

EMI ANALYSIS ON POWER SUPPLY DESIGN

Tommy Chen
Application Engineer
Oscilloscope

ROHDE & SCHWARZ

Make ideas real



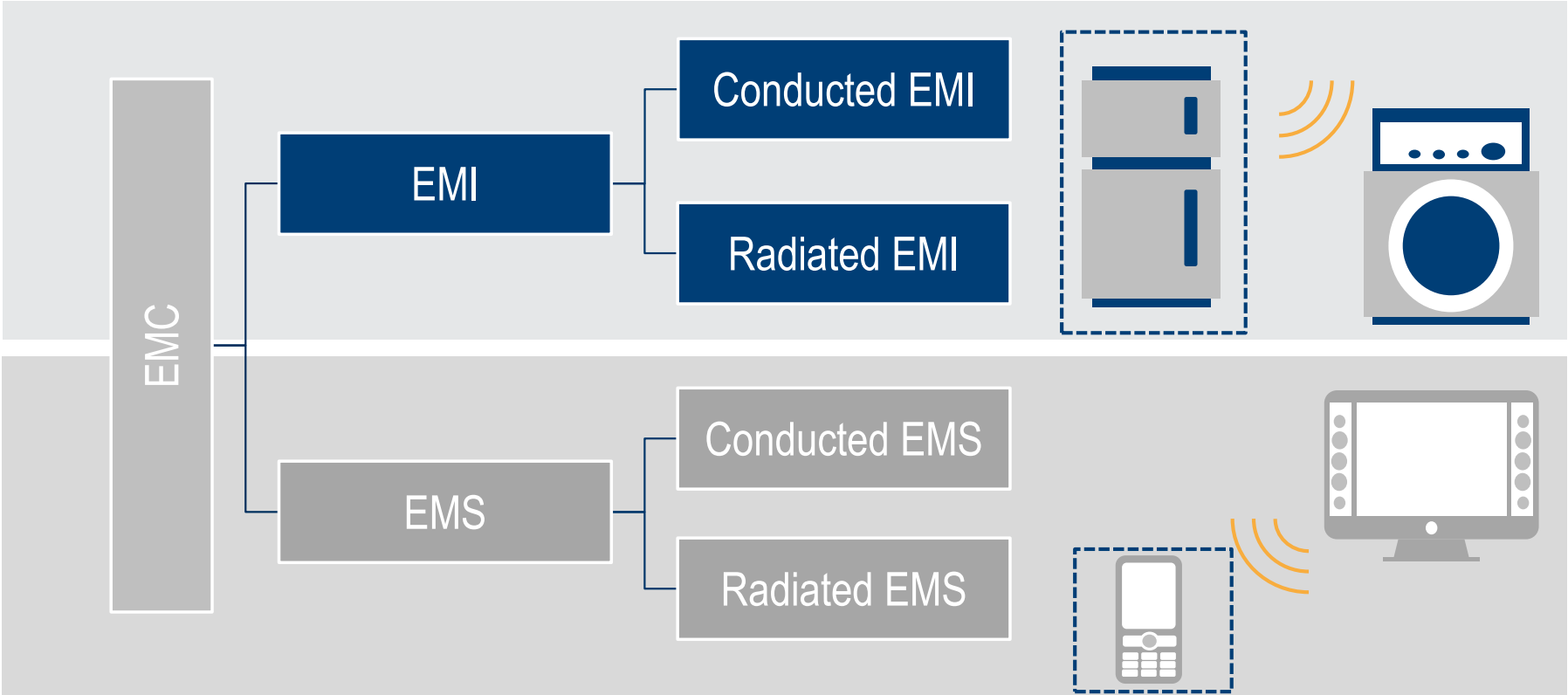
COMPANY RESTRICTED

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?



MODES OF EMISSION

EMI

Radiated EMI

- ▶ Magnetic radiation
- ▶ Electric radiation

Conducted EMI

- ▶ Voltage disturbance
- ▶ Power disturbance



MODES OF SUSCEPTIBILITY

EMS

Radiated EMS

- ▶ Magnetic radiation



Conducted EMS

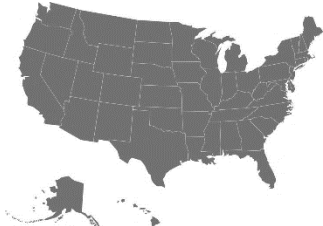
- ▶ Voltage/ current disturbance

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)



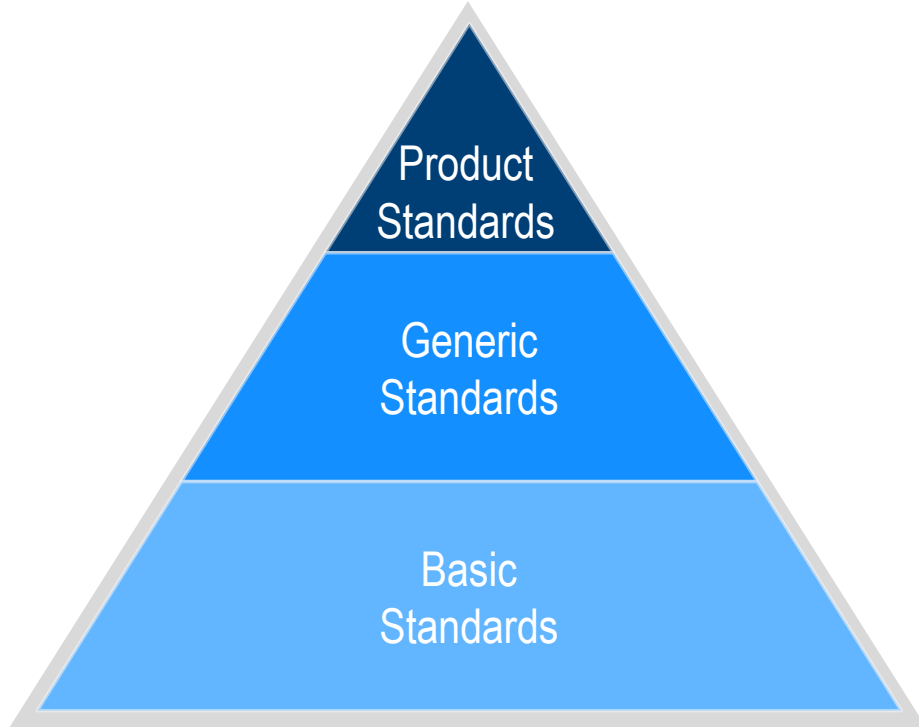
China Compulsory Certification
(GB - GuoBiao)



Bureau of India Standards
(BIS)



EMC STANDARDS STRUCTURE



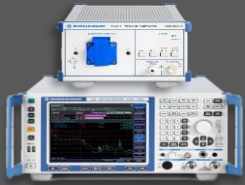
Measurement methods and limits, adjusted to respective product group
(e.g. CISPR 11/15/32)

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



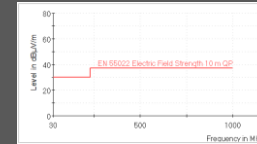
Protection of on-board & off-
board receivers of vehicles
E.g. CISPR 12, CISPR 25

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	79	66
	0.5 - 30.0	73	60
Class B	0.15 – 0.5	66 to 56 *	56 to 46 *
	0.5 – 5	56	46
	5 - 30	60	50

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

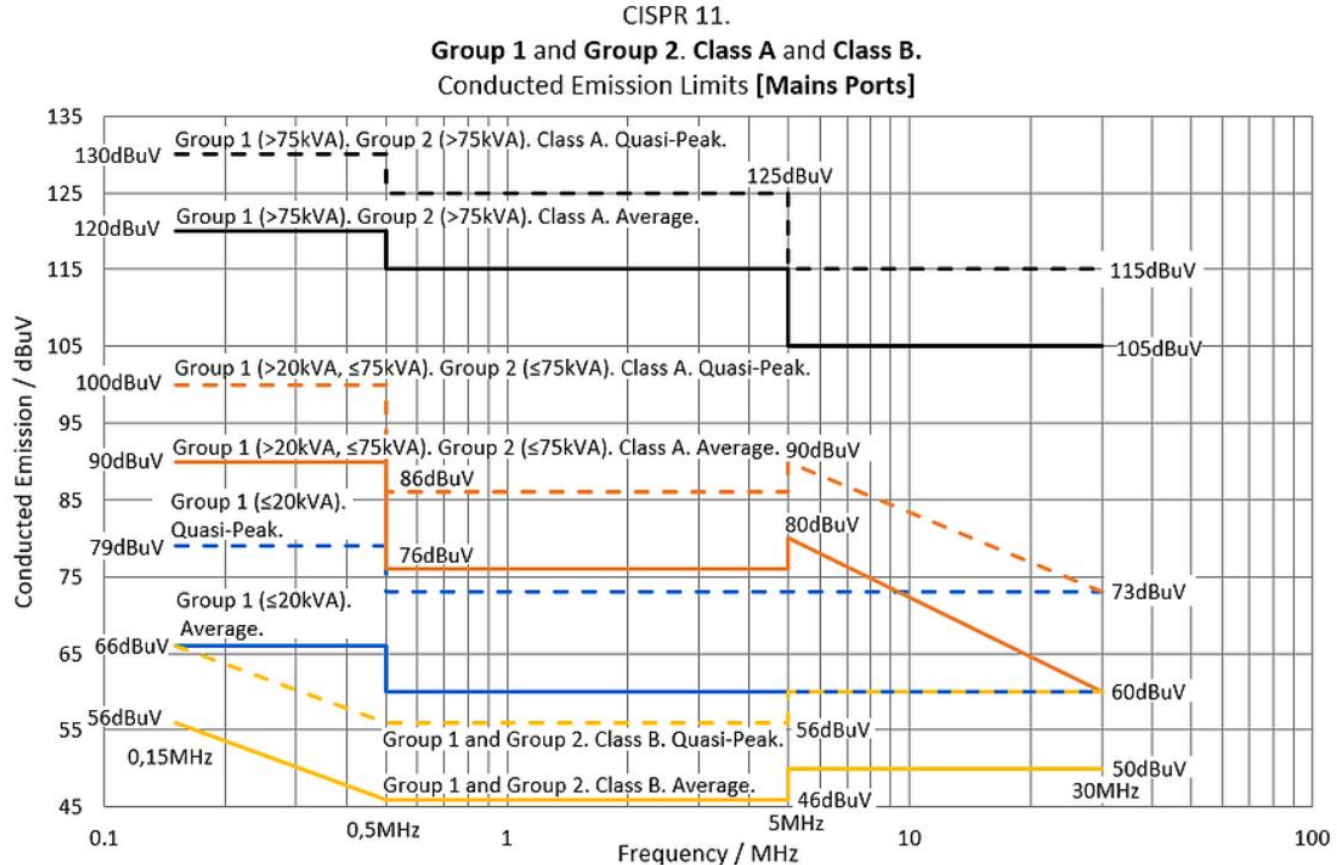
► EU Standard (Emission)

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

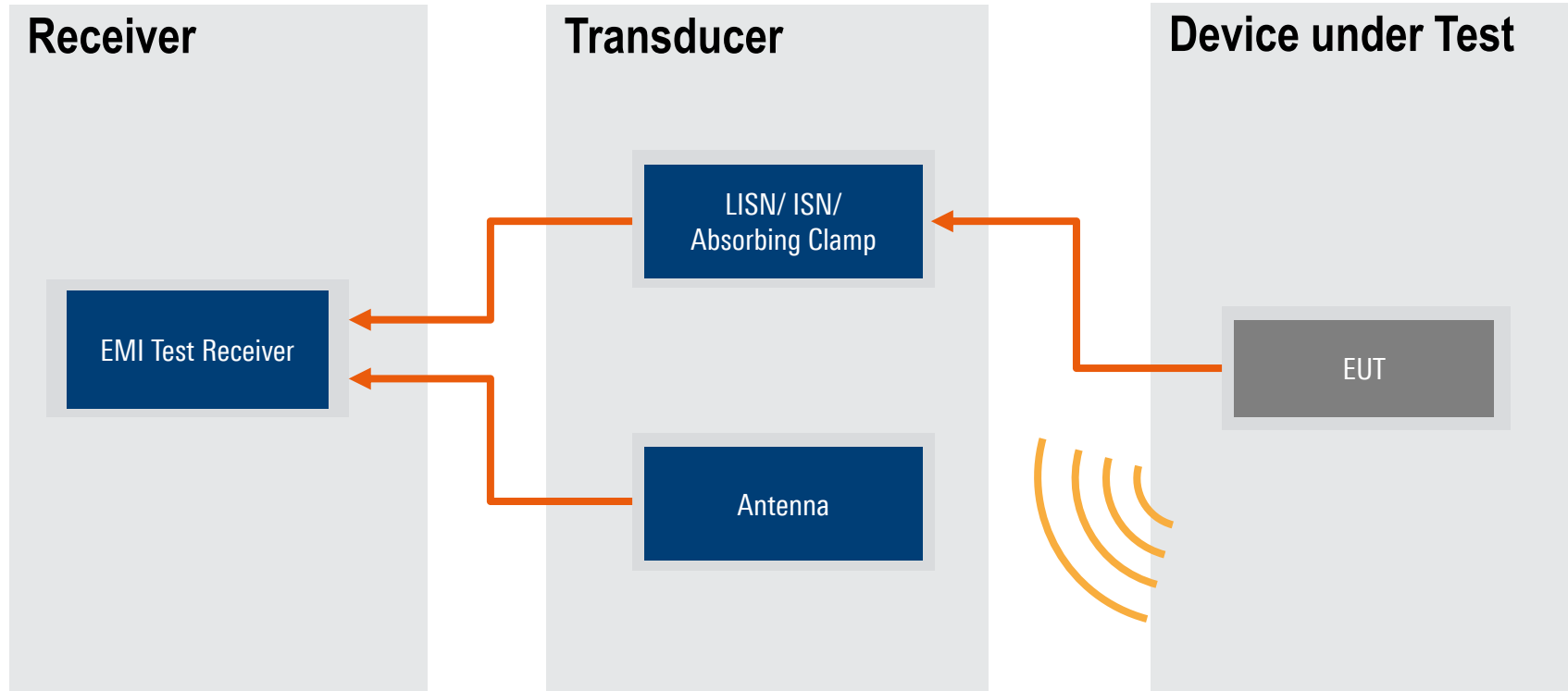


EMI TESTS IN SUMMARY

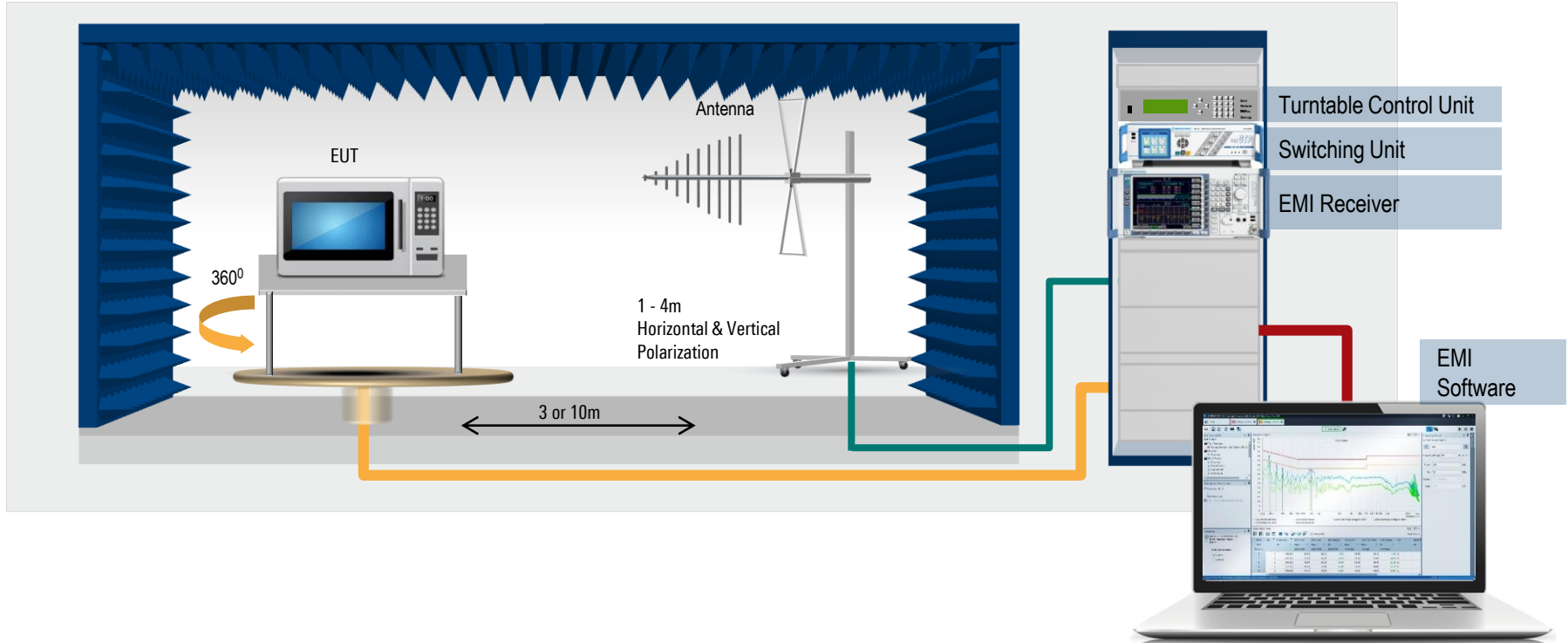
	CISPR 11 ISM	CISPR 14 HOUSEHOLD EQUIPMENT	CISPR 15 LIGHTINGS	CISPR 32 MUTLIMEDIA EMC
CONDUCTED EMI (MAINS PORTS)	✓	✓	✓	✓
CONDUCTED EMI (TELECOM PORTS)				✓
RADIATED EMI (MAGNETIC FIELD)	✓	✓	✓	
RADIATED EMI (ELECTRIC FIELD)	✓	✓	✓	✓
POWER DISTURBANCE		✓		

SETUP AND TOOLS FOR EMC MEASUREMENTS

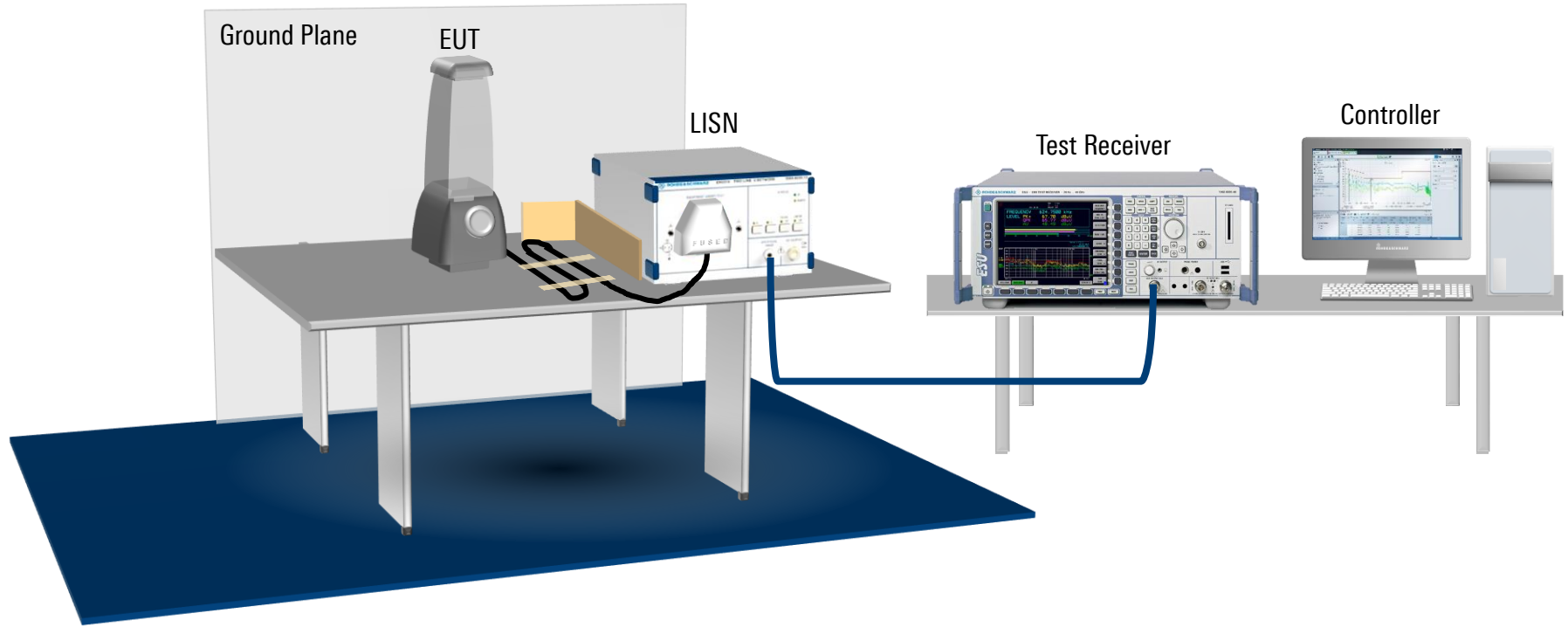
SYSTEM CONFIGURATION



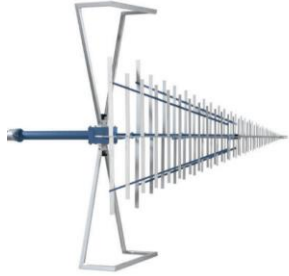
COMPLIANCE RADIATED EMISSION TEST



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



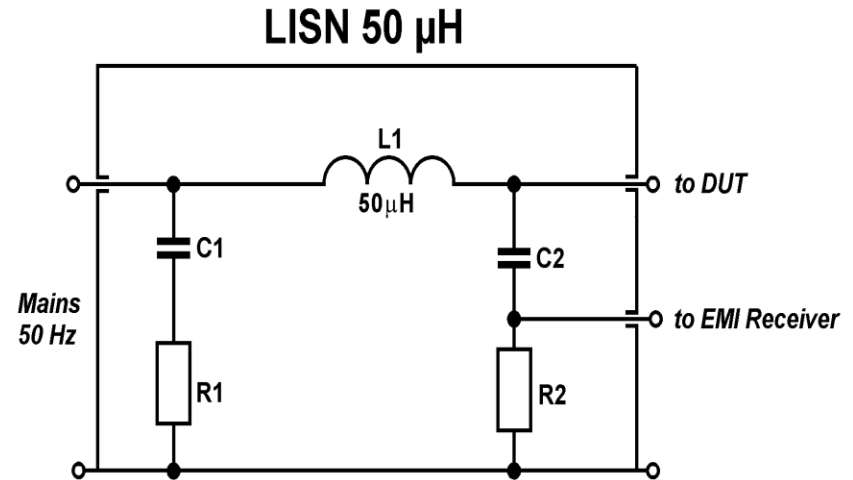
Current probe – conducted current



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



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



EMI testing referring to limits



Full
compliance
measurement

Pre-compliance measurement
or compliance measurements
to CISPR 16-1-1 Ed. 3

Diagnostic measurements in engineering
and pre-compliance EMI testing

Diagnostic
measurements
without relation
to limits

Top class spectrum analyzers



General purpose spectrum analyzers



Low cost spectrum analyzers, voltmeters, oscilloscopes



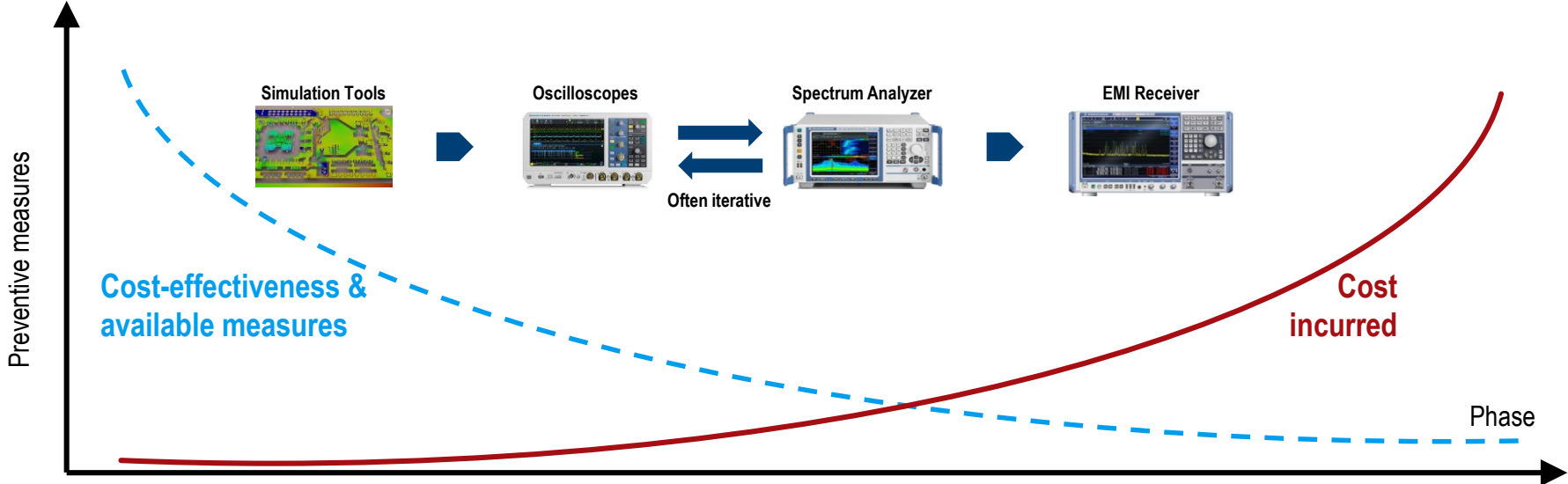
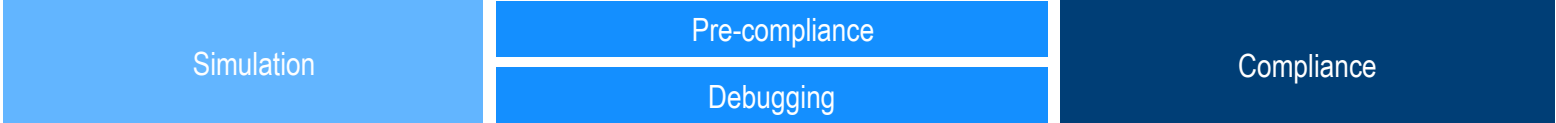
Receivers

Rohde & Schwarz

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



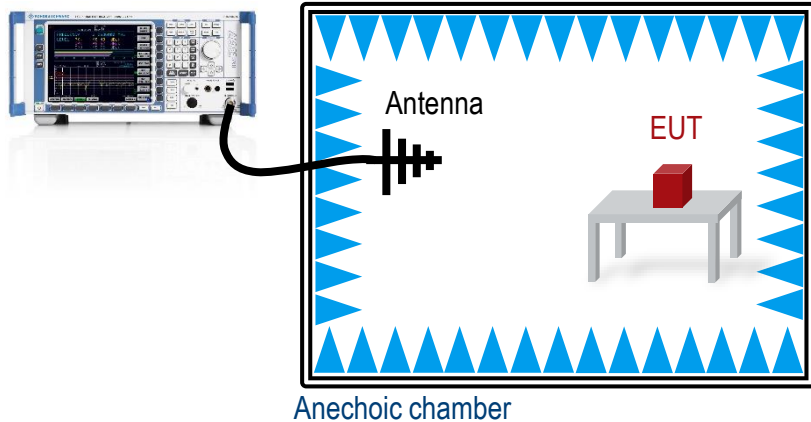
PREVENTION IS BETTER THAN CURE



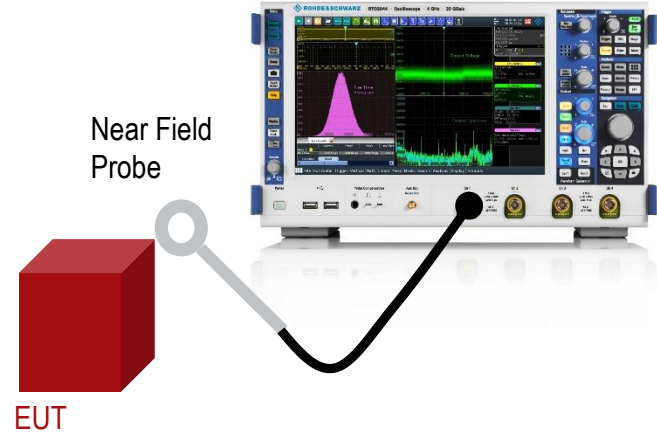
Similar to medical check-up for preventive health care, we diagnose early on circuit to avoid future issues

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

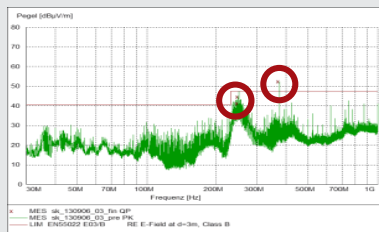
EMI Measurement with Scope or Spectrum

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

GENERAL EMI DEBUGGING PROCEDURE

ANALYSIS STEPS

A) Far-field measurement

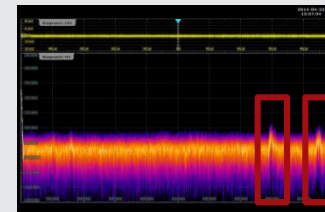


B) "Know your DUT":

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?!



EDN Asia

Design Centre | News Centre | Product Centre | Resource Centre | Webcasts

Path: EDN Asia >> Design Centre >> Test & Measurement >> Oscilloscope for EMI debugging? Really? (Part 1)

Test & Measurement

Oscilloscope for EMI debugging? Really? (Part 1)

31 May 2013 | Alvin Ding, Markus Herdin

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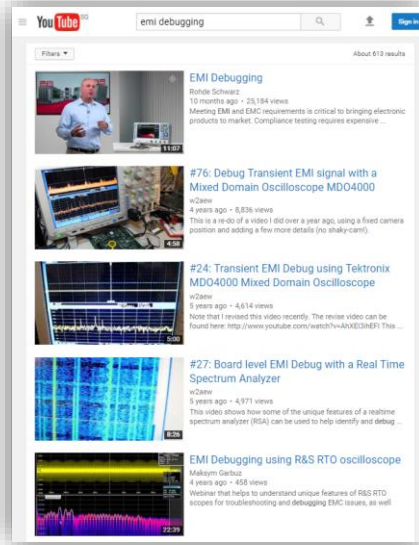
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With the availability of high-performance oscilloscopes providing powerful FFT analysis and excellent noise performance, a new tool exists for debugging EMI problems. Based on the results from compliance testing, the oscilloscope proves to be a valuable tool to quickly understand unwanted emissions and identify their root cause. Having access to both time-domain and frequency-domain, in the same instrument, allows for faster analysis of unwanted emissions. Since the oscilloscope is usually available at the desk of the design engineer, it enables debugging of EMI problems in R&D and allows tests before going to the EMC lab, thereby significantly increasing the likelihood of a successful compliance test.

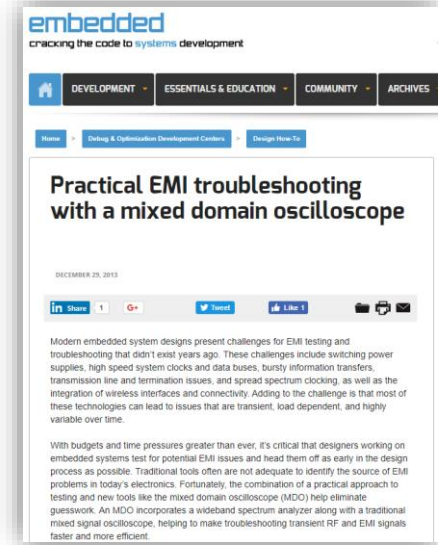
This is the first in a series that discusses various use cases and highlights limitations of high-performance oscilloscopes with powerful FFT implementations for EMI applications.

New digital oscilloscopes, such as the Rohde & Schwarz RTO, which we will use in this use-case analysis, bring EMI debugging capabilities directly onto the desk of the design engineer. This model offers front-end sensitivity that compares with spectrum analysers and allows simultaneous access to both the time domain and the frequency domain.



YouTube search results for "emi debugging".

- EMI Debugging**
Rohde Schwarz
10 months ago • 23,194 views
Meeting EMI and EMC requirements is critical to bringing electronic products to market. Compliance testing requires expensive...
- #76: Debug Transient EMI signal with a Mixed Domain Oscilloscope MDO4000**
wZawv
4 years ago • 8,836 views
This is a re-do of a video I did over a year ago, using a fixed camera position and adding a few more details (no shaky-cam!).
- #24: Transient EMI Debug using Tektronix MDO4000 Mixed Domain Oscilloscope**
wZawv
5 years ago • 4,114 views
Note that I revised this video recently. The revised video can be found here: <http://www.youtube.com/watch?v=4XVE3HEE1> This...
- #27: Board level EMI Debug with a Real Time Spectrum Analyzer**
wZawv
4 years ago • 4,971 views
This video shows how some of the unique features of a real-time spectrum analyzer (RSA) can be used to help identify and debug...
- EMI Debugging using R&S RTO oscilloscope**
Makymy Garbuz
4 years ago • 455 views
Video that helps to understand unique features of R&S RTO scopes for troubleshooting and debugging EMI issues, as well...



embedded
cracking the code to systems development

DEVELOPMENT | ESSENTIALS & EDUCATION | COMMUNITY | ARCHIVES

Practical EMI troubleshooting with a mixed domain oscilloscope

DECEMBER 29, 2013

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Modern embedded system designs present challenges for EMI testing and troubleshooting that didn't exist years ago. These challenges include switching power supplies, high speed system clocks and data buses, bursty information transfers, transmission line and termination issues, and spread spectrum clocking, as well as the integration of wireless interfaces and connectivity. Adding to the challenge is that most of these technologies can lead to issues that are transient, load dependent, and highly variable over time.

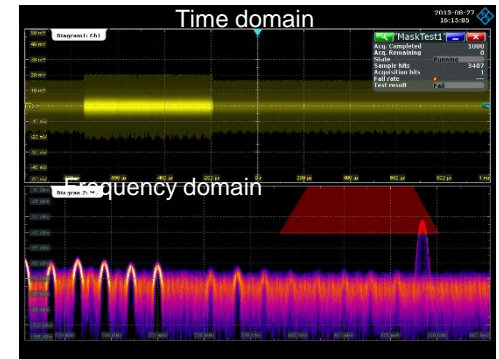
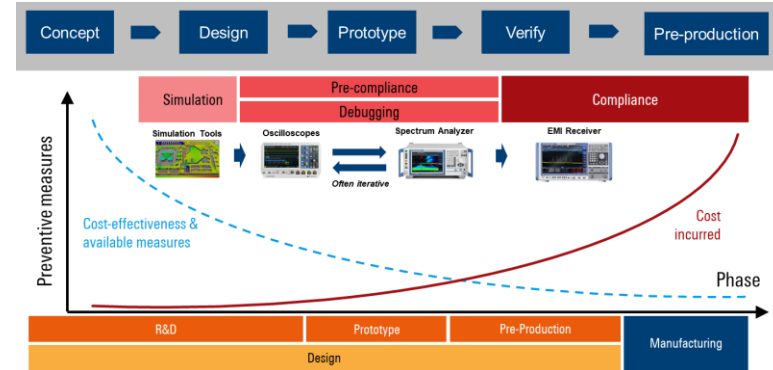
With budgets and time pressures greater than ever, it's critical that designers working on embedded systems test for potential EMI issues and head them off as early in the design process as possible. Traditional tools often are not adequate to identify the source of EMI problems in today's electronics. Fortunately, the combination of a practical approach to testing and new tools like the mixed domain oscilloscope (MDO) help eliminate guesswork. An MDO incorporates a wideband spectrum analyzer along with a traditional mixed signal oscilloscope, helping to make troubleshooting transient RF and EMI signals faster and more efficient.

Better instruments progressively changes debug methodologies

EMI DEBUGGING WITH OSCILLOSCOPES?

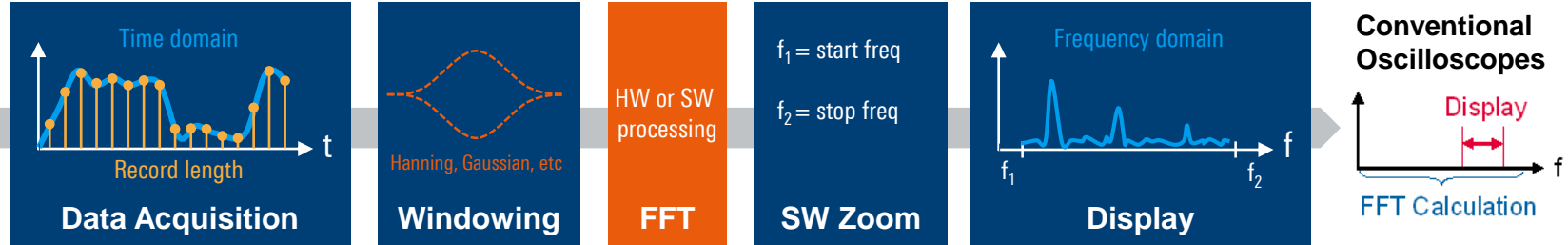
YES, WE CAN! (AND ITS VERY HELPFUL)

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

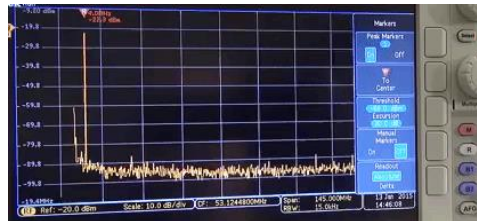
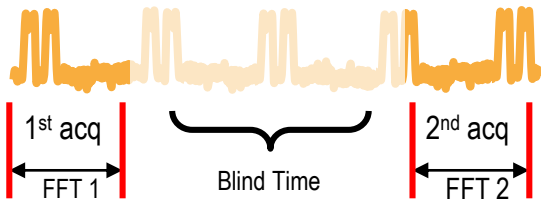


SPECTRUM MEASUREMENTS

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



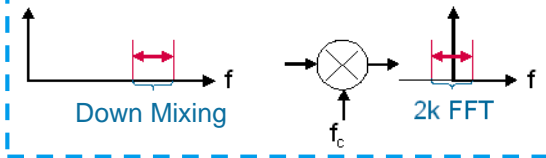
- Disadvantages of conventional FFT :**
- ▶ Very slow speed / update rate
 - ▶ Limited RBW due to insufficient RL
 - ▶ Complex configuration (TD settings)

SPECTRUM MEASUREMENTS

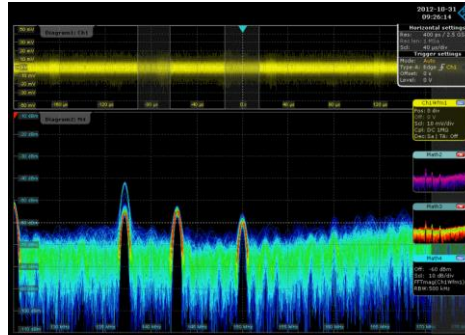
R&S MODERN OSCILLOSCOPE SPEEDING UP FFT



R&S RTO



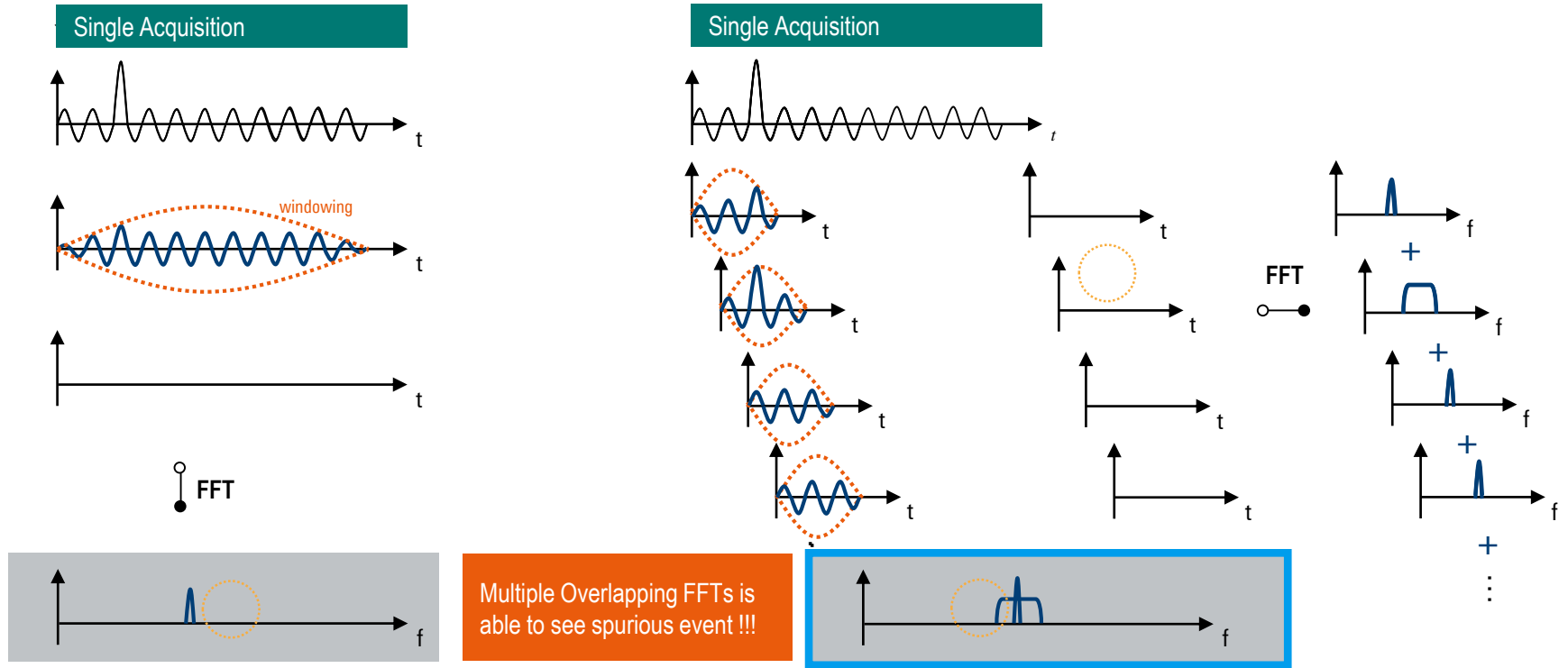
- ▶ Calculate only FFT over span of interest
- ▶ f_c = center frequency of FFT



Advantages of R&S approach:

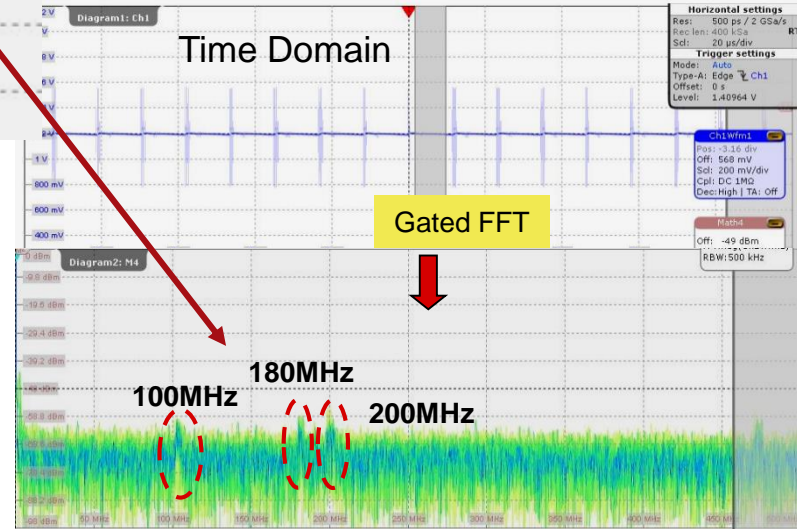
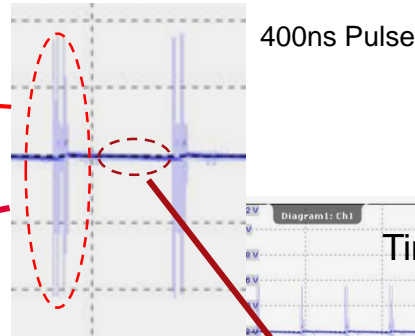
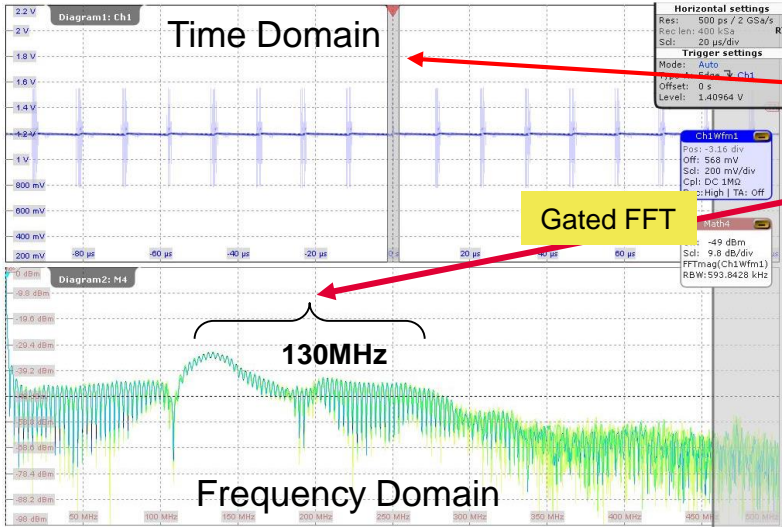
- ▶ Higher speed / update rate
- ▶ Good RBW without magnification
- ▶ Flexible configuration
- ▶ Multiple overlapping FFT able to find spurious faults

MODERN SCOPE FFT CAPABILITIES USING OVERLAPPING FFTS



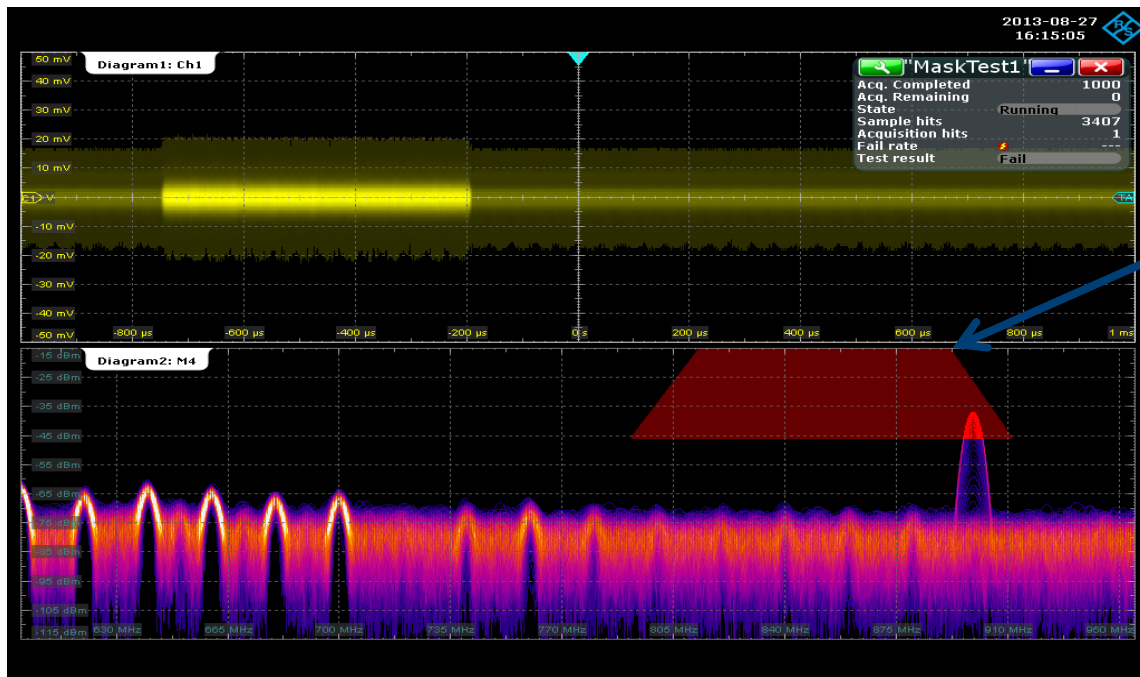
BASICS: SPECTRUM ANALYSIS ON LAB-CLASS OSCILLOSCOPES

TIME-GATED FFT APPLICATION: SWITCHED MODE POWER SUPPLIES



BASICS: SPECTRUM ANALYSIS ON LAB-CLASS OSCILLOSCOPES

SPECTRUM MASK FOR CAPTURING INTERMITTENT EMISSIONS



User-defined
spectrum mask



“Stop-on-violation”
function

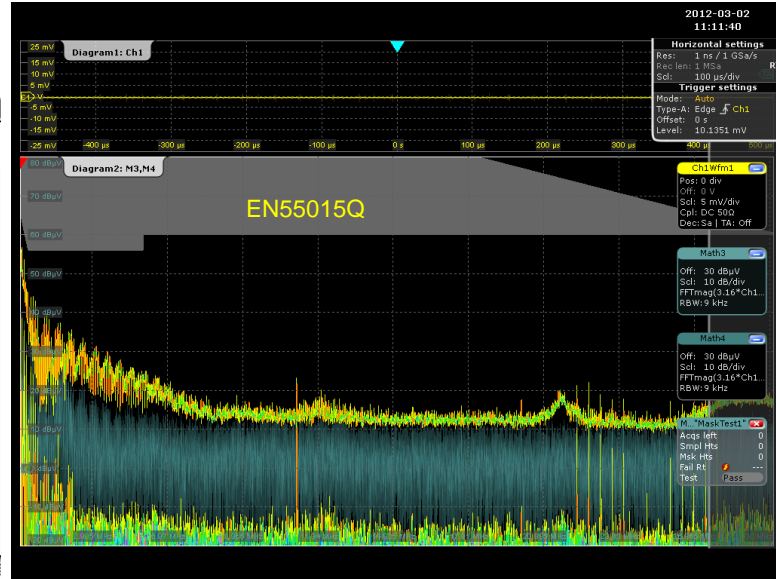
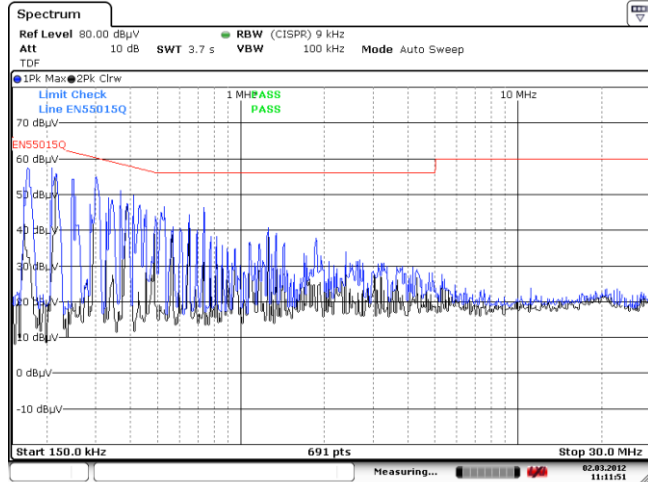


Analyze underlying source

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

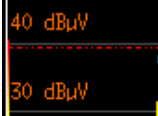
- RTO FFT1 = Normal mode
- RTO FFT2 = Envelope mode

MODERN SCOPE FFT CAPABILITIES

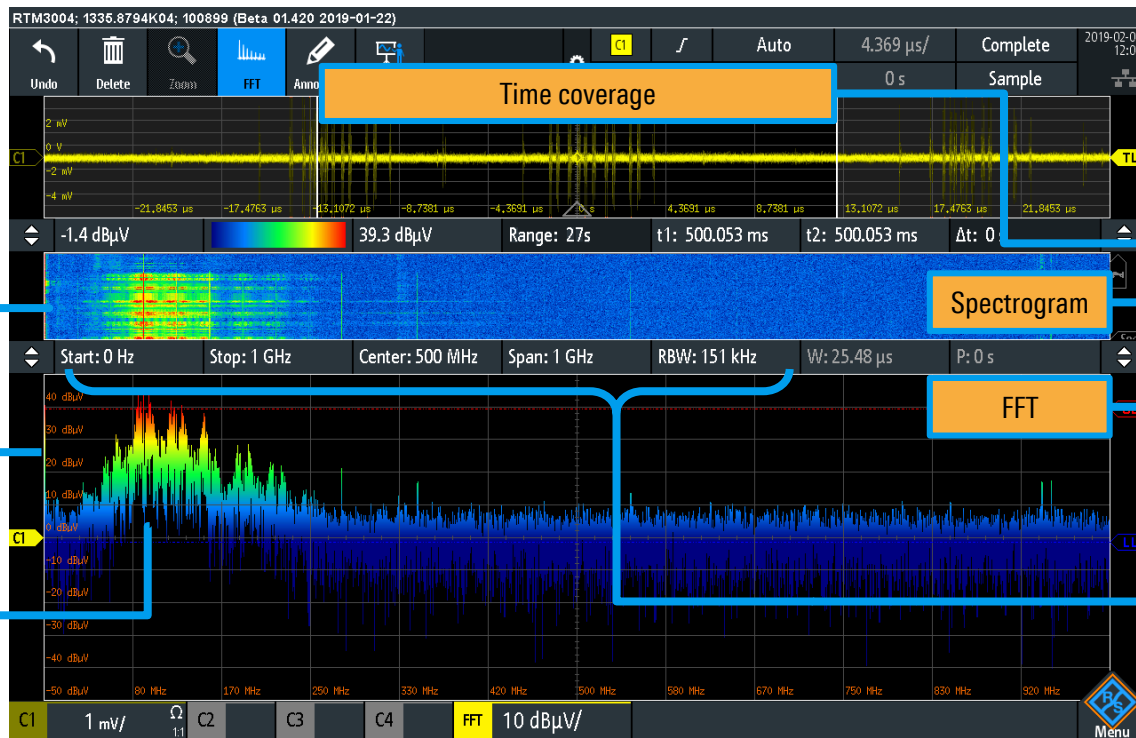
CORRELATION OF TIME AND FREQUENCY INFORMATION

Waterfall diagram helps to show short emissions

dBuV scaling like in EMI measurements



Color coding display for better visibility



Time-frequency correlation of emissions

Spectrogram

FFT

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

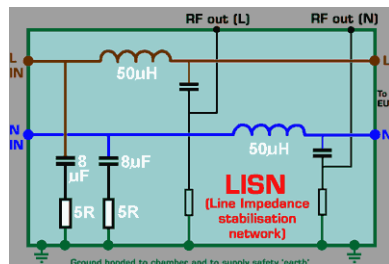
EMI

Near-field probing

Conducted Emissions Debugging



Our focus area here

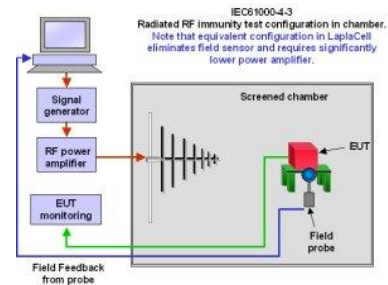


In R&D

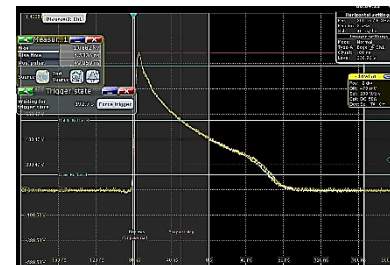
EMS

EUT Monitoring

ESD, EFT and Burst Calibration / ESD Tests



► EUT Monitoring



► Burst calibration
► ESD testing

In the test lab

EMI DEBUGGING WITH OSCILLOSCOPES

EXAMPLES

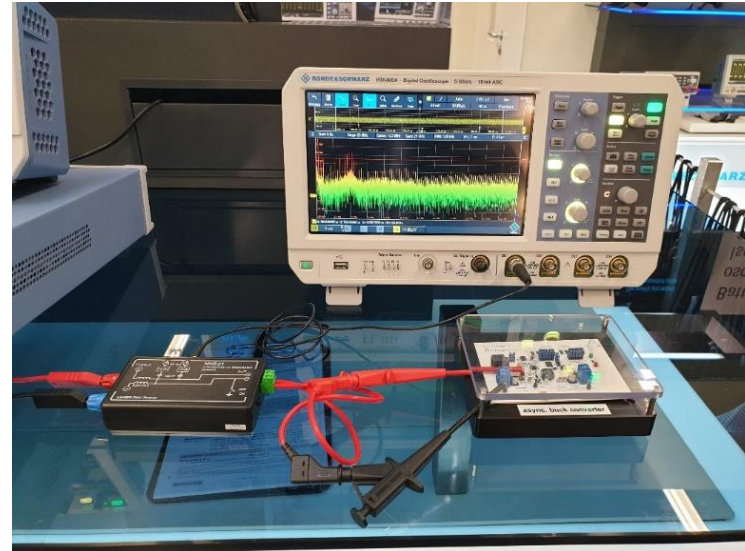
Radiated Emission

Debugging after failed Pre-Compliance or Compliance



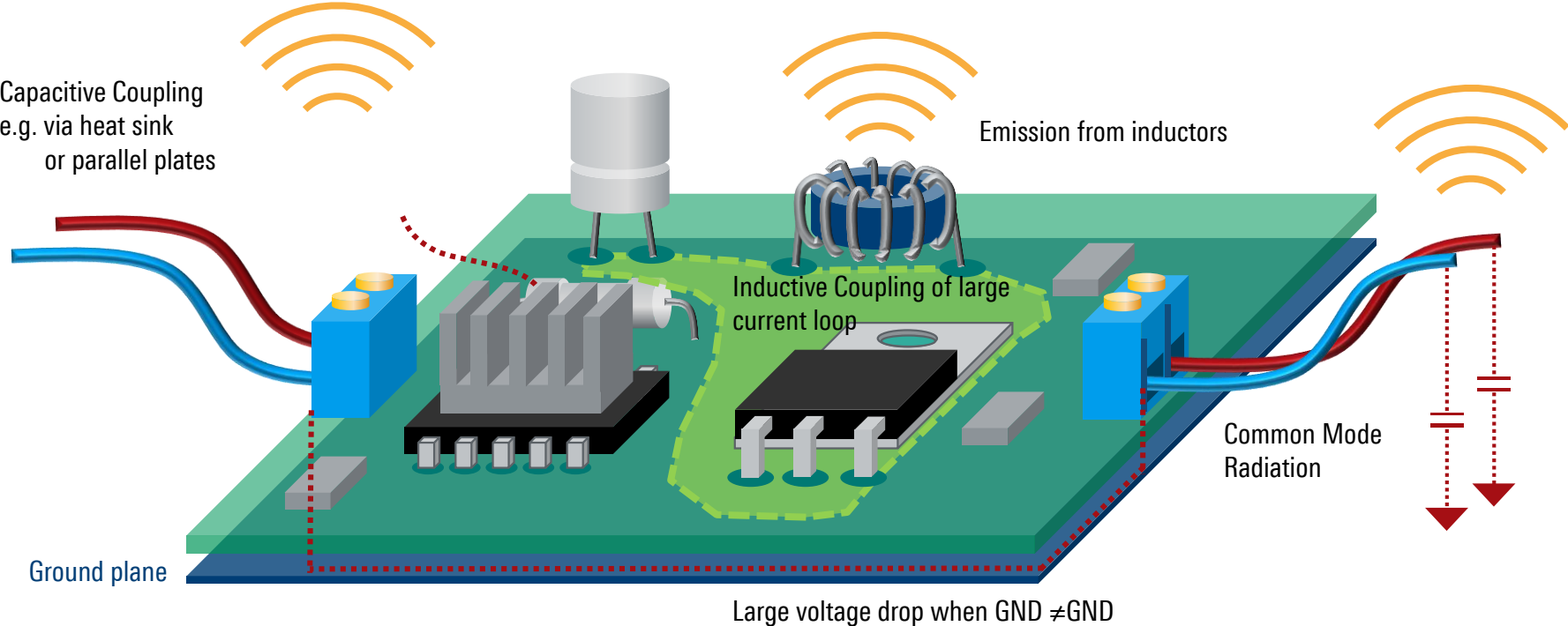
Conducted Emission

Pre-test and debugging in the R&D lab



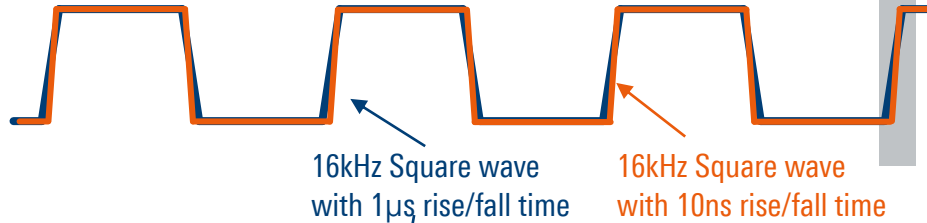
SWITCHED MODE POWER SUPPLIES AND EMC

ELECTRO-MAGNETIC EMISSION (EME) SOURCES

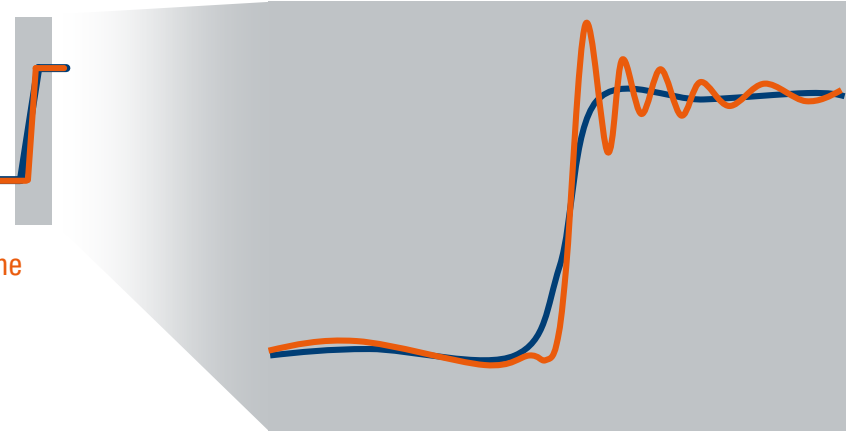
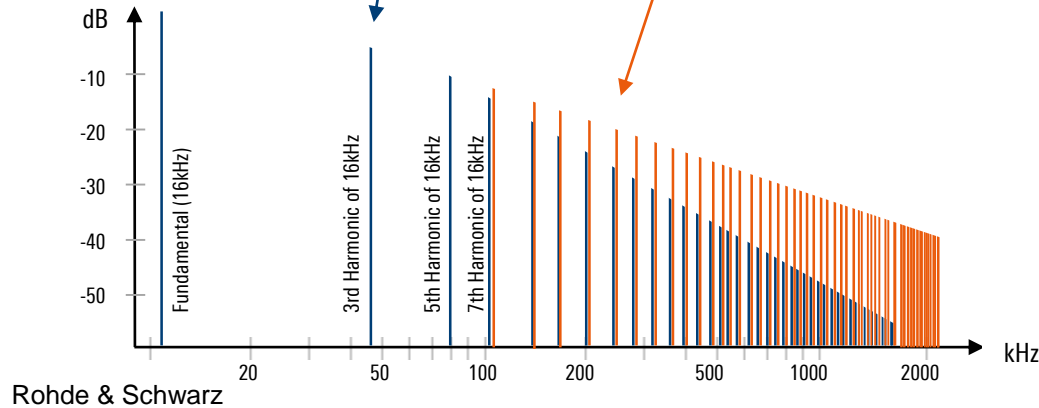


IMPACT OF FASTER SWITCHING AND STEEP EDGES ON EMI

Time Domain



Frequency Domain



High frequency Harmonics come with higher levels

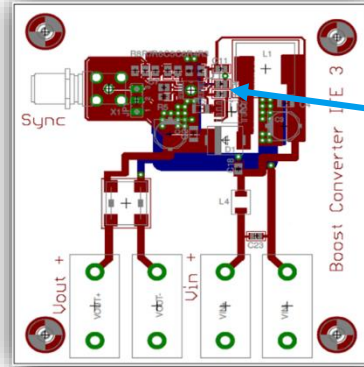


**EMI DEBUGGING
CASE STUDIES**

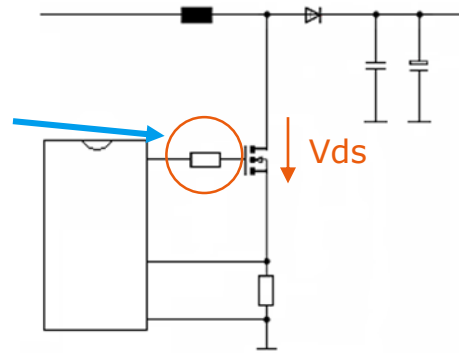
CASE STUDY

OPTIMIZING WIDE BAND-GAP SWITCHING

- Change gate resistance to modify switching behavior



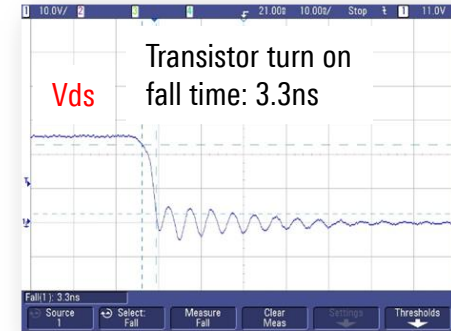
Gate resistor
(0 – 50Ω)



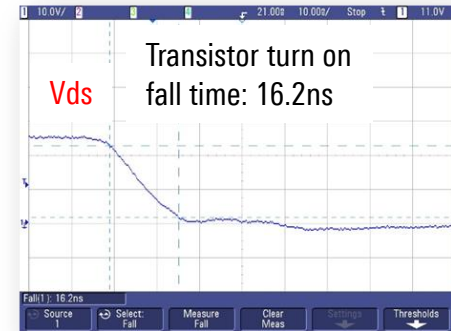
- The gate resistor will increase the switching time of the transistor.
- This helps to reduce the high dV/dt and therefore the EME.

Increasing the gate resistor will also increase the switching losses!

0 Ohm gate resistor:

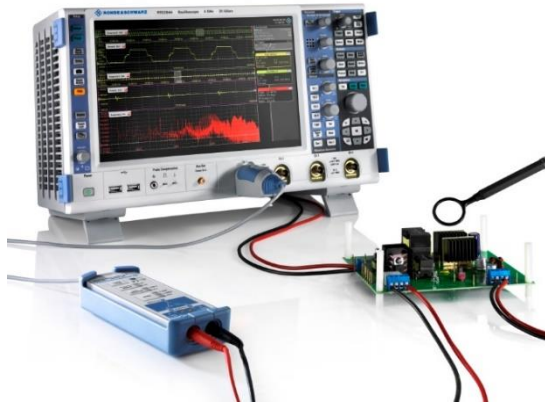


10 Ohm gate resistor:



CASE STUDY

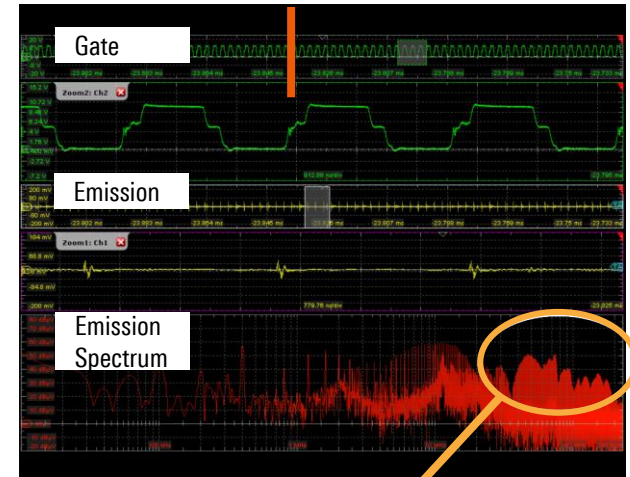
OPTIMIZING WIDE BAND-GAP SWITCHING



Fast gate driver signal

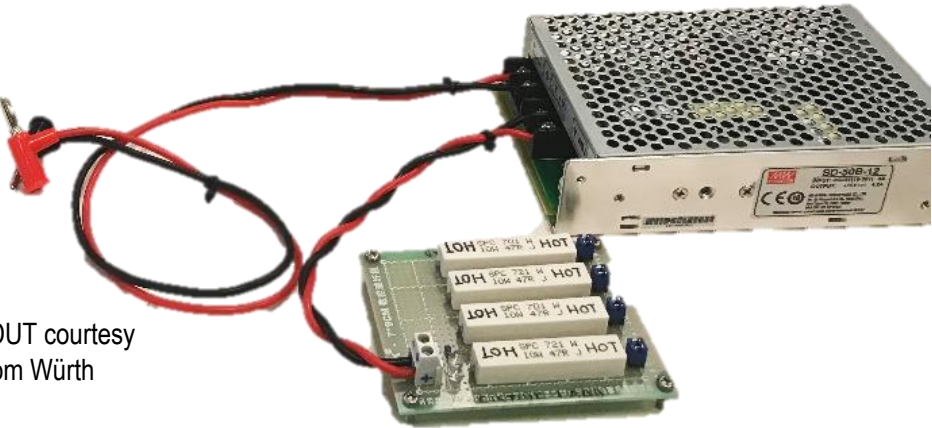


Shaped gate driver signal



Significantly reduced emissions

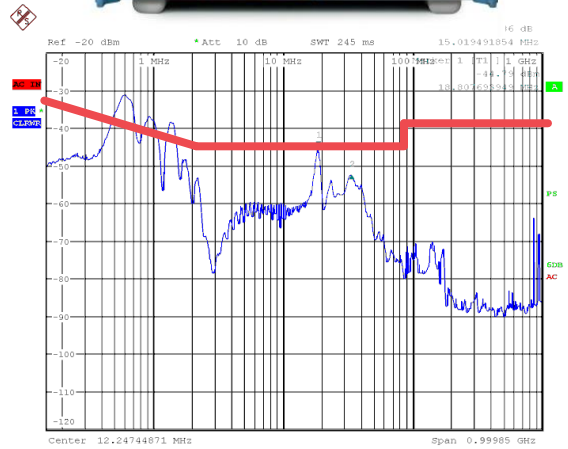
CASE STUDY: POWER SUPPLY DESIGN COMPLIANCE



*DUT courtesy
from Würth



ESU

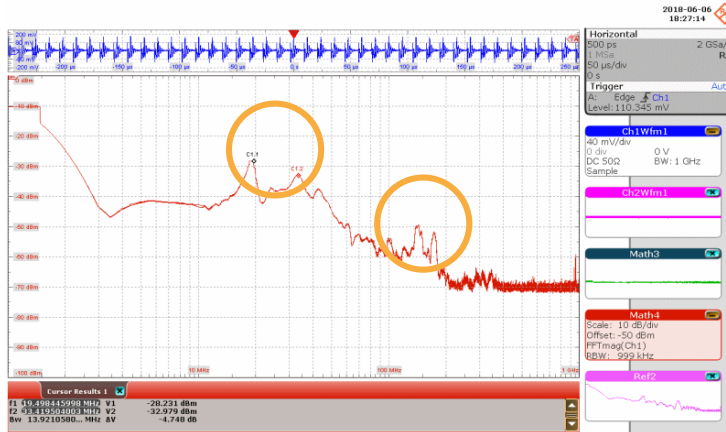


Compliance

CASE STUDY: POWER SUPPLY DESIGN COMPLIANCE



RTO



Pre-compliance

Verify

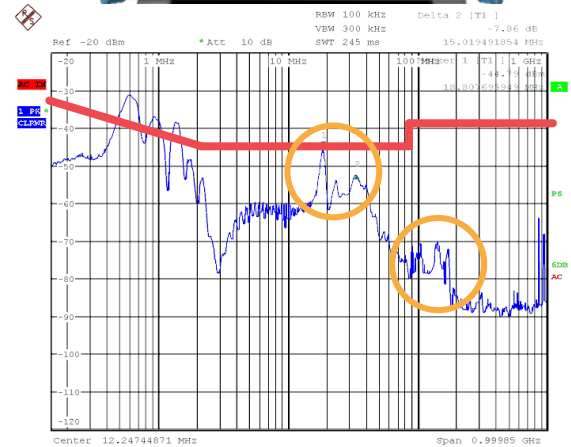


Pre-production

Compliance



ESU



Compliance

ANY
QUESTIONS?



Thank
you