EMI Interference Analysis and Troubleshooting

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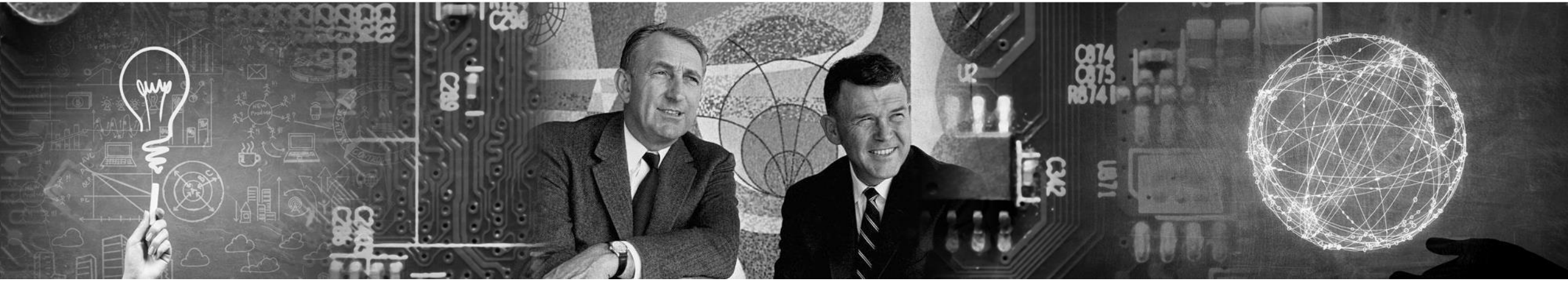
RF/uW Applications Engineer	

KEYSIGHT TECHNOLOGIES

Keysight Helps You Get to Market Faster

WE HELP YOU CREATE. INNOVATE. AND DELIVER WHAT'S NEXT.



The innovation leader in electronic design and test for over 75 years

Founded in 1939 by Bill Hewlett and Dave Packard as HP with an ongoing mission to help create new markets

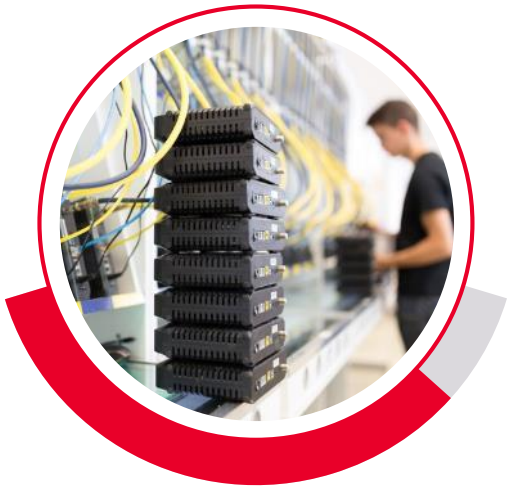
Trusted hardware, innovative software and a global network of experts

We Help You Unlock Insights to Succeed

Communications

Expertise in precision measurement across the broadest frequency ranges and modulations

We help customers develop emerging forms of connections



Network Test, Visibility, Security

Expertise in large-scale traffic and security attack simulation combined with data access into operations

We provide customers trusted environments to develop, deploy, and operate their networks

Electronic Industrial

Expertise in high density electronics of all sizes and power levels

We help customers from design, verification and manufacturing to installation and maintenance

Services

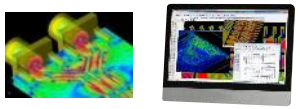
Expertise in helping customers extract the best from their test environments

We help customers find ways to maximize asset usage, streamline engineering operations and reduce risk

Best-in-Class Solutions

ACROSS DESIGN, TEST, AND OPTIMIZATION

#1



Simulation Software

#1

Signal Sources

#1

Signal Analyzers

#1

Network Analyzers

Core Solution Platforms & Market Position

#1

Ixia Network Test

#2

Ixia Network Visibility

#2

Oscilloscopes

Agenda

- EMI Concepts & Terminology
- EMI Compliance Process
- Regulatory Standards Overview
- EMI Measurement Fundamentals
- EMI Solutions

Agenda

- **EMI Concepts & Terminology**
- EMI Compliance Process
- Regulatory Standards Overview
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EMI Basics

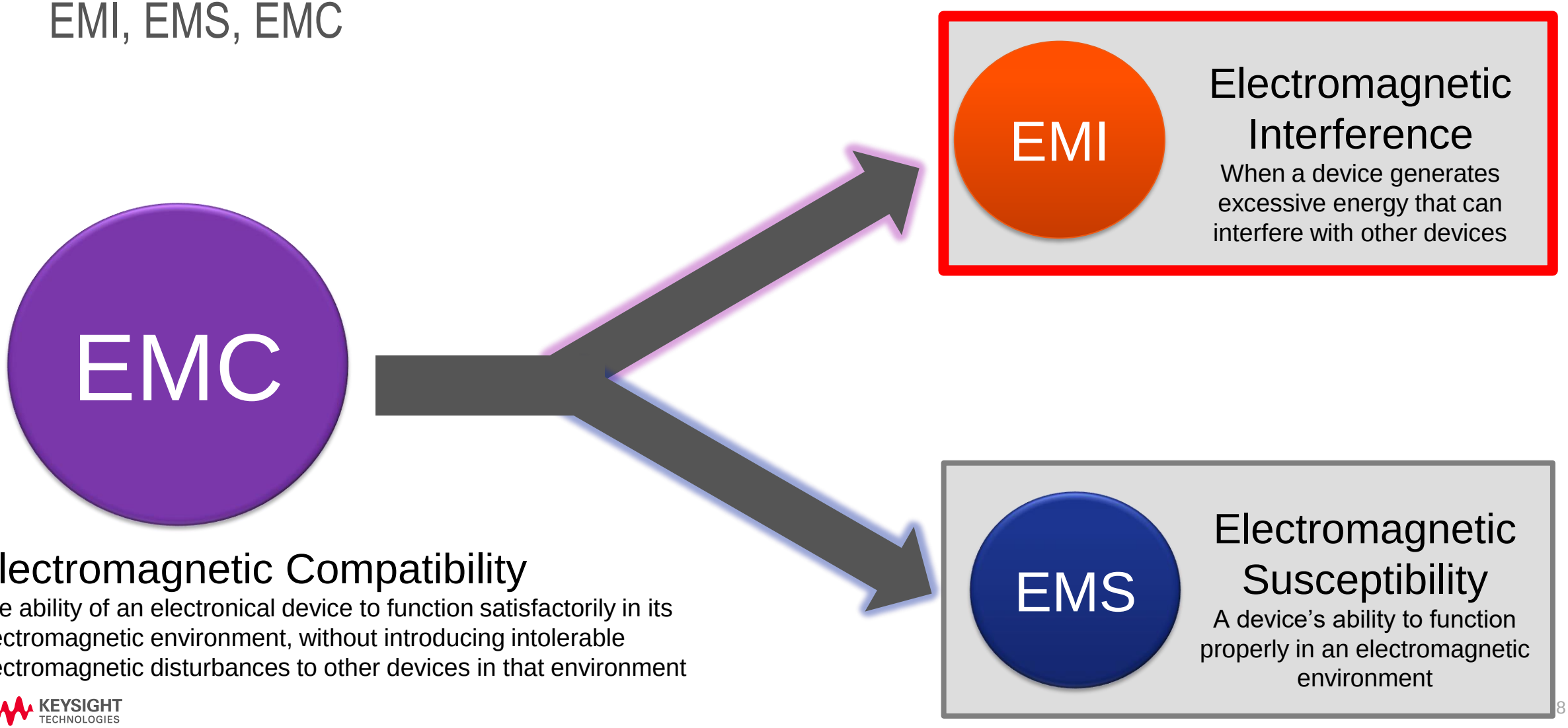
ACRONYMS LIST

- CISPR - Comité International Spécial des Perturbations Radioélectriques (Special International Committee on Radio Interference)
- EMC – Electromagnetic Compatibility
- EMI – Electromagnetic Interference
- EMS – Electromagnetic Susceptibility
- EUT – Equipment Under Test
- LISN – Line Impedance Stabilization Network
- IEC - International Electrotechnical Commission
- NPI - New Product Introduction
- CE – Conducted Emissions
- RE – Radiated Emissions
- RFI - Radio-Frequency Interference

Getting Started – Basic Terms

EMI, EMS, EMC

EMI, EMS, EMC



Electromagnetic Compatibility

The ability of an electronical device to function satisfactorily in its electromagnetic environment, without introducing intolerable electromagnetic disturbances to other devices in that environment

Getting Started - Basic Questions

1 What is EMI?

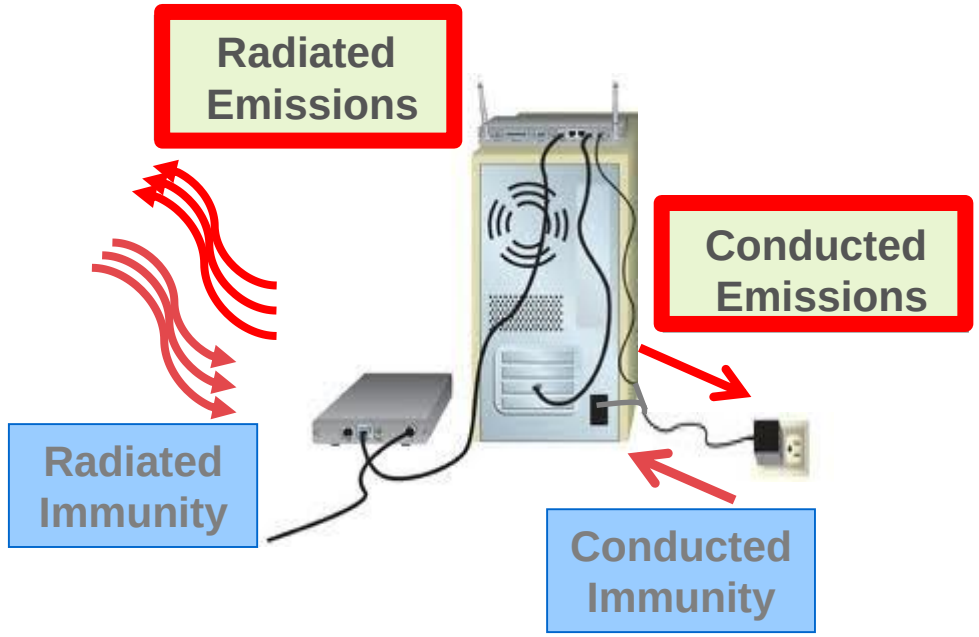
- EMI is disturbance that affects an electrical circuit

2 What analysis tool can I use?

- EMI emissions can be captured and analyzed with a spectrum analyzer

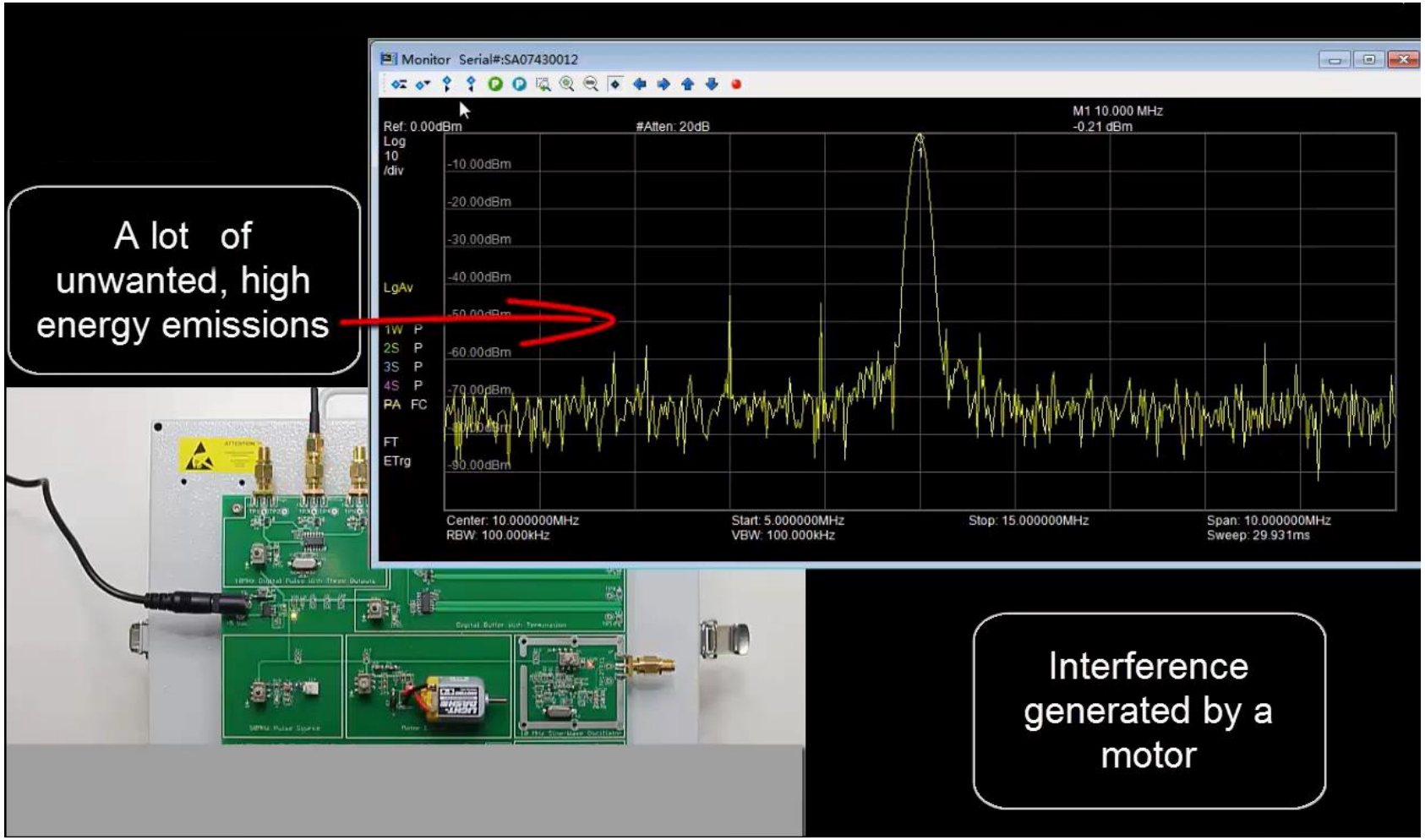
3 What do spectrum analyzers (signal analyzers) do?

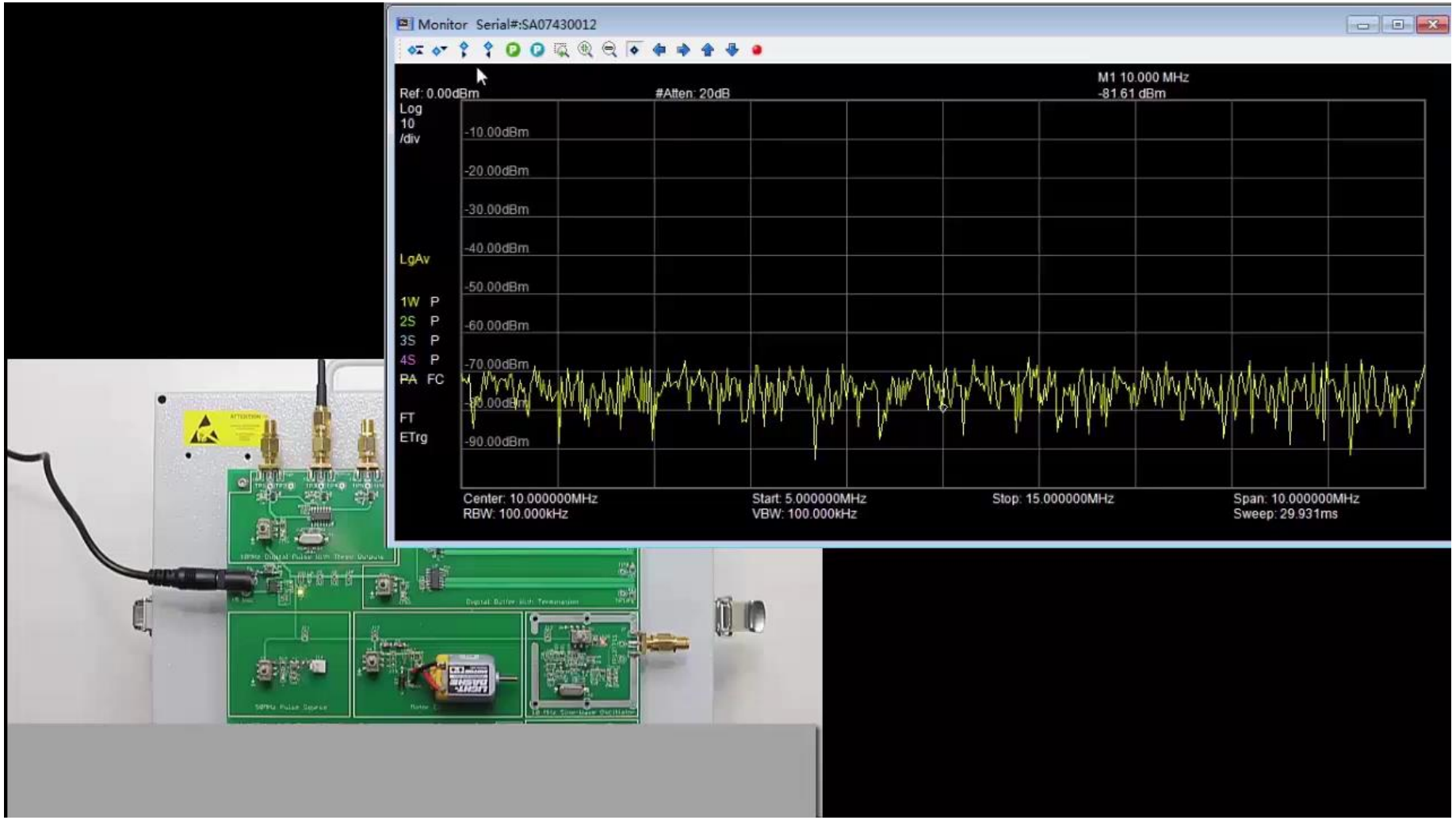
- Spectrum analyzers provide accurate frequency, power, and other important measurements of EMI emissions

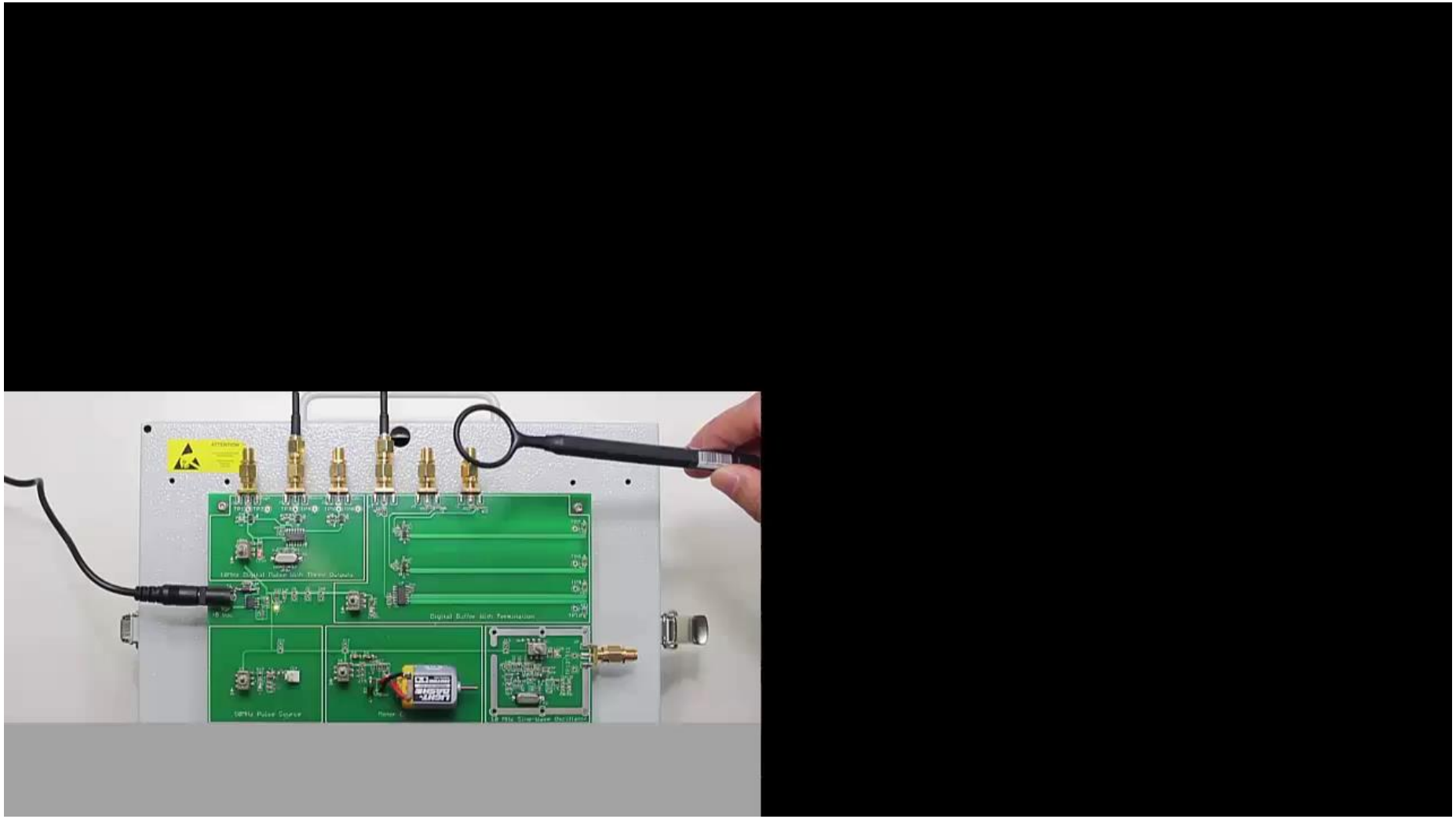


EMI Examples

INTERFERENCE FROM A HIGH-SPEED DIGITAL CIRCUIT WITH A MOTOR



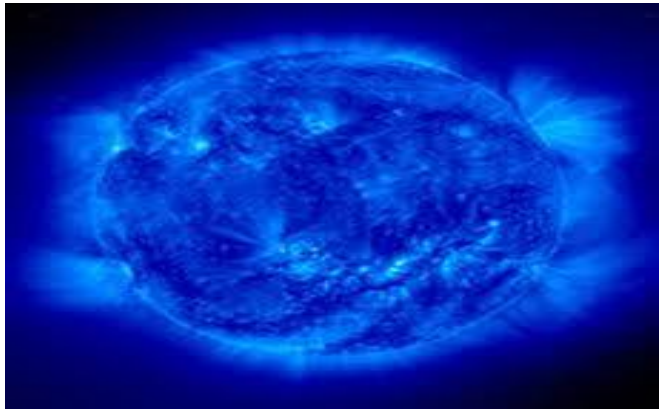

Monitor Serial#:SA07430012
Ref: 0.00dBm
#Atten: 20dB
M1 10.000 MHz
-81.61 dBm
Log
10
/div
-10.00dBm
-20.00dBm
-30.00dBm
-40.00dBm
-50.00dBm
-60.00dBm
-70.00dBm
-80.00dBm
-90.00dBm
LgAv
1W P
2S P
3S P
4S P
PA FC
FT
ETrg
Center: 10.000000MHz
RBW: 100.000kHz
Start: 5.000000MHz
VBW: 100.000kHz
Stop: 15.000000MHz
Span: 10.000000MHz
Sweep: 29.931ms



EMI Basics

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.



EMI Basics

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

EMI Basics

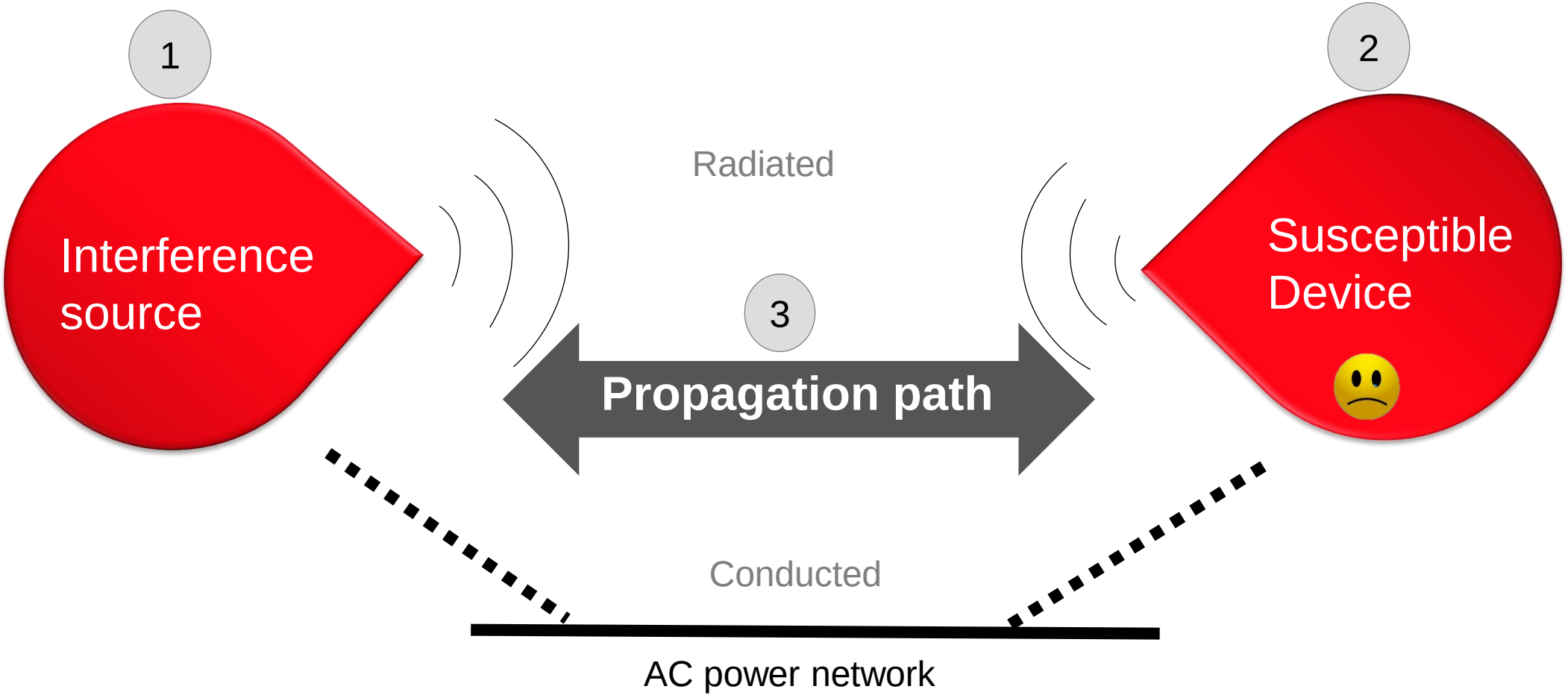
SOURCES OF EMI (3/3)

- 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 of EMC



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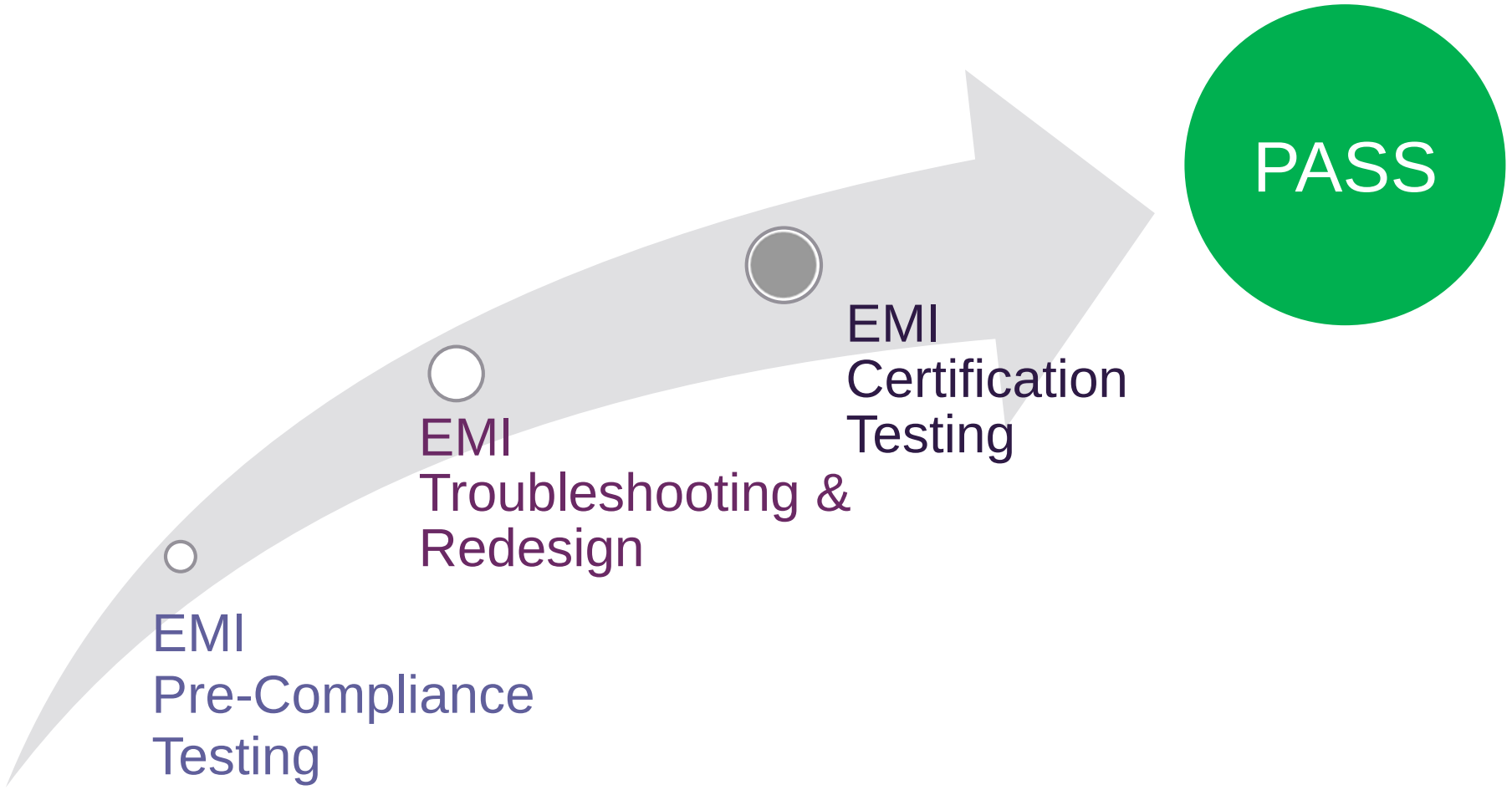
- **EMI Compliance Process**
- Regulatory Standards Overview
- EMI Measurement Fundamentals
- EMI Solutions

EMI Compliance Process Overview

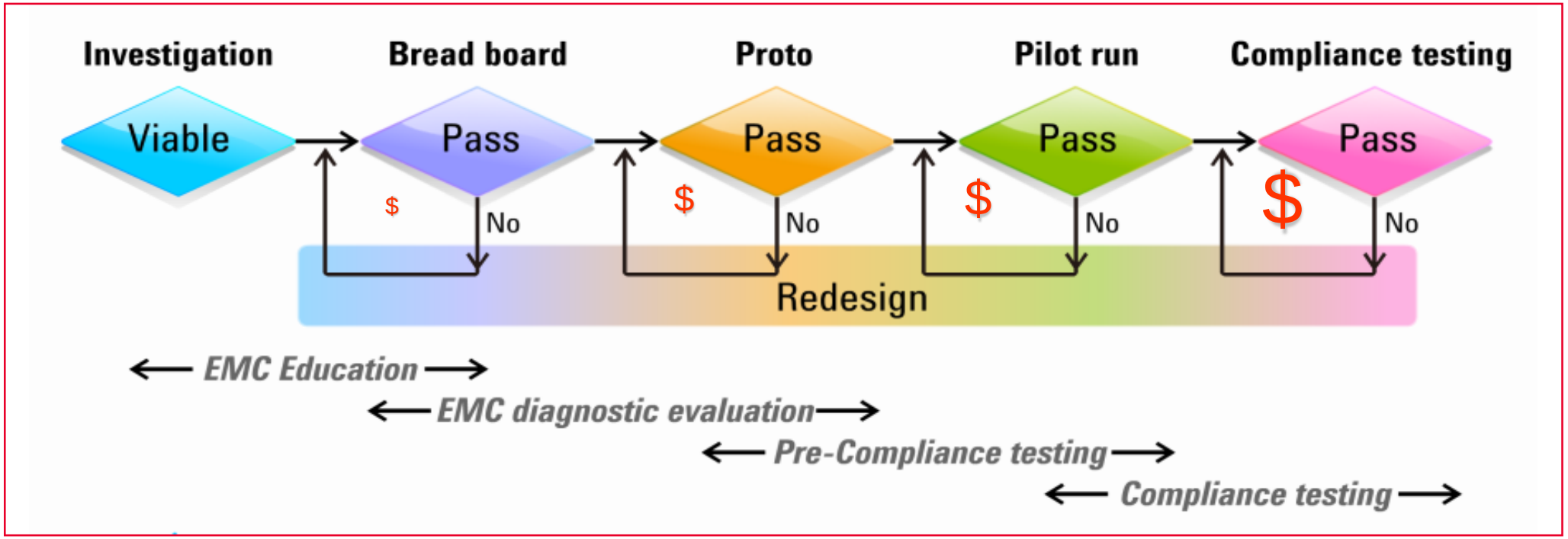


EMI Compliance vs. EMI Pre-Compliance

	Compliance Test	Pre-Compliance Testing
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

The Impact Of An EMI Failure During The Product Development Cycle

Product Development Cycle including EMI Testing



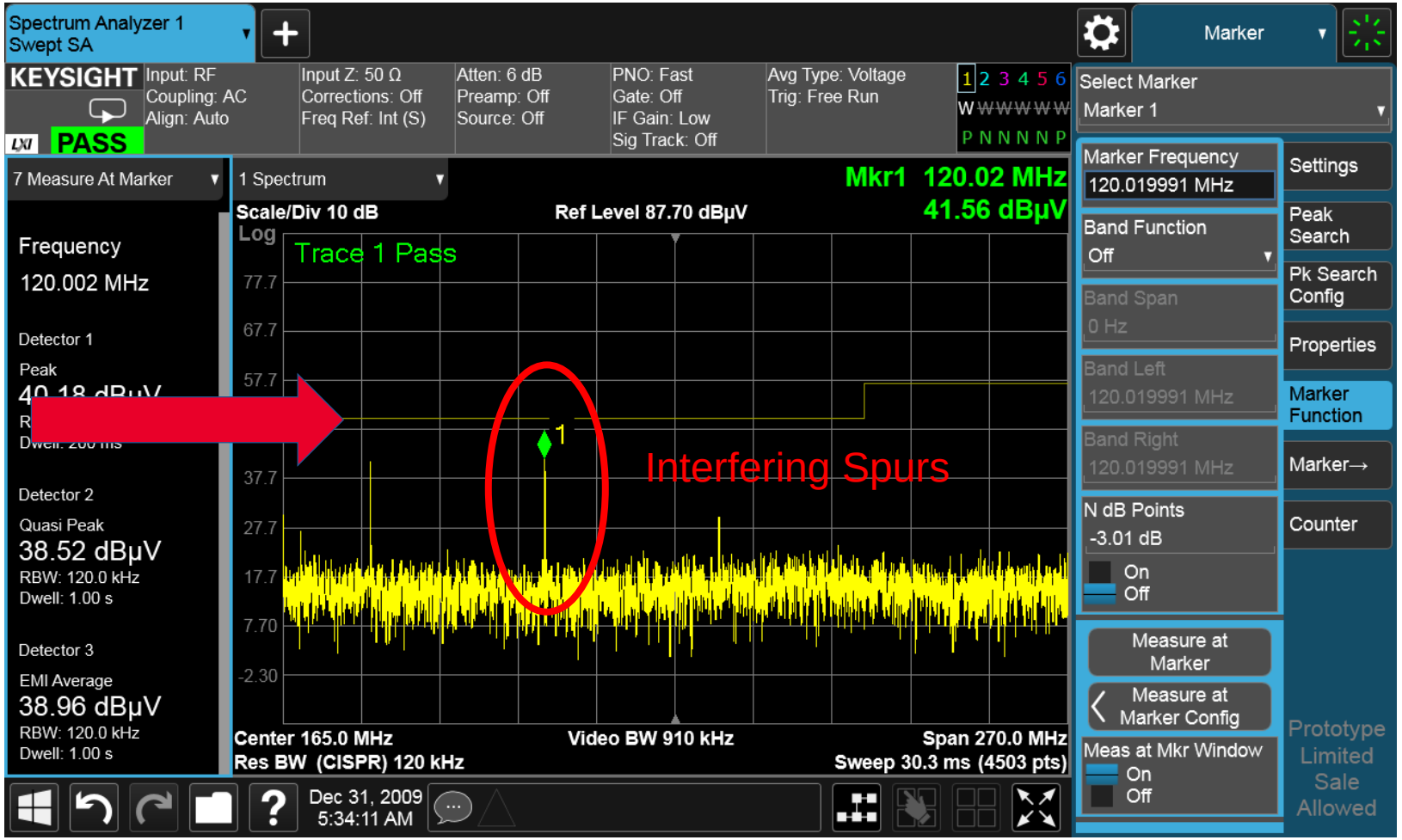
Increasing flexibility to solve EMI problems

Increased cost to solve EMI problems

What Is A Test House Looking For?

STANDARDIZED EMI PASS/FAIL CRITERIA

Limit Lines



Characterize against Pass/Fail criteria before sending DUT's to a certified EMI Test Lab

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

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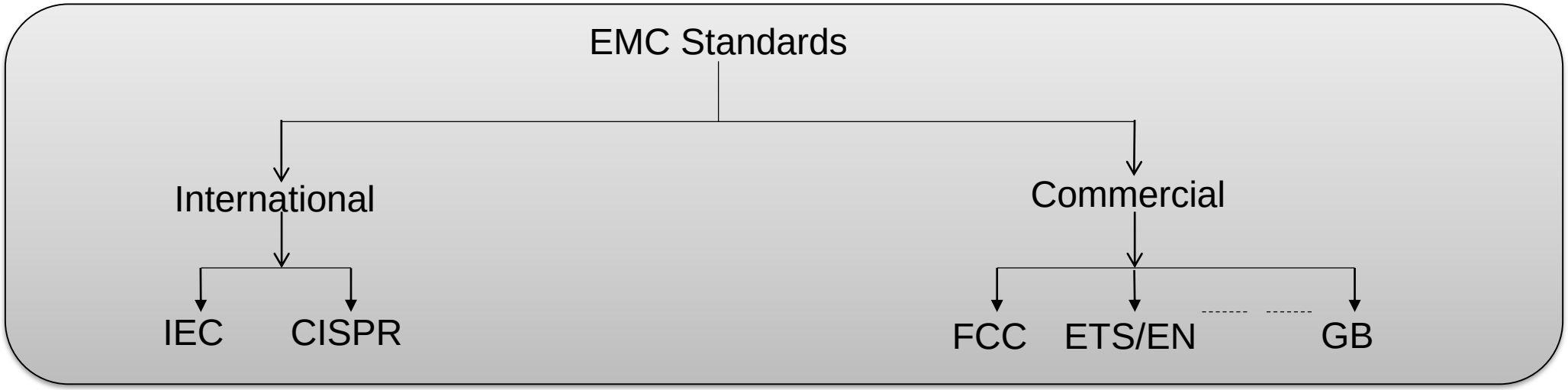
CISPR Recommends Commercial Limits, Measuring Equipment and Methodologies

- **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**

EMC Standards

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, procedures, and limits

Product Standards

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

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)

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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

Key Influencer - Commercial Regulations

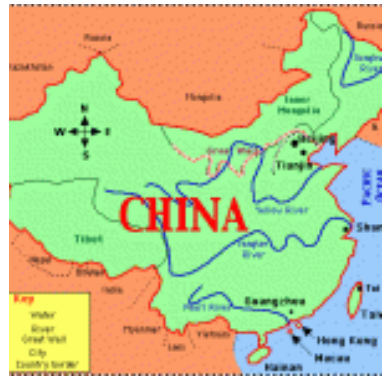
IEC/CISPR

Measurement Std. – CISPR 16

Equipment Std. – CISPR 16

Product Std. - CISPR 11-15, etc.

IEC 61XXX

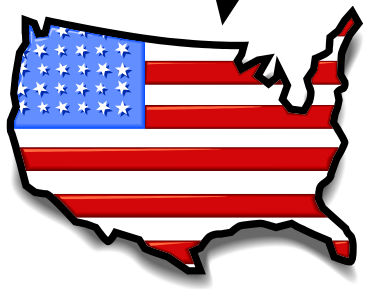


GB

VCCI

ANSI

FCC



CENELEC

EN

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

Different organizations have similar standards

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)?

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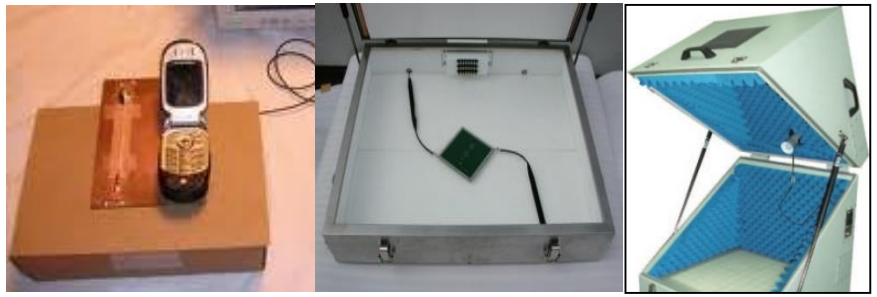
Example Radiated Emission Testing Environments



Bench Top: semi-anechoic

OATS

Chambers

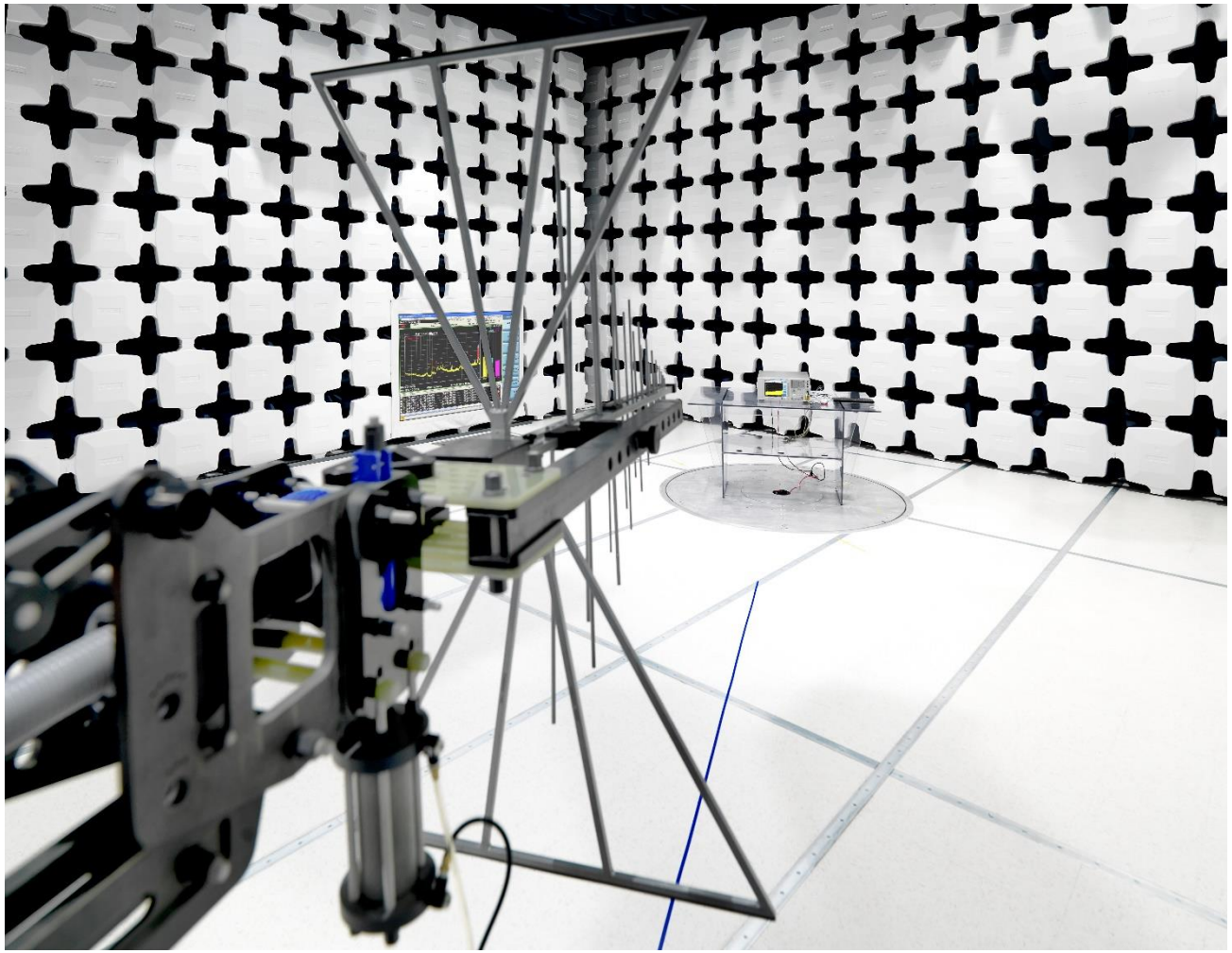
Definitions:

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

Example Radiated Emission Testing Environments



EMI Measurement Units

Conducted Emissions

- Commercial: dBµV
- Military: dBµA

Radiated Emissions

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

Assuming a 50 ohm impedance, power measurements may be converted as follows:
* Power conversion calculators available on-line

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)

Antenna Factor (AF)

IMPORTANT FOR ACCURATE EMI MEASUREMENTS

- 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):
  - $AF = {}^{9.73}/_{\lambda\sqrt{G}}$ G: the antenna gain

Antenna Factor should be provided by the Manufacturer

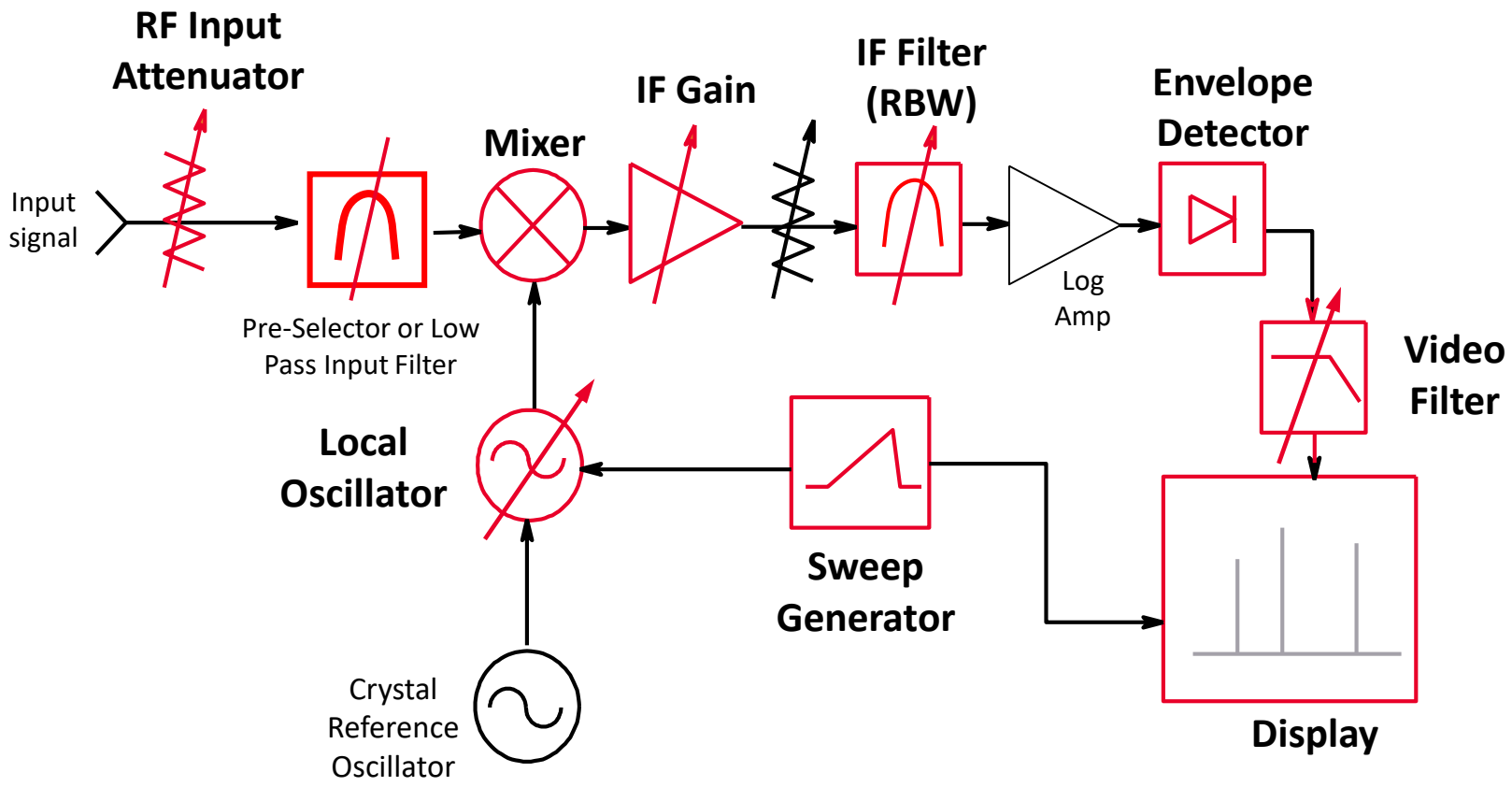
CISPR 16-1-1 Compliant Receiver

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

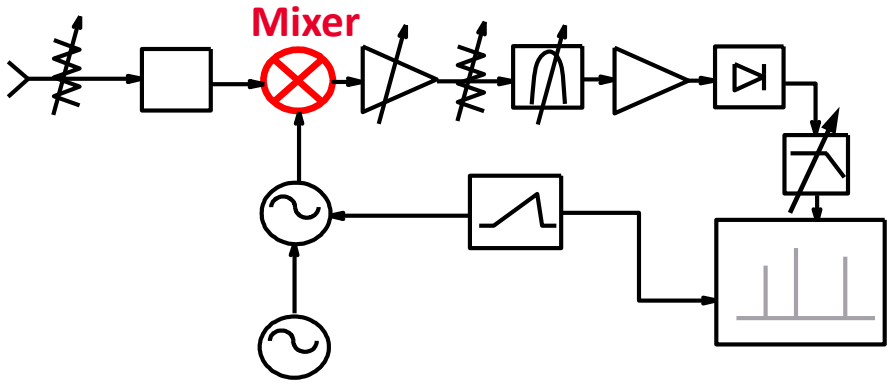
Theory of Operation

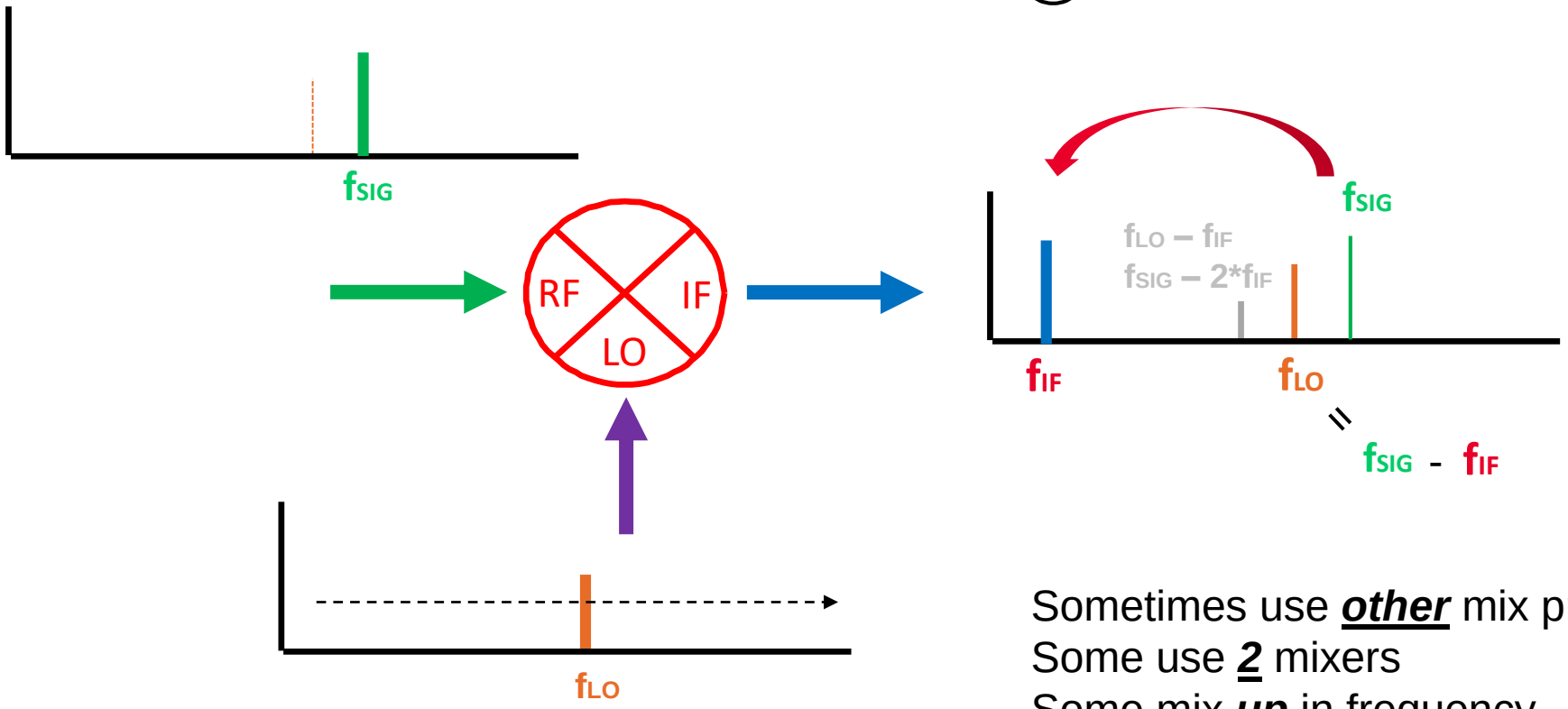
SWEPT SPECTRUM ANALYZER BLOCK DIAGRAM



Theory of Operation

MIXER

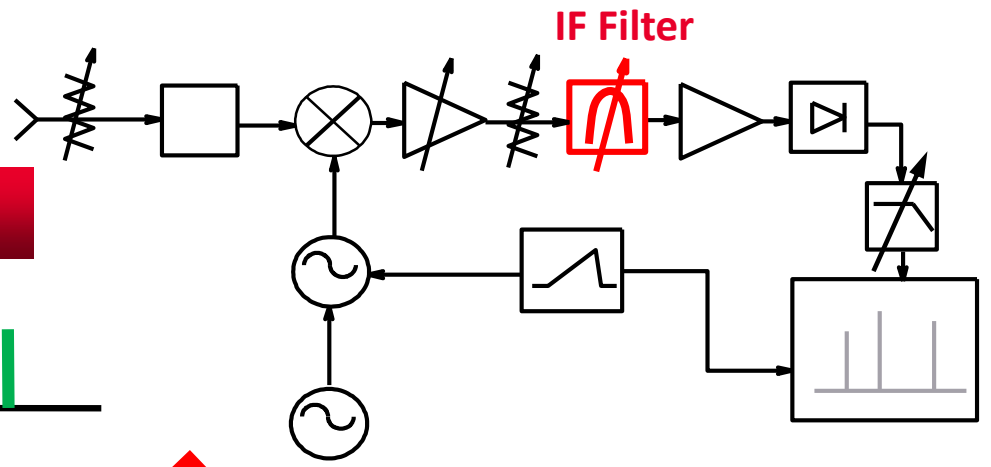


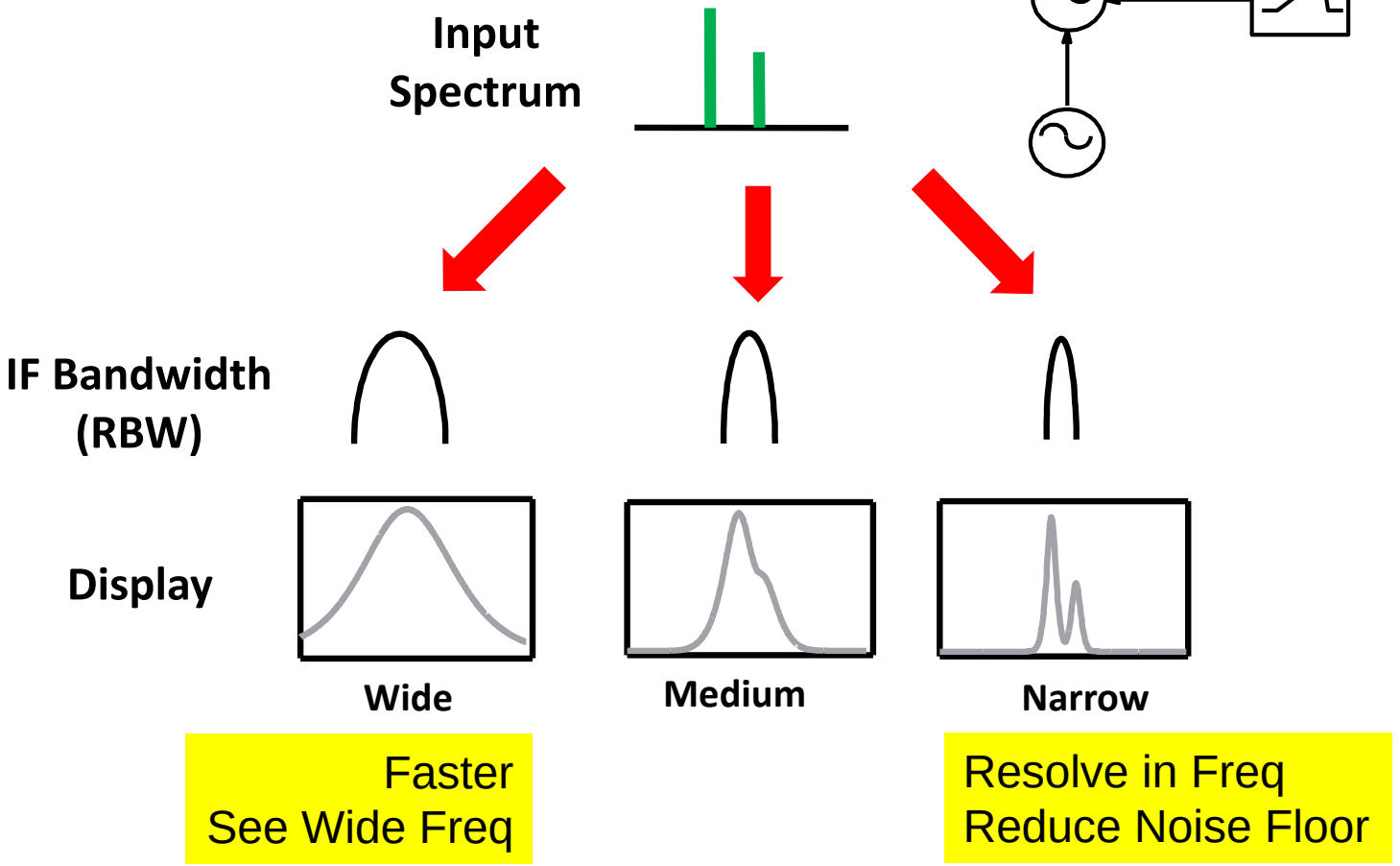


Sometimes use ***other*** mix product
Some use ***2*** mixers
Some mix ***up*** in frequency

Theory of Operation

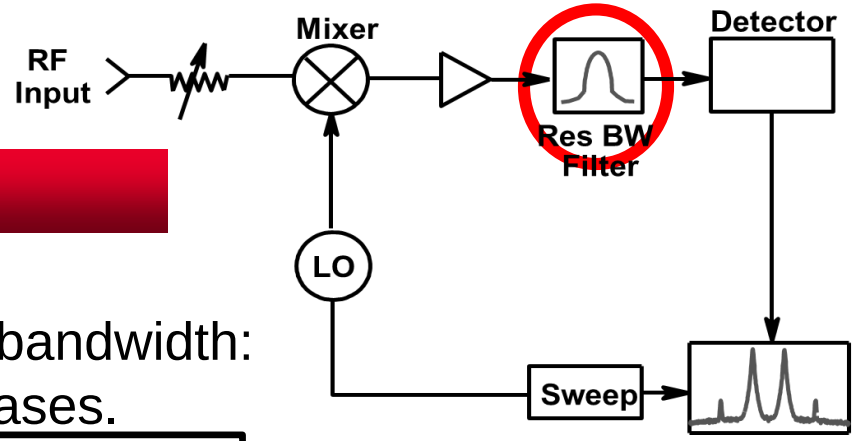
RESOLUTION BANDWIDTH (RBW)



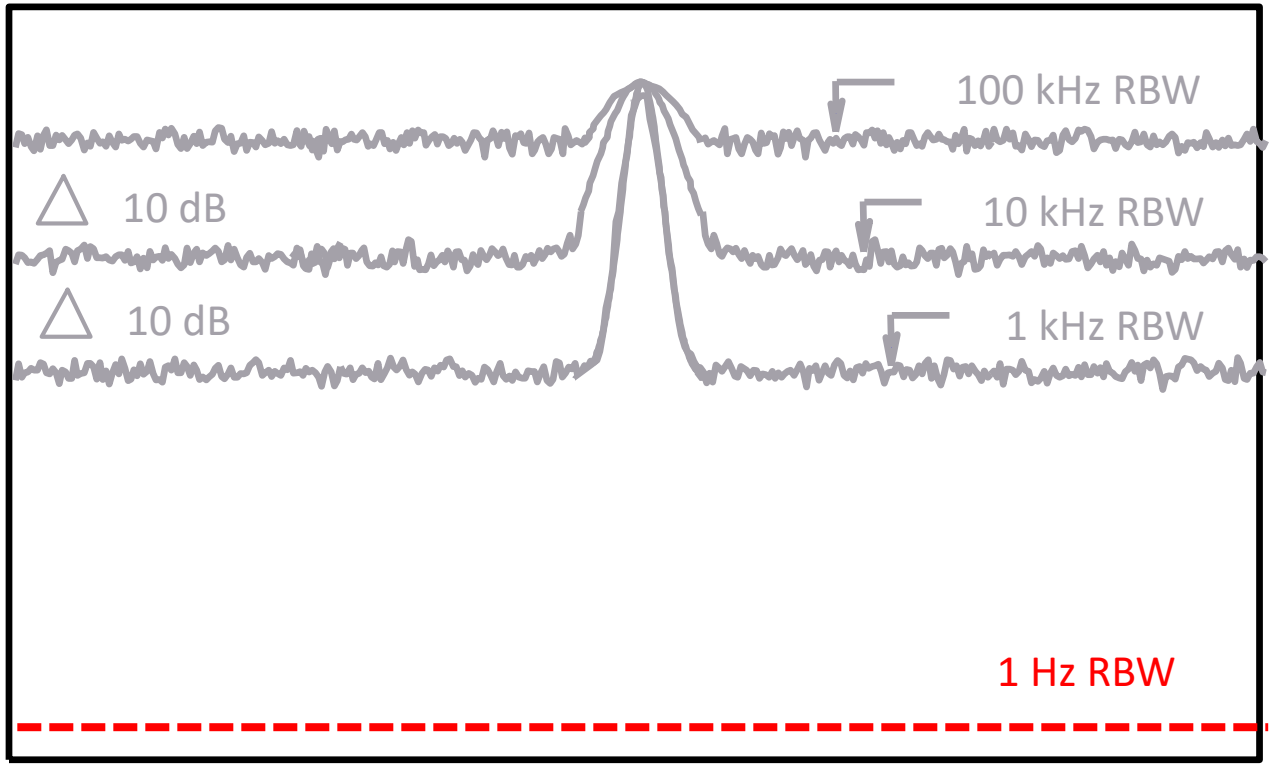


Theory of Operation

SENSITIVITY/DANL: RBW FILTER



Displayed noise is a function of RBW filter bandwidth: noise decreases as bandwidth decreases.



DANL spec'ed in 1 Hz RBW

RBWs for CISPR & MIL

Commercial (CISPR)

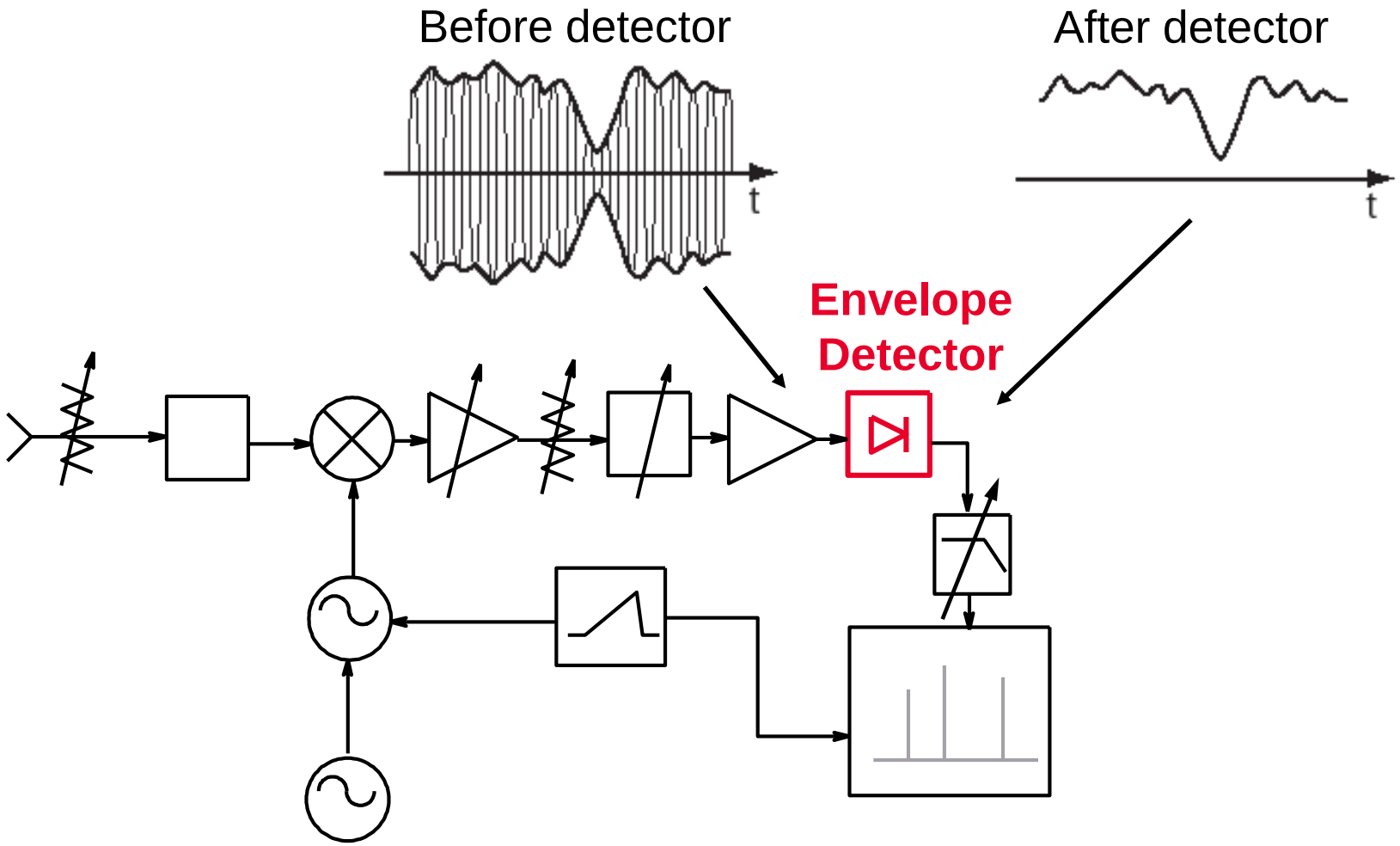
Bands	Frequency range	CISPR RBW
A	9 – 150 kHz	200 Hz
B	150 kHz – 30 MHz	9 kHz
C	30 – 300 MHz	120 kHz
D	300 MHz – 1 GHz	120 kHz
E	1 – 18 GHz	1 MHz

Military (MIL-STD-461)

Frequency range	CISPR RBW (-6 dB BW)
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

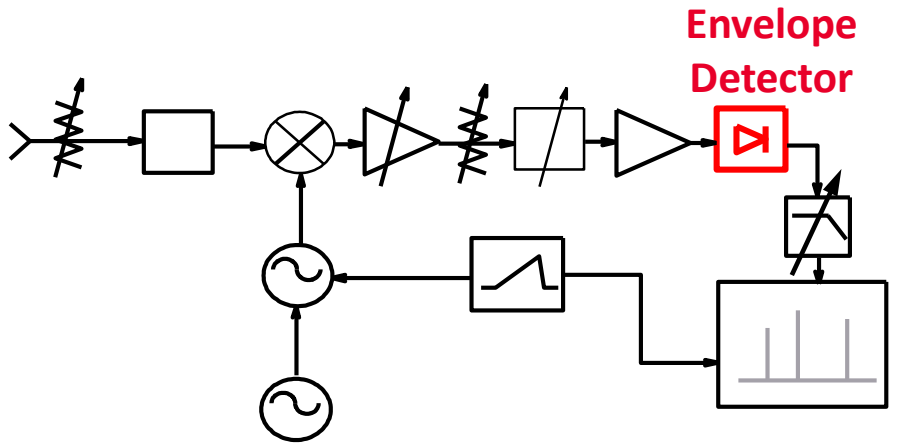
Theory of Operation

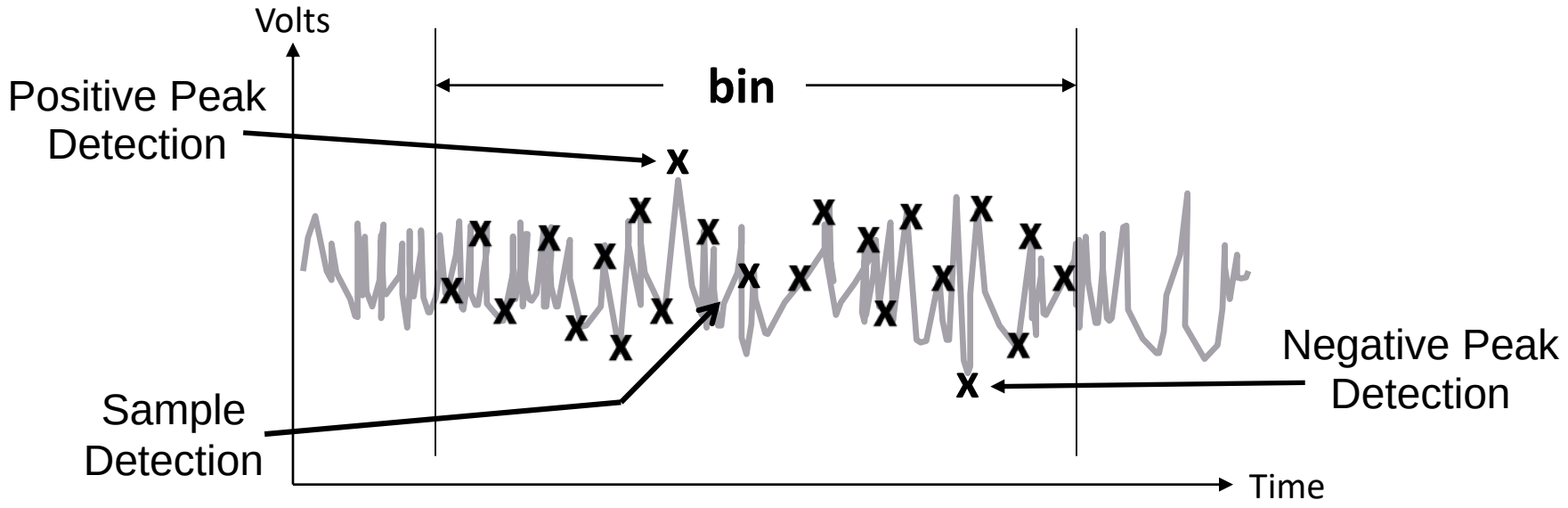
ENVELOPE DETECTOR



Theory of Operation

AVERAGE DETECTOR TYPE

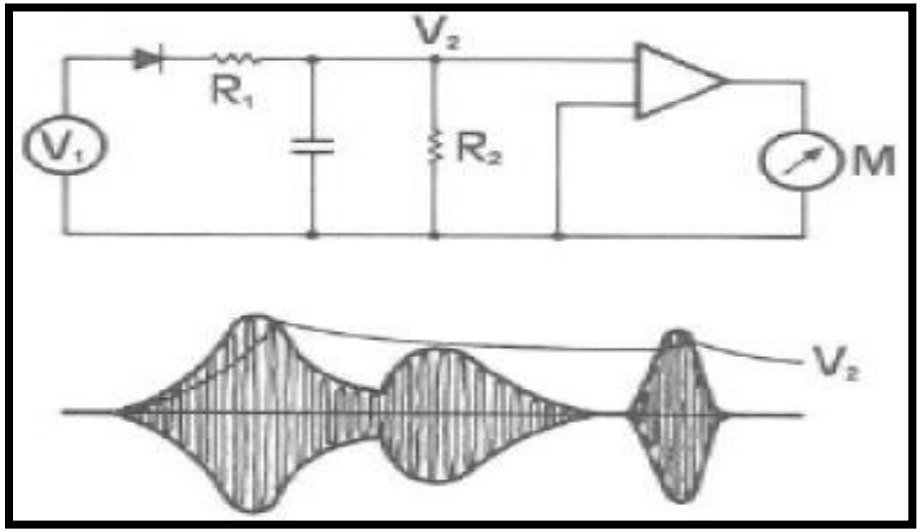


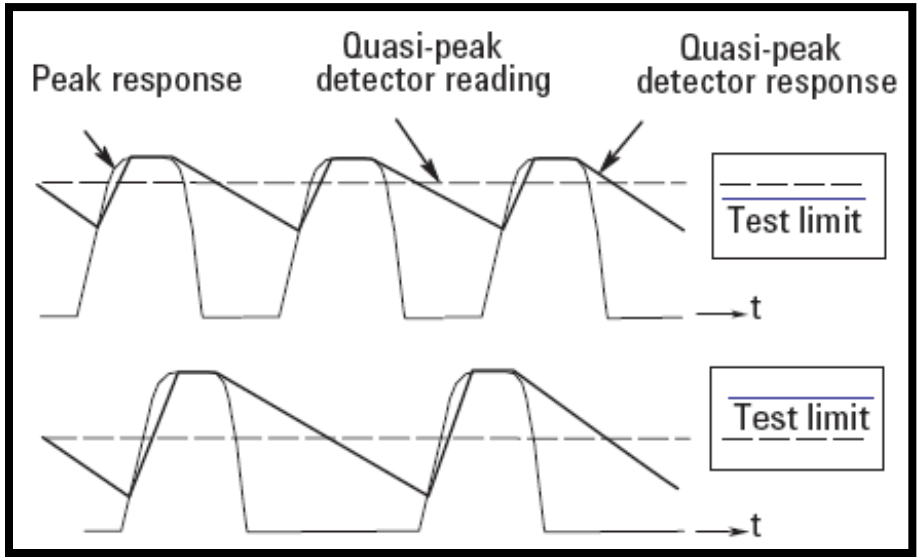


Power Average Detection (rms): Square root of the sum of the squares of ALL of the voltage data values in the bin divided by 50Ω

Quasi-Peak Detection

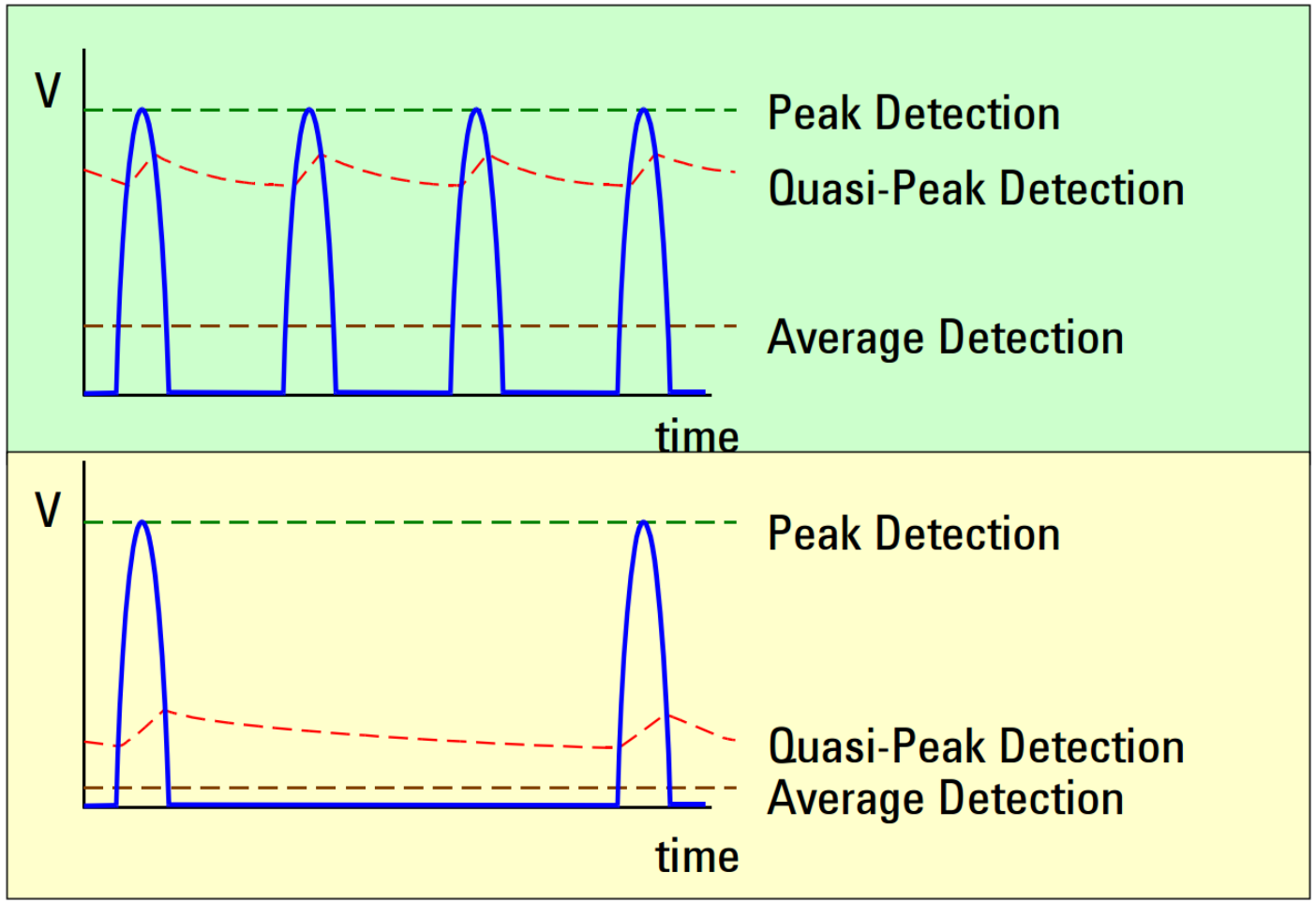
- There are three commonly used detection modes for making
  EMI measurements, including peak, average, and quasi-peak detection.
- **Why use quasi-peak detection?**
  - Used for CISPR based measurements
  - Weighting signals as a function of repetition rate
  - Lower repetition rate noise has less “annoyance factor” and thus has a lower magnitude with a quasi-peak detector
  - CISPR bandwidth: 200 Hz, 9 kHz, and 120 kHz bandwidth





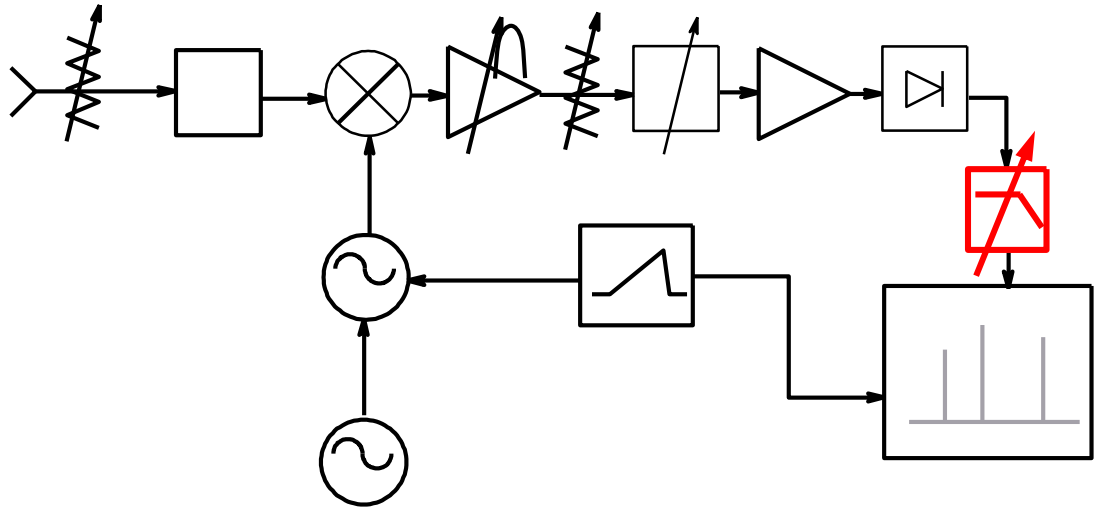
Detection Modes

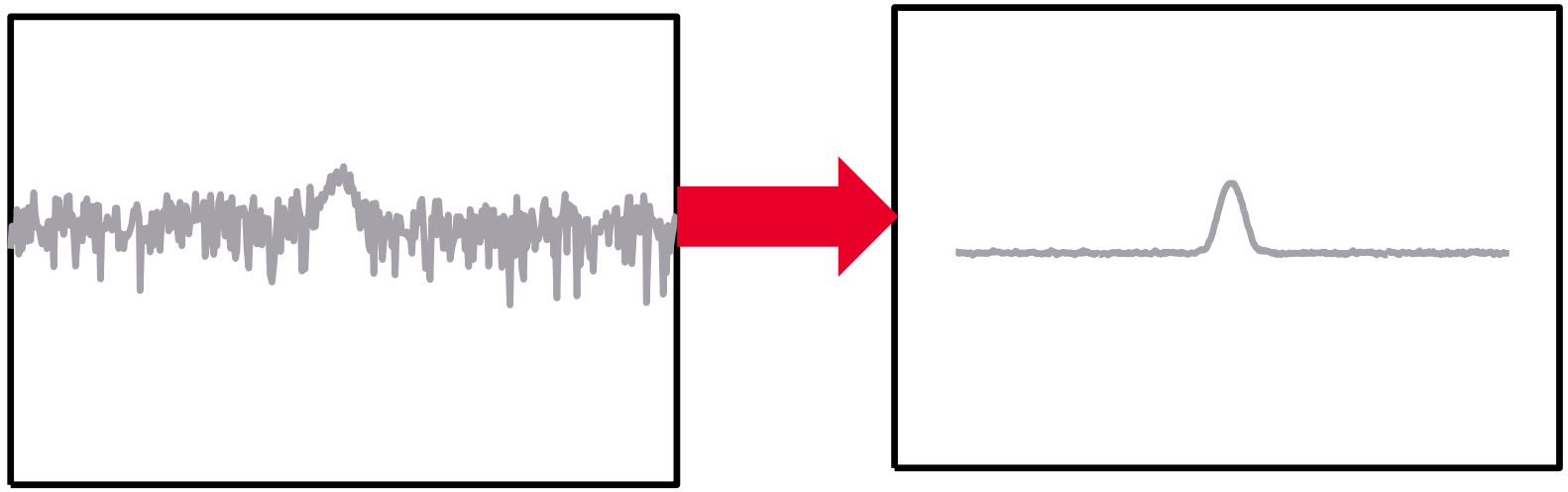
PEAK ≥ QUASI-PEAK ≥ AVERAGE



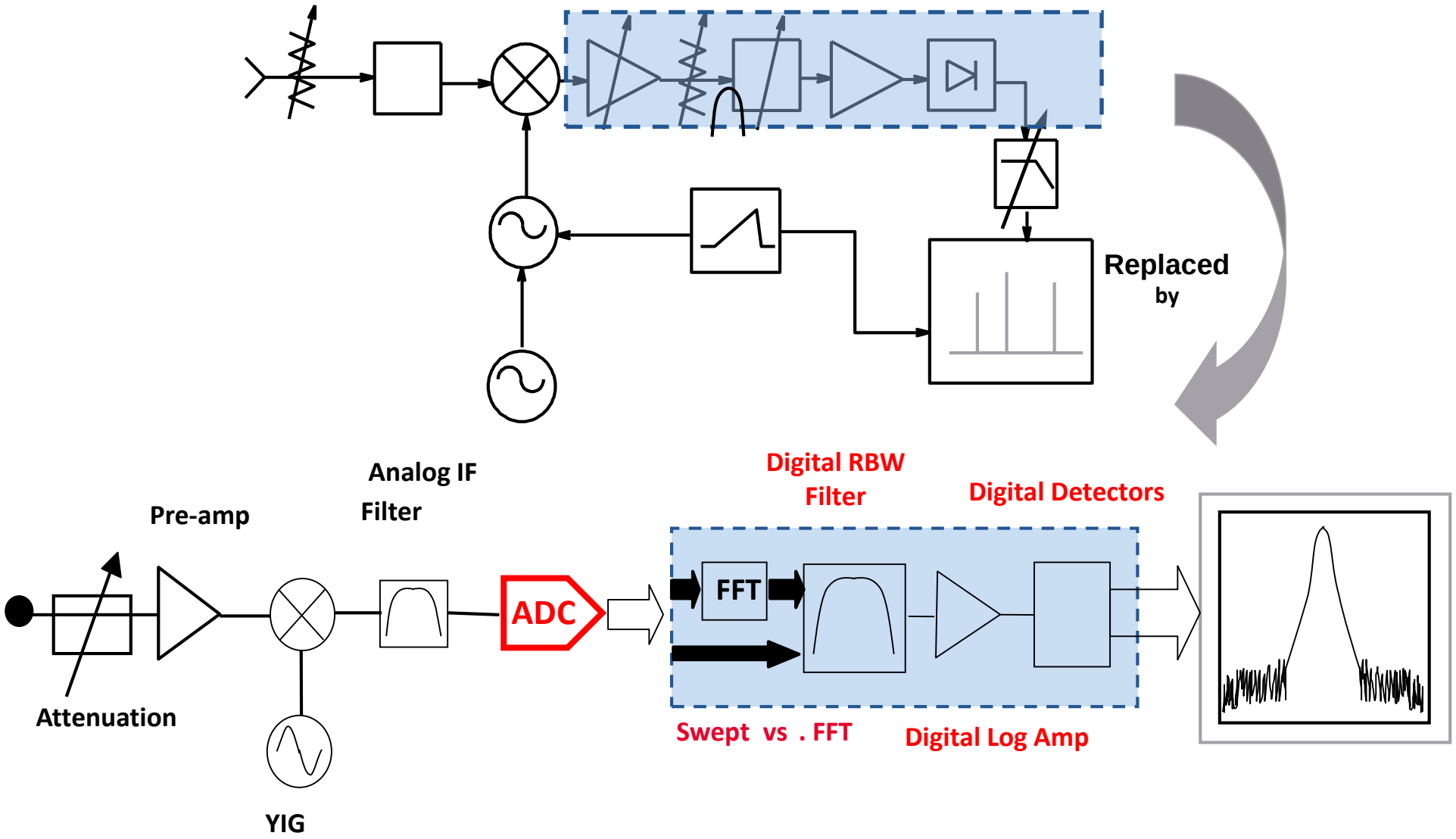
Theory of Operation

VIDEO BANDWIDTH (VBW)





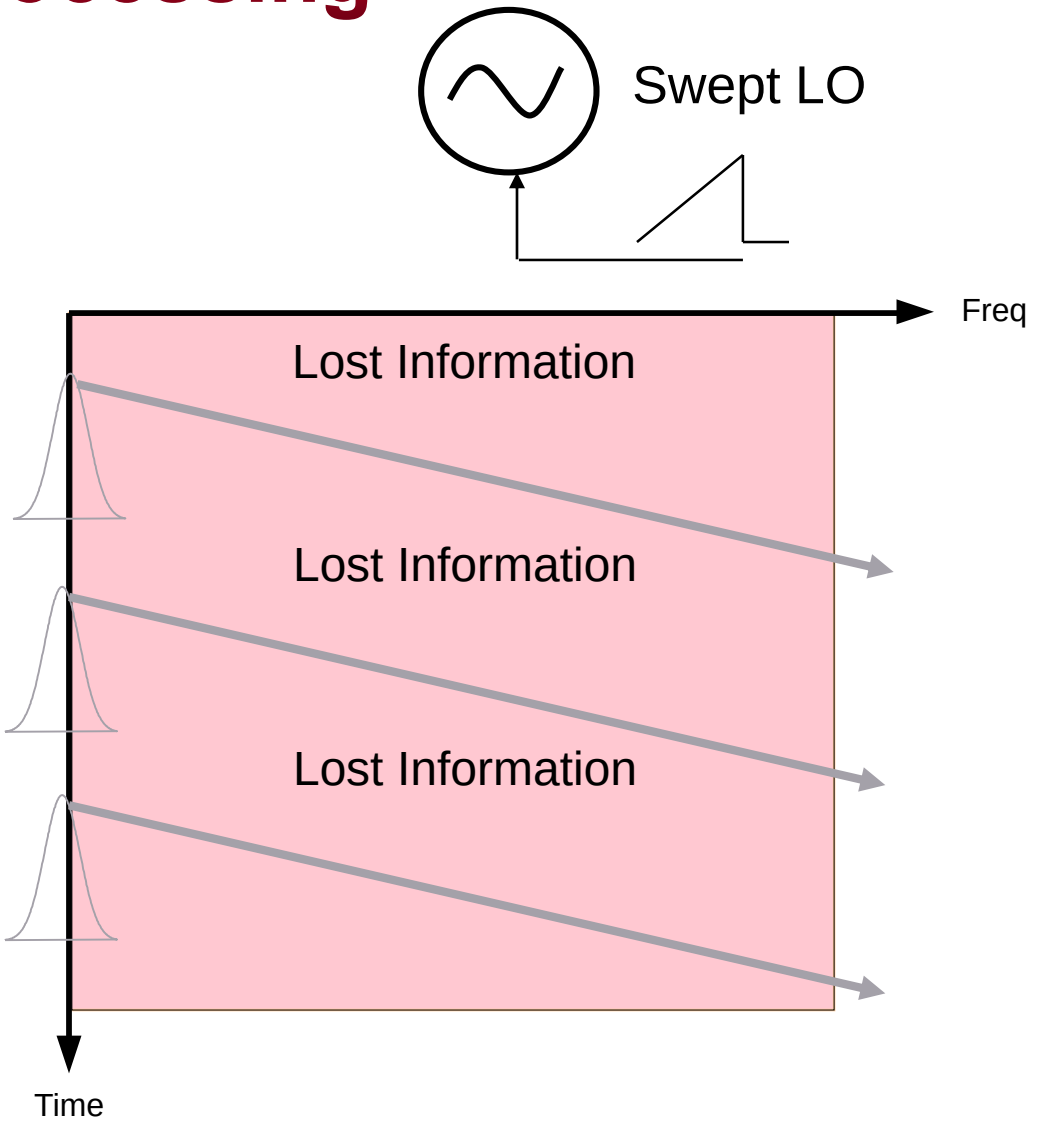
Modern Digital IF



Data Acquisition and Processing

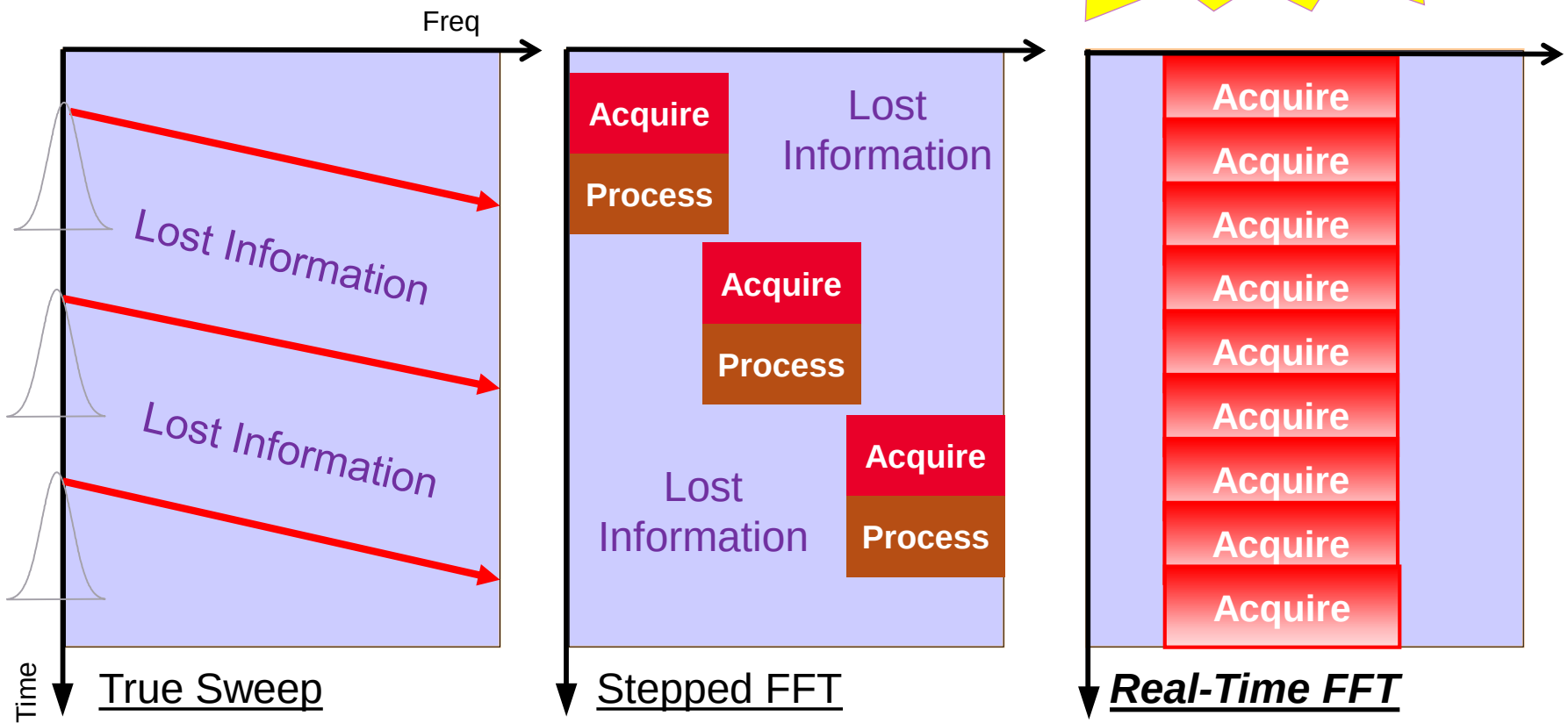
Swept Mode

- A swept LO w/ an assigned RBW.
- Covers much wider span.
- Good for events that are stable in the frequency domain.
- Magnitude ONLY, no phase information (scalar info).
- Captures only events that occur at right time and right frequency point.
- Data (info) loss when LO is “not there”.



Real-Time Spectrum Analysis

Acquisition is continuous and *gap-free*! FFT Process runs fast *during* Acquisition!



True Sweep
Very wide spans
Stationary, repetitive

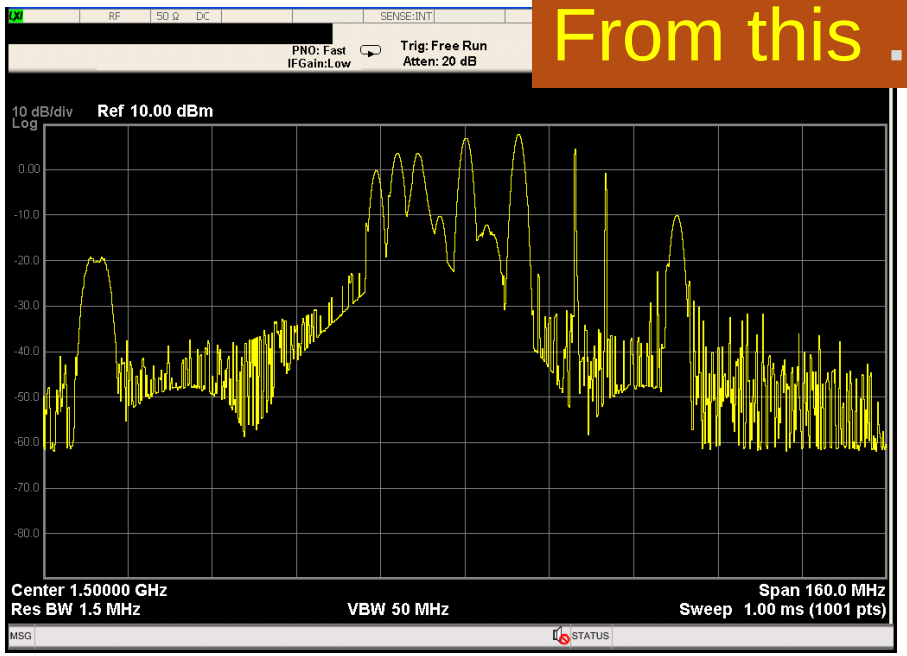
Stepped FFT
Narrow RBW

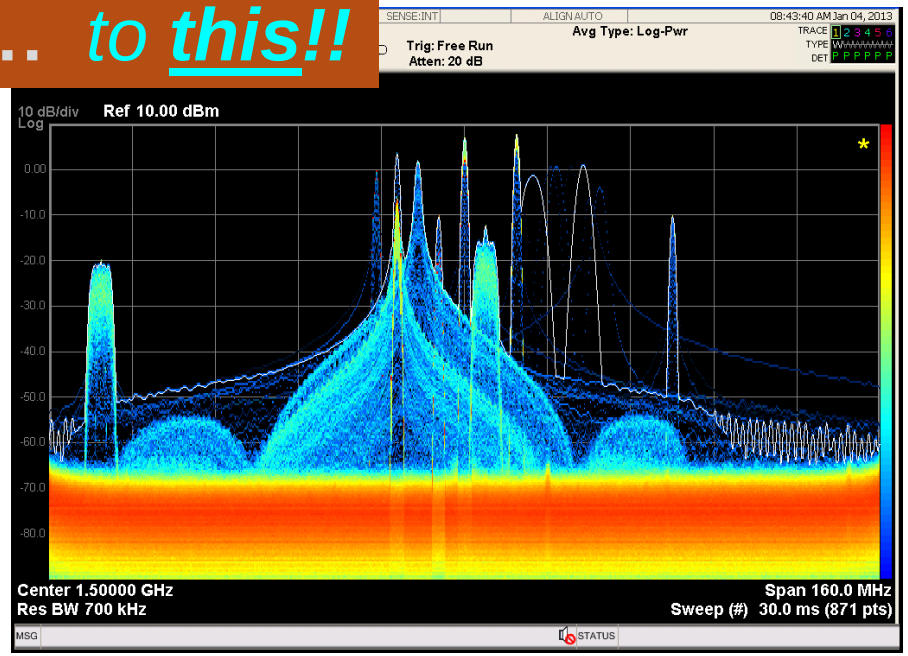
Real-Time FFT
Gap-free, high PoI
Span of Digitizer

Real-Time Spectrum Analysis

Swept vs RTSA

From this … *to **this**!!*



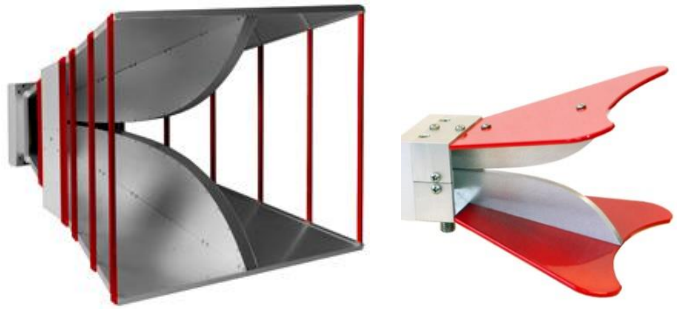


Detect signals as brief as 3.5 us
Density (histogram) color-map display
Persistence: brief events stay visible
Capture rare events with FMT trigger

Accessories for 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 DUT for testing

Accessories for EMI Testing

LISN: Line Impedance Stabilization Network

Close Field Probe Set

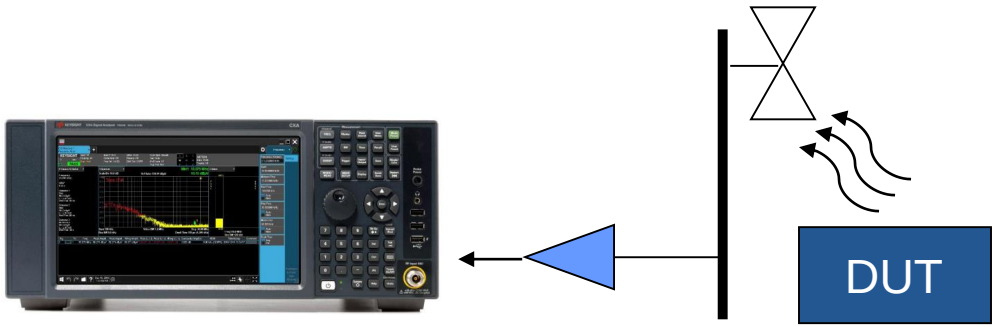
Coupling and decoupling network (CDN)

Current injection probe

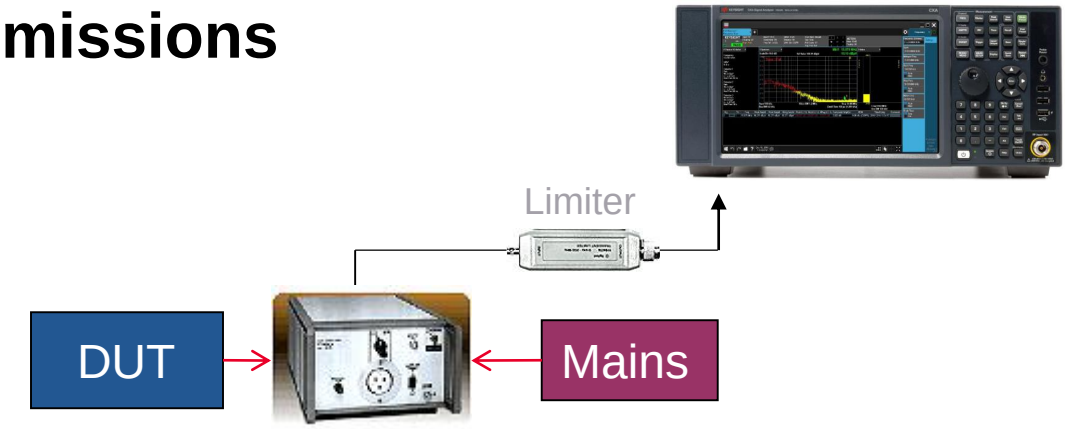
EM-Clamp

EMI Measurements

Radiated Emissions



Conducted Emissions

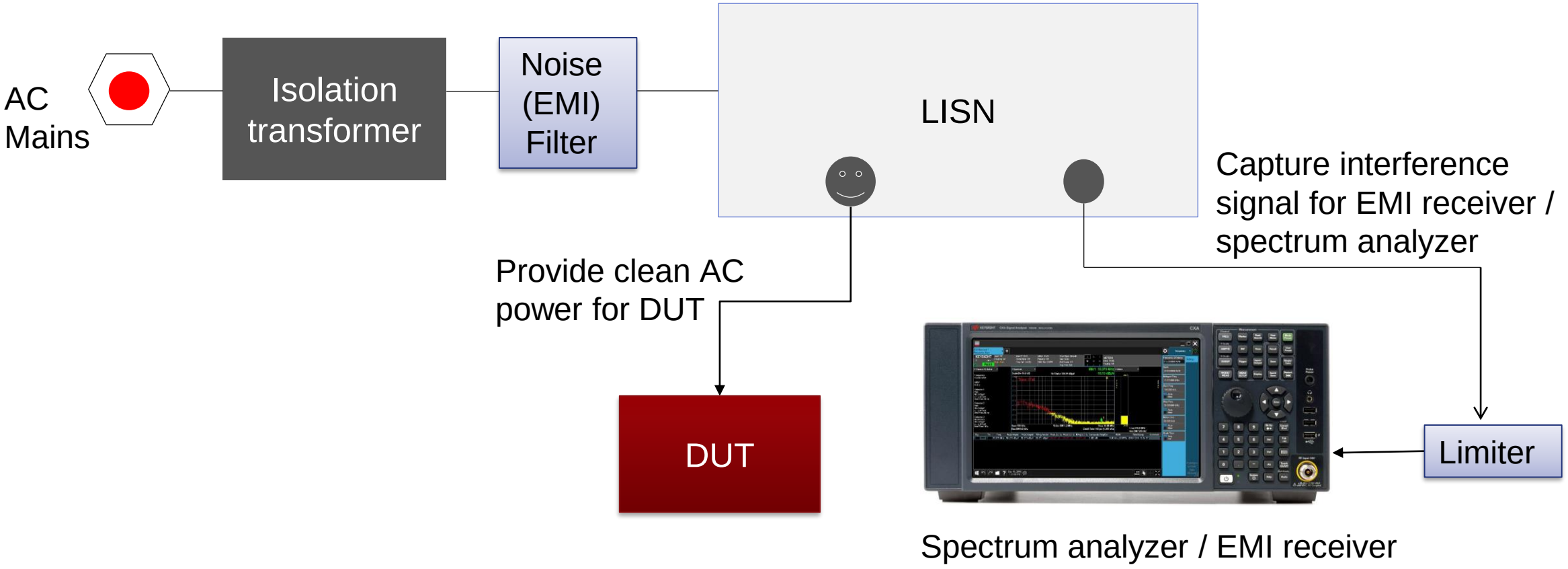


LISN - (line impedance stabilization network)

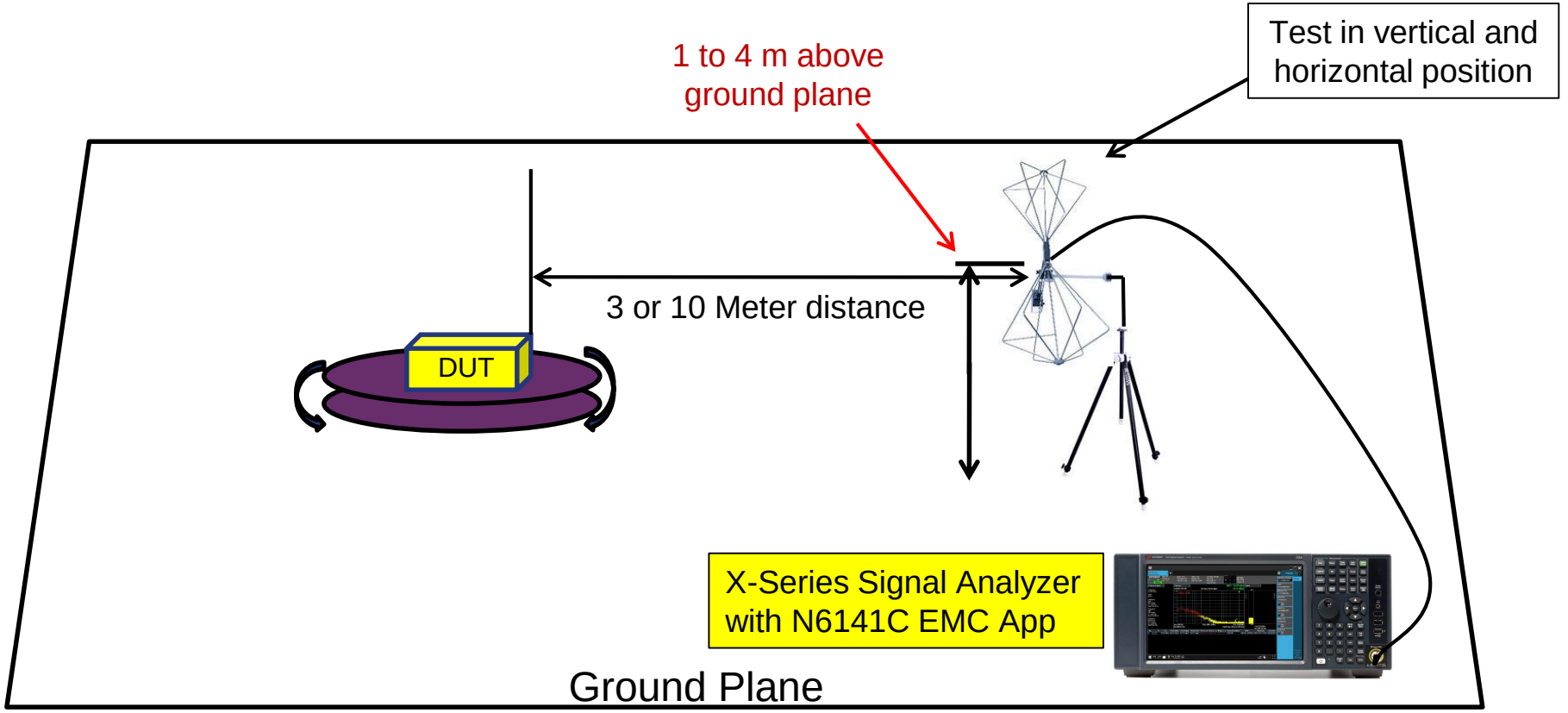
Keysight Equipment: X-Series Signal Analyzers

Conducted Emissions

9 KHZ – 30 MHZ

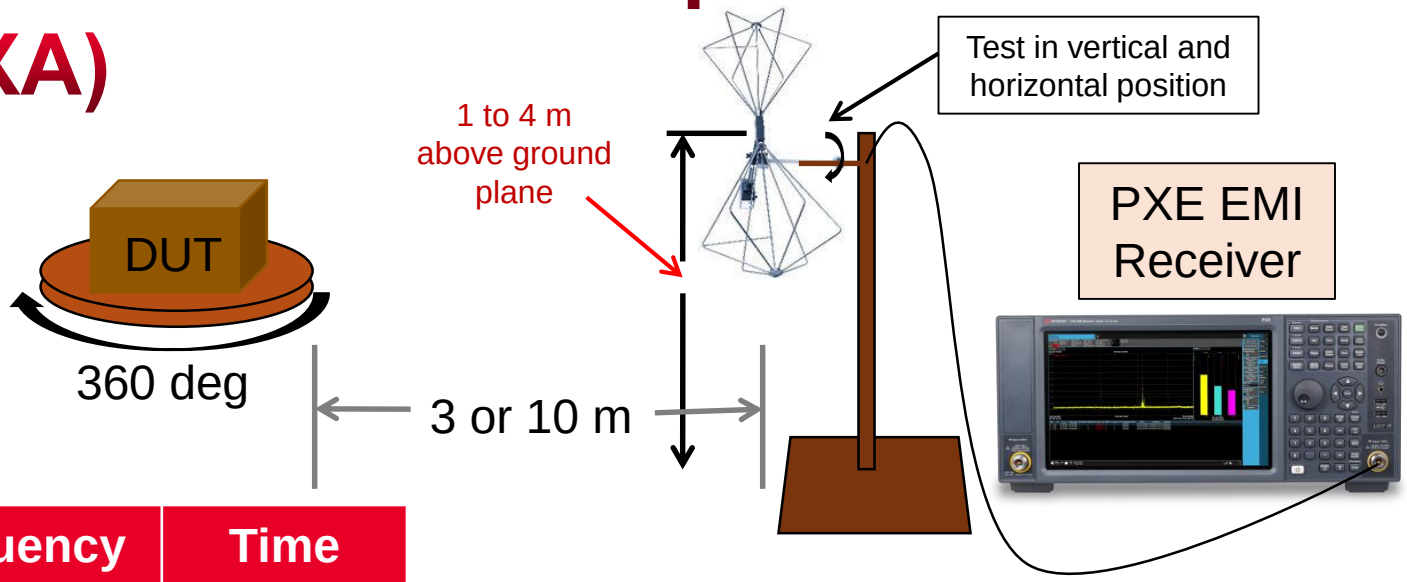


Radiated Emissions Setup



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

Use Time Domain Scan to enhance speed (Not available on CXA)



	Frequency Domain Scan	Time Domain Scan
30MHz–1GHz QPD 1s dwell time RBW =120kHz 4 pts/RBW	1 hr	~60 sec

10 **scans**

2 orientations

x~~1 hr~~/scan

~~20 hours~~

2 minutes

Not counting antenna and turntable positioning time

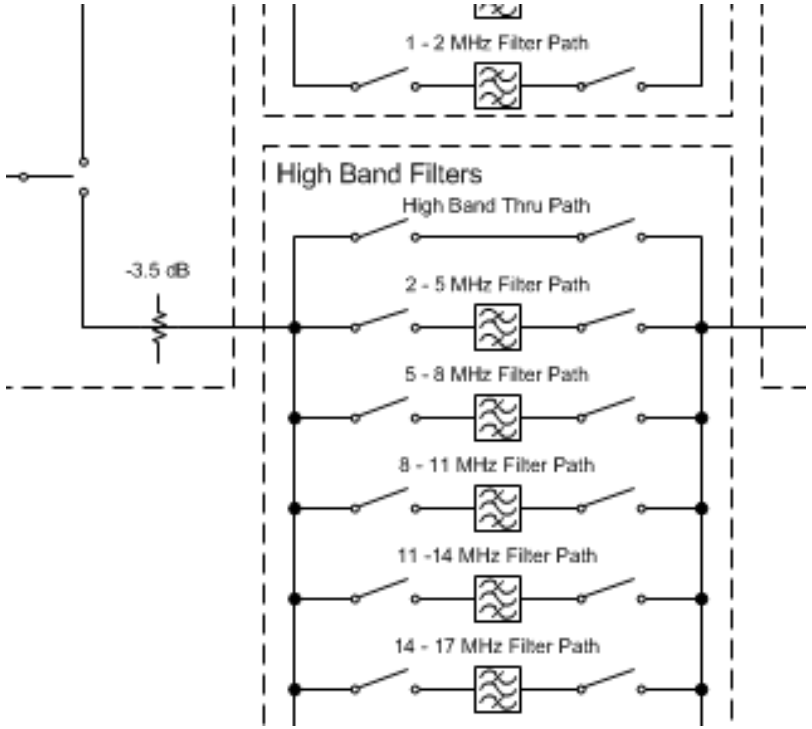
Agenda

- EMI Concepts & Terminology
- EMI Compliance Process
- Introduction to Regulatory Standards
- EMI Measurement Fundamentals
- **EMI Solutions**

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.
Characterizes the EMI performance of the DUT.

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



N9000B CXA Signal Analyzer

N9000B CXA Signal Analyzer, Multi-touch

- 9 kHz – 3 / 7.5 / 13.6 / 26.5 GHz
- -162 dBm DANL performance
- TOI: +17 dBm

Standard EMI features:

- Built-in CISPR limit lines
- Correction data management

Option EMC:

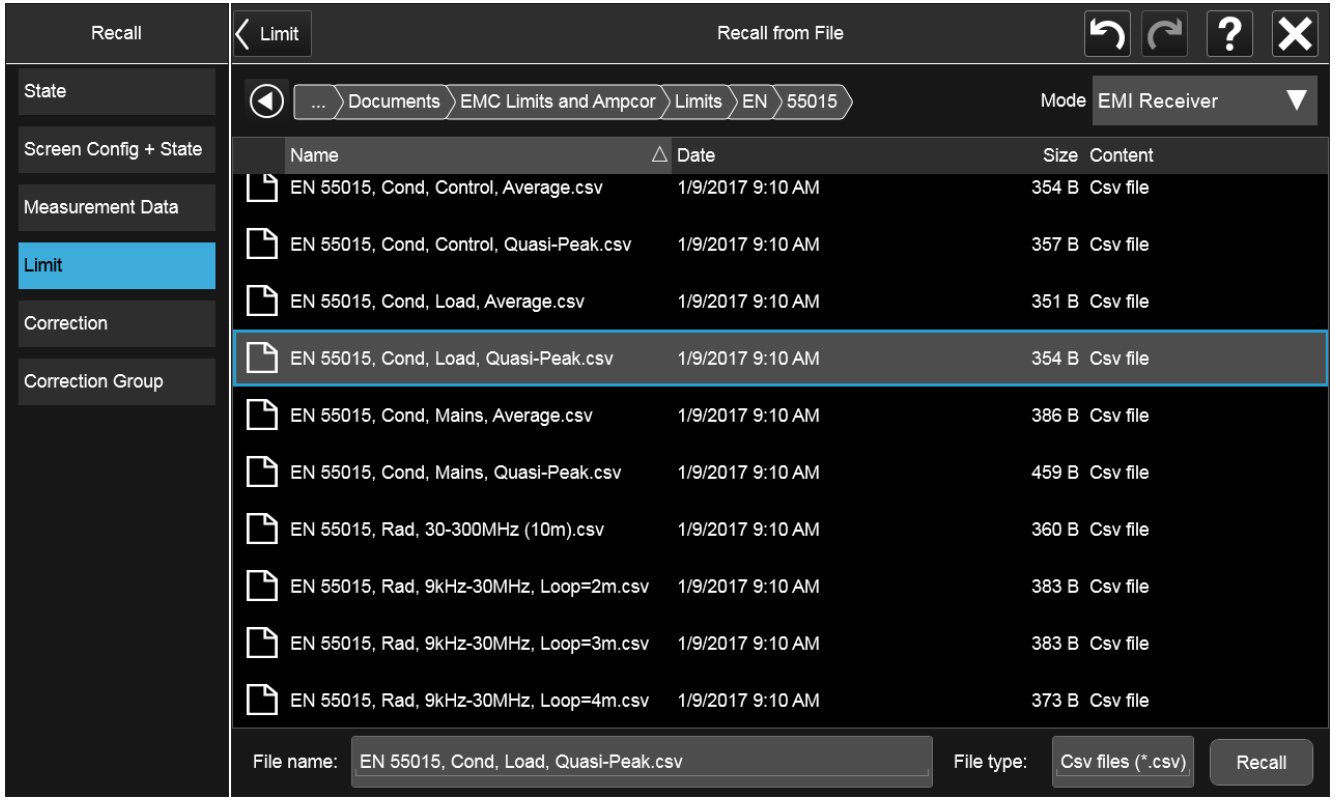
- Provides basic EMI test features
- CISPR band presets, bandwidths, and detectors
- Measure at marker (with 3 detectors simultaneously)

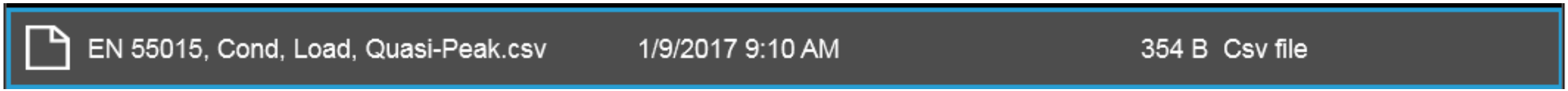
N6141C EMI measurement application:

- Performs pre-compliance radiated and conducted emissions measurements
- Comprehensive EMI signal analysis capability

Built-in CISPR and MIL-STD Limit Line

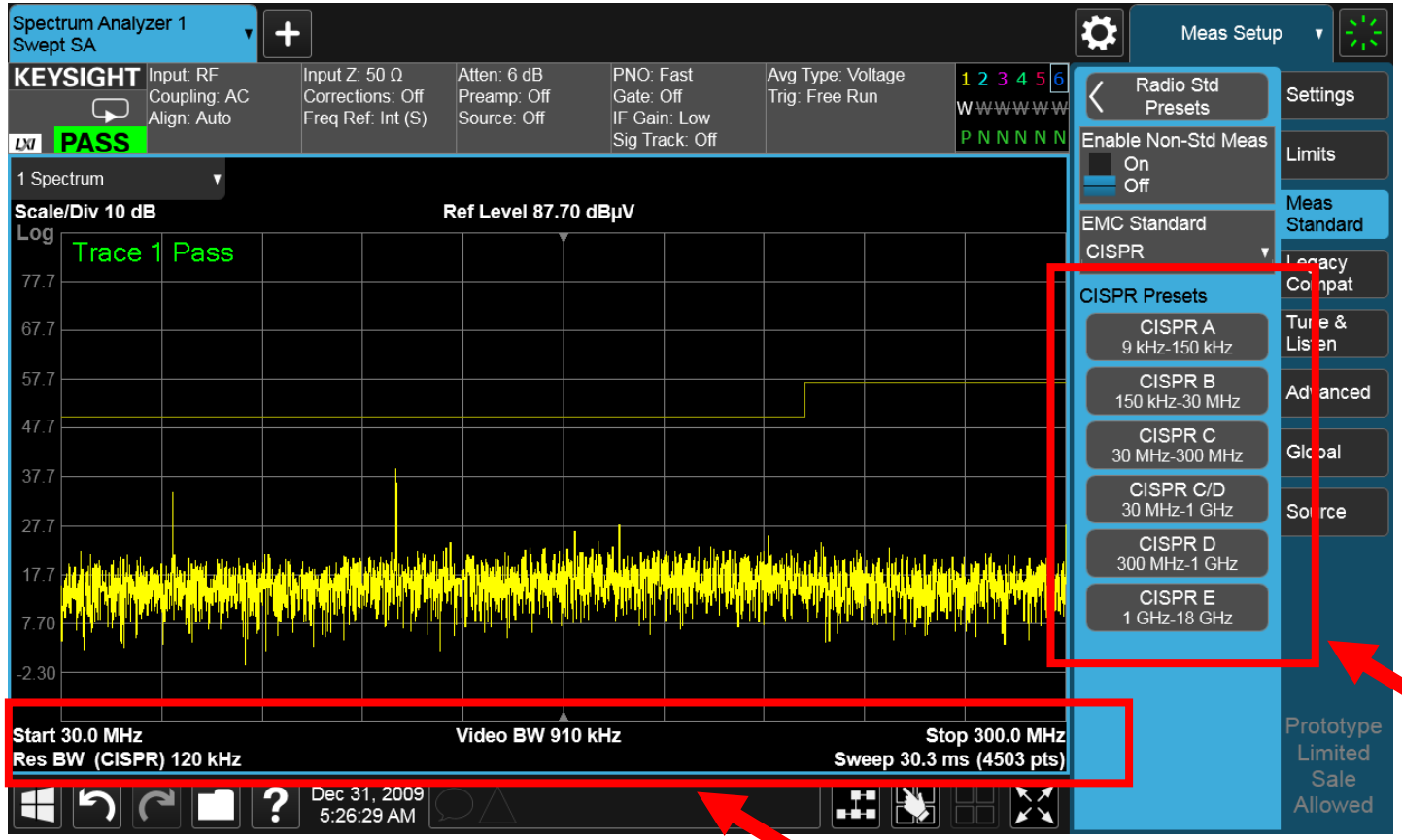
A LIST OF COMMERCIAL LIMITS FOR RECALLING





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

One-button EMI presets

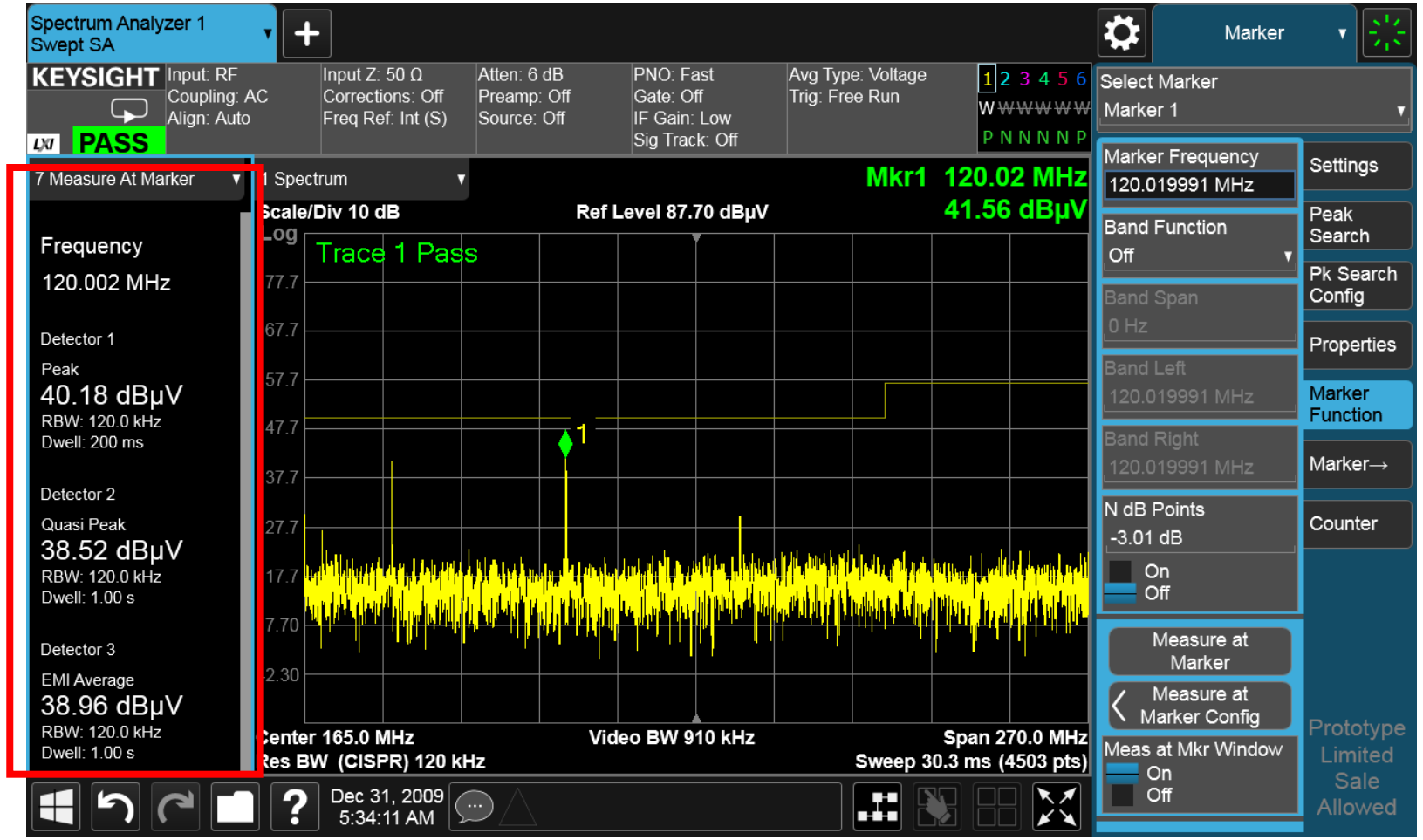
Measurement parameters set according to CISPR bands

N9000B Option EMC

MEASURE AT MARKER WITH 3 DETECTORS SIMULTANEOUSLY

Measure at marker with three detectors:

- Peak
- Quasi-peak
- EMI average



N6141C EMI Measurement Application

RUNS INSIDE CXA SIGNAL ANALYZER

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

N6141C Measurement Procedure

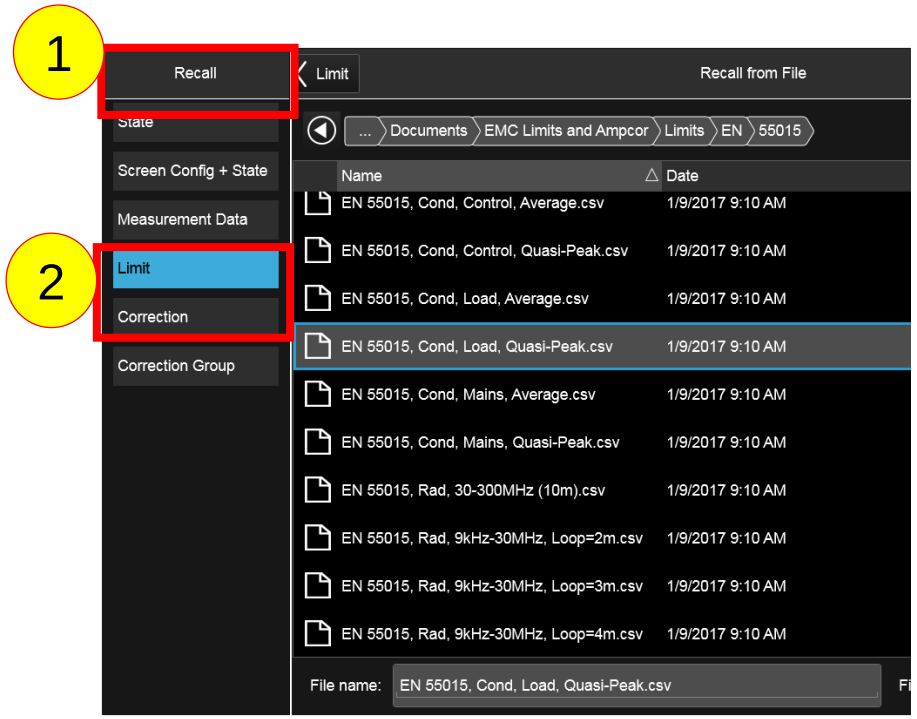
STEP 1. SET UP THE SCAN TABLE

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

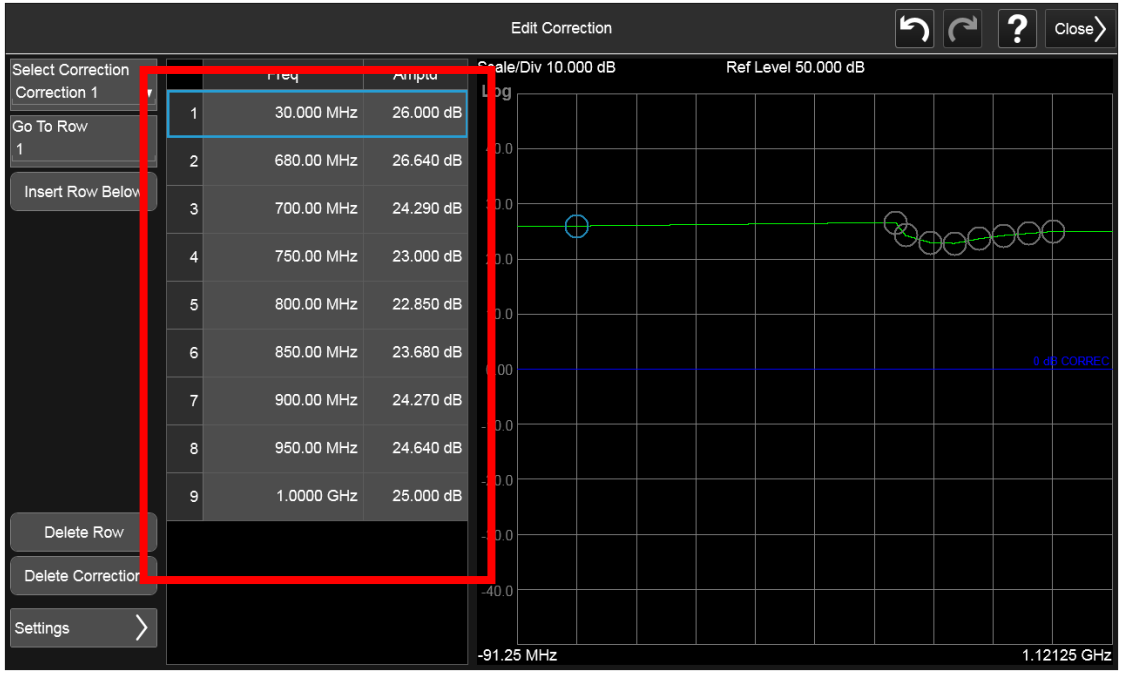
The X-series signal analyzer will set the EMI measurement parameters according to the scan table automatically

N6141C Measurement Procedure

STEP 2. LOAD LIMIT LINE. LOAD CORRECTION DATA.



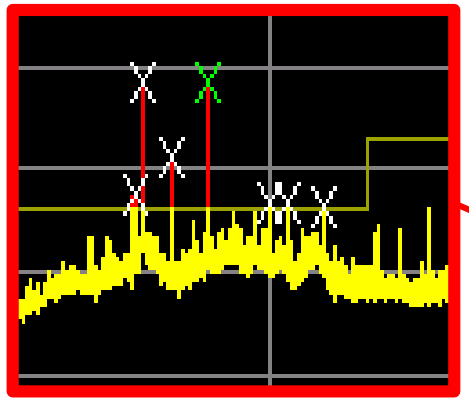
- Press [Recall] → {Limit} to load a pre-defined limit file
- Press [Recall] → {Correction} to load a pre-defined correction file



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

N6141C Measurement Procedure

STEP 3. SCAN, SEARCH, AND MEASURE



Capture out of limit emissions and listing them in the table below

Three meters let you observe single emission, with 3 detectors simultaneously

View results for each failure with their deviations from the limit

N9000B CXA Signal Analyzer

– 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

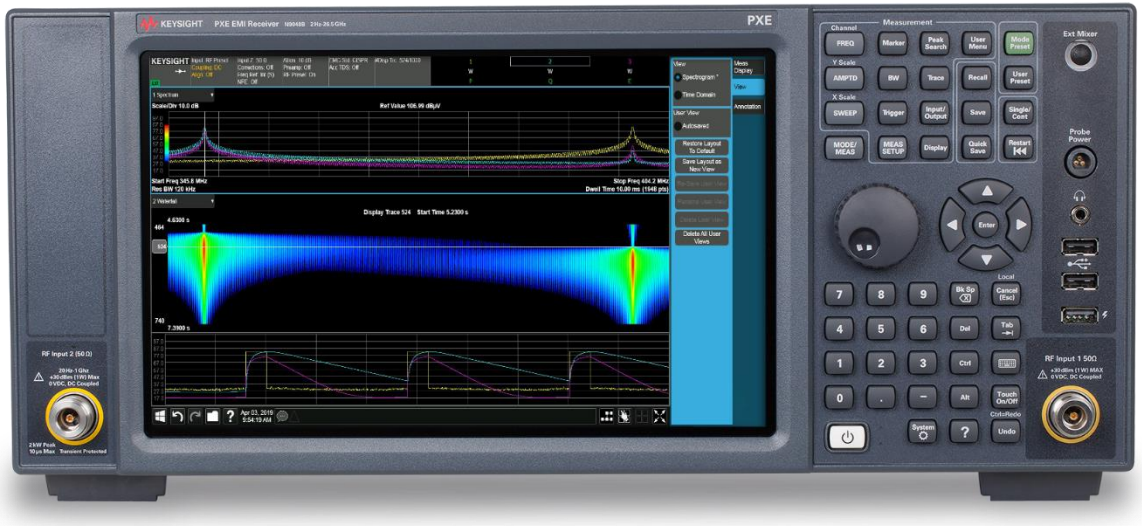
Go to www.Keysight.com/find/CXA
for more product information

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

N9048B PXE EMI Receiver, 2 Hz to 26.5 GHz

CISPR 16-1-1 & MIL-STD-461 COMPLIANT

- Standards-compliant EMI receiver hardware
- Software supports full compliance tests



N934xC HSA and N9322C BSA

AVAILABLE THROUGH TESTEQUITY

- Portable, rugged, fanless design
- Benchtop performance with –144 dBm DANL, ±1.3 dB amplitude accuracy, and < 0.95 s full span (20 GHz) sweep time
- EMI bandwidths and detectors

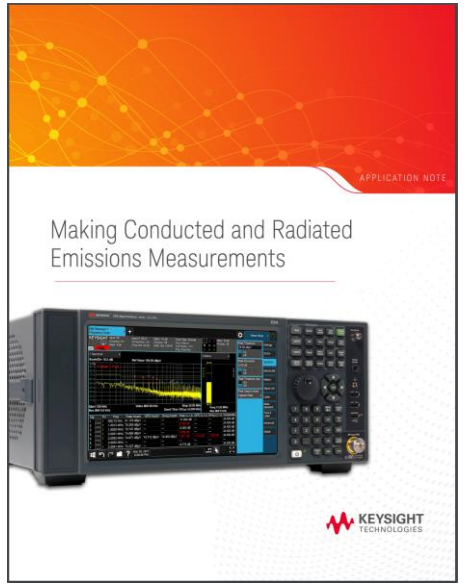
- Fast, value-priced, general-purpose performance up to 7 GHz
- Straightforward and efficient operation with marker demodulation, one-button optimization, and user-definable soft keys

Keysight's RF Test Equipment

www.keysight.com/find/RFBench

Reference Material

You may download following literature from Keysight.com/find/EMI	
Application note	Making conducted and radiated emissions measurements
YouTube Series	The ABCs of EMC
White paper	EMI troubleshooting: The need for close field probes



Summary: EMI Pre-Compliance with a Signal Analyzer

PERFORM TESTING IN-HOUSE TO SAVE TEST TIME AND COSTS

How to measure EMI?
Use a spectrum analyzer or EMI receiver. It should have the following features:
CISPR resolution bandwidth and detectors
Able to load antenna factor
Able to set trace points, dwell time, etc.

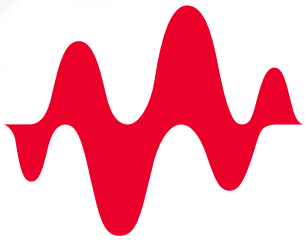
Which test environment?
Semi-anechoic chamber
Open area
Boardroom
Parking garage

Selection of antenna?
Biconical: broad-band dipole antenna, omnidirectional, fit for 30~230 MHz EMI test
Log-periodic: wide frequency range, directional antenna, fit for 230 MHz ~ 1 GHz EMI test
Whip: Used in automotive electronic devices' EMI test
Close field probe: Used for near field interference hunting

Understand the value in Pre-Compliance testing
Identify EMI issues with your device early in the design process
Save time & money

EMI Interference Analysis and Troubleshooting

QUESTIONS?



KEYSIGHT
TECHNOLOGIES