Ettenheim, Nov. 9, 2021, AM

EMC Workshop

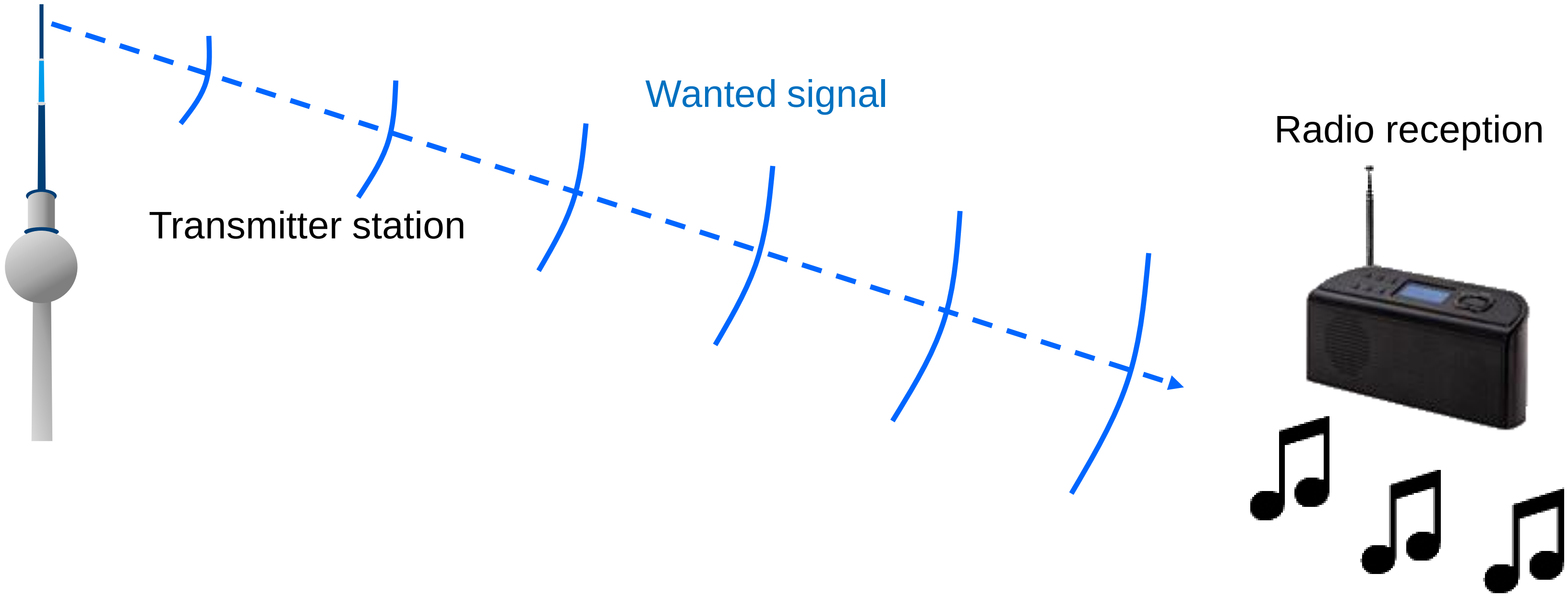
EMC Testing from First-Level Debugging to the Compliance Stage (Presented by Christian Reimer, R&S - 45min)

ROHDE&SCHWARZ

Make ideas real

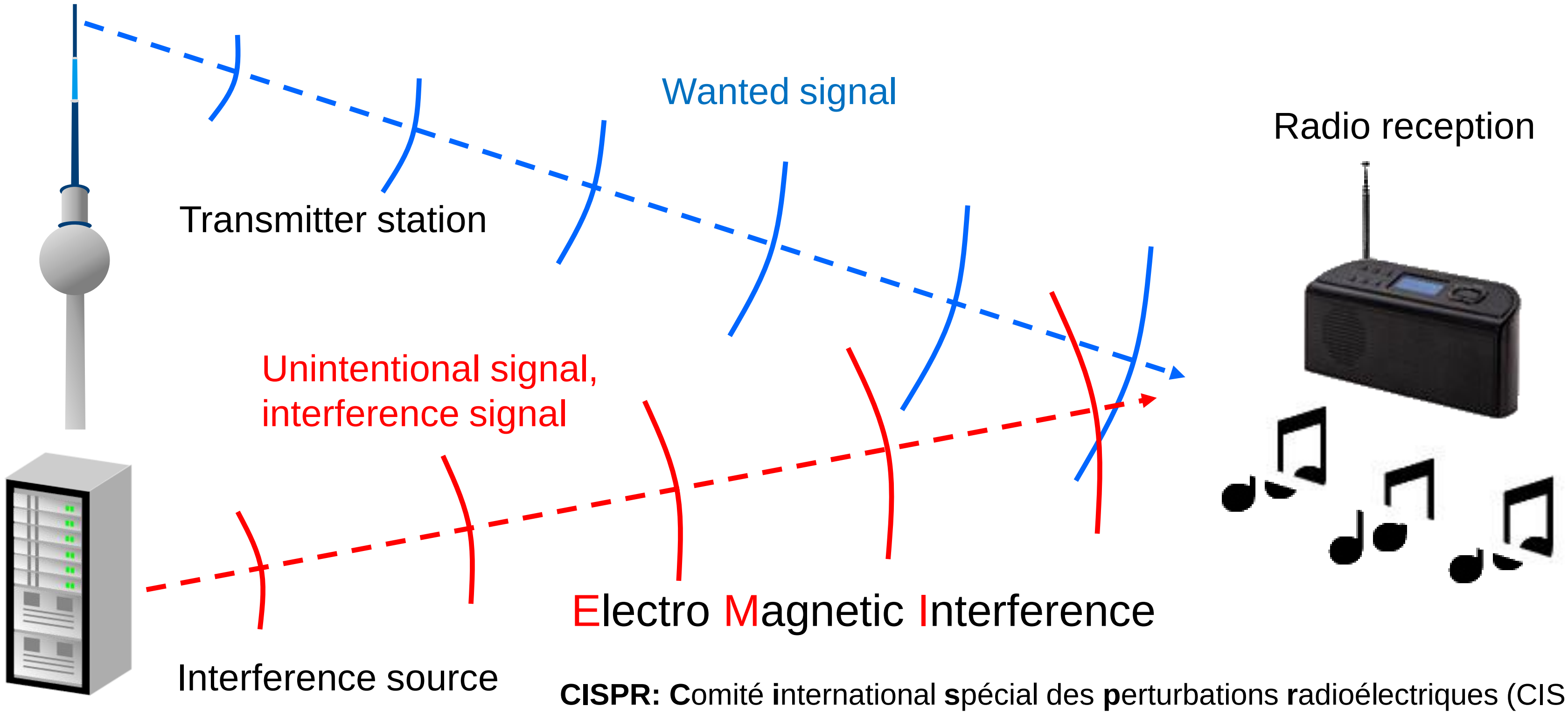
INFLUENCE OF RF EMISSIONS

Example: interference of radio reception



INFLUENCE OF RF EMISSIONS

Example: interference of radio reception

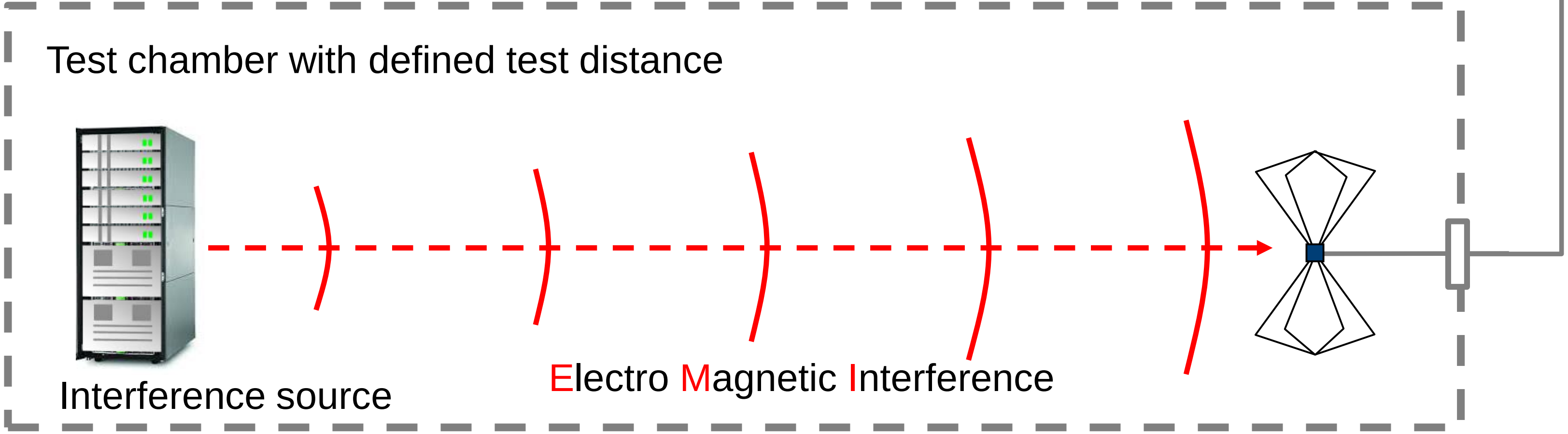


CISPR: Comité **i**nternational **s**pécial des **p**erturbations **r**adioélectriques (CISPR)
International Special Committee on Radio Interference (CISPR)

ISOLATION & EVALUATION

Target: defined and reproducible test

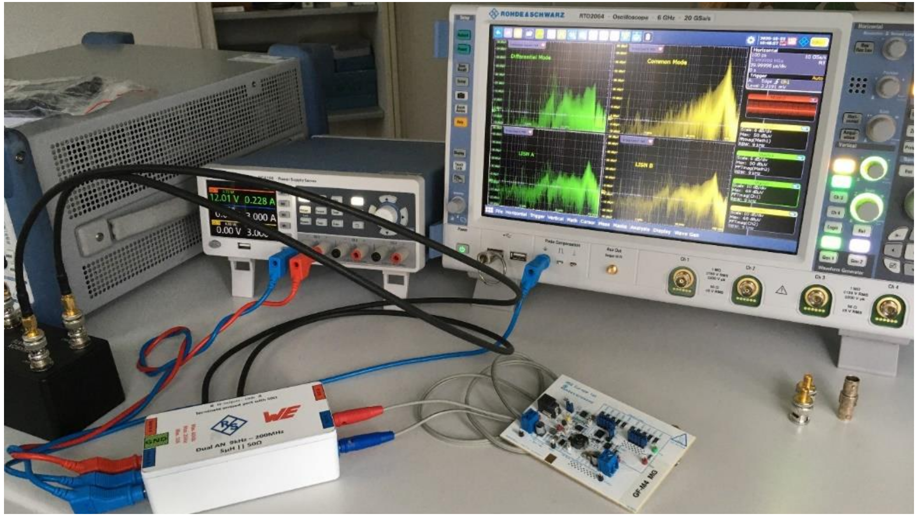
- Isolation:
  The Equipment Under Test (EUT) is located in the shielded test chamber.
- Evaluation:
  The receiver evaluates the received field strength and compares the result with a defined limit.



HOW MUCH ”EMC” DO YOU DO?

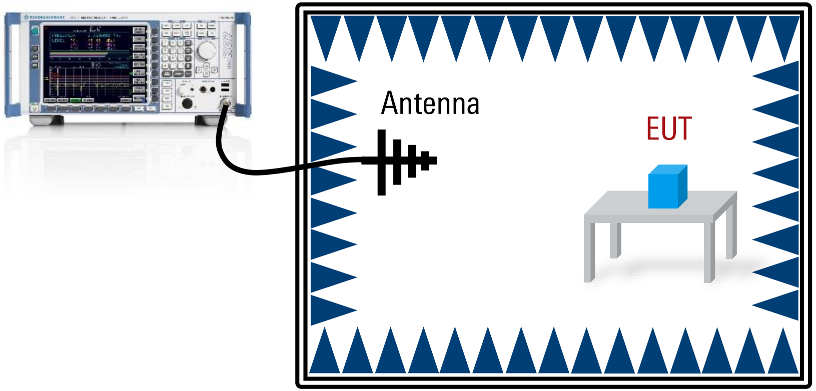
”EMC” may look like this….

or ”EMC” may look like this.

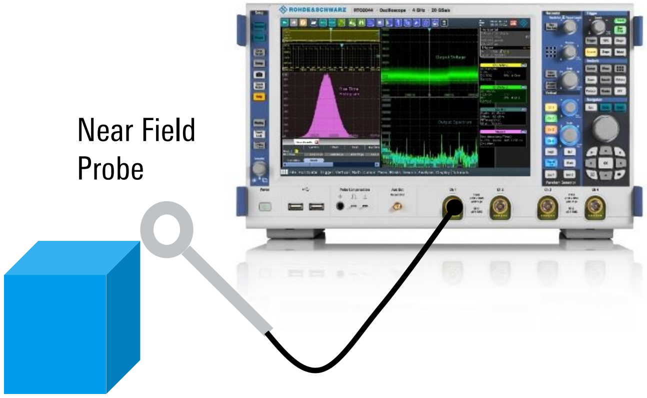


HOW MUCH ”EMC” DO YOU DO?

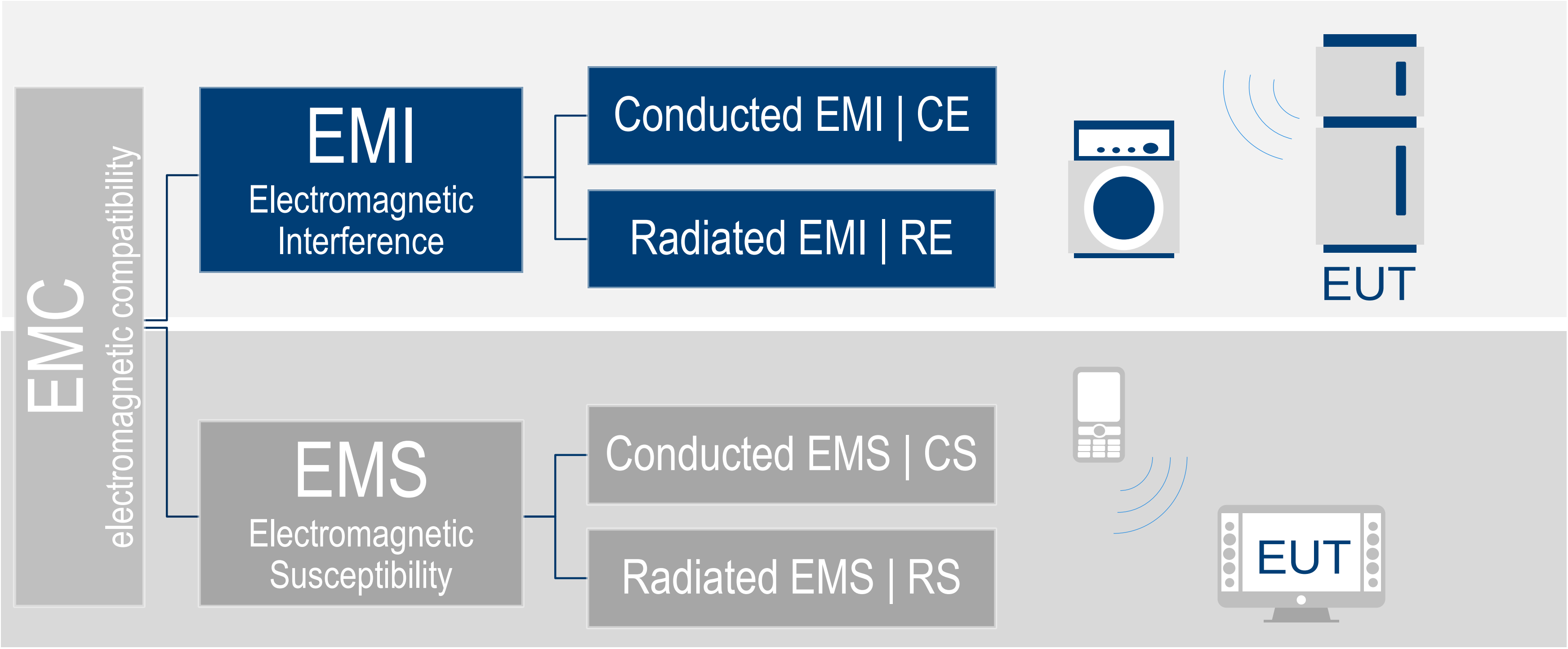
”EMC” according to standard…



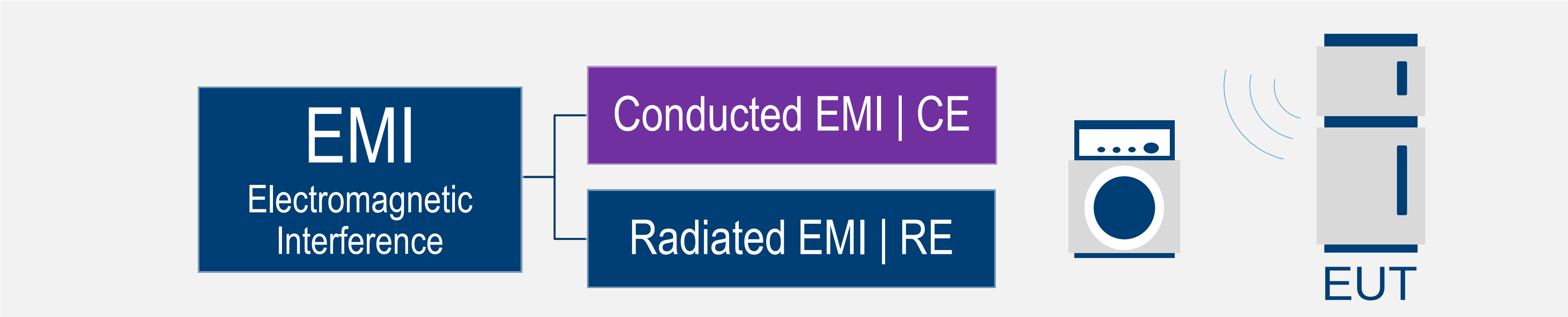
”EMC” in the design phase…



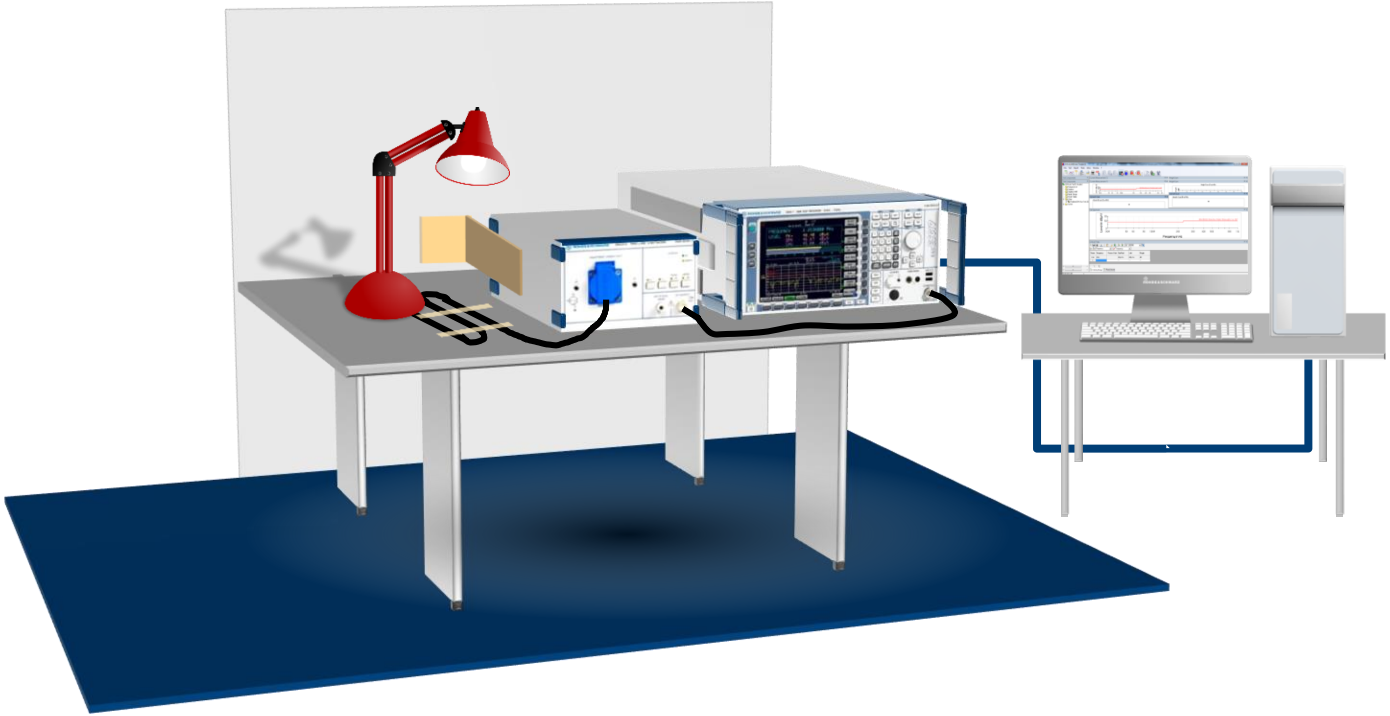
DIFFERENT TYPES OF EMC TESTS



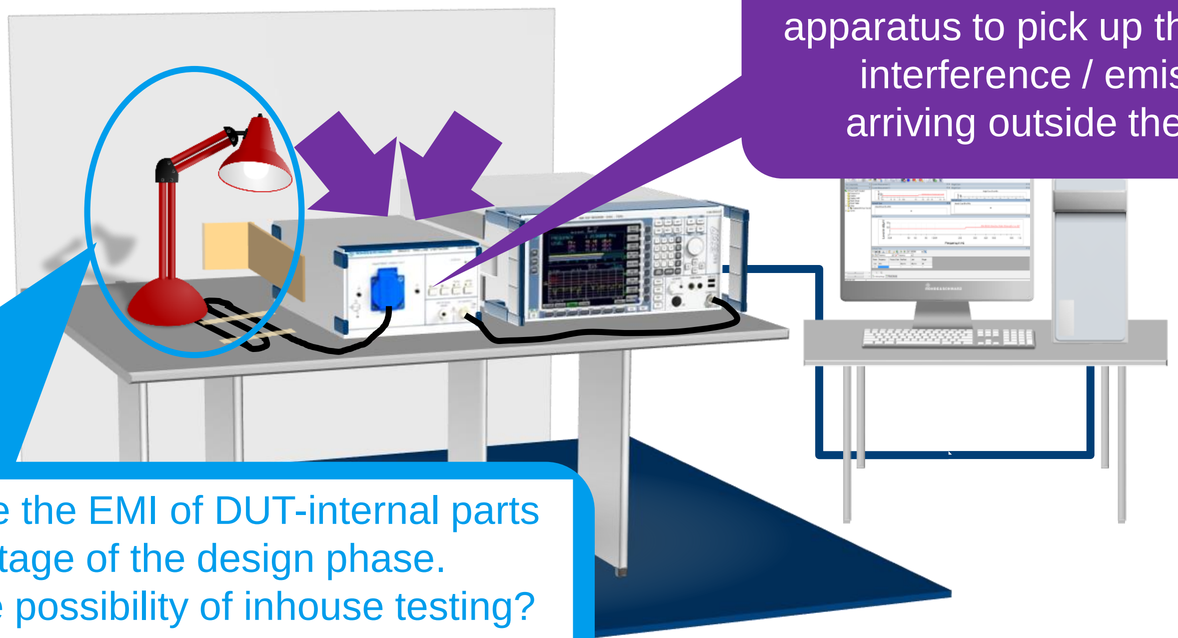
SUBSET OF EMC TESTS: EMI TESTS



CONDUCTED EMISSION SETUP - EXAMPLE



CONDUCTED EMISSION SETUP - EXAMPLE

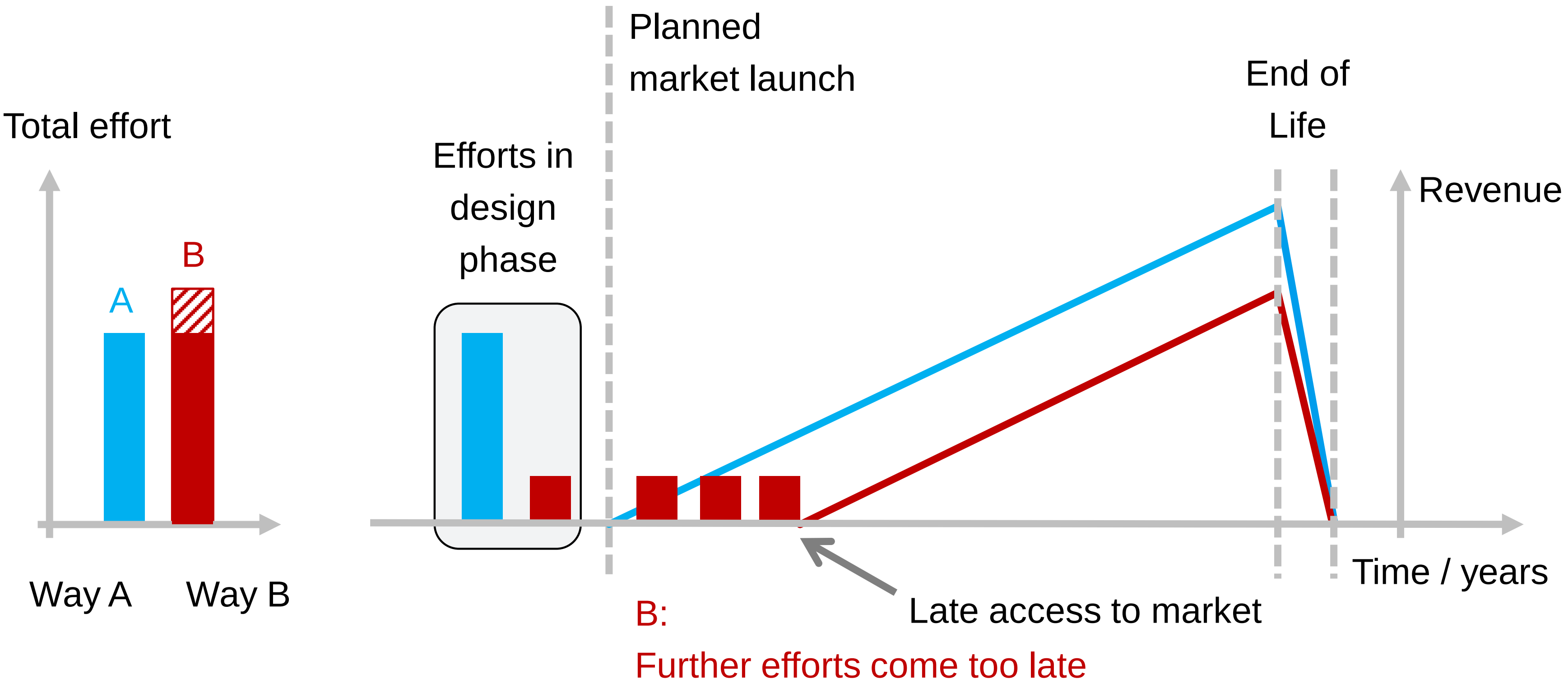


Final test:
apparatus to pick up the noise / interference / emission arriving outside the DUT

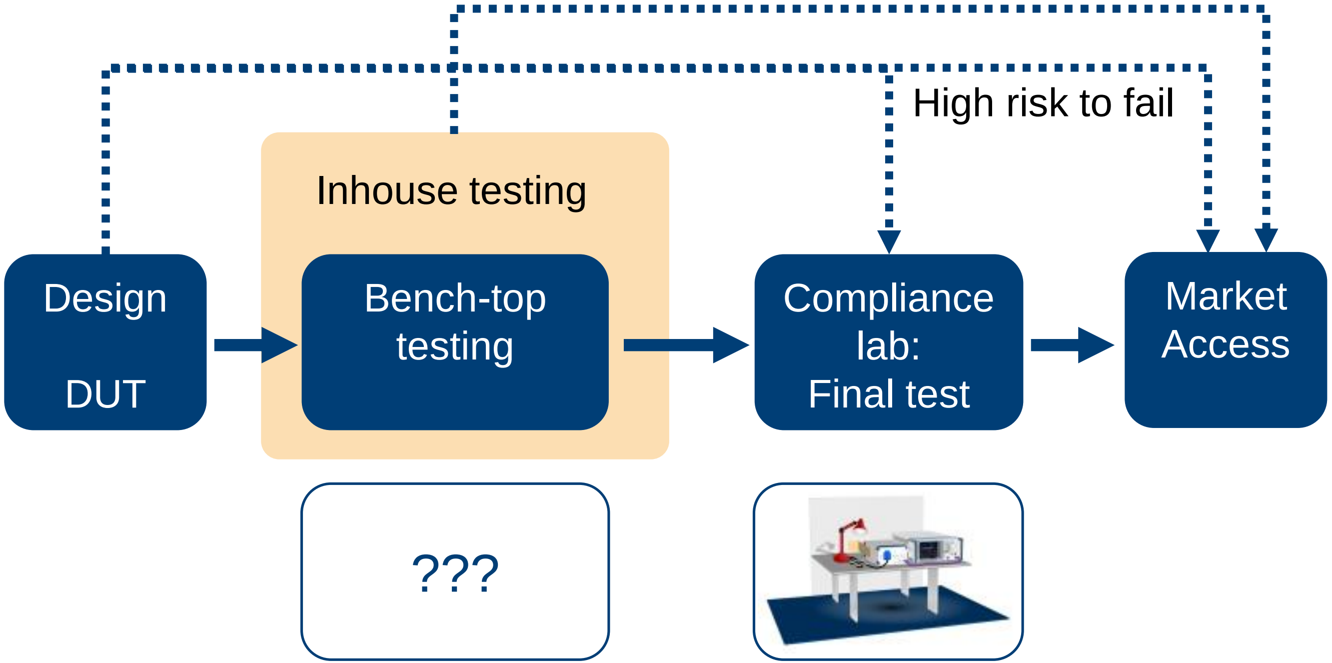
Consider to measure the EMI of DUT-internal parts already in an early stage of the design phase.
Did you evaluate the possibility of inhouse testing?
“EMC” as “swimming lane” in your project pipeline helps you to access the market in time.

Crucial for market launch and ROI

TIMING OF EMC EFFORTS



IMPORTANT MILE STONES



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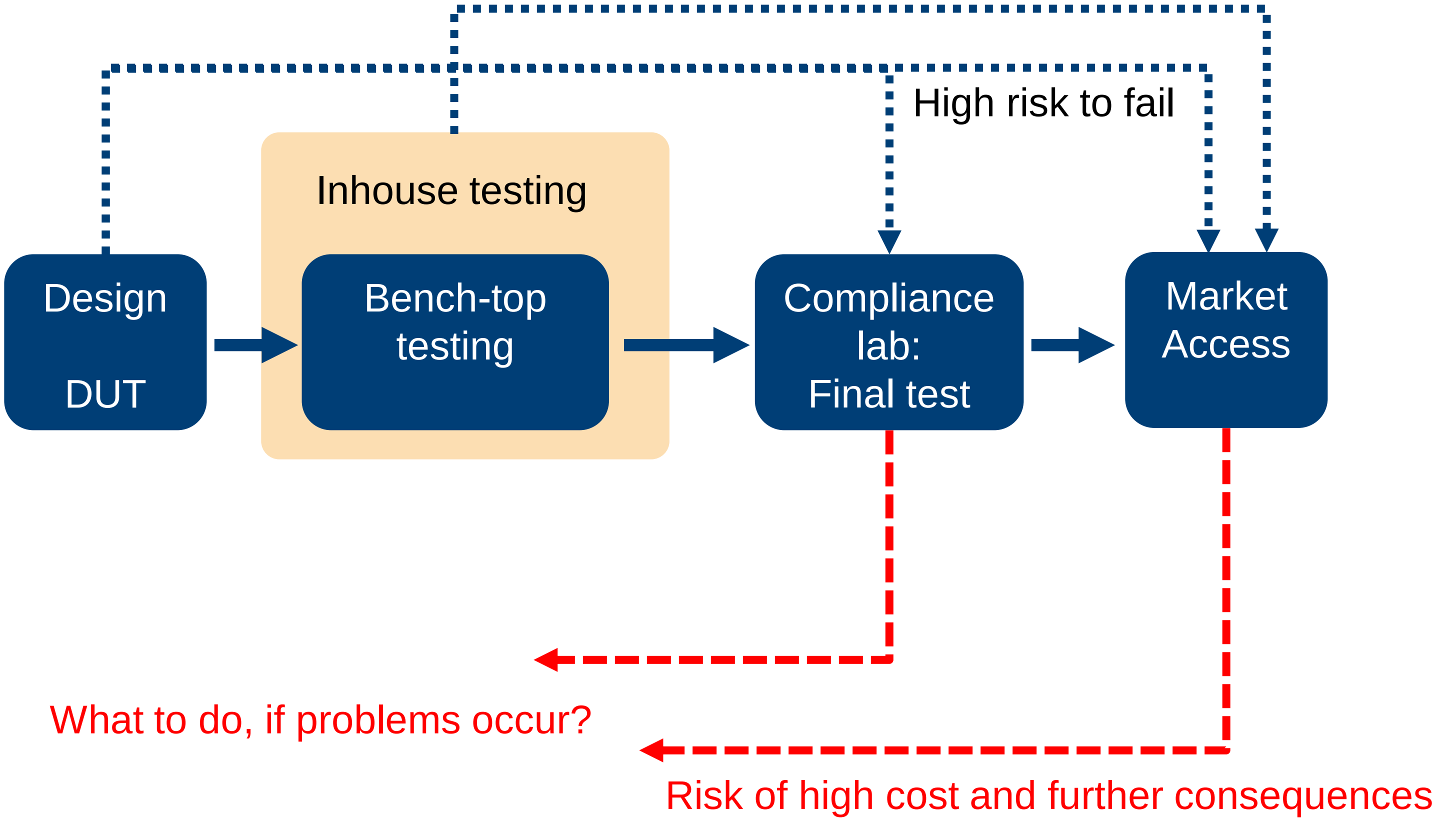
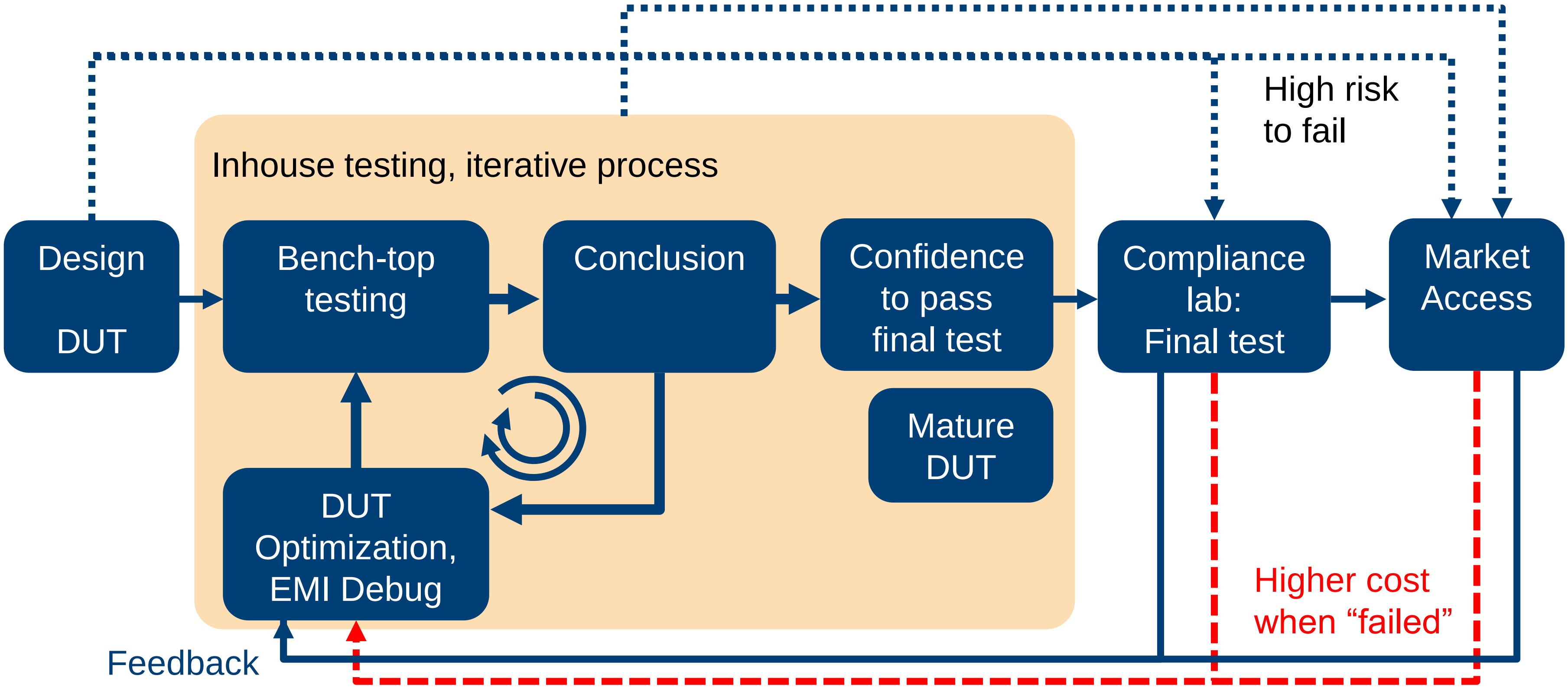
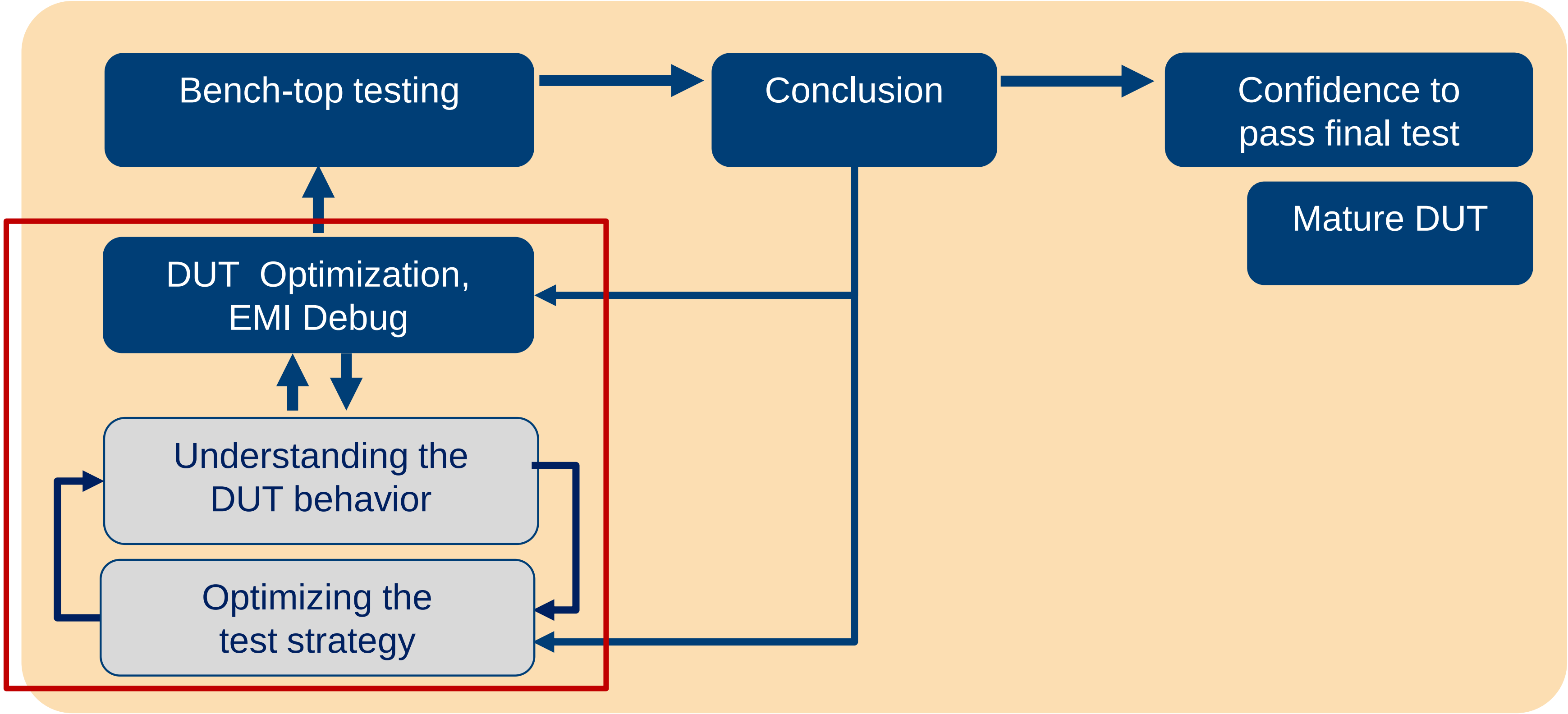


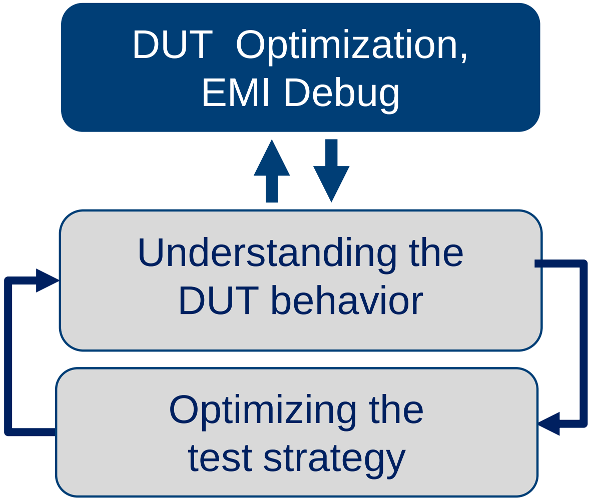
INHOUSE TESTING



DUT DESIGN OPTIMIZATION



KEY TO SUCCESSFUL DUT OPTIMIZATION



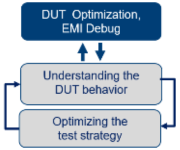
Understanding the..

- basic standard setup requirements
- standard test methods
- behavior of reference designs
- effects due to high dv/dt
- effects due to high di/dt
- ringing
- coupling effects
- typical use cases
- installation conditions:
  e.g. larger metal parts or cables nearby
- how to capture the interference
- etc.

Typically, the process to build up the required knowledge is an iterative process.

Optimizing the test strategy

TEST STRATEGY AND TECHNOLOGY



DUT View

Important hints on capturing and analyzing the DUT behavior

Locate

Finding the location of the emission.

Which PCB?
Which area on the PCB?
Which component?

Capture

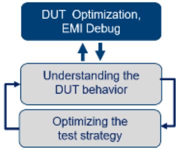
Catch the worst-case of the emission.

When does it occur?
Find the timing behavior of the emission.

Analyze

Which levels do occur?
Compare to a reference.
Has the recent DUT optimization been successful?
Is a further level reduction required?
Understand the DUT behavior in respect to emission occurrence and strength.
Is the DUT behavior related to the SMPS behavior?

TEST STRATEGY AND TECHNOLOGY



Probe View

Important criteria for the selection and the use of near field probes.

Locate

Use different sizes of probes:
Take larger probes for larger areas.
Take smaller probe for spotting smaller areas or for identifying the individual component.
There are small probes that allow the measurement on single lines on the PCB.

Capture

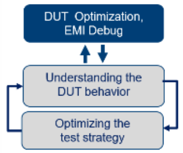
Keep the probe in a fixed position until you can be sure that the emission has occurred.

Change the orientation of the probe, especially when using a magnetic near field probe. Only the magnetic flux with its direction pointing through the loop aperture can be captured.

Analyze

Which probe is more sensitive? Depending on the coupling physics, one probe might be more appropriate for the search in specific PCB areas than the other. To quantify an emission level to a certain extent, you need to know the probe sensitivity. On top of that a certain level distance from the noise floor is required.

TEST STRATEGY AND TECHNOLOGY



Instrument View

Important criteria for the correct use of the available instrument technology.

Such technologies are...

- FFT-segment acquisition
- Sweep
- Stepped Scan

Locate

Depending on the available technology: multiple….
- sweeps,
- stepped scans,
- FFT-segment acquisitions

while different probe positions / orientations are selected

Capture

The complete spectral worst case information per probe position is required.

EMC standards follow a gapless spectrum measurement approach.
Rule of thumb:
each frequency point must see the interferer at least one time.
MaxHold mode can be of big help.

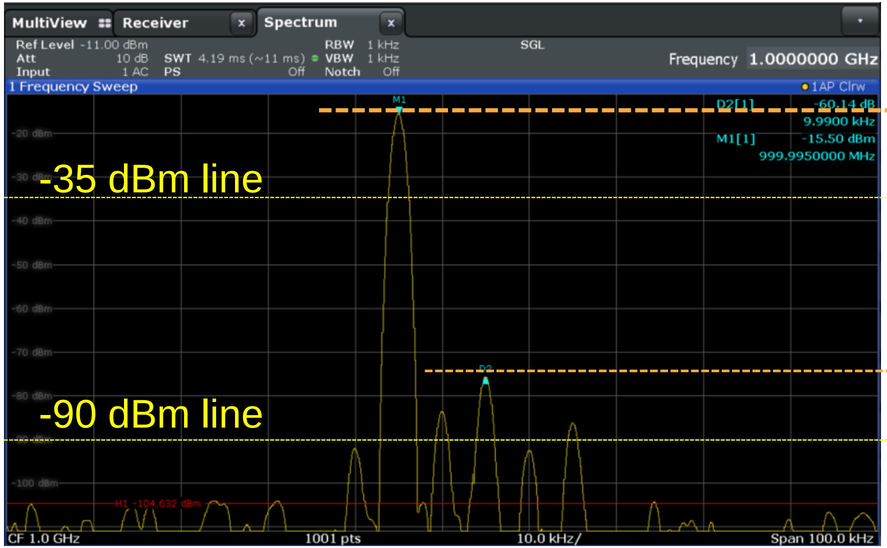
Analyze

Sweep or stepped scan: manual pre-analysis to find out the correct measurement time.

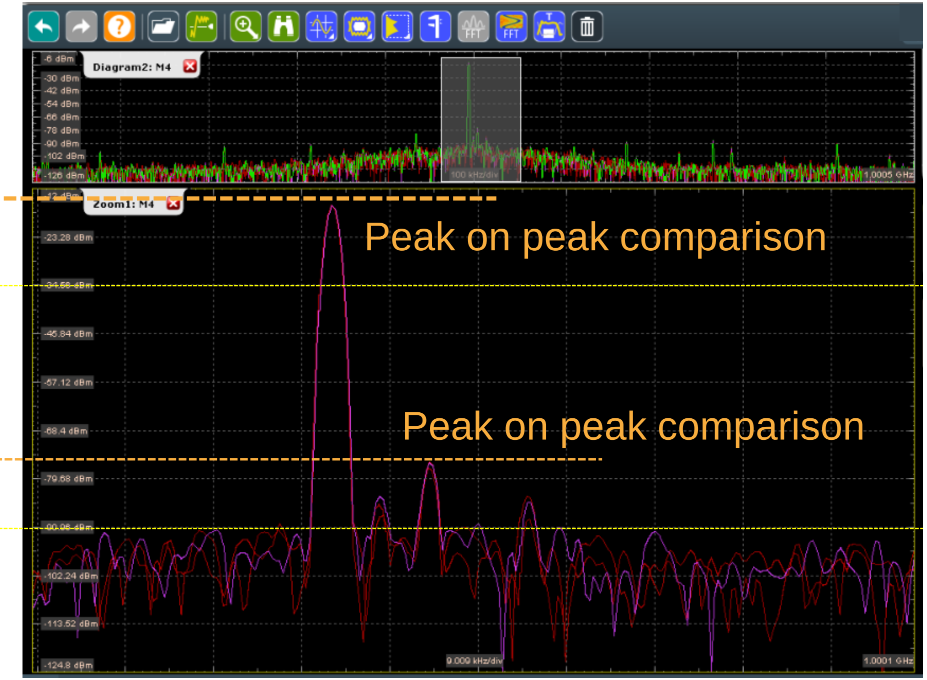
FFT-segment @ osci.: for recurrent interferers timing is easy to check.
Time-gated sections can be analyzed for their contributions to the emission spectrum
Examples:
- spectrum of ringing area
- area of high dv/dt or di/dt

COMPARISON OF RESULTS

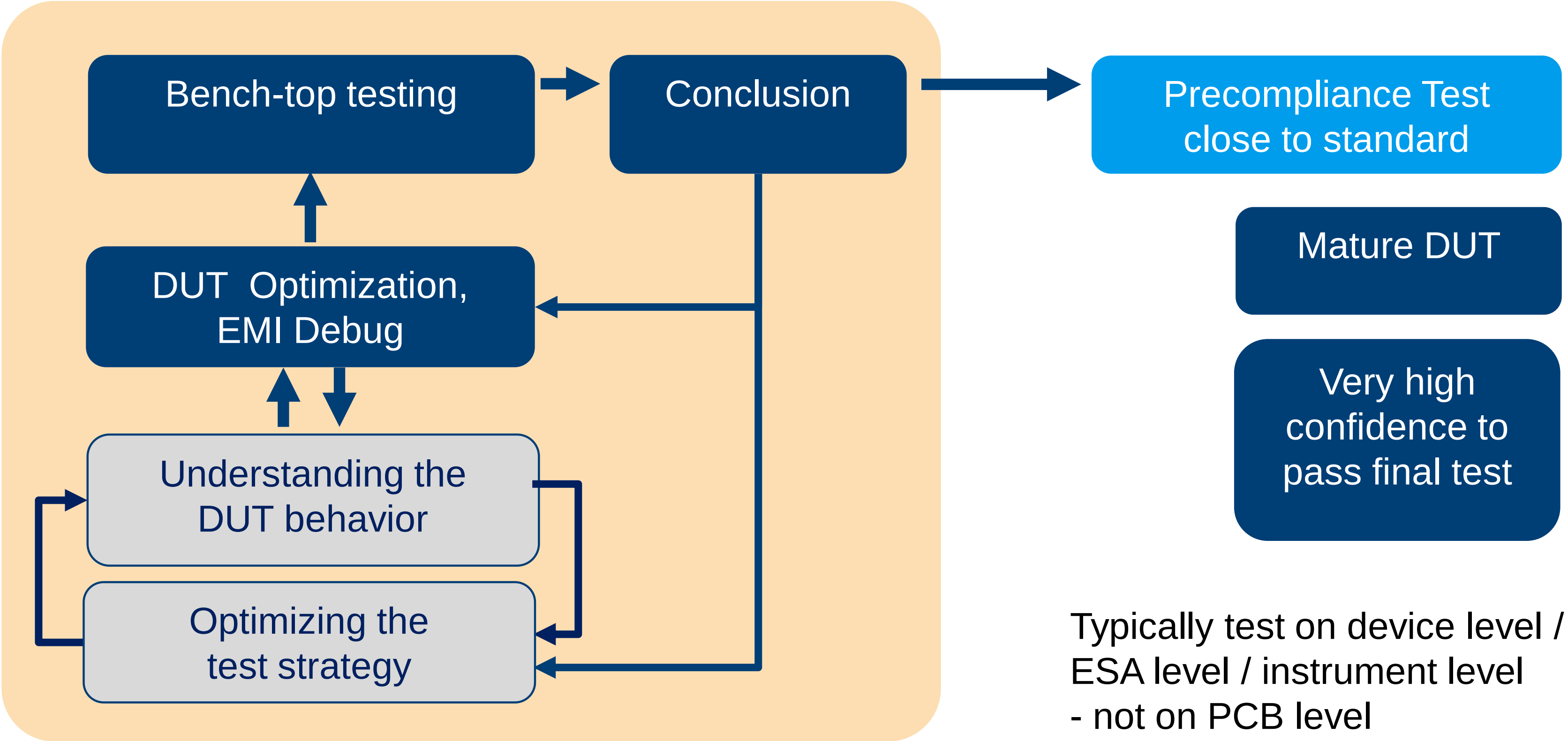
Preview-Result on Spectrum Analyzer



Spectrum view on Oscilloscope



ITERATIVE PROCESS + PRECOMPLIANCE TEST



Typically test on device level / ESA level / instrument level
- not on PCB level
”No surgery at the open heart”

PRECOMPLIANCE TEST

- Precompliance receiver or analyzer
  - Best effort for lower price
    - Compared to full-compliant receiver:
      - Restricted but useful selection of EMI detectors
      - less dynamic range available
      - intermittent interferers with very low pulse repetition rate can not be evaluated correctly
- Precompliance chamber
  - Reduced dimensions
  - Limited height scan or no height scan at all
  - Absorber quality only available for certain frequency range(s)
- Antenna
  - Antenna distance not large enough.
  - EUT size does not fit inside the area sensed by the antenna
  - Distance to ground, ceiling, walls is too small → influence on test results

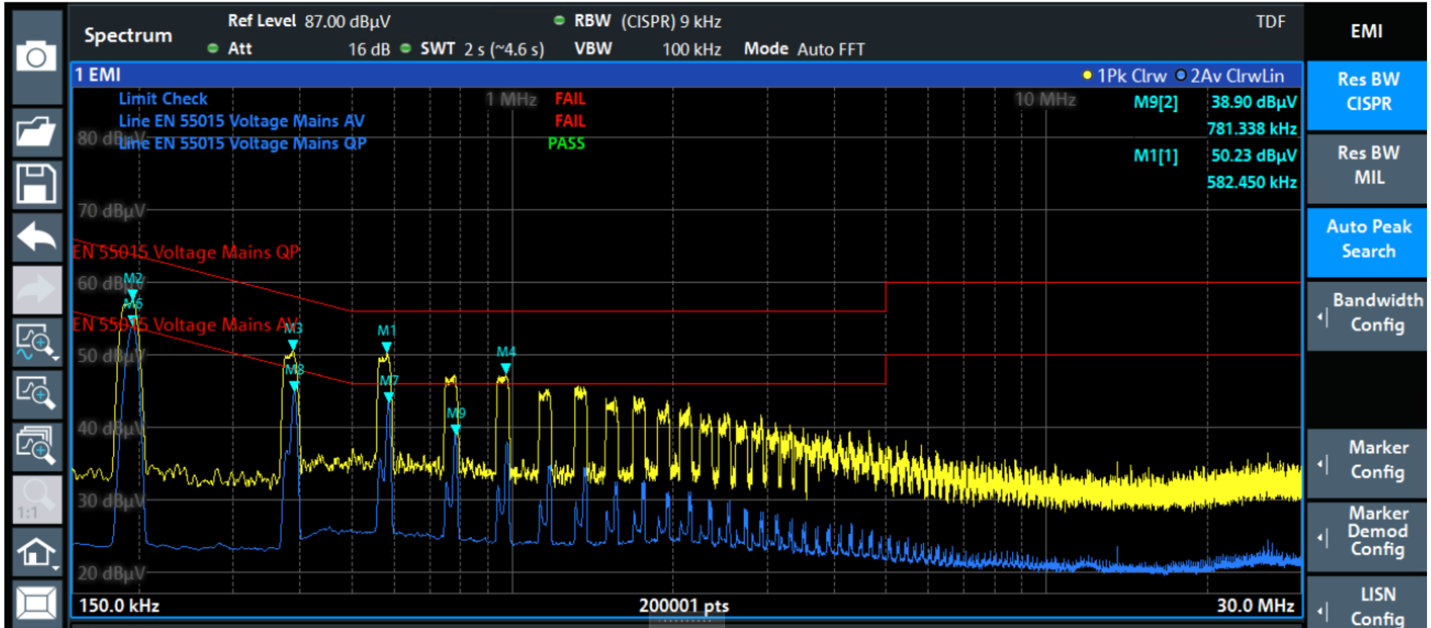
PRECOMPLIANCE TEST

- Test procedures as close as possible to the procedures described by applicable standards
  - Same look and feel; test automization partly possible
- Graphs, tables, peak lists, reporting as in the tests according to applicable standards
  - Logarithmic scaling of both, frequency axis and level axis of graphs
  - Level correction
    - Transducer factors like antenna factors can be regarded
  - Resolution Bandwidths according to CISPR (-6 dB)
- Limit lines
  - Handling of limit lines
  - Work with margins (distance to limits)
- Detectors
  - Quasipeak Detector available.
- Stepped scan or carefully defined sweeps
  - Test time per frequency point
  - Number of frequency points in the instrument (either fixed or customizable)

Testing close to standard

PRECOMPLIANCE TEST

Screenshot from spectrum analyzer FPL with EMI Firmware FPL-K54

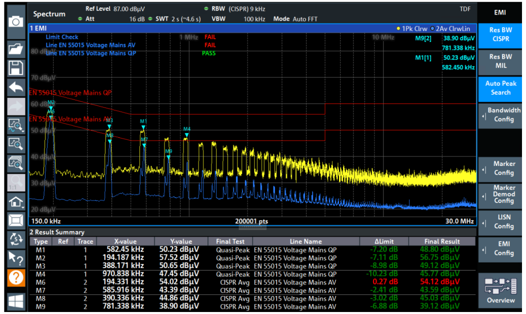


2 Result Summary

Type	Ref	Trace	X-value	Y-value	Final Test	Line Name	ΔLimit	Final Result
M1		1	582.45 kHz	50.23 dBµV	Quasi-Peak	EN 55015 Voltage Mains QP	-7.20 dB	48.80 dBµV
M2		1	194.187 kHz	57.52 dBµV	Quasi-Peak	EN 55015 Voltage Mains QP	-7.11 dB	56.75 dBµV
M3		1	388.171 kHz	50.65 dBµV	Quasi-Peak	EN 55015 Voltage Mains QP	-8.98 dB	49.12 dBµV
M4		1	970.838 kHz	47.45 dBµV	Quasi-Peak	EN 55015 Voltage Mains QP	-10.23 dB	45.77 dBµV
M6		2	194.331 kHz	54.02 dBµV	CISPR Avg	EN 55015 Voltage Mains AV	0.27 dB	54.12 dBµV
M7		2	585.916 kHz	43.39 dBµV	CISPR Avg	EN 55015 Voltage Mains AV	-2.41 dB	43.59 dBµV
M8		2	390.336 kHz	44.86 dBµV	CISPR Avg	EN 55015 Voltage Mains AV	-3.02 dB	45.03 dBµV
M9		2	781.338 kHz	38.90 dBµV	CISPR Avg	EN 55015 Voltage Mains AV	-6.88 dB	39.12 dBµV

PRECOMPLIANCE TEST

Spectrum analyzer
FPL with EMI Firmware FPL-K54



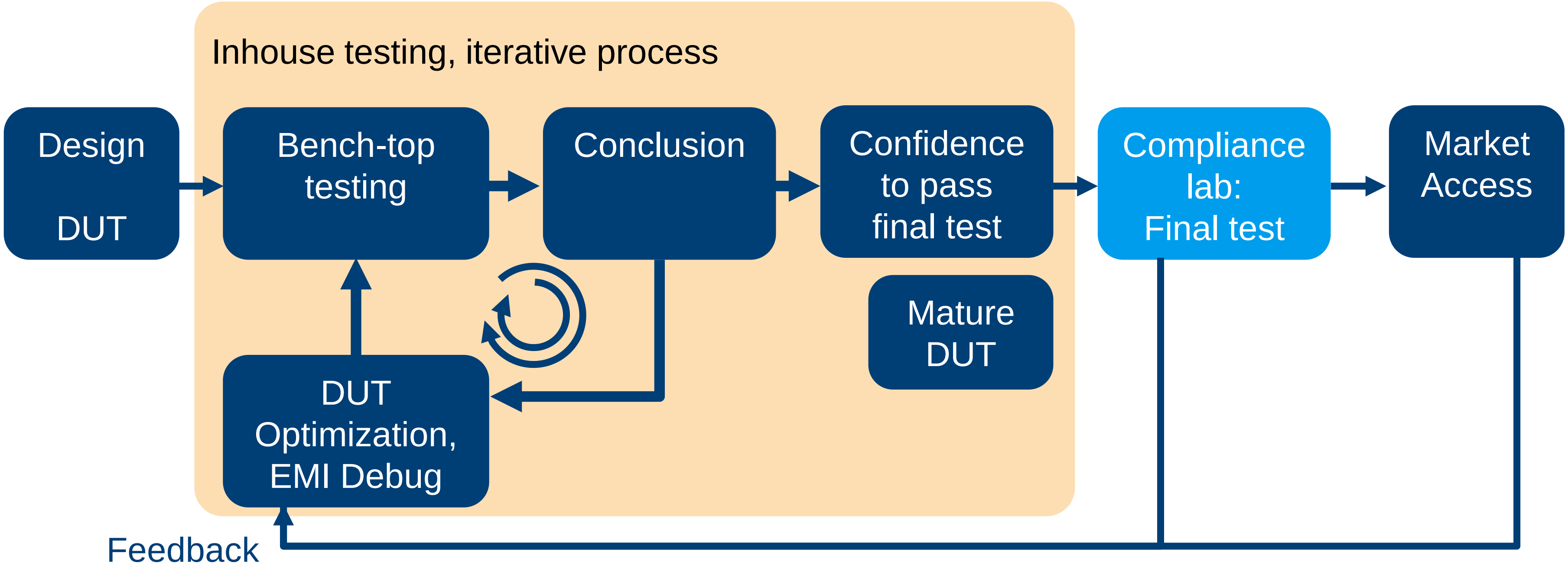
- Find, classify and eliminate interferences!
- EMI Resolution Bandwidths
- EMI detectors in line with CISPR
  - Quasi Peak
  - CISPR Average
  - CISPR RMS
- Measurement markers for evaluation
  - Link markers to EMI detectors
- Wide selection of limit lines
- Choose between linear or logarithmic scale of frequency axis!

PRECOMPLIANCE TEST

Spectrum analyzer
FPL with EMI Firmware FPL-K54

Specification **selected data for FPL1007**	**R&S®FPL1000** **spectrum analyzer**
Frequency range	5 kHz to 7.5 GHz
Screen	1280 x 800 pixel, multi-touch
Battery operation	Optional
12 V/24 V DC operation	Optional
Internal generator	optional
Analysis bandwidth	10 MHz standard, 40 MHz opt.
DANL at 1 GHz preamp = OFF	< –149 dBm (–152 dBm typ.)
DANL at 1 GHz preamp = ON	< –163 dBm (–166 dBm typ.)
SSB phase noise at 1 GHz (10 kHz offset)	< –108 dBc/Hz typ.
SSB phase noise at 1 GHz (1 MHz offset)	< –135 dBc/Hz typ.
Total level measurement uncertainty	< 0.3 dB (@ 50 MHz)
Third-order intercept point at 1 GHz	> 15 dBm
Weight including battery option	Around 7.3 kg (around 16 lbs)

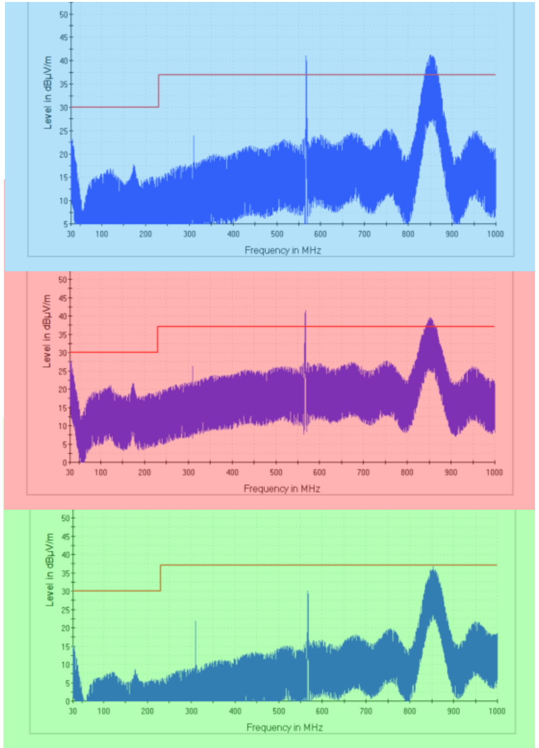
FINAL TEST


Inhouse testing, iterative process
Design
DUT
Bench-top testing
Conclusion
Confidence to pass final test
Compliance lab: Final test
Market Access
Mature DUT
DUT Optimization, EMI Debug
Feedback

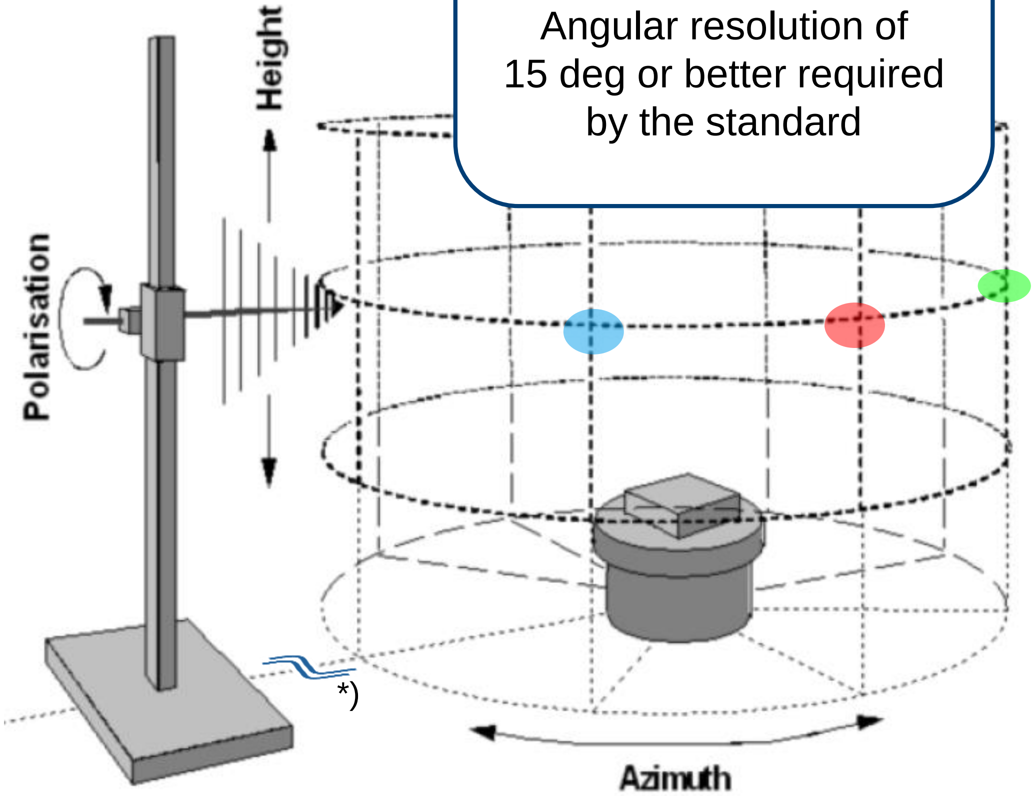
FINAL TEST

Radiated emission measurements in a standard-compliant test lab

All cylinder grid points require a complete preview result.
Angular resolution of 15 deg or better required by the standard



Example previews of 3 selected grid points.



*) The distance d has been shortened for this figure .

Testing according to standard

FINAL TEST

Radiated emission measurements in a standard-compliant test lab

- ► Receivers compliant to international EMI standard CISPR 16-1-1
  - Specified **6 dB bandwidths**, **detectors** (Quasi-Peak, CISPR-Average, RMS-Average)
  - High **dynamic range** required
    - Repetition frequency of pulses down to single pulse
  - Measurement Applications (**Click Rate, (Multi) APD, Bargraph**)
  - **Limit Line** checking and **Transducer correction**

R&S ESW

R&S ESR

INFORMATION EXCHANGE AND LEARNING

Inhouse testing

Table

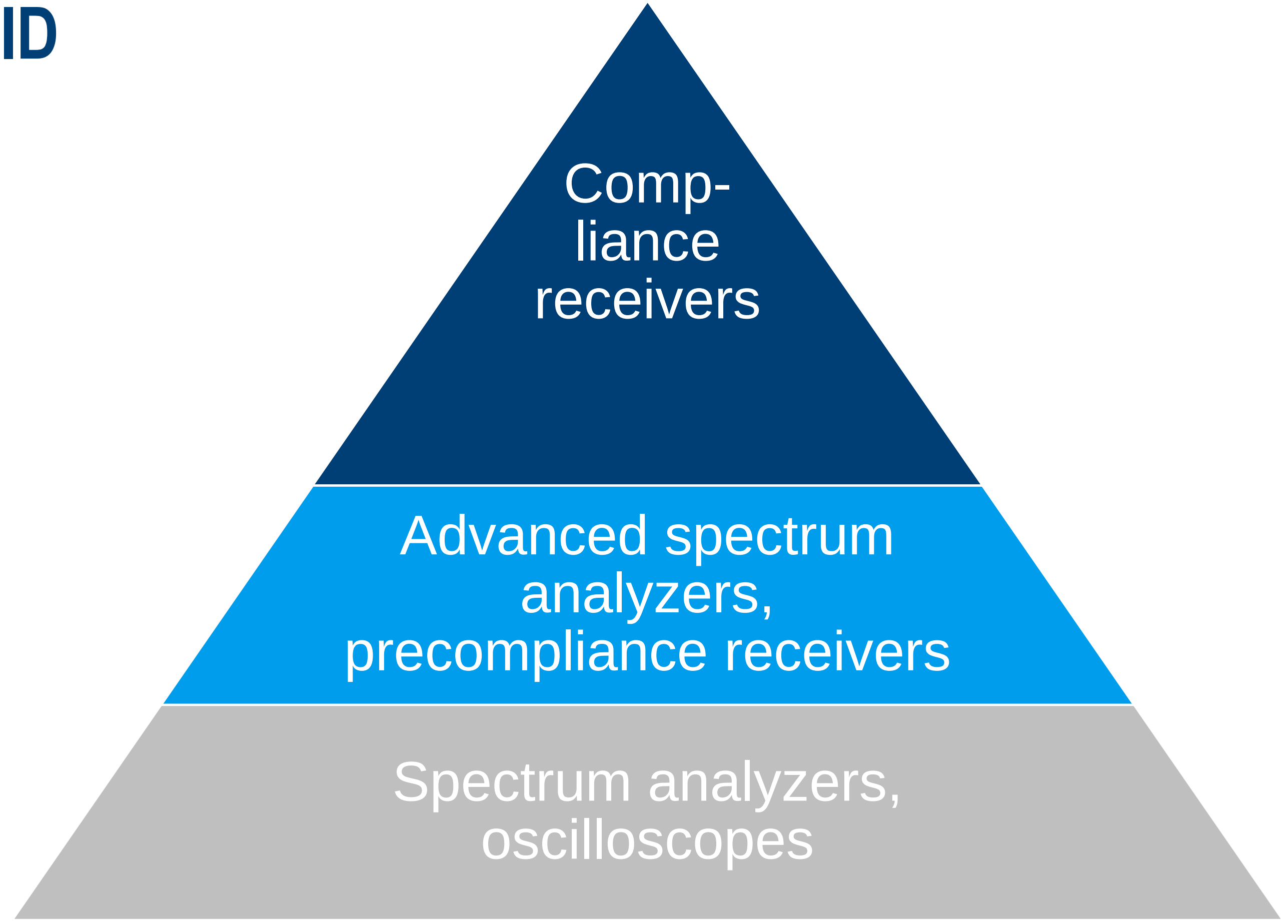
Frequencies	Own results from R&D	Maximum values taken from the test lab's report

Standard-compliant test lab

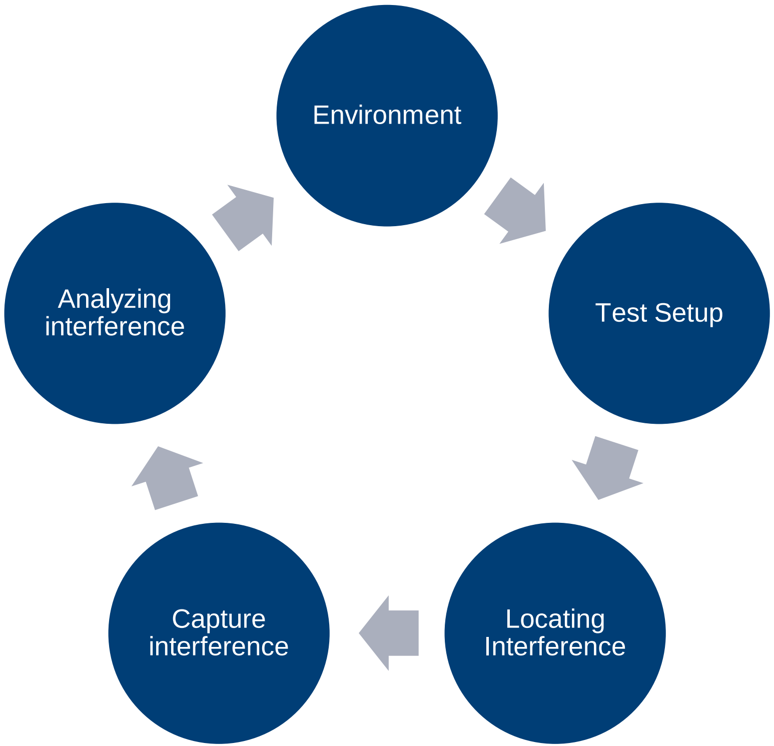
Frequencies of interest derived from the tests in the own premises are put in a list and handed over to the test lab e.g. for searching the maximum level e.g. over the entire cylinder grid.

Do not forget to inform your findings about the required measurement time!

DEVICE PYRAMID



OPTIMIZING THE TEST STRATEGY



ANNEX

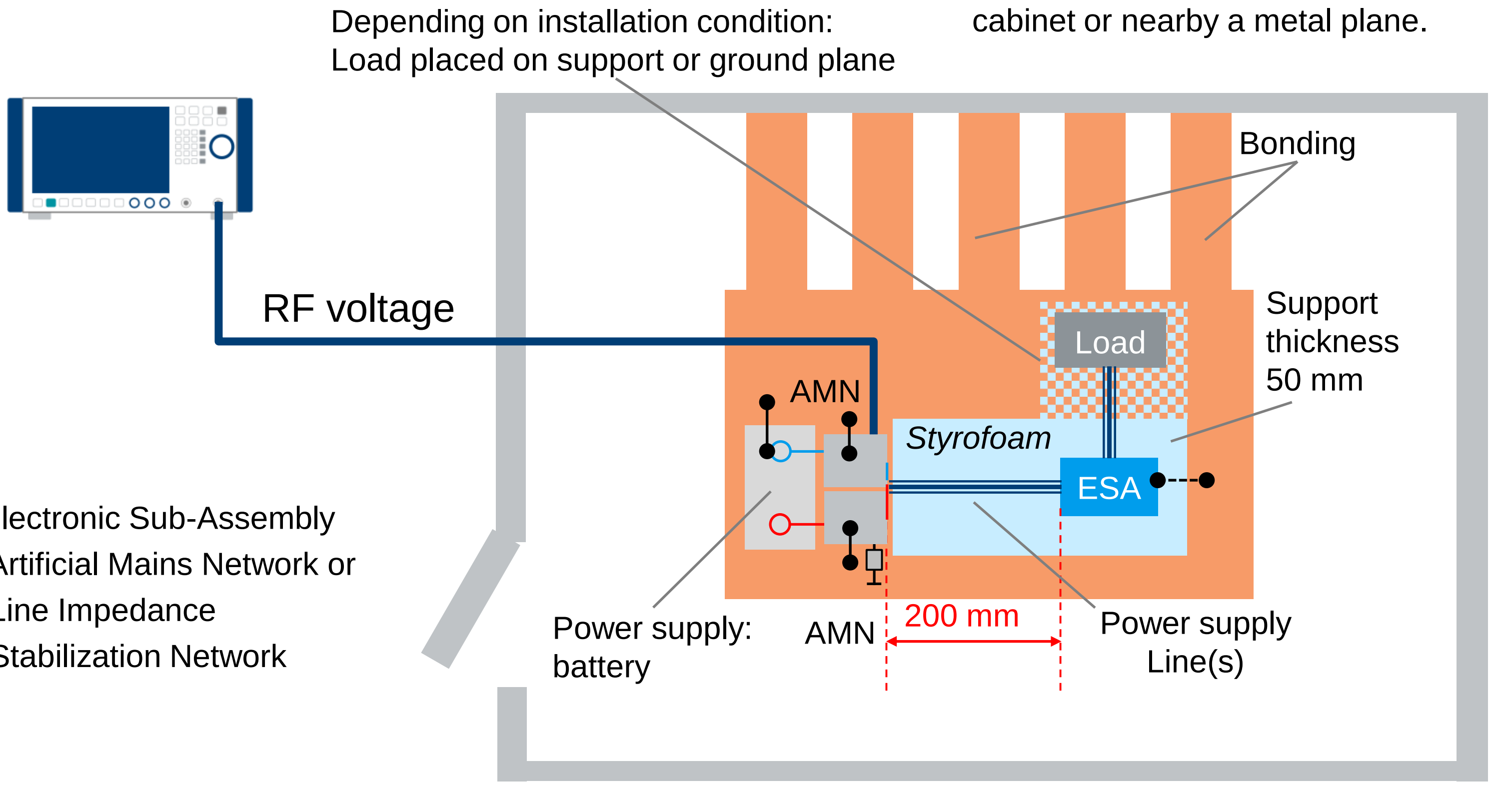
► Practical Hints

UNDERSTANDING…

- Installation conditions and test setups

CISPR25 SETUP

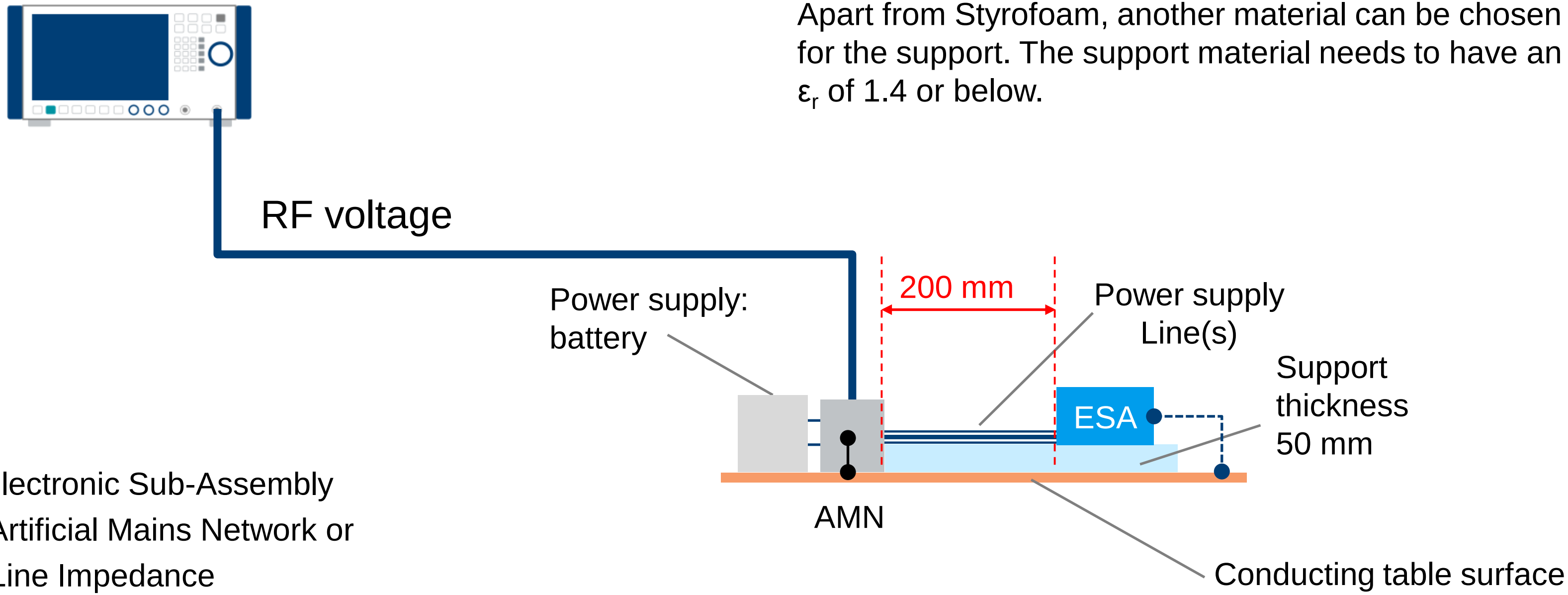
The metal ground plane on the table simulates a metal chassis in the vicinity of the DUT.
This approach could be reused for optimizing circuit boards intended for the use inside a metal cabinet or nearby a metal plane.



ESA = Electronic Sub-Assembly
AMN = Artificial Mains Network or
LISN = Line Impedance Stabilization Network

CISPR25 SETUP: SIDE VIEW

Apart from Styrofoam, another material can be chosen for the support. The support material needs to have an ε_r of 1.4 or below.



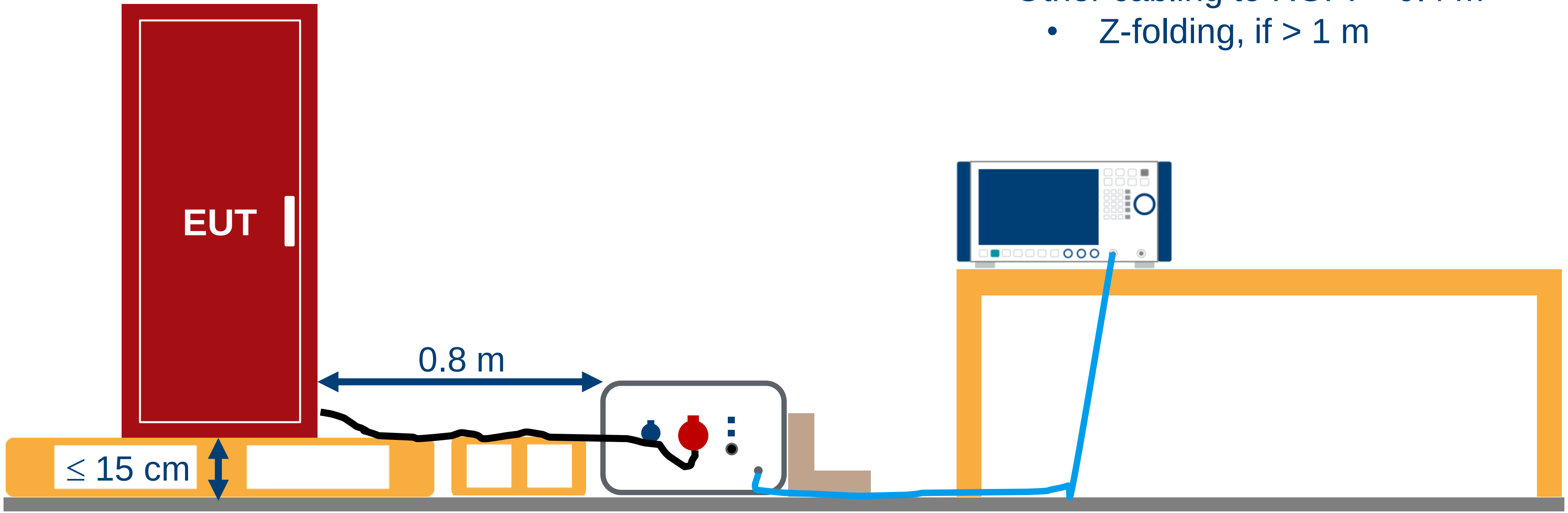
ESA = Electronic Sub-Assembly

AMN = Artificial Mains Network or

LISN = Line Impedance Stabilization Network

CONDUCTED | FLOOR-STANDING

- EUT insulated from ground plane
  - insulation up to 15 cm
- EUT to AMN: 0.8 m
- Impedance AMN to RGP
  - < 10 Ω @ 30 MHz
- Other cabling to RGP: > 0.4 m
  - Z-folding, if > 1 m



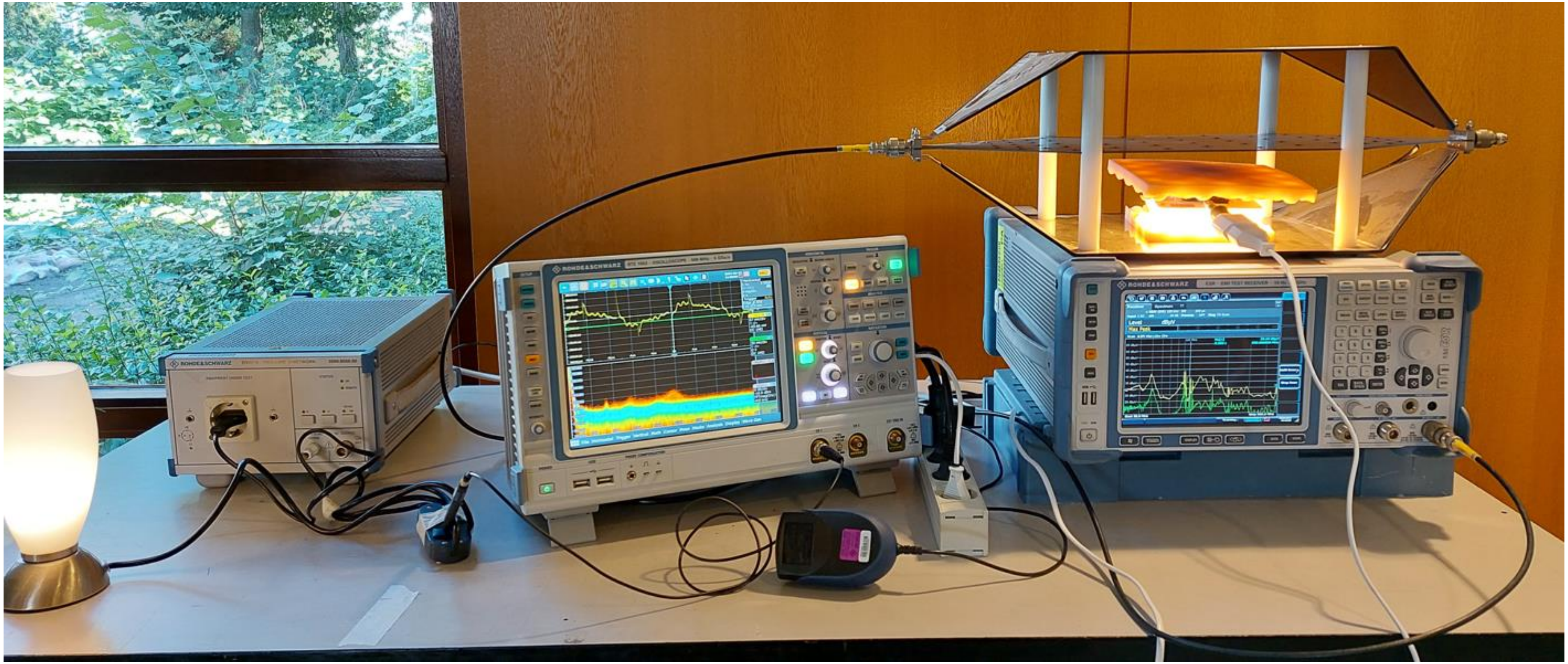
Reference ground plane (RGP): 2 m x 2 m min. Shall extend EUT boundaries at least 50 cm

UNDERSTANDING…

- Different possibilities to catch / touch / transduce the interference signal

EXAMPLES OF DIFFERENT TRANSDUCERS

LISN and small TEM cell



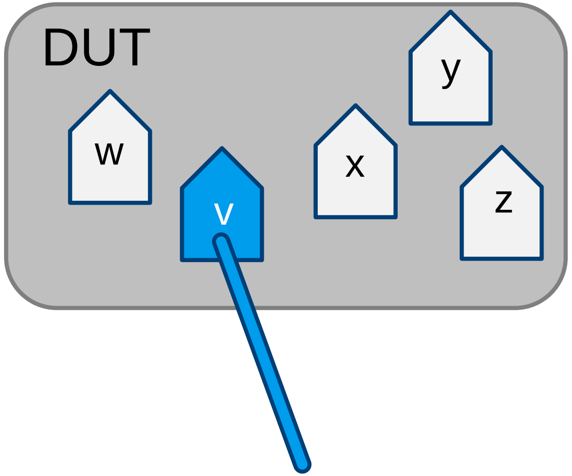
EXAMPLES OF DIFFERENT TRANSDUCERS

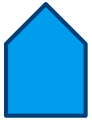
Near field probe tied to a dimmer circuit

ANNEX FOR ETTENHEIM

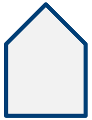
ROHDE&SCHWARZ

Make ideas real





Near field probe position has to be kept during the sweep or scan or FFT-segment acquisition time.



Other probe positions of interest (example)

DUT Device under test. The DUT can be for example circuit sections on a PCB.

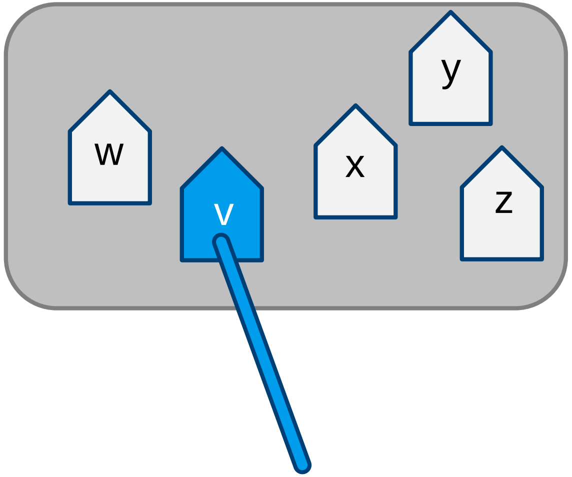
Optimizing the test strategy

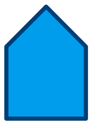
FINDING THE WORST CASE UNDER TYPICAL OPERATION CONDITION

FINDING THE WORST CASE

Is one test point per probe sufficient?

Device under test
e.g. PCB, circuit area





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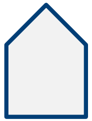
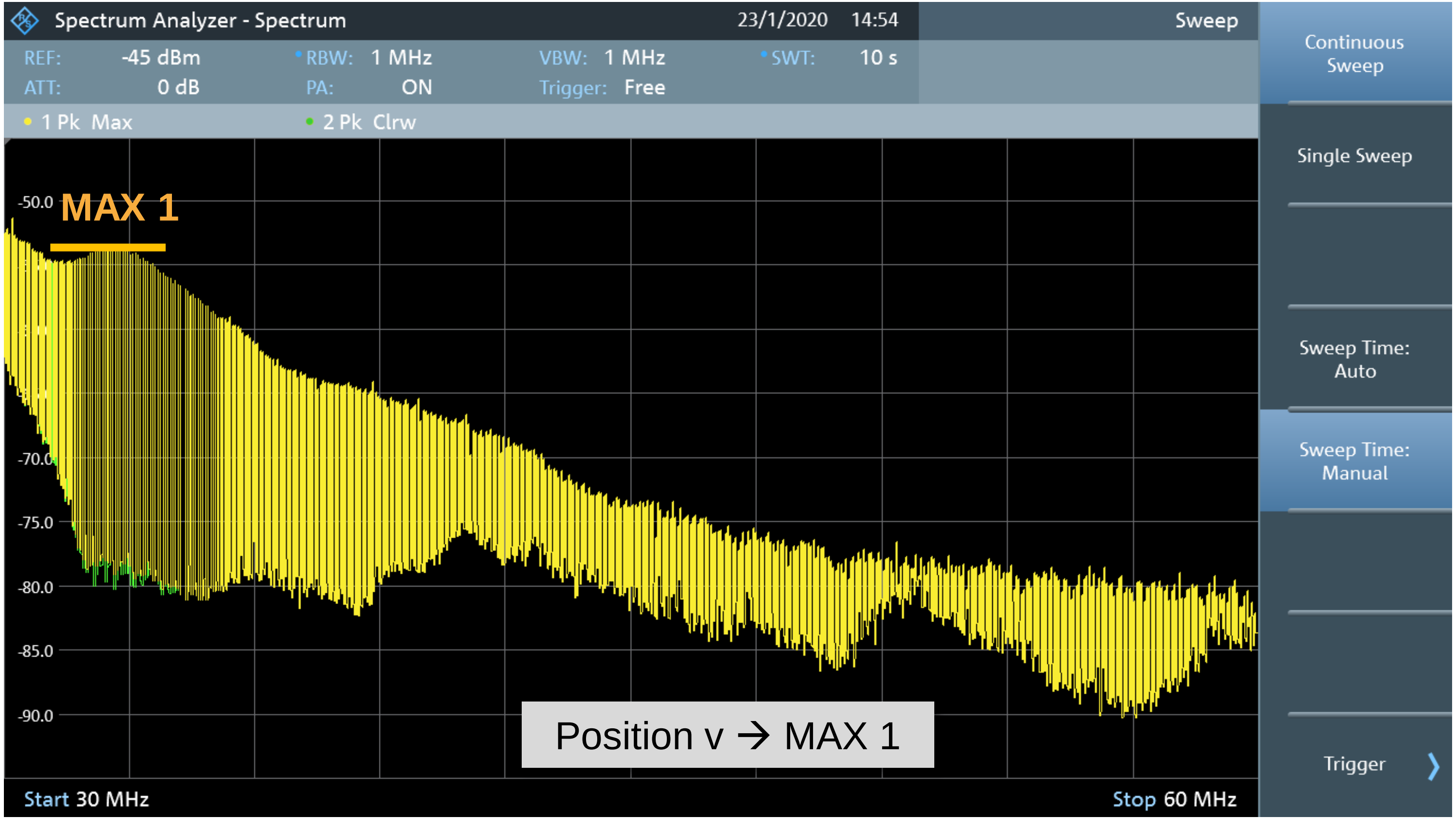


Other probe positions of interest (example)

Example positions *v, w, x, y, z*
per position / probe orientation
one complete set of information
regarding worst level over frequency
is needed!

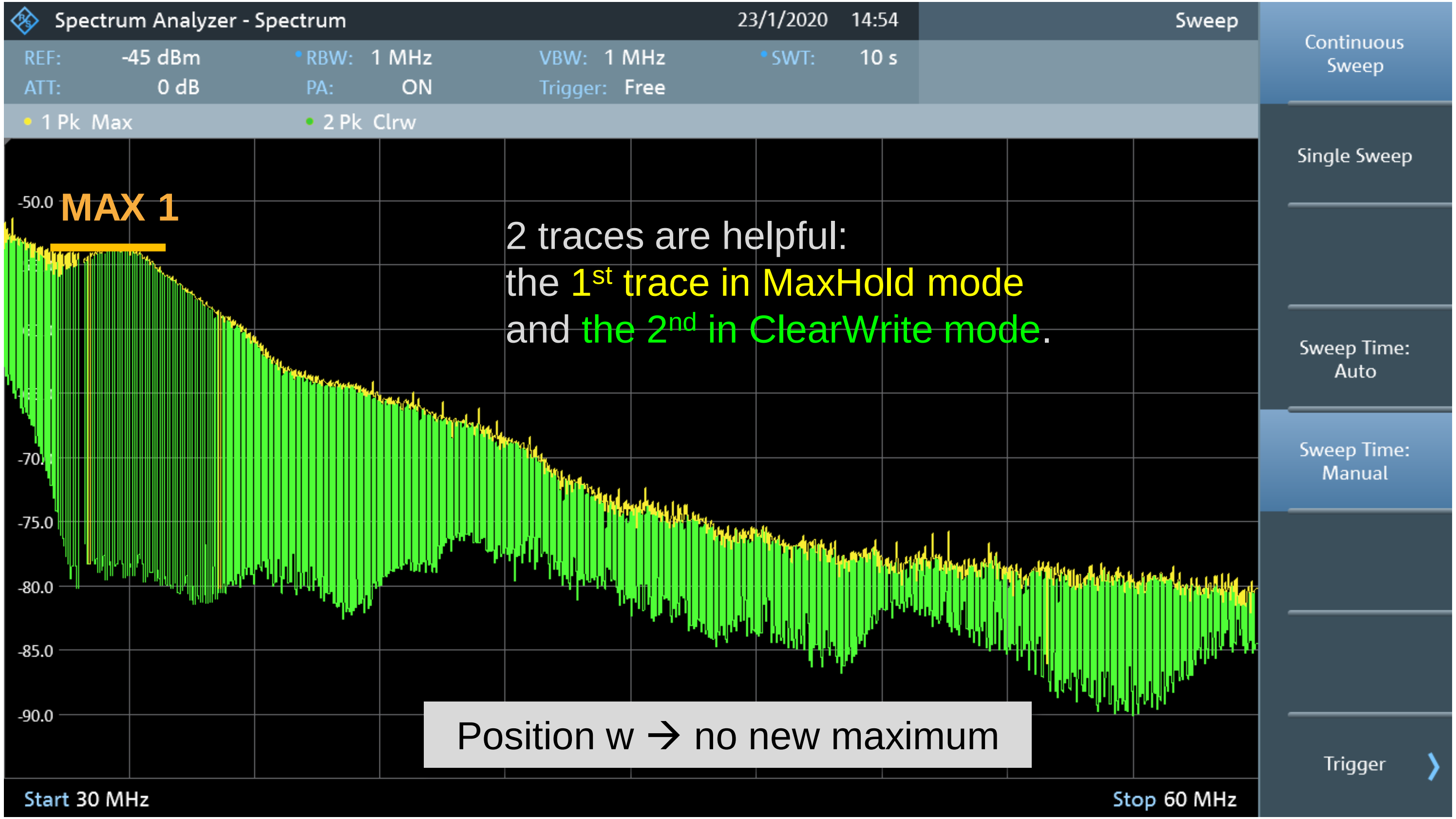
FINDING THE WORST CASE

Nearfield probe fixed to position v



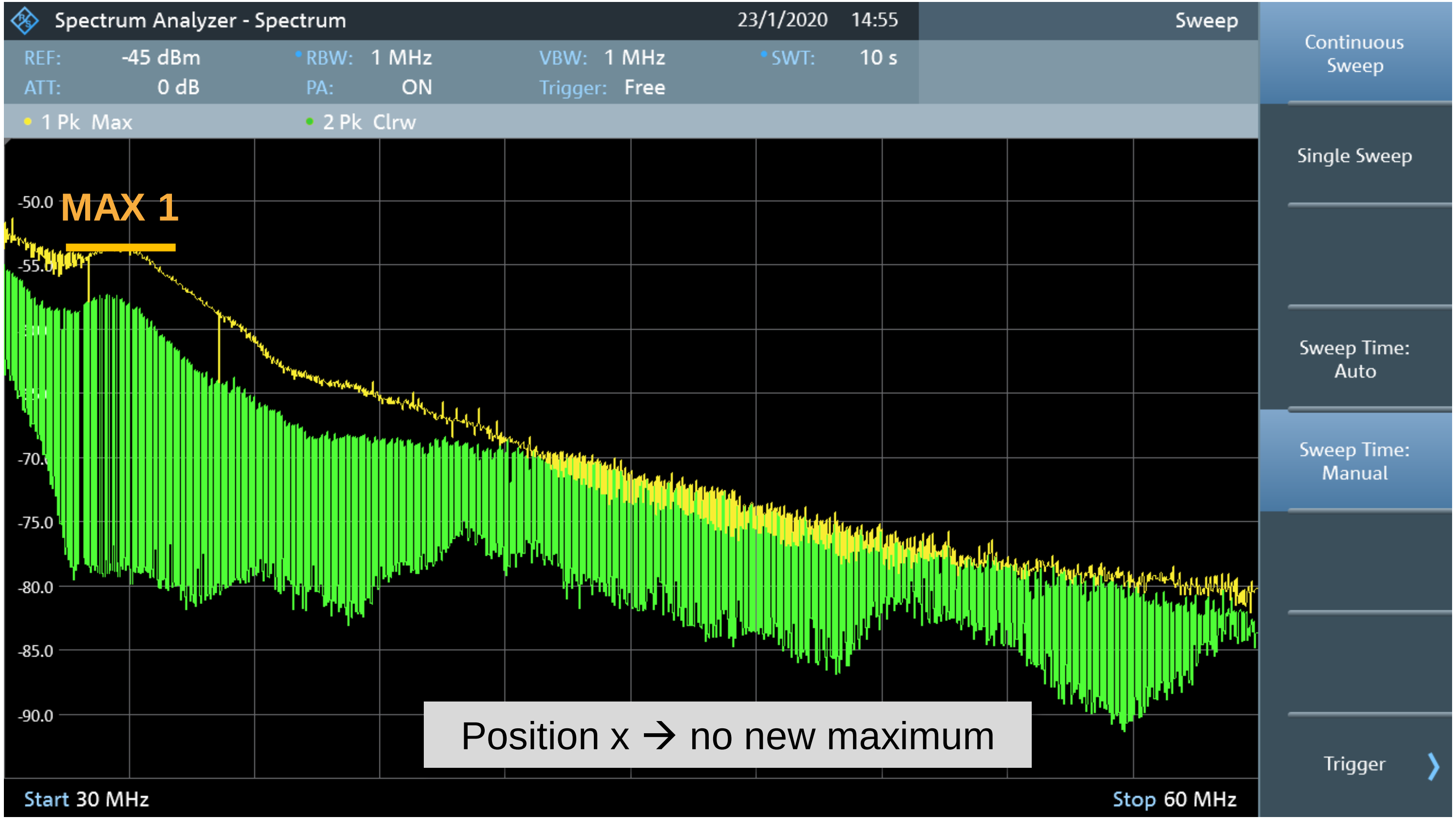
FINDING THE WORST CASE

Nearfield probe fixed to position w



FINDING THE WORST CASE

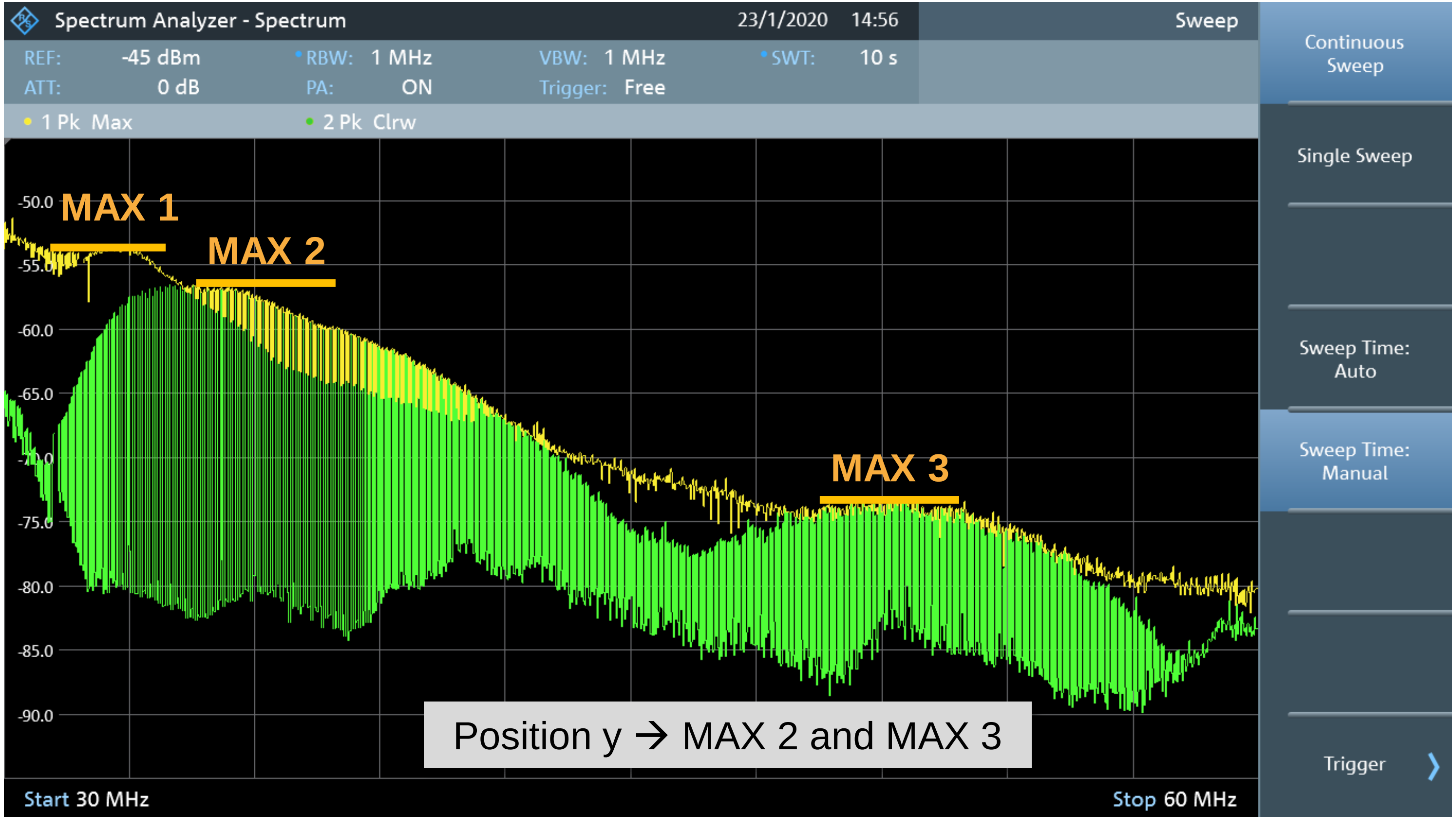
Nearfield probe fixed to position x



Position x → no new maximum

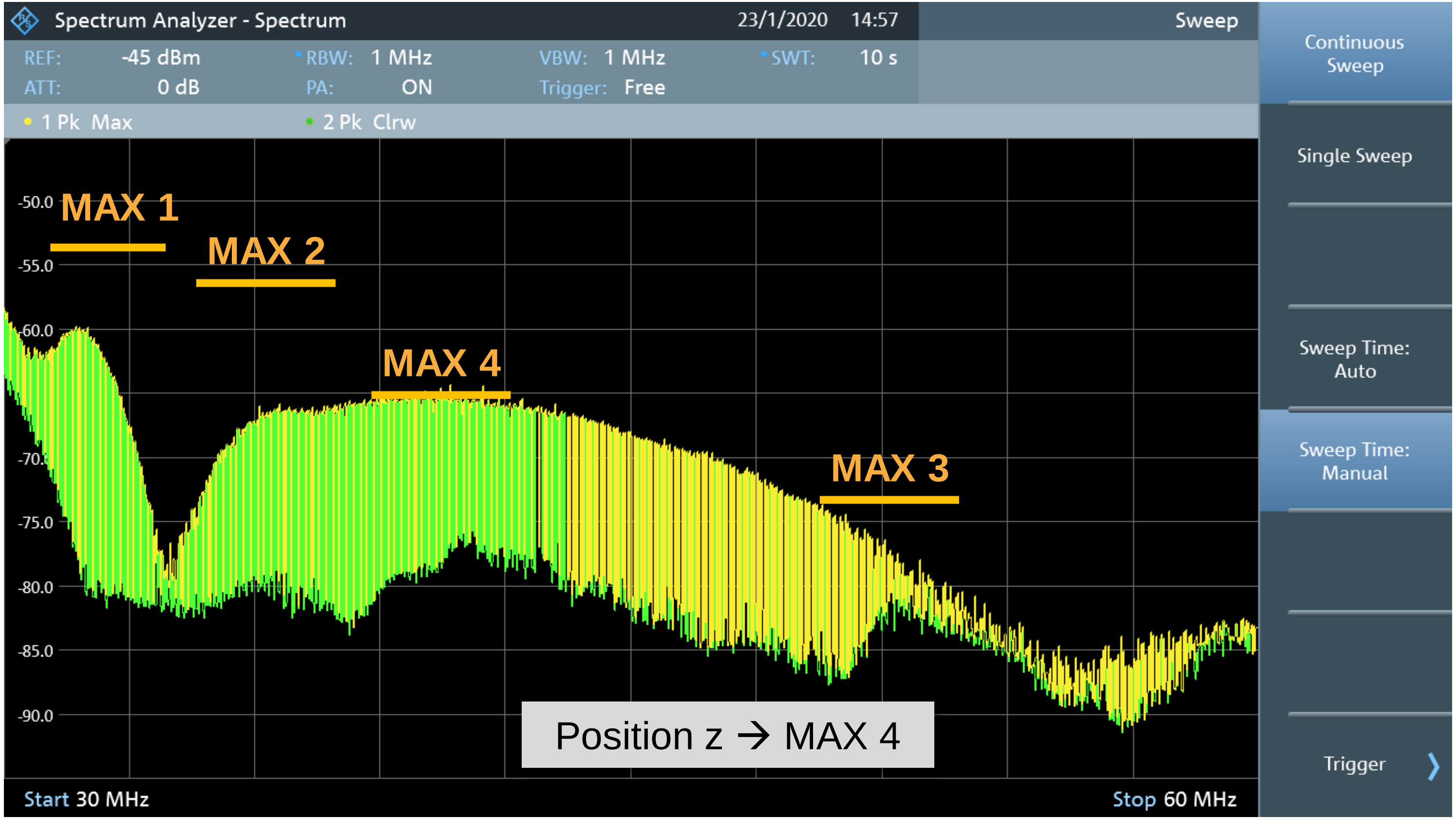
FINDING THE WORST CASE

Nearfield probe fixed to position y



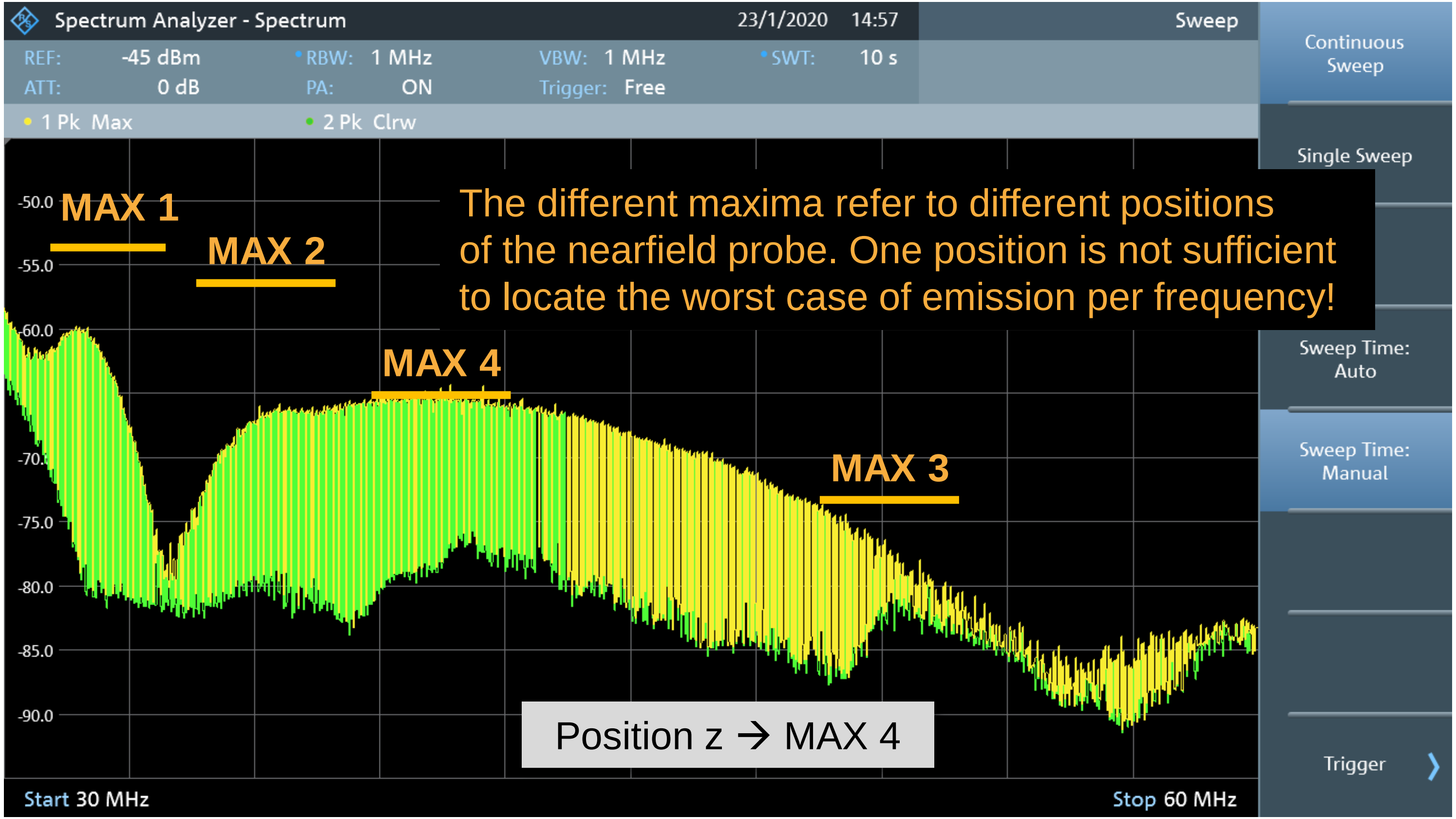
FINDING THE WORST CASE

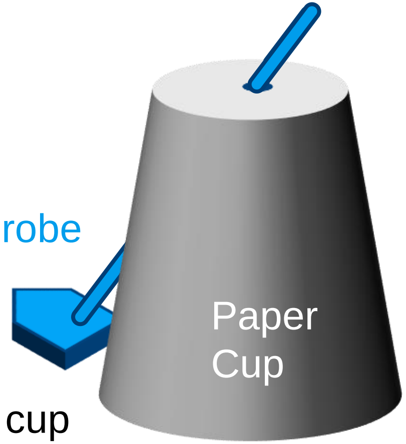
Nearfield probe fixed to position z



FINDING THE WORST CASE

Nearfield probe fixed to position z





Fixing example: paper cup

Different possibilities to fix a near field probe

- plastic tripod,
- paper cup,
- tape
- cable tie
- etc.

FIXING THE PROBE

FIXING THE PROBE – WHY?

Key word in the standard:
"no change in the set-up"

Understanding the requirement given by the applicable test method standard:
CISPR 16-2-1, CISPR 16-2-2 and CISPR 16-2-3

”Determination of the required measurement time”

→ applicable to EUT* with intermittent emission character

Can be done by comparing the max-hold with … clear/write function ….
and observing the emission for a period of 15 s.
During this period…
- no change of lead should be made → CISPR 16-2-1
- no change in the set-up should be made (no movement of absorbing clamp) → CISPR 16-2-2
- no change in the set-up should be made (no change of lead in case of conducted emission, no movement of absorbing clamp, no movement of turntable or antenna in case of radiated emission) → CISPR 16-2-3

*) EUT = Equipment Under Test; corresponds to DUT + cable section(s)

FIXING THE PROBE

Key word in the standard:
"no change in the set-up"

Probe fixing example: paper cup

For this PC the touch panel is one window for unintended emissions.

FIXING THE PROBE

Key word in the standard:
"no change in the set-up"

Probe fixing example: cable tie

Nearfield probe with spade shape fixed on dimmer control circuit case by means of a cable tie.

Optimizing the test strategy

WORST CASE OPERATING MODE

Find out in which operating the EUT does show the highest emission

EMISSION PER OPERATING MODE

Table lamp with touch dimmer.

EMISSION PER OPERATING MODE

Table lamp with touch dimmer.

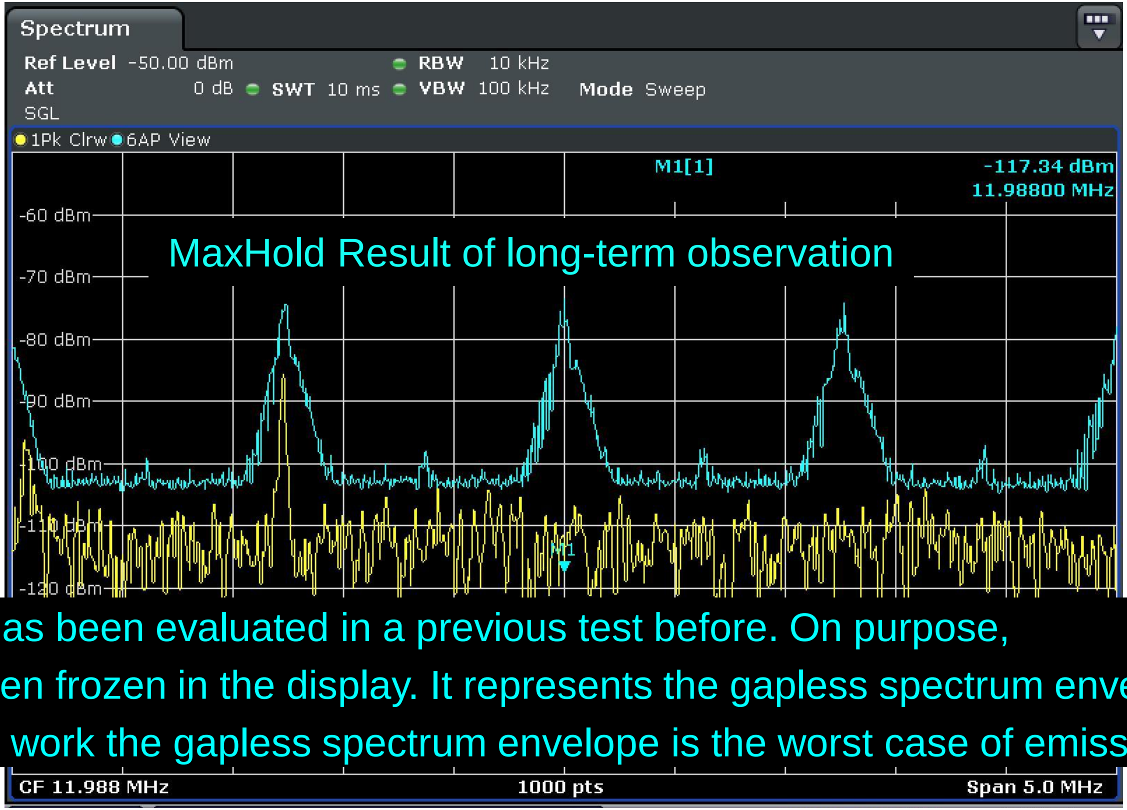
Optimizing the test strategy

FINDING THE WORST CASE

Detecting the gapless spectrum envelope

FINDING THE WORST CASE

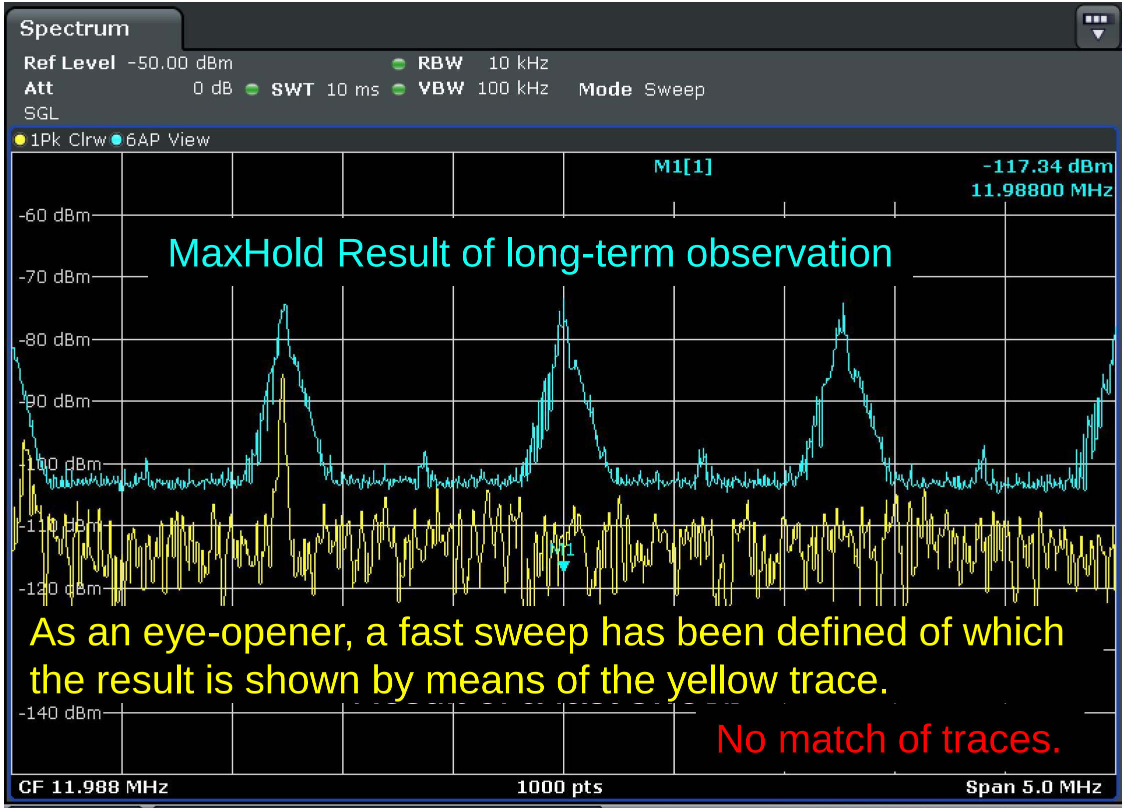
Sweep Time = 10 ms



The blue trace has been evaluated in a previous test before. On purpose, the trace has been frozen in the display. It represents the gapless spectrum envelope very well. For the practical work the gapless spectrum envelope is the worst case of emission.

FINDING THE WORST CASE

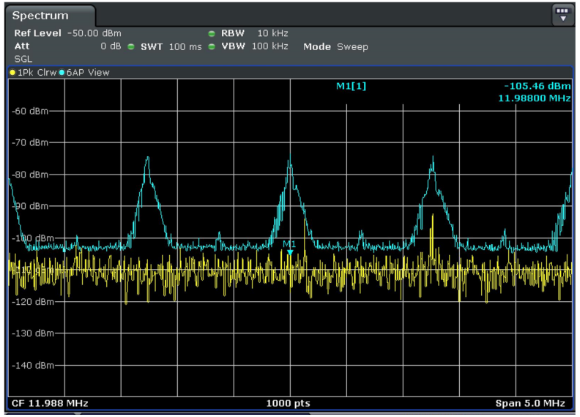
Sweep Time = 10 ms



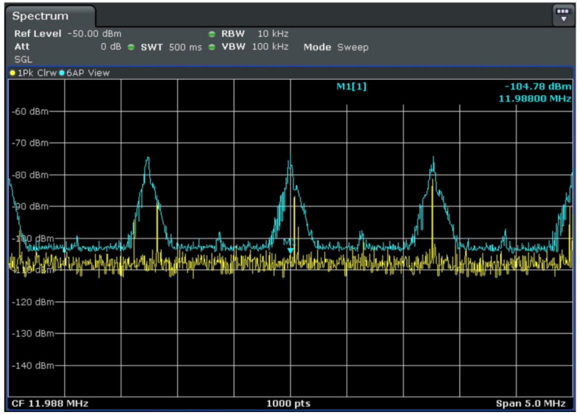
Optimizing the test strategy

FINDING THE WORST CASE

Warning



The increase of the sweep time from 10 ms to 100 ms does not help, too. No reliable catch of trace points that match with the spectrum envelope.

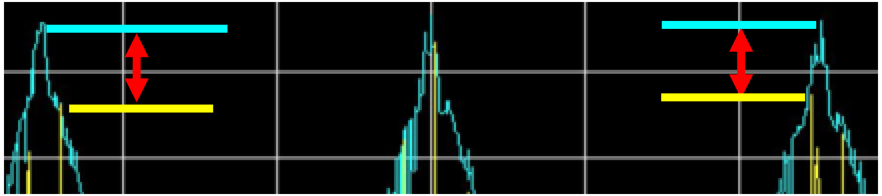


Also the increase of the sweep time to 500 ms has not been successful.

If you do not care at all the timing behavior, you will not get reliable test results.

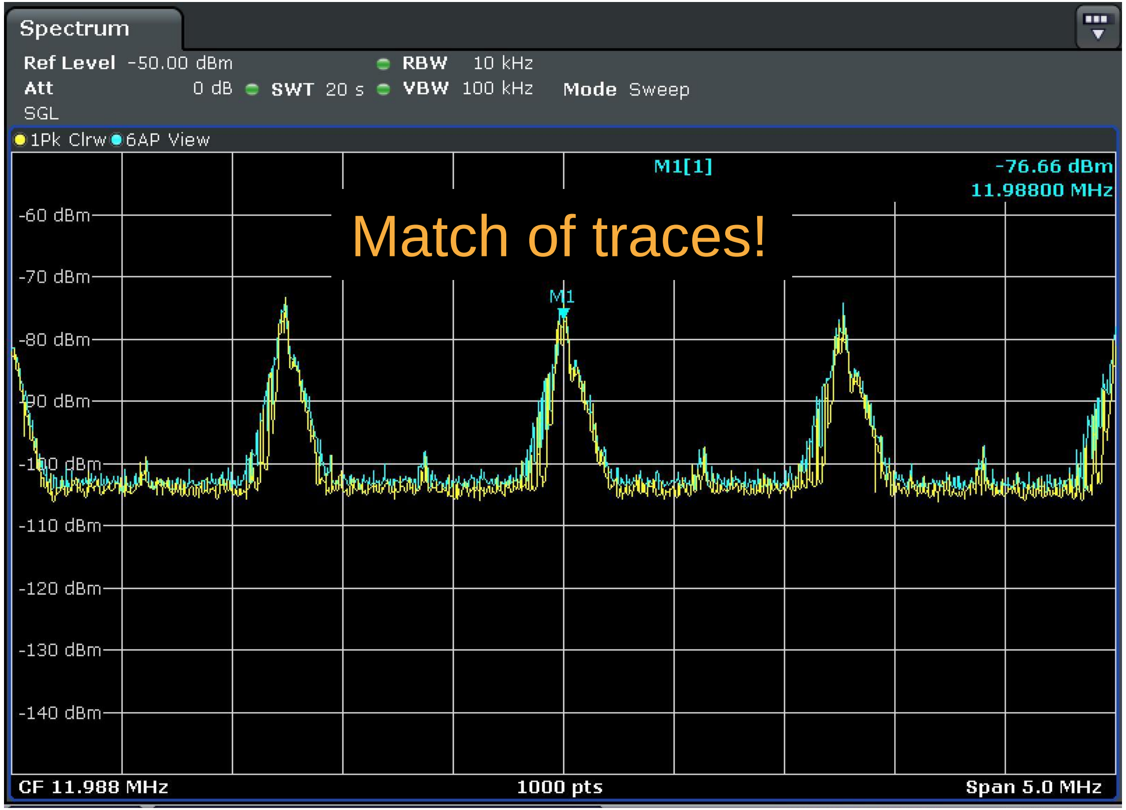
Gaps between fast-measurement results and the spectrum envelope curve can reach values larger than 8 dB.

>9 dB match >8 dB



FINDING THE WORST CASE

Sweep Time = 20 sec



PRACTICAL EXPERIENCE

Peak Detector → enough points → Watch 15 sec → ”fat trace” → placing a marker → Center frequency = marker frequency → Timing analysis in zero span

Measurement Parameter

Start frequency	30 MHz
Number of sweep points (number of frequency points)	1,183
Number of steps	1,182
Bandwidth	
RBW	100 kHz
Stepsize*	
50% of RBW	50.0 kHz
Maximum value for stop frequency	89.10 MHz
Maximum value for frequency span	59.10 MHz
Measurement time per frequency step (depending on DUT behavior)	20 ms
Minimum sweep time (every frequency point can see the disturbance at least 1 time during the measurement)	23,660 ms
	24 s

Advice for spectrum analyzer users:
The result of the DUT timing analysis shall be used as input parameter of the frequency point and measurement time calculation.

Every 20 ms the DUT emits a short pulse.

PRACTICAL EXPERIENCE

Peak Detector → enough points → Watch 15 sec → ”fat trace” → placing a marker → Center frequency = marker frequency → Timing analysis in zero span

Understanding the detectors (CISPR 16-1-1 background)

→ Peak Detector result is worse or equal to Quasipeak Detector result

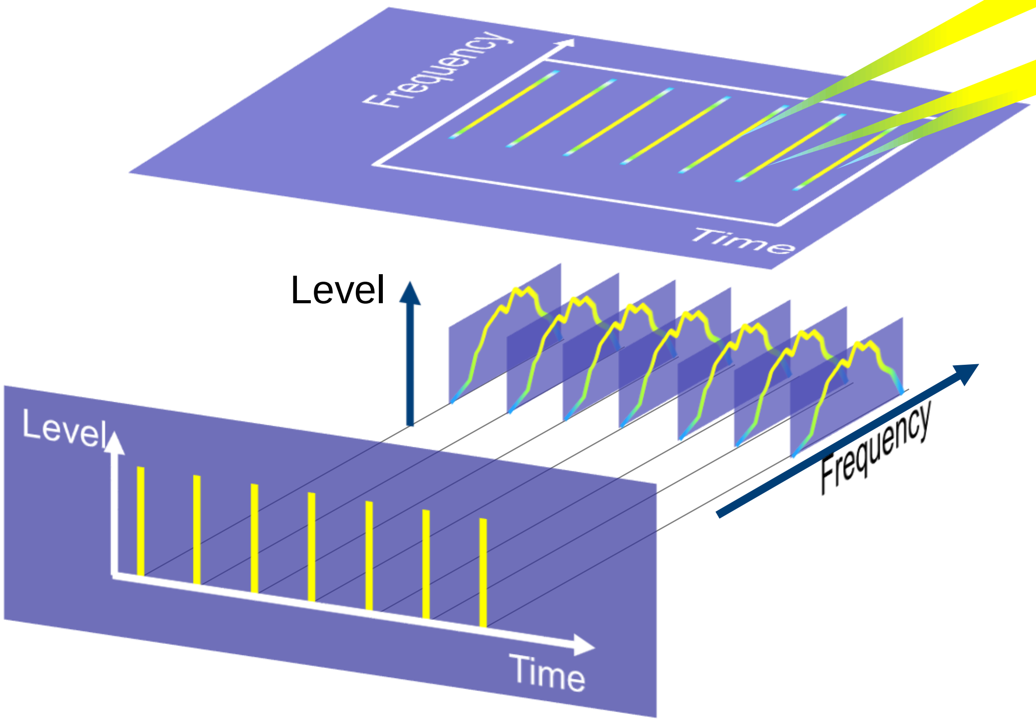
Understanding gapless measurement of the spectrum envelope (CISPR 16-2-1/-2/-3 background)

→ step size is 50% of RBW size. Number of points ≈ frequency range / step size.

→ Instrument with fixed number of points → check data sheet and adjust frequency window (span)

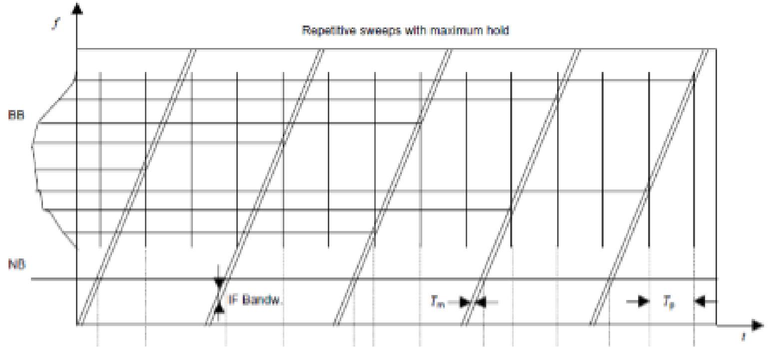
→ Instrument with customizable number of point

INTERMITTENT BROADBAND SPECTRUM



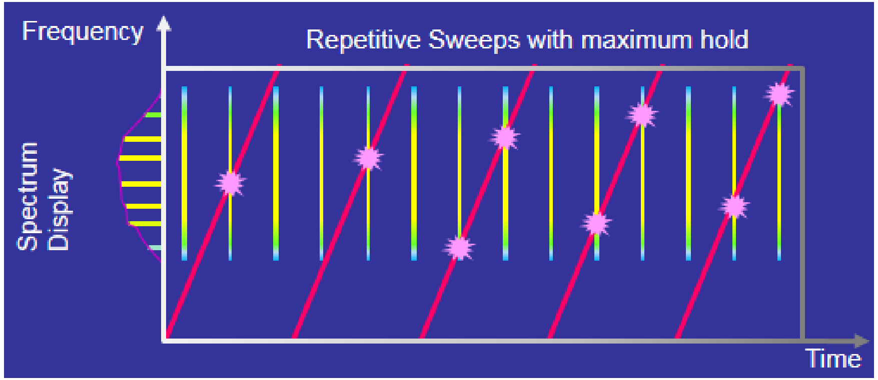
CISPR16-2 ALL PARTS – SINCE EDITION 1
IMPORTANT GRAPH: VISUALIZATION OF INTERCEPTIONS

Intercept chart
in standard



IEC 752/10

Intercept chart
with color



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