EMI ANALYSIS ON POWER SUPPLY DESIGN

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Application Engineer
Oscilloscope

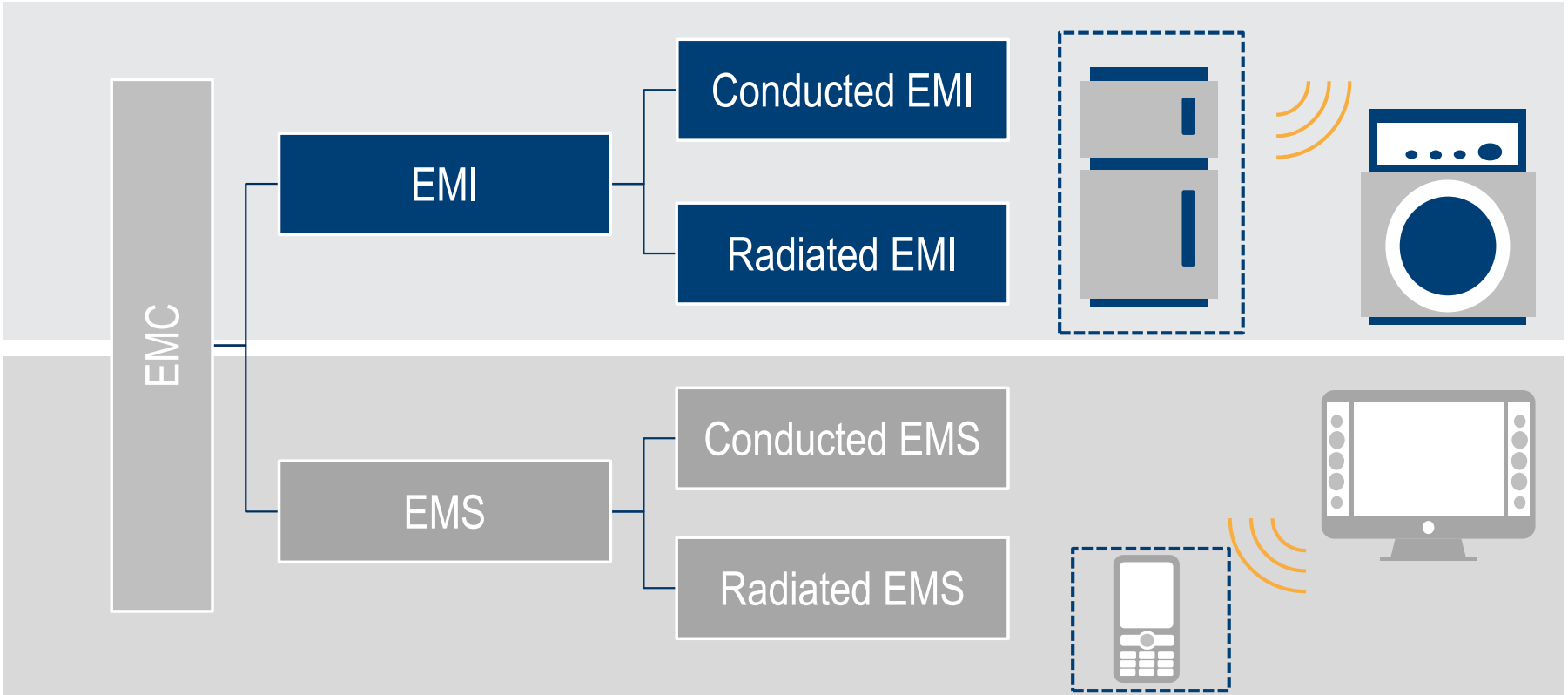
ROHDE&SCHWARZ
Make ideas real

OBJECTIVE

- To have general idea about EMC testing, standards and limits
- To understand EMC challenges specific to power electronics designs –
  in particular in the view of new semiconductor technologies like SiC or GaN devices
- To understand the basic EMC debugging process and instruments used in different design phases
- To learn about how to use oscilloscopes during the design phase to debug EMI problems
- Case Study

BASIC INTRODUCTION TO EMC AND EMC STANDARDS

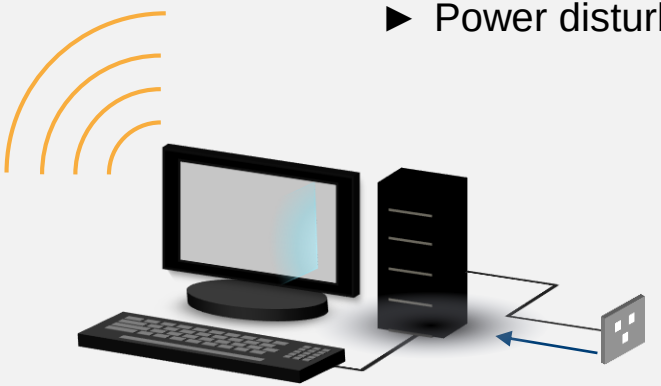
WHAT IS EMC?


EMC
EMI
Conducted EMI
Radiated EMI
EMS
Conducted EMS
Radiated EMS

MODES OF EMISSION

EMI

Radiated EMI	Conducted EMI
► Magnetic radiation	► Voltage disturbance
► Electric radiation	► Power disturbance



MODES OF SUSCEPTIBILITY

EMS

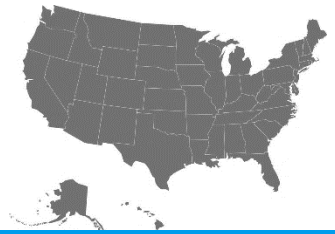
Radiated EMS	Conducted EMS
► Magnetic radiation	► Voltage/ current disturbance

STANDARDS

International Organization for Standardization (ISO)

International Electrotechnical Commission (IEC)

Comité International Spécial des Perturbations Radio (CISPR)



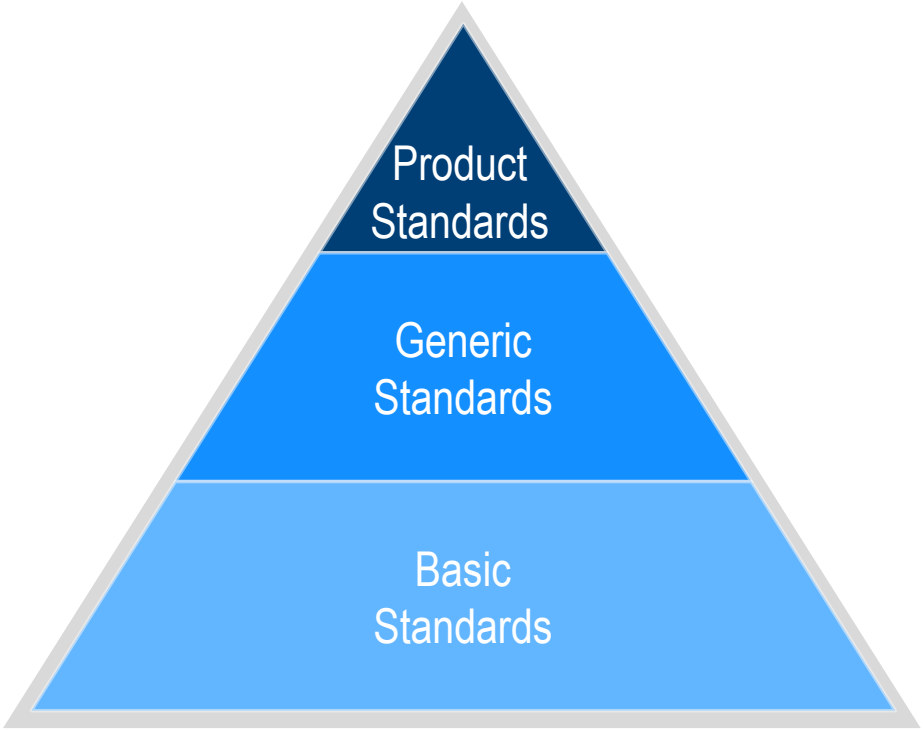
Federal Communications Commission (FCC)

European Committee for Electrotechnical Standardization (CENELEC)

China Compulsary Certification (GB - GuoBiao)

Bureau of India Standards (BIS)

EMC STANDARDS STRUCTURE



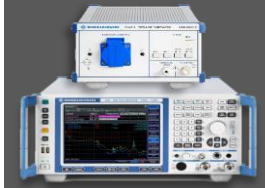
Measurement methods and limits, adjusted to respective product group
(e.g. CISPR 11/15/32)

Applied when no product standards present and are divided by operation environment of EUT (e.g. IEC 61000-6-x)

Basic requirement on measurement methods and limit levels
(e.g. CISPR 16-1-1 , CISPR 16-2-3)

CISPR SUB-COMMITTEES

CISPR A



Measurements & statistical methods
E.g. CISPR 16

CISPR B

ISM RF apparatus
E.g. CISPR 11

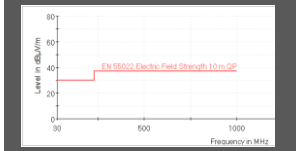
CISPR D

Protection of on-board & off-board receivers of vehicles
E.g. CISPR 12, CISPR 25

CISPR F

Household appliances, tools lighting and similar equipment
E.g. CISPR 14, CISPR 15

CISPR H



Sets limits for protection of radio services

CISPR I

Measurements & statistical methods
E.g. CISPR 22, CISPR 32

CISPR EMI STANDARDS (COMMERCIAL PRODUCTS)

CISPR 11

Industrial, Science and Medical

CISPR 14-1

Household Appliances

CISPR 15

Lighting

CISPR 32

Multimedia Equipment

DIFFERENT EMC STANDARDS

► FCC Part15

Conducted Emissions			
	Frequency (MHz)	Quasi-Peak Limit (dBuV)	Average Limit (dBuV)
Class A	0.15 – 0.5 0.5 - 30.0	79 73	66 60
Class B	0.15 – 0.5 0.5 – 5 5 - 30	66 to 56 * 56 60	56 to 46 * 46 50

General Radiated Emission		
	Frequency (MHz)	Field Strength Limit (uV/m)
Class A (10 meters)	30 – 88 88 – 216 216 – 960 above 960	90 150 210 300
Class B (3 meters)	30 – 88 88 – 216 216 – 960 above 960	100 150 200 500

► MIL-STD-461E

Req't	Description
CE101	Conducted Emissions, Power Leads, 30 Hz to 10 kHz
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CE106	Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 50 kHz
CS103	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz
CS105	Conducted Susceptibility, Antenna Port, Cross Modulation, 30 Hz to 20 GHz
CS109	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
CS116	Conducted Susceptibility, Dampened Sinusoidal Transients, Cables & Power Leads, 10 kHz to 100 MHz
RE101	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz
RS101	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz
RS103	Radiated Susceptibility, Electric Field, 10 kHz to 40 GHz
RS105	Radiated Susceptibility, Transient Electromagnetic Field

DIFFERENT EMC STANDARDS

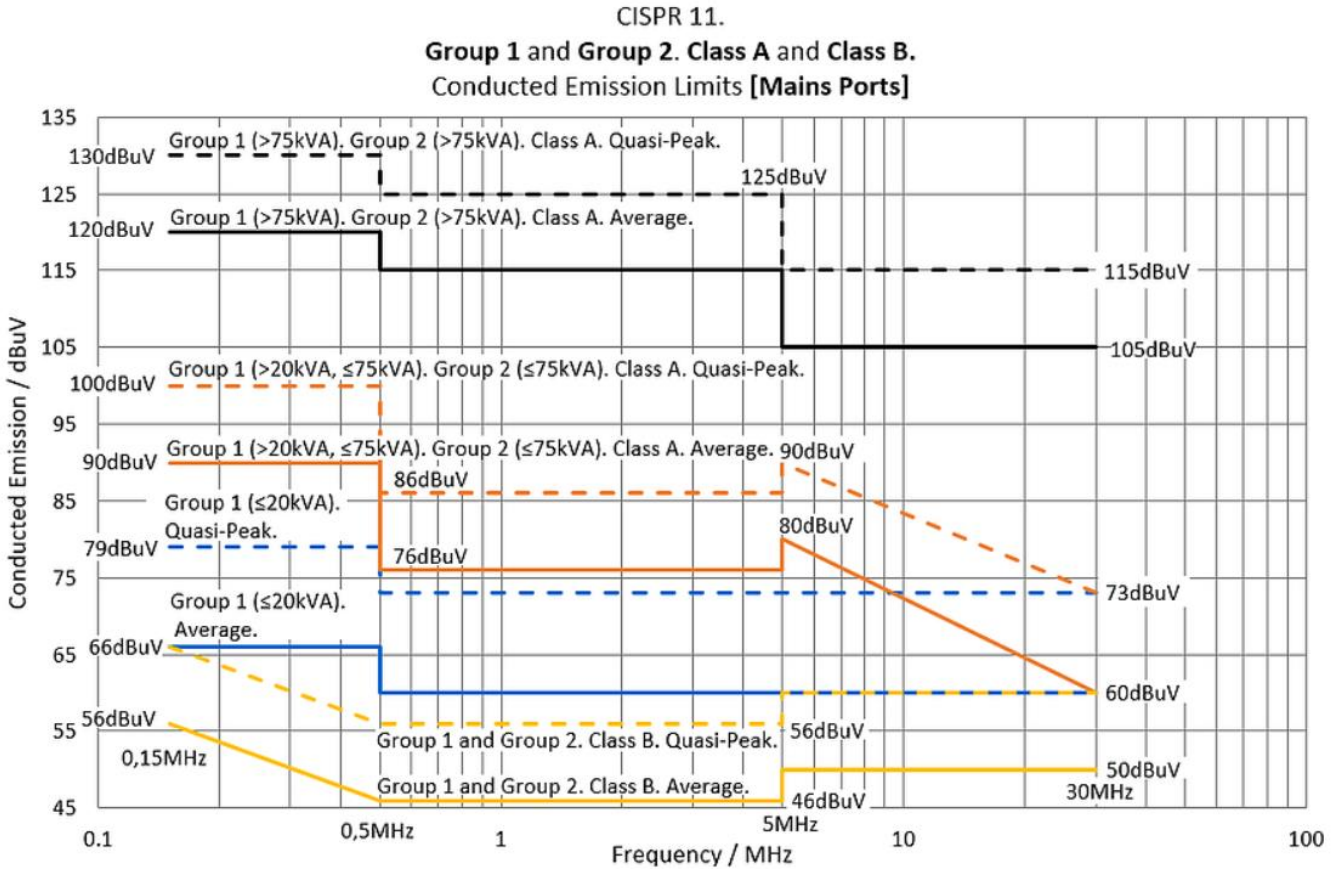
► EU Standard (Emission)

Standard	Description
EN50081-1	Generic emissions standard for residential, commercial and light industrial environments.
EN50081-2	Generic emissions standard for industrial environment
EN55022	Limits and methods of measurement of radio disturbance characteristics of information technology equipment (Also known as CISPR-22)
EN55011	Industrial, scientific and medical (ISM) radio frequency equipment - Radio disturbance characteristics - Limits and methods of measurement (Also known as CISPR-11)
EN55013	Limits and methods of measurement of radio disturbance characteristics of broadcast receivers and associated equipment
EN55014-1	Emission requirements for household appliances, electric tools and similar apparatus
EN55015	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
EN61000-3-2	Limits for harmonic current emissions (equipment input current up to and including 16 A per phase)
EN61000-3-3	Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems

► EU Standard (Immunity)

Standard	Description
EN61000-4-2	Electrostatic Discharge
EN61000-4-3	Radiated Susceptibility Test
EN61000-4-4	Electrical Fast Transient/Burst Test
EN61000-4-5	Surge Test
EN61000-4-6	Conducted Immunity Test
EN61000-4-8	Power Frequency Magnetic Test
EN61000-4-11	Voltage Dips and Interruptions Test
EN61000-6-1	Immunity for residential, commercial and light-industrial environments
EN61000-6-2	Immunity for industrial environments
EN61547	Equipment for general lighting purposes — EMC immunity requirements
EN12016	Electromagnetic compatibility — Product family standard for lifts, escalators and passenger conveyors — Immunity

CISPR11 LIMITS

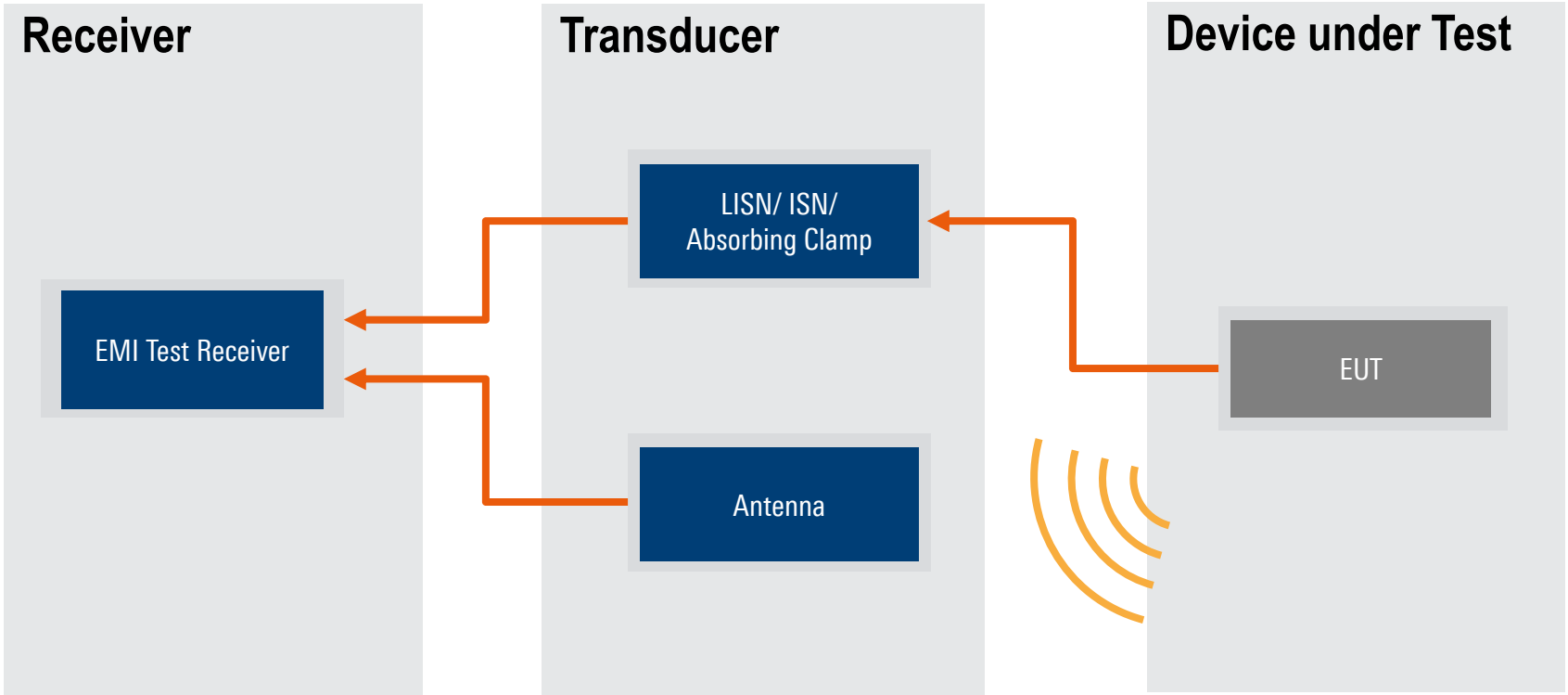


EMI TESTS IN SUMMARY

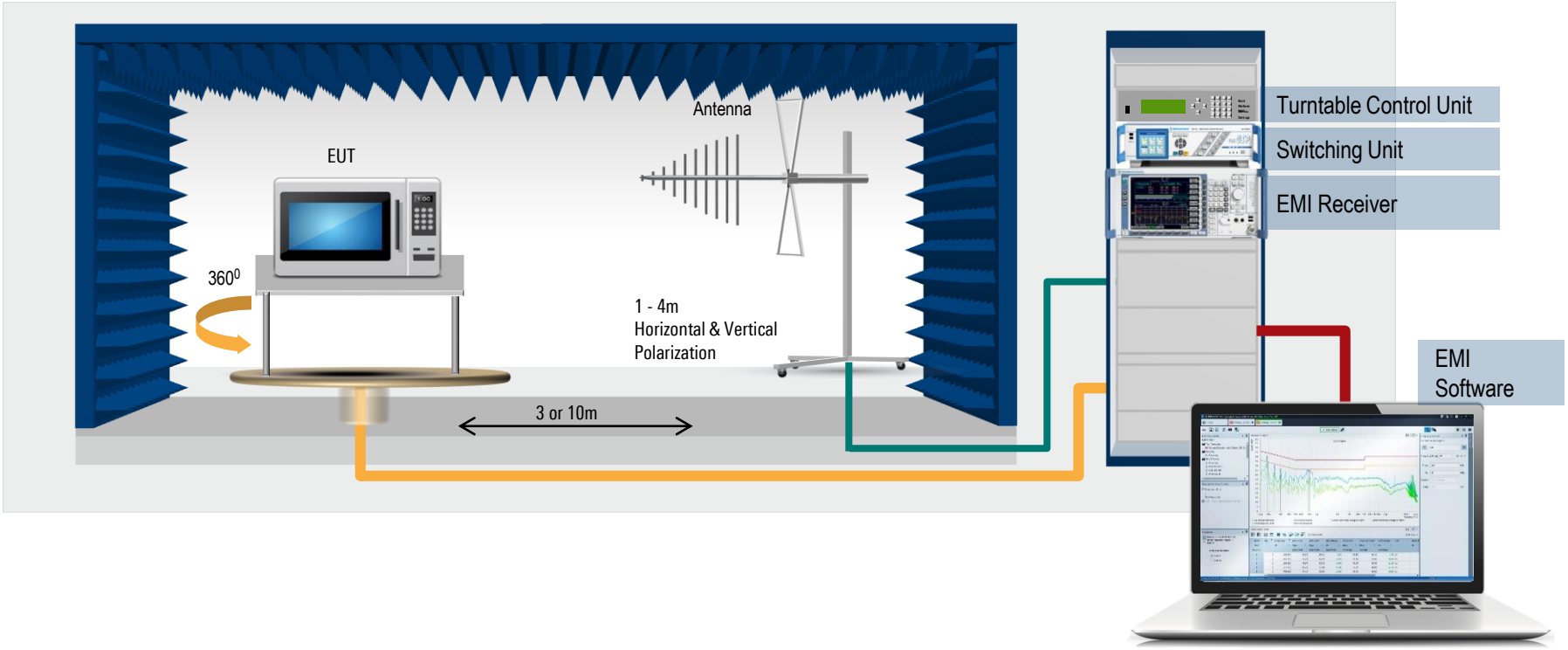
	CISPR 11 ISM	CISPR 14 HOUSEHOLD EQUIPMENT	CISPR 15 LIGHTINGS	CISPR 32 MUTLIMEDIA EMC
CONDUCTED EMI (MAINS PORTS)	✓	✓	✓	✓
CONDUCTED EMI (TELECOM PORTS)				✓
RADIATED EMI (MAGNETIC FIELD)	✓	✓	✓	
RADIATED EMI (ELECTRIC FIELD)	✓	✓	✓	✓
POWER DISTURBANCE		✓		

SETUP AND TOOLS FOR EMC MEASUREMENTS

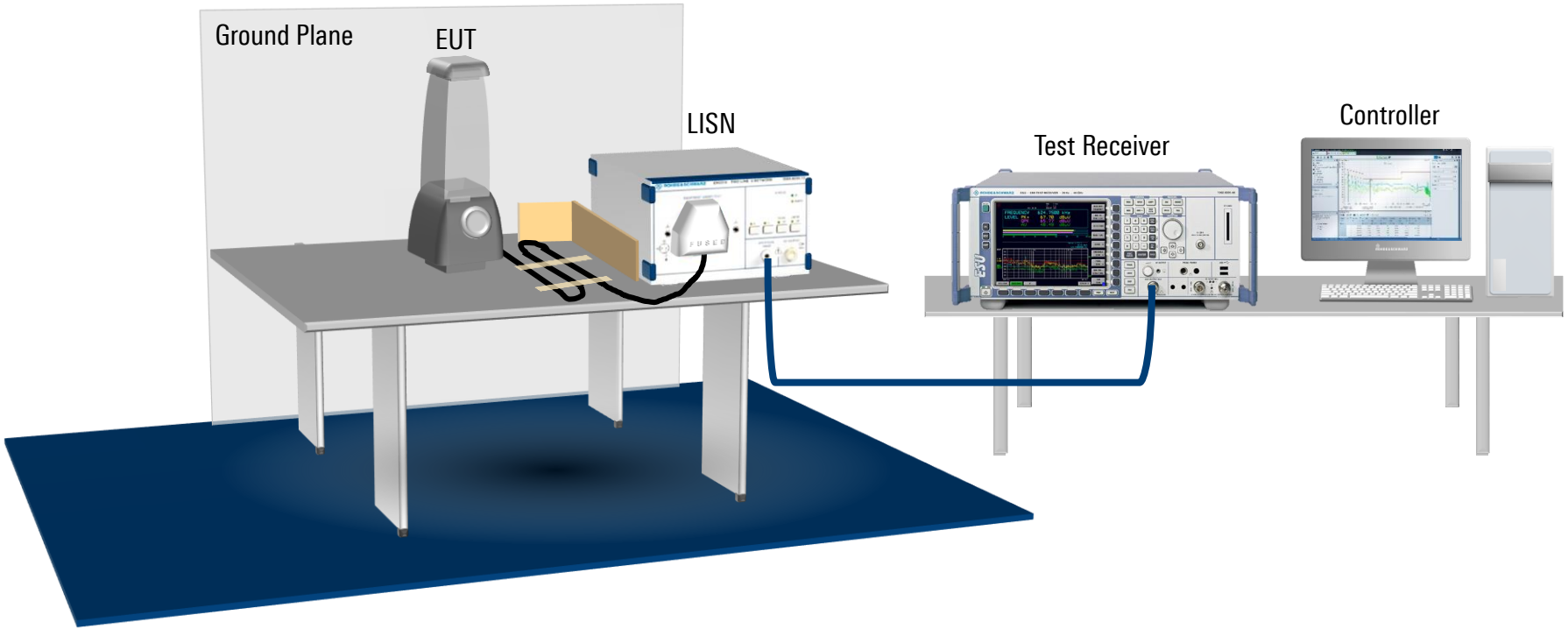
SYSTEM CONFIGURATION



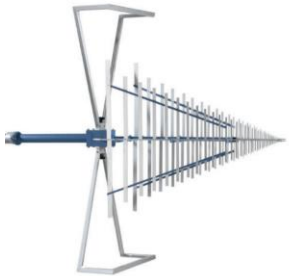
COMPLIANCE RADIATED EMISSION TEST



COMPLIANCE CONDUCTED EMISSION TEST



COMPLIANCE EMC TESTING: MEASURING EQUIPMENT
TRANSDUCERS



Antenna – electric radiated emission

Antenna – magnetic radiated emission

Artificial Network – Conducted voltage

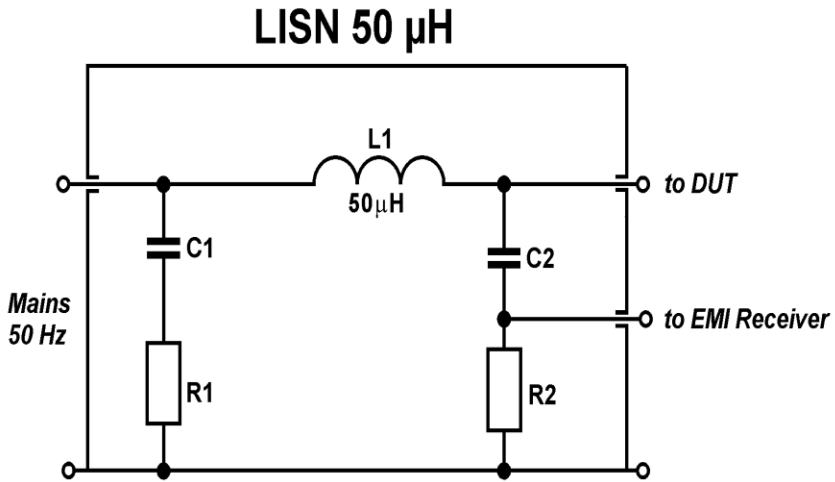
ISN - Conducted voltage

Current probe – conducted current

Absorbing clamp – disturbance power

LINE AND IMPEDANCE STABILIZING NETWORK (LISN)

- Stable Line Impedance as a function of frequency on the power line
- Prevent External Noise (from the power line) Coupling in
- Provide an RF noise measurement port (50 ohm)
- Characteristics are defined in CISPR 16-1-2



PERFORMANCE LEVELS OF INSTRUMENTATION
SELECTING THE RIGHT TOOL

EMI receivers compliant to CISPR 16-1-1, FCC (40 GHz), MIL-Std

ESW

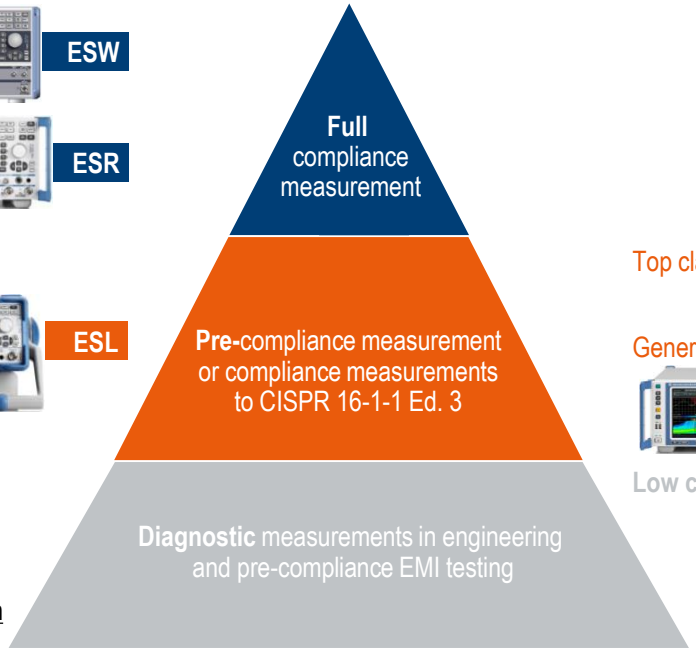
Compliance EMI testing CISPR 16-1-1, 26 GHz

ESR

EMI testing referring to limits

ESRP

ESL



Diagnostic measurements **without relation to limits**

Top class spectrum analyzers

FSW

General purpose spectrum analyzers

FSVR

FSV3000

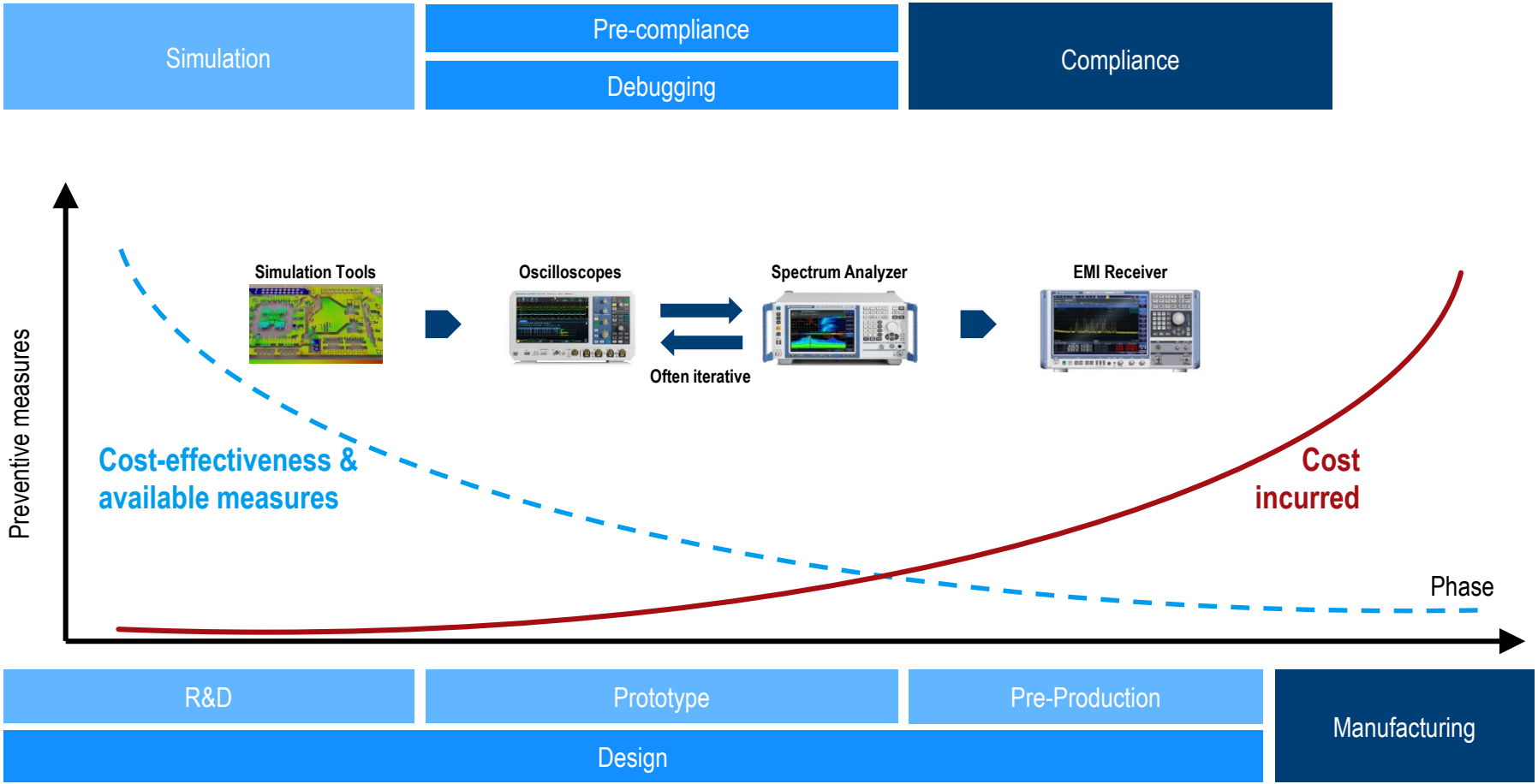
Low cost spectrum analyzers, voltmeters, oscilloscopes

Receivers

Scopes & Spectrum Analyzer

COMPARISON BY FEATURES

Feature	EMI Receiver	Spectrum Analyzer	Oscilloscope
Auto-ranging		-	-
EMI detectors / bandwidths		(K54 Option)	-
Gapless recording	Very long	Long	-
Limit lines		(K54 Option)	Only masks / indicative
Dynamic / Sensitivity	Very high / Very good (With pre-selector)	High / Very Good	Medium / Good
Log-scale View		(K54 Option)	(some models)
Scan types	All (Sweep, step, time-domain, zero-span)	Some (Sweep, zero-span)	No scan (full bandwidth measurement)
Time/frequency correlation possible	(real-time option)	(real-time option, selected models)	
Typically available at	EMC test lab (in-house or external)	Pre-compliance test setup	R&D department

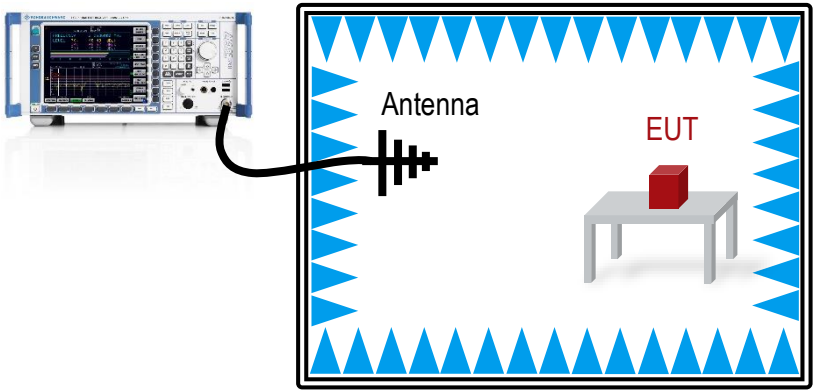

Simulation
Pre-compliance
Debugging
Compliance
Simulation Tools
Oscilloscopes
Often iterative
Spectrum Analyzer
EMI Receiver
Preventive measures
Cost-effectiveness &
available measures
Cost
incurred
Phase
R&D
Prototype
Pre-Production
Manufacturing
Design

PREVENTION IS BETTER THAN CURE

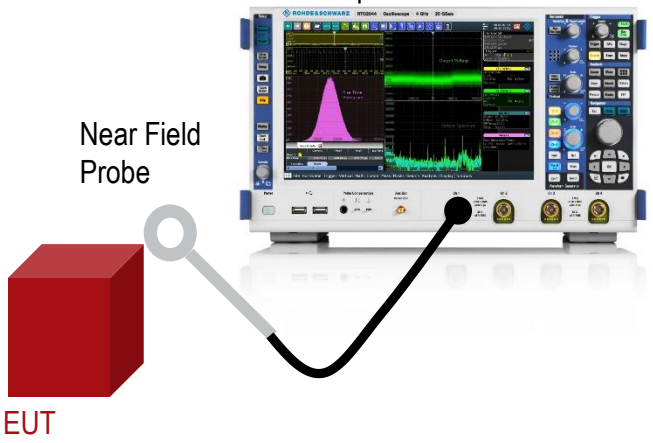
Similar to medical check-up for preventive health care, we diagnose early on circuit to avoid future issues

EMC STANDARDS VS EMI MEASUREMENTS

Test Receivers



Oscilloscope



Typical EMC Measurement

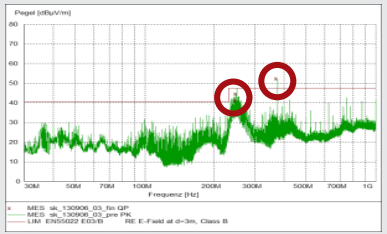
- Mostly far field in nature
- More accurate with less ambience noise
- More expensive to setup

EMI Measurement with Scope or Spectrum

- Near field measurements
- More noise and less accurate
- Cheap and flexible

GENERAL EMI DEBUGGING PROCEDURE
ANALYSIS STEPS

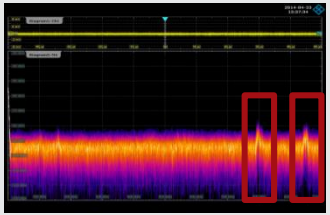
A) Far-field measurement



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



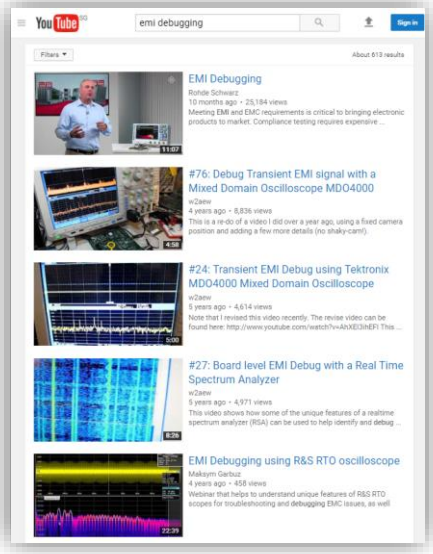
D) Interferer current measurement to find out the coupling type

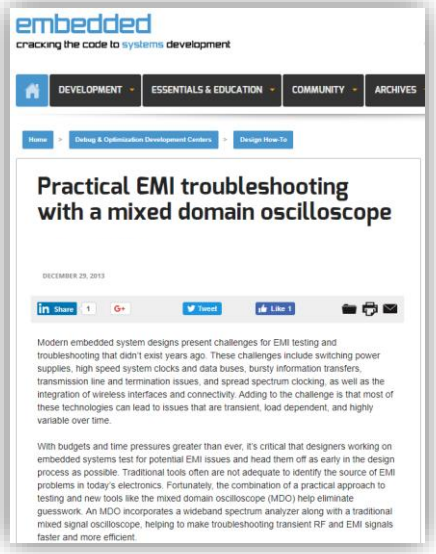
E) Nearfield probe to localize the interferer source

F) Analysis of counter-measures

DEBUGGING EMC PROBLEMS WITH OSCILLOSCOPES

EMI DEBUGGING WITH SCOPE IS NOT NEW?!

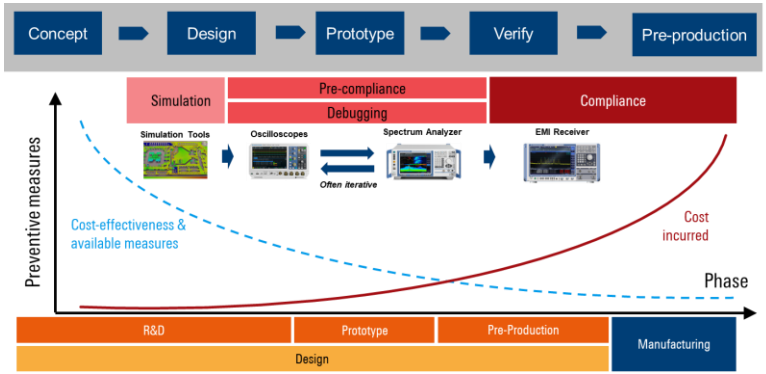


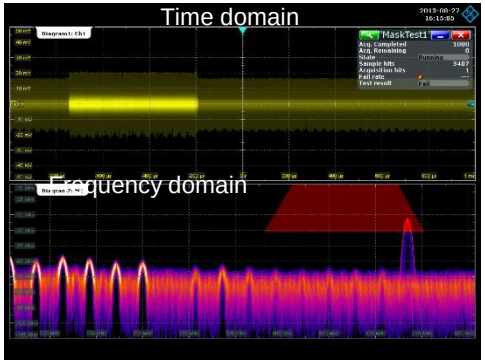


Better instruments progressively changes debug methodologies

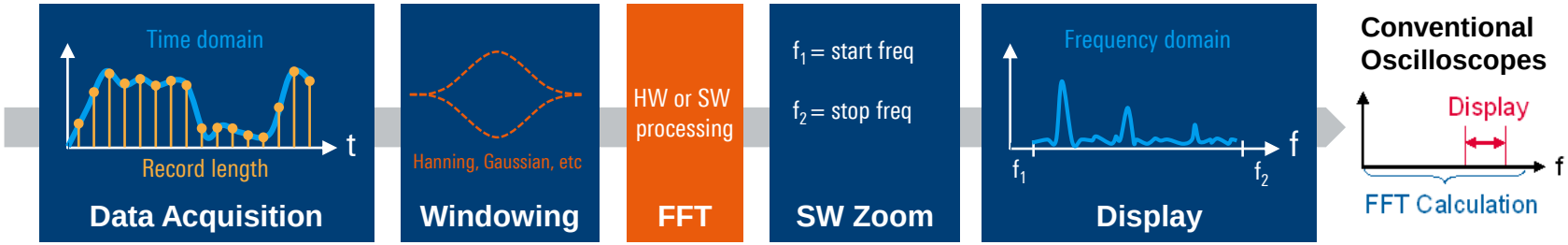
EMI DEBUGGING WITH OSCILLOSCOPES?
YES, WE CAN! (AND ITS VERY HELPFUL)

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

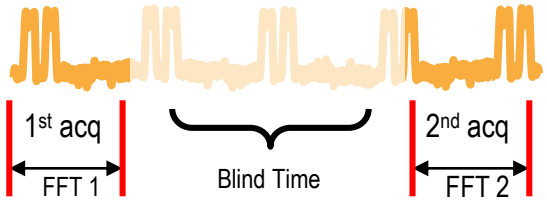


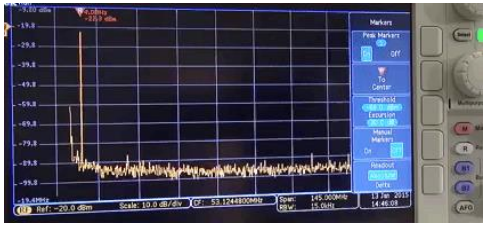


SPECTRUM MEASUREMENTS
OSCILLOSCOPE USES FFT



- Calculate FFT over entire acquisition
- Conventional Scope usually acquire one RL and reconstruct FFT then go on to acquire the next RL to compute the next FFT → Missing sporadic event

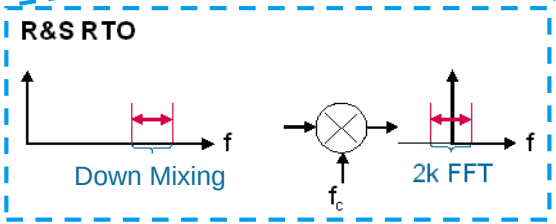




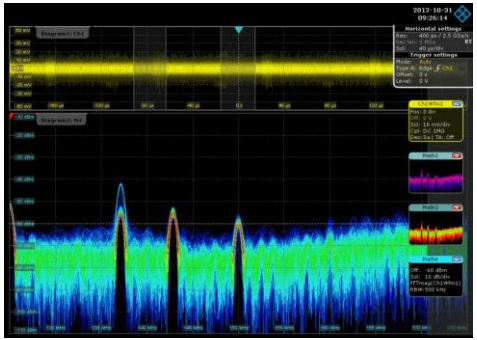
Disadvantages of conventional FFT :

- Very slow speed / update rate
- Limited RBW due to insufficient RL
- Complex configuration (TD settings)

SPECTRUM MEASUREMENTS
R&S MODERN OSCILLOSCOPE SPEEDING UP FFT



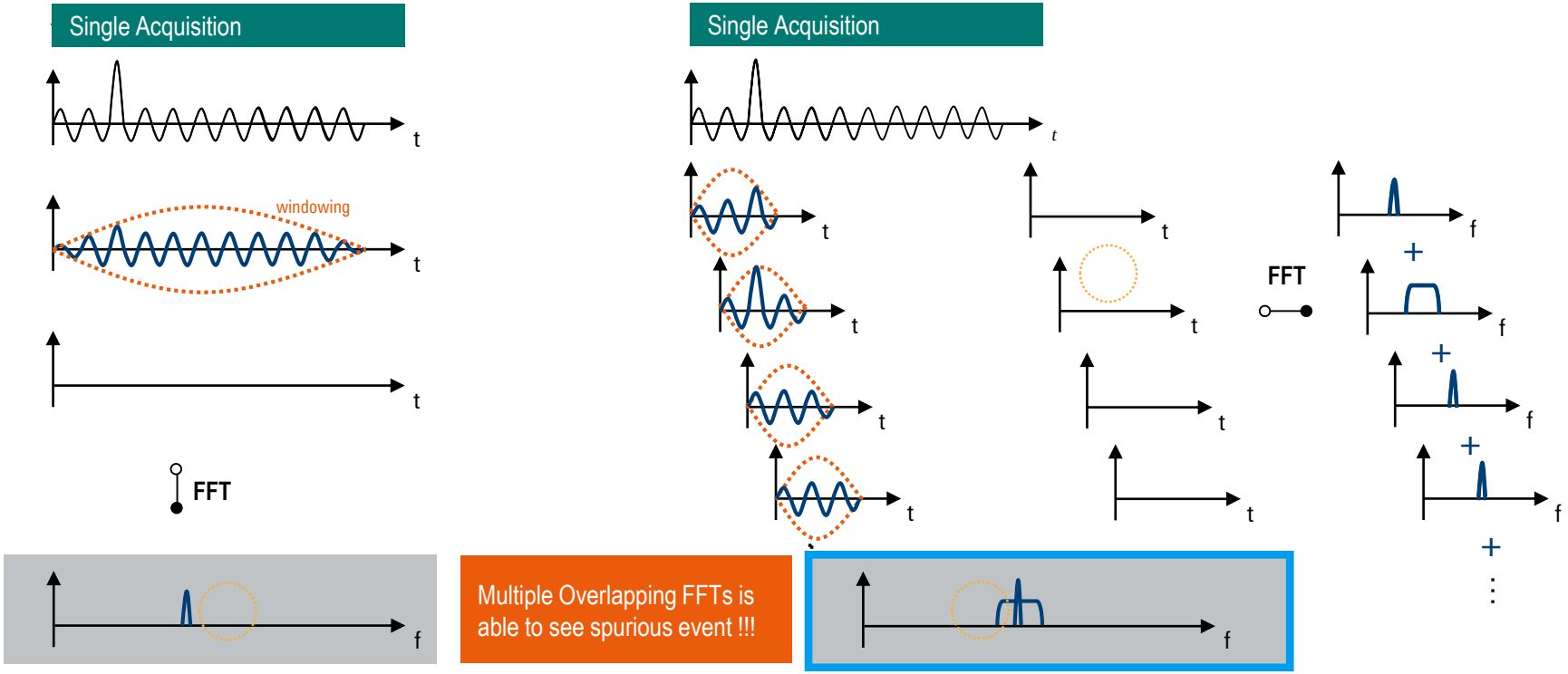
- Calculate only FFT over span of interest
- f_C = center frequency of FFT



Advantages of R&S approach:

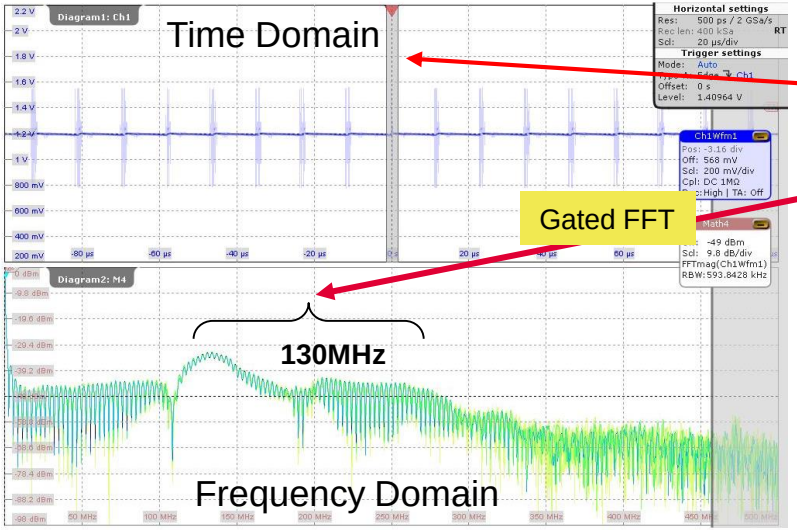
- Higher speed / update rate
- Good RBW without magnification
- Flexible configuration
- Multiple overlapping FFT able to find spurious faults

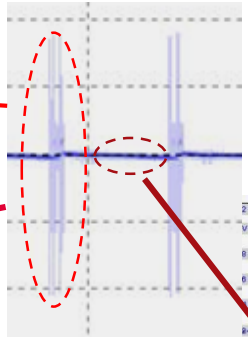
MODERN SCOPE FFT CAPABILITIES
USING OVERLAPPING FFTS



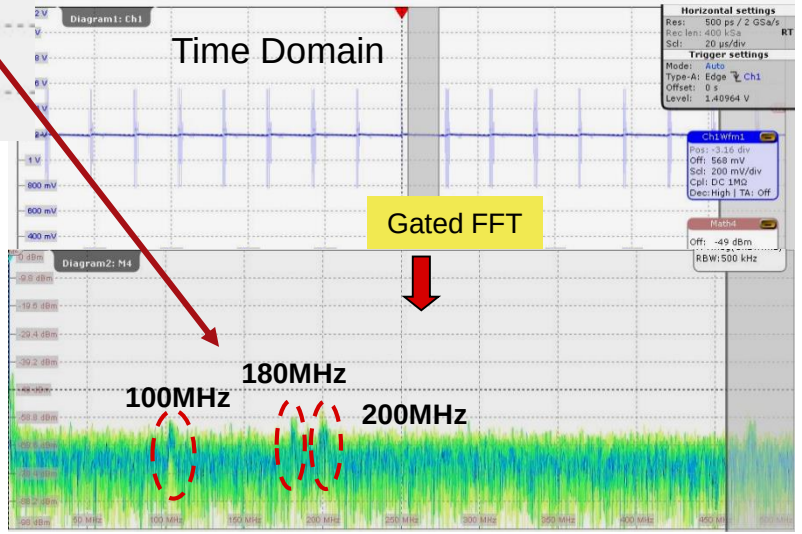
BASICS: SPECTRUM ANALYSIS ON LAB-CLASS OSCILLOSCOPES

TIME-GATED FFT APPLICATION: SWITCHED MODE POWER SUPPLIES



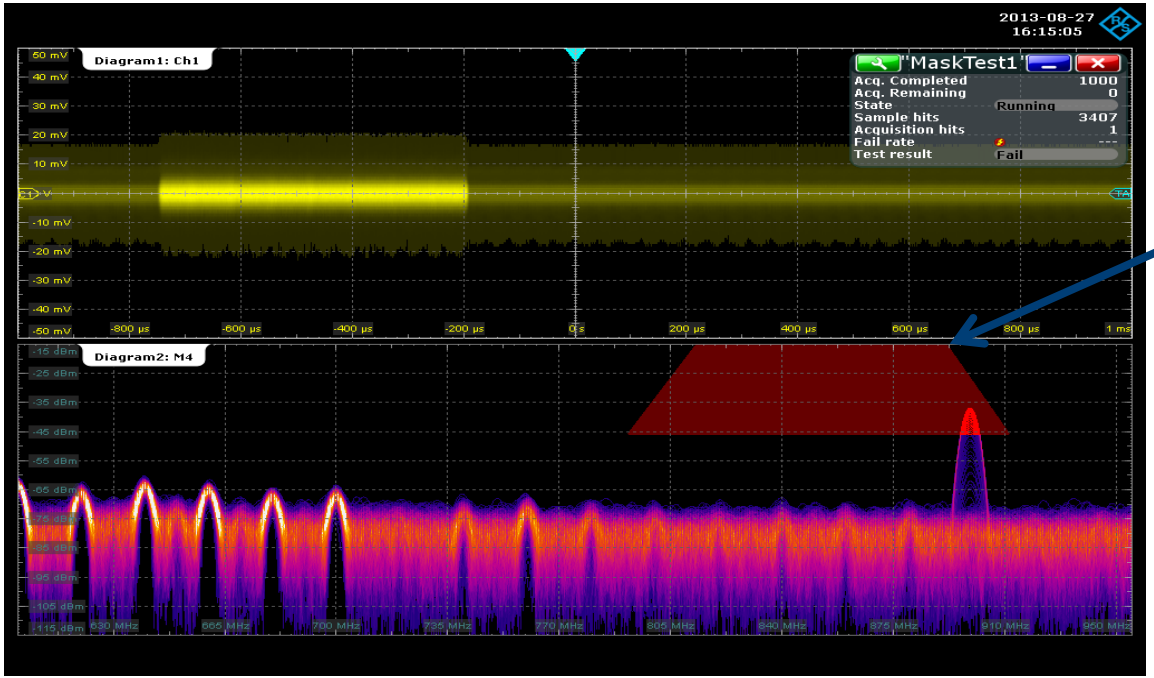


400ns Pulse



BASICS: SPECTRUM ANALYSIS ON LAB-CLASS OSCILLOSCOPES

SPECTRUM MASK FOR CAPTURING INTERMITTENT EMISSIONS



User-defined spectrum mask

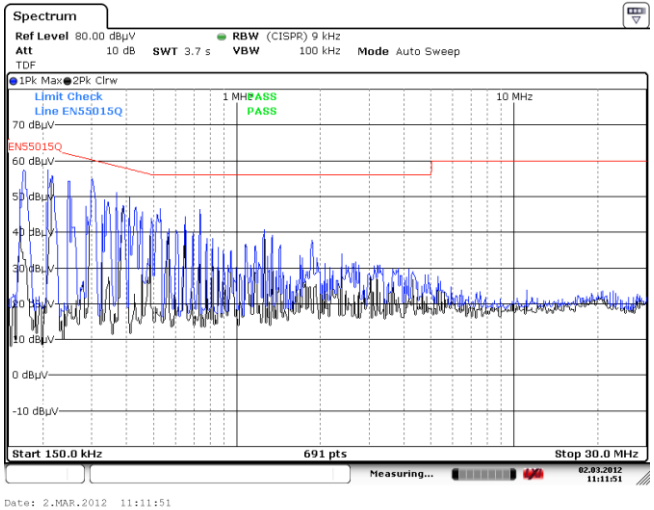
“Stop-on-violation” function

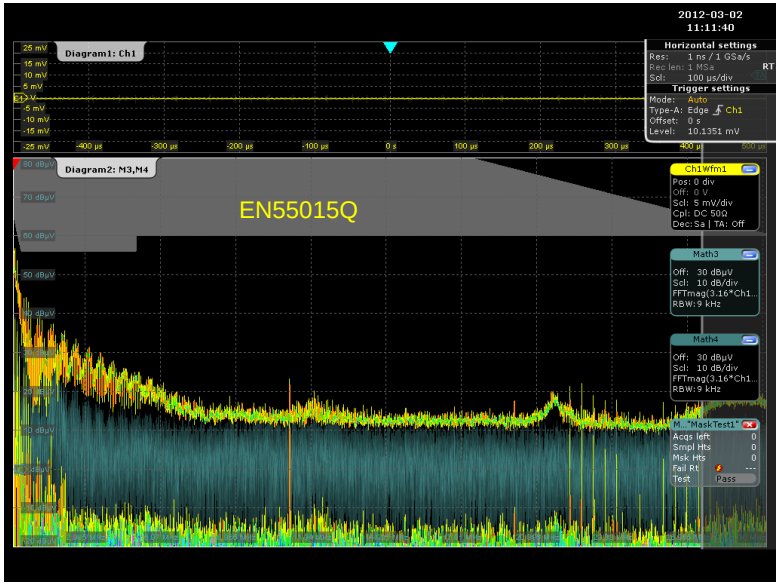
Analyze underlying source

CREATE MASK TEMPLATE ON FFT TO SIMULATE LIMIT LINE

Pre-Compliance Analysis with Scope

- Conducted Emission using LISN
- 9 kHz – 30 MHz





- FSV trace 1 = Max hold / Pos Peak
- FSV trace 2 = Clear Write / Auto Peak

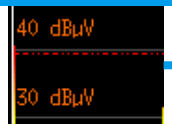
RTO FFT1 = Normal mode

RTO FFT2 = Envelope mode

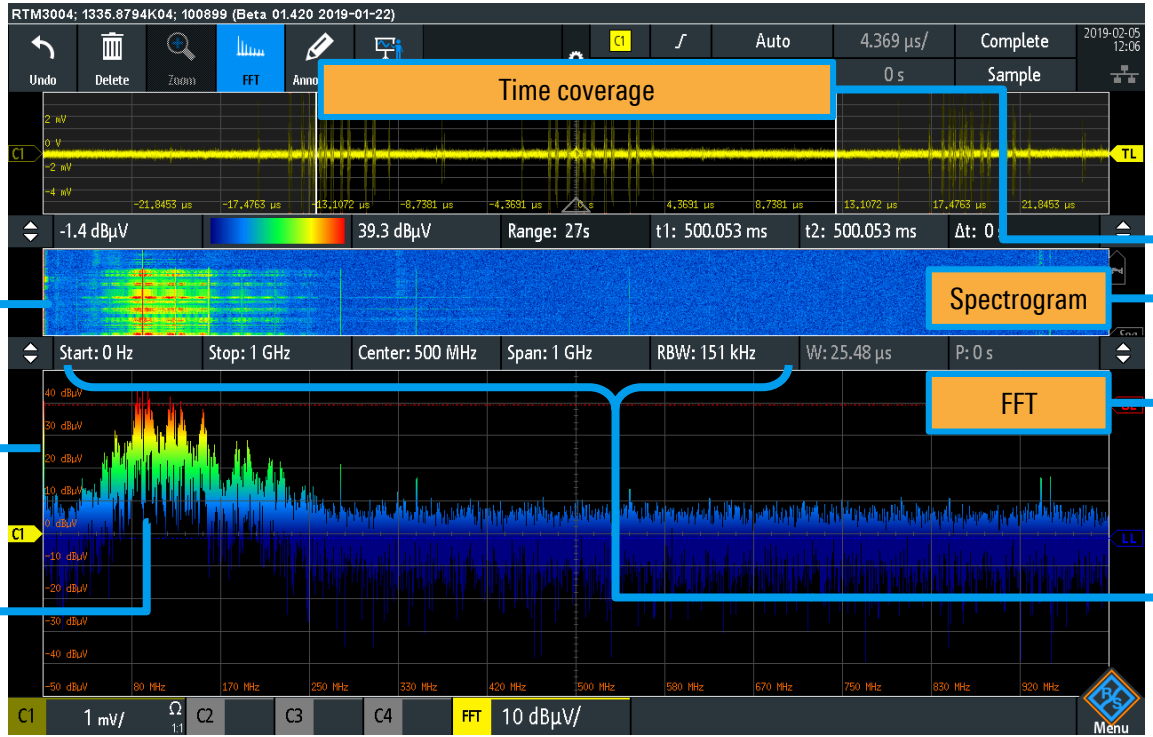
MODERN SCOPE FFT CAPABILITIES
CORRELATION OF TIME AND FREQUENCY INFORMATION

Waterfall diagram helps to show short emissions

dBuV scaling like in EMI measurements



Color coding display for better visibility



Time-frequency correlation of emissions

Directly set start, stop and resolution bandwidth

LAB VS MID-CLASS SCOPES FOR EMI DEBUGGING
COMPARISON

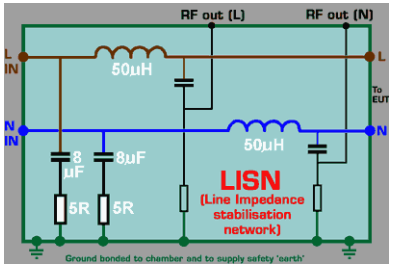
Feature	Lab-Class Oscilloscopes RTE1000, RTO2000	Mid-Class Oscilloscopes RTB2000, RTM3000, RTA4000
(Widely) independent choice of time scale and frequency settings	✓	-
Overlap FFT functionality	✓	-
Frequency masks	✓	-
Time gated FFT	✓	-
Log frequency scale	✓	-
dBuV scale	✓	✓
Direct frequency setting	✓	✓
Time-frequency correlation	✓	✓
Waterfall Diagram	✓	✓

EMC APPLICATION FIELDS OF OSCILLOSCOPES

EMI

Near-field probing

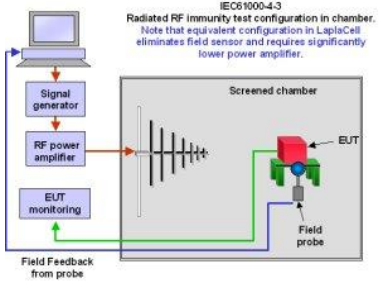
Conducted Emissions Debugging



Our focus area here

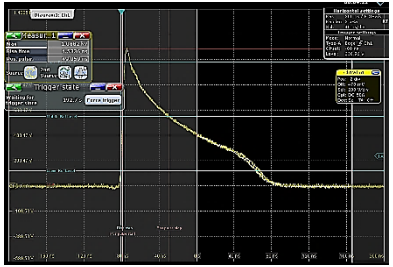
EMS

EUT Monitoring



► EUT Monitoring

ESD, EFT and Burst Calibration / ESD Tests



► Burst calibration
► ESD testing

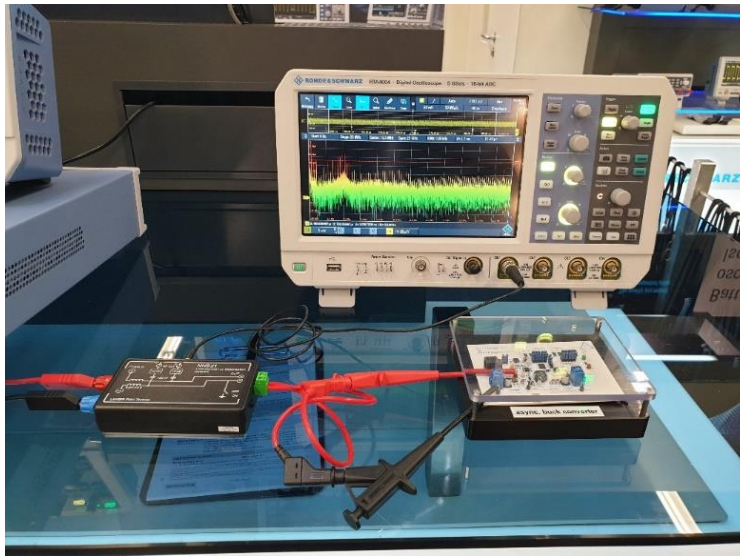
In R&D

In the test lab

EMI DEBUGGING WITH OSCILLOSCOPES
EXAMPLES

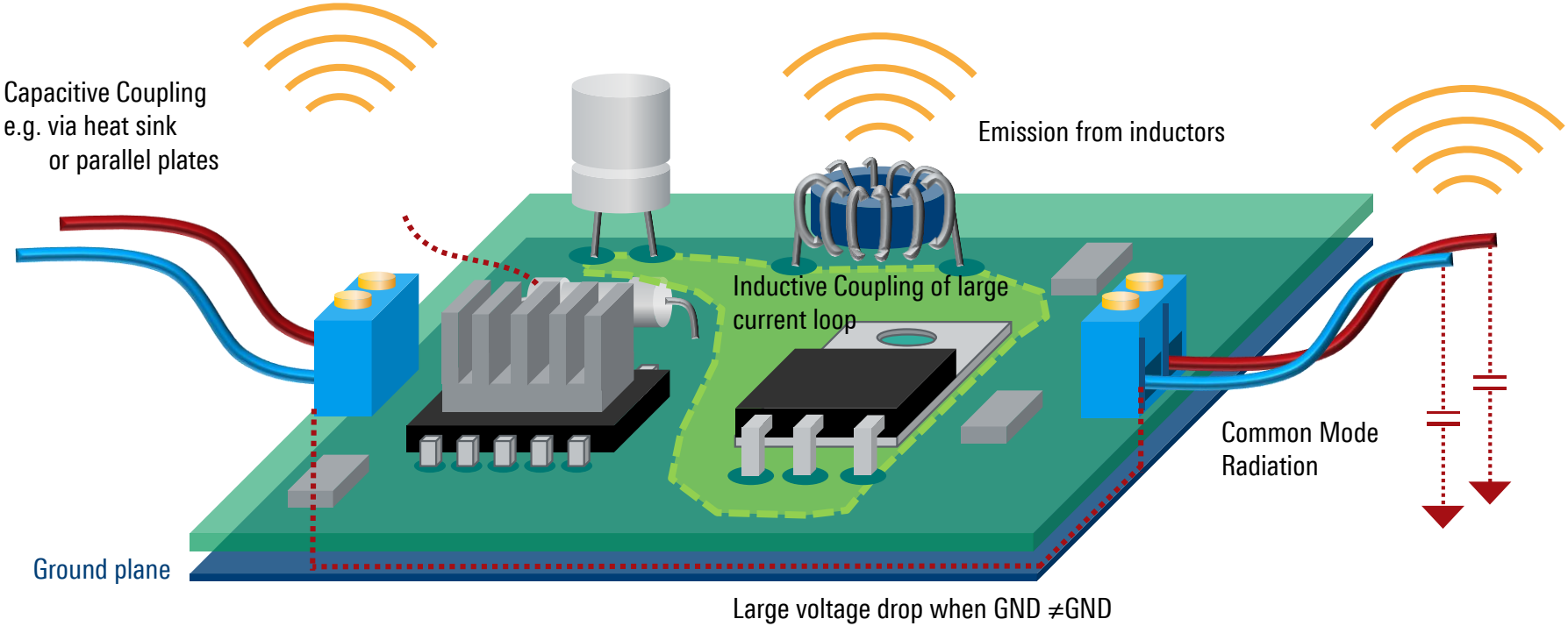
Radiated Emission
Debugging after failed Pre-Compliance or Compliance

Conducted Emission
Pre-test and debugging in the R&D lab



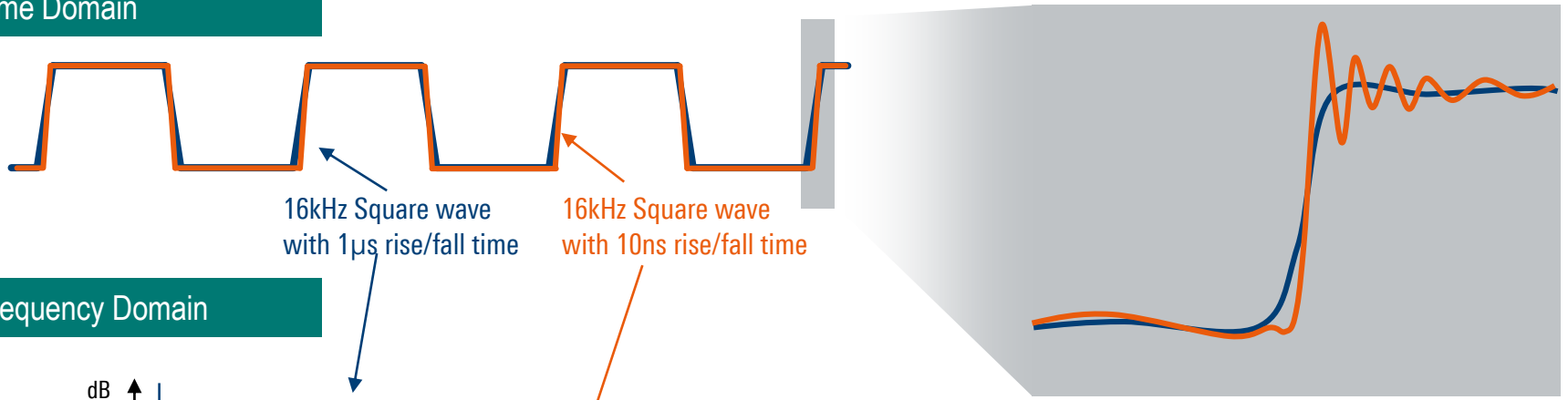
SWITCHED MODE POWER SUPPLIES AND EMC

ELECTRO-MAGNETIC EMISSION (EME) SOURCES

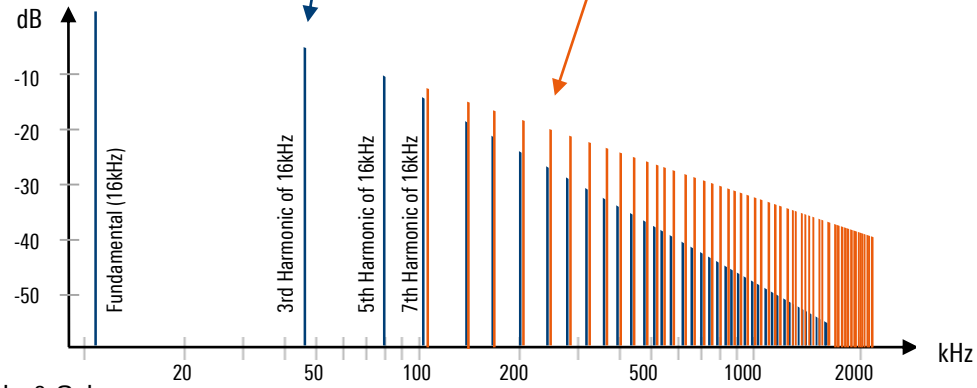


IMPACT OF FASTER SWITCHING AND STEEP EDGES ON EMI

Time Domain



Frequency Domain

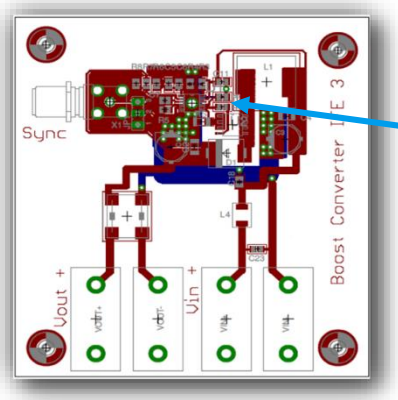


High frequency Harmonics come with higher levels

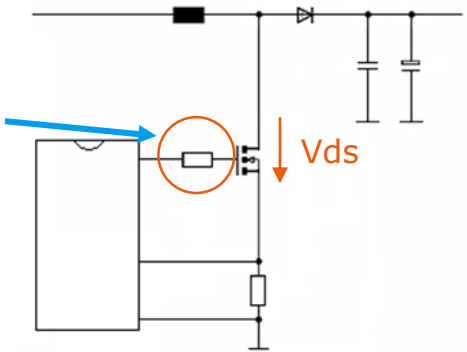
EMI DEBUGGING CASE STUDIES

CASE STUDY
OPTIMIZING WIDE BAND-GAP SWITCHING

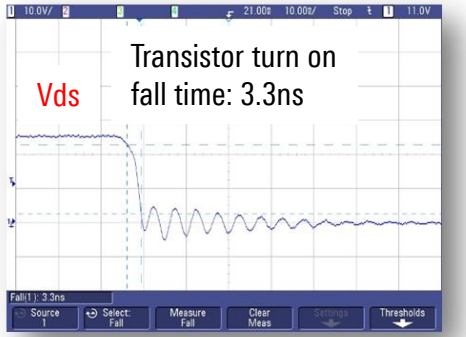
- Change gate resistance to modify switching behavior



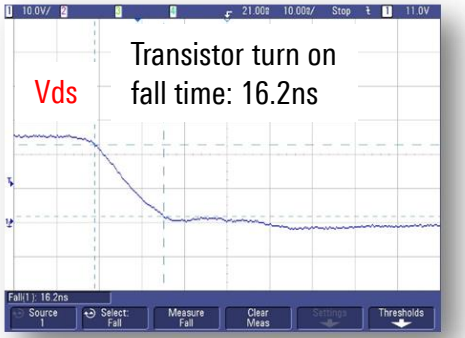
Gate resistor
(0 – 50Ω)



0 Ohm gate resistor:



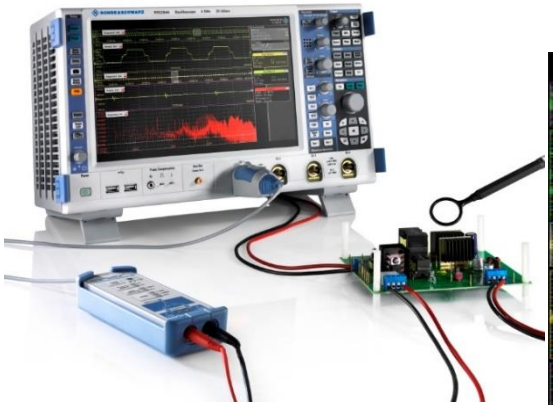
10 Ohm gate resistor:



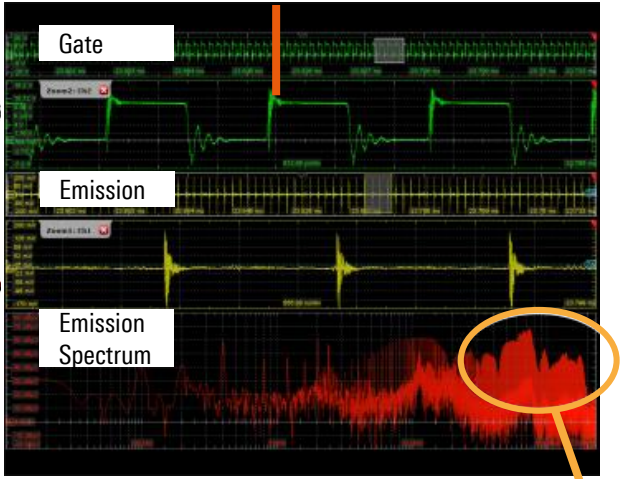
- The gate resistor will increase the switching time of the transistor.
- This helps to reduce the high dV/dt and therefore the EME.

Increasing the gate resistor will also increase the switching losses!

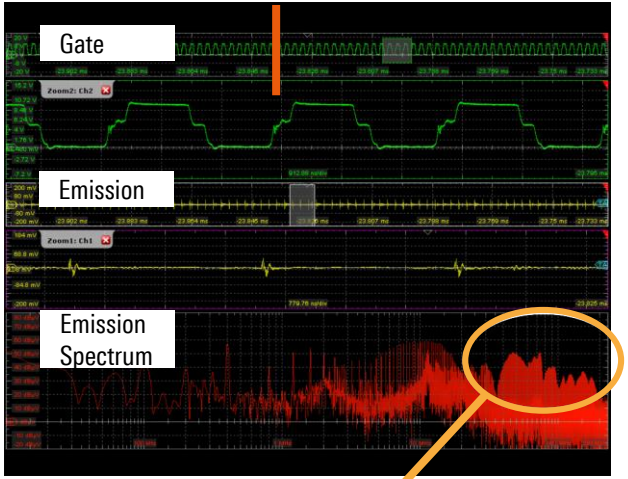
CASE STUDY
OPTIMIZING WIDE BAND-GAP SWITCHING



Fast gate driver signal

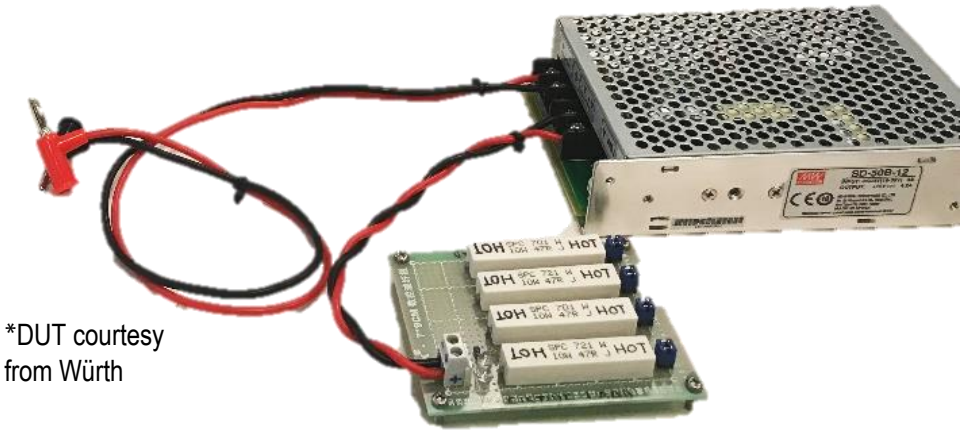


Shaped gate driver signal



Significantly reduced emissions

CASE STUDY:
POWER SUPPLY DESIGN COMPLIANCE



*DUT courtesy from Würth

Verify → Pre-production

Compliance

ESU

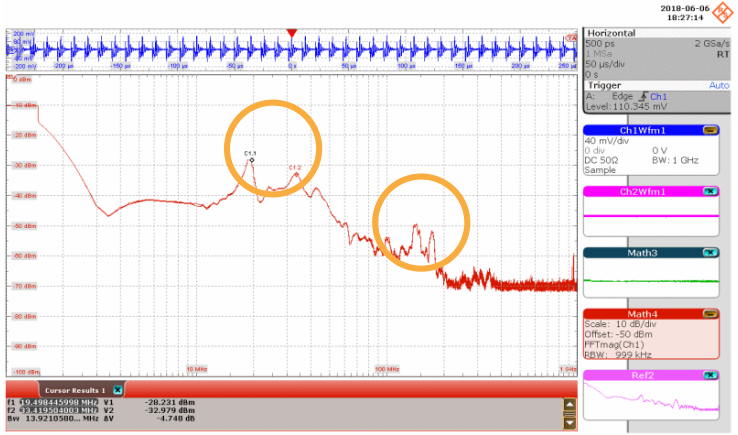
Compliance

CASE STUDY:
POWER SUPPLY DESIGN COMPLIANCE

Verify → Pre-production

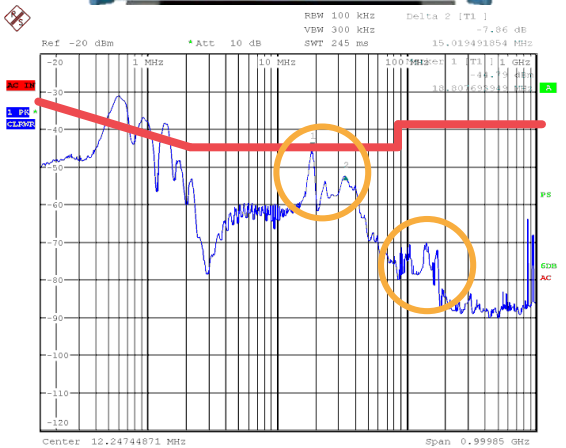
Compliance

RTO



Pre-compliance

ESU



Compliance


ANY
QUESTIONS?


thank
you