Practical EMI Precompliance Test – with a CXA signal analyzer

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Xiaowei Zhang
CXA/Value RF Product Line
Brand Manager

KEYSIGHT TECHNOLOGIES

EMI is about unwanted interference

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

Agenda

– EMC Basics

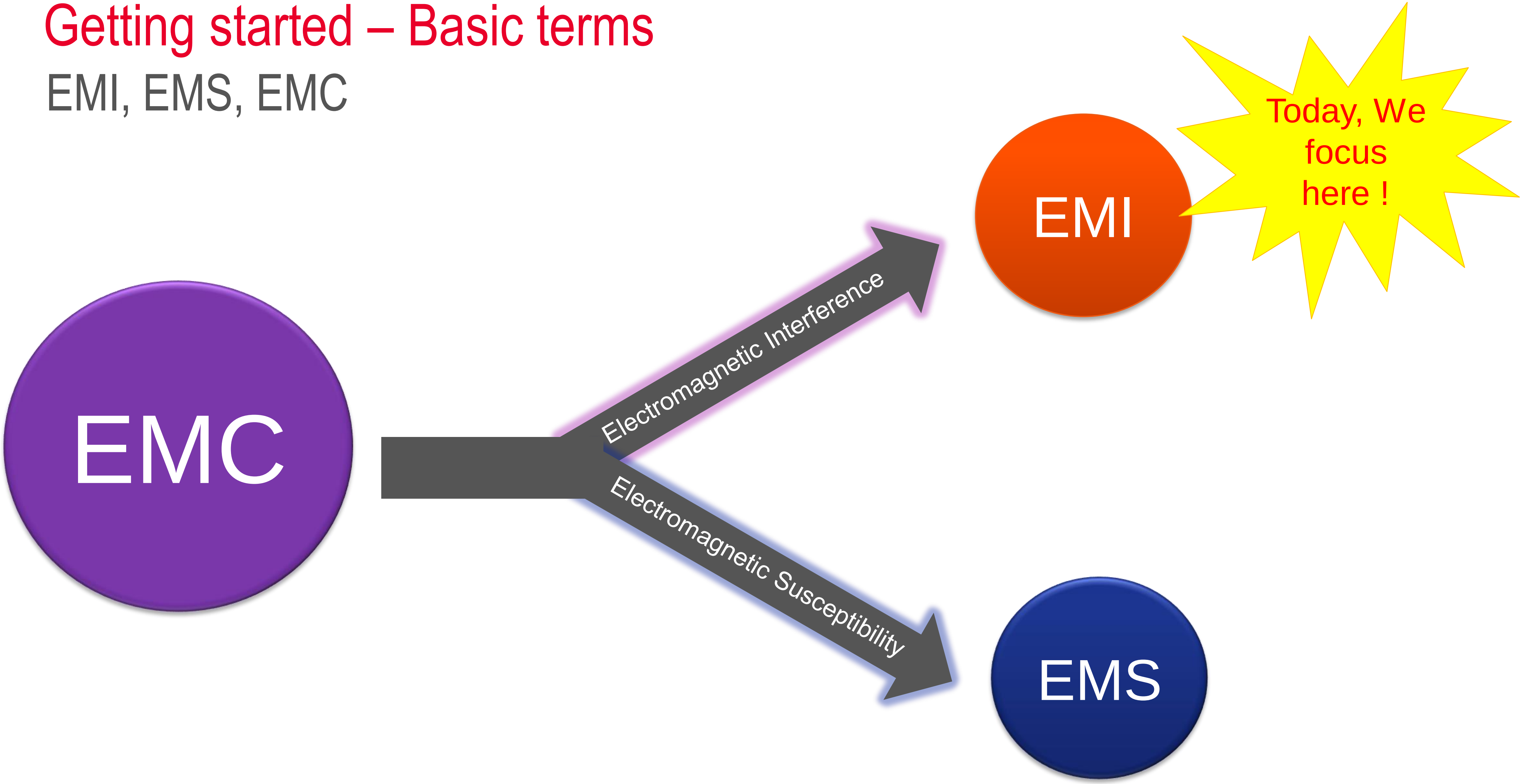
– An introduction of regulatory standards

– The best practice during the product development cycle

Section 1 – EMI Basics

Getting started – Basic terms

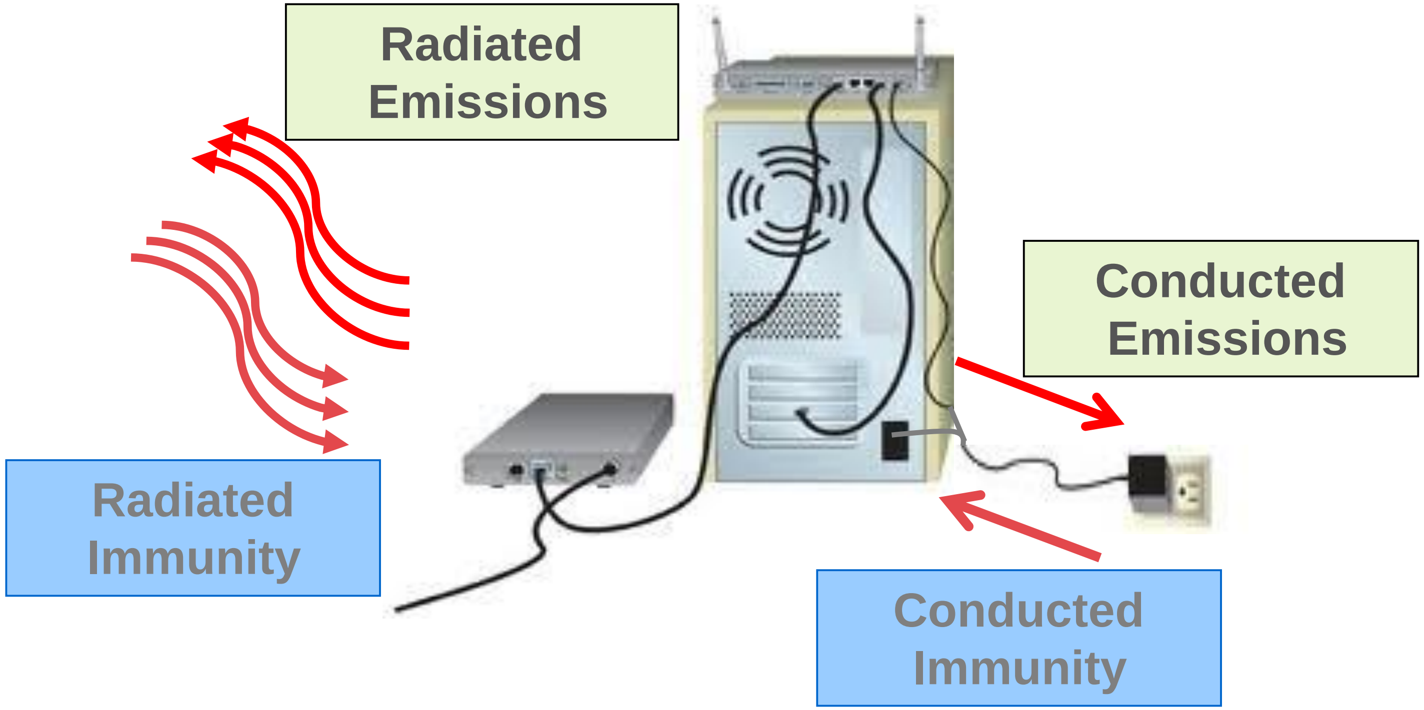
EMI, EMS, EMC



What is EMI?

Electromagnetic Interference

- Wikipedia: 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



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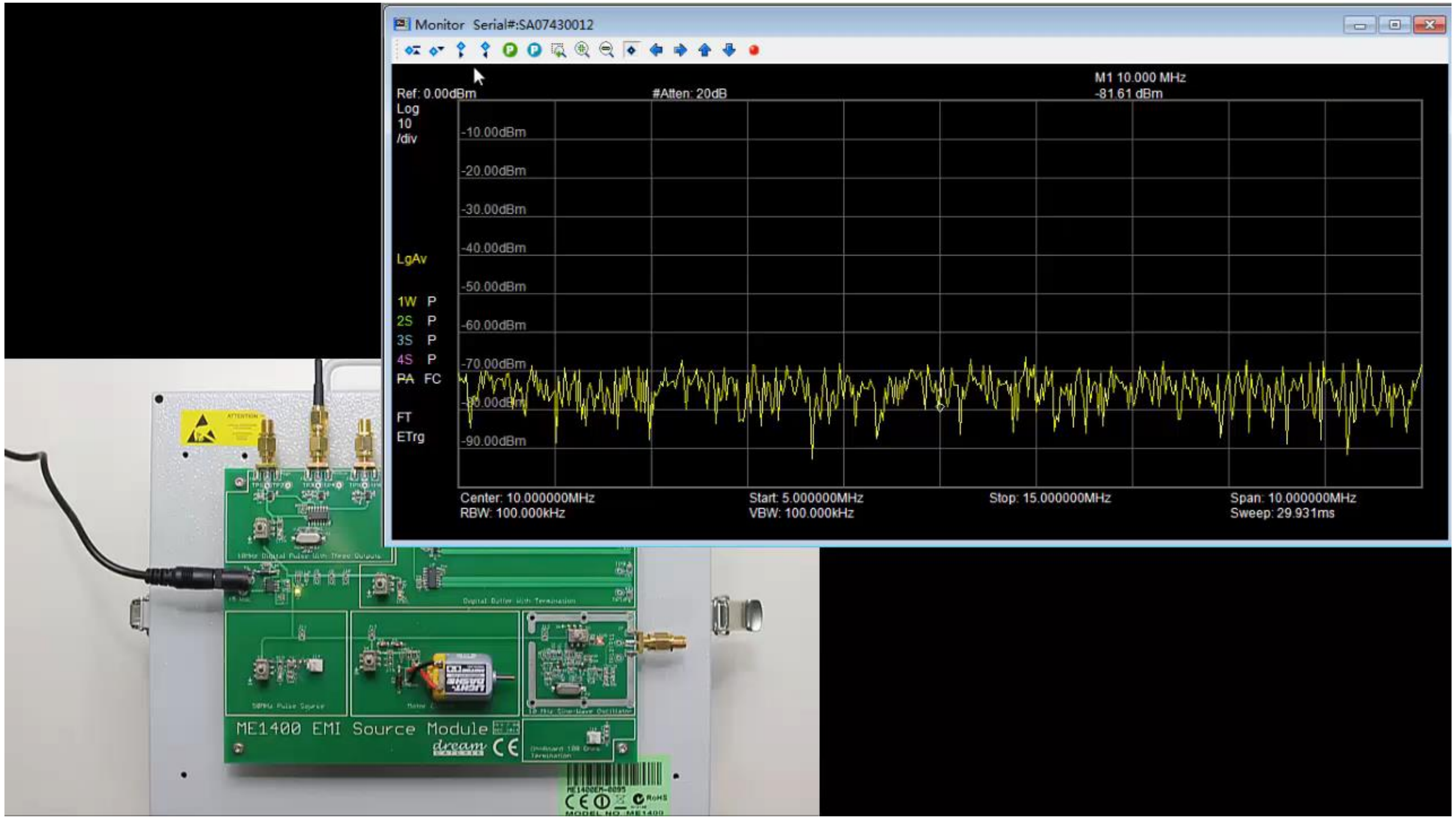
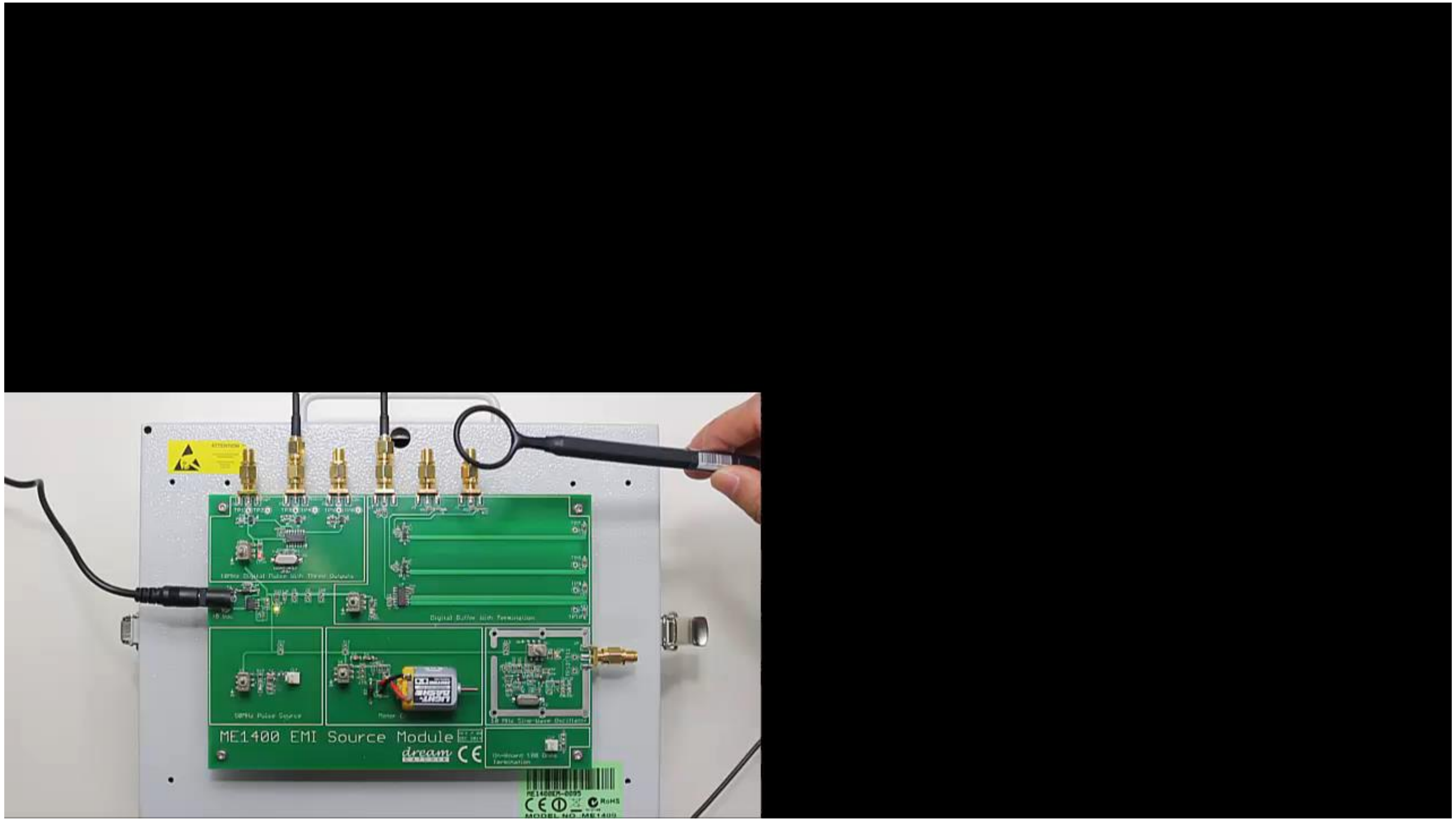
EMI Phenomena

Interference from motor circuit



EMI Phenomena

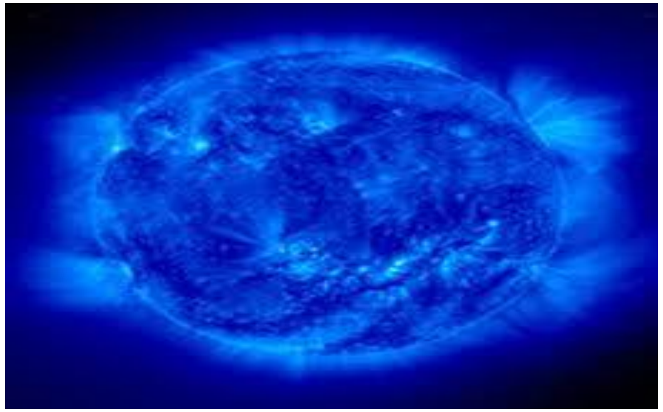
Interference from High speed digital circuit



Sources of EMI (1/3)

Natural Sources (also called **radio-frequency interference** or **RFI**)

- Natural sources below 10MHz are dominated by atmospheric noise generated by electrical storms.
  - Lighting
- Above 10 MHz natural sources consist primarily of cosmic noise and solar radiation.



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Sources of EMI (2/3)
Intentional Man Made Sources

- 2-way radio communication
- Cellular Phones
- Radio and TV broadcasters
- Internet Of Things (IoT)
- Oscillators

Caused by:

– Transmitted signal
  - Intended transmission of a frequency
  - Sometimes called ‘On carrier’ or ‘Carrier frequency’
  - A Continuous Wave (CW) signal
    - Control Signal
    - Beacon
  - Modulated Signal
    - Analog Voice or Data
    - Digital Voice or Data

Sources of EMI (3/3)

Un-Intentional Man Made Sources

- Toaster ovens
- Bug zappers
- Hair dryers
- Electric Motors
- Etc.

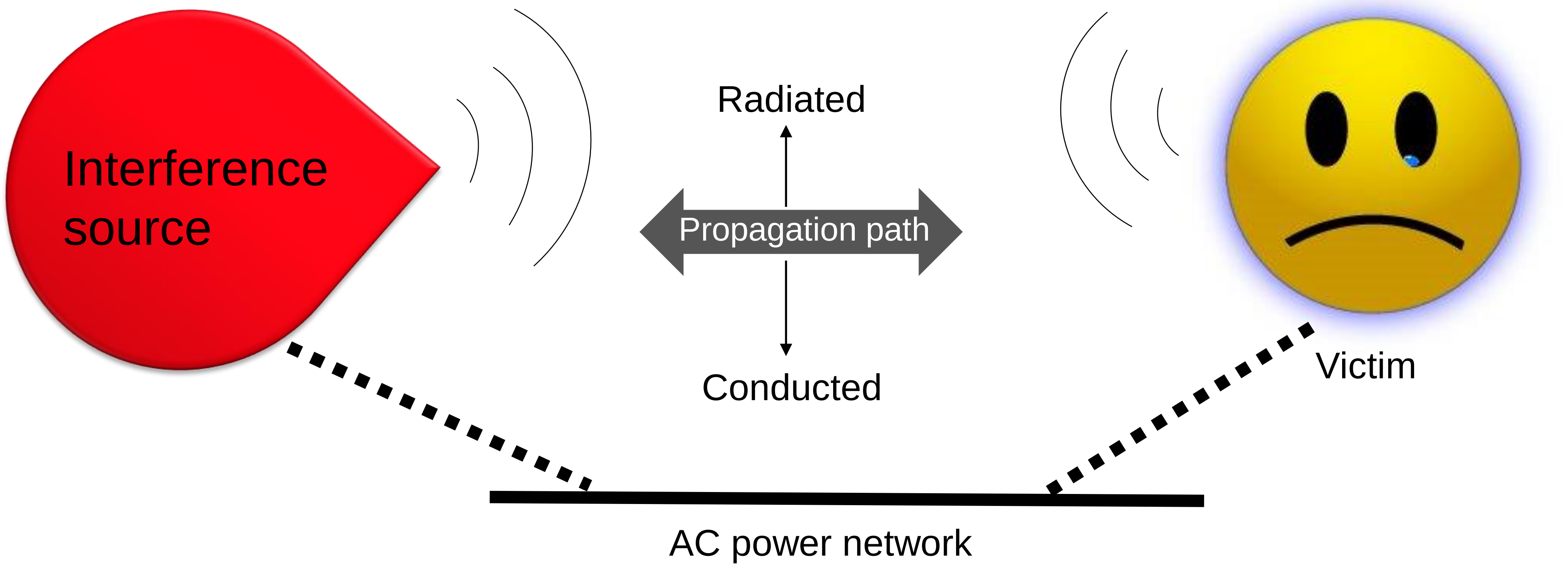
Caused by:

– Leakage
  - RF frequency leaking out of an enclosure

– Harmonics
  - Multiples of a frequency

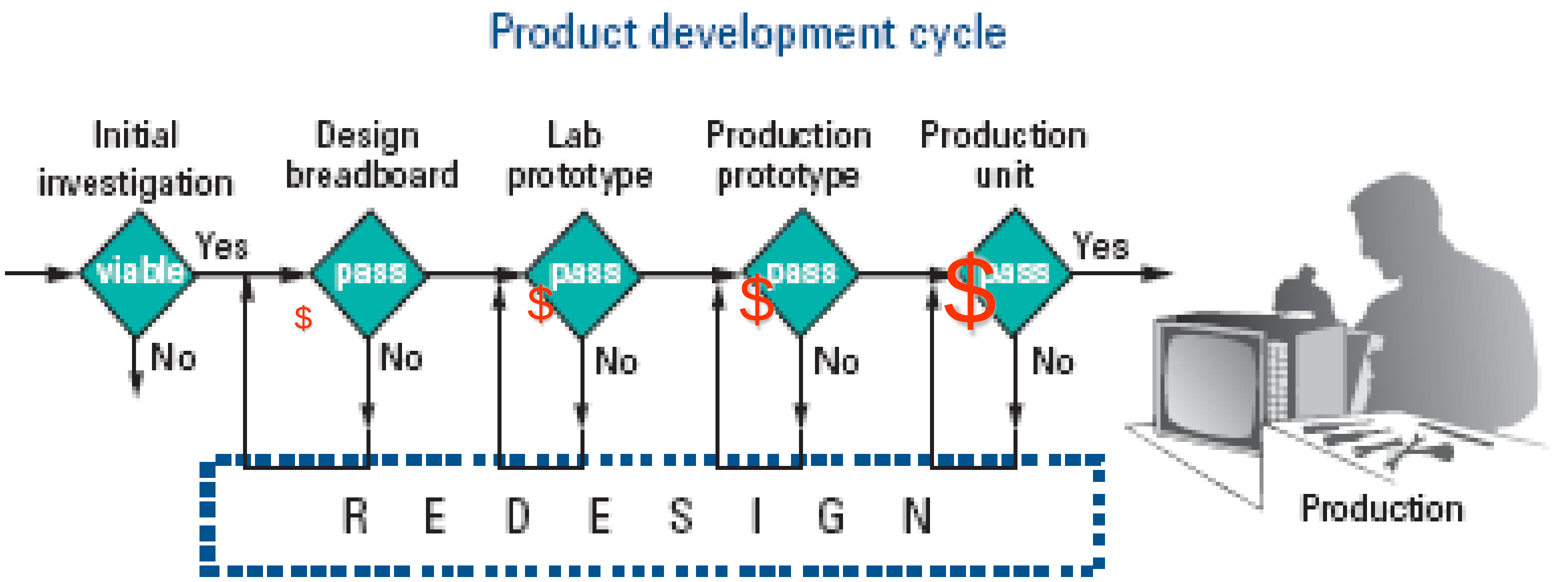
– Spurs
  - Addition and subtraction of frequencies can generate spurs

3 elements in EMC



The impact of an EMI failure during the product development cycle

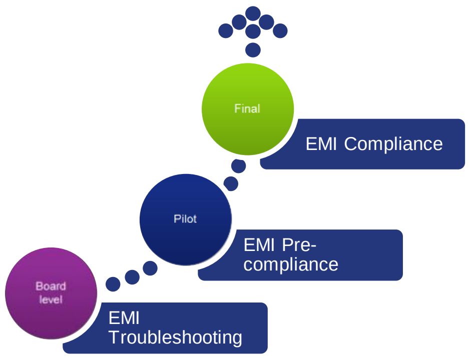
Many manufacturers use (EMI) measurement systems to perform conducted and radiated EMI emissions evaluation prior to sending their product to a test facility for full compliance testing.

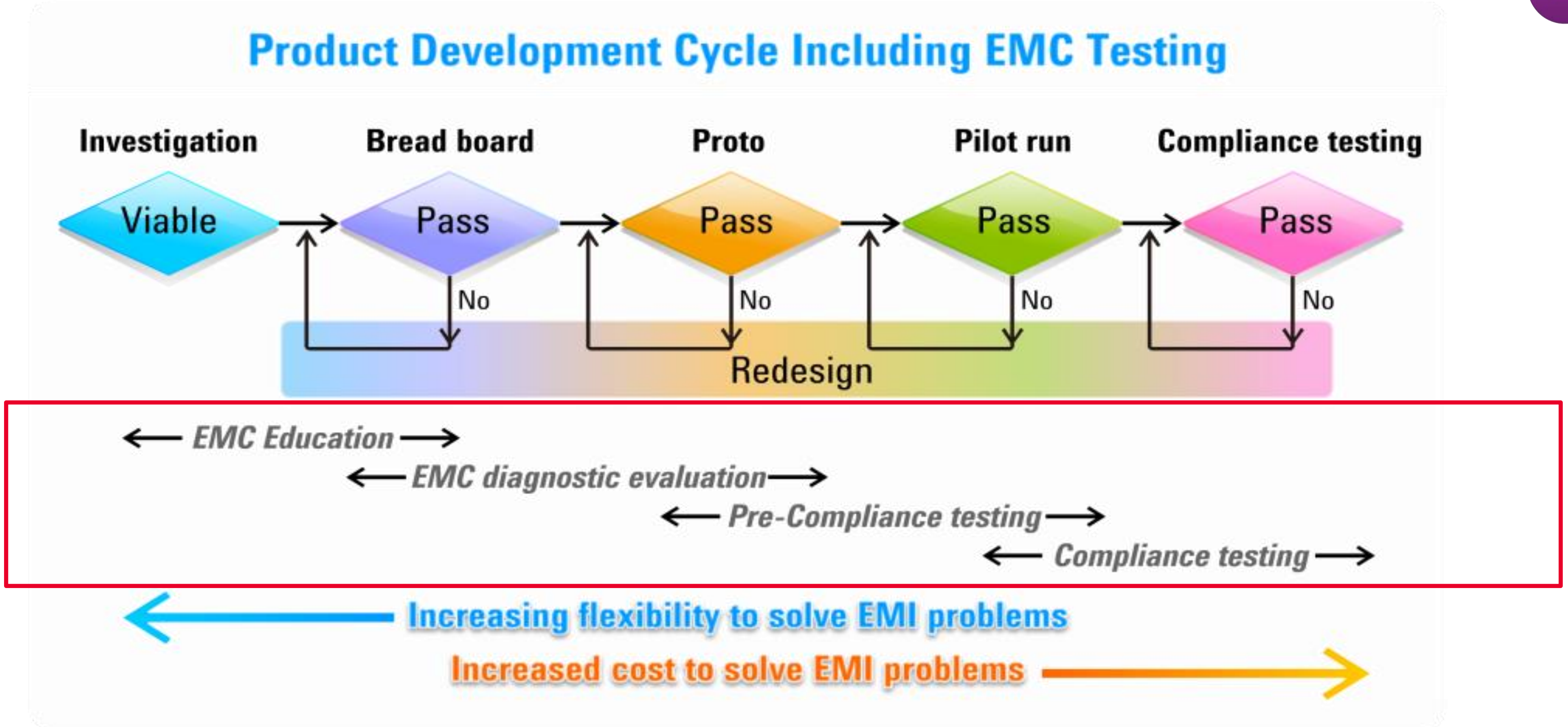


The cost of an EMI failure increases as the product development cycle moves on !

Important !

EMC evaluation is along with your product NPI cycle



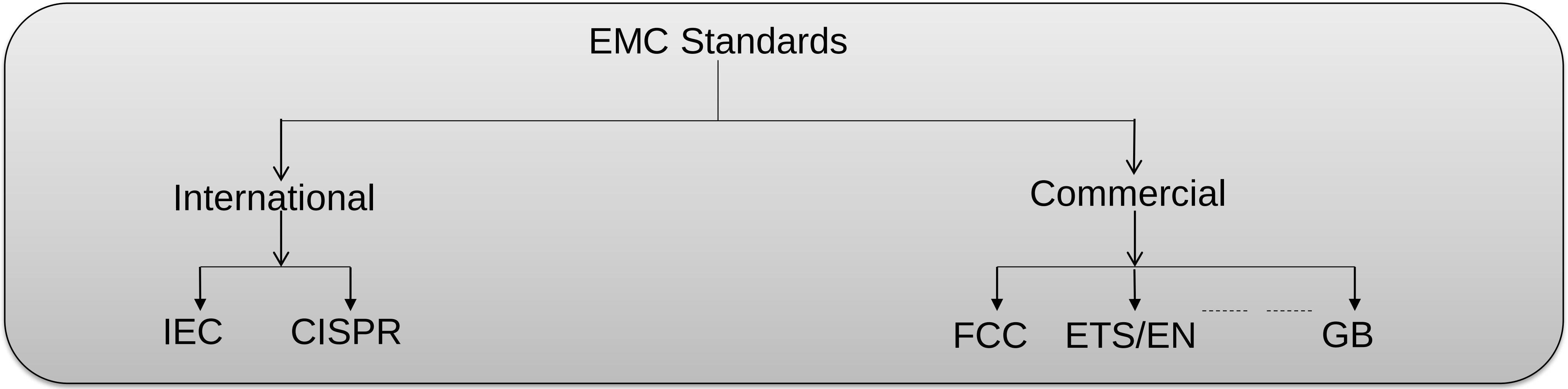


Section 2 - An introduction of regulatory standards

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

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CISPR Recommends Commercial Limits, Measuring Equipment and Methodologies

– **CISPR** ***(Comité International Spécial des Perturbations Radioélectriques***)
English: (Special International Committee on Radio Interference)

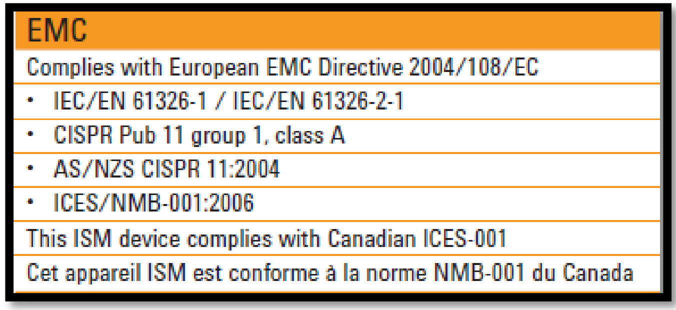
- A sub committee of the IEC (International Electrotechnical Commission)
- Determines and recommends required emissions and immunity:
  - **limits** for products sold in the worldwide commercial market
  - **test equipment requirements**
  - **test procedures/methodologies**

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)

Example of Products subject to CISPR 11 Testing

T&M instruments follows CISPR 11


EMC

Complies with European EMC Directive 2004/108/EC

- IEC/EN 61326-1 / IEC/EN 61326-2-1
- CISPR Pub 11 group 1, class A
- AS/NZS CISPR 11:2004
- ICES/NMB-001:2006

This ISM device complies with Canadian ICES-001

Cet appareil ISM est conforme à la norme NMB-001 du Canada

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Examples of Products Subject to CISPR 14 Testing






Key Influencer - Commercial Regulations

<u>IEC/CISPR</u>

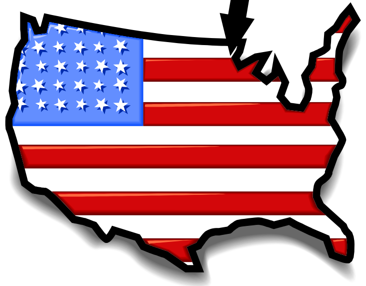
Measurement Std. – CISPR 16
Equipment Std. – CISPR 16
Product Std. - CISPR 11-15, etc.
IEC 61XXX

GB

VCCI

CENELEC
EN

ANSI
FCC



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

Which Standards to test against?

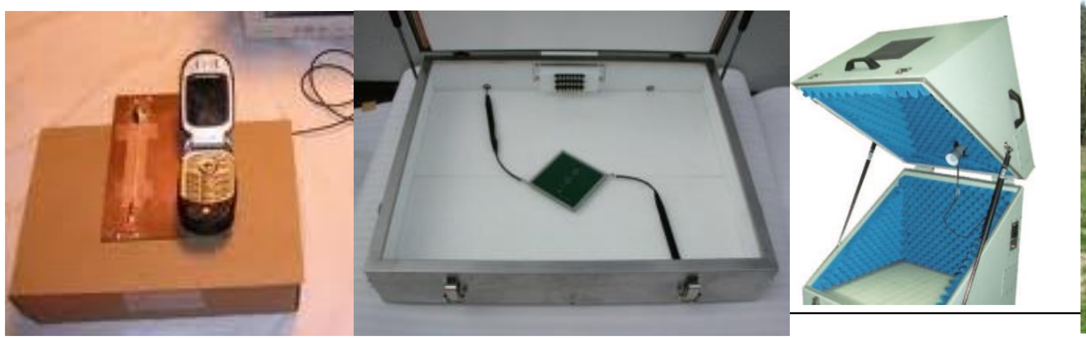
Depends on your product plan

Three preliminary questions to answer when developing a product:

1. Where will the product be sold (for example, Europe, United States, Japan)?
2. What is the classification of the product?
   a) Information technology equipment (ITE)
   b) Industrial, scientific or medical equipment (ISM)
   c) Automotive or communication
   d) Generic (equipment not found in other standards)
3. Where will the product be used (for example home, commercial, light industry or heavy industry)?

Section 3 – EMI precompliance measurement overview

Example Radiated Emission Testing Environments



Bench Top – semi-anechoic

OATS

Chambers

Definitions:

Anechoic Chamber → Room with no echoes; absorbers on all 6 sides

Semi-anechoic → Ground plane; reflection like OATS; correlation to OATS

OATS → Open Area Test Site

EMI Measurement Units

– **<u>Conducted Emissions</u>**

- Commercial: dBμV
- Military: dBμA

– **<u>Radiated Emissions</u>**

- Electric field strength: dBμV/m
- Magnetic flux density: dBpT

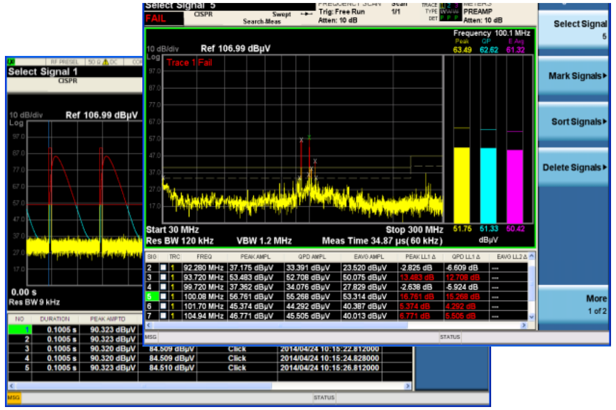
Assuming a 50 ohm impedance, power measurement may be converted as follows:

dBμV = dBm + 107
dBm = dBμV – 107
dBμA = dBμV - 34
dBμA = dBm + 73
dBμV/m = dBμV + AF (Antenna Factor)
dBpT = dBμA /m + 2.0

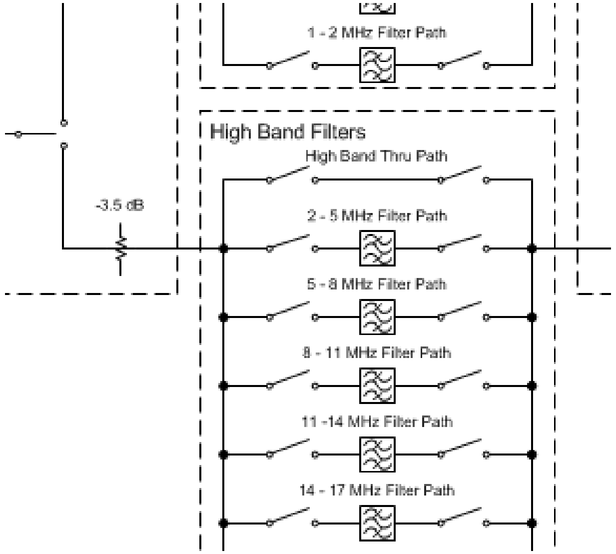
/m=meter
pT= pico Teslas (magnetic flux density)

Many power converting tools available on-line

Pre-compliance vs. Full Compliance Solutions



Pre-compliance Measurement Solutions:
Evaluate the conducted and radiated emissions of a device using correct detectors and bandwidths **before going to a test house** for compliance testing. Gives an approximation of the EMI performance of the EUT



Full Compliance Measurement Solutions:
Full compliance testing requires an EMI receiver that is tested to meet all CISPR 16-1-1 requirements.

Compliance vs. Precompliance

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

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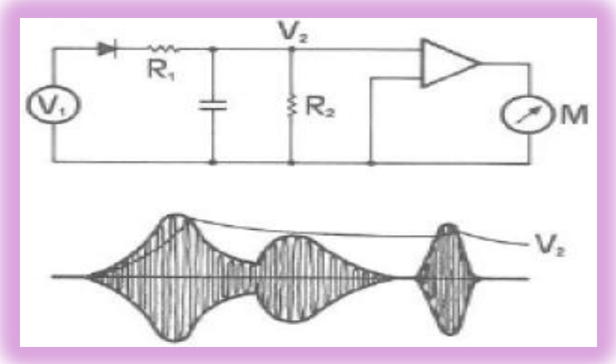
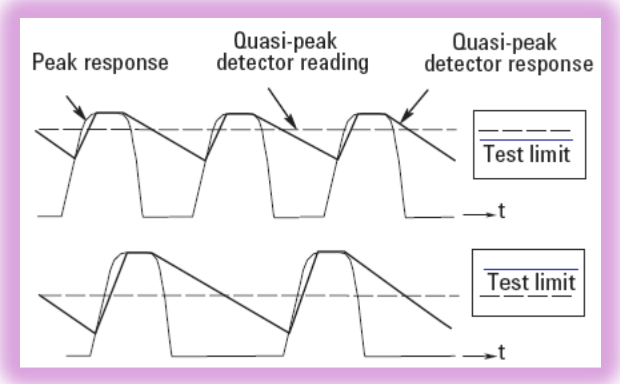
About quasi-peak detection

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

– Why use Quasi-peak detection?

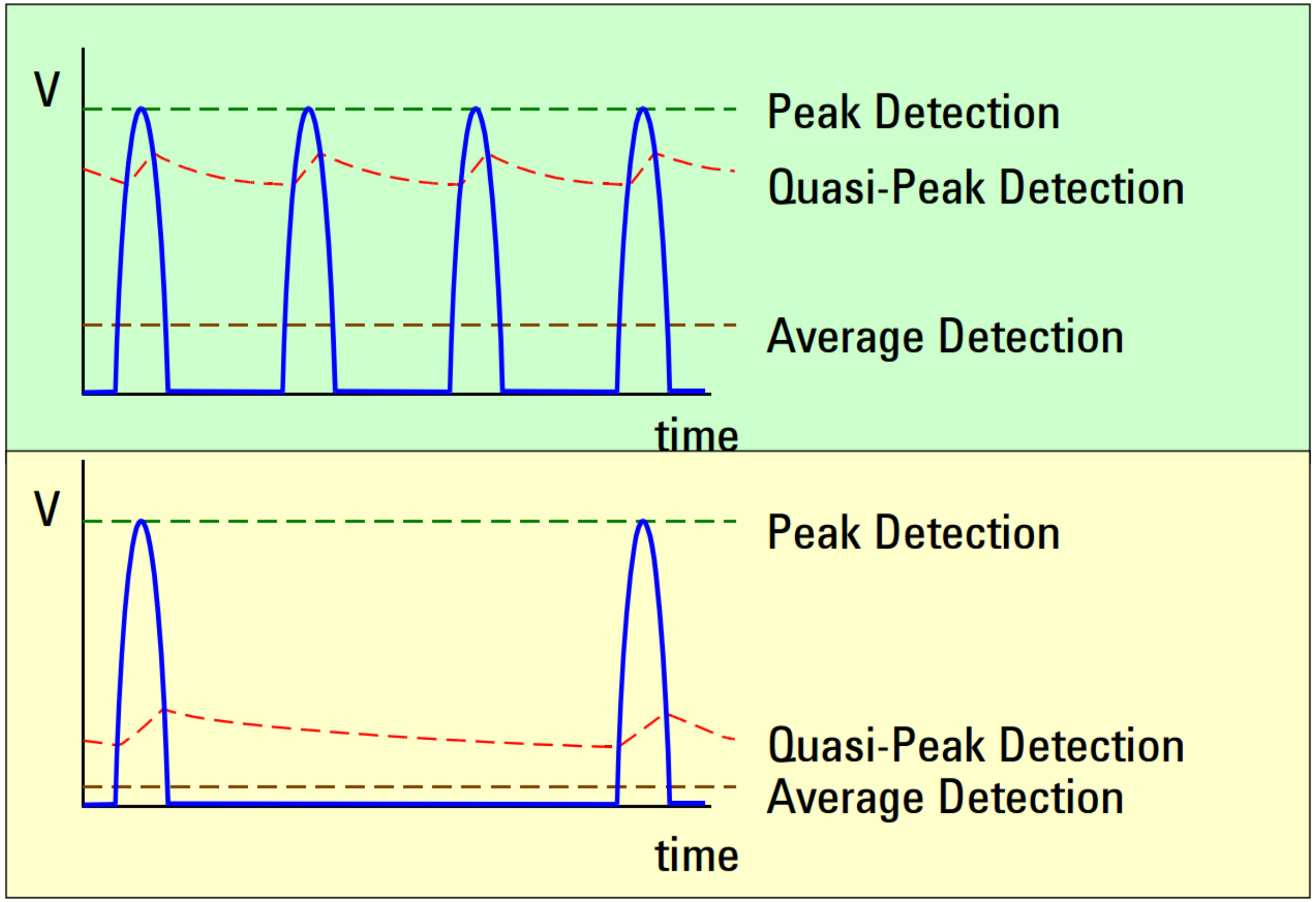
- Used for CISPR based measurements.
- weighting signals as a function of repetition rate.
- Lower repetition rate noise has less "annoyance factor" and thus gets less emphasis
- CISPR bandwidth: 200 Hz, 9 kHz, and 120kHz bandwidth.





Detection Modes

Peak ≥ Quasi-Peak ≥ Average



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

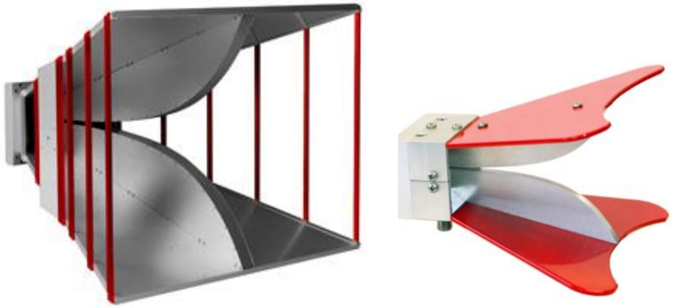
Military (MIL-STD-461)

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

Accessories of an 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)

More example items

LISN: Line Impedance
Stabilization Network

Close Field Probe Set:
Diagnostics antennas

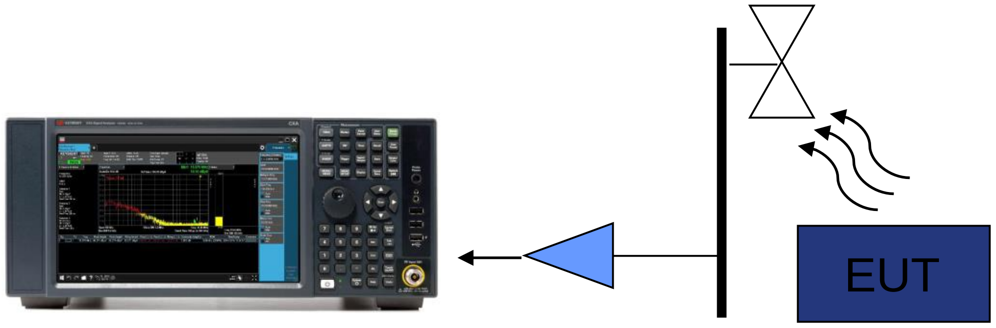
Coupling and decoupling
network (CDN)

Current injection probe

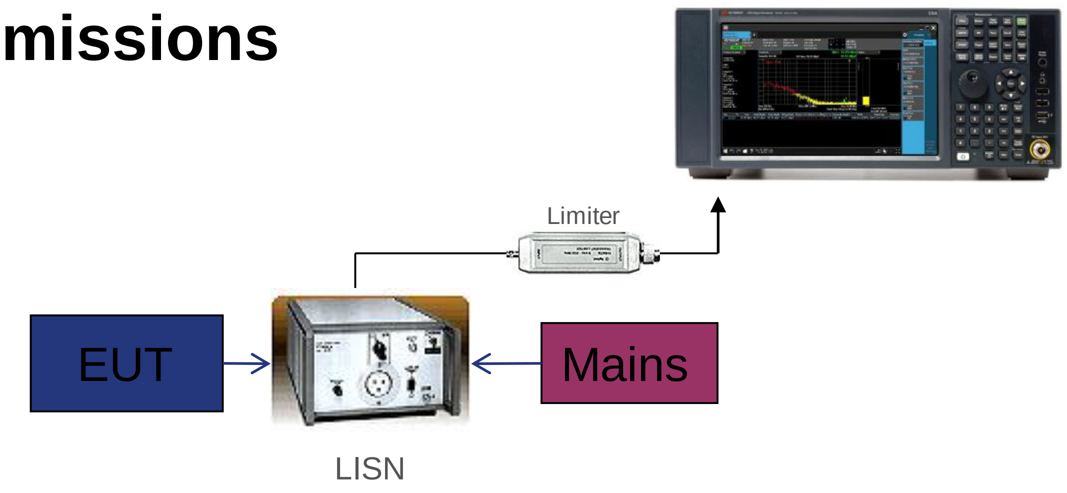
EM-Clamp

EMI Measurements

Radiated Emissions



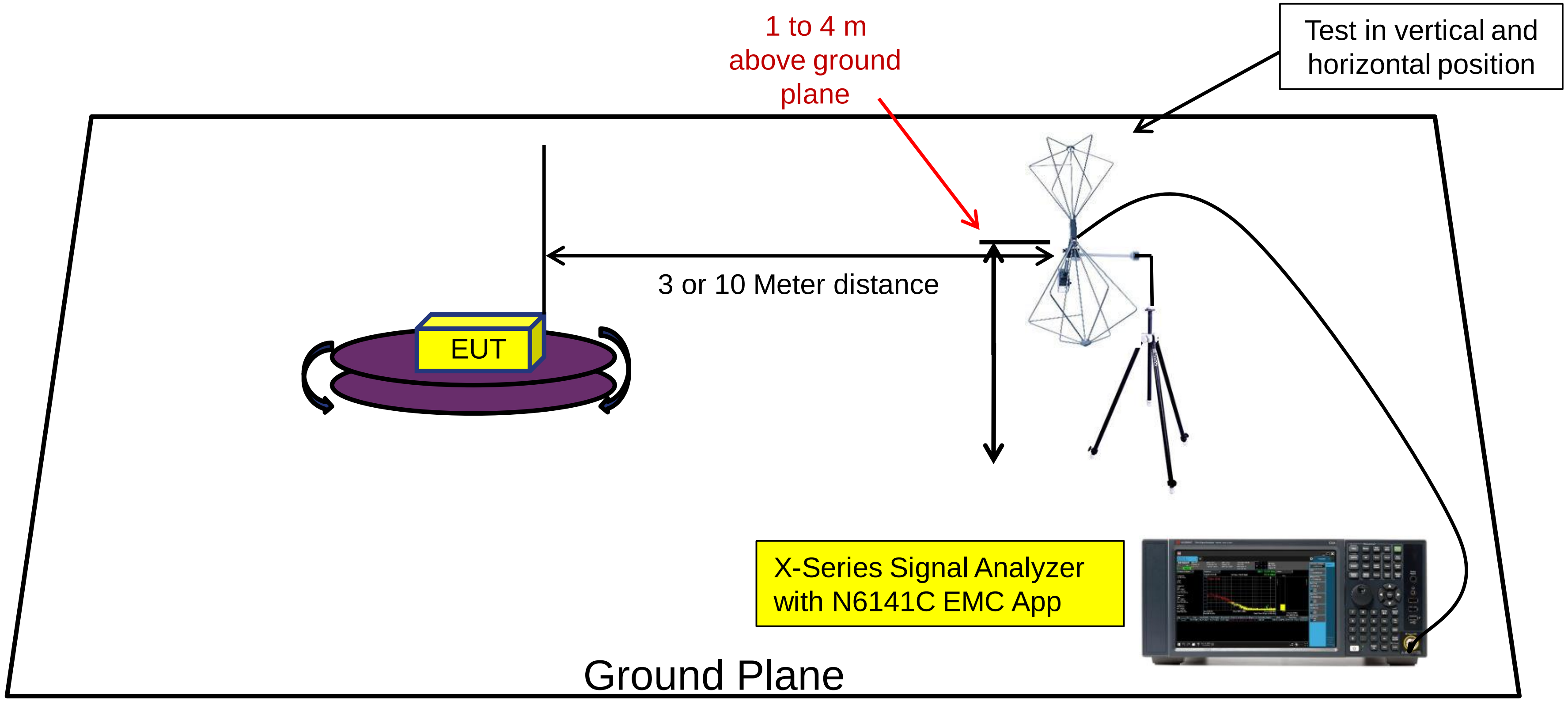
Conducted Emissions



Keysight Equipment: X-series signal analyzers

LISN - (line impedance stabilization network)

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.

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.

– 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

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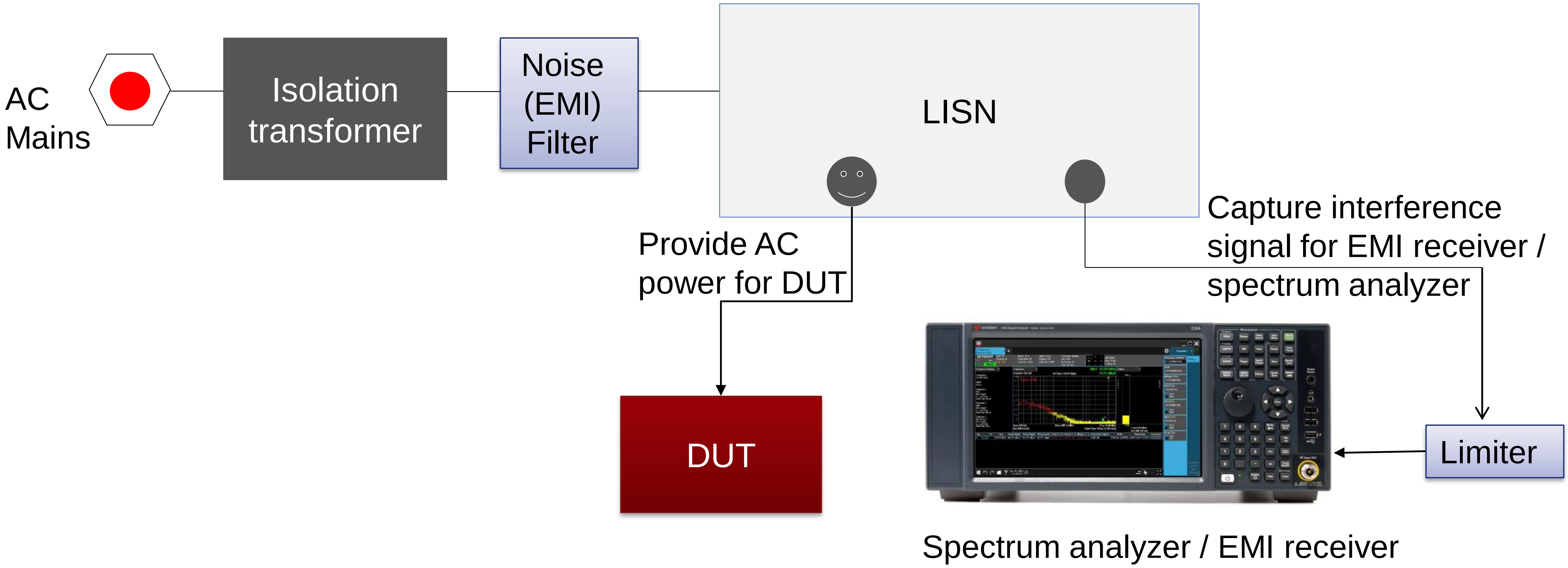
Conducted Emissions

9 kHz – 30 MHz



KEYSIGHT TECHNOLOGIES

Environment setups for conducted emission test

General practice

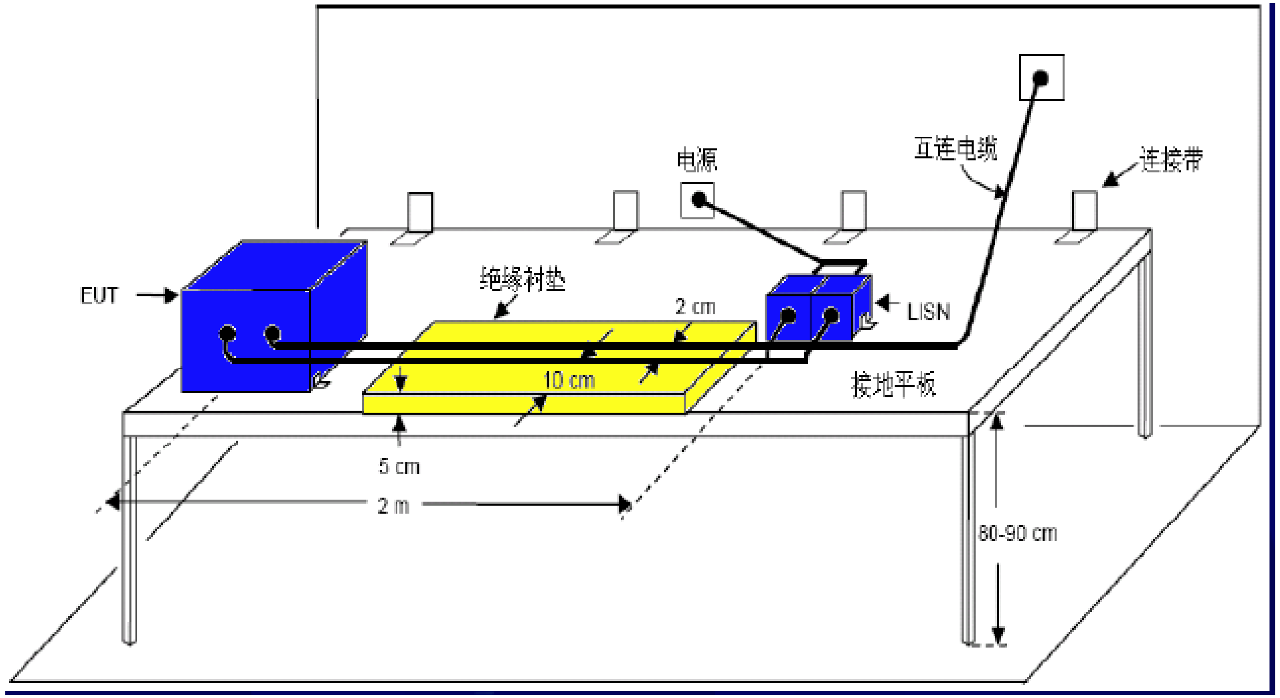
Table:

- 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

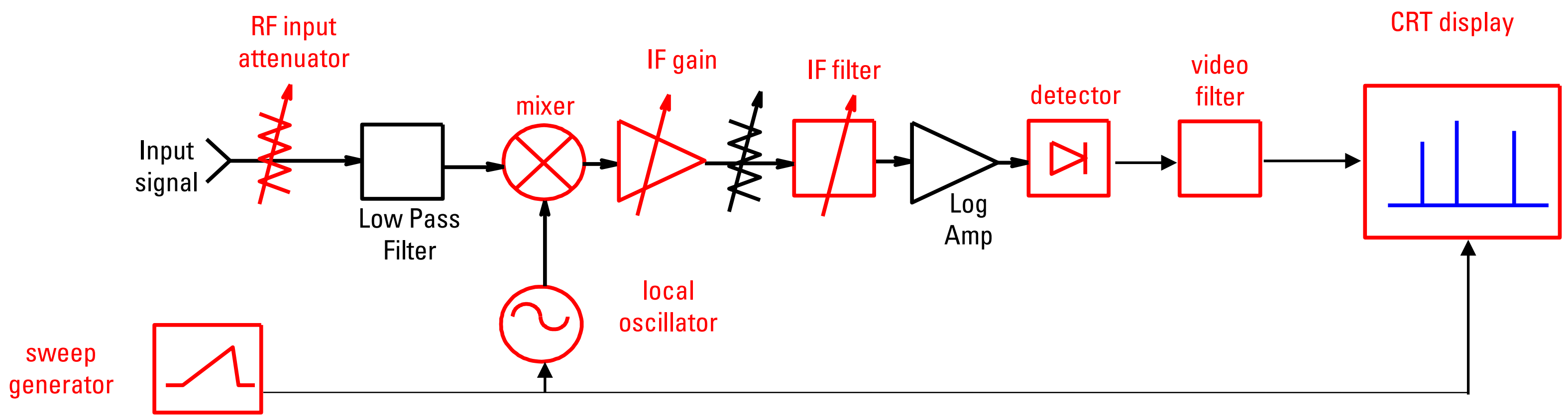
Compliance test needs be done in a shielded room



A flexible and low cost EMI Interference analysis tool –

CXA signal analyzer

CXA signal analyzers

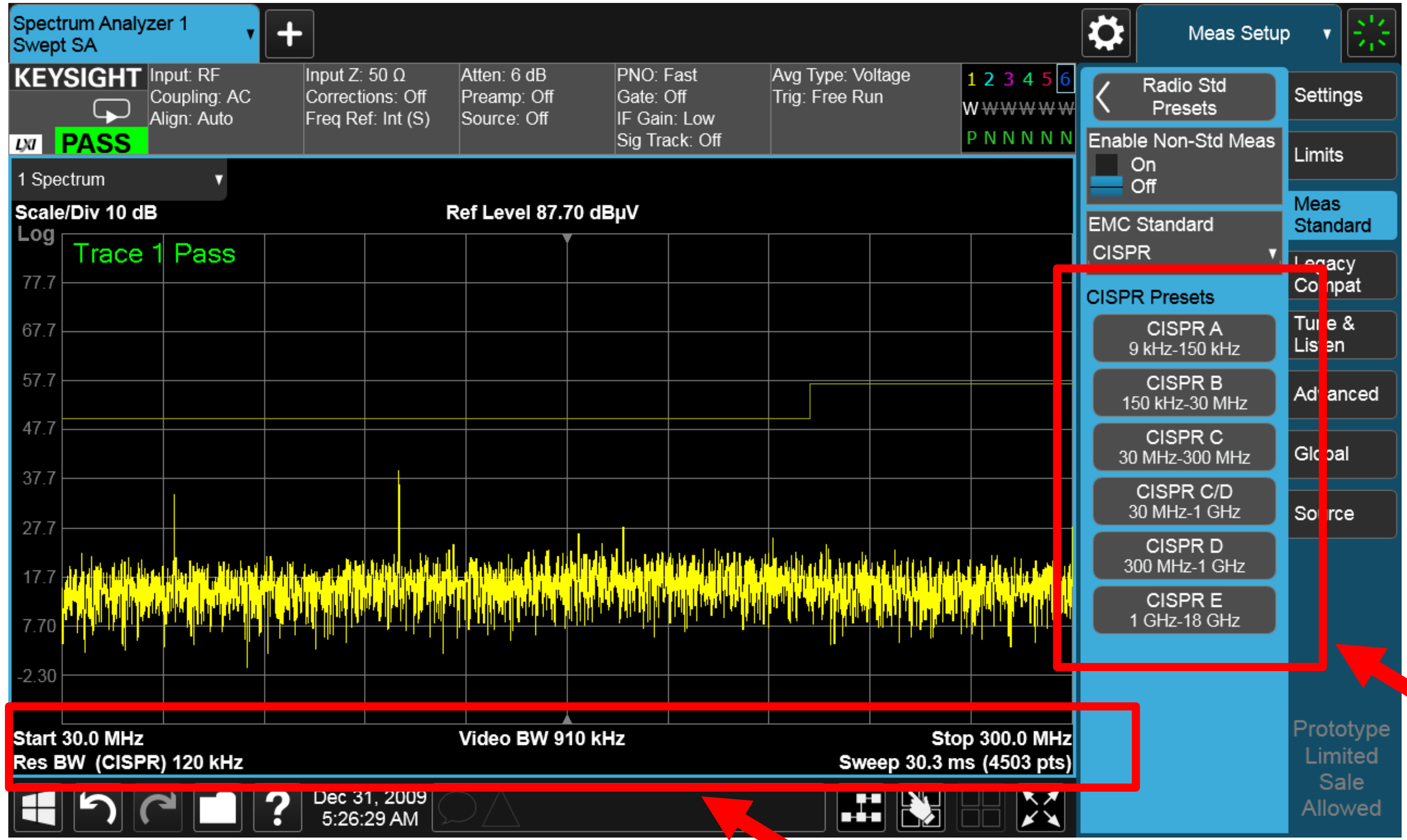


Spectrum / Signal analyzers:

- Starting frequency: 9 kHz
- Maximum frequency: 3/7.5/13.6/26.5 GHz
- Good sensitivity: -162 dBm DANL performance
- Good dynamic range: +17 dBm TOI
- CISPR band presets, BWs, and detectors
- Good for EMI precompliance test, and EMI troubleshooting

N9000B option EMC

Provides the essential capabilities on EMI interference analysis



N9000B-EMC option 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
- List price: $1,638

One-button EMI presets

Measurement parameters set according to CISPR bands

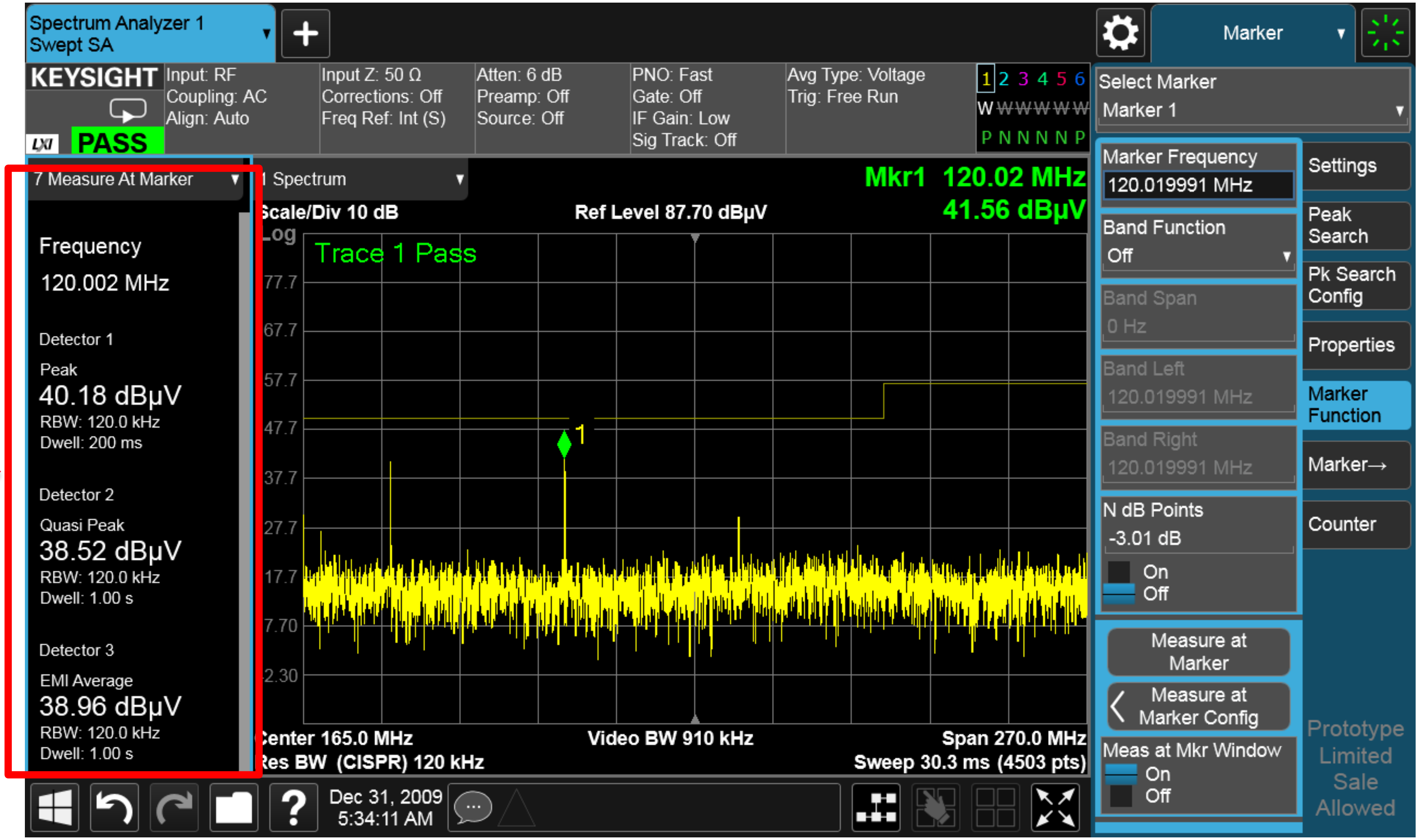
KEYSIGHT TECHNOLOGIES

N9000B option EMC

Measure at marker with 3 detectors simultaneously

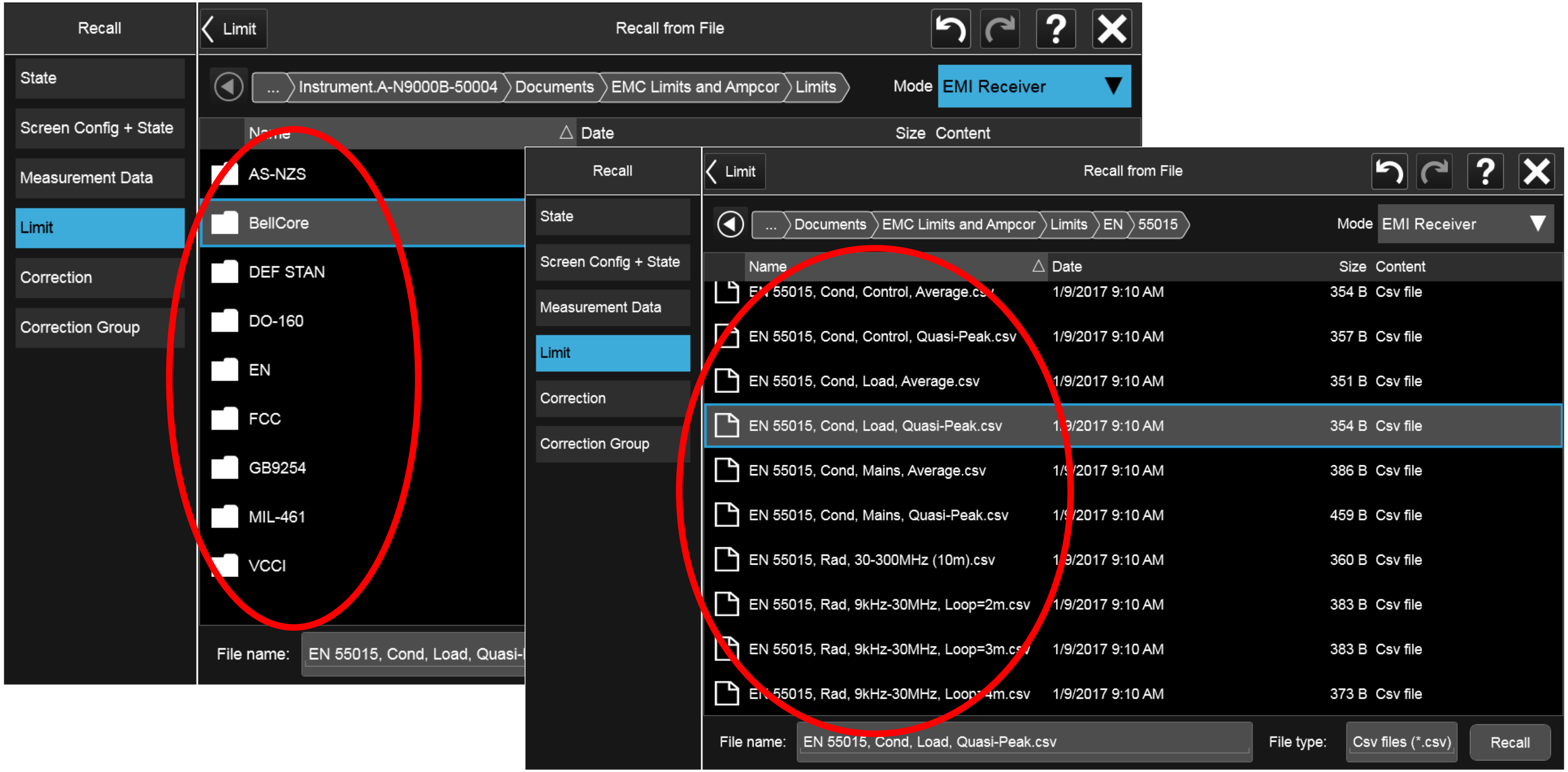
Measure at marker with three detectors:

- Peak
- Quasi-peak
- EMI average



Built-in CISPR and MiL-STD limit line

A list of commercial limits for recalling



N6141C EMI measurement application

Runs inside CXA signal analyzer

Ordering info:
N9000B: Starting from $12,989
N6141C-2FP/2TP: $5,326 / $6,923

EMI precompliance test capabilities:

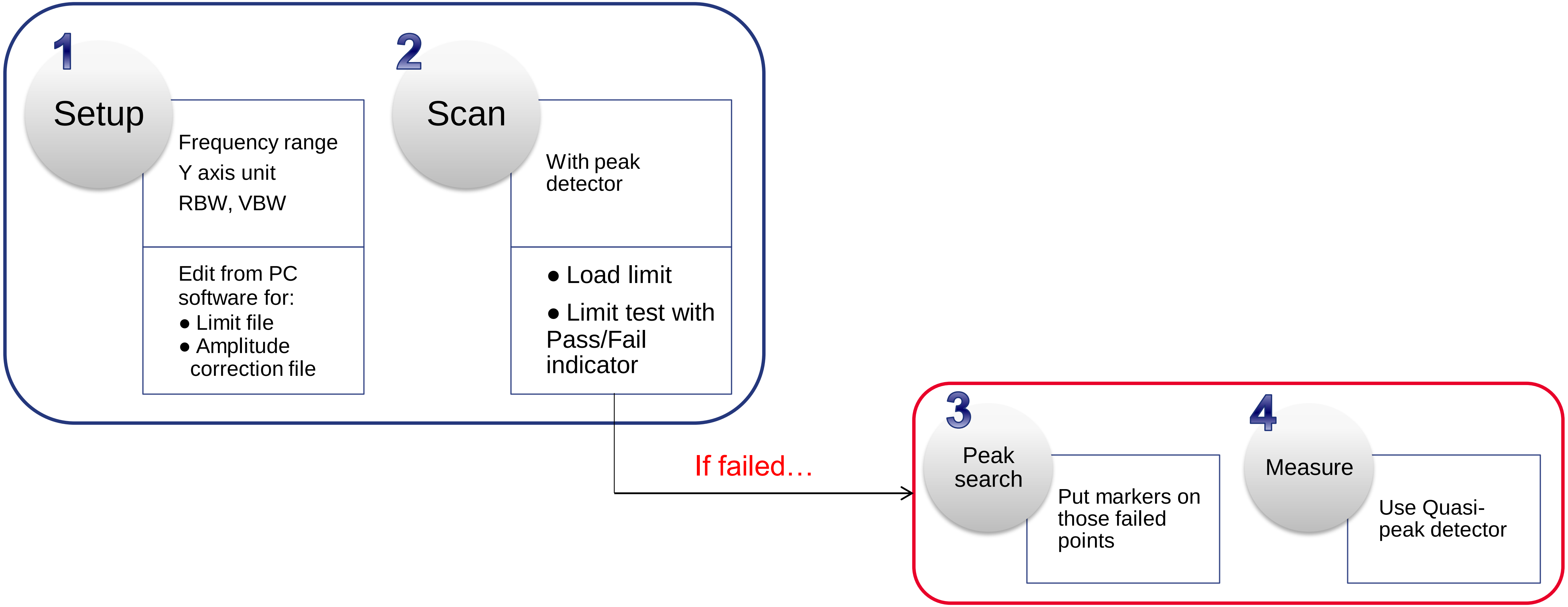
- Built-in CISPR and Mil-STD compliant BW, detectors and band presets
- Automated testing to regulatory limit lines with user-selected margins
- Amplitude corrections for antennas, LISNs, NF probes, etc

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



N6141C Measurement procedure

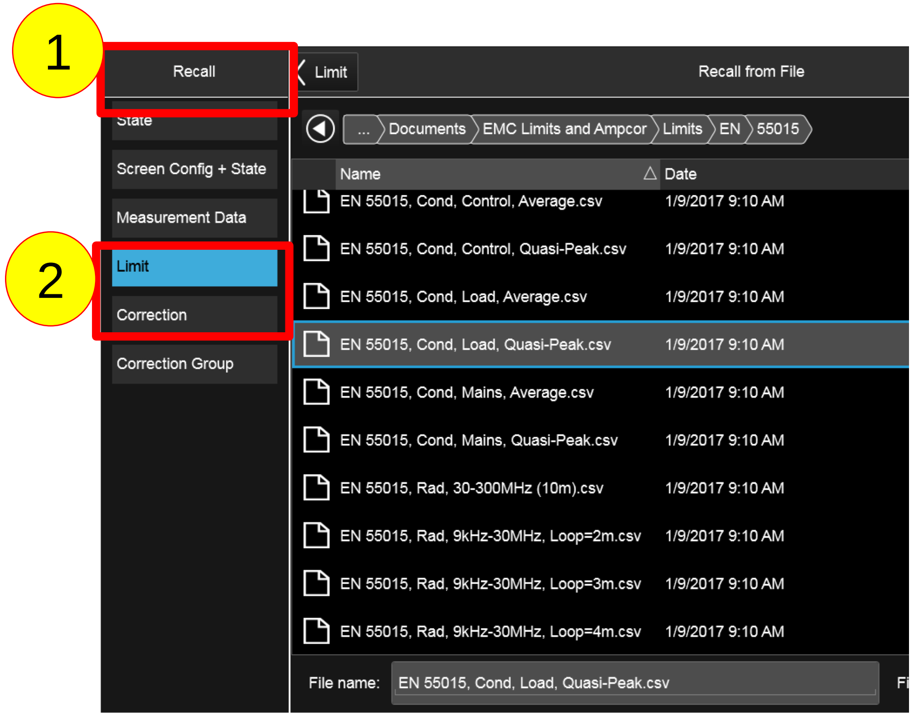
Step 1. Set up the scan table

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

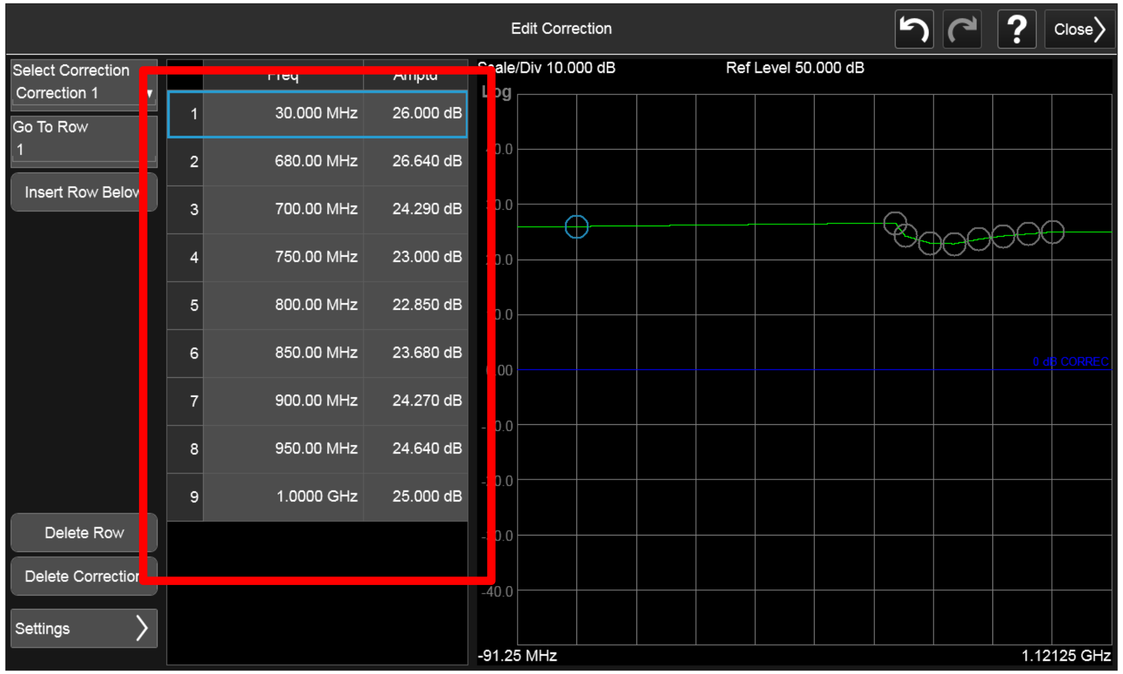
The X-series signal analyzer will set the EMI measurement parameters according to the scan table automatically

N6141C 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

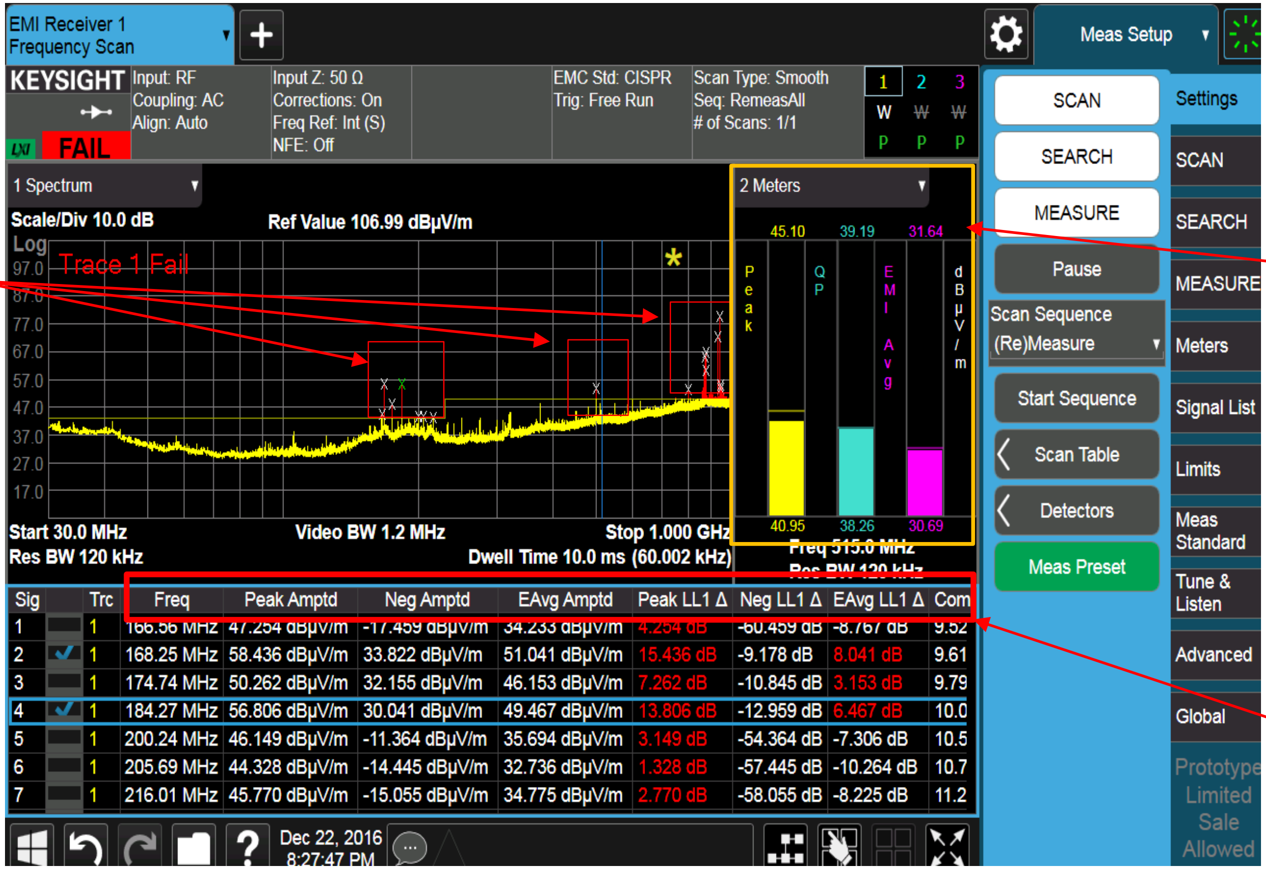


To edit a correction, press [Input/Output] → {Correction}, to manually edit correction data

N6141C 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

Wrap up

EMI basics and EMI measurement

- **3 elements in EMC: interference source, propagation path, and the EMI sensitive device**
- **It is important to evaluate your new product’s EMI performance before you go to the test house**
- **The conducted and radiated emissions can be captured and analysis with a spectrum analyzer and corresponding accessories**
- **Spectrum analyzers help you on EMI precompliance test, and the EMI diagnostics**

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

Ordering information

– N9000B CXA signal analyzer
  - Option 503/507/513/526
  - Option P03/P07/P13/P26
  - Option EMC

If you need more flexible and comprehensive EMI analysis, also order: N6141C EMI measurement application

For EMI diagnostic purpose, a near field probe set is required. Refer to N9311X-100 (H field)

Back up

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

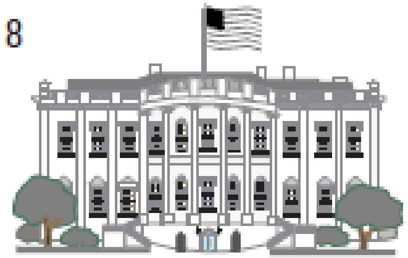
KEYSIGHT TECHNOLOGIES

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

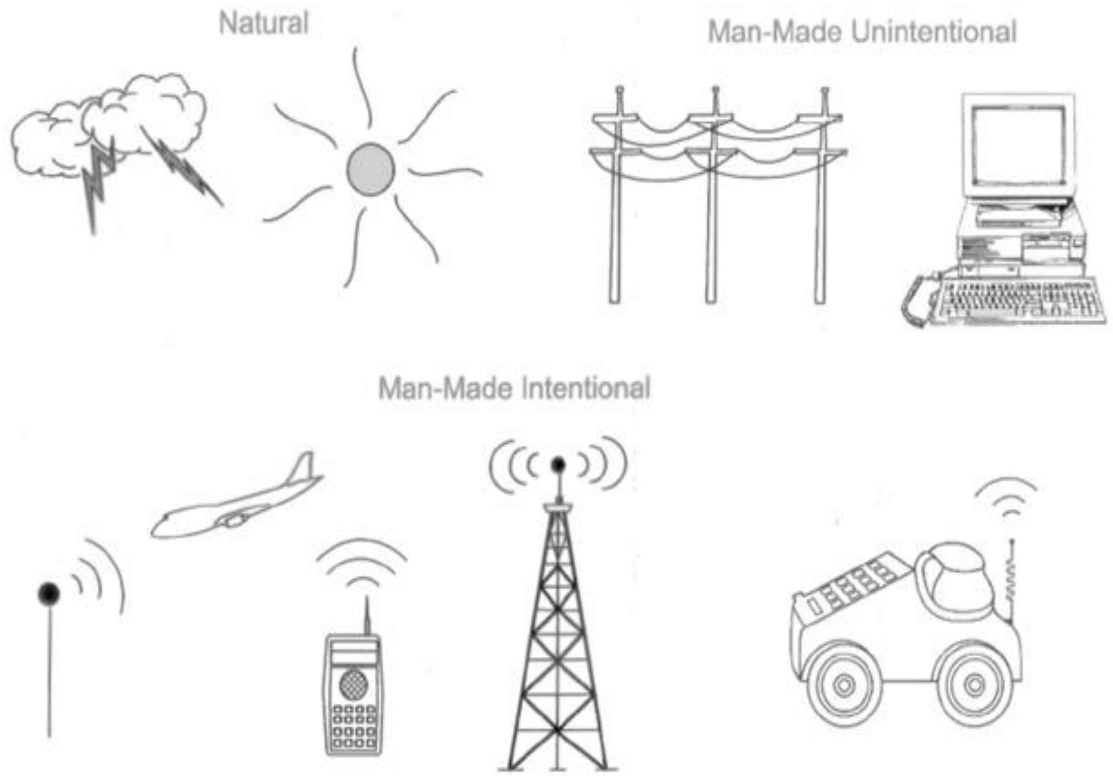
Note:
FCC part 15 states that any digital device which uses timing pulses (clocks) in excess of 9kHz, must not unintentionally emit radiation over certain limits. This testing is required up to the 5th harmonic of the fastest clock but less than 40 GHz. For example, a computer or radio with a 1.2 GHz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

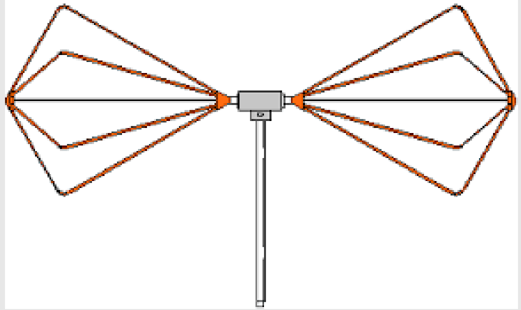
From Man-made Intentional:

- 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.