Current Consumption with Device Activities

- **Device activity:**
  - React on TPC – transmitter power control steps
- **R&S RTO2000**
  - Triggers on current peak
  - LTE signal power correlates with current consumption (green)
  - Display LTE signal power differences in the spectrum with gated FFTs



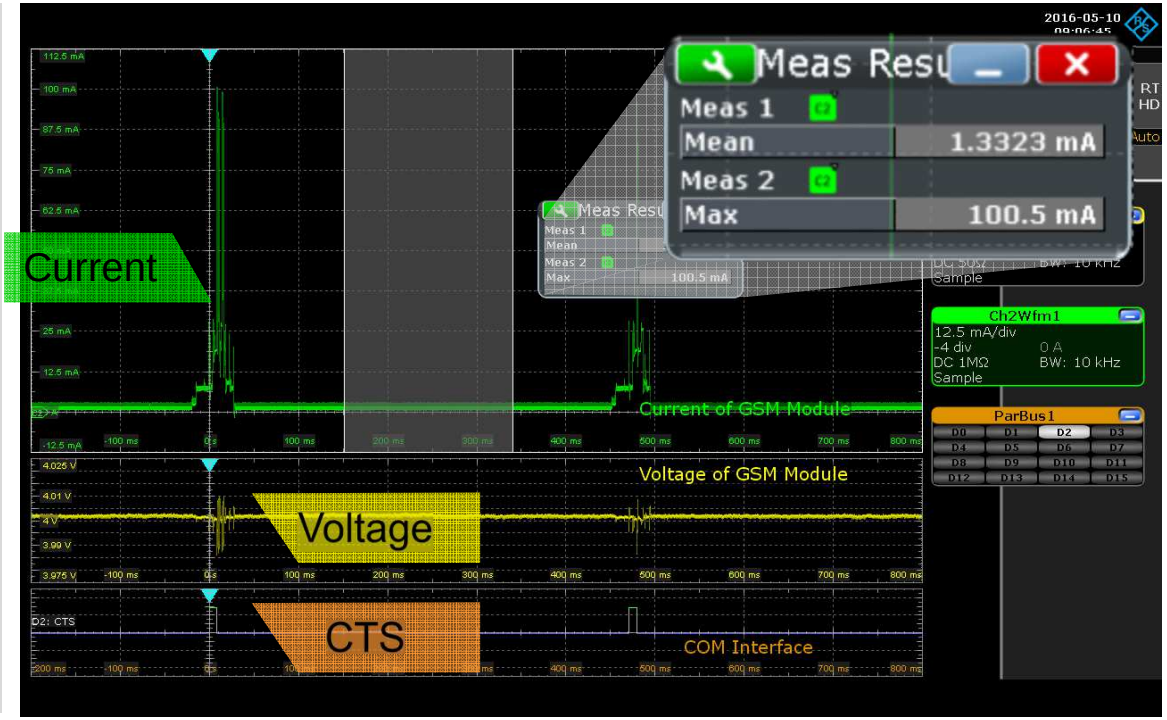
Example 1b: Correlation of Current Consumption with Device Activities

- **Device activity:**
  - GPRS connection in different timeslots
- **R&S RTO2000**
  - Triggers on start of GSM bursts
  - GSM bursts correlate with voltage drops (yellow) and current peaks (green)
  - Display spectrum on gated GSM slot



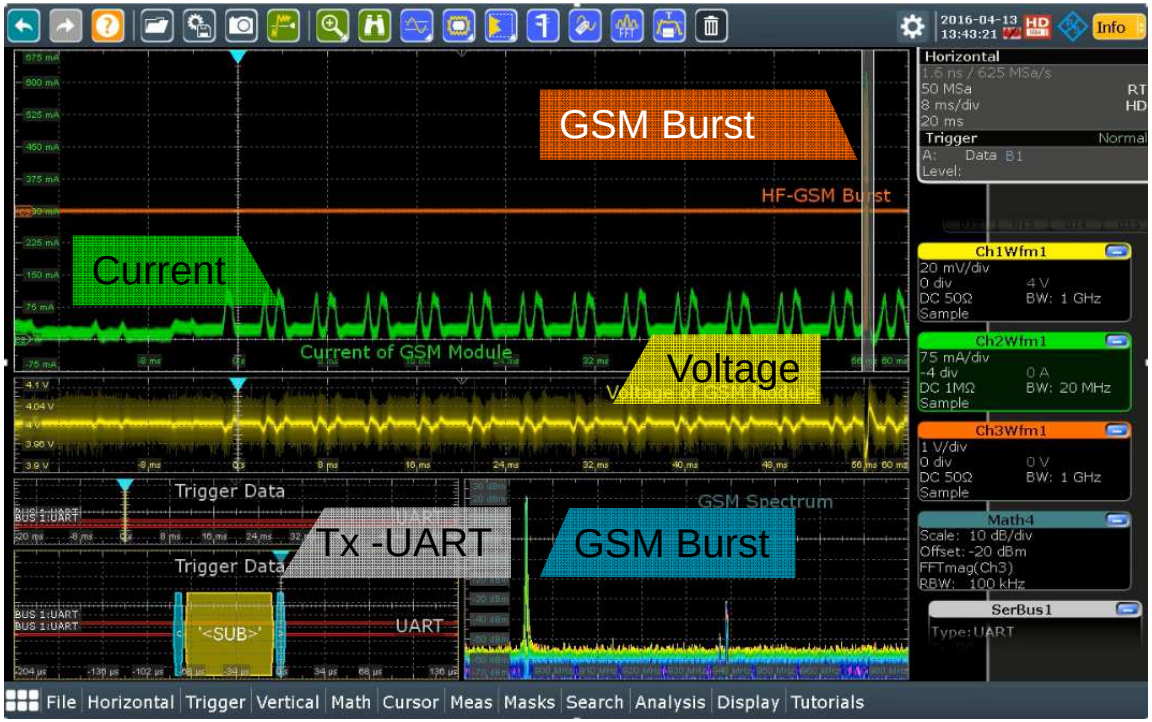
Example 1c: Minimum Current Consumption at Sleep Mode

- **Device activity:**
  - Sleep mode and reacting on paging sequences
- **R&S RTO2000**
  - Trigger on CTS pulse
  - Measures Mean and Max current in sleep interval

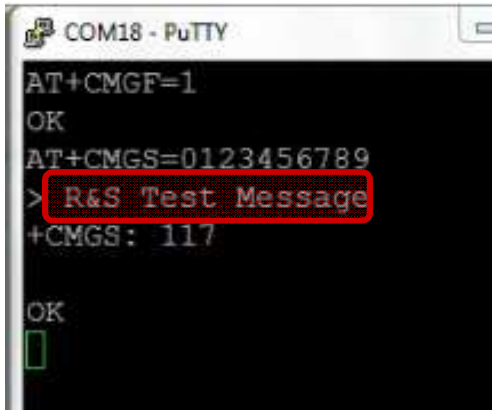


Example 2: Time-correlated Debugging of System Functionality

- **Device activity:**
  - Sent SMS message (GSM)
- **R&S RTO**
  - Triggers on sending the SMS message at the UART
  - Observe the delay of the GSM burst
  - Correlate GSM burst with current
  - Observe GSM burst in spectrum

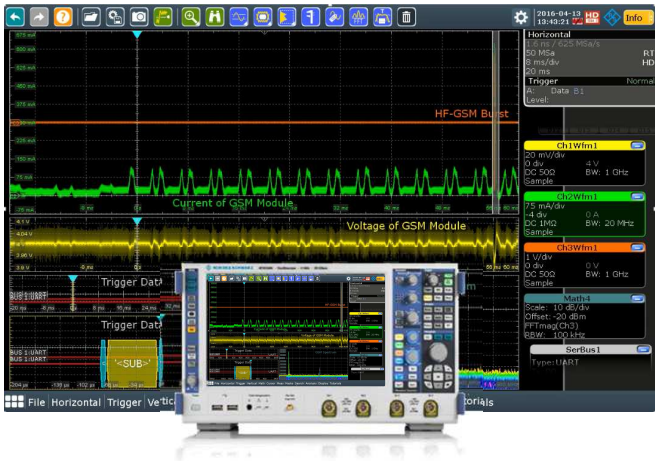


Example 2: Time-correlated Debugging of System Functionality (II)



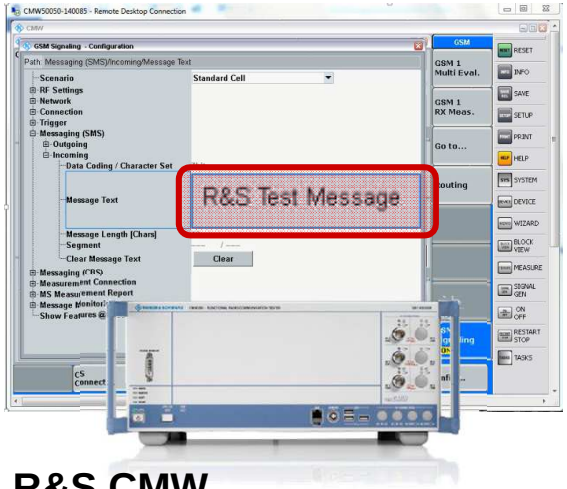
PC

- Writes message (PuTTY)
- Sends message (UART)



R&S RTO Oscilloscope

- Triggers on SMS message sent on UART
- Observe the delay of the GSM burst
- Correlate GSM burst with current
- Observe GSM burst in spectrum



R&S CMW

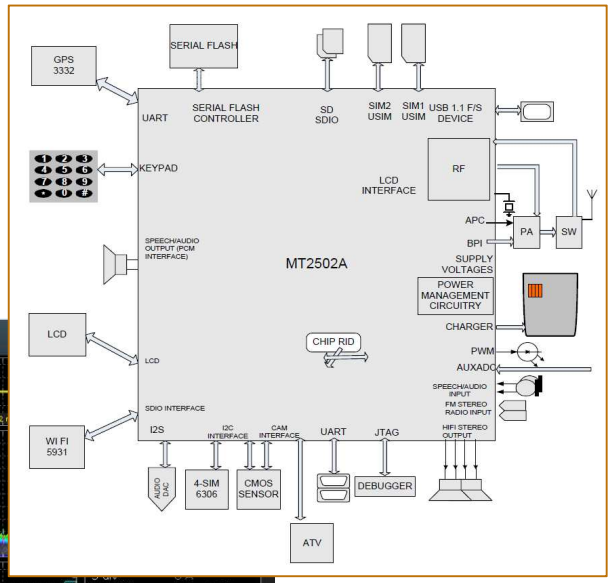
- Receives message,
- Reads message

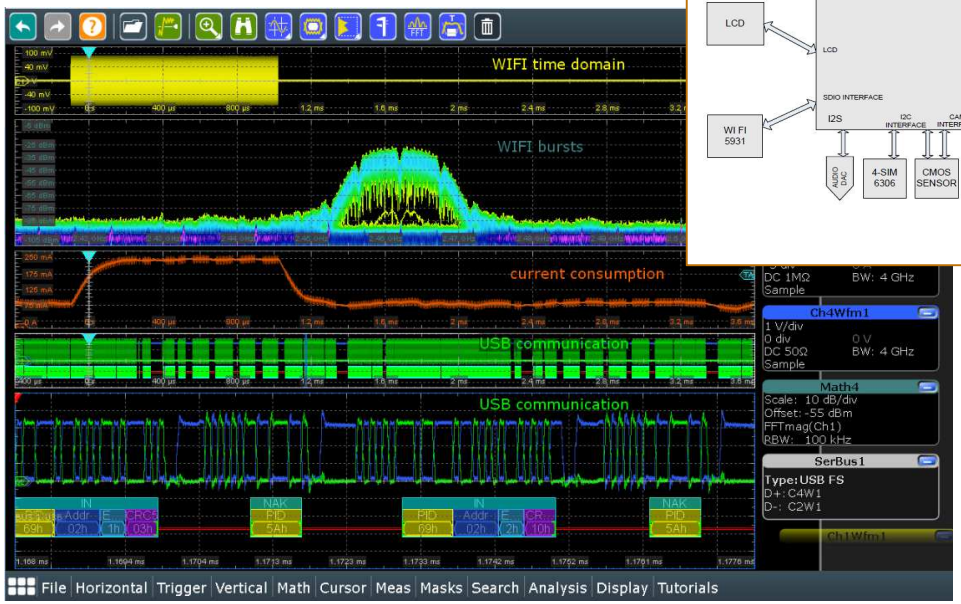
Example 3: Analysis of the Wireless Output Signal

- **Device activity:**
  - Uplink communication of the GSM module
- **R&S RTO2000**
  - Use VSE Analysis SW for GSM signal analysis
    - Synchronization packets, output power, bandwidth, EVM measurements, etc.

Example 4: MediaTek IoT Device: MT2502A

- **Device activity:**
  - WiFi and USB communication
- **R&S RTO**
  - Triggers on WiFi burst related current peak
  - Correlate current / voltage with WiFi and USB traffic



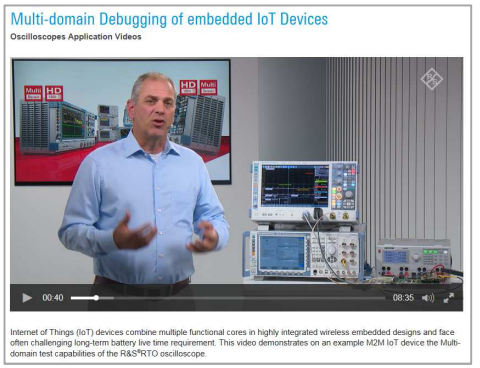


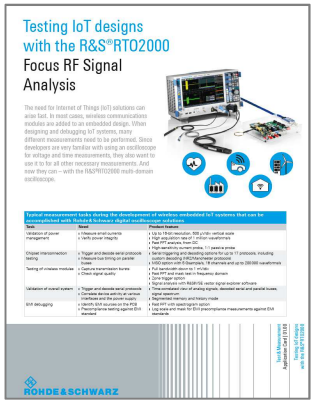
Demo Time

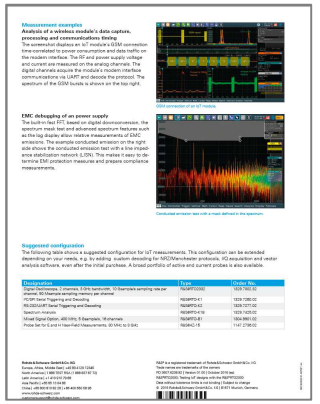
- Measurements on TDD LTE Data card

R&S Material: Debugging IoT Designs

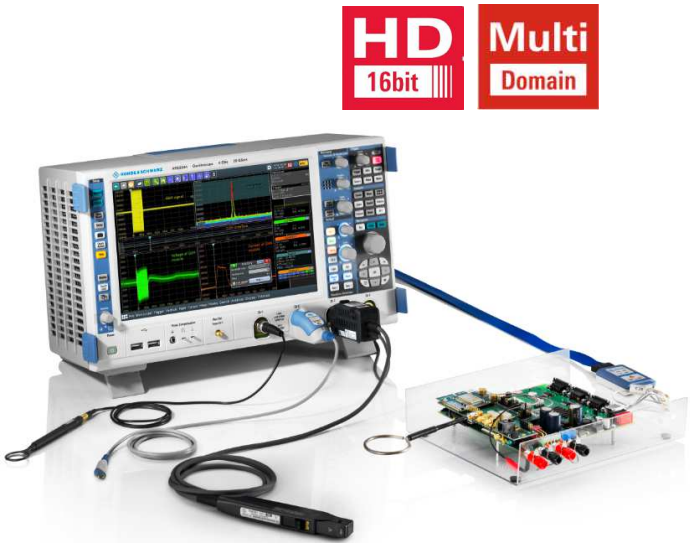
- IoT Conference in Nuernberg, May 2016
  http://iot-design.com/index.php/conference
- Application video: M2M – IoT device (Gemalto Cinterion 2G)
  - R&S web
  - YouTube
- Application Cards
  - Focus EMI
  - Focus RF-Signal Analysis







Let‘s sum up

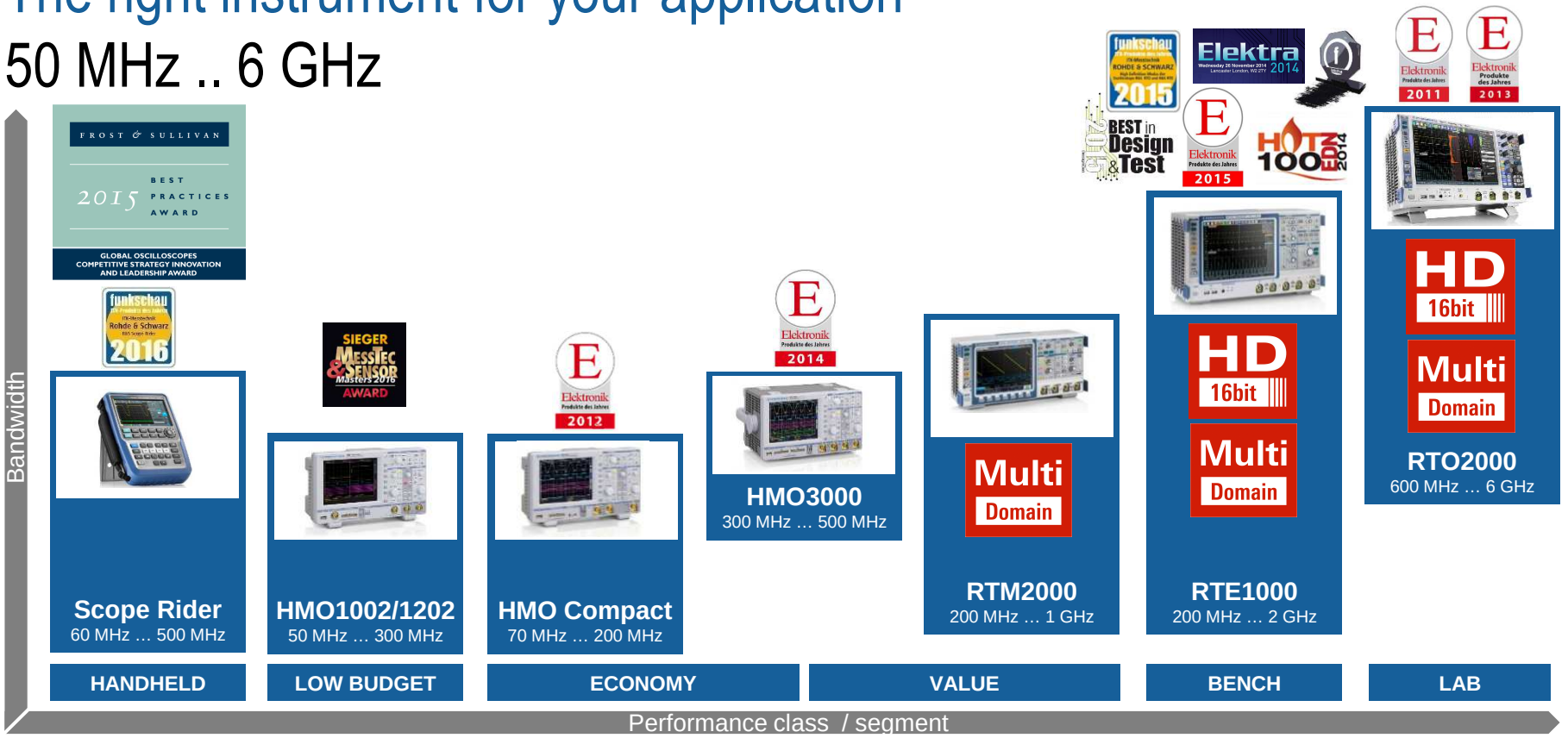


Powerful Embedded Wireless debug solution

- **R&S®RTO oscilloscope supports:**
  - Time-correlated debugging on system level
    - Analog, logical, protocol and frequency signals
  - Small current measurements
  - Analysis of wireless interfaces

The right instrument for your application

50 MHz .. 6 GHz



Thanks for your attention.