Automotive EMC testing with Keysight

11/7/2018

Jon Kinney
RF/uW Applications Engineer

KEYSIGHT
TECHNOLOGIES

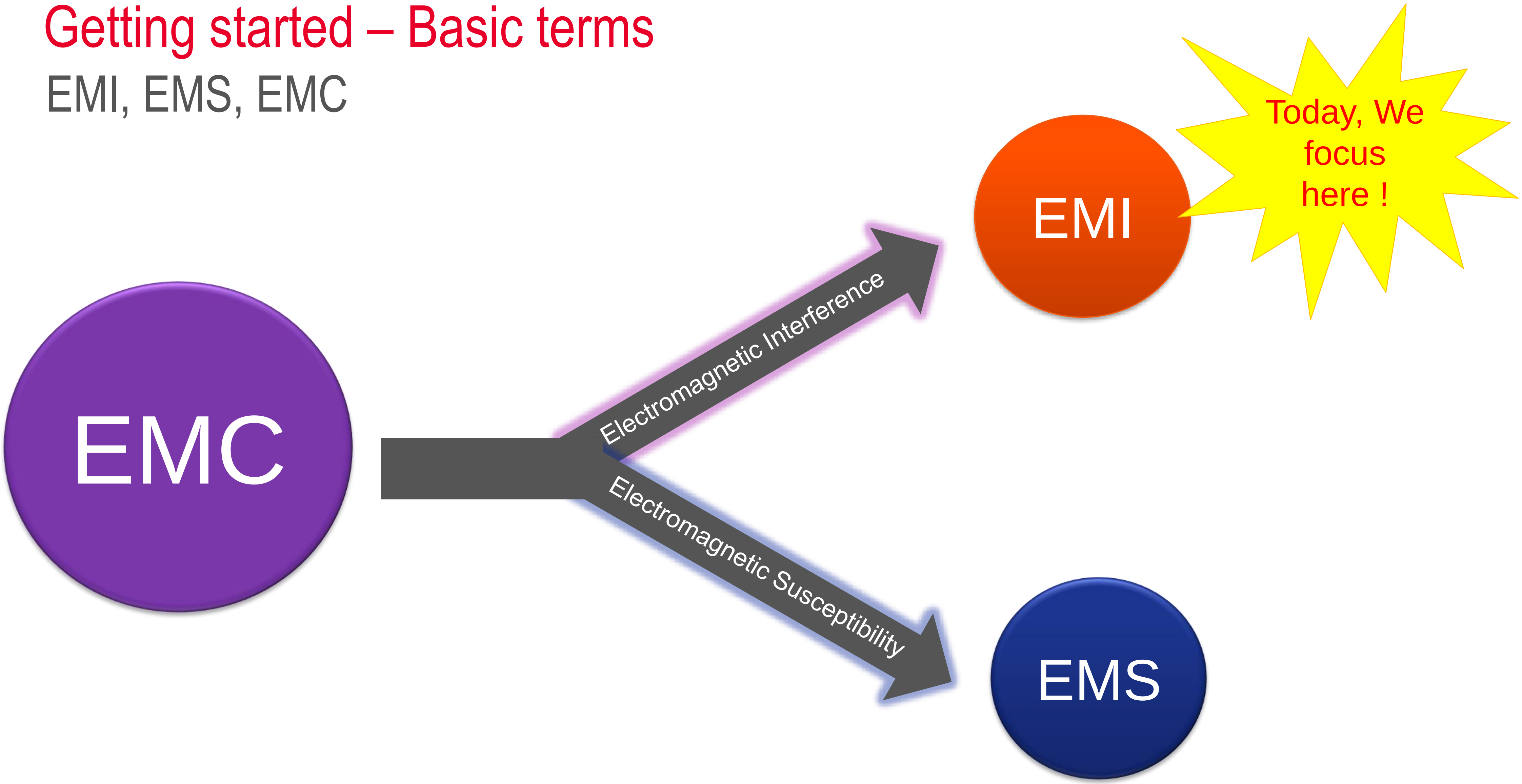
EMI is about unwanted interference

↓

How to evaluate EMI emissions with a spectrum/signal analyzer ?

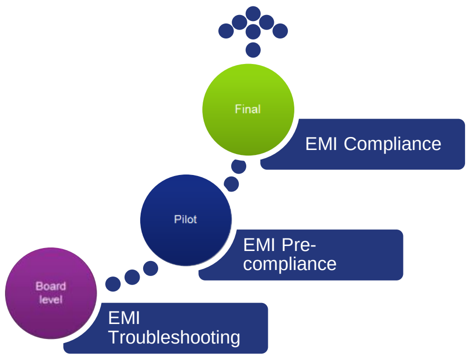
Getting started – Basic terms

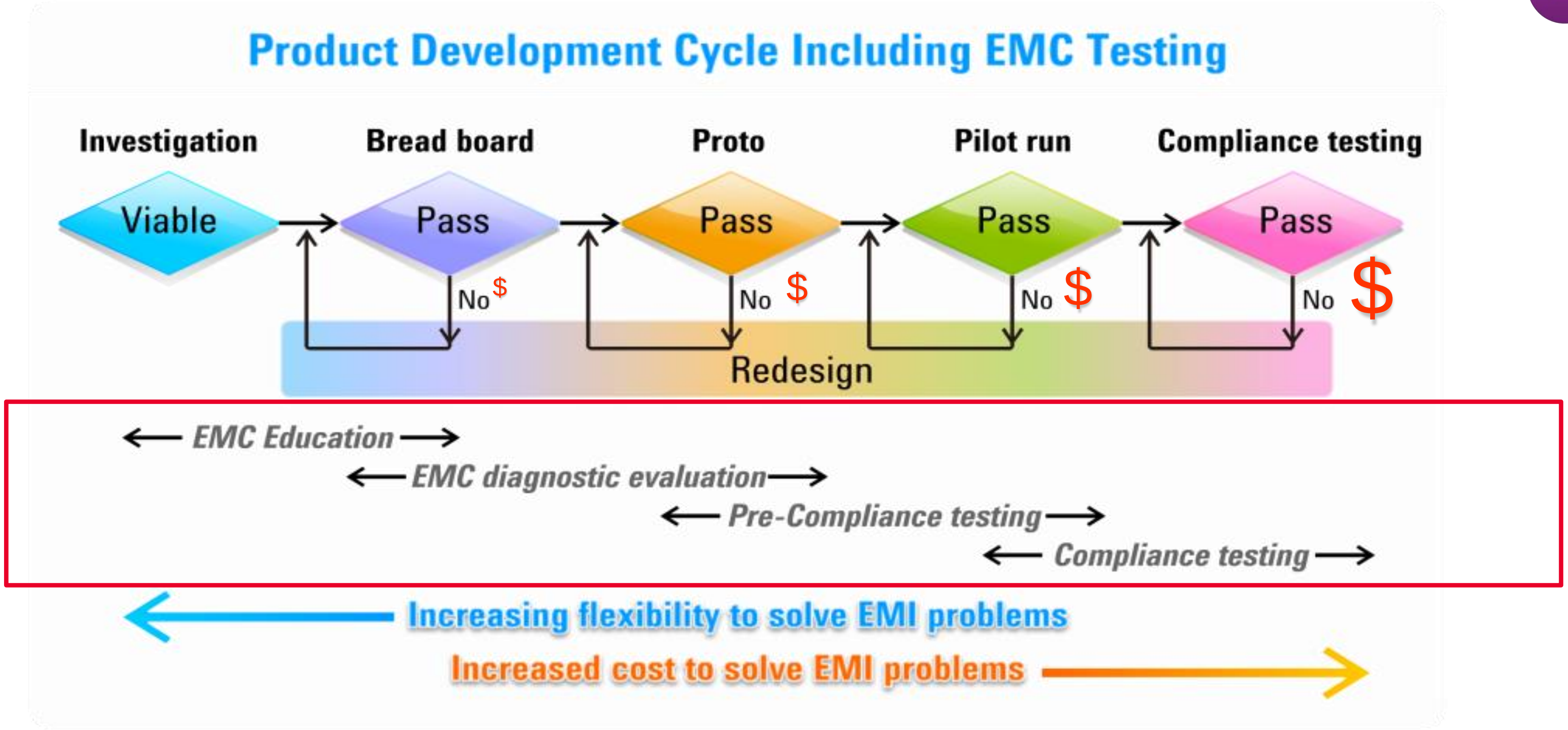
EMI, EMS, EMC



Why bother?

EMC evaluation is along with your product NPI cycle





Agenda

– EMI pre-compliance measurement overview

– Keysight EMI solutions

– Emerging instrumentation in automotive labs

Agenda

– EMI pre-compliance measurement overview

– Keysight EMI solutions

– Emerging instrumentation in automotive labs

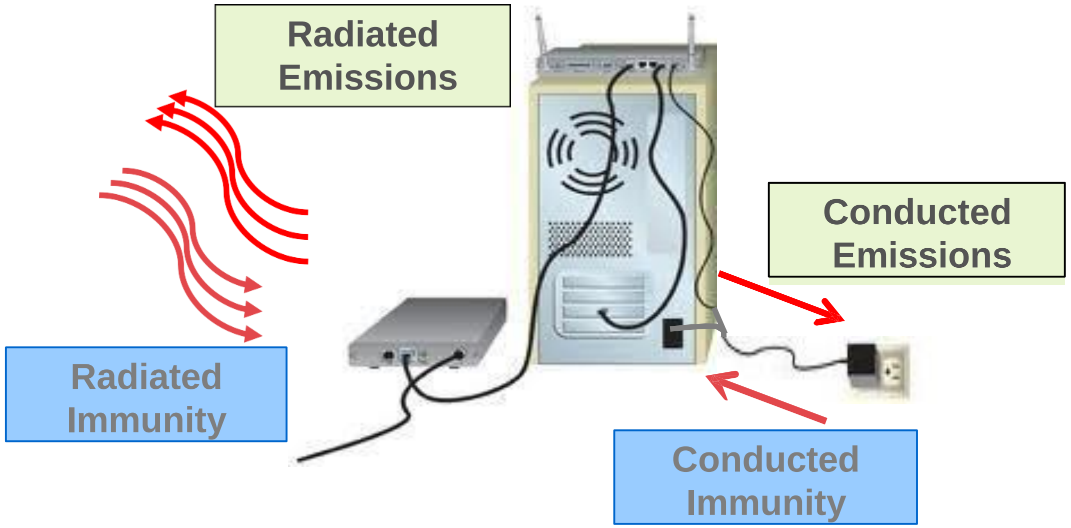
What is EMI?

Electromagnetic Interference

– EMI is disturbance that affects an electrical circuit due to either **electromagnetic conduction** or **electromagnetic radiation** emitted from an external source

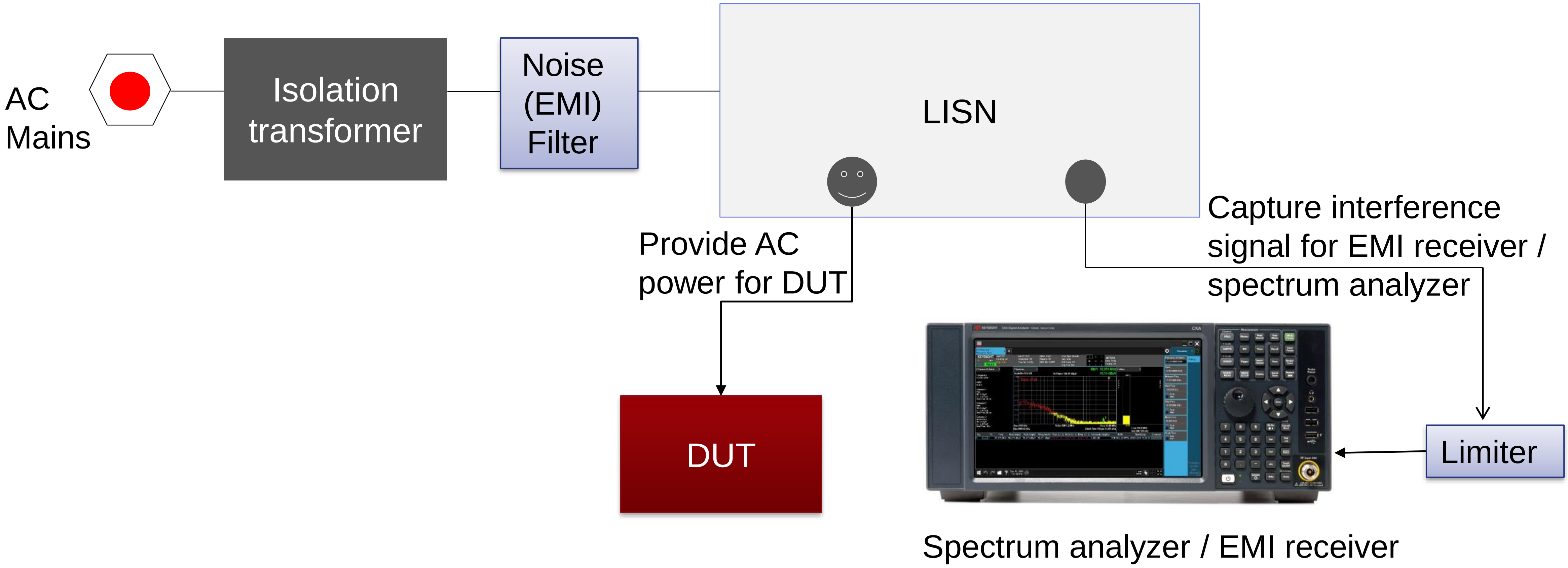
– EMI emissions can be well captured by a spectrum analyzer

– A spectrum analyzer tells you the frequency, power, and other important properties of an EMI emission



Conducted Emissions

9 kHz – 30 MHz



Conducted Emissions Test Setup

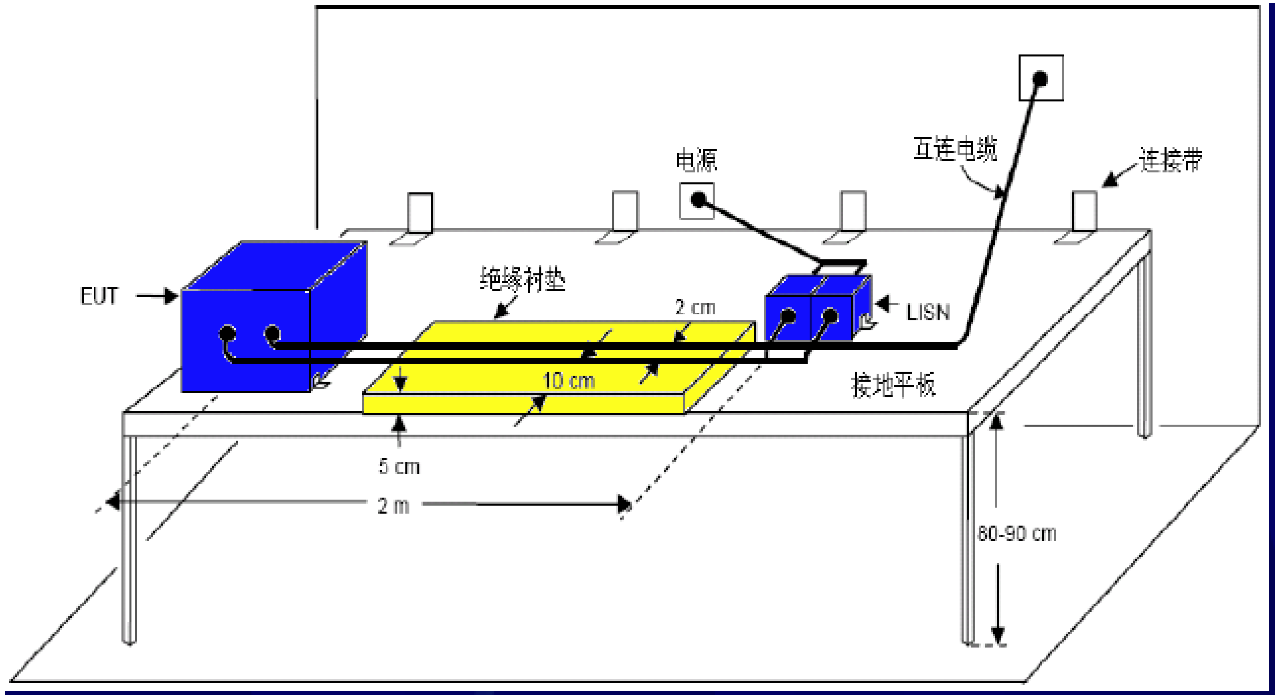
Table:

- Surface area > 1.5 * 1 m^2
- Height > 0.8 m
- A metal grounding panel must be placed on the surface of the table

Grounding panel:

- Size > 2*2 m^2
- 0.5 m margin against the other setups on the table
- Must connect to the ground
- Ground resistance < 2 ohm

Compliance test needs be done in a shielded room



Accessories of EMI testing

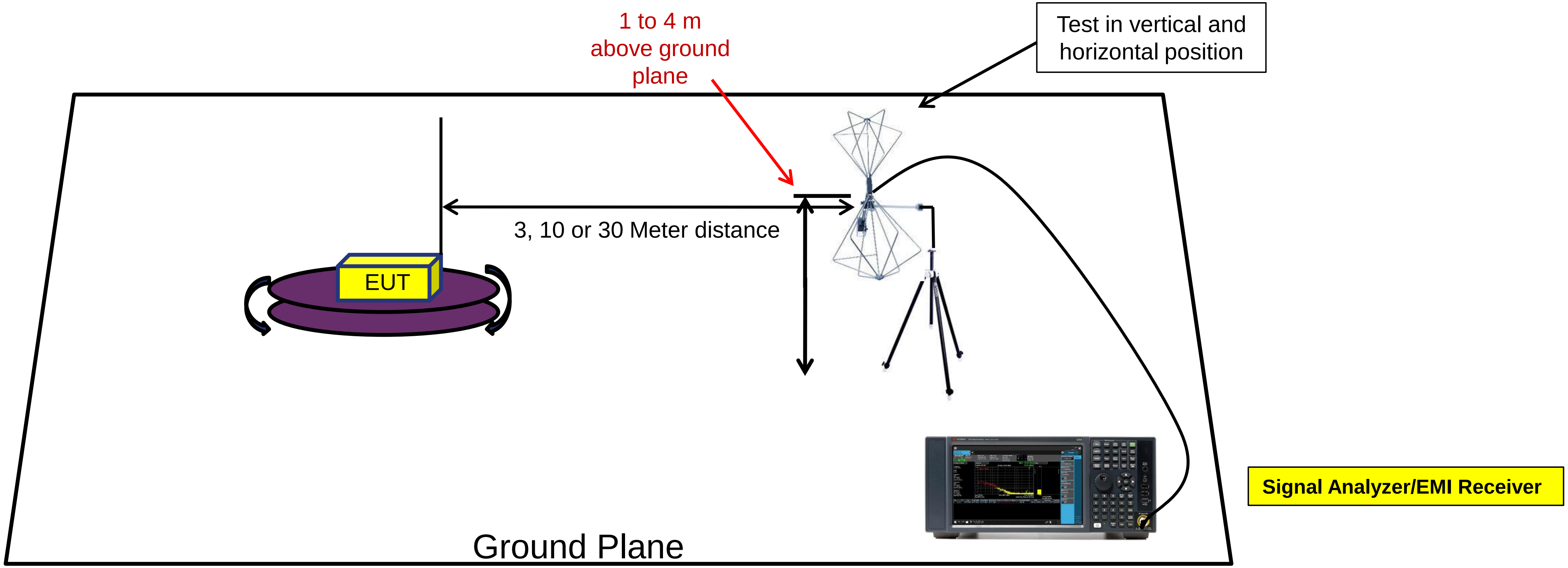
LISN: Line Impedance
Stabilization Network

Close Field Probe Set:
Diagnostics antennas

Current injection probe

EM-Clamp

Radiated Emissions Setup

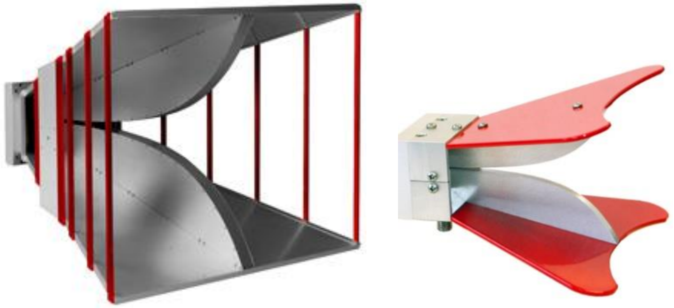


The goal is to find and record the maximum emissions from the EUT by rotating the turn table, changing the polarity and the height of the antenna.

Accessories of EMI testing

Log Periodic Antenna:
200 to 1000 MHz

Biconical Antenna:
30 to 300 MHz



Double ridged horn antennas
18 GHz or even higher

Hybrid log periodic
Broadband
30 MHz to 2 GHz

Tripods: used to raise and
lower antennas

Rotating Table:
To rotate EUT for testing

EUT: Equipment Under Test, same as Device Under Test (DUT)

About antenna factor (AF)

Very important in EMI measurement

– AF is defined as the ratio of the electric field strength to the voltage induced across the terminals of an antenna.

– Think of it as a “correction factor” for a given receiver

– For an electronic field antenna (V/m, or µV/m):

- Expressed in linear quantity: $AF = \frac{E}{V}$ (1/meter)
- Expressed in log quantity: $AF = E_{dB\mu V/m} - V_{dB\mu V}$

– For a magnetic field antenna (A/m):

- $AF = {}^{9.37}/_{\lambda\sqrt{G}}$ G: the antenna gain

EMI Measurement Video

Pre-compliance vs. Compliance

	Pre-compliance testing	Compliance Test
Purpose	To increase the confidence level at final compliance test	To achieve certificates (e.g. C-tick, CE, UL, KC, CCC, FCC
Overall	Not identical to, but can simulate the standard procedure as much as possible	Must follow the standard procedure
Physical setup requirements	Can be done in house, throughout the design process	Must be done in test house (for certification)
	Can be done in a shielded room, or an open area	Must be in an anechoic chamber
	EMI receiver or spectrum analyzer	Must use an EMI receiver
	Simplified test setup	Must use standard test setup
Cost	Much less expensive, and quick turn-around	Very expensive and time consuming
Result	Will report an EMI risk	Will report an EMI failure
	Able to track to the interference source with a NF probe	Cannot tell where the failure comes from

CISPR 16-1-1 Compliant Receiver

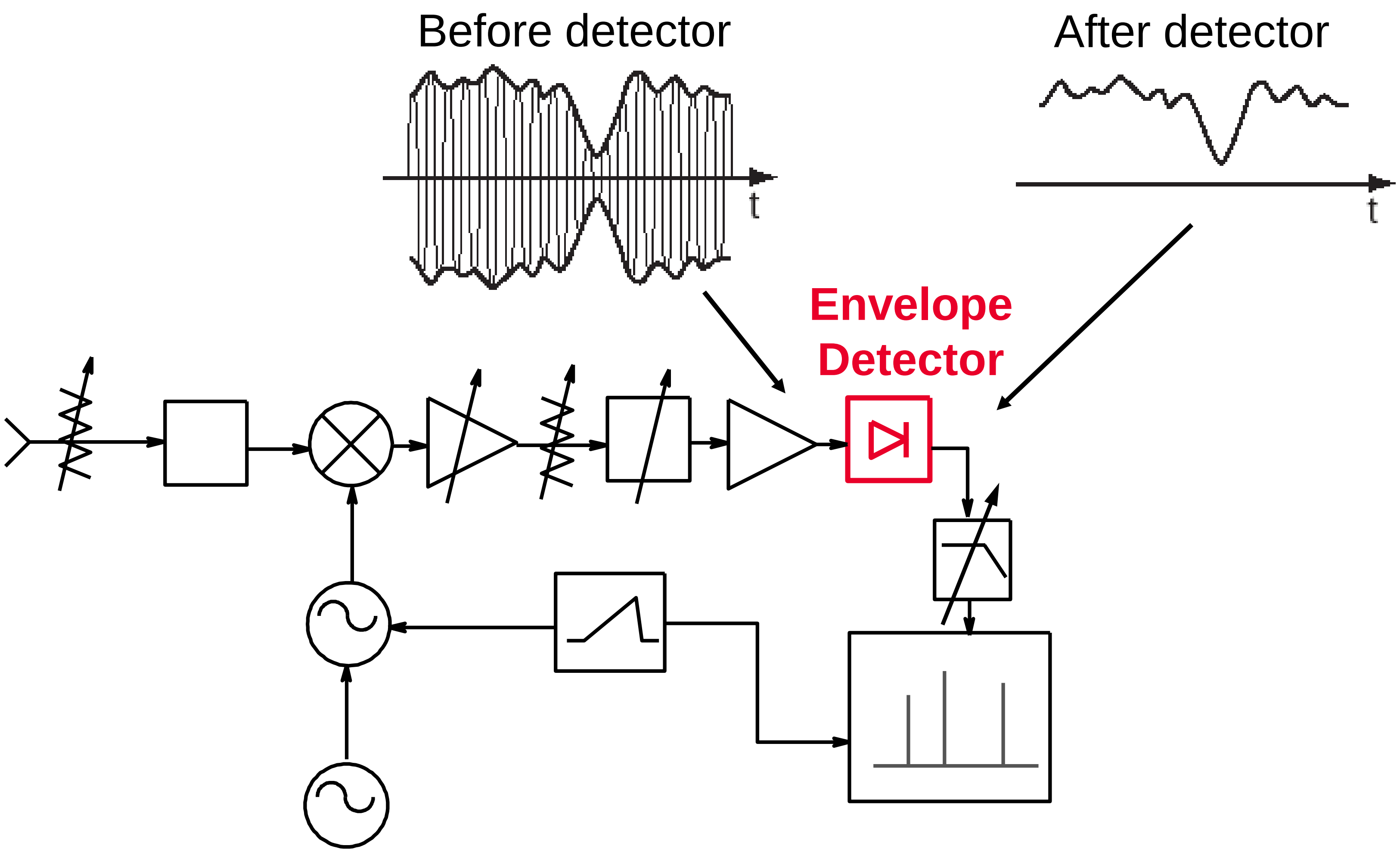
A CISPR 16-1-1 receiver must have the following functionality in the range 9 kHz - 18 GHz:

- A normal +/- 2 dB absolute accuracy
- CISPR-specified resolution bandwidths (-6 dB)
- Peak, quasi-peak, EMI average, and RMS average detectors
- Specified input impedance with a nominal value of 50 ohms; deviations specified as VSWR
- Be able to pass product immunity in a 3 V/m field
- Be able to pass the CISPR pulse test (implies pre-selector below 1 GHz)
- Other specific harmonic and intermodulation requirements

KEYSIGHT TECHNOLOGIES

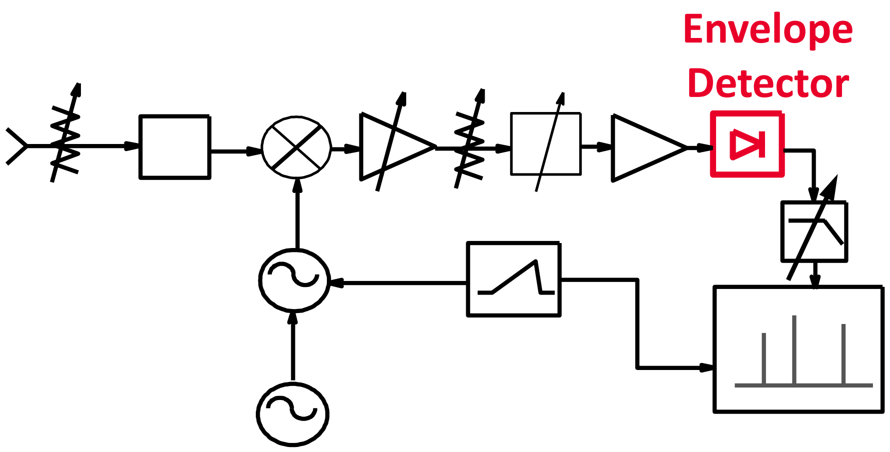
Theory of Operation

Envelope Detector

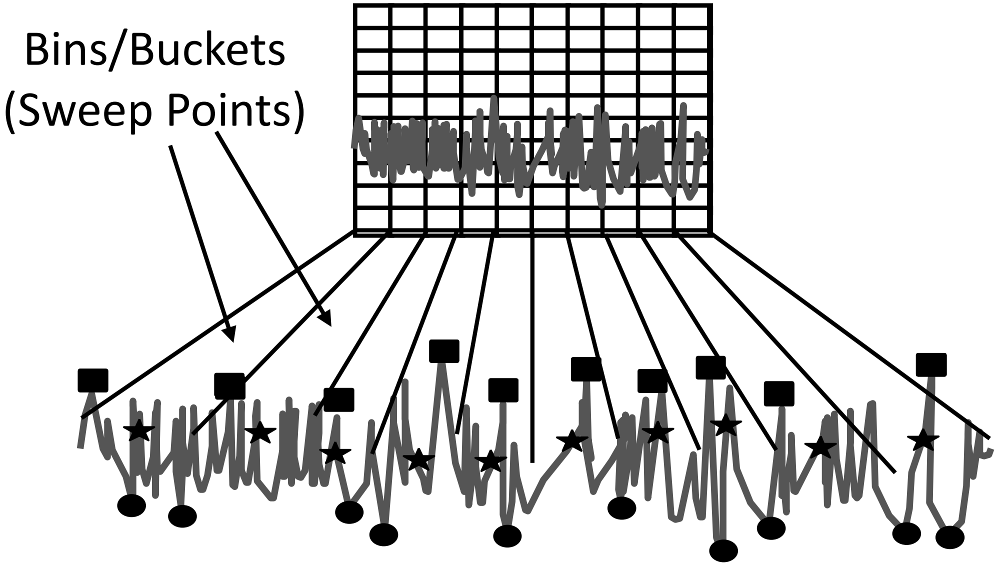


Theory of Operation

Envelope Detector and Detection Types



Digitally Implemented Detection Types



■ **Positive Detection:** largest value in bin displayed

● **Negative detection:** smallest value in bin displayed

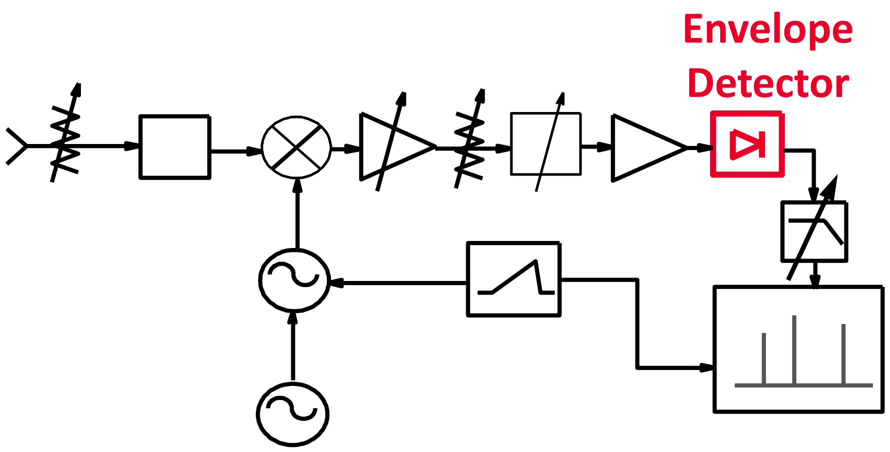
★ **Sample detection:** middle value in bin displayed

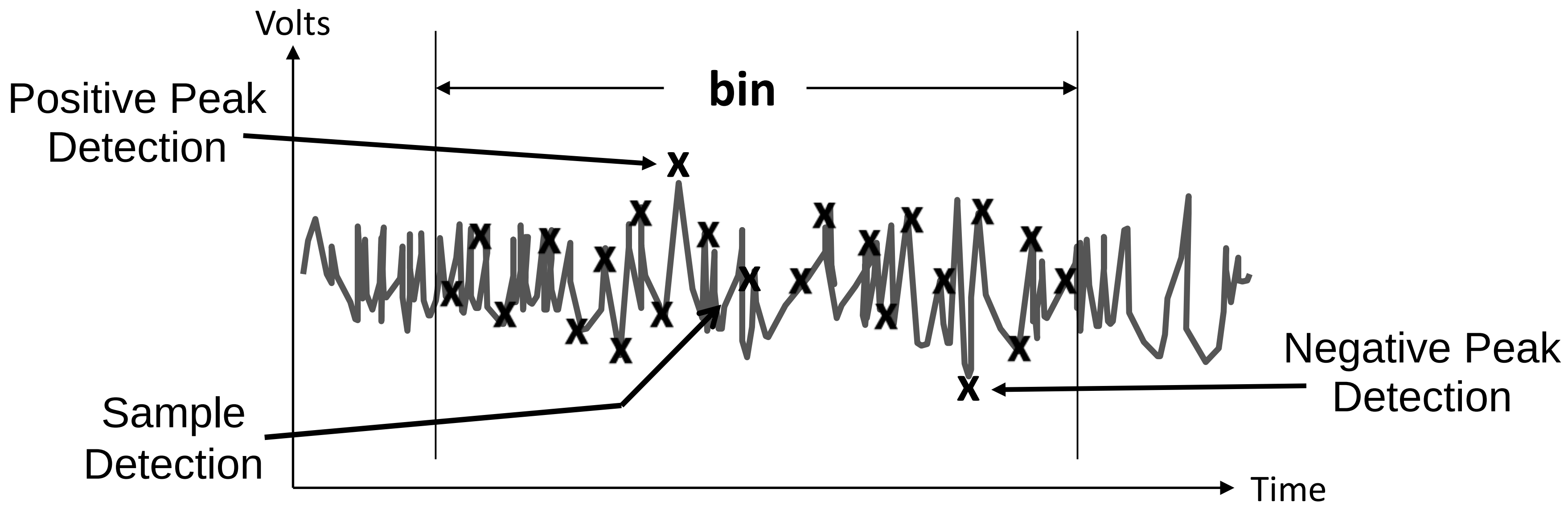
Other Detectors: Normal (Rosenfell), Average (RMS Power)

KEYSIGHT TECHNOLOGIES

Theory of Operation

Average Detector Type





Power Average Detection (rms): Square root of the sum of the squares of ALL of the voltage data values in the bin divided by 50Ω

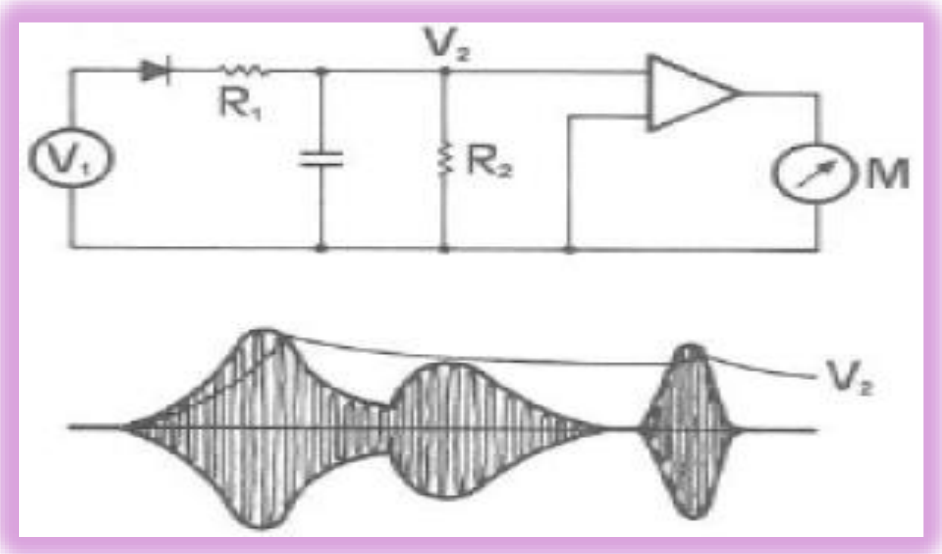
KEYSIGHT TECHNOLOGIES

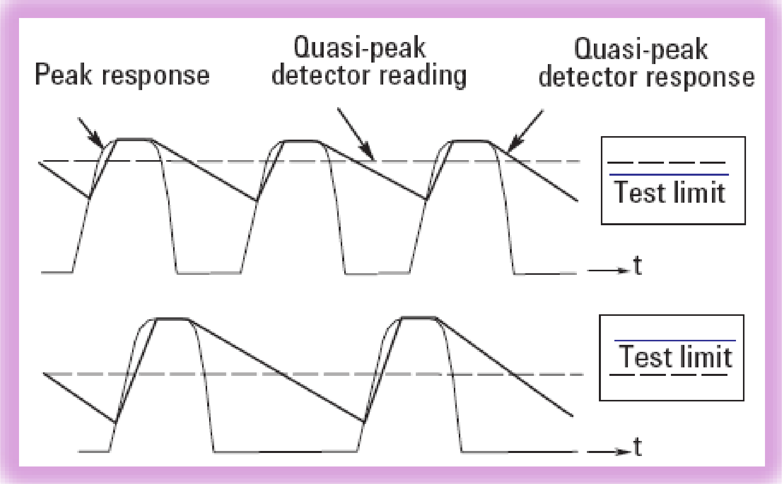
About quasi-peak detection

– There are three commonly used detection modes for making EMI measurements, including peak, average, and quasi-peak detection.

– Why use Quasi-peak detection?

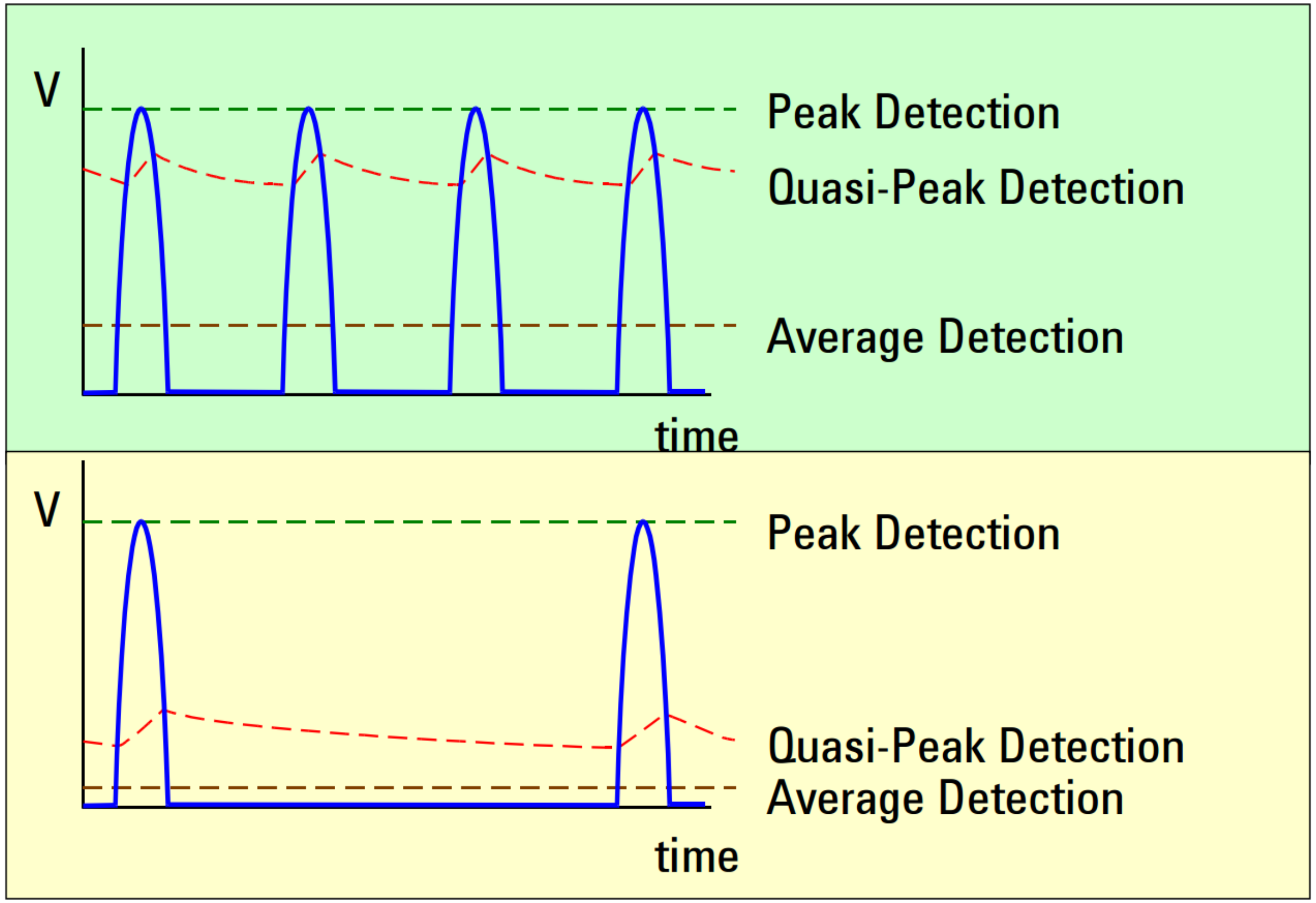
- Used for CISPR based measurements.
- Weights signals as a function of repetition rate.
- Lower repetition rate noise has less “annoyance factor” and thus gets less emphasis
- CISPR bandwidth: 200 Hz, 9 kHz, and 120kHz bandwidth.





Detection Modes

Peak ≥ Quasi-Peak ≥ Average



Agenda

– EMI pre-compliance measurement overview

– Keysight EMI solutions

– Emerging instrumentation in automotive labs

Keysight Analyzers

– Pre-compliance
  - X series Analyzers
    - N9000B CXA
    - N9010B EXA
    - N9020B MXA
    - N9030B PXA
    - N9040B UXA

  - N934xC Handheld Analyzer

– Compliance
  - EMI receiver

KEYSIGHT TECHNOLOGIES

Introducing: N9048B PXE EMI Receiver

The new PXE EMI Receiver series enables you to make radiated and conducted emissions tests, certifying that a product meets local regulatory compliance standards.

- Determine if product meets local EMC standards
- Diagnose causes for compliance failures
- Troubleshoot product’s emission problem areas

N9048A PXE EMI Receiver Offers World-Class EMI Measurement Capability

- **Three frequency ranges**
  - 2 Hz – 3.6 GHz
  - 2 Hz – 8.4 GHz
  - 2 Hz – 26.5 GHz

- **Fully CISPR Compliant**
  - CISPR bandwidths (6dB and impulse BW)
  - Quasi-Peak, EMI-Avg and
  - RMS-Avg detectors

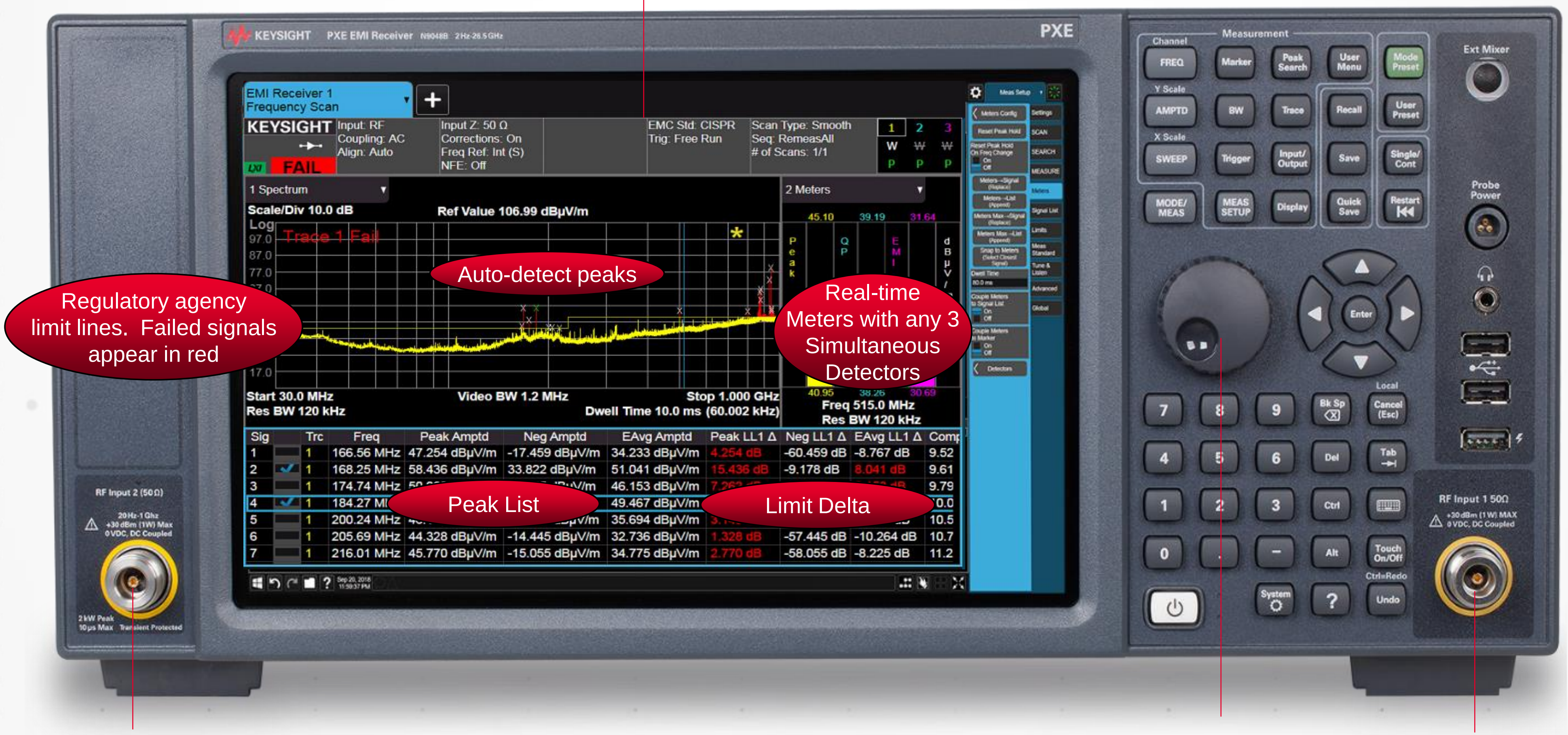
- **Fully MIL-STD-461 Compliant**
  - 6dB bandwidths
  - Peak detector

- **New RF Pre-Selector & LNA Design**
  - Enables you to tune out multiple frequencies and image responses while improving dynamic range
  - Amplify your signal of interest without adding noise

- **Most Competitive Sensitivity in the World**

Front Panel and User Interface

10.6 inch **multi-touch screen**
simplifies measurement setup



Input 2
2 Hz to 1 GHz
Surge protected to 2 kW
(built-in limiter)

Navigate the interface and help system using the front-panel keys, or a mouse and keyboard

Input 1
2 Hz to 3.6/8.4/26.5 GHz

Keysight Software

– Keysight Spectrum Analyzers have 2 EMI software applications

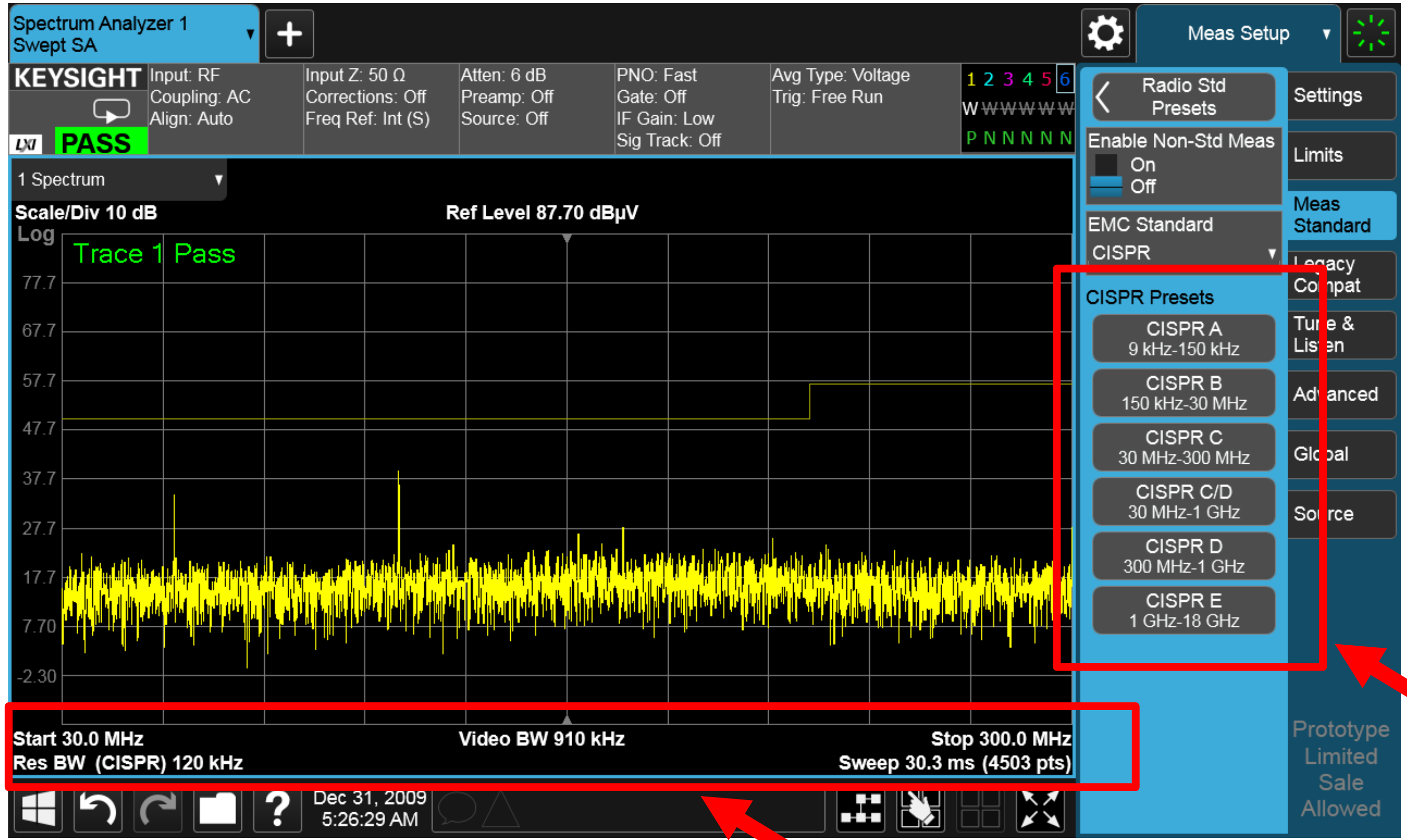
  • N6141x (EMI Measurement Application) and Option EMC

Comparison of EMI measurement application and Option EMC features

Feature	EMI Measurement Application	Option EMC
CISPR 16-1-1 detectors	•	•
CISPR 16-1-1 bandwidths	•	•
MIL-STD 461 bandwidths	•	
Log and linear display	•	
Signal list	•	
Scan table	•	
Simultaneous detectors	•	
Automatic limit testing	•	
Measure at marker	•	
Delta to limit	•	
Strip chart	•	
Step and swept scans	•	
Report generation	•	
Time domain scan[1]	•	
Monitor spectrum[1]	•	
Amplitude probability distribution (APD)[1]	•	
Disturbance analyzer (click measurements)	•	
UI commonality with MXE receiver	•	

Option EMC

Provides the essential capabilities on EMI interference analysis



Option EMC provides:

- CISPR 16-1-1 (2010) fully-compliant detectors
- CISPR band presets to 18 GHz
- Measure at marker with three detectors
- Tune and listen for signal discrimination

One-button EMI presets

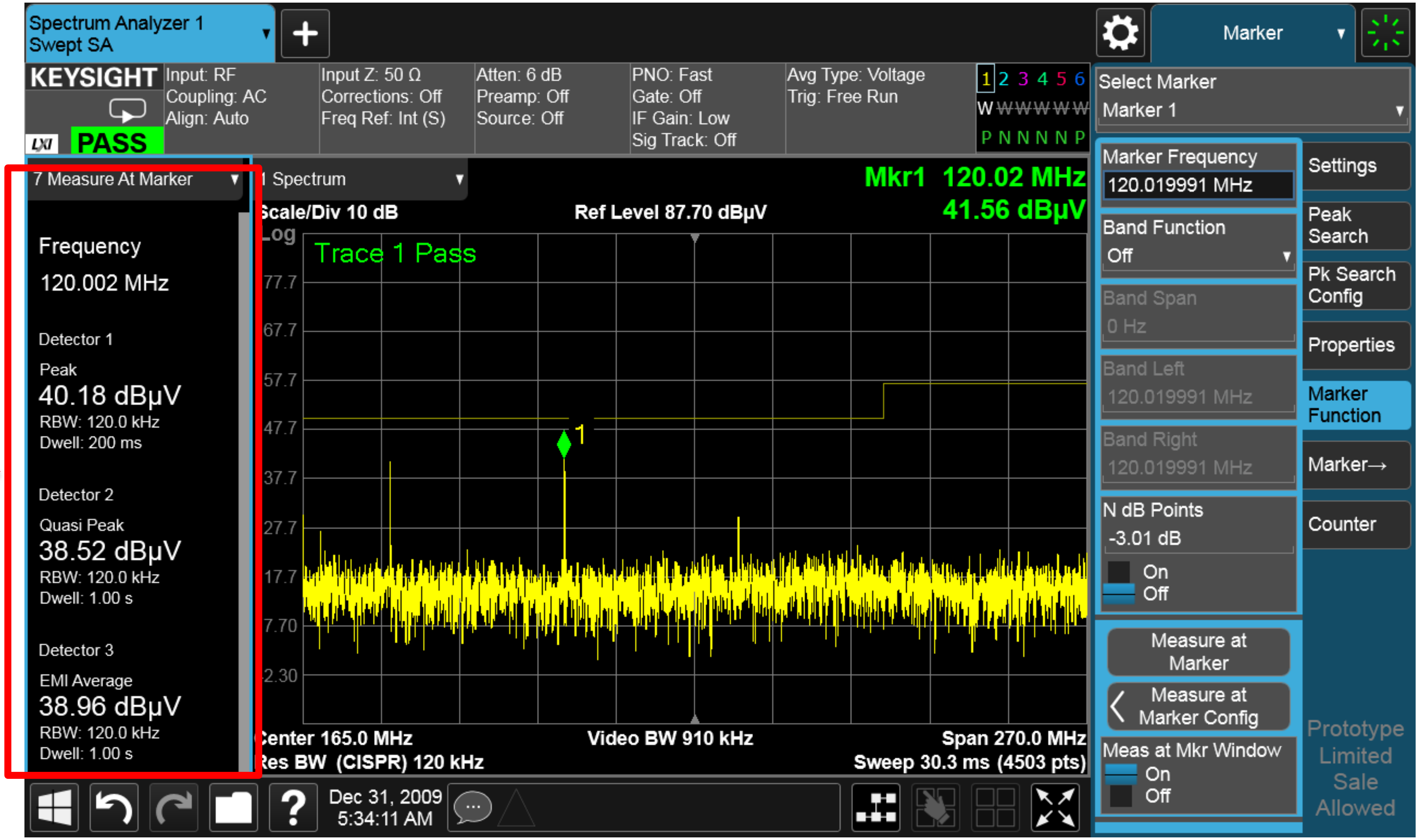
Measurement parameters set according to CISPR bands

Option EMC (cont.)

Measure at marker with 3 detectors simultaneously

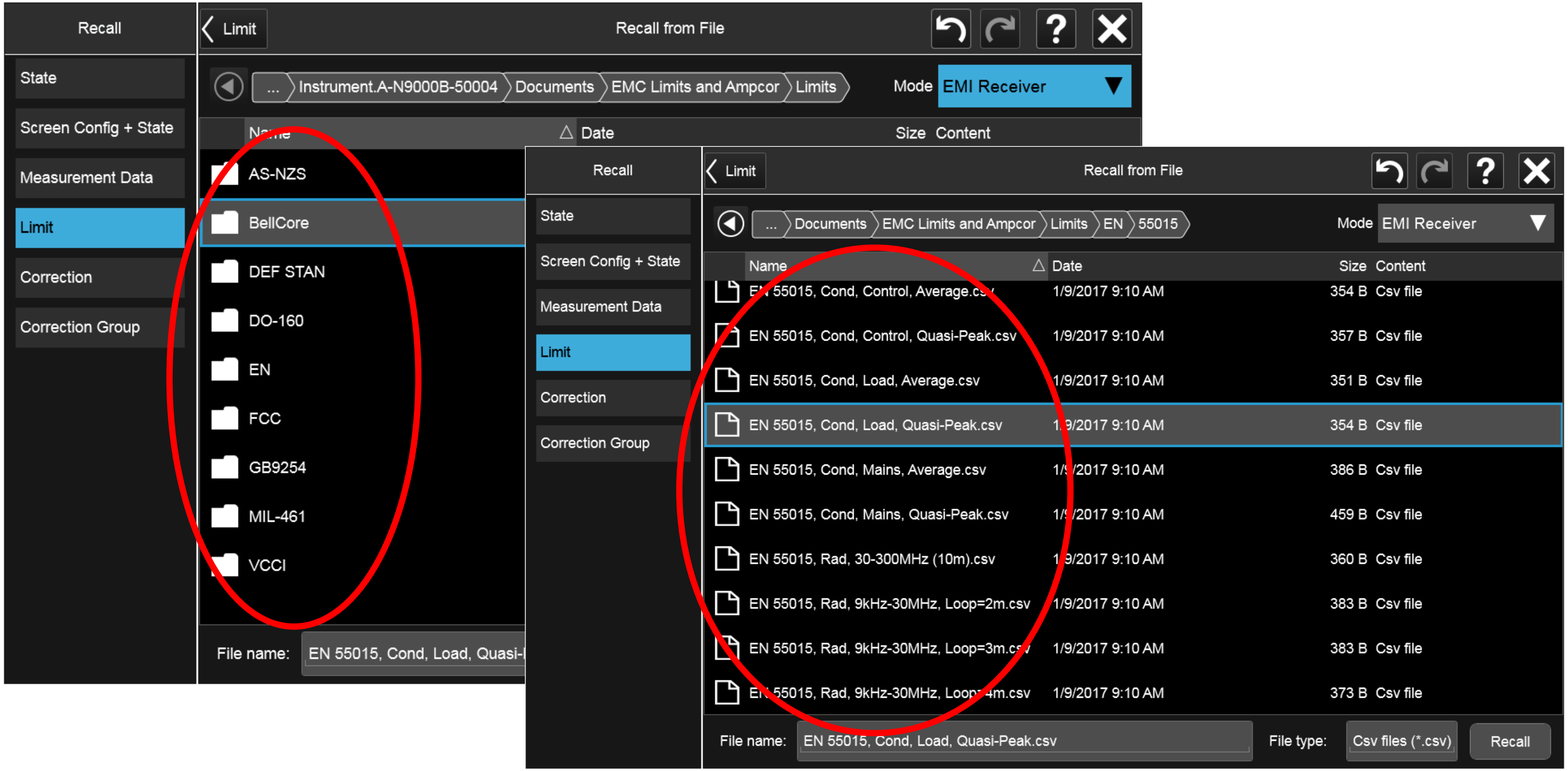
Measure at marker with three detectors:

- Peak
- Quasi-peak
- EMI average



Built-in CISPR and MiL-STD limit line

A list of commercial limits for recalling



KEYSIGHT TECHNOLOGIES

RBWs for CISPR & MIL

Commercial (CISPR)

Bands	Frequency range	CISPR RBW
A	9 – 150 kHz	200 Hz
B	150 kHz – 30 MHz	9 kHz
C	30 – 300 MHz	120 kHz
D	300 MHz – 1 GHz	120 kHz
E	1 – 18 GHz	1 MHz

Military (MIL-STD-461)

Frequency range	RBW
30 Hz – 1 kHz	10 Hz
1 – 10 kHz	100 Hz
10 – 150 kHz	1 kHz
150 kHz – 30 MHz	10 kHz
30 MHz – 1 GHz	100 kHz
Above 1 GHz	1 MHz

N6141x EMI measurement application

Runs inside signal analyzer

Follows CISPR 16-1-1 reference work flow

EMI precompliance test capabilities:

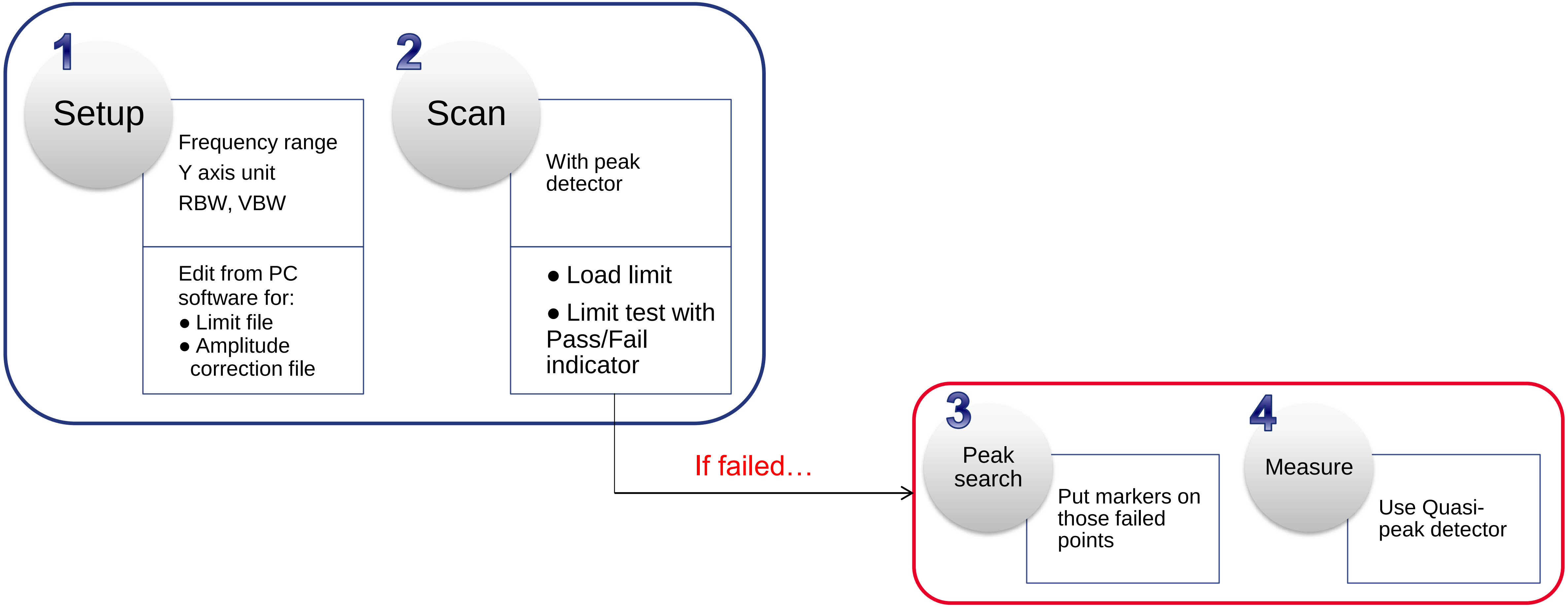
- Built-in CISPR and Mil-STD compliant BW, detectors and band presets
- Automated testing to regulatory limit lines with user-selected margins
- Amplitude corrections for antennas, LISNs, NF probes, etc

Measurement features:

- 3 simultaneous detectors (Peak, Quasi-peak, Average)
- Built-in signal list tracking those non-compliance emissions
- Strip chart for analysis of emissions versus time
- Supports precompliance “Click” measurements

Reference work flow:

Instrument Setup → Scan → Peak search → Measure



N6141x Measurement procedure

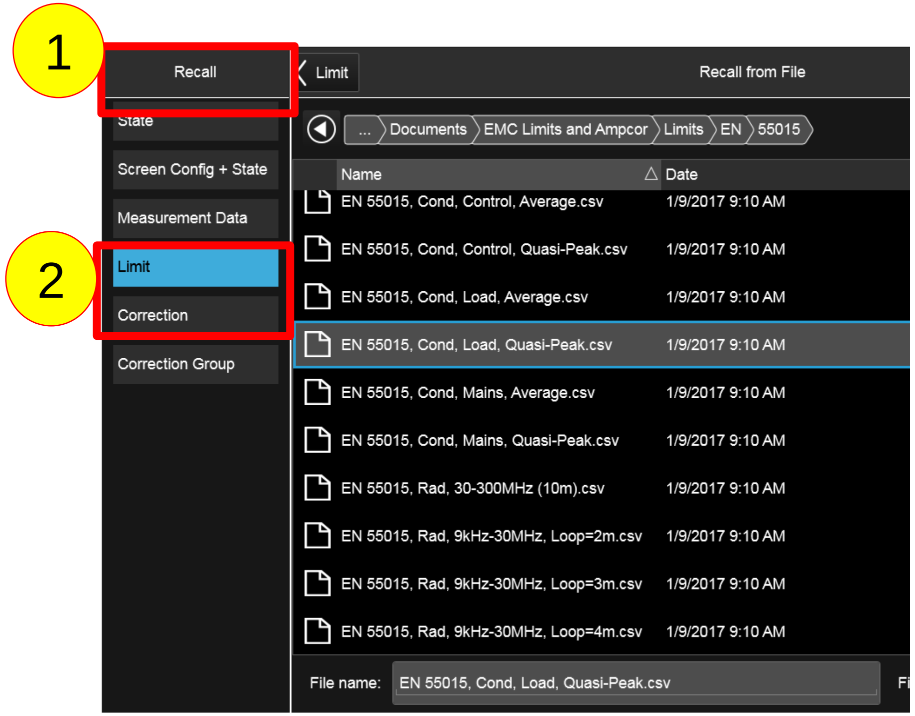
Step 1. Set up the scan table

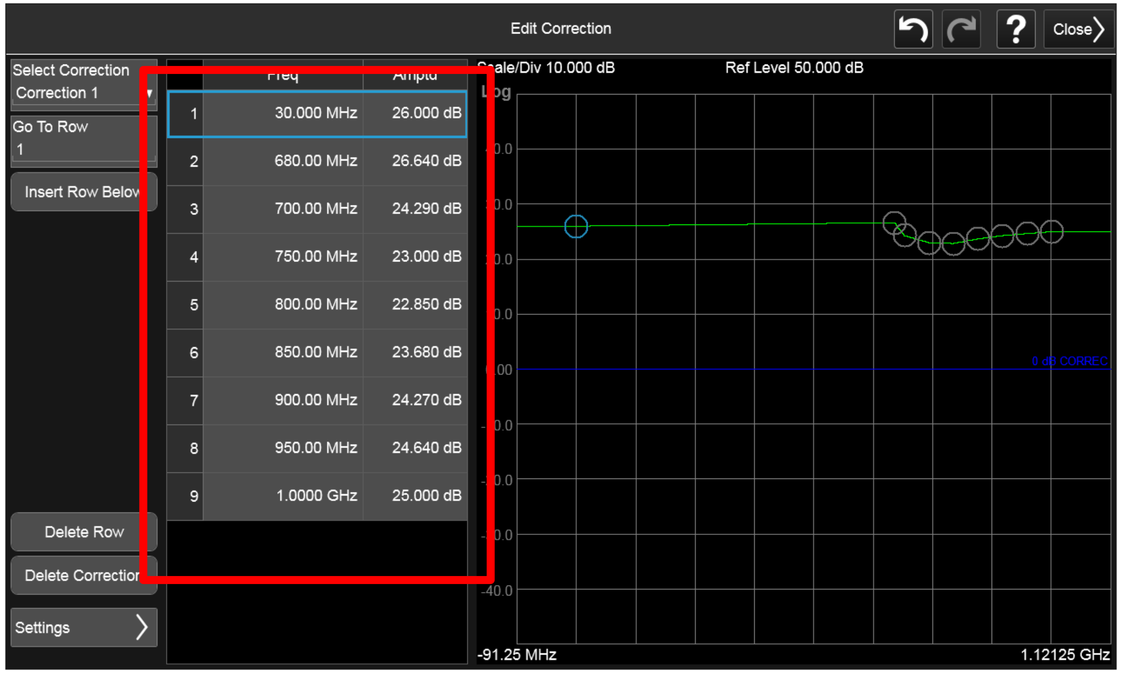
Press [Meas Setup] → {Scan table} to configure the measurement range, as well as other parameters, if needed

The X-series signal analyzer will set the EMI measurement parameters according to the scan table automatically

N6141x Measurement procedure

Step 2. Load limit line. Load correction data.





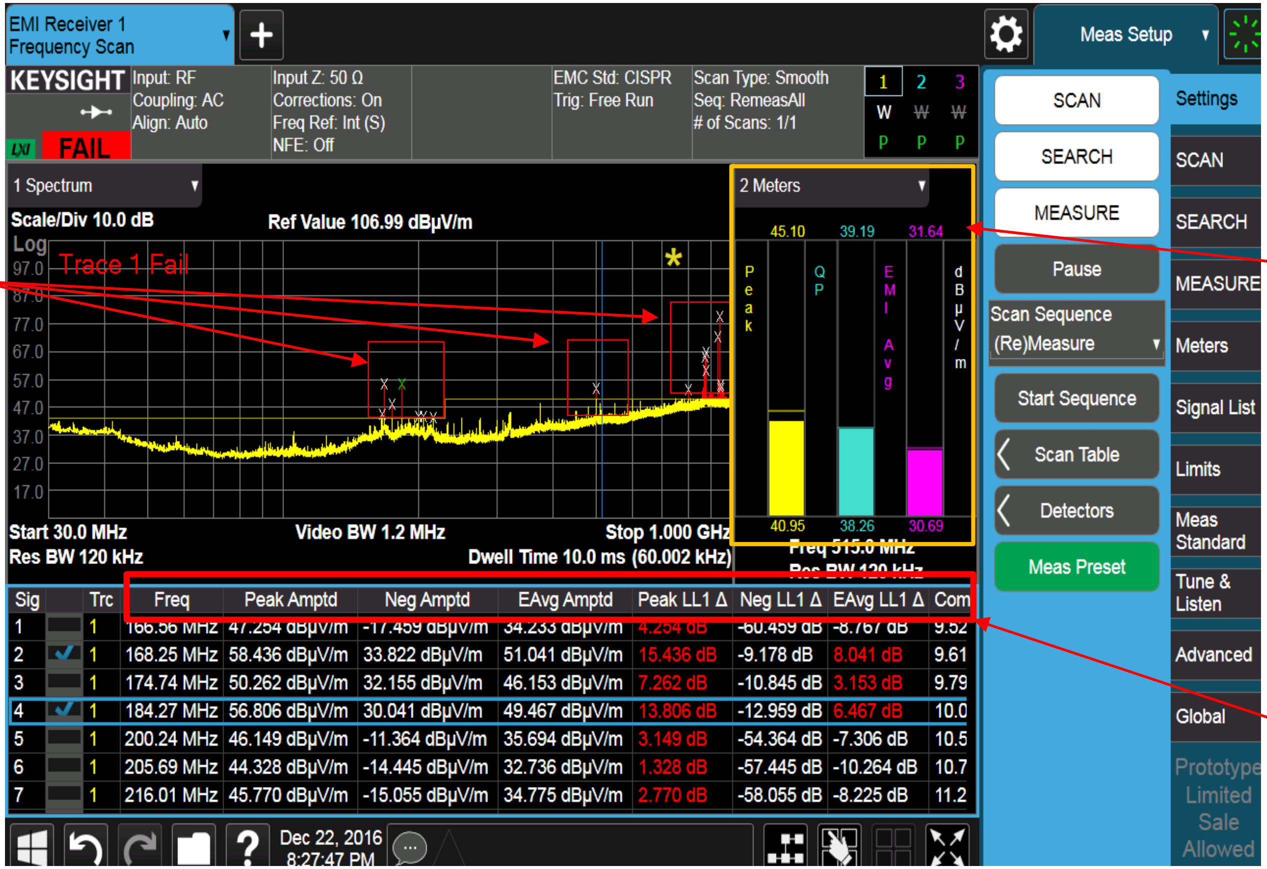
- Press [Recall] → {Limit} to load a pre-defined limit file
- Press [Recall] → {Correction} to load a pre-defined correction file

To edit a correction, press [Input/Output] → {Correction}, to manually edit correction data

N6141x Measurement procedure

Step 3. Scan, search, and measure

Capturing out of limit emissions and list them into the table below



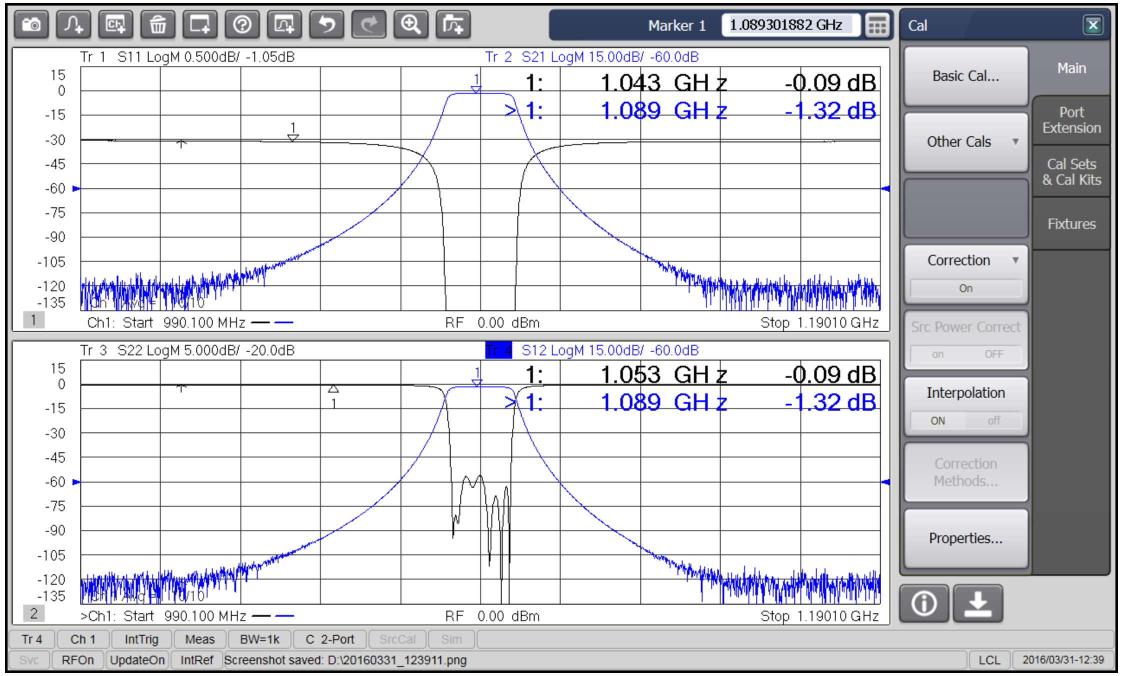
Strip chart lets you view signals over a long time period to identify widely spaced discontinuities

Measure each point with 3 detectors simultaneously, also shows their deviations from the limit

Agenda

- EMI pre-compliance measurement overview
- Keysight EMI solutions
- Emerging instrumentation in automotive labs

Who has used a Vector Network Analyzer?



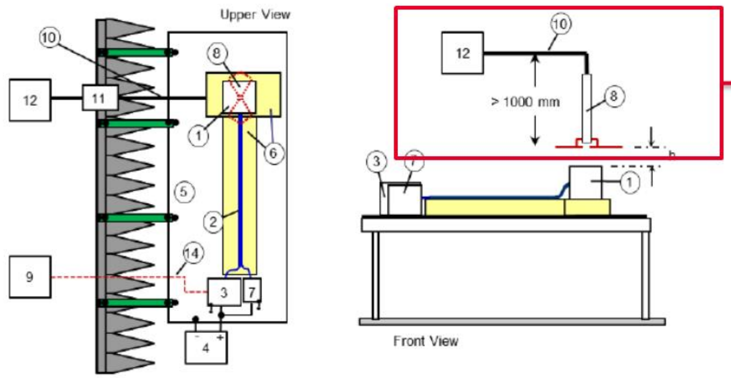
KEYSIGHT TECHNOLOGIES

RF Immunity: FMC1278 RI 115

Test Setup

RI 115 simulates near-field electromagnetic field exposure from cellular transmitters and covers the frequency range from 360 to 2700 MHz.

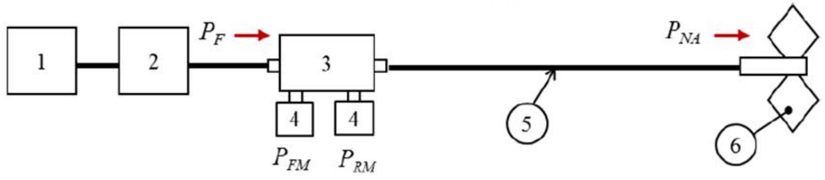
Figure 12-6: RI 115 Test Setup



Key:

1. DUT
2. Test Harness
3. Load Simulator
4. Power Supply
5. Ground Plane
6. Dielectric Support ($\varepsilon_r \leq 1.4$)
7. Artificial Network
8. Test antenna (Schwarzbeck antenna SBA9113 with elements 420NJ)
9. Support Equipment
10. Low loss coaxial cable assembly (See Annex C). Cable can be no closer than 1000 mm to antenna elements.
11. Bulkhead RF Coaxial Connector
12. RF Generation Equipment

Figure 12-7: RF Generation Equipment Setup



Key:

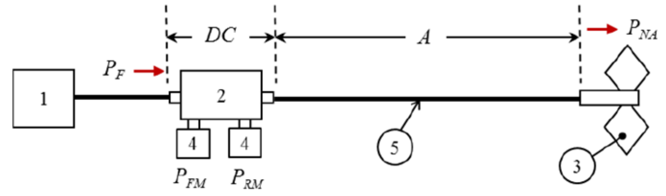
1. RF/uW Signal Generator
2. RF/uW Amplifier
3. Dual Directional Coupler (e.g. Werlatone C7711)
4. Peak Wideband Power Sensor (e.g. R&S NRP-Z81)
5. Low Loss Coaxial Cable
6. SBA Antenna

Prior to testing, characterization of test setup shall be performed in accordance with the procedures delineated in Annex C. The characterization will determine the forward power required to generate the specified net power.

Annex C (Normative): RI 115 Characterization Procedures

- Facilitates accurate delivery of net power to the transmit antenna.
- Procedure is **based on ISO 11451-3**, but considers the effects of **mismatch losses** that if not controlled will impact the accuracy of the net power.

Figure C-1: Simplified RI 115 Test Setup



Key:
1. Signal Source
2. Dual Directional Coupler
3. Transmit Antenna
4. Peak Wideband Power Sensor (e.g. R&S NRP-Z81)
5. Low Loss Coaxial Cable

The relationship between the measured forward and reflected power (P_{FM}, P_{RM}) and net power (P_{NA}) delivered to the antenna is:

$$P_{FM} = \frac{CF_F \cdot P_{NA}}{(A \cdot DC) \cdot (1 - \rho^2)} \quad \text{and} \quad P_{RM} = \frac{CF_R \cdot A \cdot \rho^2 \cdot P_{NA}}{(1 - \rho^2)}$$

Where:

P_{NA}: Net power to the antenna as delineated for Table 12-7

P_{FM}: Measured forward power at the directional coupler

P_{RM}: Measured reflected power at the directional coupler

ρ: Magnitude of reflection coefficient of transmit antenna.

$$\rho = \frac{VSWR - 1}{VSWR + 1}$$

A: Transmission loss of the cable (< 1).

$$A = 10^{\frac{A(dB)}{10}}$$

DC: Transmission loss of the directional coupler.

$$DC = 10^{\frac{DC(dB)}{10}}$$

CF_F: Forward coupling factor (< 1).

$$CF_F = 10^{\frac{CF_F(dB)}{10}}$$

CF_R: Reflected coupling factor (< 1).

$$CF_R = 10^{\frac{CF_R(dB)}{10}}$$

ISSUE:

The equations for forward/reflected power neglect the effect of mismatch losses which can impact the net power if not controlled. To assure accurate delivery of the net power to the transmit antenna, all transmission and mismatch losses must be managed or accounted for.

KEYSIGHT TECHNOLOGIES

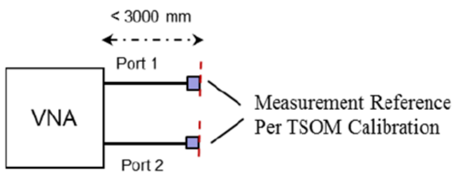
Annex C (Normative): RI 115 Characterization Procedures

Note:
Differences between EMC-CS-2009.1 (FEB10) and FMC1278 (JUL15): New Characterization procedure presented in Annex C. **Requires use of vector or scalar network analyzer.**

All measurements shall be performed using a Vector Network Analyzer (VNA) with S-parameter measurement capability. The VNA, when properly calibrated shall be capable of making loss measurements with an accuracy of less than 0.1 dB. The VNA shall be calibrated using the TSOM (Transmission, Short, Open, Match) method via high quality reference (traceable) standards. Cable connections between the VNA and sample shall consist of low loss cables of sufficient length to facilitate connection. Cable length shall not exceed 3000 mm. The cables shall be included in the VNA calibration per Figure C-3. Adaptors should be avoided, but if used, they shall be included in the VNA calibration.

Refer to Figure C-2 for component references for all measurements presented herin

Figure C-3: VNA TSOM Calibration



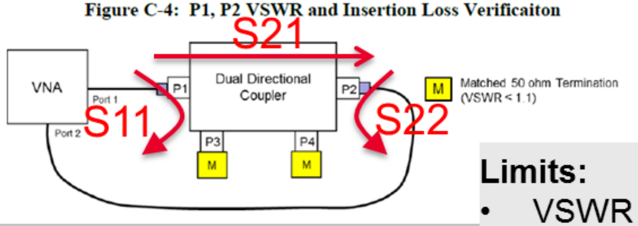
Test Parameters	Limits @ RI 115 Frequencies (360 MHz to 2700 MHz)
C.1 Directional Coupler Parameter Verification	
C.1.1 VSWR and Transmission Loss Measurement	• VSWR < 1.3 • Insertion Loss (DC) < 0.5 dB
C.1.2 VSWR and Forward Coupling Factor Measurement	• VSWR < 1.3 • Forward Coupling Factor (CF_F) > 20 dB
C.1.3 VSWR and Reflected Coupling Factor Measurement	• VSWR < 1.3 • Reverse Coupling Factor (CF_F) > 20 dB
C.2 SBA Antenna Reflection Coefficient Measurement	
C.3 RF Component VSWR Verification	• VSWR < 1.3
C.4 Characterization of VSWR and Transmission Loss for the Coupler/Antenna Interconnect	• VSWR < 1.3 of respective connections • Transmission loss (T1) < 4 dB

Annex C (Normative): RI 115 Characterization Procedures

C.1 Directional Coupler Parameter Verification

C.1.1 VSWR and Transmission Loss Measurement

Figure C-4: P1, P2 VSWR and Insertion Loss Verificaiton

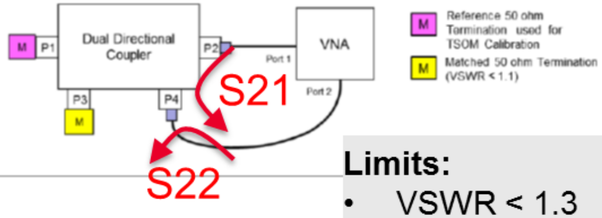


Limits:

- VSWR < 1.3
- Insertion Loss (DC) < 0.5 dB

C.1.3 VSWR and Reflected Coupling Factor Measurement

Figure C-6: Setup for Reflected Coupling Factor (CF_R) and P4 VSWR Verification

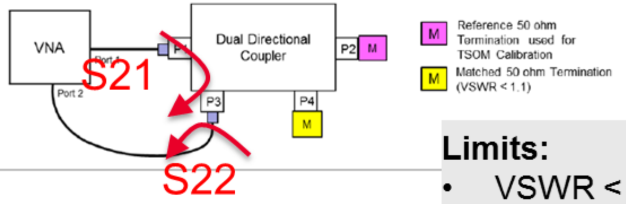


Limits:

- VSWR < 1.3
- Reverse Coupling Factor (CF_F) > 20 dB

C.1.2 VSWR and Forward Coupling Factor Measurement

Figure C-5: Setup for Forward Coupling Factor (CF_F) and P3 VSWR Verificaiton



Limits:

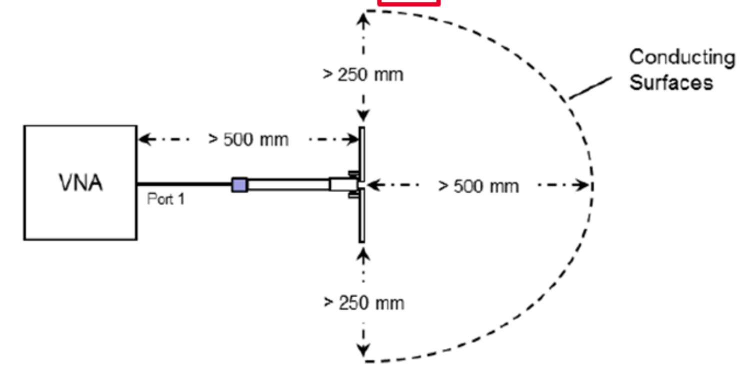
- VSWR < 1.3
- Forward Coupling Factor (CF_F) > 20 dB

KEYSIGHT TECHNOLOGIES

Annex C (Normative): RI 115 Characterization Procedures

C.2 SBA Antenna Reflection Coefficient Measurement

Figure C-7: Measurement of ρ of Transmit Antenna



Note: Only Schwarzbeck antenna SBA9113 with elements 420NJ shall be used for this test.

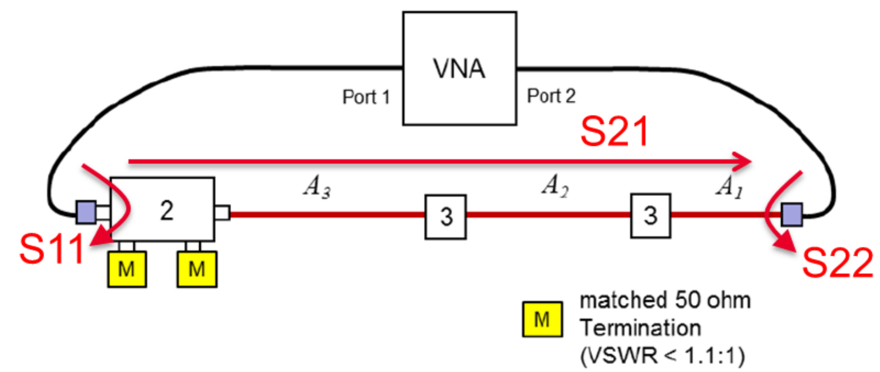
C.3 RF Component VSWR Verification

Each of the components used in the RI 115 test setup (e.g. cables, adapters, coaxial connectors) shall be verified to have a **VSWR of less than 1.3** over the entre RI 115 frequency range.

Annex C (Normative): RI 115 Characterization Procedures

C.4 Characterization of VSWR and Transmission Loss for the Coupler/Antenna Interconnect

Figure C-8: Measurement of T_1



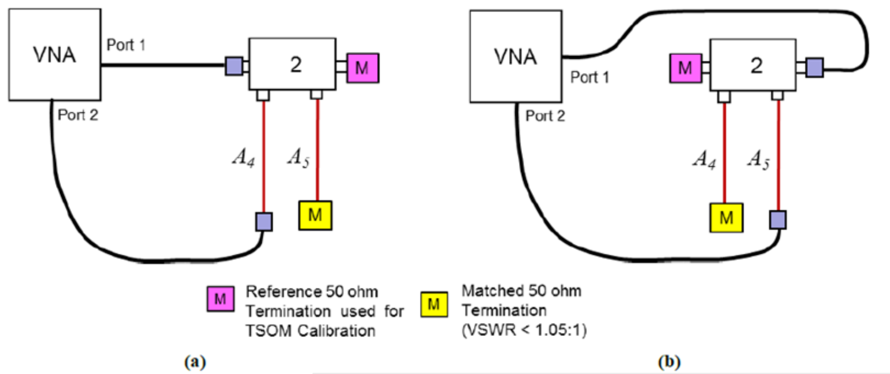
See Figure C-2 for compon

Limits:

- VSWR < 1.3 of respective connections
- Transmission loss (T1) < 4 dB

C.4 Characterization of VSWR and Transmission Loss for the Coupler/Power Sensor Interconnect

Figure C-9: Measurement of T_2 and T_3

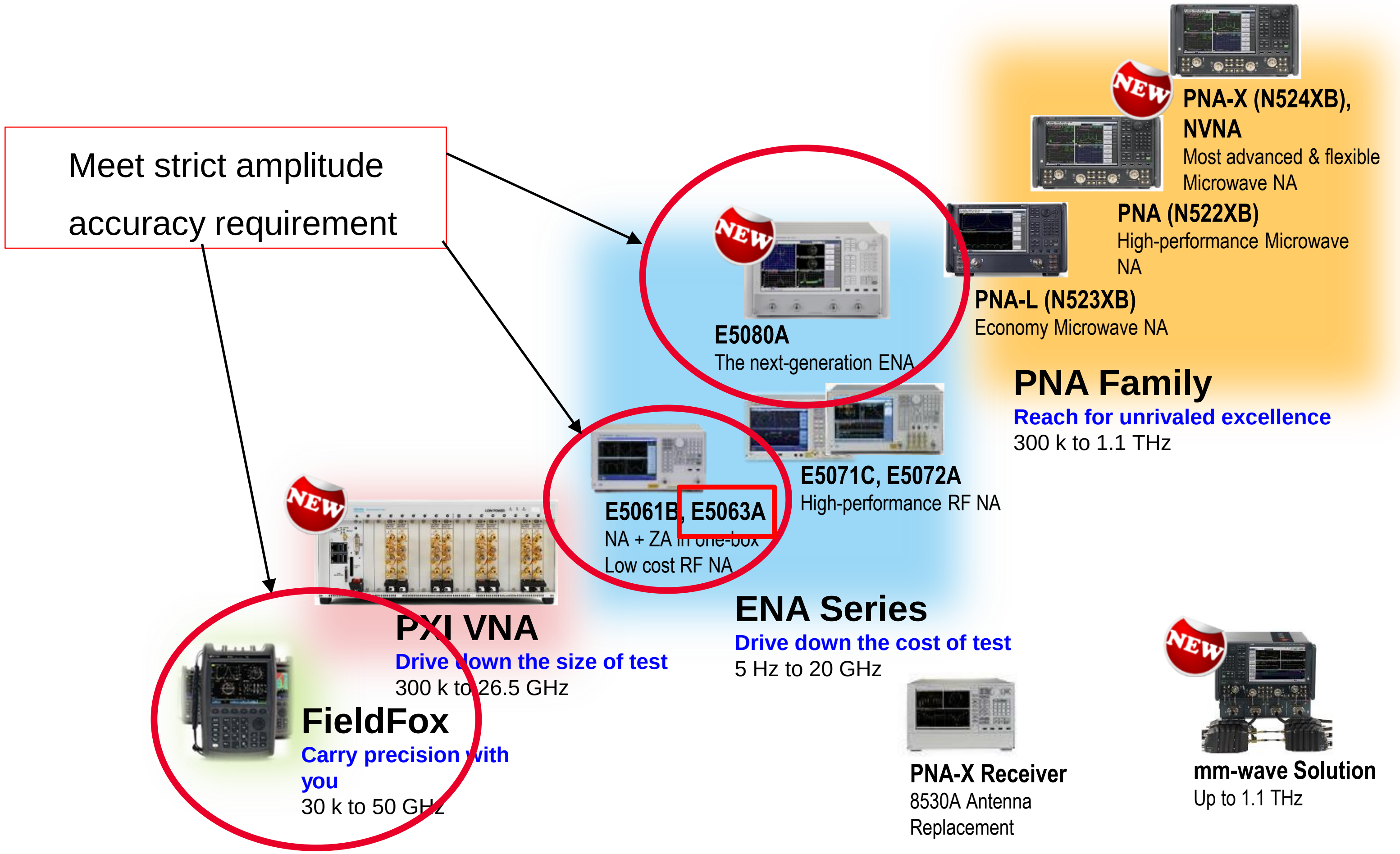


Limits:

- VSWR < 1.3 of respective connections

Keysight VNA Portfolio

Industry's Broadest Price/Performance Choices



Industry Challenge

HIGH FREQUENCY AND WIDE BANDWIDTHS FOR HIGH DATA THROUGHPUT

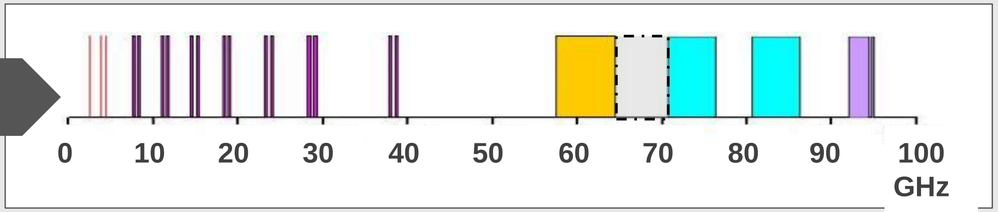
5G Industry Drivers

Massive growth in demand for mobile data

Radar Industry Drivers

Need for higher resolution requires wider bandwidth

Move to cm & mmWave for more bandwidth



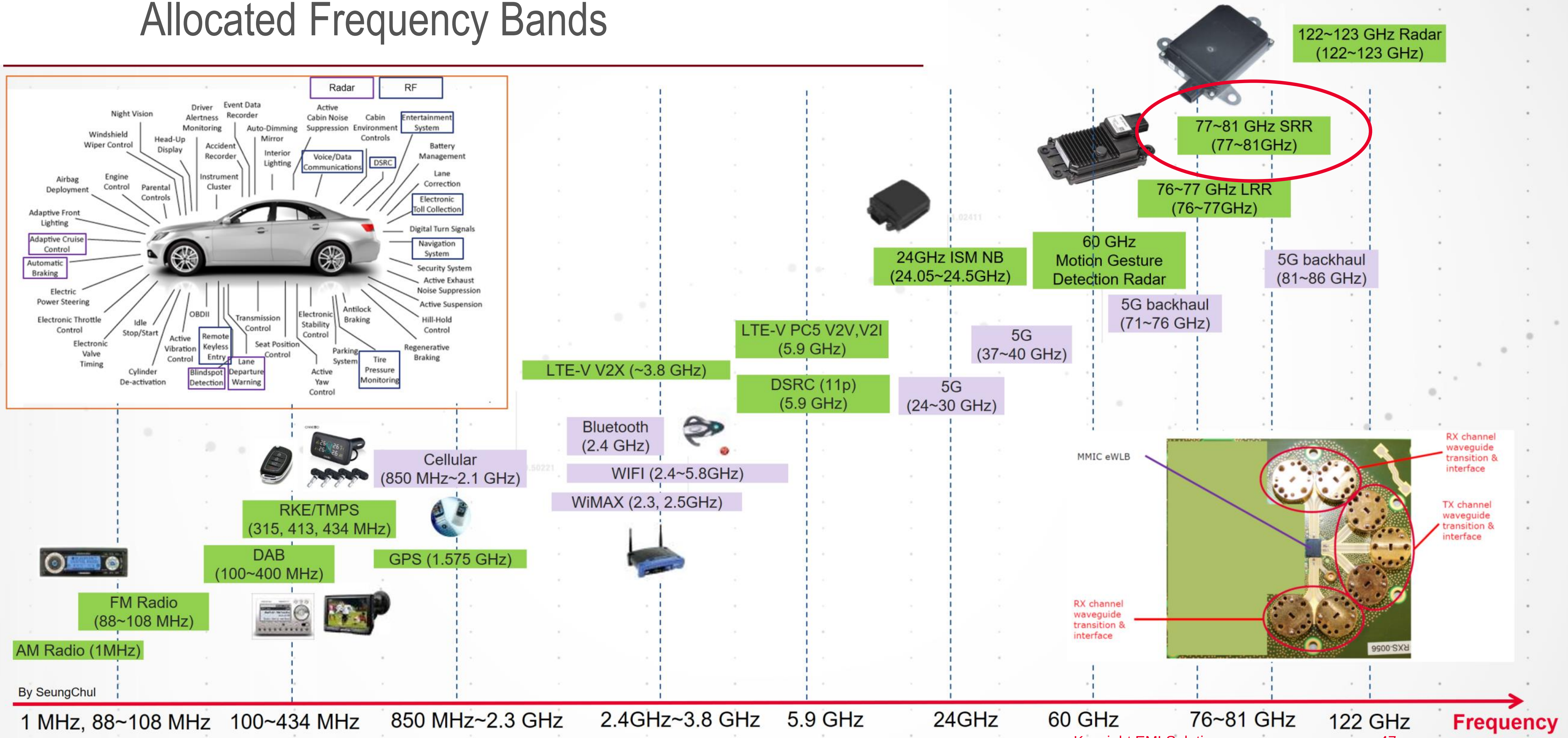
Design and measurement challenges

Challenging very wideband mmWave measurements

- Phase noise, IQ & freq response errors worse at mmW
- Wide bandwidth means more noise, more spurs, worse EVM

Insights

Allocated Frequency Bands



Who is working on Standards

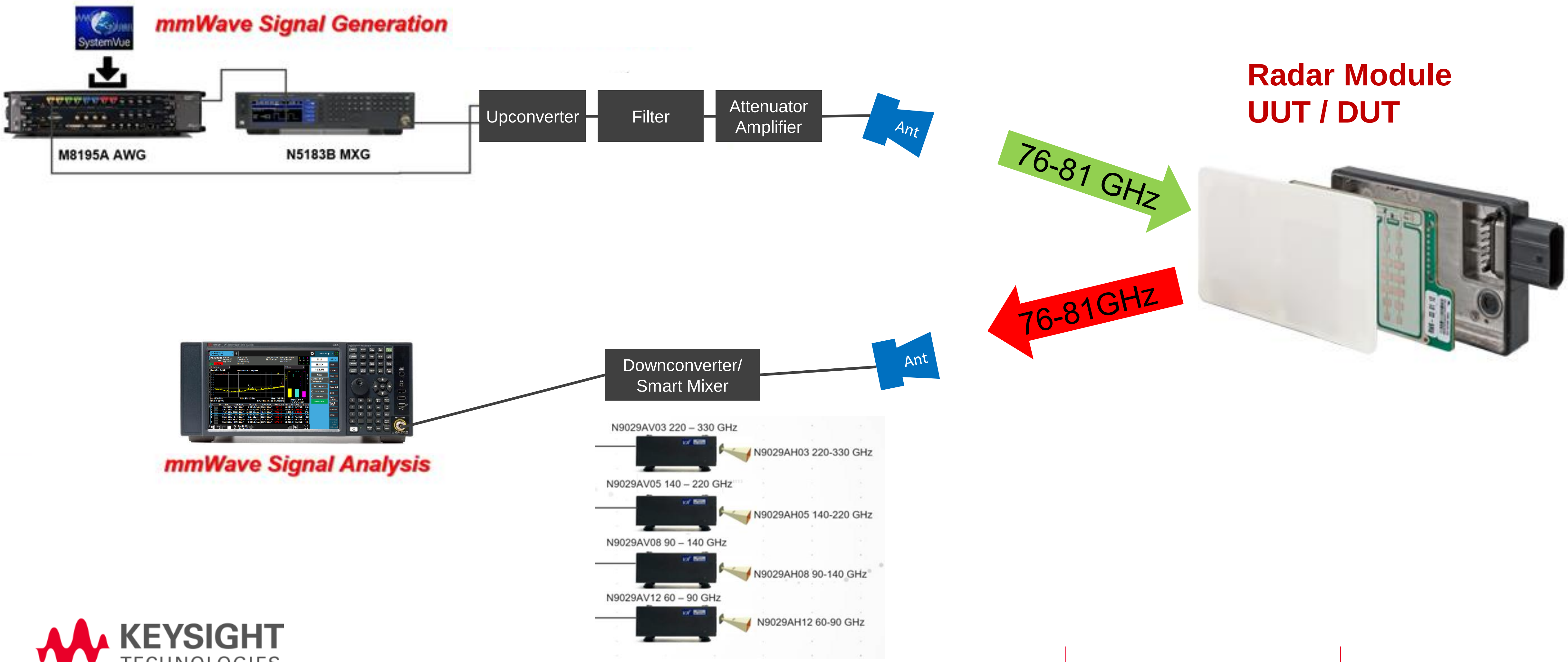
ETSI – European Telecommunications Standards Institute

Harmonised Standard ETSI EN 301 091-1				
Requirement			**Requirement Conditionality**	
No	**Description**	**Reference: Clause No**	**U/C**	**Condition**
1	Operating Frequency Range	4.3.1	U	
2	Mean Power	4.3.2	U	
3	Peak Power	4.3.3	U	
4	Unwanted emissions in the out-of-band domain	4.3.4	U	
5	Unwanted emissions in the spurious domain	4.3.5	U	
6	Receiver spurious emissions	4.4.2	C	It applies for any mode other than transmit mode.
7	Receiver in-band, out-of-band and remote-band signal handling	4.4.3	U	

**Out of band emissions requires testing up to 3x the maximum operating frequency

81 GHz x 3 = 243 GHz!

How do we achieve mmWave measurements?



Wrap up

EMI basics and EMI measurement

- **Which standard(s) to follow? *Depends on what, where, and how of product* (Generally, start from CISPR 25 for automobiles)**
- **The conducted and radiated emissions can be captured and analyzed with a spectrum analyzer and corresponding accessories**
- **Keysight spectrum analyzers help you on EMI pre-compliance test**

Understand the compromises/value in the precompliance scanning

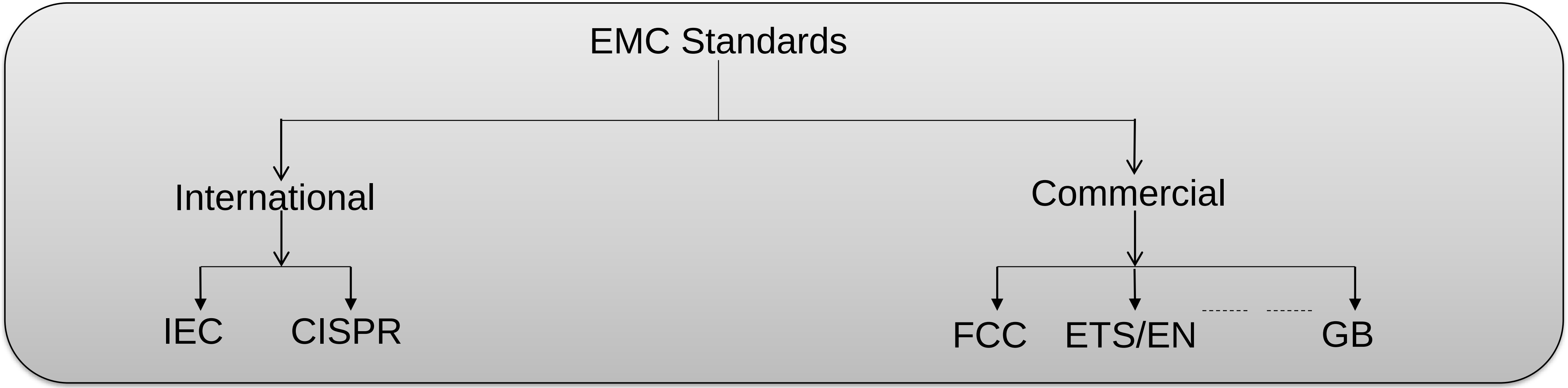
It cannot duplicate the final compliance test, but it can tell you the EMI trend and the change of trend in your device

Back up

EMC standards

From international to commercial

Categories:



CISPR standard Structure:

Basic Standards

- Provide general and fundamental rules
- Serve as a reference but not applicable to specific products

Generic Standards

- Provide essential test requirements and procedure in a specific environment
- Also provide limits

Product Standards

- Apply to specific products or families of products
- Provides test procedures and limits for these products

Emissions regulations

Comparison of regulatory agency requirements

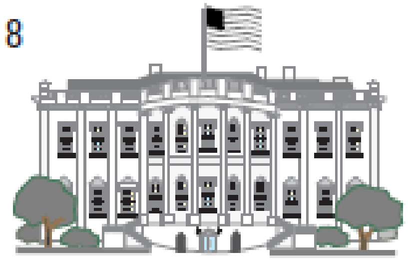
FCC	CISPR	EN's	Description
18	11	EN 55011	Industrial, scientific and medical equipment
—	12	—	Automotive
15	13	EN 55013	Broadcast receivers
	14	EN 55014	Household appliances/tools
	15	EN 55015	Fluorescent lights/luminaries
15	22	EN 55022	Information technology equipment
	—	EN61000-6-3,4	Generic emissions standards
	16	—	Measurement apparatus/methods
	25	EN 55025	Automotive component test

Emissions regulations in US

FCC regulatory agency requirements

Federal Communications Commission

Equipment Type	FCC
• Broadcast receivers • Household appliances • Fluorescent lights / luminaries • Information technology / equipment (ITE)	Part 15 Class A Industrial Class B Residential
• Industrial, scientific, and medical (ISM)	Part 18



• Conducted measurements: 9 kHz – 30 MHz
• Radiated measurements: 30 MHz - 1000 MHz, 40 GHz

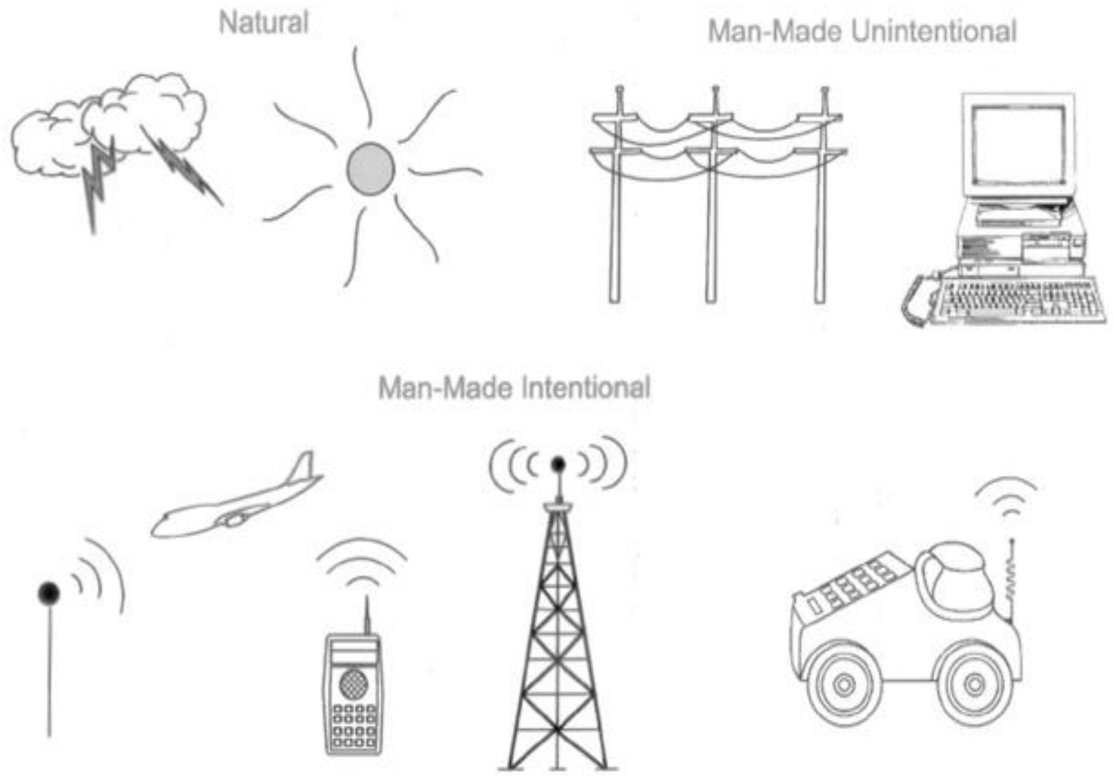
Note:
FCC part 15 states that any digital device which uses timing pulses (clocks) in excess of 9kHz, must not unintentionally emit radiation over certain limits. This testing is required up to the 5th harmonic of the fastest clock but less than 40 GHz. For example, a computer or radio with a 1.2 GHz processor must meet FCC Class B limits up to 6 GHz.

FCC Part 18 requires devices that operate (transmit) from 30 MHz to above 1Ghz test to 10^{th} Harmonic, examples:

250 MHz 10^{th} harmonic: 2.5 GHz
500 MHz 10^{th} harmonic: 5.0 GHz
1.0 GHz 10^{th} harmonic: 10 GHz
2.4 GHz 10^{th} harmonic: 24 GHz

KEYSIGHT TECHNOLOGIES

Source of EMI



From Natural power:

- thunder; volcano, typhoon
- electrostatic discharge
- sun, outer space
- …

From Man-made Unintentional:

- Switching power supplies
- Switching frequencies and harmonics
- Load-dependent emissions
- Clock and Data
- High speed clocks, data, edges
- High speed interfaces
- Switching controls
- …

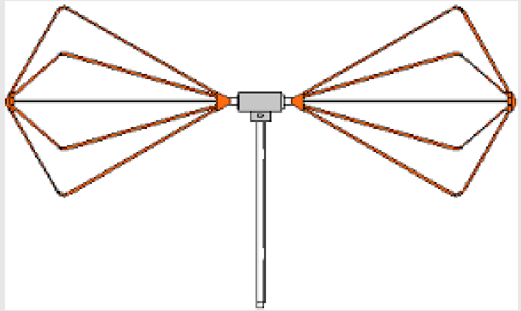
From Man-made Intentional:

- Broadcasting, cellular communication
- Radar, GPS
- Wireless charging
- …

About Antenna type

	Commercial electronics	Automotive electronics	Military
Frequency range	30 MHz – 1 GHz	10 kHz – 1 GHz	10 kHz – 18 GHz
Antenna type	Biconical Log periodic	Biconical Log periodic Whip antenna	Whip antenna Biconical 喇叭天线

Log periodic antenna



Biconical antenna

Whip antenna

Horn antenna

Recommended design practices

Recommended Design Practices: Device Selection

- Use lowest clock speed possible.
- *Use multiple clock oscillators instead of routing clock lines whenever possible.*
- Use minimum acceptable rise-time parts.
- Use low-ESR , low - ESL capacitors for decoupling/filtering.
- *Use multilayer PCBs whenever possible.*
- Always use toroidal transformers in switching power supplies.
- Watch out for DC saturation of ferrites in power supply lines.
- Use SMT parts whenever possible.
- Avoid IC sockets whenever possible.
- Avoid using ribbon cables for data or clock signals.
- Keep cables as short as possible.

Recommended Design Practices: PCB layout

- Segment board to separate high-frequency logic from low-frequency I/O as much as possible.
- Always route lines over ground/power plane "bridges" over segmentation "moats". The width of the bridges should extend at least 2 trace widths past outside traces.
- Ground the PCB to a metal plate parallel to it in a 2" grid. The ground plate should be as close to the PCB as possible, and should lip up to be higher than the PCB on the sides. The plate itself should be either the base of the enclosure or single-point grounded near the safety ("green-wire") ground attachment point.
- *If a 2-layer board is used, fill one side with ground as much as possible,* and eliminate as much trace work from that side as possible.
- Place decoupling capacitors as close to the IC Vcc and GND pins as possible -*even on analog parts* - we have seen Hall-effect sensor IC's oscillate at 40 MHz when no decoupling was used !
- Filters should always be place as close to the end of the trace as possible.
- I/O connector filters must go as close to the I/O port as possible; avoid ground planes between a common-mode filter and the connector it is filtering - the ground plane should stop at the circuit side of the CM choke.
- Buss lines, clock lines, and other periodic lines should be routed on layers adjacent to inner plane layers. Slower and low-susceptibility lines should be routed on outer layers.
- Always route clocks first and lock them. Avoid placing other lines within 2 trace widths of a clock line
- Ferrites and other filters should be reviewed to see if shapes can be used to allow replacement of the series elements with 0-ohm resistors at the prototype stage.
- Whenever possible, 45-degree bends should be used at corners.
- Minimize vias (connections between layers on a PCB).
- Do not route clock traces along edges of PCB or PCB segments.
- Allow at least 2 trace widths between edge-most trace and outside edge of power-plane.
- Treat Read/Write traces as clock traces.

Recommended Design Practices: Mechanical design

- Try to provide an adjacent sheet metal plane with multiple attachments (every 2 inches recommended) to any PCB. Attachments (usually standoffs) should be short and wide as possible. If the product has a non-metallic enclosure, this "ground plate" is a requirement.
- Minimize longest side of any enclosure seam or opening. Greater than 2" is usually unacceptable.
- Allow for overlapping at seams.
- Do not allow paint to cover mating surfaces.
- Avoid dissimilar metals.
- All I/O connectors should be co-located.
- Avoid openings through which ESD can jump to electrical components. ESD can jump about 1/2 ", but can crawl almost 2" over plastic surfaces at 15kV.
- Ground all metal with short, wide ground bonds; the "green-wire" ground should not extend into the product interior more than 1.5".
- Avoid requiring large holes in PCB's.
- Allow for secure mounting of cables (up against metal whenever possible).
- Avoid long sections of metal which extend over electronics and are not grounded at short intervals.
- Use mechanical means for switches which would otherwise have long leads back to PCB.
- Avoid stacking PCBs or placing PCBs in parallel without having shielding wall in between.
- Avoid long lines to motors.
- Motor leads must be twisted, and should be run along metal as much as possible. Motors will usually require shielding.
- Review all sensor locations for ESD susceptibility. Sensor lines should be twisted and should be run along metal whenever possible.
- High-sensitivity analog circuitry will always require extremely tight shielding.

CISPR Product Groups

- **CISPR 11 -** Industrial, Scientific, and Medical (ISM) Radio-Frequency Equipment
- **CISPR 12 -** Vehicles, Motorboats, and Spark-Ignited Engine-Driven Devices
- **CISPR 13 -** Sound and Television Broadcast Receivers and Associated Equipment
- **CISPR 14 -** Household Appliances, Electric Tools, and Similar Apparatus
- **CISPR 15 -** Electrical Lighting and Similar Equipment.
- **CISPR 17 -** Suppression Characteristics of Passive Radio Interference Filters and Suppression Components.
- **CISPR 18 -** Overhead Power Lines and High-Voltage Equipment
- **CISPR 20 -** Sound and Television Broadcast Receivers and Associated Equipment
- **CISPR 21 -** Interference to Mobile Radio communications
- **CISPR 22 -** Information Technology Equipment–Radio Disturbance Characteristics
- **CISPR 24 -** Information Technology Equipment–Immunity Characteristics
- **CISPR 25 -** Receivers Used on Board Vehicles, Boats, and on
- **CISPR 32** – Multimedia devices emission testing (under development)
- **CISPR 35** – Multimedia devices immunity testing (under development)

Commercial EMC Standards and Entities - Examples

Country /Organization	Entity	Standards
IEC	CISPR	CISPR Pub. xx
IEC	TC77	IEC 6xxxx
EC	CENELEC	EN 550xx
US	**FCC, DoD**	FCC Part xx, MIL-STD. xxx
Canada	CSA	ICES xxx
Australia/NZ	AS/NZS	AS/NZS CISPR xx
Japan	VCCI	J550xx
China (Mainland)	CCC, MoD	GB xxxx- xxxx GJB xxx- xx (equivalent to Mil-STD)
Korea	MIC	Equivalent to EN 550xx
Taiwan	BSMI	CNS xxxx