Spectrum Analysis Back to Basics

Agilent Technologies

Agenda

Introduction

Overview:

- What is Spectrum and Signal Analysis?
- What Measurements are available?

Theory of Operation

Specifications

Modern spectrum analyzer designs & capabilities

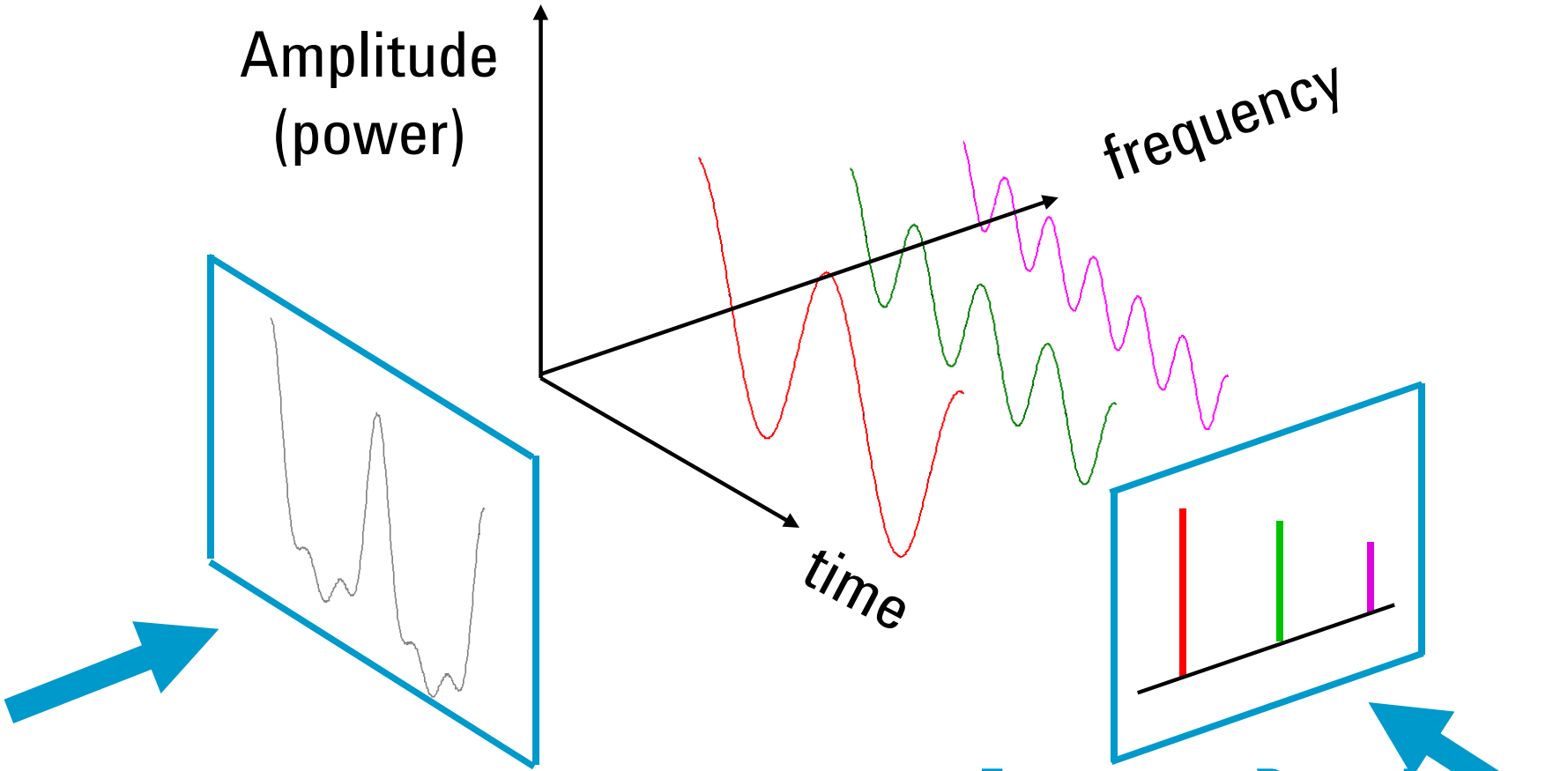
Applications

Automation Tools

Wrap-up

Overview

Frequency versus Time Domain



Time domain Measurements (Oscilloscope)

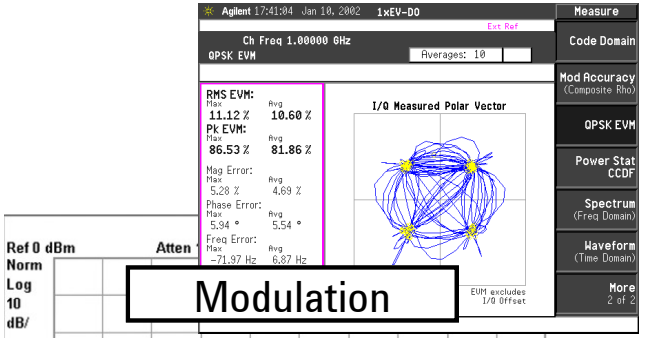
Frequency Domain Measurements (Spectrum Analyzer)

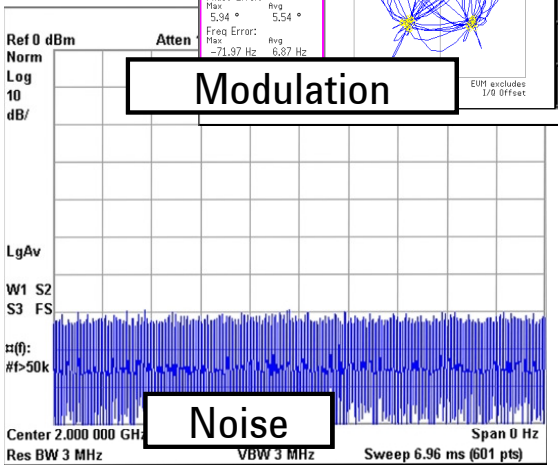
Overview

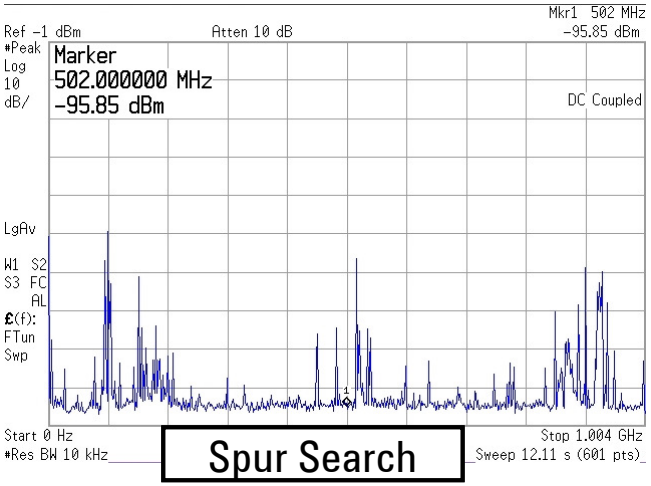
Types of Measurements Available

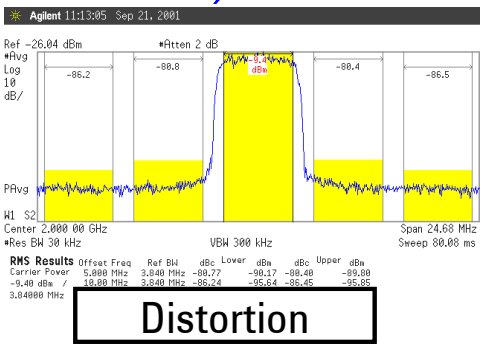
Frequency, power, modulation, distortion & noise

- Spectrum monitoring
- Spurious emissions
- Scalar network analysis
- Noise figure & phase noise
- Harmonic & intermodulation distortion
- Analog, digital, burst & pulsed RF Modulation
- Wide bandwidth vector analysis
- Electromagnetic interference
- *Measurement range (-172 dBm to +30 dBm)*
- *Frequency range (3 Hz to 325 GHz)*









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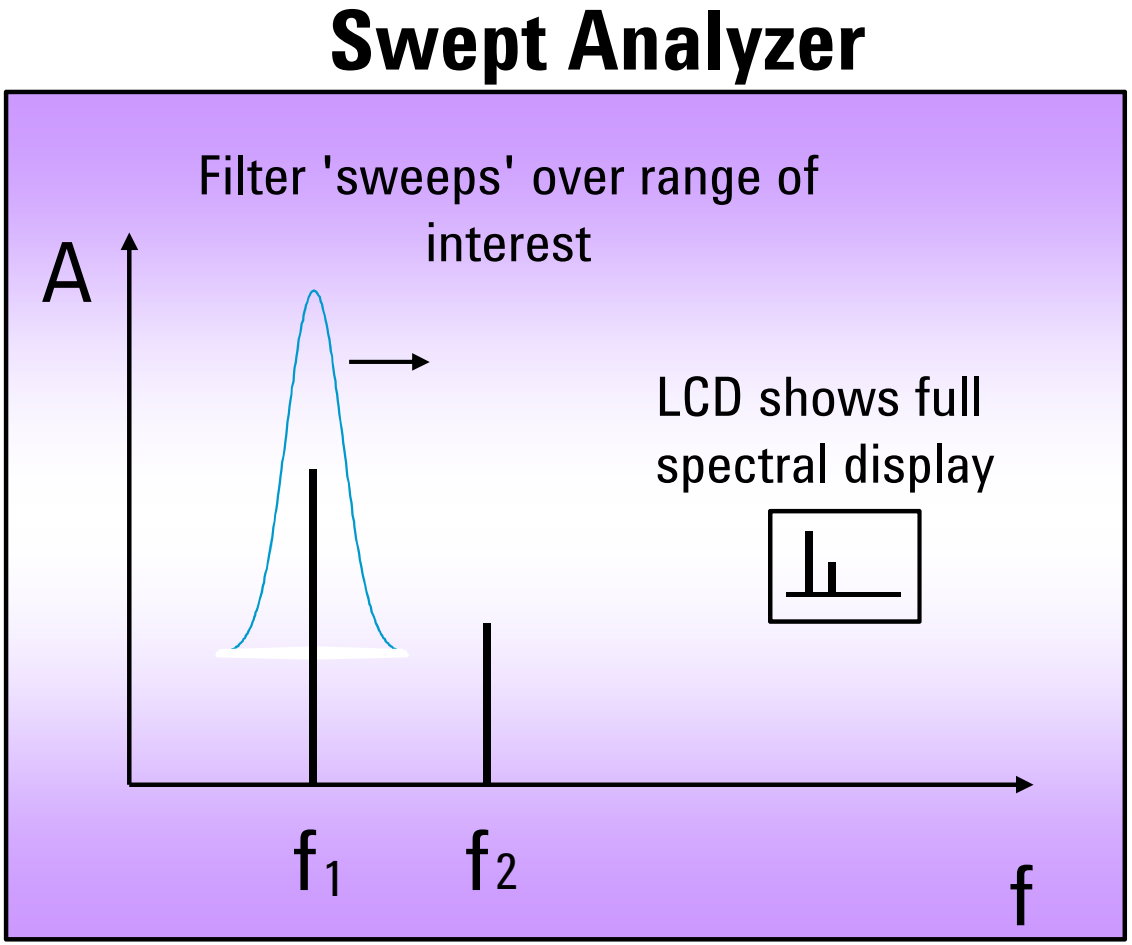
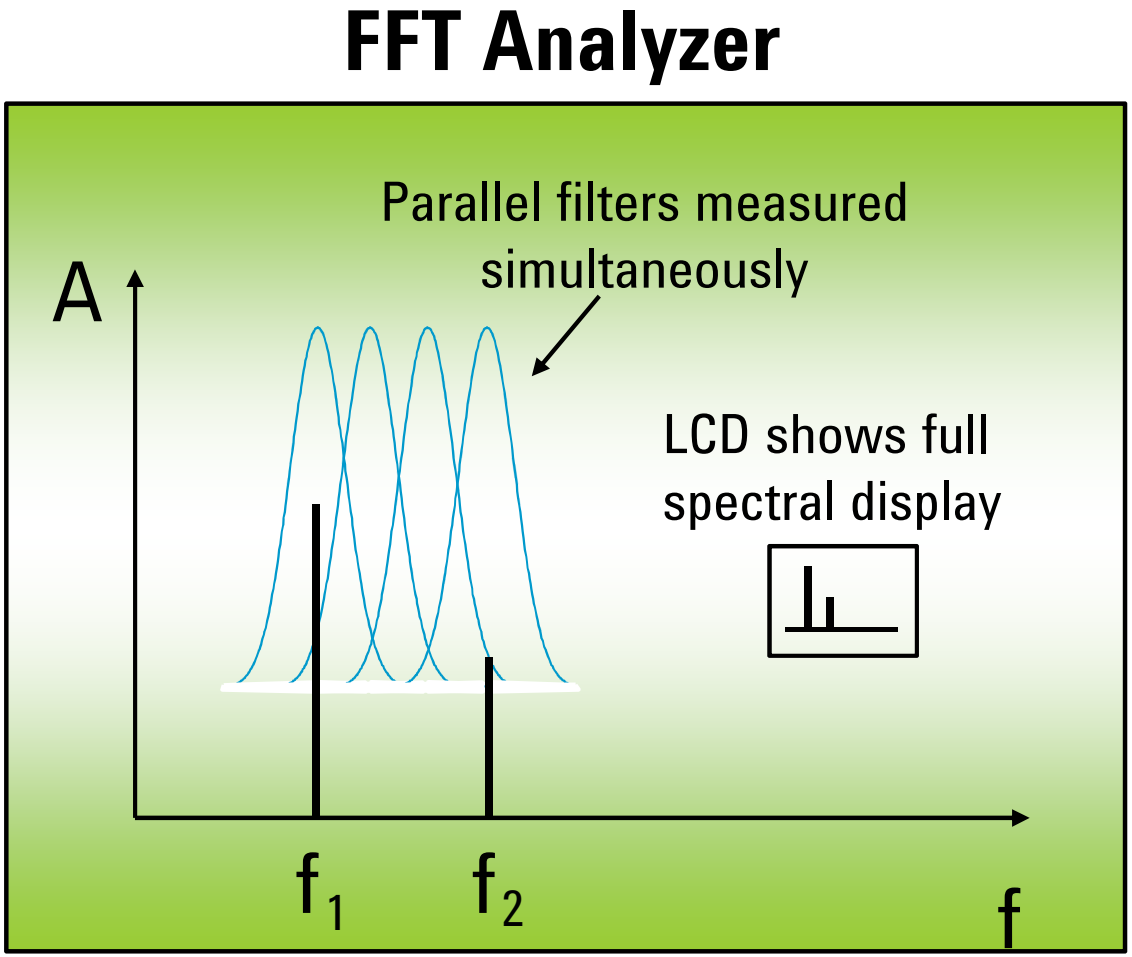
Overview

Different Types of Analyzers



Overview

Different Types of Analyzers



Agenda

Introduction

Overview

Theory of Operation:

- Swept Spectrum Analyzer Hardware

Specifications

Modern spectrum analyzer designs & capabilities

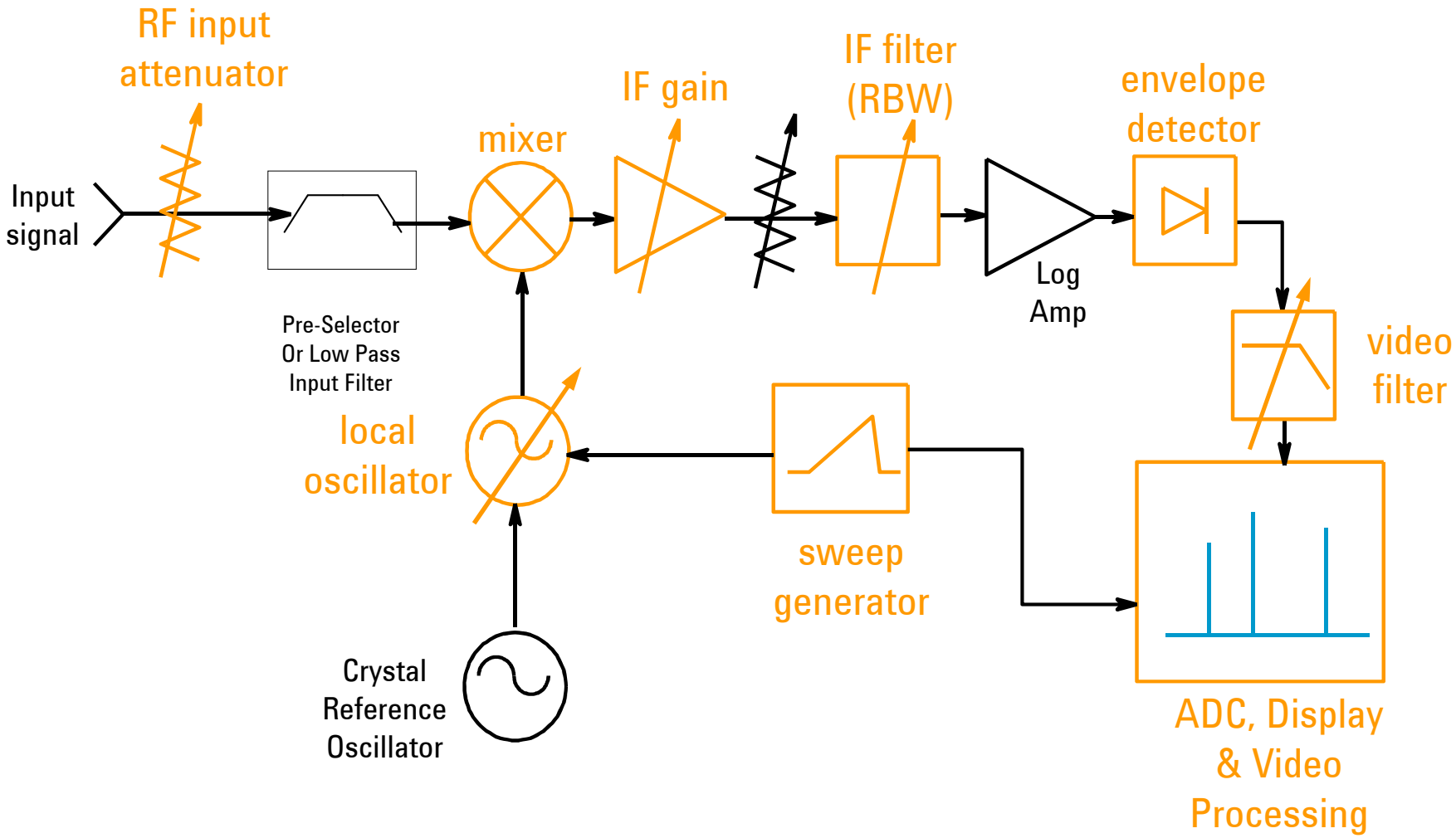
Applications

Automation Tools

Wrap-up

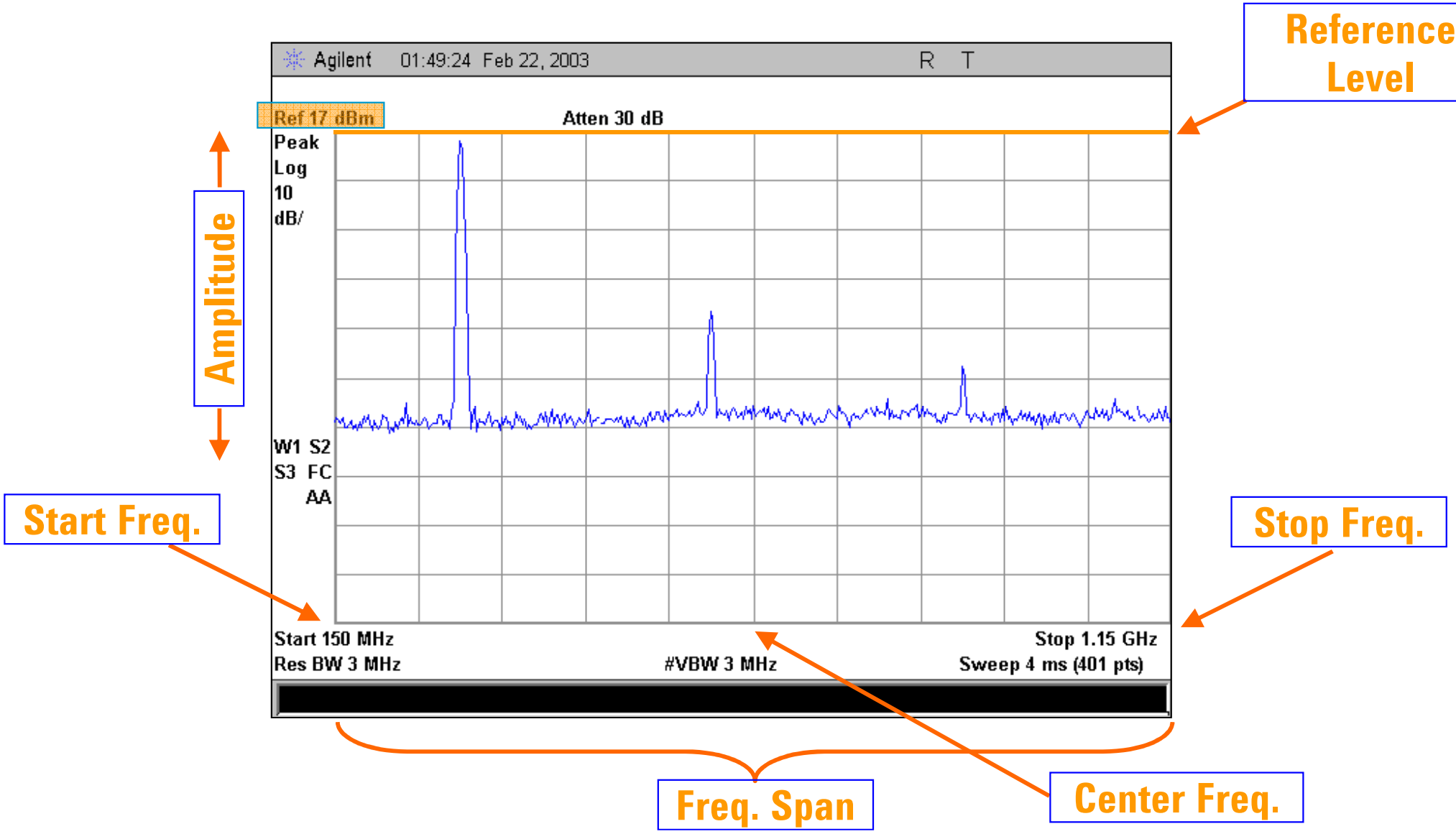
Theory of Operation

Swept Spectrum Analyzer Block Diagram



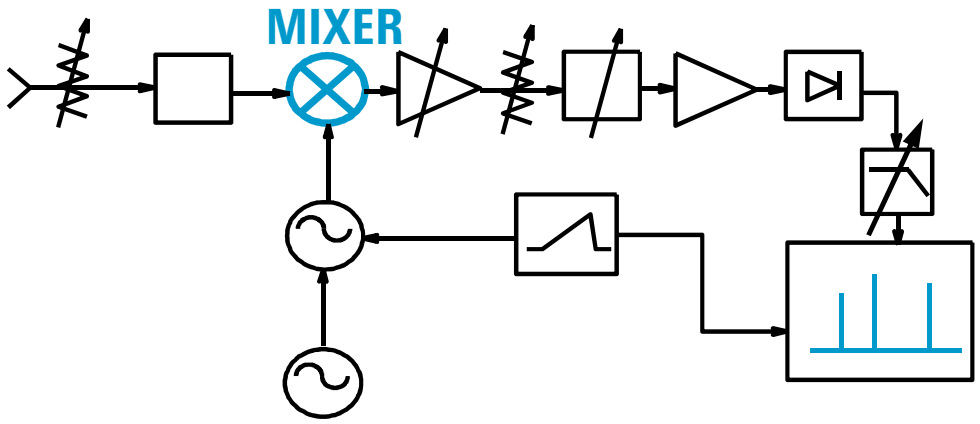
Theory of Operation

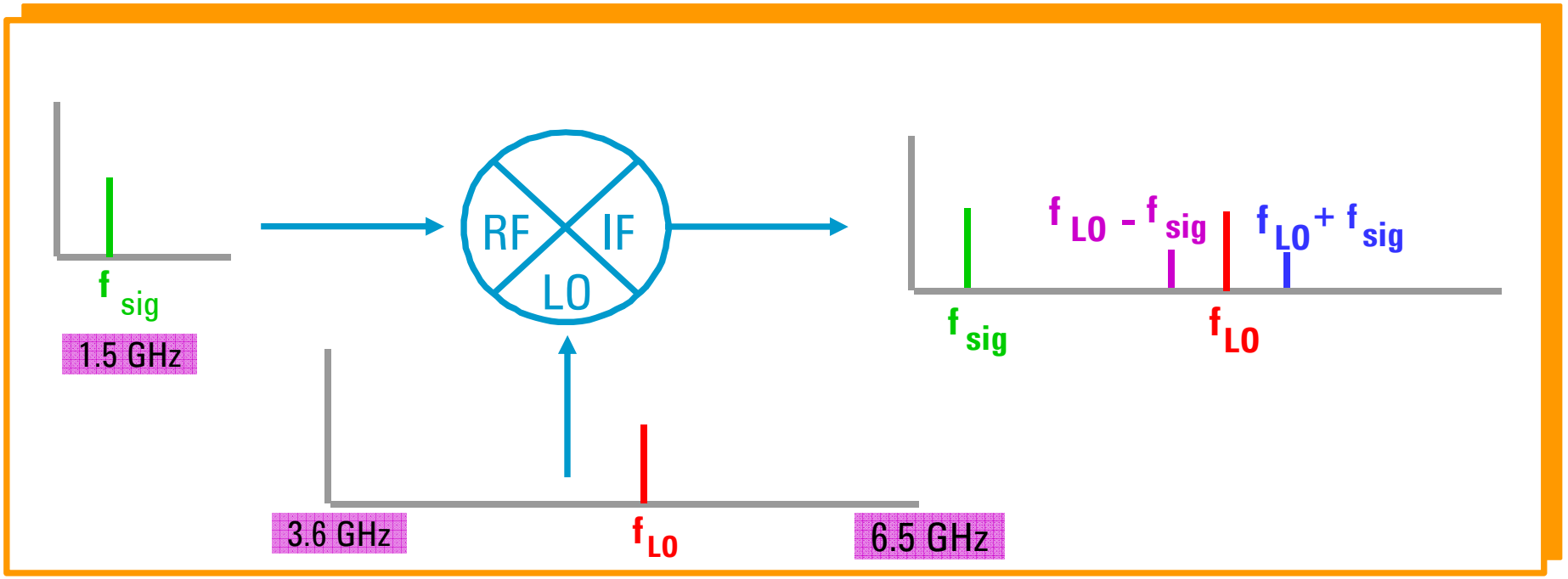
Display terminology



Theory of Operation

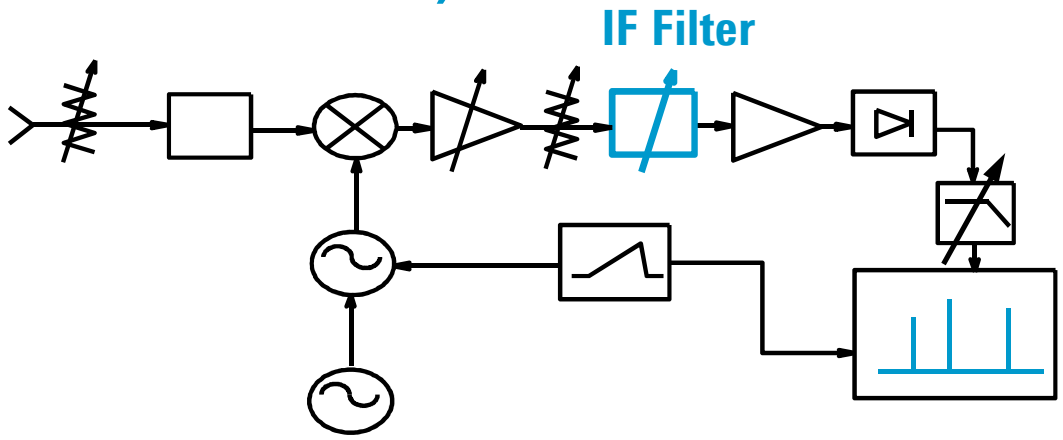
Mixer

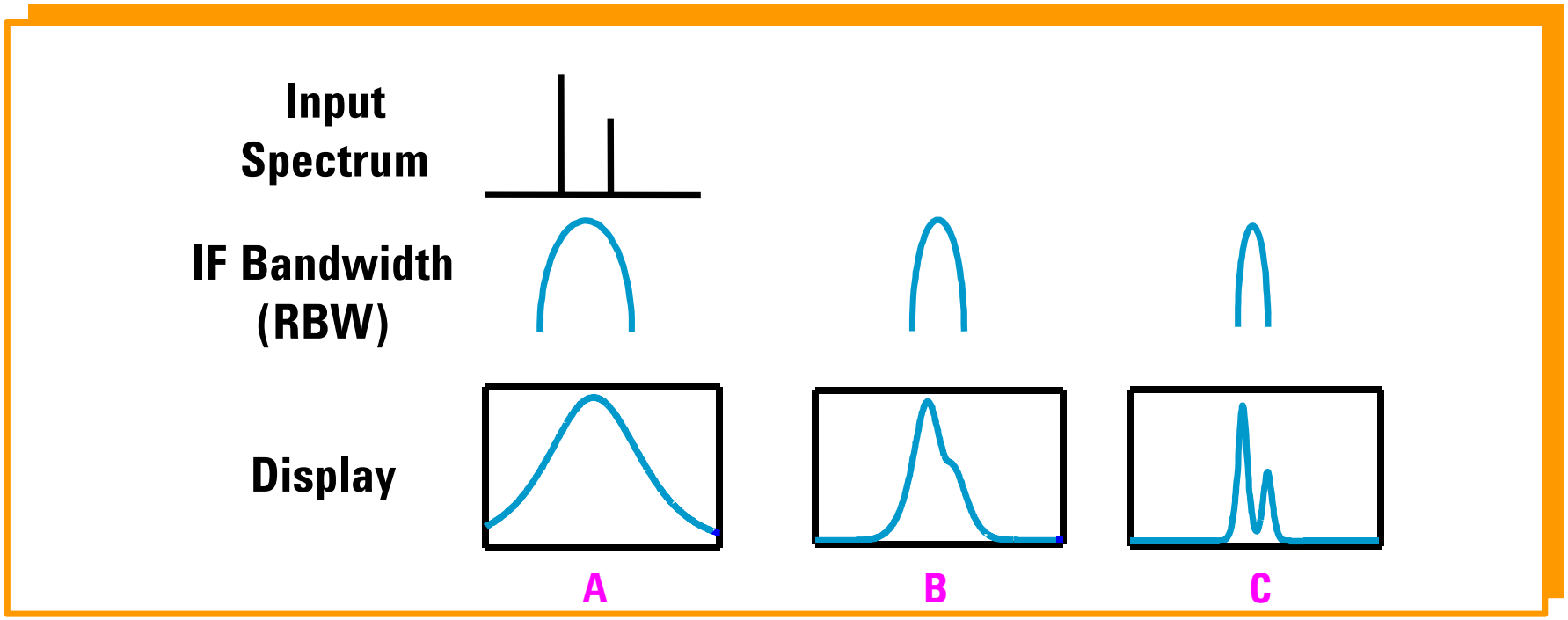




Theory of Operation

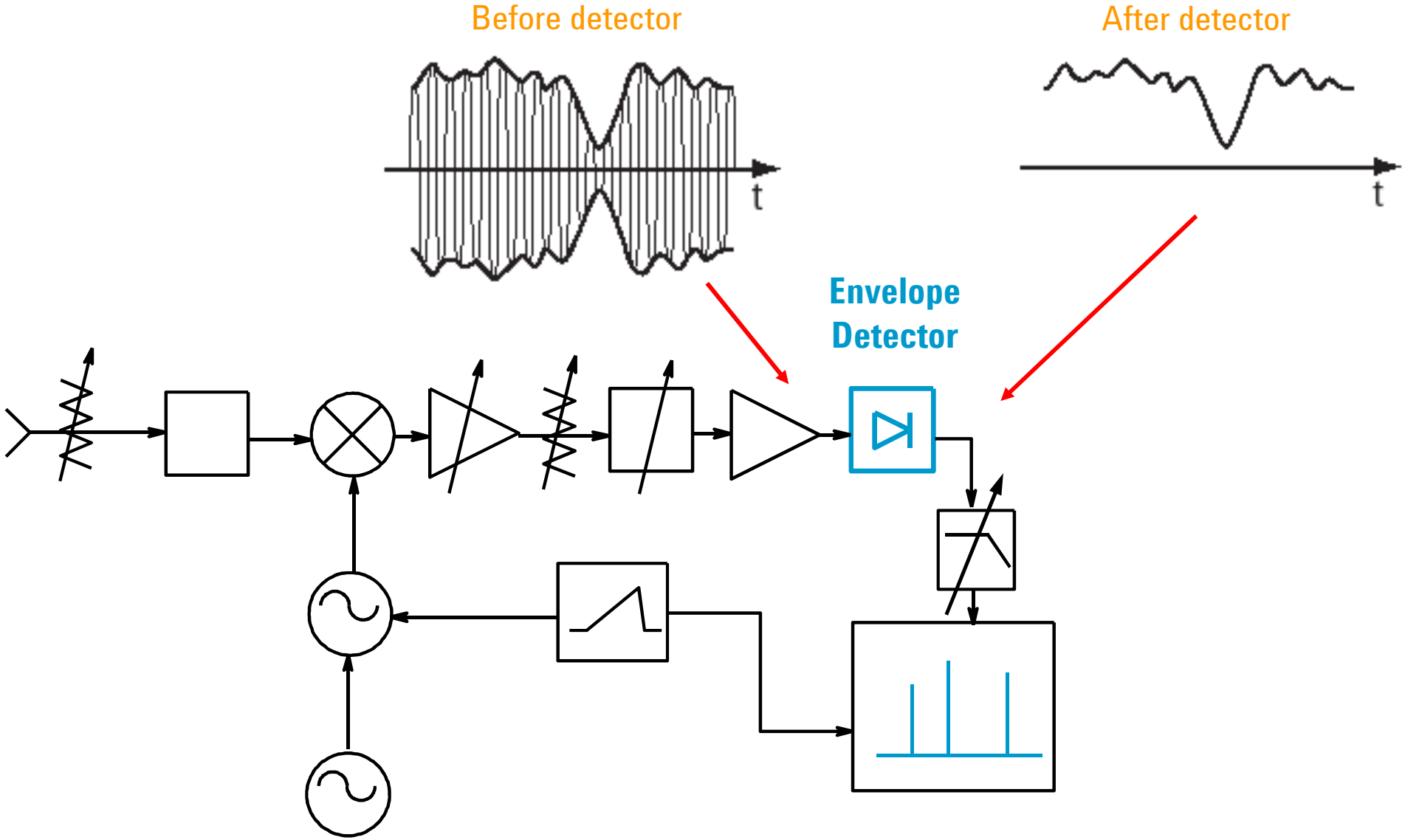
IF Filter (Resolution Bandwidth – RBW)





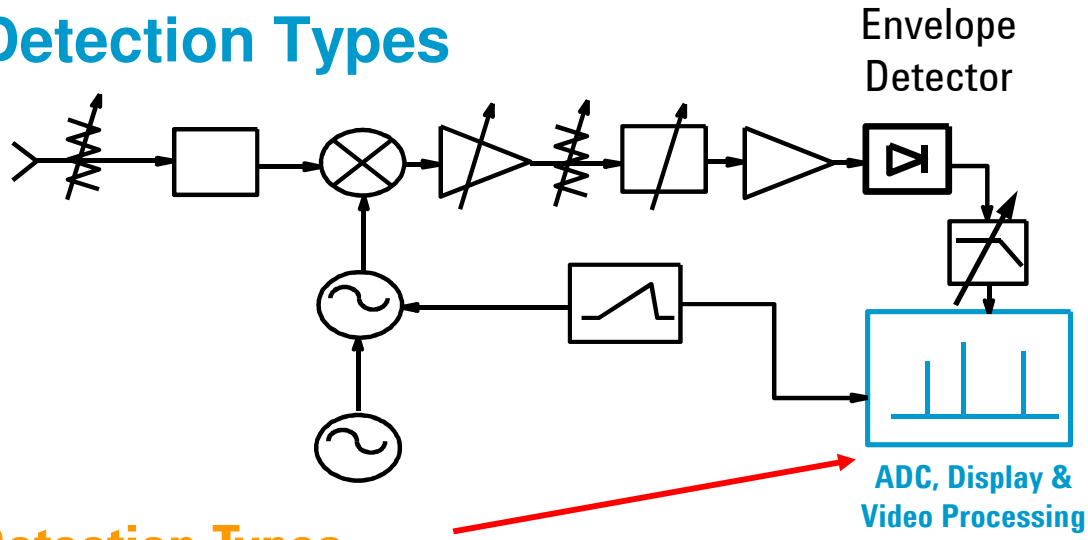
Theory of Operation

Envelope Detector

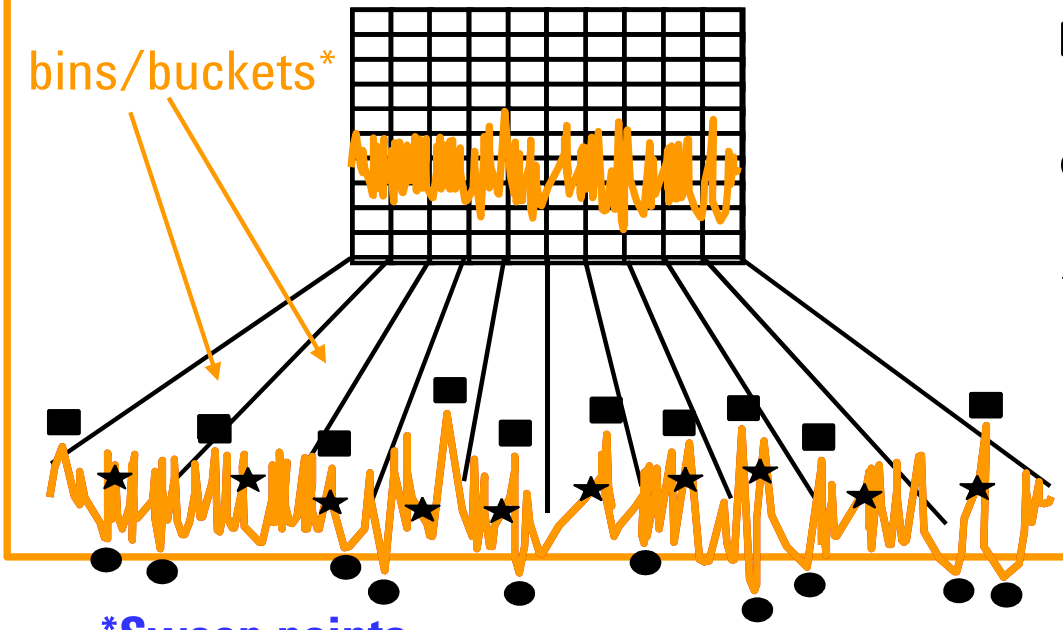


Theory of Operation

Envelope Detector and Detection Types



Digitally Implemented Detection Types

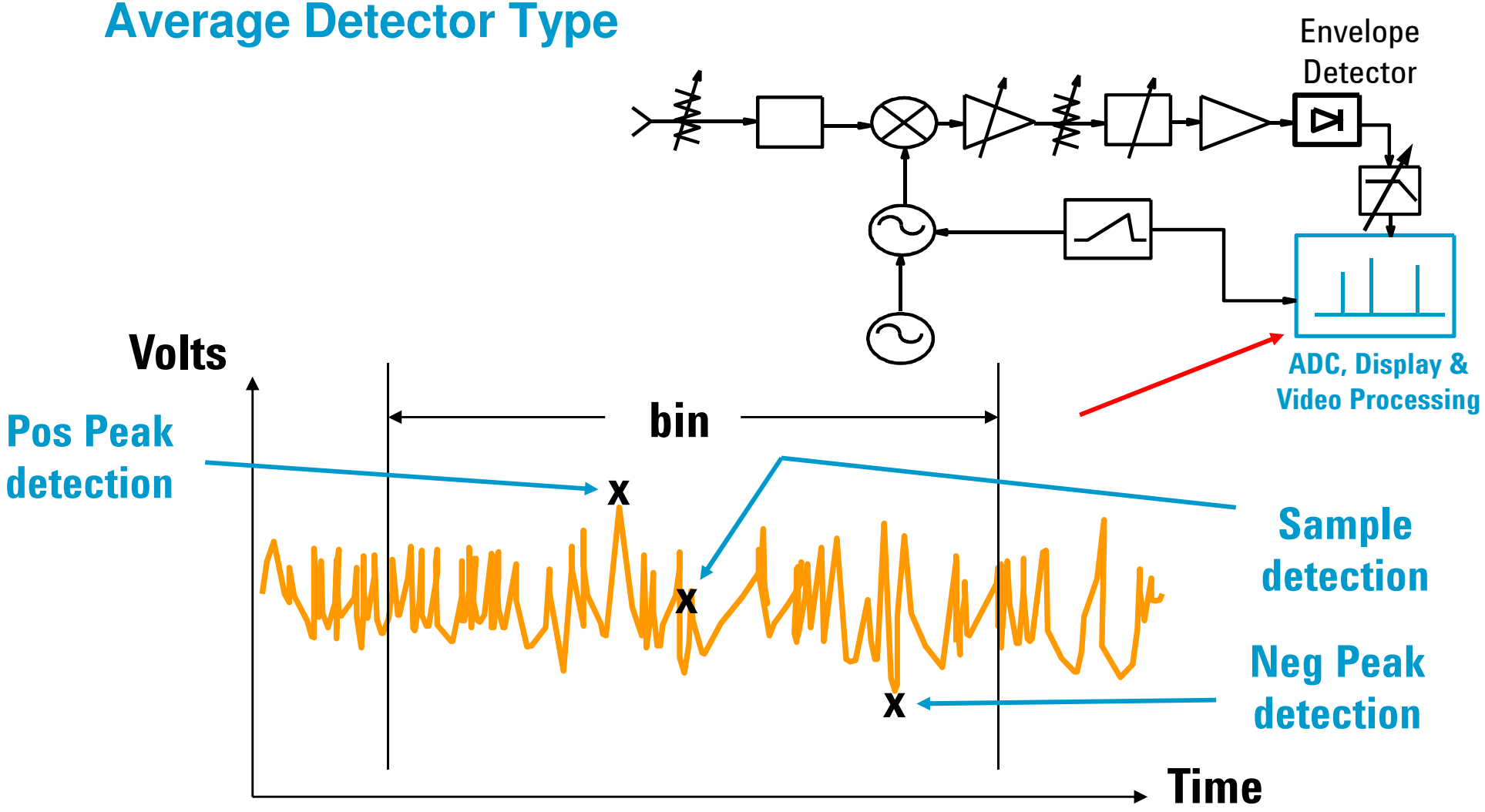


- ■ Positive detection: largest value in bin displayed
- ● Negative detection: smallest value in bin displayed
- ★ Sample detection: middle value in bin displayed

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

Theory of Operation

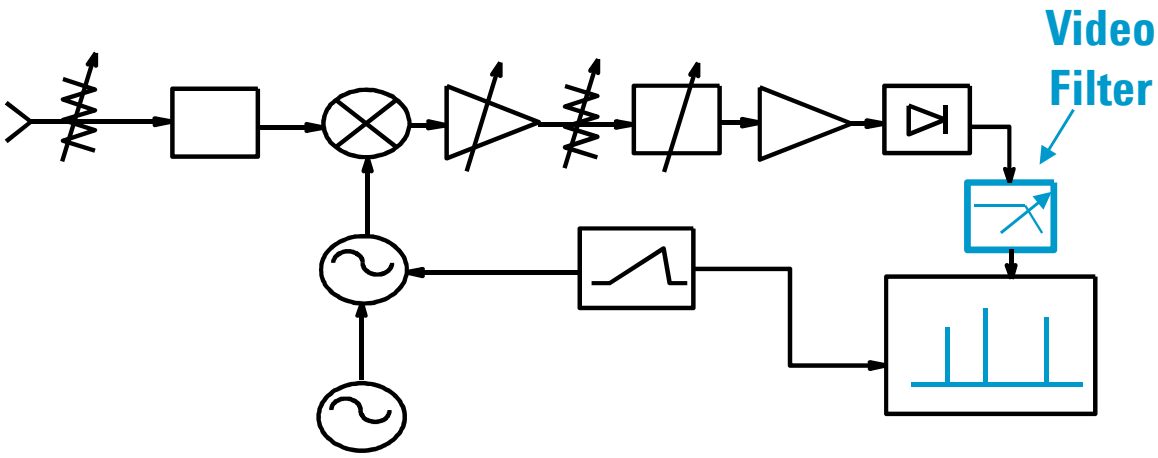
Average Detector Type

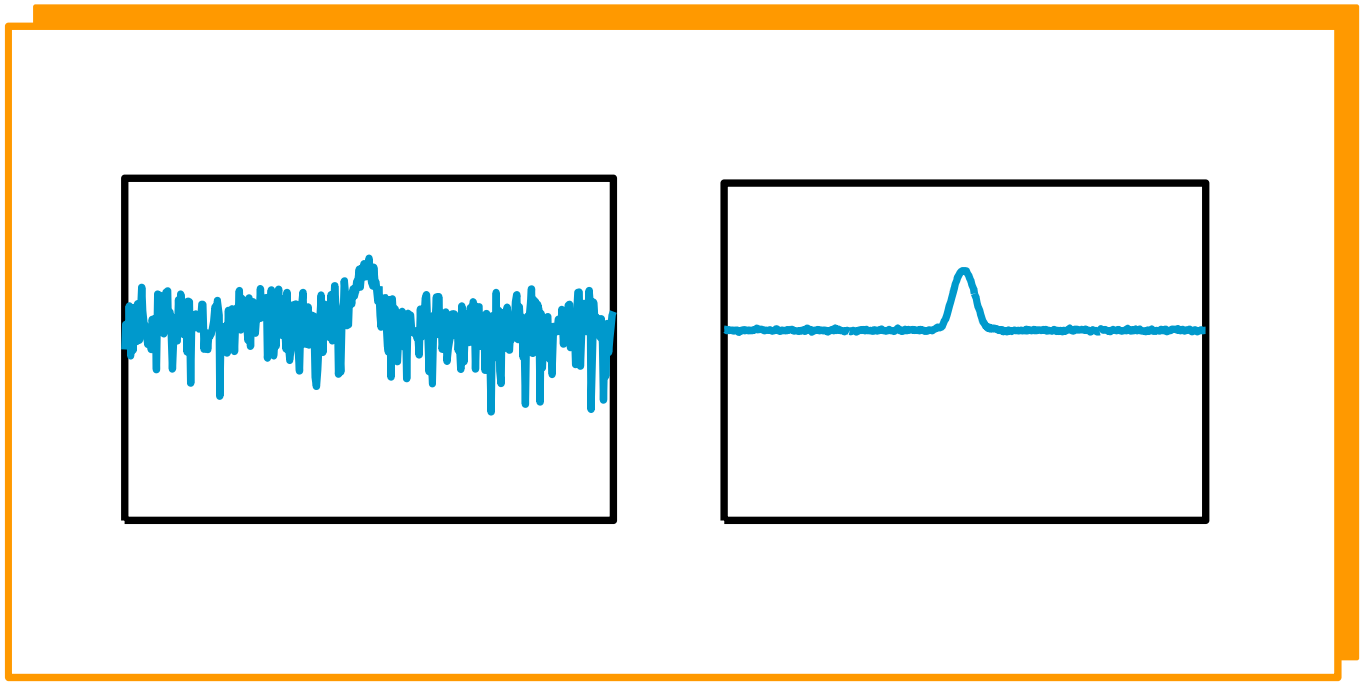


Power Average Detection (rms) = Square root of the sum of the squares of **ALL** of the voltage data values in the bin /50Ω

Theory of Operation

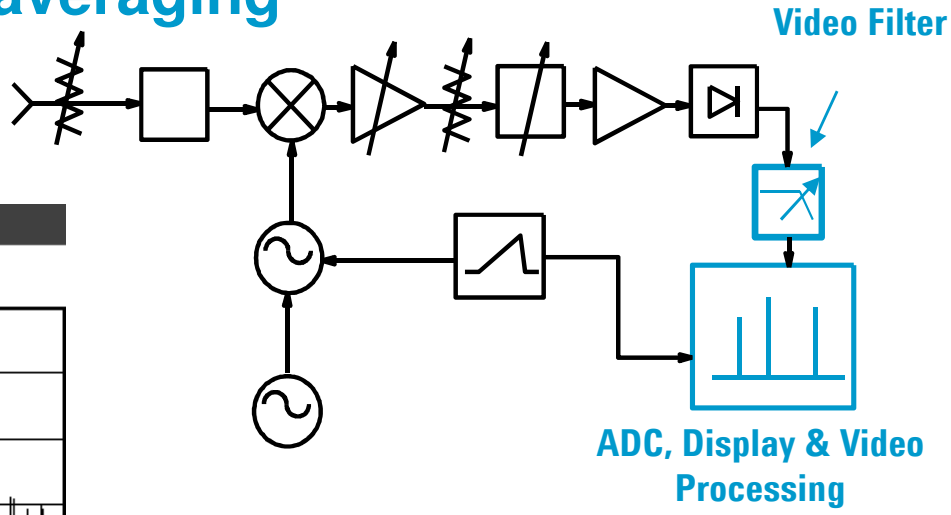
Video Filter (Video Bandwidth – VBW)

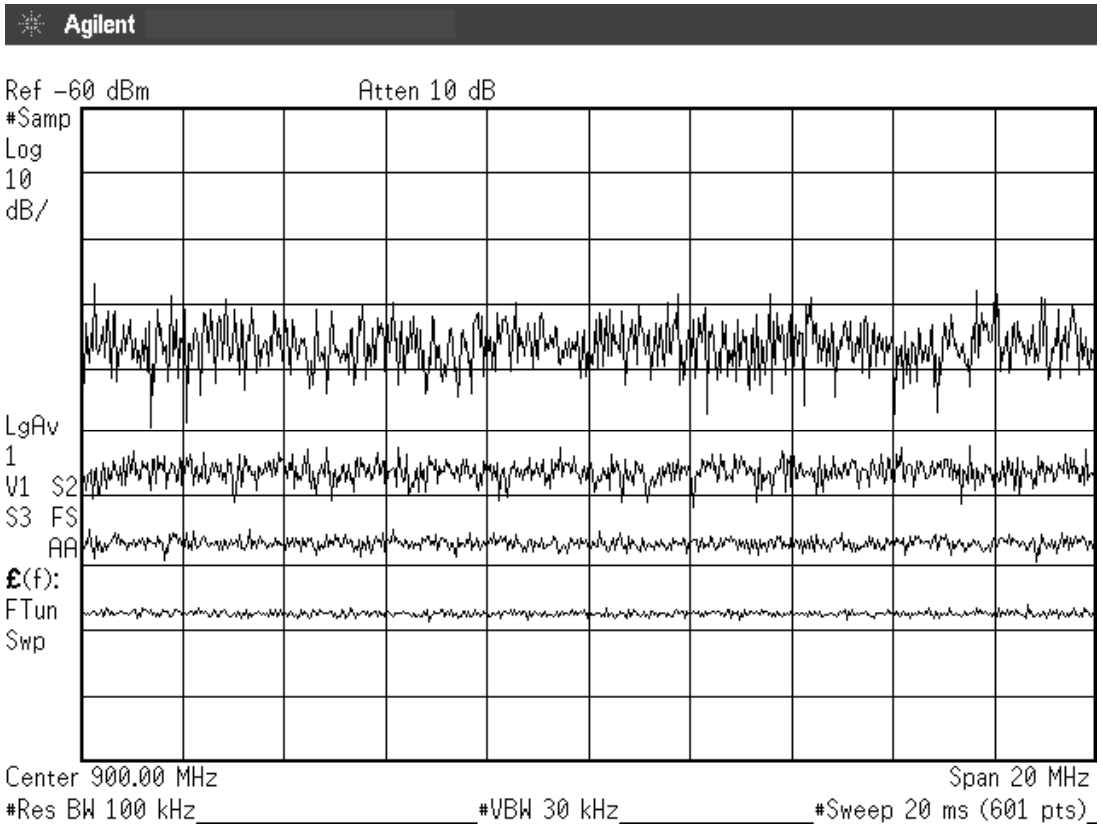




Theory of Operation

Video Filter vs. Trace/Video averaging



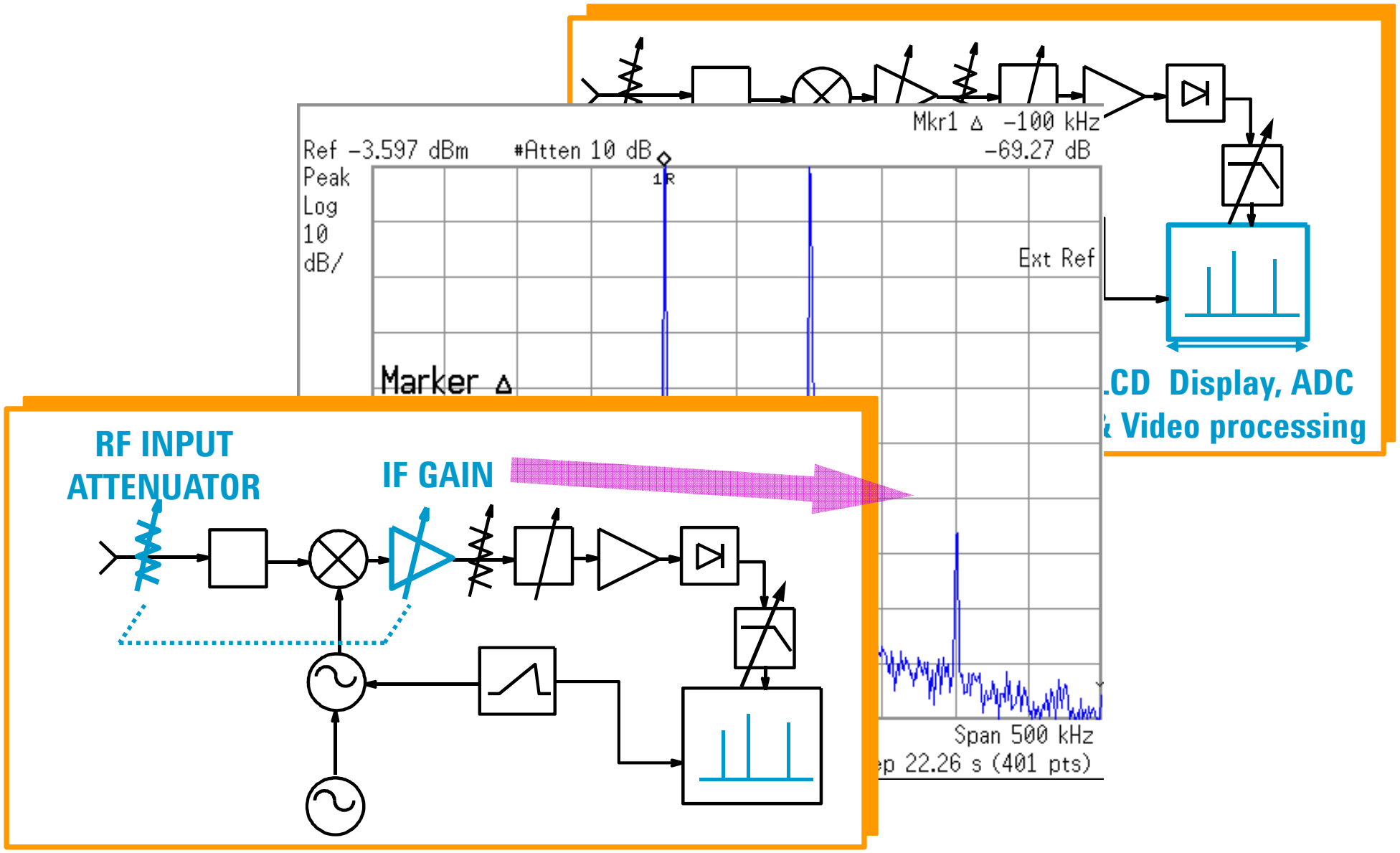


Trace averaging for 1, 5, 20, and 100 sweeps, top to bottom (trace position offset for each set of sweeps)

- Video Filter operates as the sweep progresses, sweep time may be required to slow down by the transient response of the VBW filter.
- Trace/Video Average takes multiple sweeps, sweep time for each sweep is not affected
- Many signals give the same results with either video filtering or trace averaging

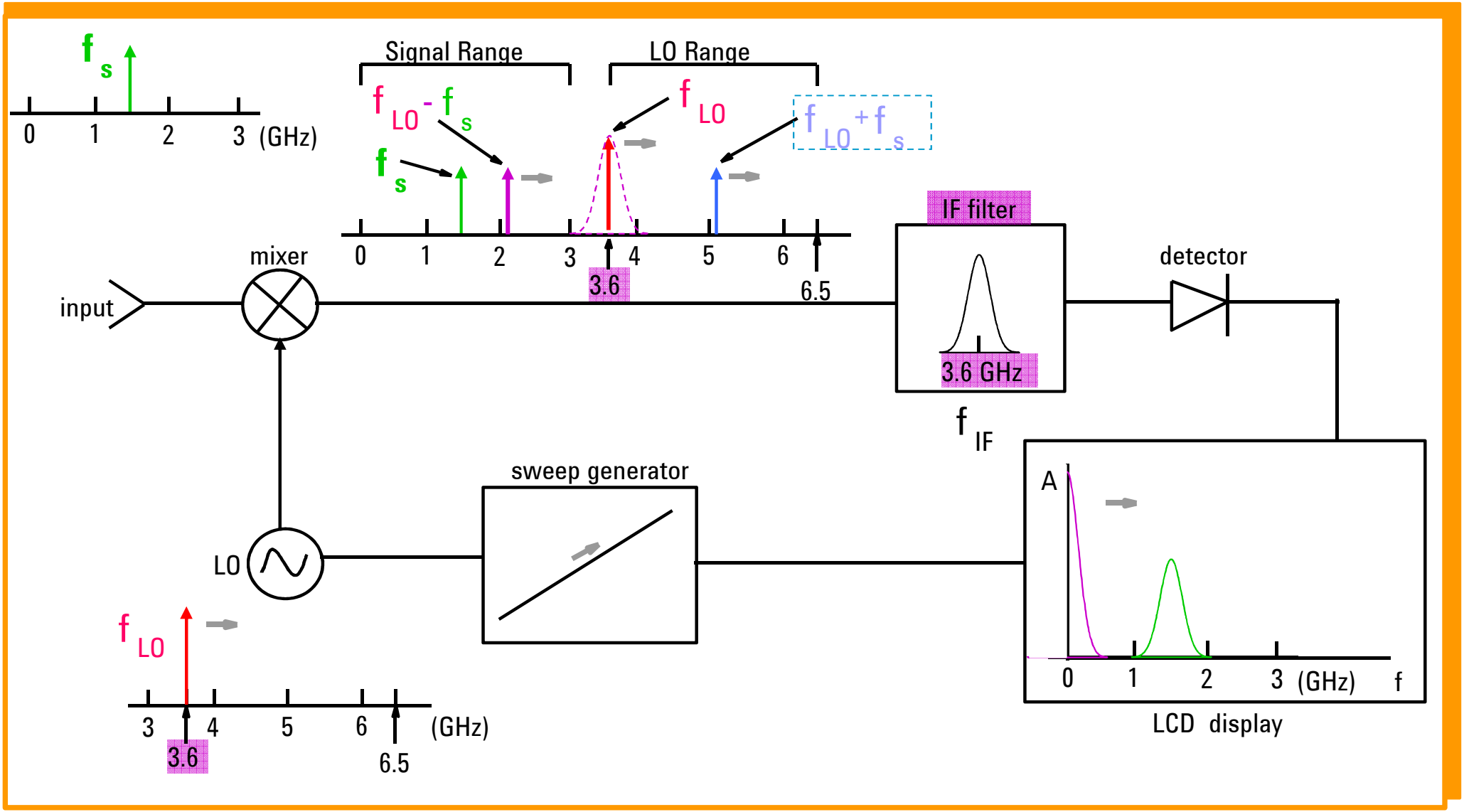
Theory of Operation

Other Components



Theory of Operation

How it All Works Together - 3 GHz spectrum analyzer



Agenda

Introduction

Overview

Theory of Operation

Specifications:

- Which are important and why?

Modern spectrum analyzer designs & capabilities

Applications

Automation Tools

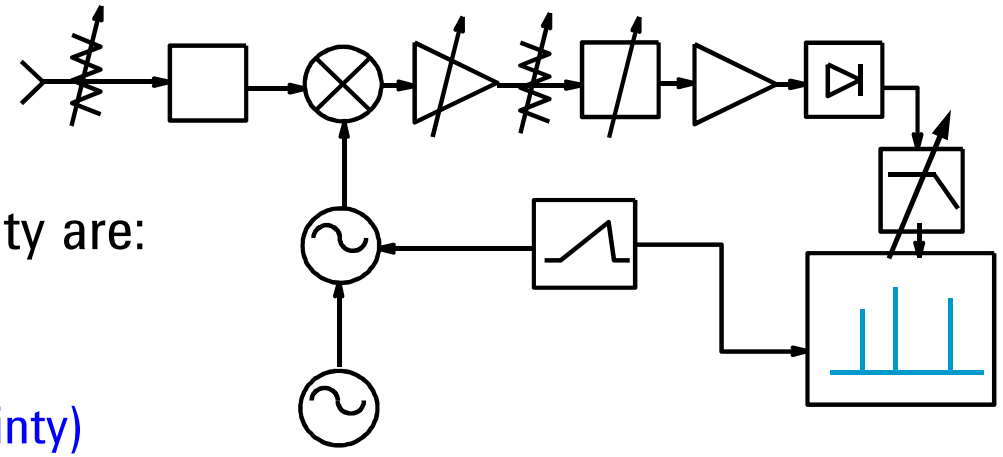
Wrap-up

Key Specifications

- Frequency Range
- Accuracy: Frequency & Amplitude
- Resolution
- Sensitivity
- Distortion
- Dynamic Range

Specifications

Accuracy: Frequency & amplitude

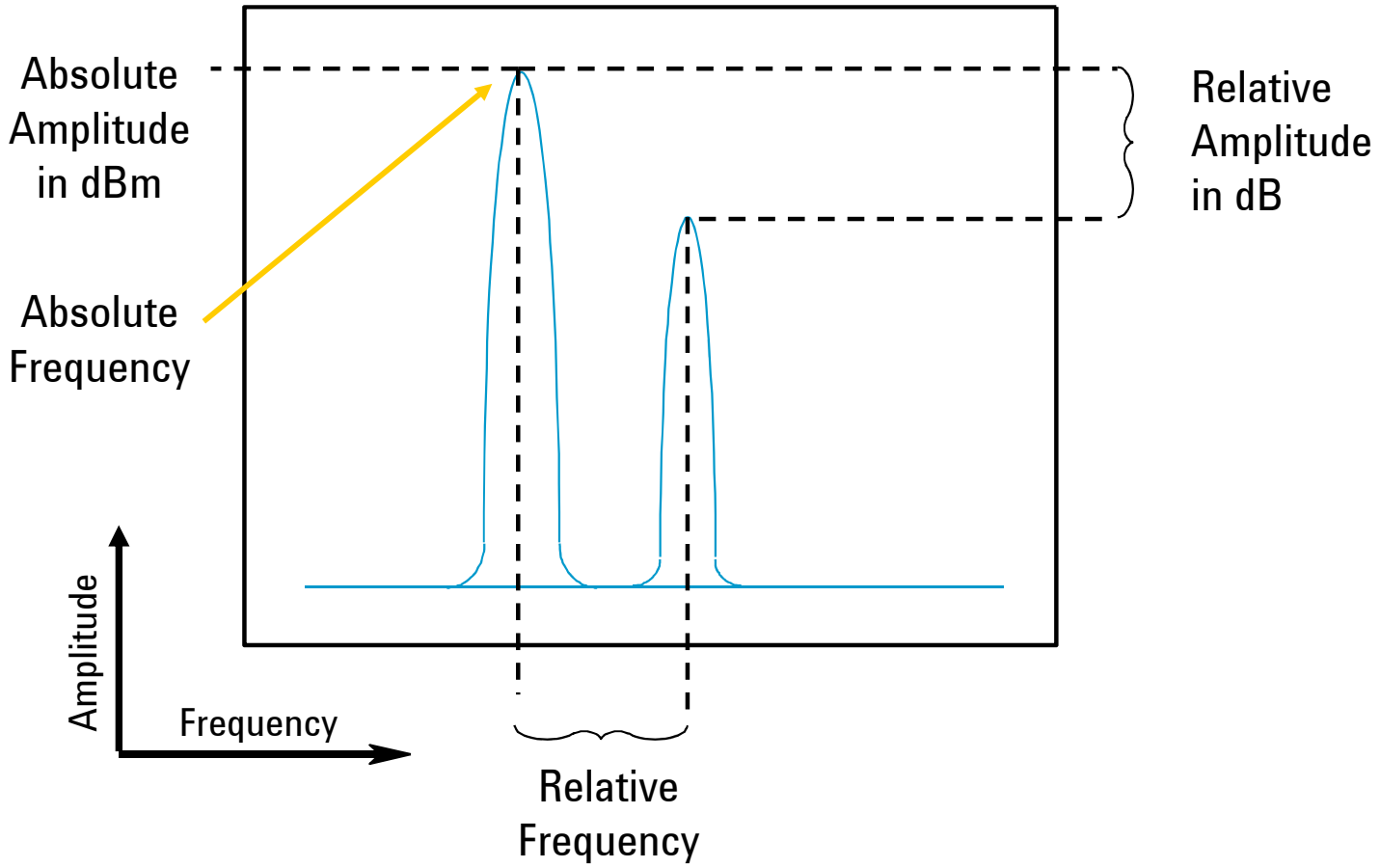


Components which contribute to uncertainty are:

- Input mismatch (VSWR)
- RF Input attenuator (Atten. switching uncertainty)
- Mixer and input filter (frequency response)
- IF gain/attenuation (reference level accuracy)
- RBW filters (RBW switching uncertainty)
- Log amp (display scale fidelity)
- Reference oscillator (frequency accuracy)
- Calibrator (amplitude accuracy)

Specifications

Absolute and Relative Accuracy: Frequency & Amplitude



Note: Absolute accuracy is also "relative" to the calibrator reference point

Specifications

Accuracy: Frequency Readout Accuracy

- From the PXA Data Sheet:

± (marker frequency x freq reference accuracy +
0.1%*span + 5% of RBW + 2Hz + 0.5 x Horiz. Res.*)

Determined by Reference Accuracy

Span Accuracy

RBW Error
IF filter center frequency error

Residual Error

*Horizontal resolution is span/(sweep points – 1)

Specifications

Accuracy: Frequency Readout Accuracy Example

Frequency: **1 GHz**
Span: **400 kHz**
RBW: **3 kHz**
Sweep points: **1000**

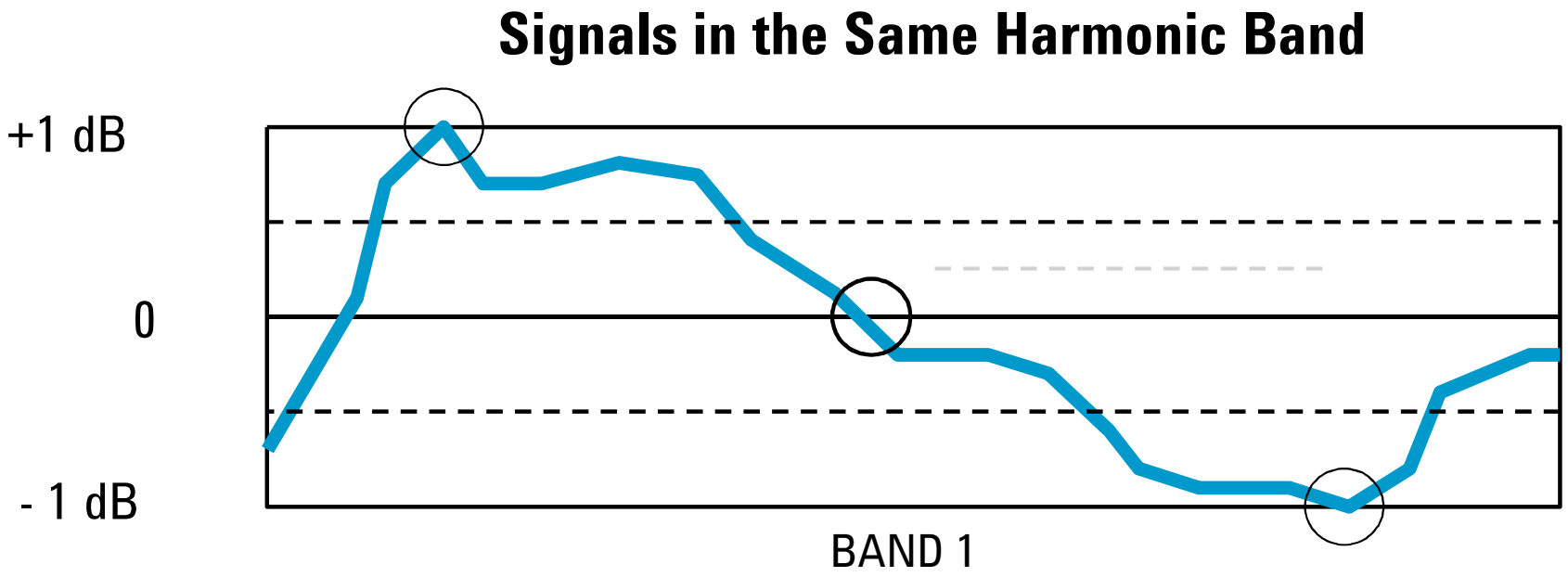
Calculation :

$(1 \times 10^{9}\text{Hz}) \times (\pm 1.55 \times 10^{-7}/\text{Year ref. Error})$	**= 155Hz**
400kHz Span x 0.1%	**= 400Hz**
3kHz RBW x 5%	**= 150Hz**
2Hz + 0.5 x 400kHz/(1000-1)	**= 202Hz**
Total uncertainty	**= ±907Hz**

Utilizing internal frequency counter improves accuracy to ±155Hz

Specifications

Accuracy: Frequency Response

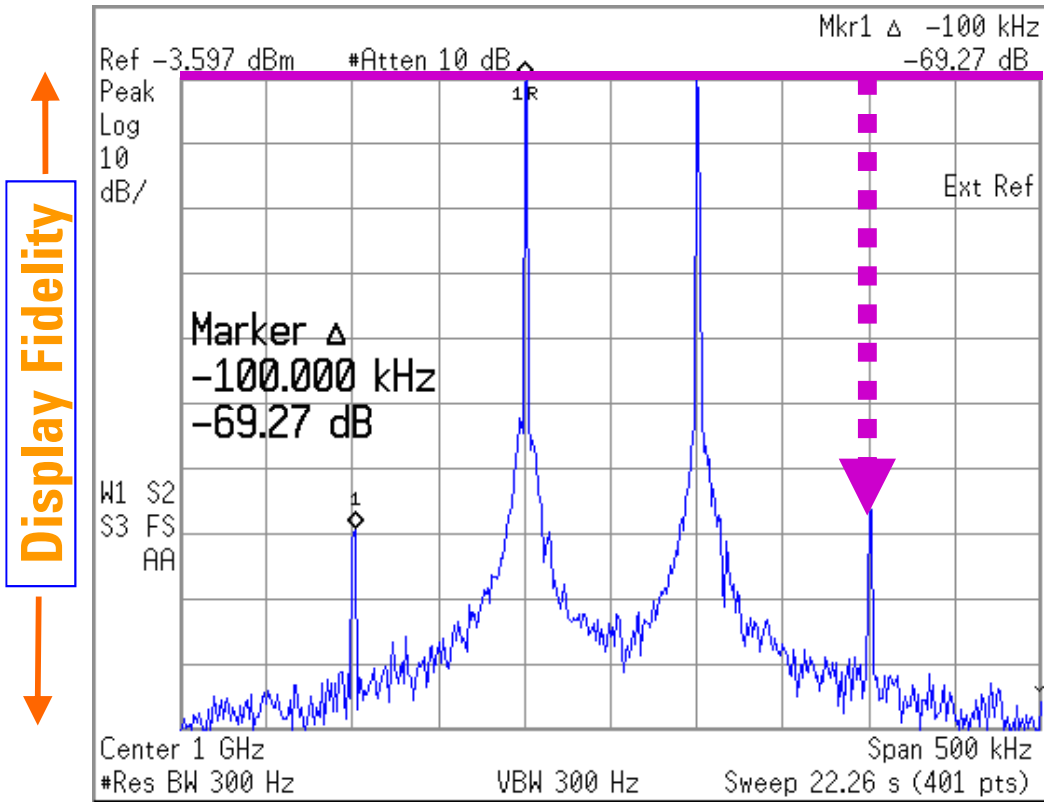


Absolute amplitude accuracy – Specification: ± 1 dB

Relative amplitude accuracy – Specification: ± 2 dB

Specifications

Accuracy: Display Fidelity



Display Fidelity includes:

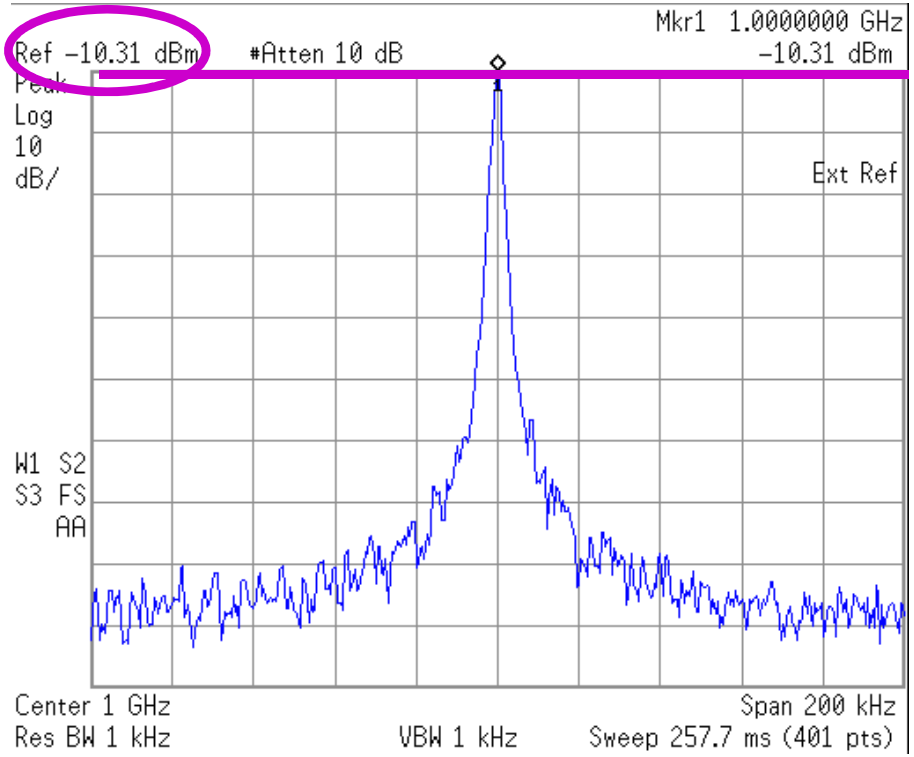
- Log Amp Fidelity
- Envelope Detector Linearity
- Digitizing Circuit Linearity

Display fidelity error applies when signals are not at the same reference level amplitude when measured

In the past, technique for best accuracy was to move each measured signal to the reference line, eliminating display fidelity error.

Specifications

Amplitude Accuracy: Reference Level Switching



Uncertainty applies when changing the Ref. Level

Also called IF Gain Uncertainty

Decision: Do I change the reference level or live with the display fidelity uncertainty in my measurements?

Specifications

Accuracy: Key Amplitude Uncertainty Contributions

Relative and absolute:	PXA Uncertainties
• Input impedance mismatch	(±0.13 dB)
• Input attenuator switching uncertainty	(±0.14 dB)
• Frequency response	(±0.35 dB)
• Reference level accuracy	(0 dB)
• RBW switching uncertainty	(±0.03 dB)
• Display scale fidelity	(±0.07 dB)
Absolute only:	
• Calibrator accuracy	(±0.24 dB)

Specifications

Amplitude Accuracy - Summary

Optimize measurement setup & techniques for best accuracy

- Minimize changes to uncertainty contributors
  - Or change contributor with least error impact
  - Or stay within the optimum accuracy envelope parameters that modern auto-alignment calibration techniques provide

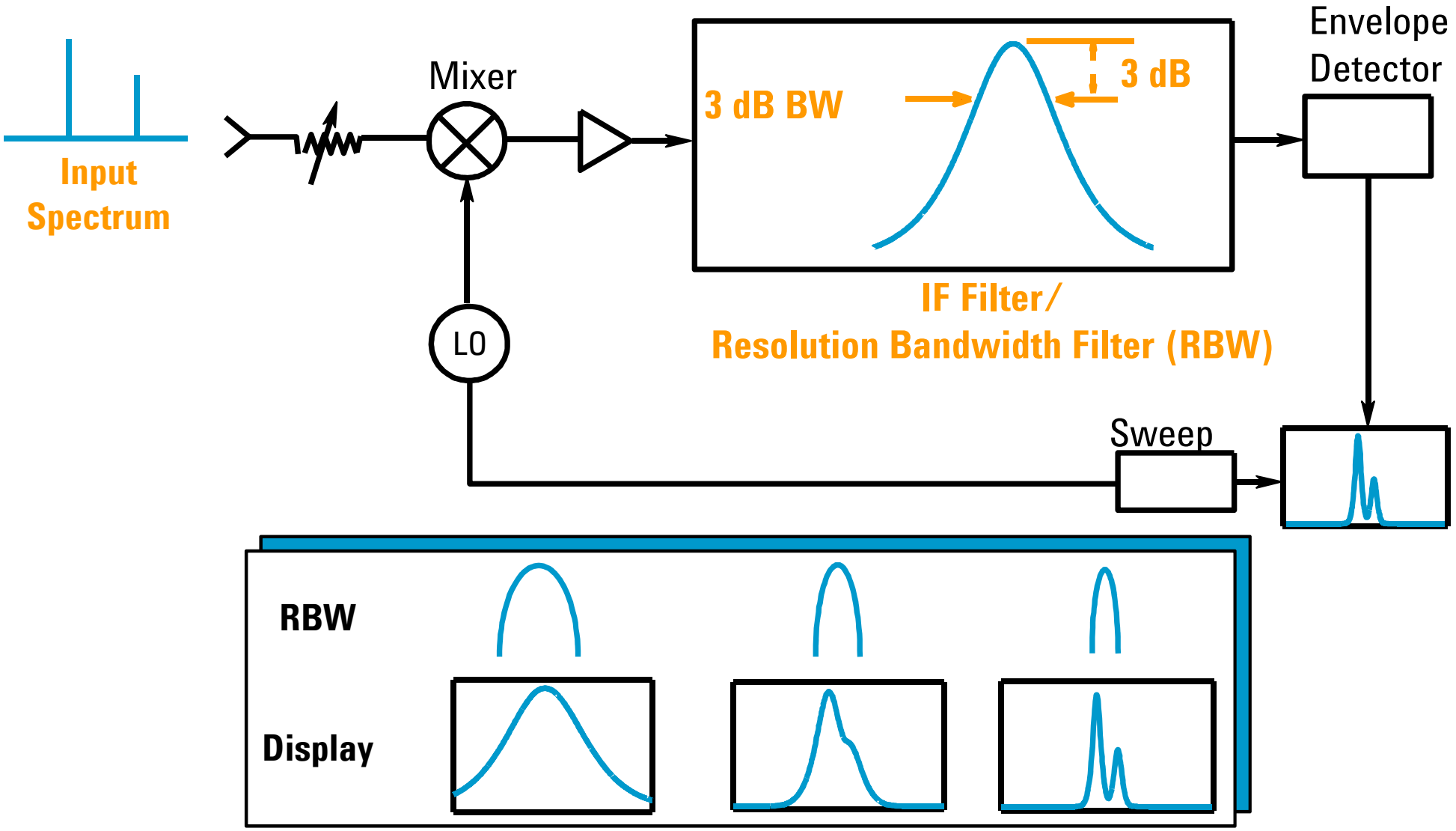
- Traditionally, one technique for best accuracy was to move each measured signal to the reference line, eliminating display fidelity error. However, in today's designs, display fidelity has improved to the point where there is generally less error just to leave the signals where they occur on the display.

- Except for frequency response, uncertainty contributors that impact both signals equally in a relative measurement can be ignored.

- In the absence of specified relative frequency response, the relative response uncertainty is assumed to be 2x specified absolute error.

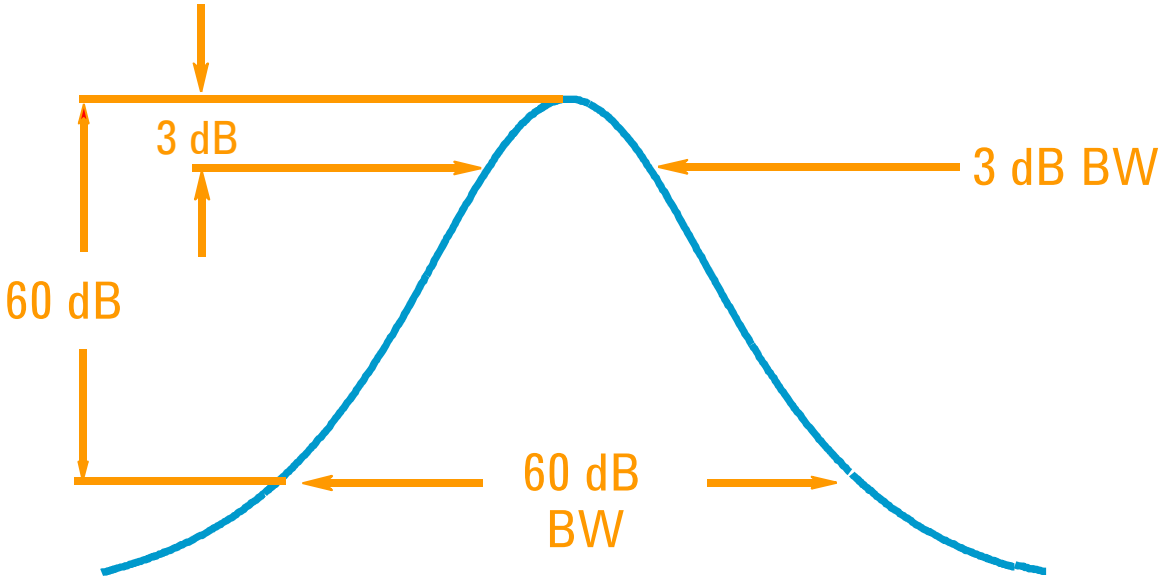
Specifications

Resolution: Resolution Bandwidth



Specifications

Resolution BW Selectivity or Shape Factor

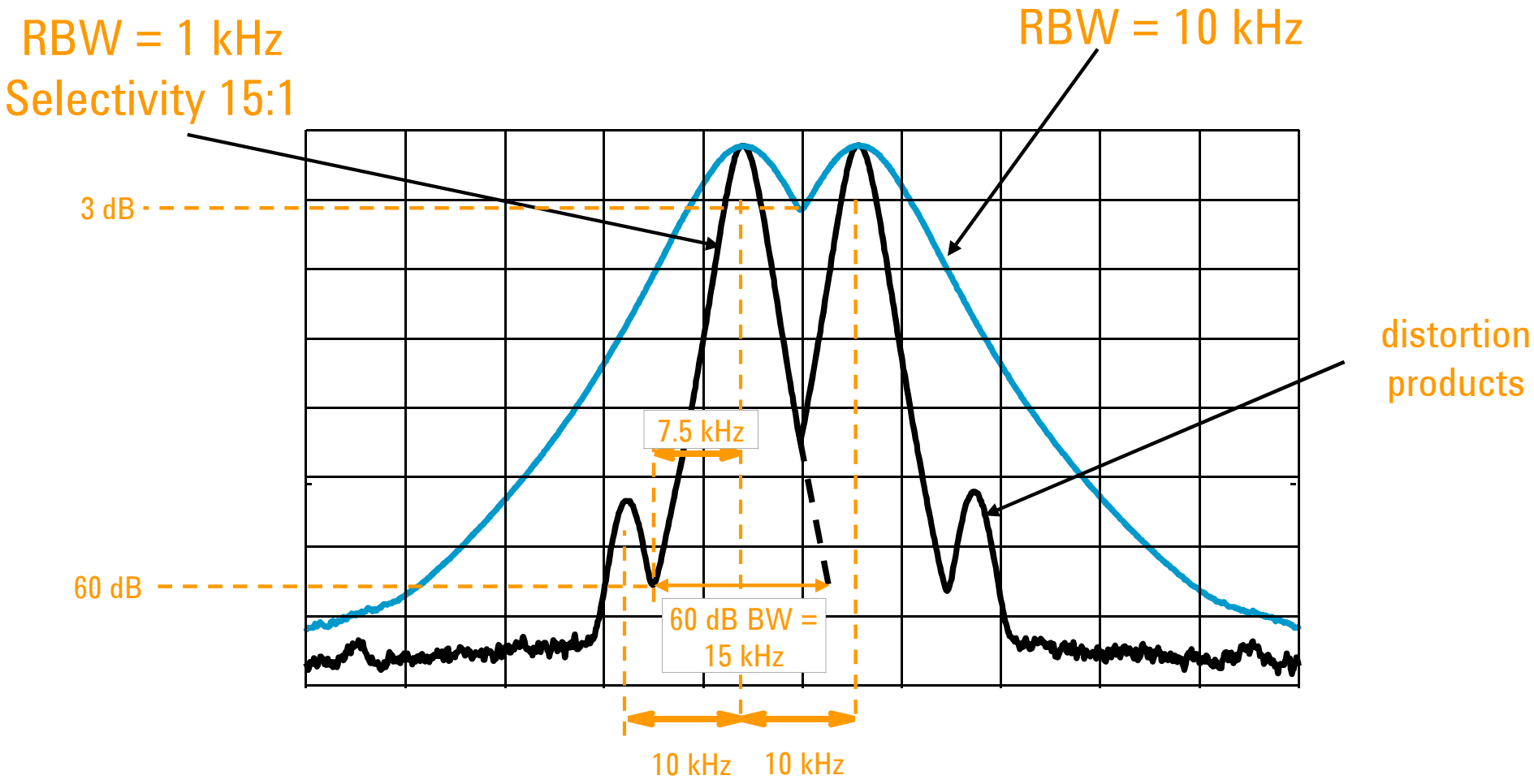


$$\text{Selectivity} = \frac{\text{60 dB BW}}{\text{3 dB BW}}$$

Determines resolvability of unequal amplitude signals

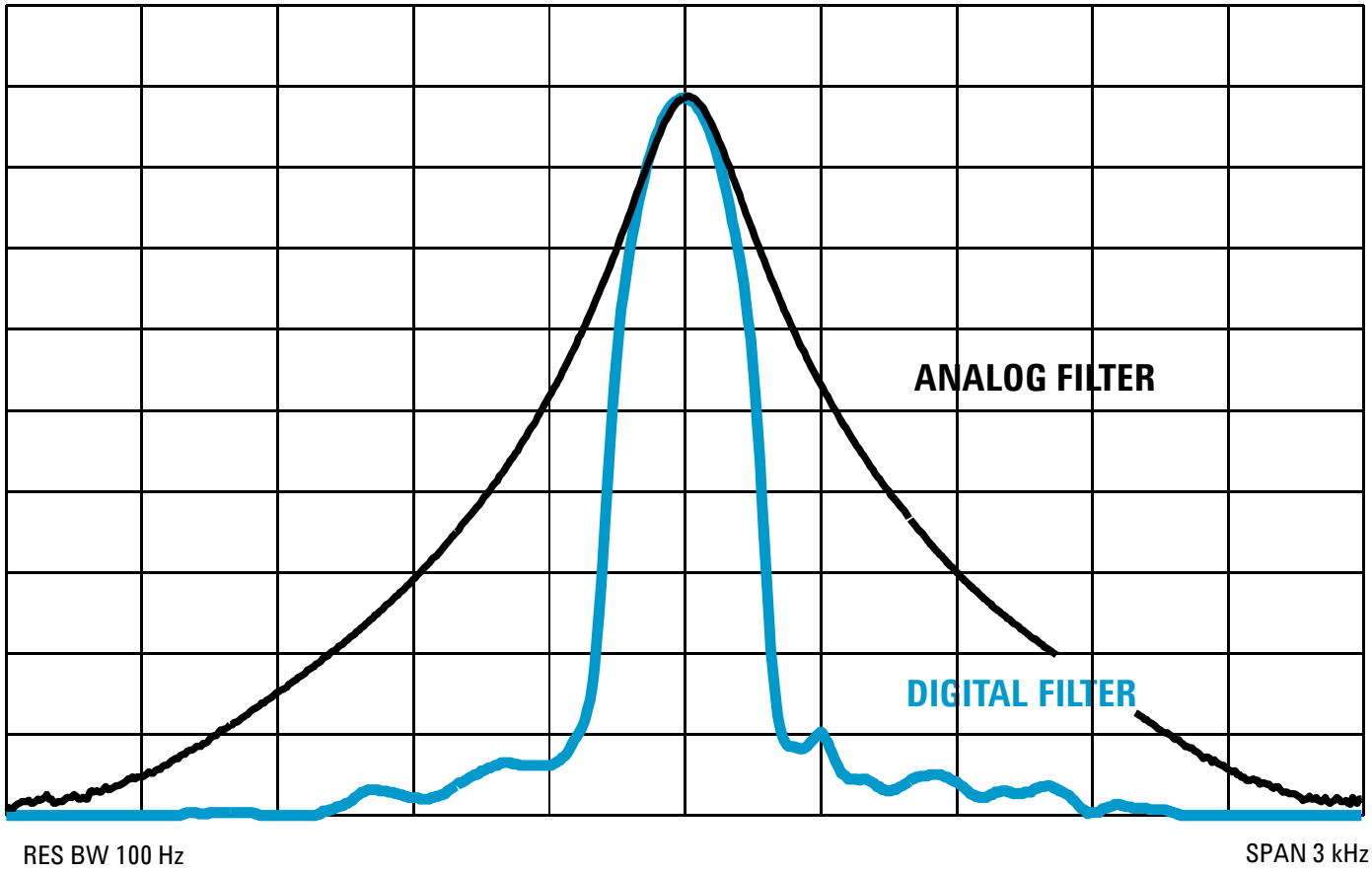
Specifications

Resolution BW Selectivity or Shape Factor



Specifications

Resolution: RBW Type and Selectivity



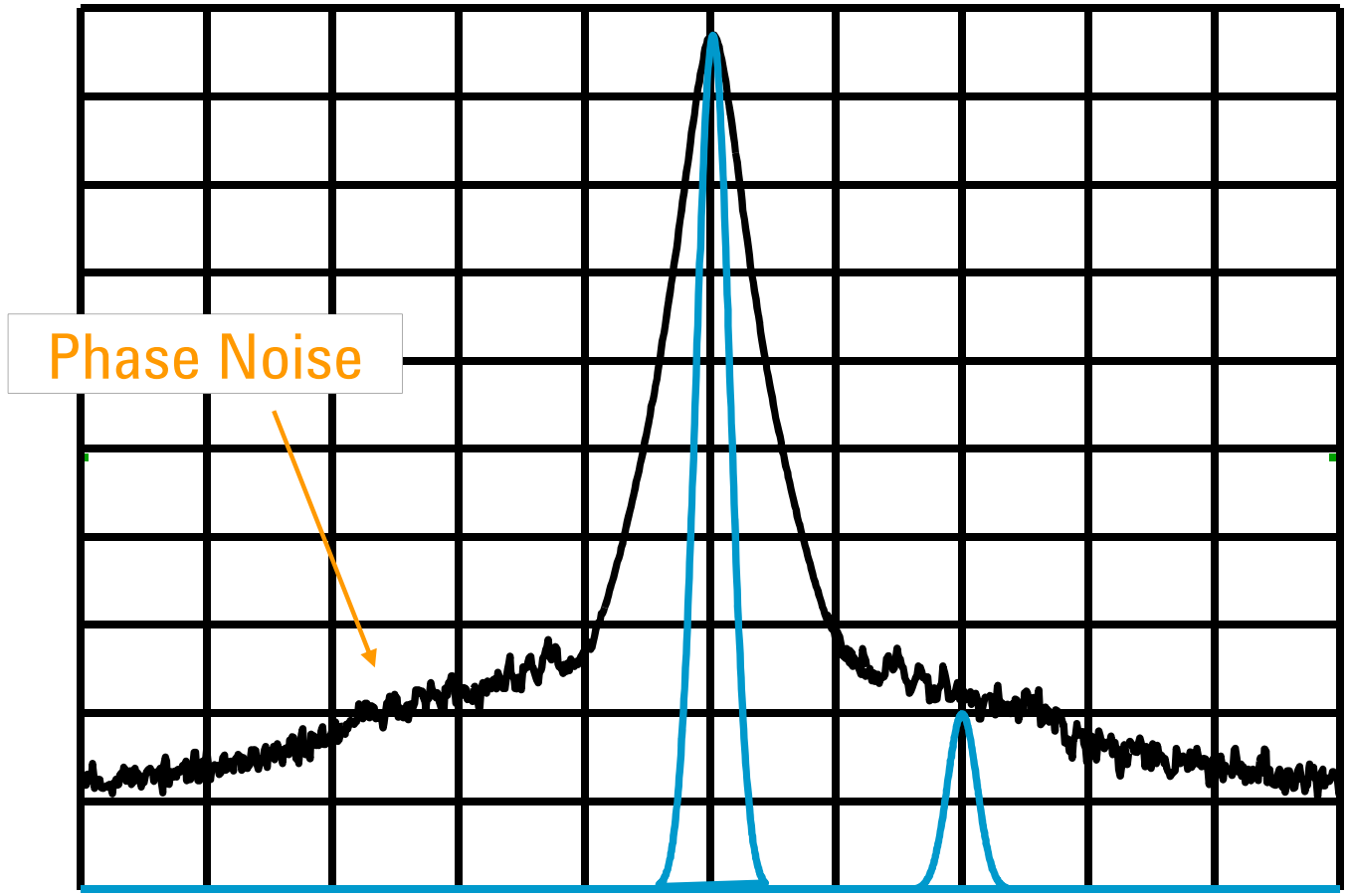
Typical Selectivity

Analog 15:1

Digital ≤5:1

Specifications

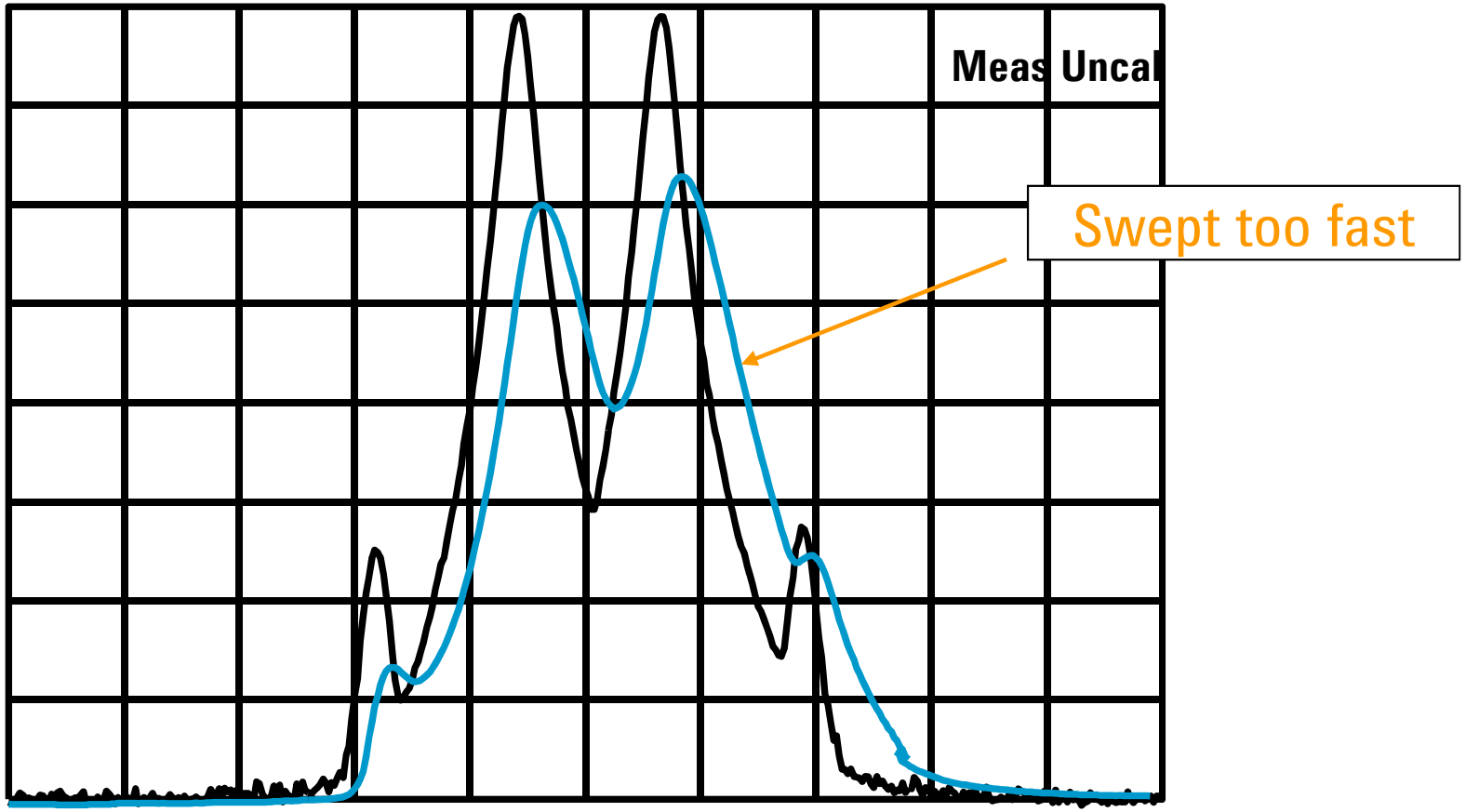
Resolution: Noise Sidebands



Noise Sidebands can prevent resolution of unequal signals

Specifications

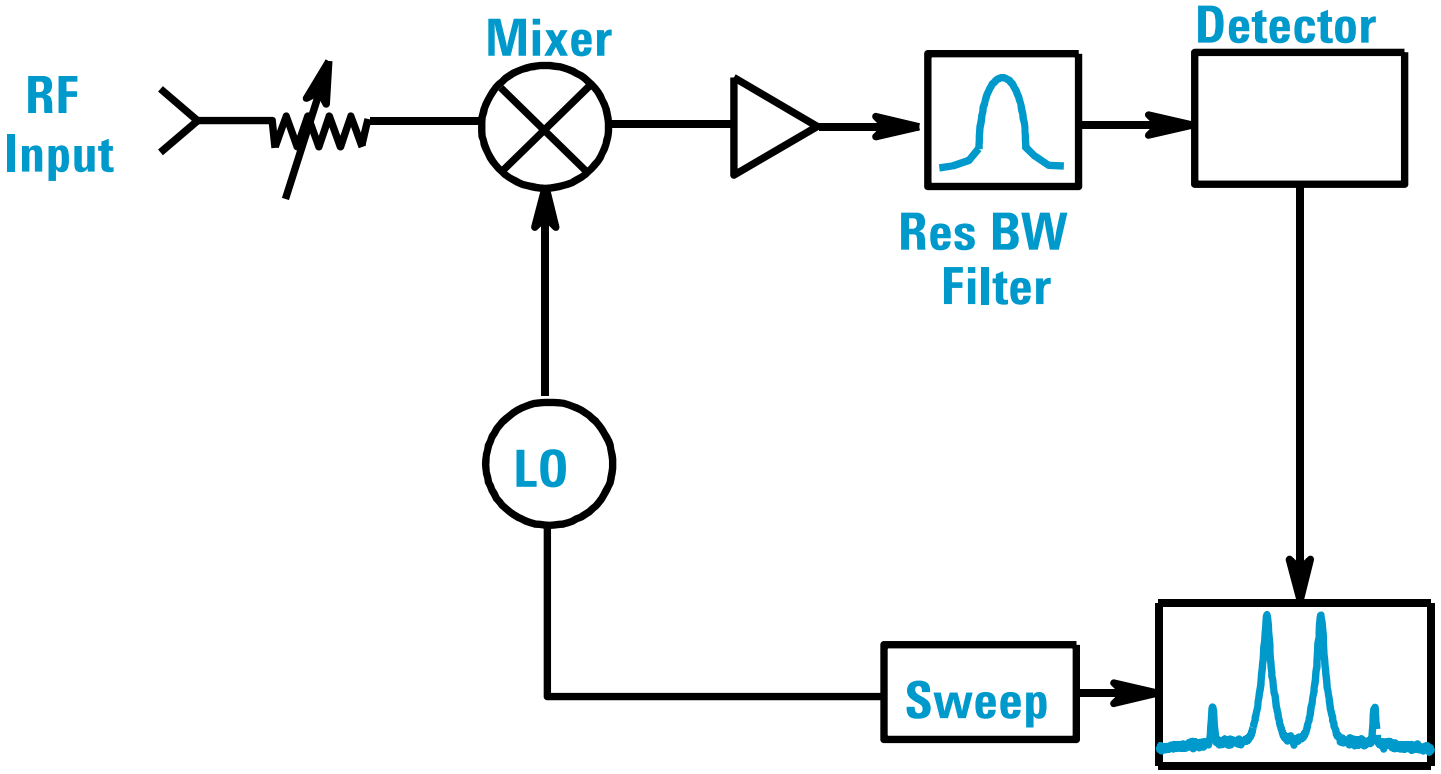
Resolution: RBW Determines Sweep Time



Penalty For Sweeping Too Fast
Is An Uncalibrated Display

Specifications

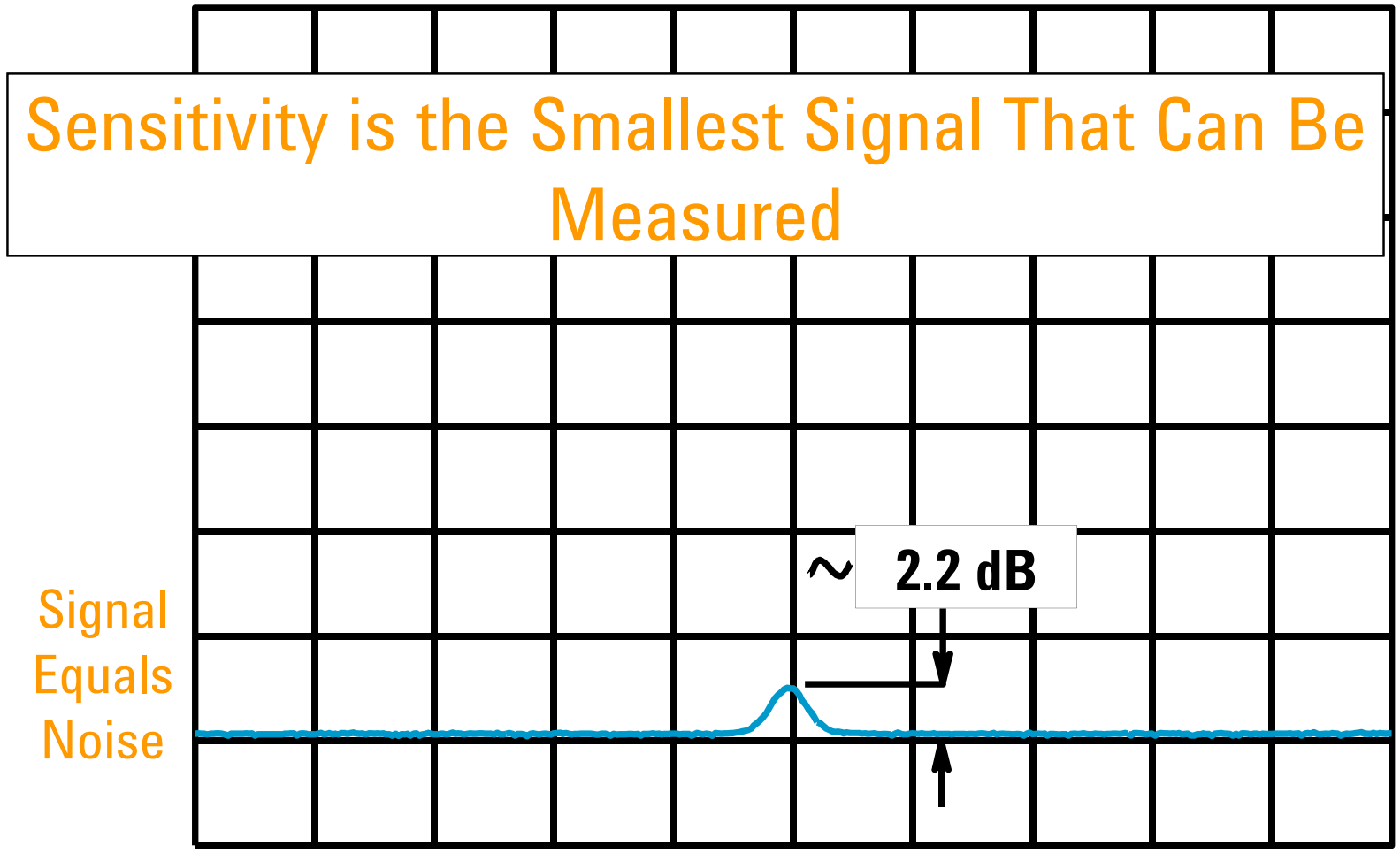
Sensitivity/DANL



A Spectrum Analyzer Generates and Amplifies Noise Just Like Any Active Circuit

Specifications

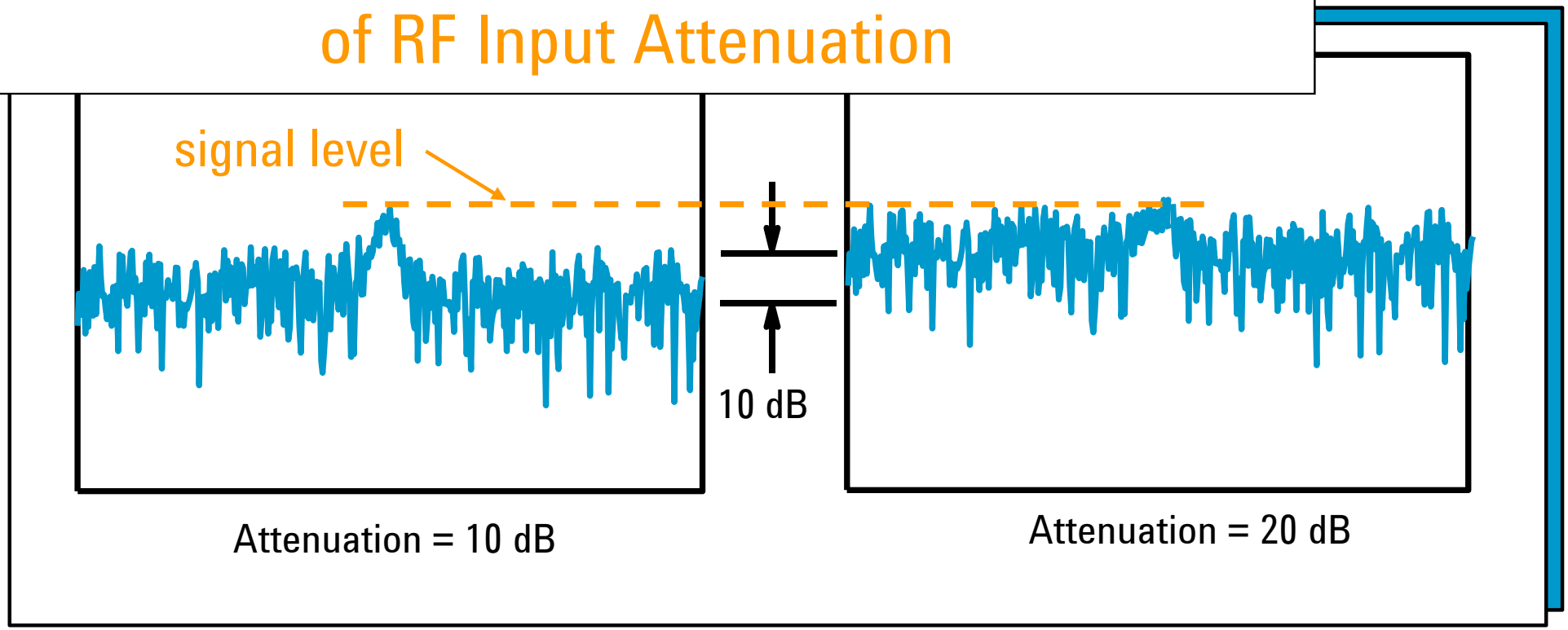
Sensitivity/DANL



Specifications

Sensitivity/DANL

Effective Level of Displayed Noise is a Function of RF Input Attenuation

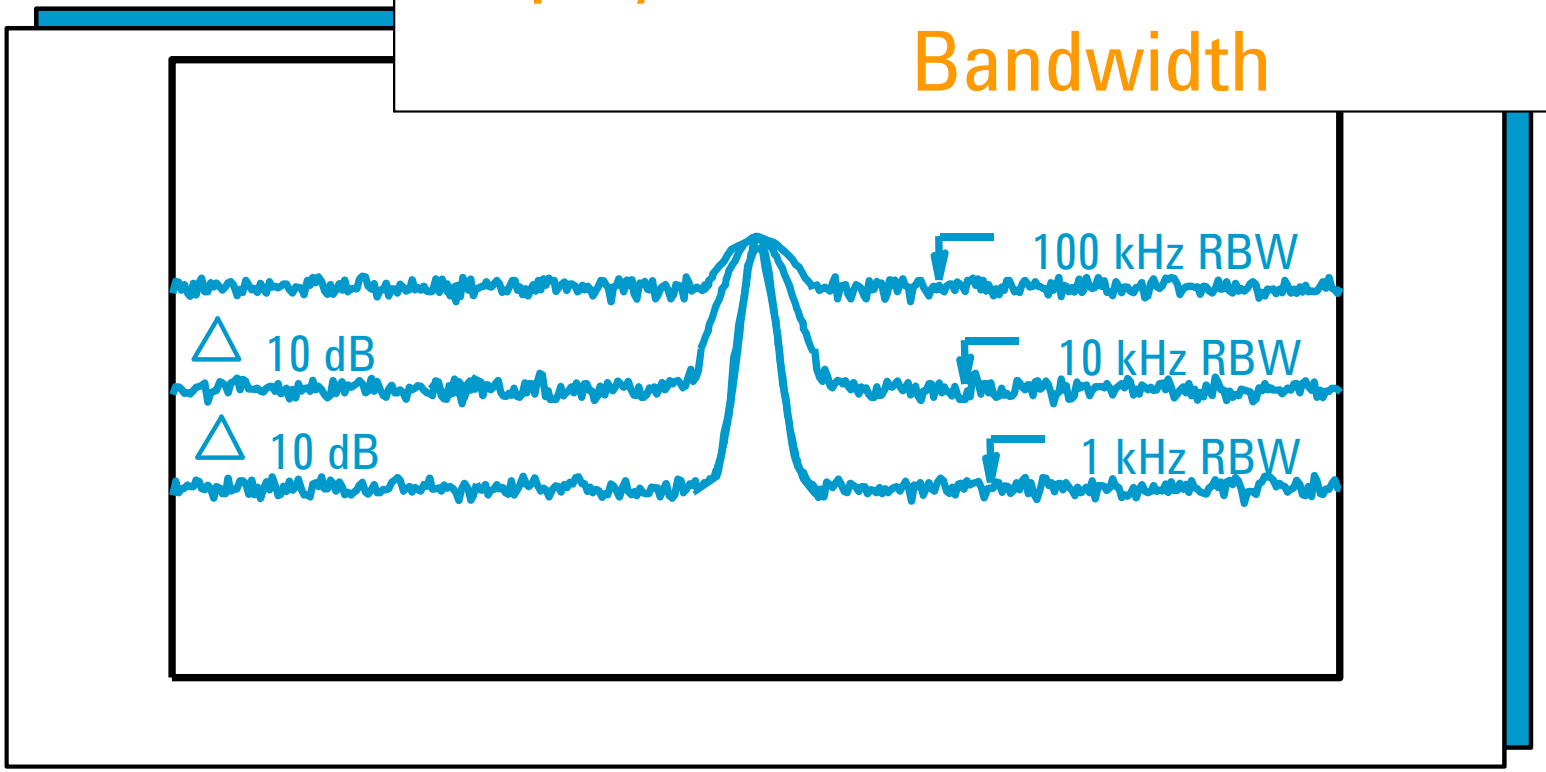


Signal To Noise Ratio Decreases as RF Input Attenuation is Increased

Specifications

Sensitivity/DANL: IF Filter(RBW)

Displayed Noise is a Function of IF Filter Bandwidth

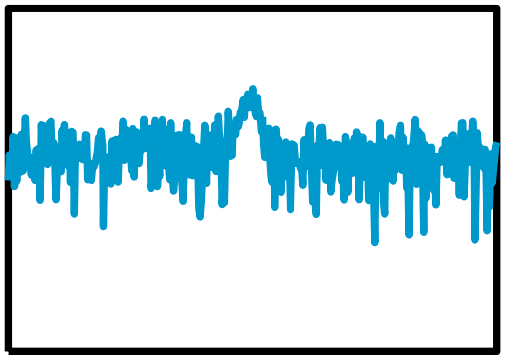


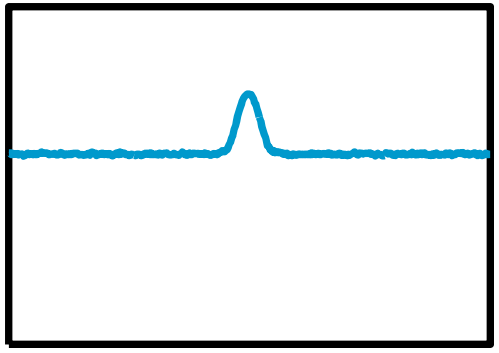
Decreased BW = Decreased Noise

Specifications

Sensitivity/DANL: Video BW filter (or Trace Averaging)

Video BW or Trace Averaging Smoothes Noise for Easier Identification of Low Level Signals

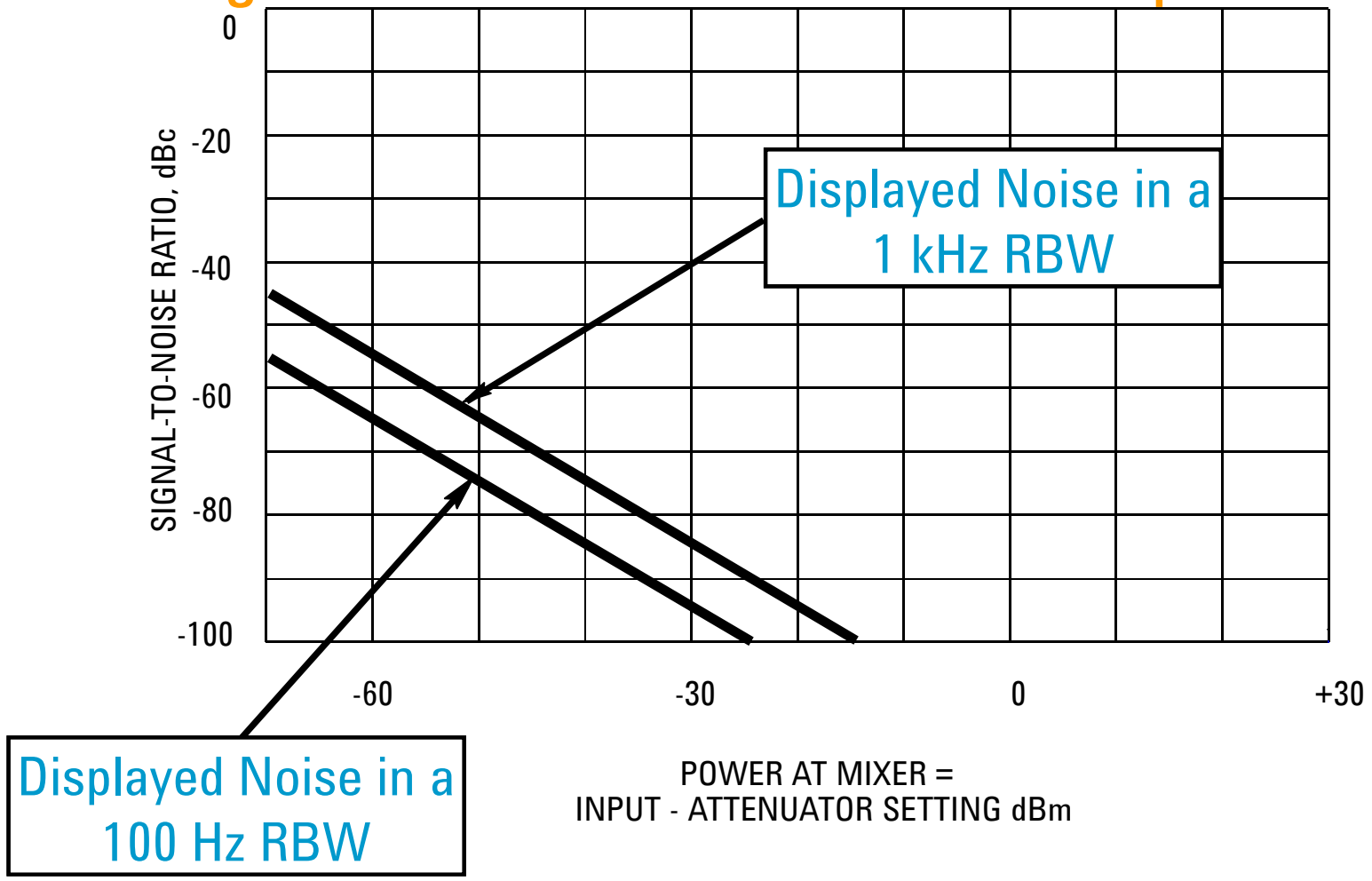




Specifications

Sensitivity/DANL:

Signal-to-Noise Ratio Can Be Graphed



Specifications

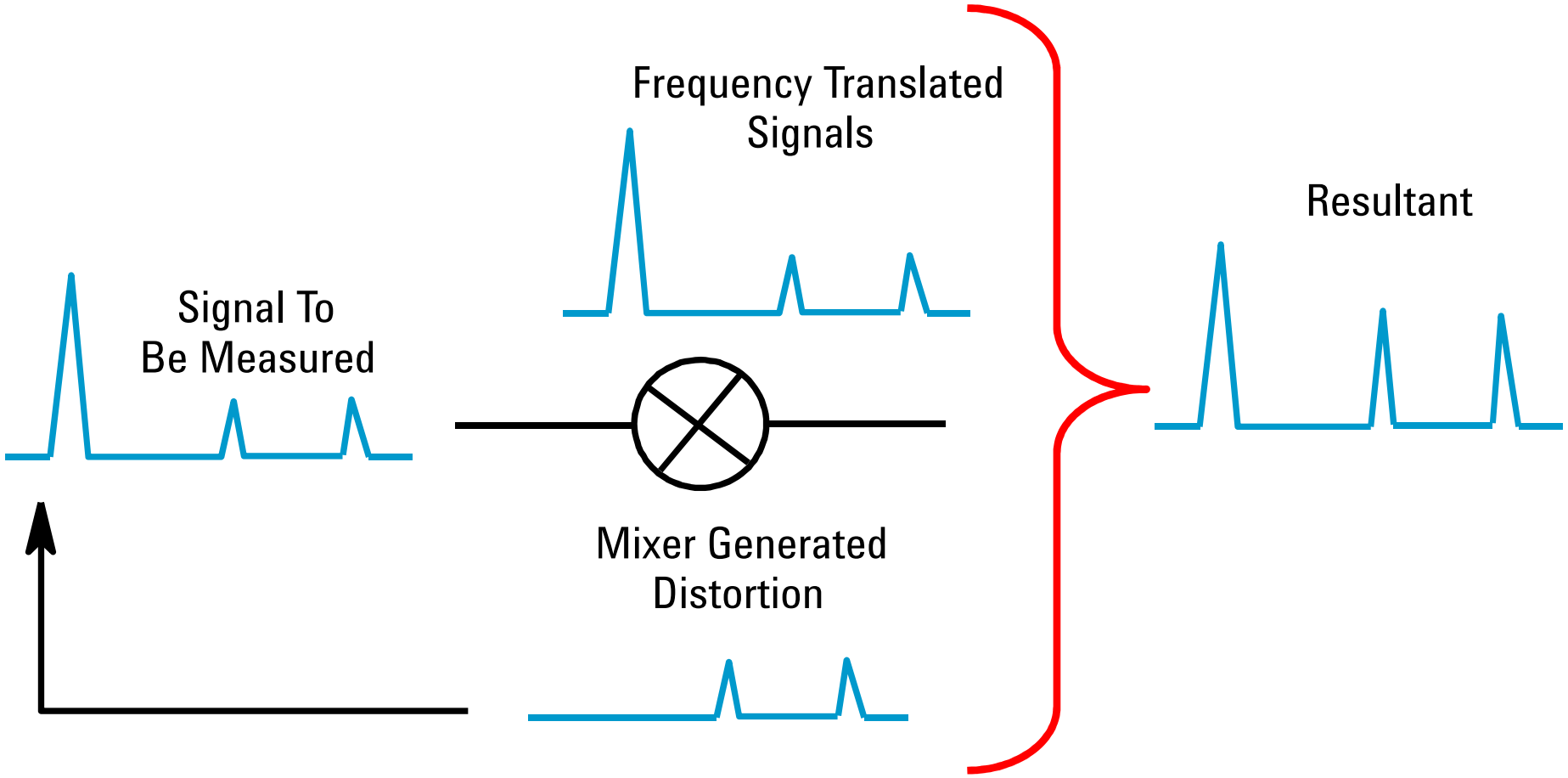
Sensitivity/DANL: Summary

For Best Sensitivity Use:

- Narrowest Resolution BW
- Minimum RF Input Attenuation
- Sufficient Averaging (video or trace)

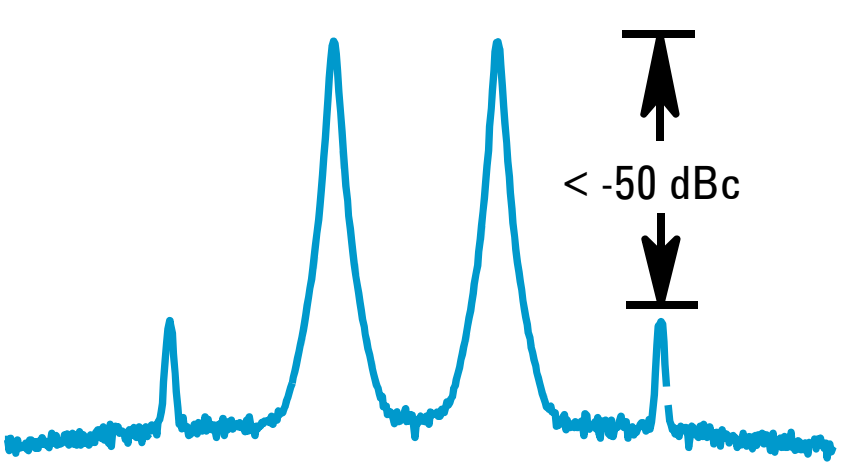
Specifications
Distortion

Mixers Generate Distortion

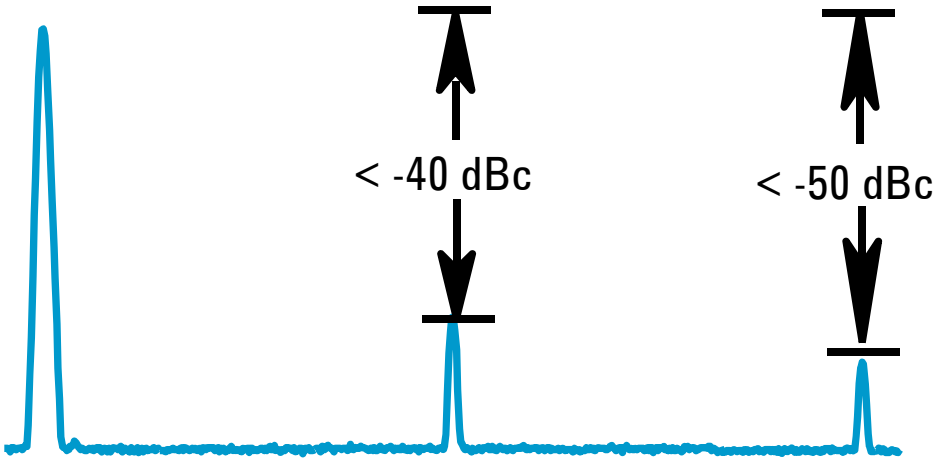


Specifications
Distortion

Most Influential Distortion is the Second and Third Order



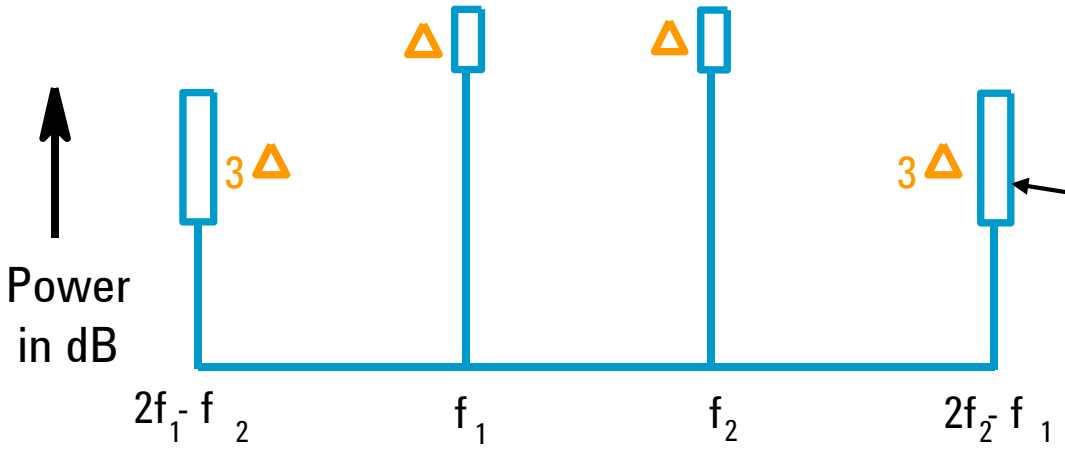
Two-Tone Intermod



Harmonic Distortion

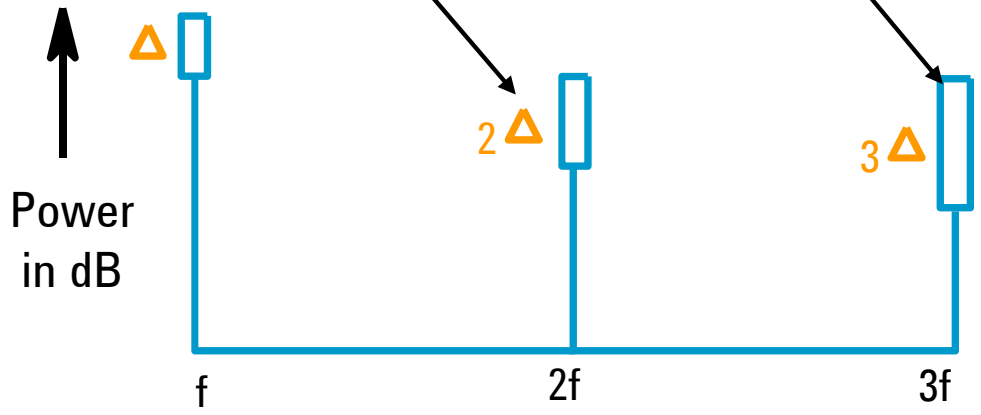
Specifications
Distortion

Distortion Products Increase as a Function of Fundamental's Power



Two-Tone Intermod

Second Order: △2 dB/dB of Fundamental
Third Order: △3 dB/dB of Fundamental



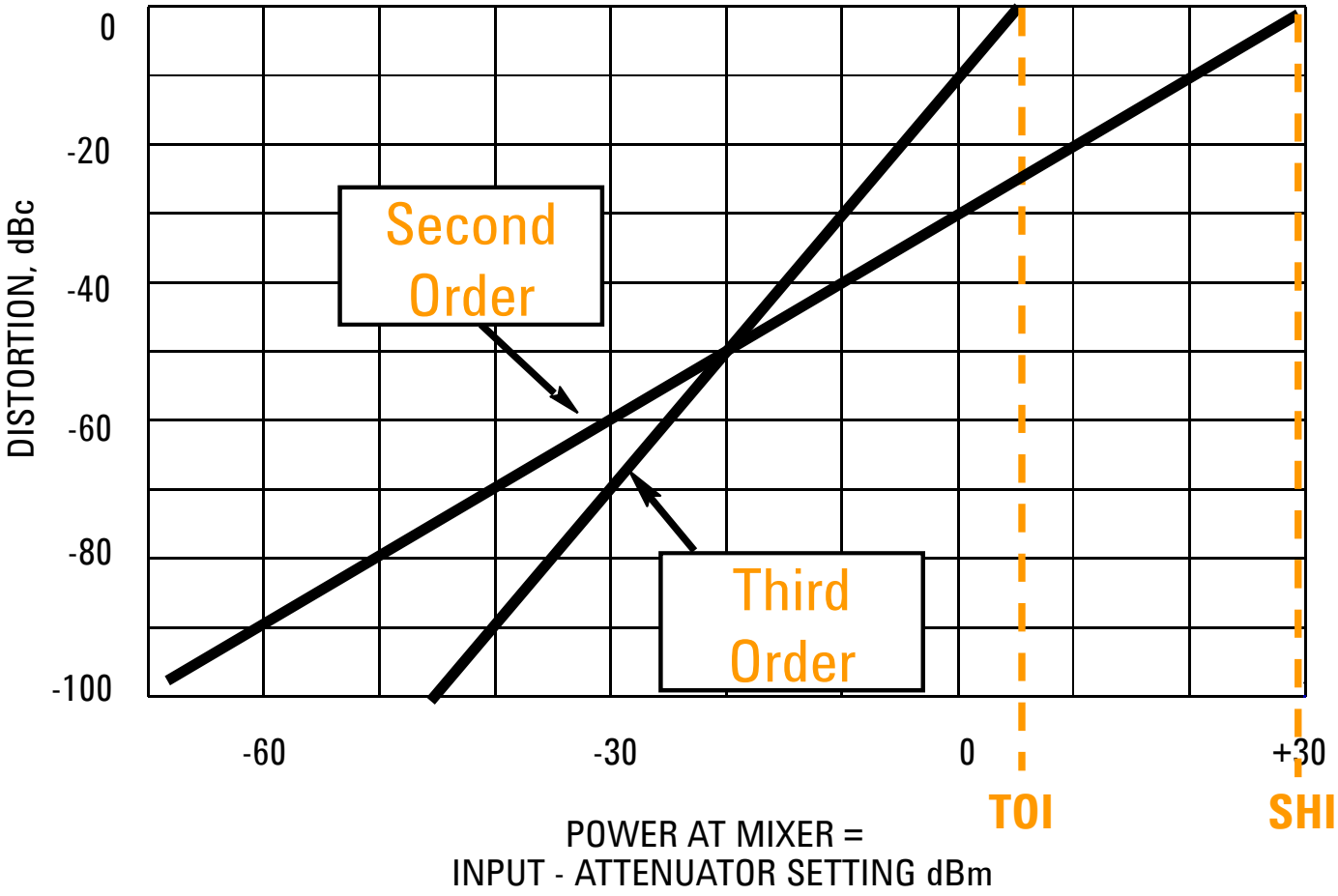
Harmonic Distortion

Third-order distortion

Second-order distortion

Specifications
Distortion

Distortion is a Function of Mixer Level



Specifications

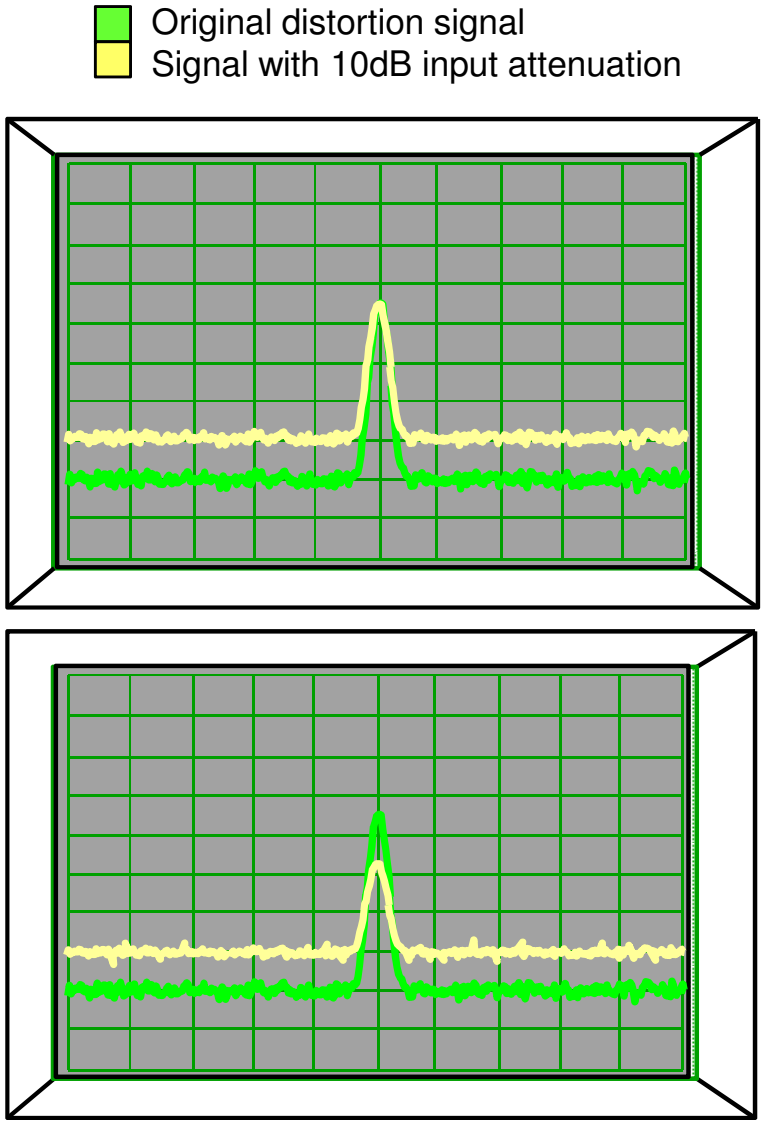
Distortion – Internal or External?

Attenuator Test:
Change power to the mixer

1. Change input attenuator by 10 dB
2. Watch distortion amplitude on screen

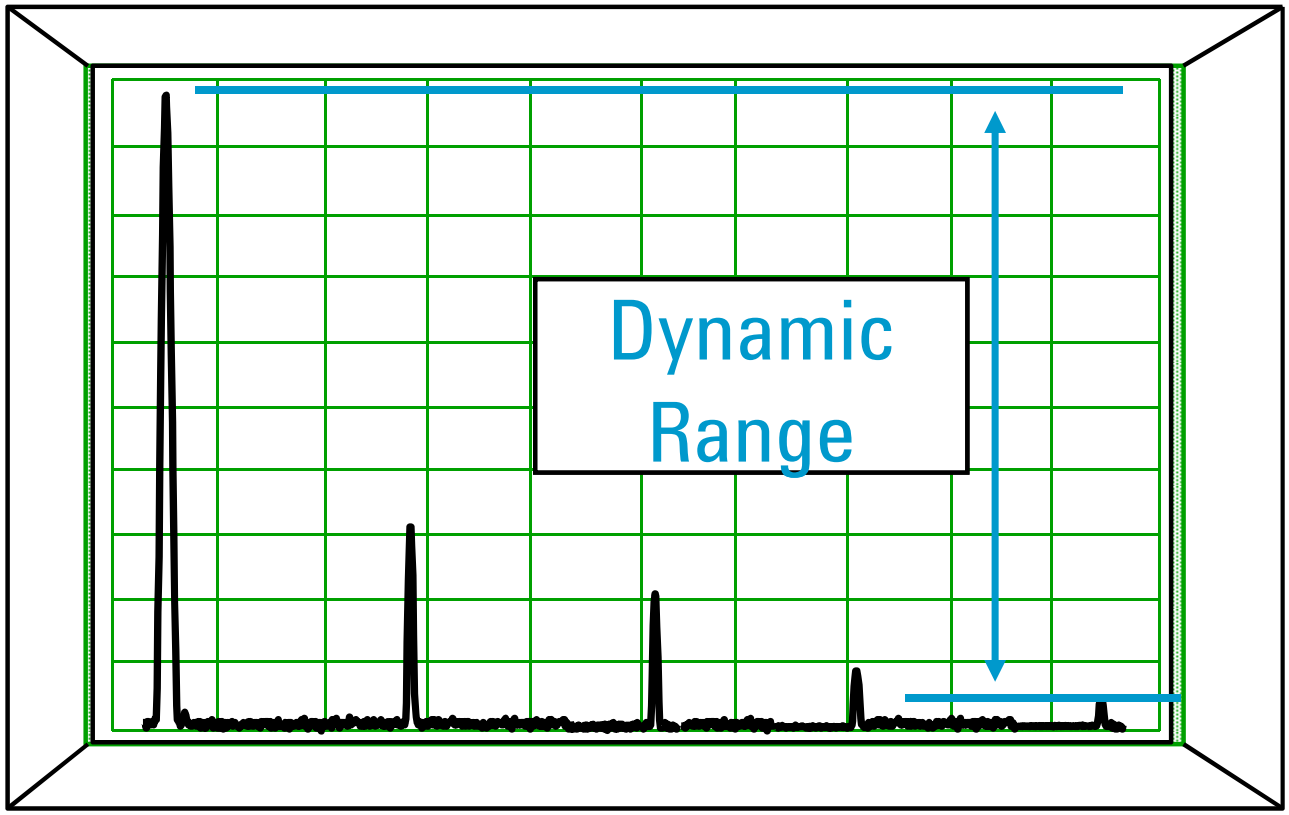
No change in amplitude: distortion is part of input signal (external)

Change in amplitude: at least some of the distortion is being generated inside the analyzer (internal)



Specifications

Spectrum Analyzer Dynamic Range

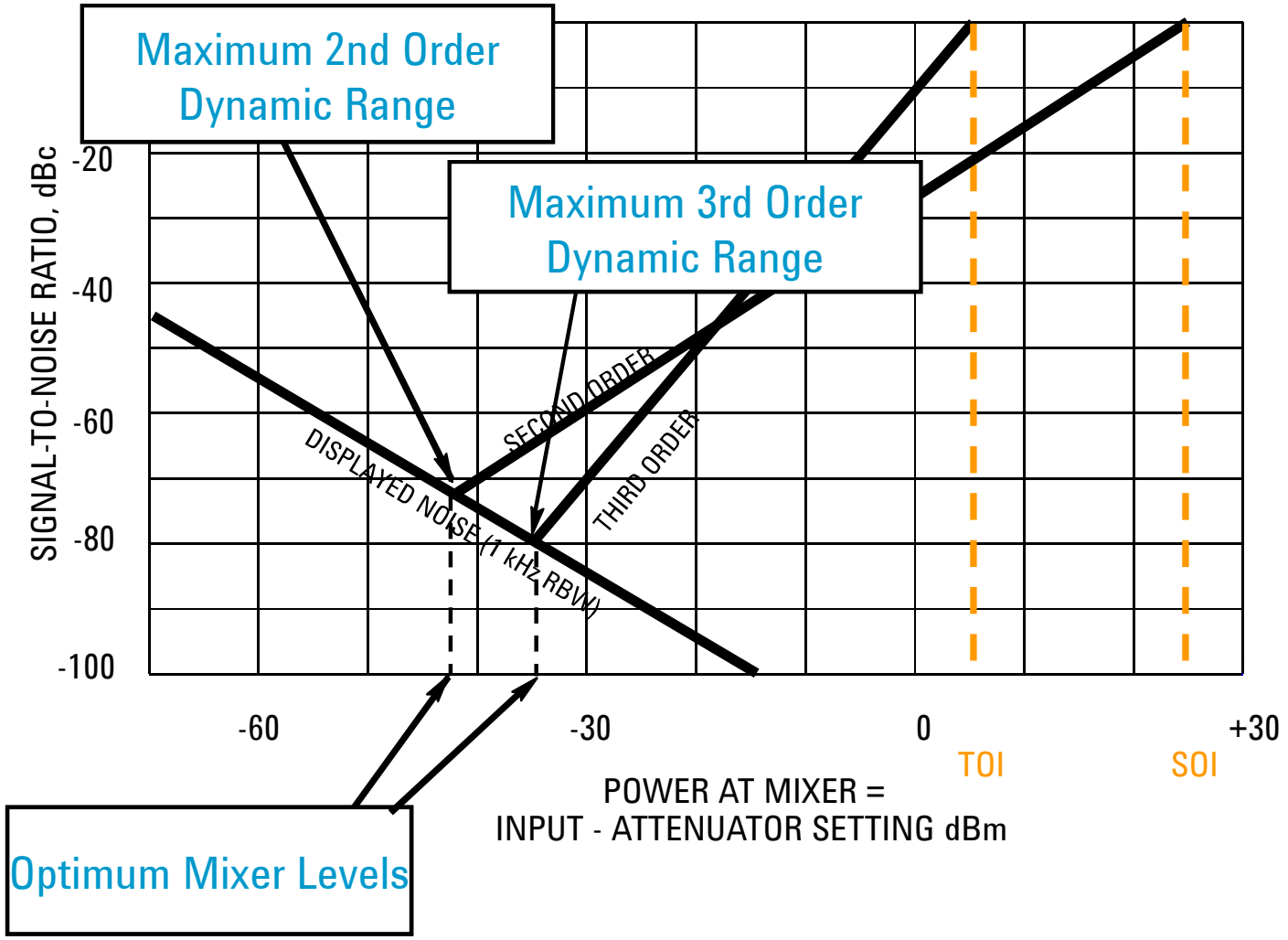


The ratio, expressed in dB, of the largest to the smallest signals simultaneously present at the input of the spectrum analyzer that allows measurement of the smaller signal to a given degree of uncertainty.

Specifications

Dynamic Range

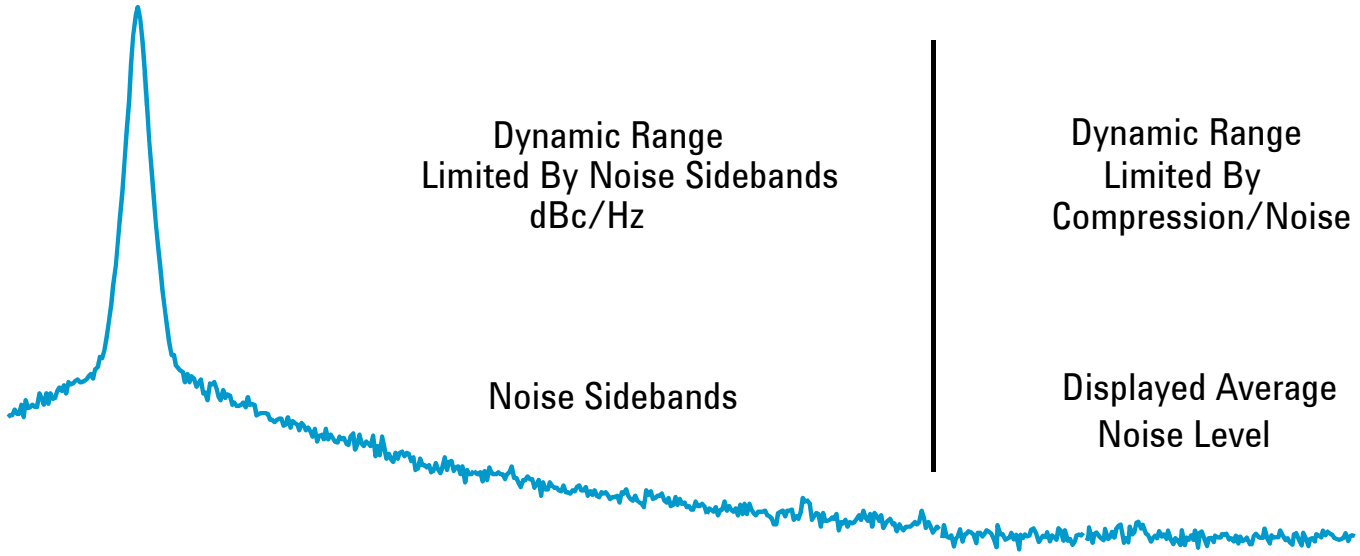
Dynamic Range Can Be Presented Graphically



Specifications

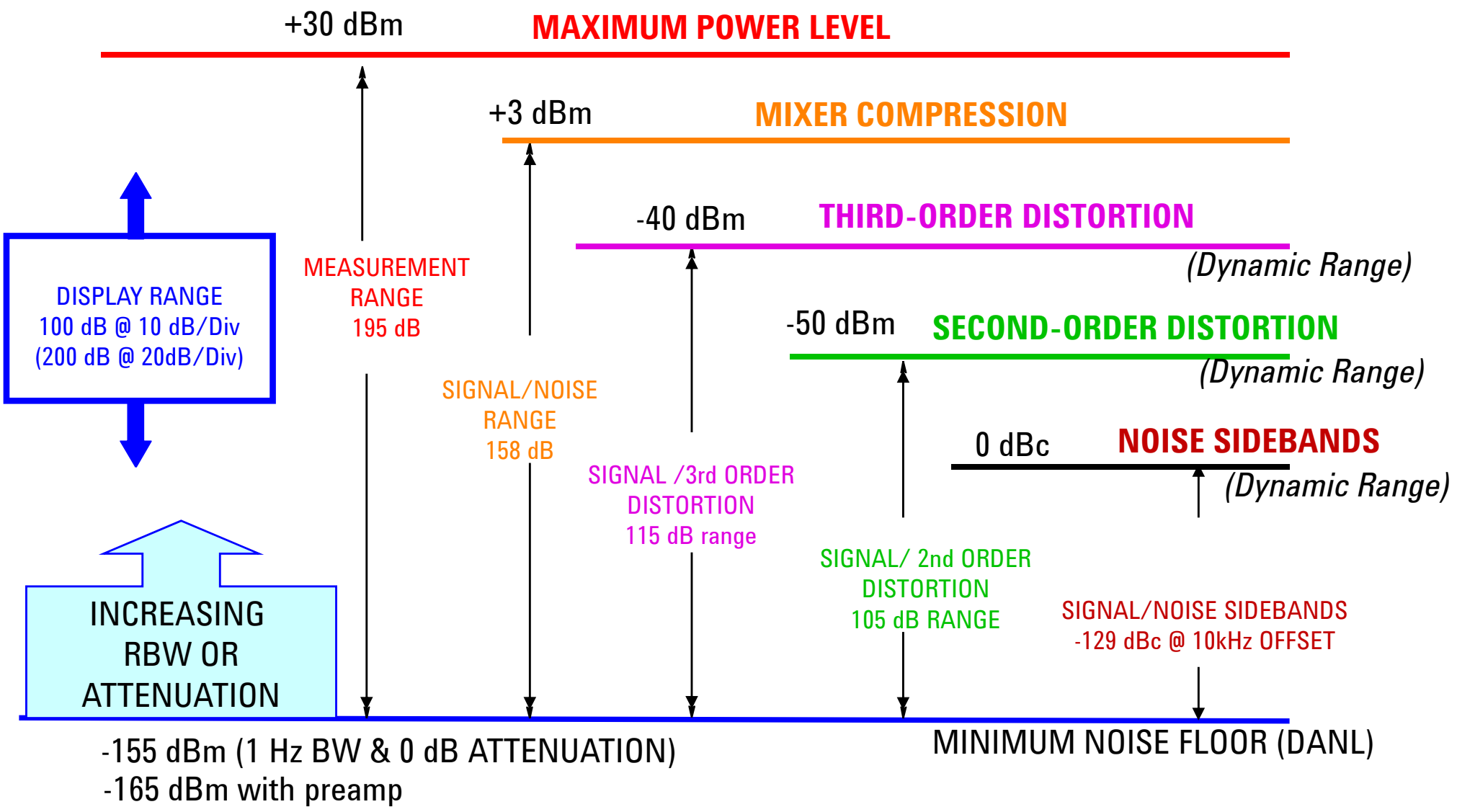
Dynamic Range

Dynamic Range for Spur Search Depends on Closeness to Carrier



Specifications

Dynamic Range vs. Measurement Range



Specifications

Summary: Optimizing Dynamic Range

- What settings provide the best sensitivity?
  - Narrowest resolution bandwidth
  - Minimal input attenuation
  - Sufficient averaging
- How do you test for analyzer distortion?
  - Increase the input attenuation and look for signal amplitude changes
  - Then set the attenuator at the lowest setting without amplitude change
- What determines dynamic range?
  - Analyzer distortion, noise level, and sideband/phase noise

Agenda

Introduction

Overview

Theory of Operation

Specifications

Modern spectrum analyzer designs & capabilities

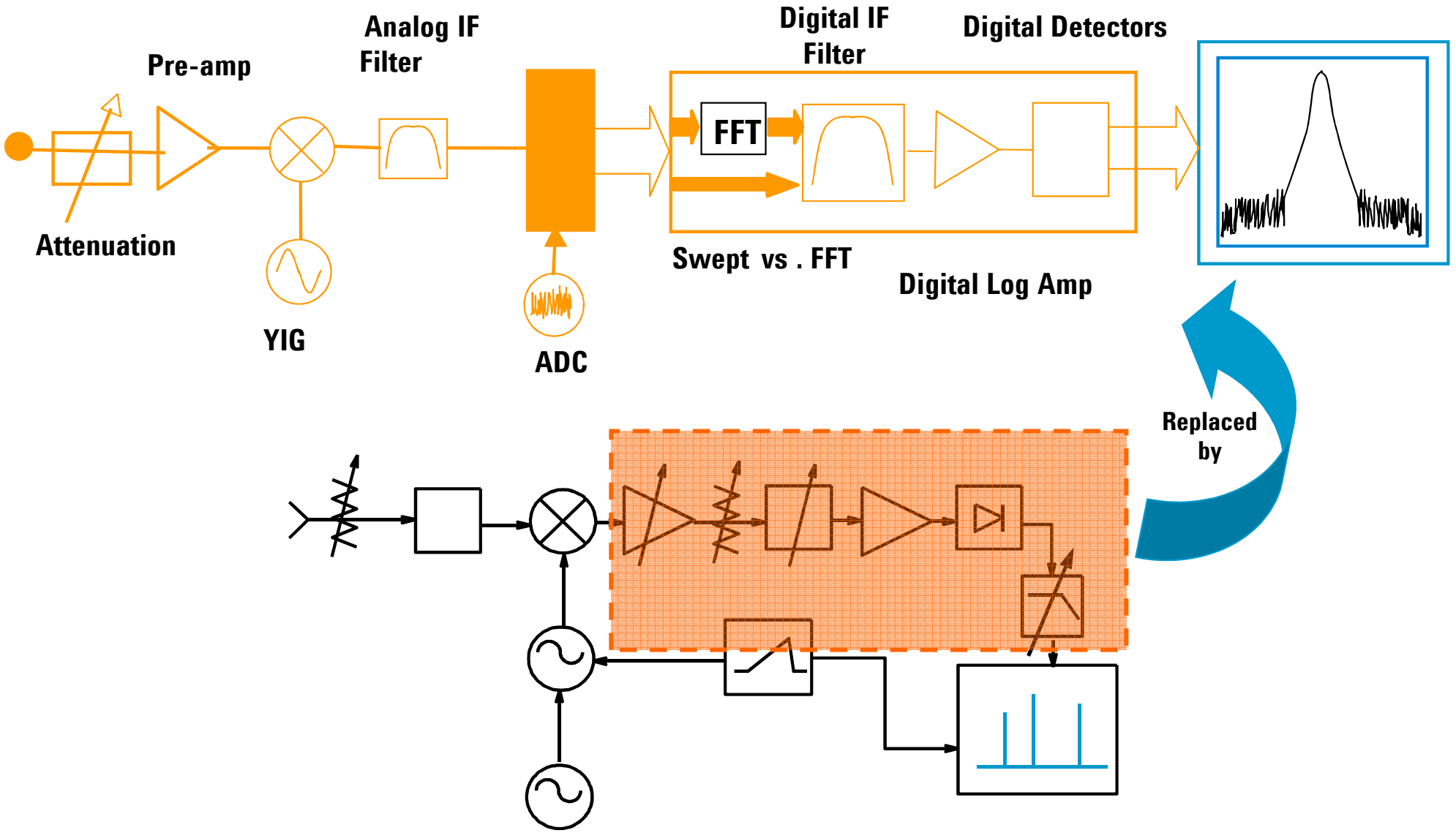
- Wide Analysis Bandwidth Measurements

Applications

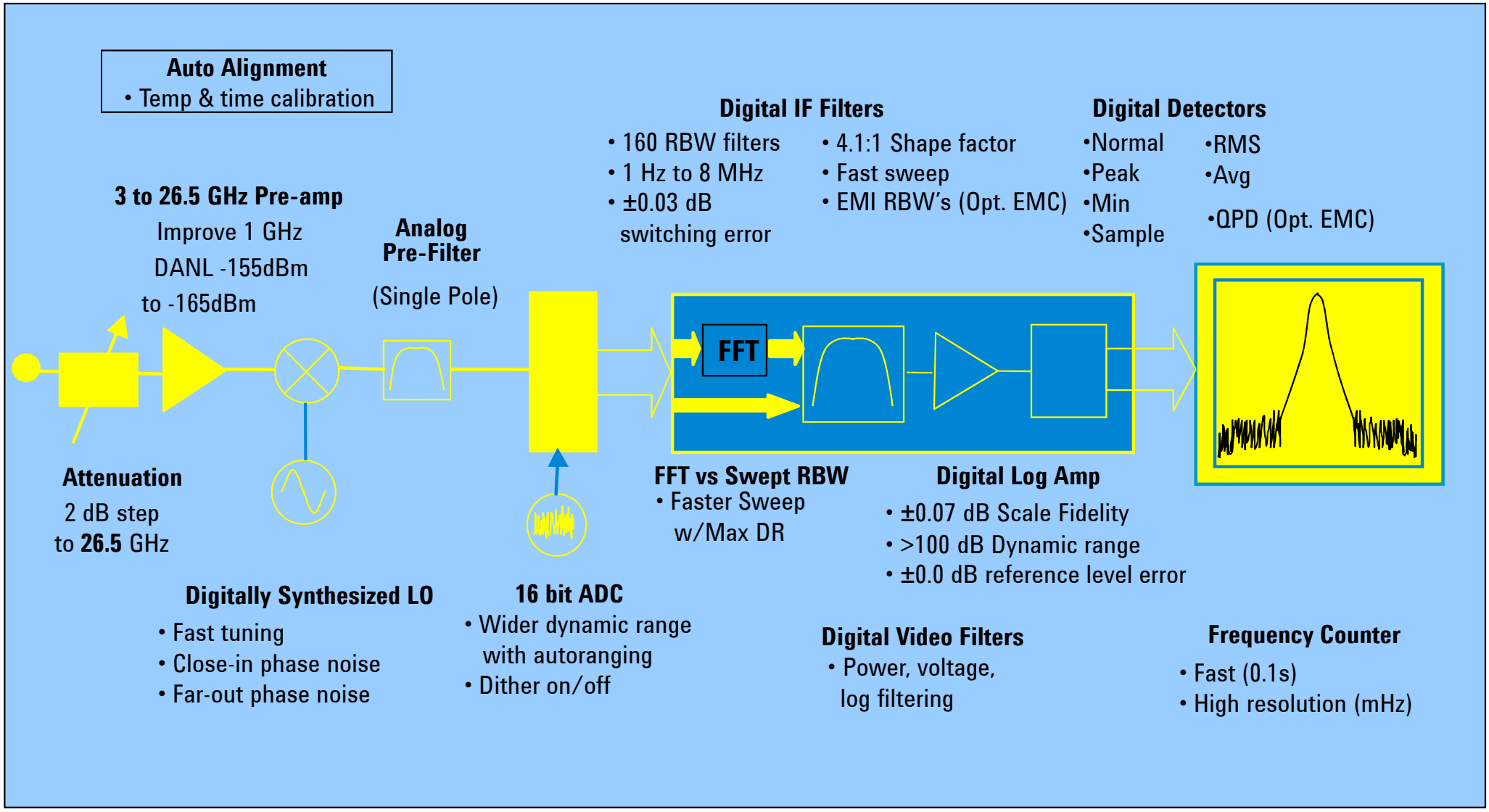
Automation Tools

Wrap-up

Modern Spectrum Analyzer Block Diagram



Modern Spectrum Analyzer Block Diagram



Modern Spectrum Analyzer - Specifications

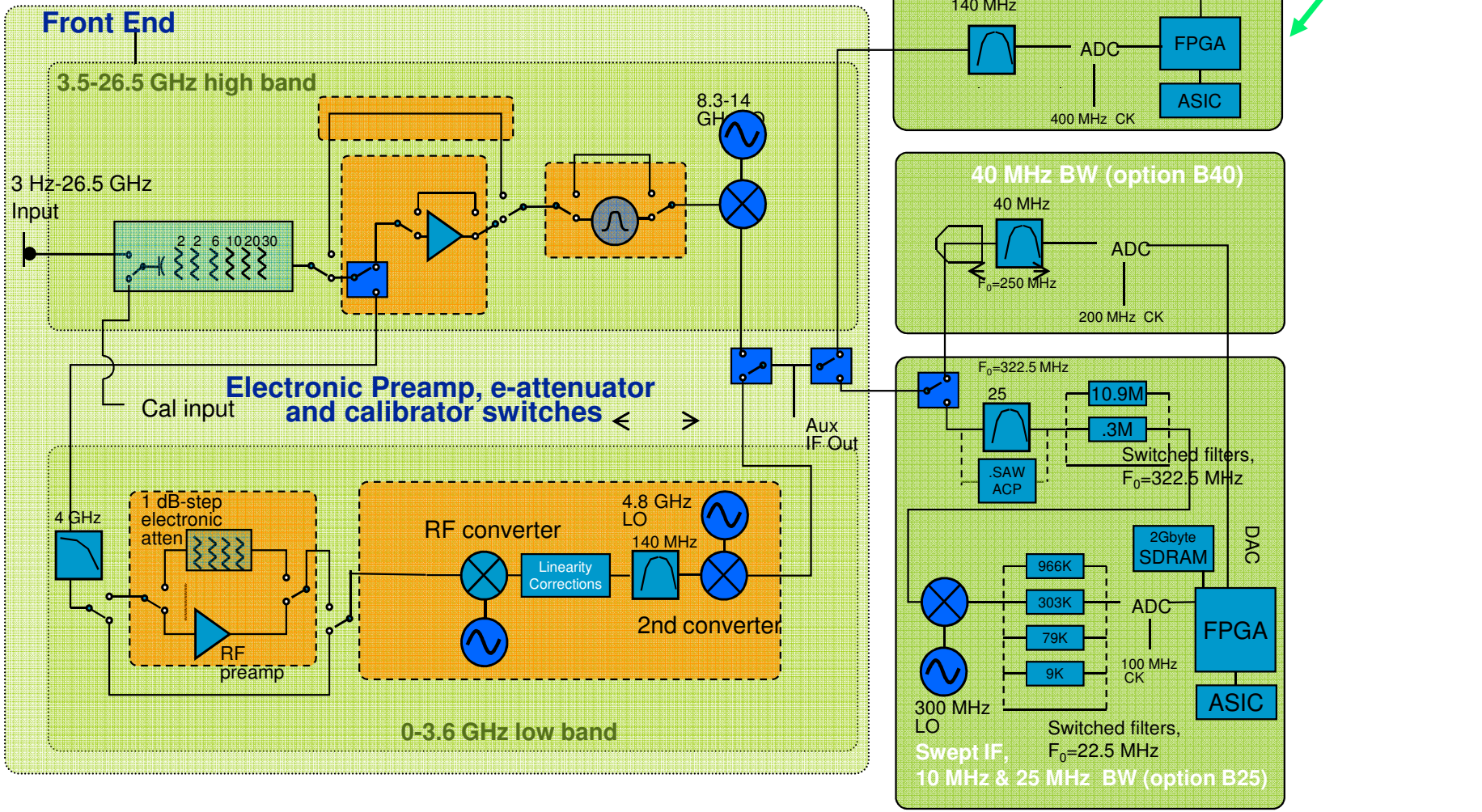
Digital IF provides improved accuracy

	PXA	vs. Traditional
• Input impedance mismatch	±0.13	±0.29 dB
• Input attenuator switching uncertainty	±0.14	±0.6 dB
• Frequency response	±0.35	±1.8 dB
• Reference level accuracy	±0.0	±1.0 dB
• RBW switching uncertainty	±0.03	±0.5 dB
• Display scale fidelity	±0.07	±0.85 dB
• Calibrator accuracy	±0.24	±0.34 dB
Total accuracy (up to 3 GHz)	**±0.59 dB**	vs. **±1.8 dB**
95% Confidence	**±0.19 dB**	

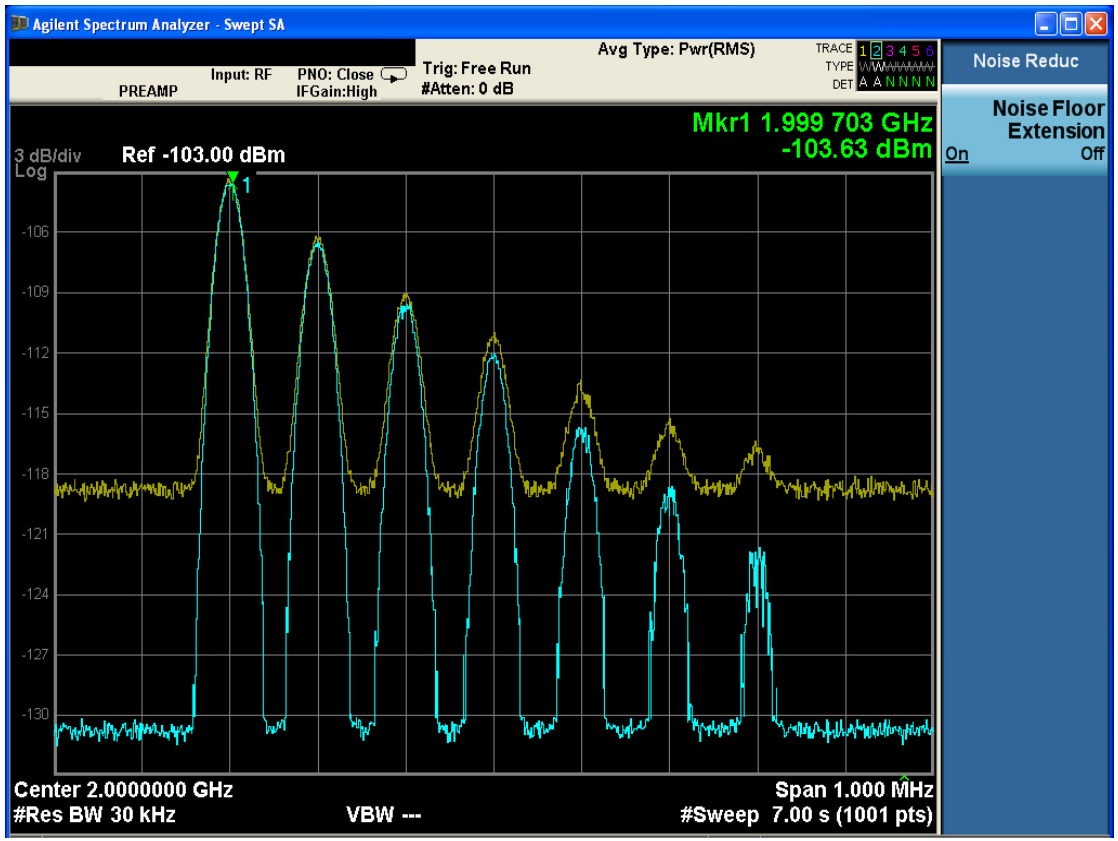
Wide band analysis

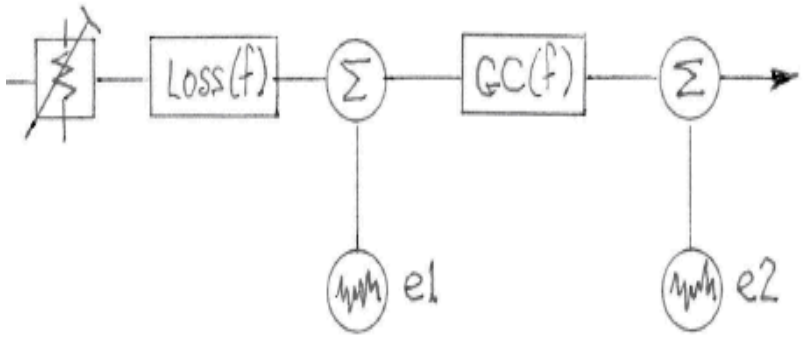
140 MHz Path
ADC Nominal bits: 14
ADC Effective bits: 11.2
SFDR: up to 75 dBc

PXA Simplified Block Diagram (140 MHz BW)



Noise Floor Extension





- The combination of real-time measurement processing with an unprecedented characterization of the analyzer's own noise to allow that noise to be accurately removed from measurements.
- The improvement from *noise floor extension* varies from about 3.5 dB for CW and pulsed signals to approximately 8 dB for noise-like signals, and up to 12 dB or more in some applications.
- DANL at 2 GHz is–161 dBm without a preamp and –172 dBm with the preamp.

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Applications

- Digital Modulation
- Phase Noise
- Noise Figure

Automation Tools

Wrap-up

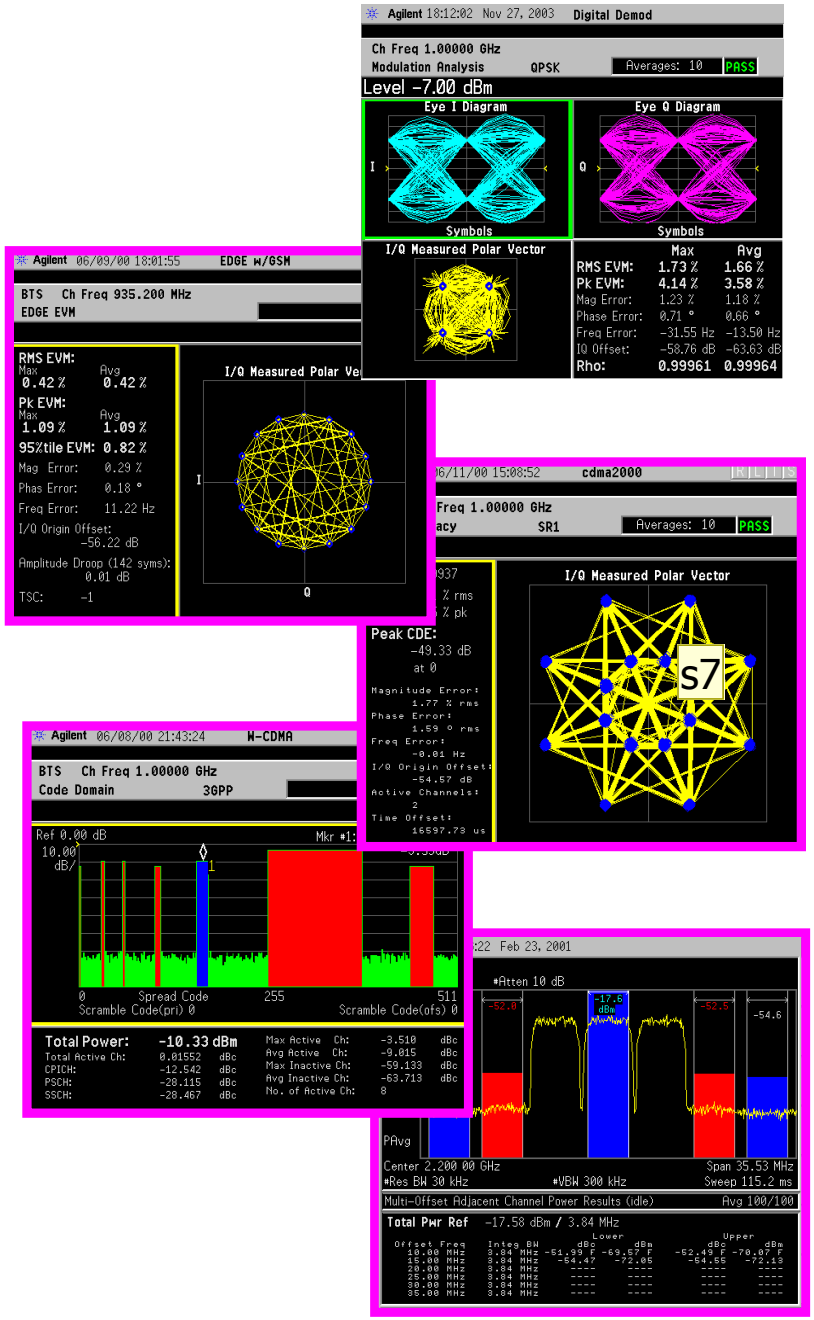
Application Focused Internal Software

General purpose applications

Flexible digital modulation analysis

Power & digital modulation measurements for wireless comms formats

Phase noise
Ext. source control
Noise figure
Code compatibility suite
EMI pre-compliance
Analog demod
Flexible demod
LTE FDD, TDD
W-CDMA/HSPA/HSPA+
GSM/EDGE/EDGE Evo
cdma2000 & 1xEV-DO
cdmaOne
DVB-T/H/C/T2
TD-SCDMA/HSPA
WLAN (802.11a/b/g/p/j)
802.16 OFDMA
Bluetooth



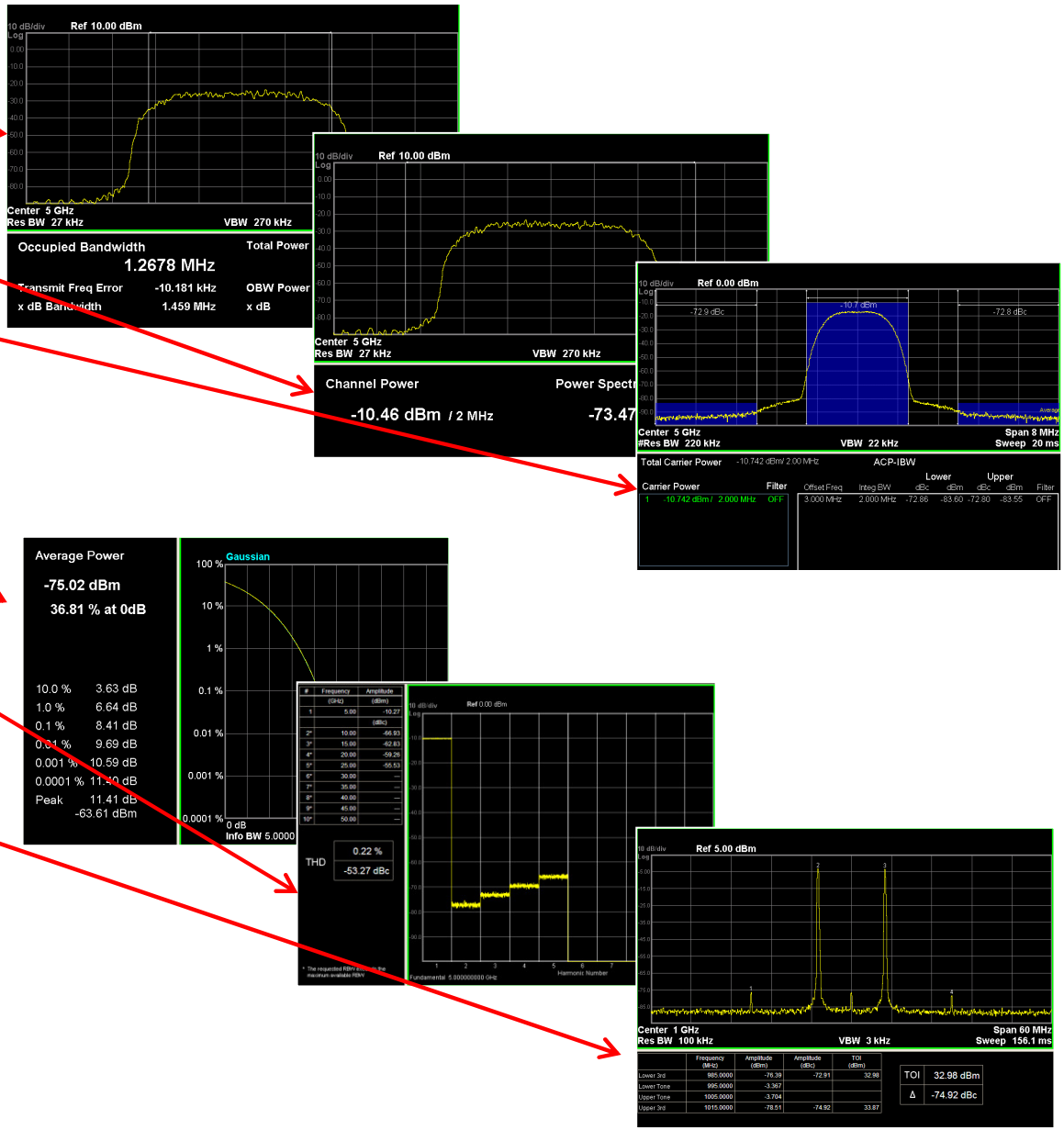
Agilent Technologies

Slide 60

s7 change pictures for PXA
shanscon, 12/2/2010

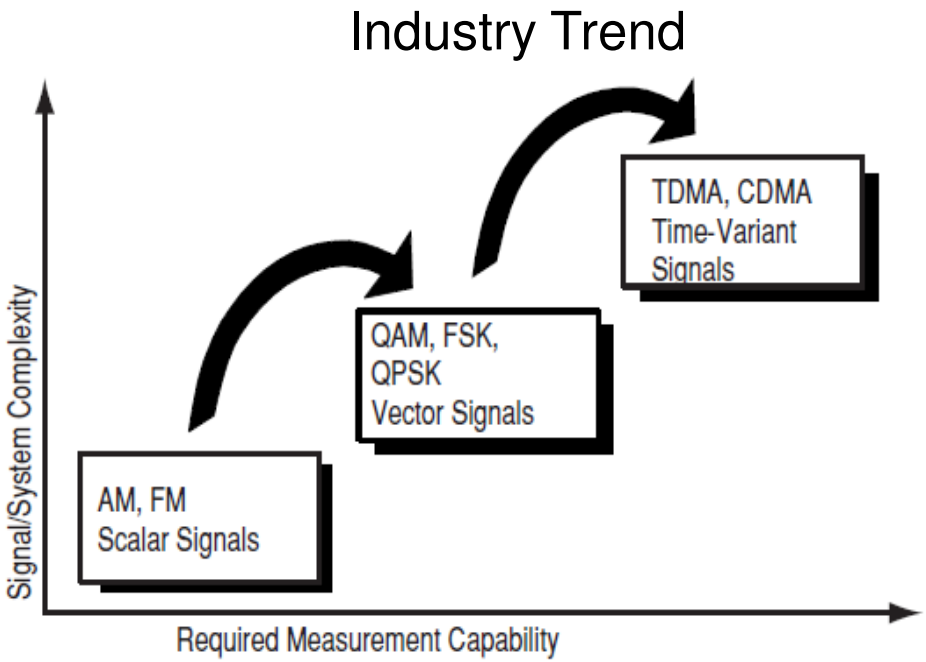
Built-in One-Button Power Measurements

- Occupied Bandwidth
- Channel Power
- ACP
- Multi-carrier ACP
- CCDF
- Harmonic Distortion
- Burst Power
- TOI
- Spurious Emissions
- Spectral Emissions Mask



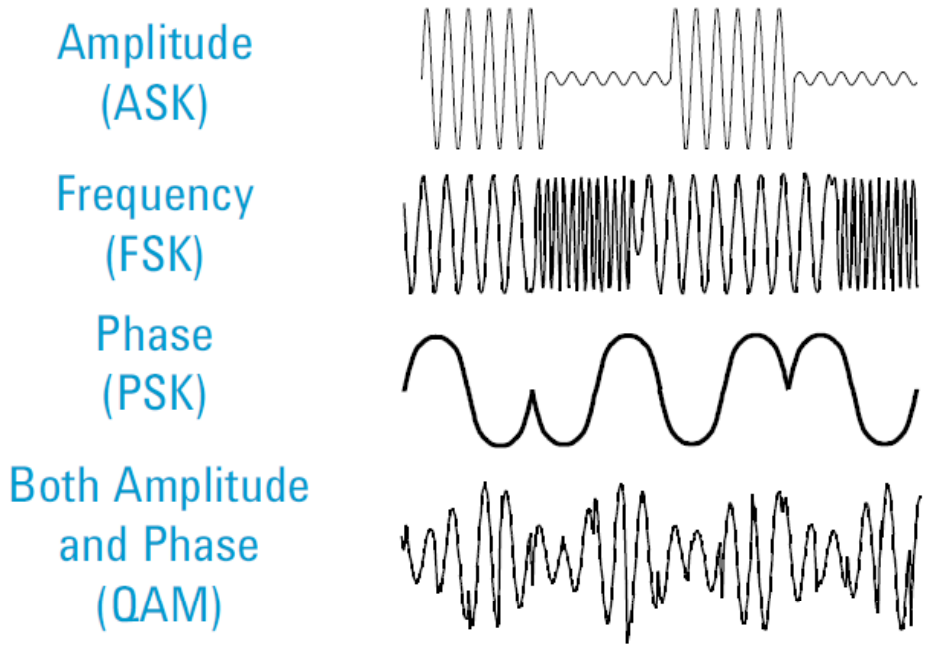
Why Use Digital Modulation?

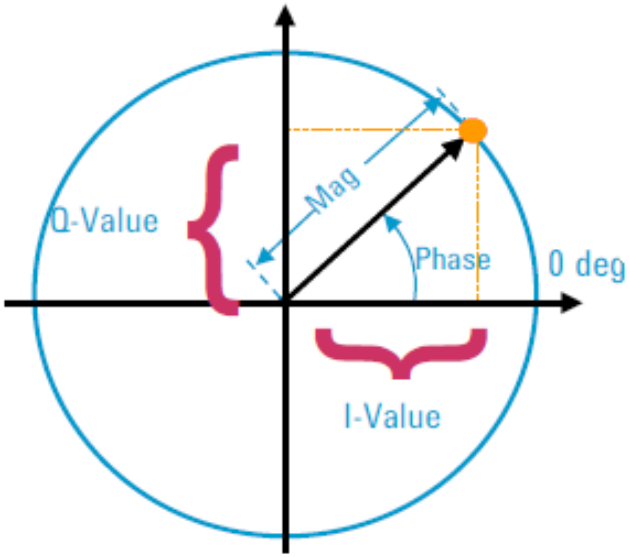
- More information capacity & more spectrally efficient than analog modulation
- Compatibility with digital data services
- Higher data security
- Better quality communication



What is Digital Modulation?

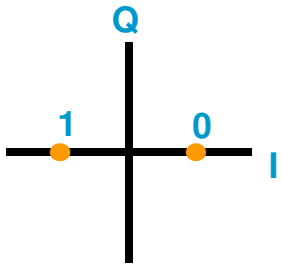
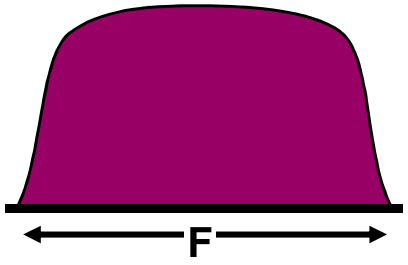
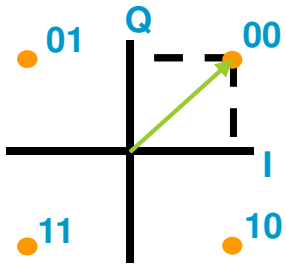
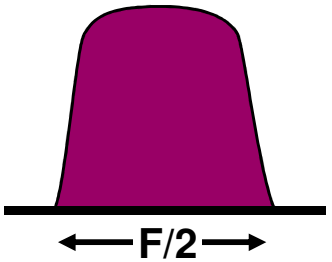
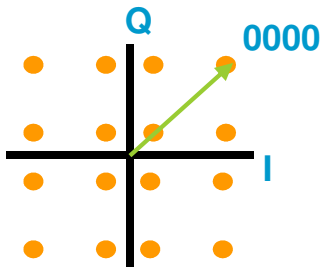
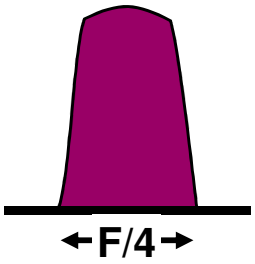
- Restricts modulating baseband signal to discrete states (Digital)





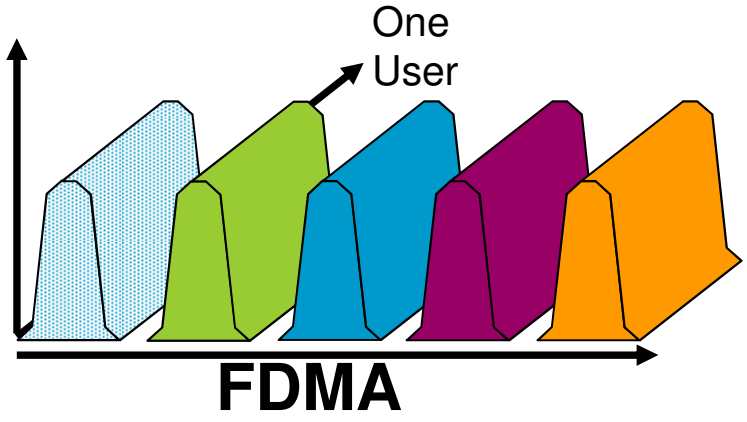
- Project Signals to “I” and “Q” Axes
- Polar to Rectangular Conversion
- IQ Plan Shows 2 Things
  - What the modulated carrier is doing relative to the unmodulated carrier
  - What baseband I and Q inputs are required to produce the modulated carrier

Some Simple Examples of Digital Modulation

Modulation format	Number of bits per symbol	Constellation	Transmission bandwidth
BPSK	1		
QPSK	2		
16 QAM	4		

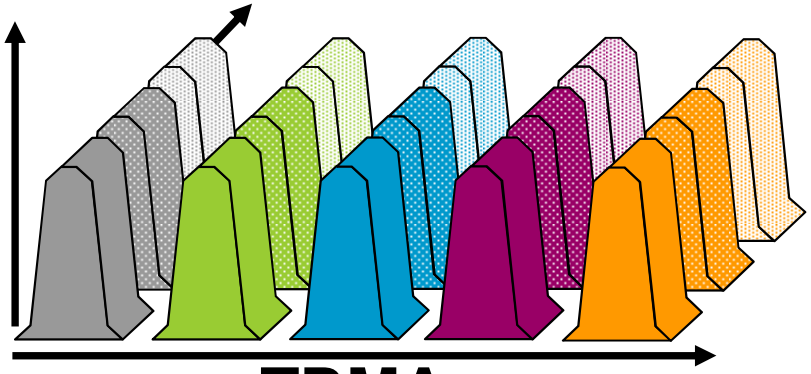
Symbol Rate = #symbols/sec. (Hz)

Digital Format Access Schemes

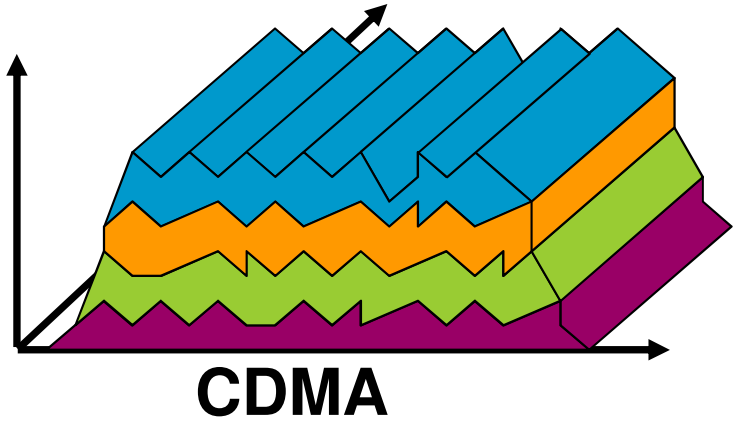


Different channel - different Users

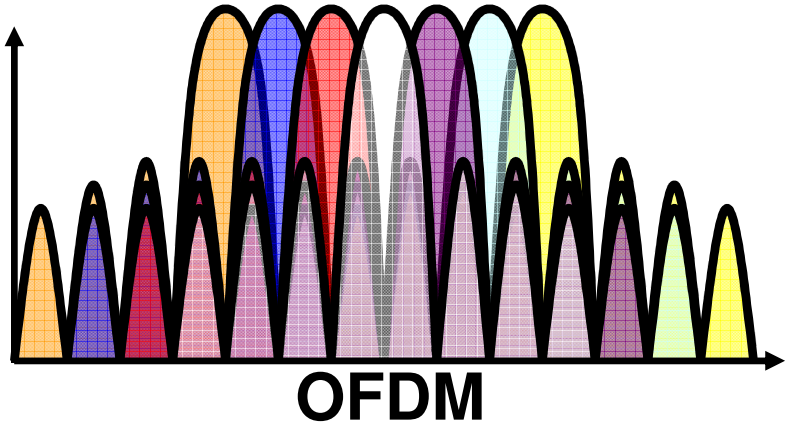
Different time - different Users



Different time - different Users

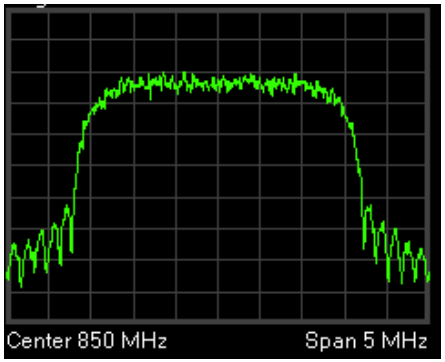


Same channel – many users

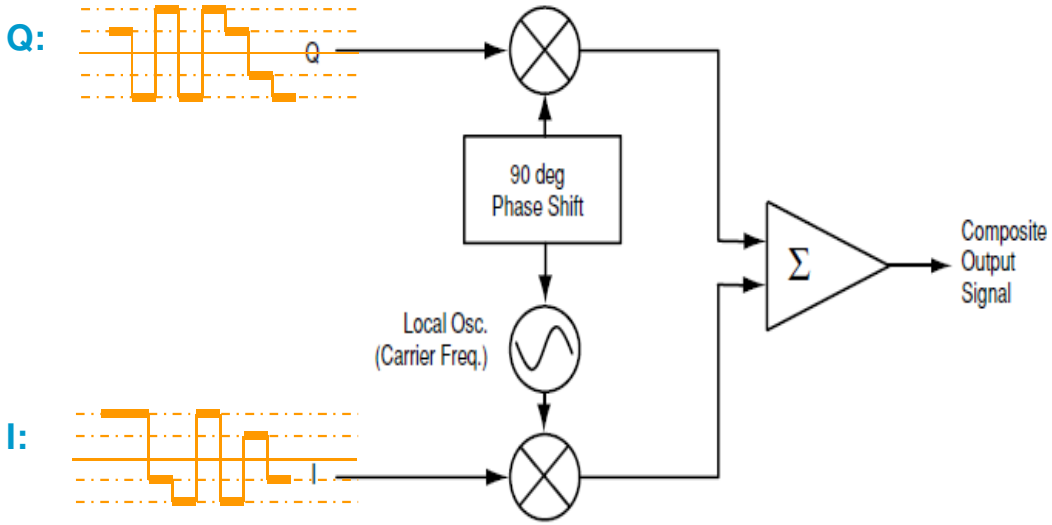


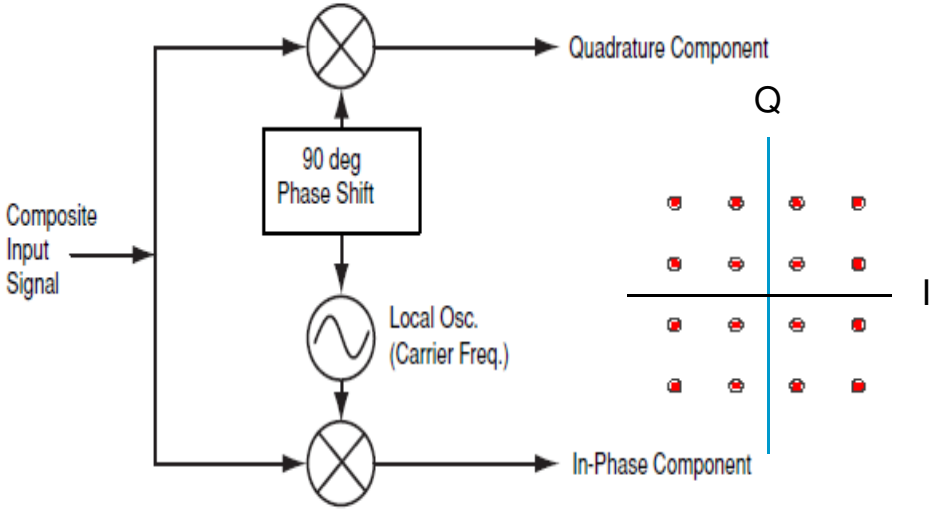
How to Digitally Modulate/Demodulate?

Modulate



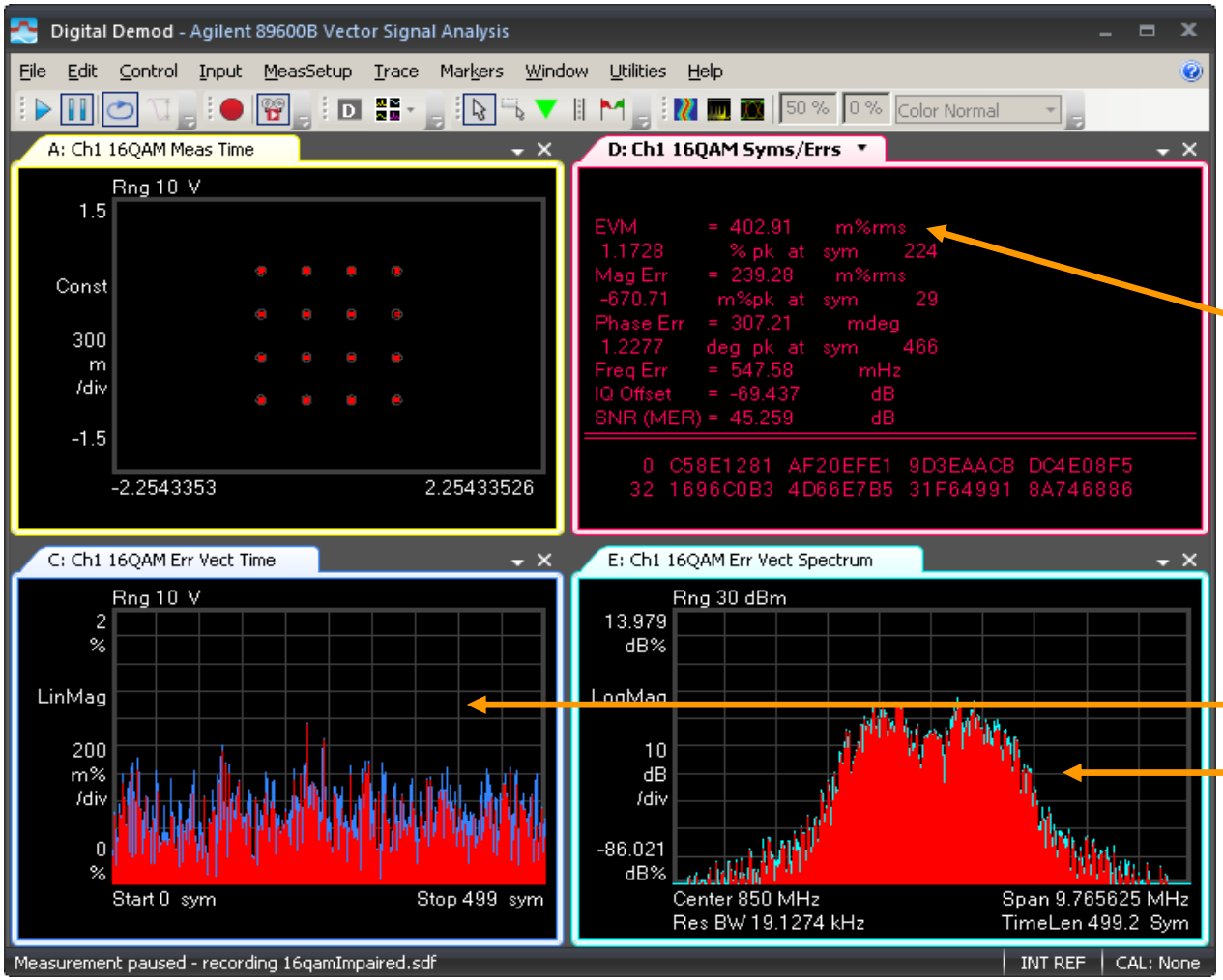
Demodulate

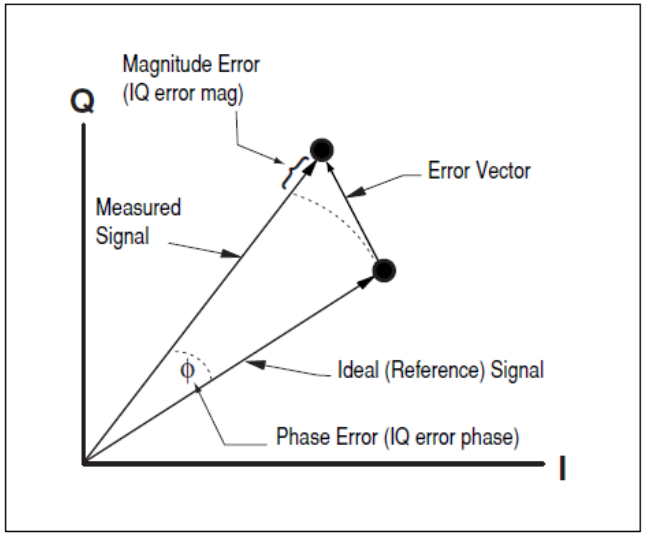




Measurements of Quality for Digital Modulation

Demodulated signal I/Q values are compared with ideal expected constellation location. The difference is the Error Vector Magnitude (EVM)





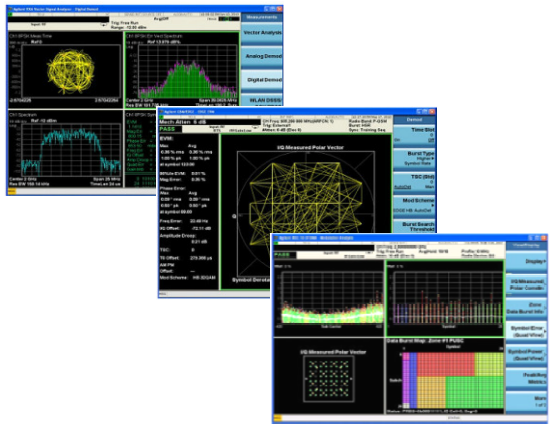
Overall measurement of signal quality is rms EVM given in percent of dB.

EVM can also be displayed versus time and versus frequency

Tools for Digital Modulation Analysis

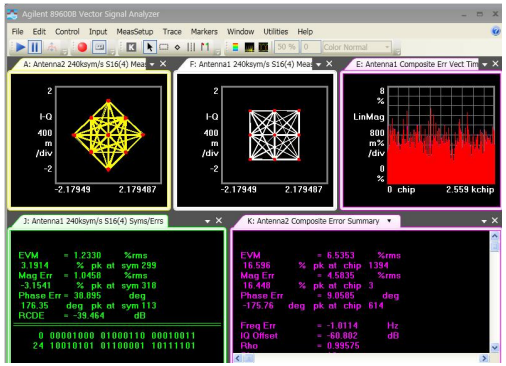
Embedded Software Applications :

- Over 30 modulation format specific measurement applications which run inside the X-series analyzers.
- Best solution for manufacturing where speed is required.



Software: 89601B VSA Software

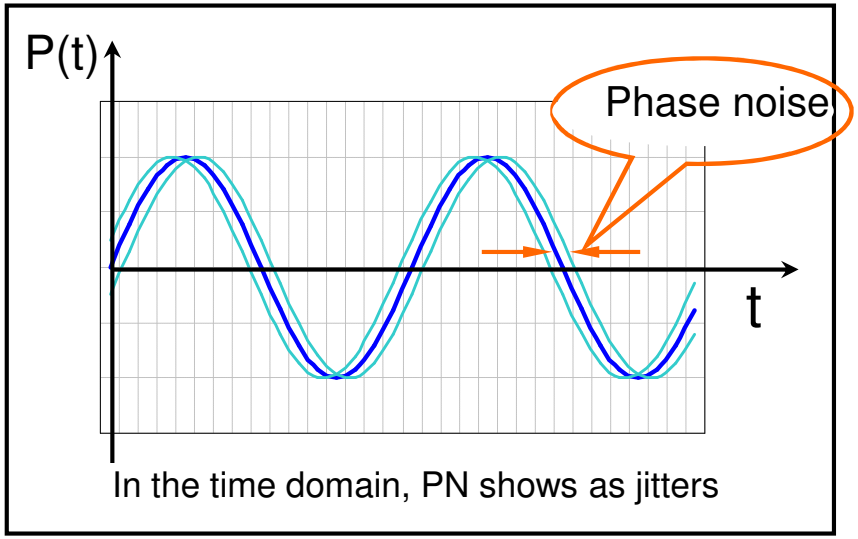
- Supports over 70 modulation formats.
- Runs on an external PC, or inside hardware.
- Best solution for R&D where flexibility and troubleshooting tools are required

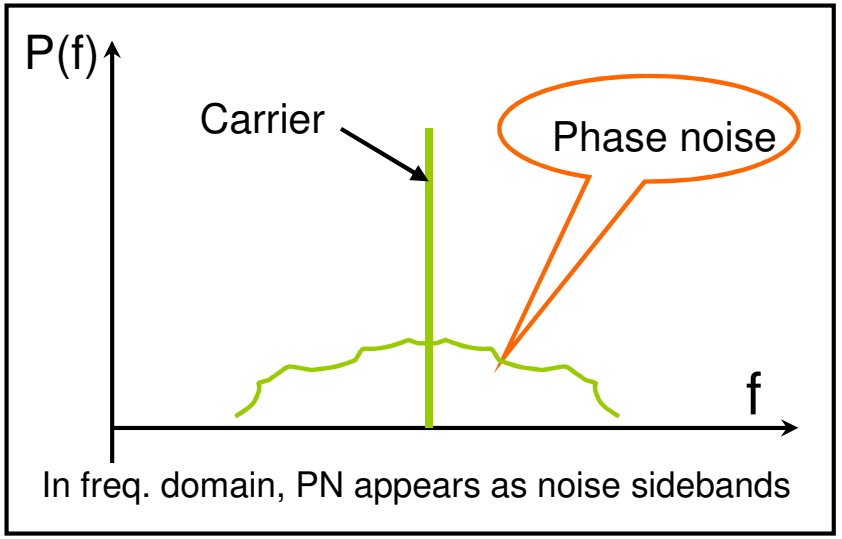


Phase Noise Overview

What is “Phase Noise”?

- A random, side band noise
- Caused by phase fluctuations of an oscillator





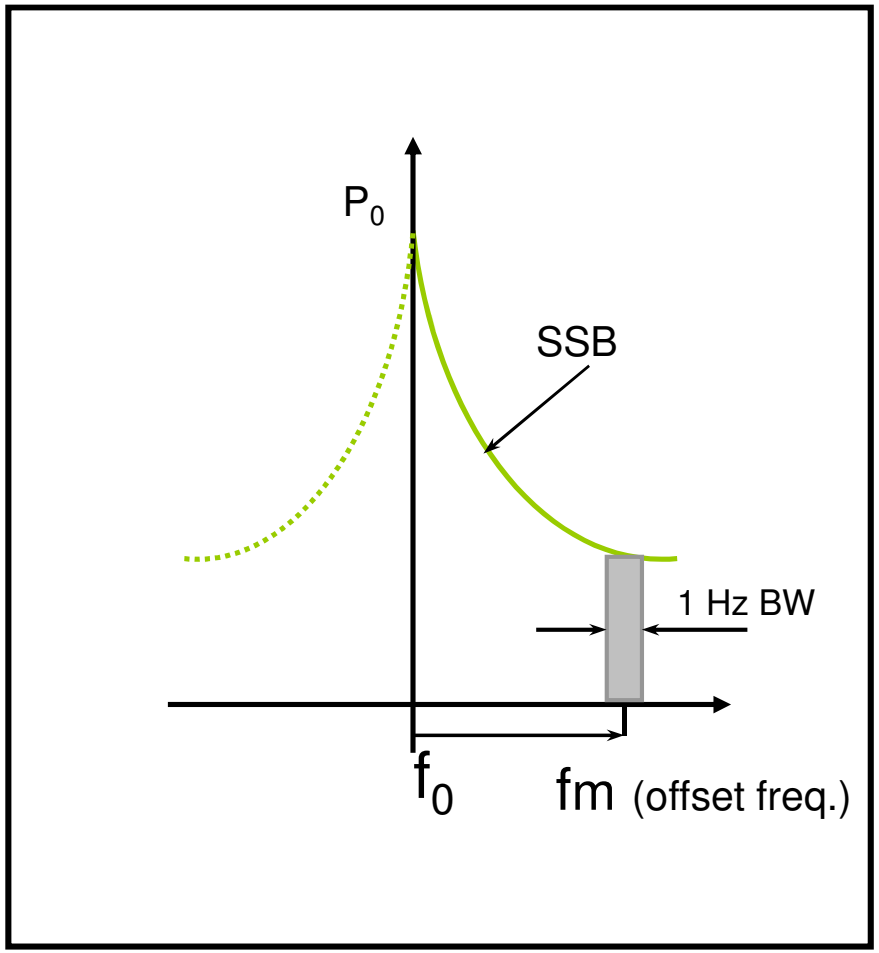
Phase Noise Overview

How to define “Phase Noise”?

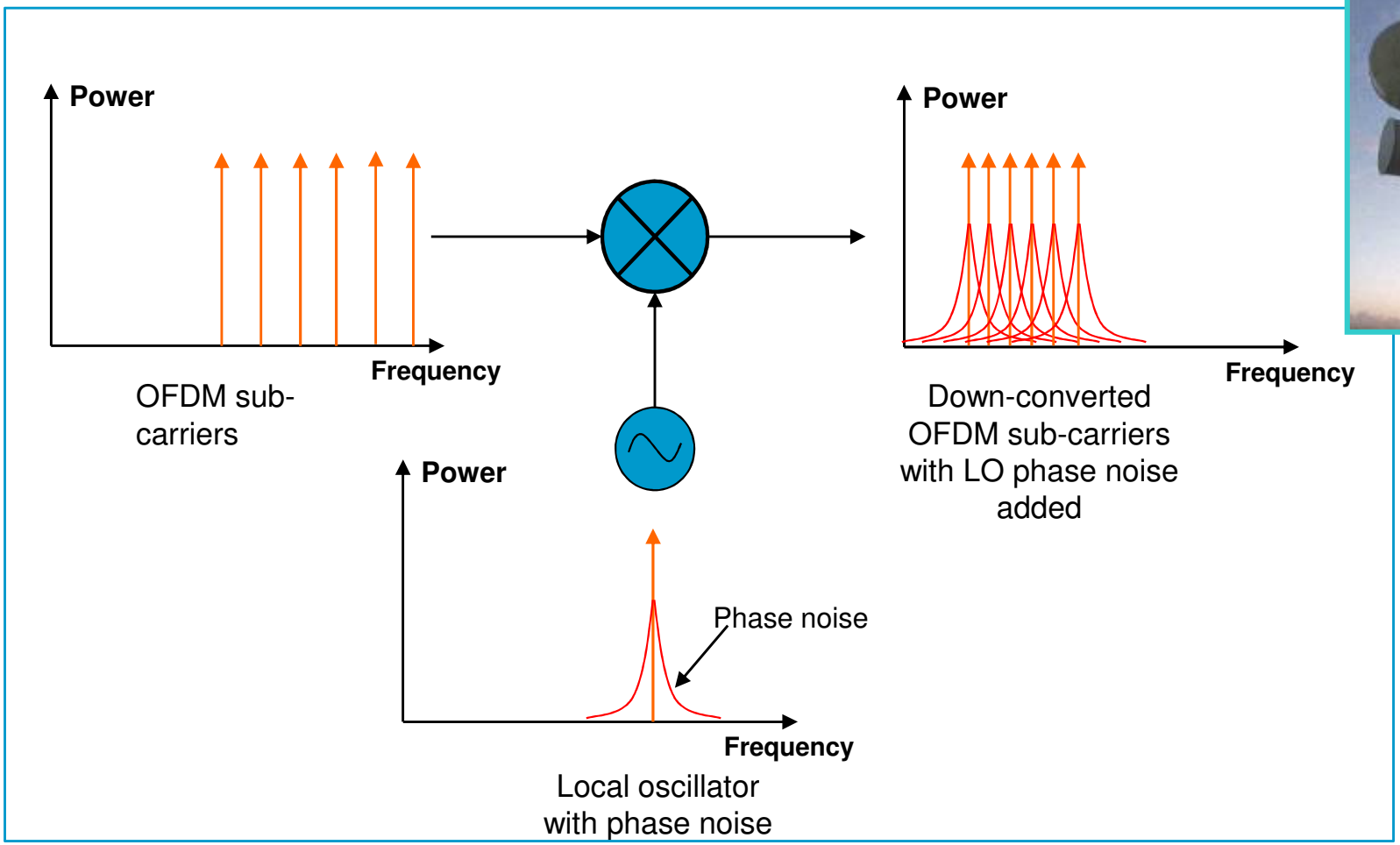
3 elements:

- Offset freq. from carrier freq.
- Power spectral density (in 1 Hz BW)
- Relative to carrier power in dBc

dBc/Hz @ offset freq. fm

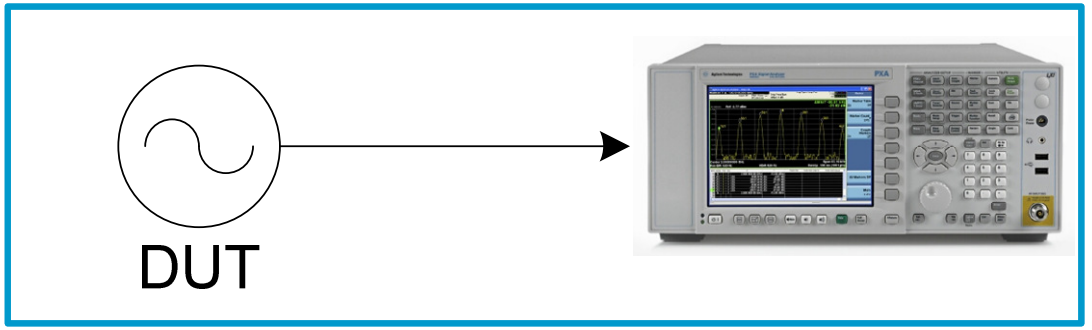


Why is phase noise important?

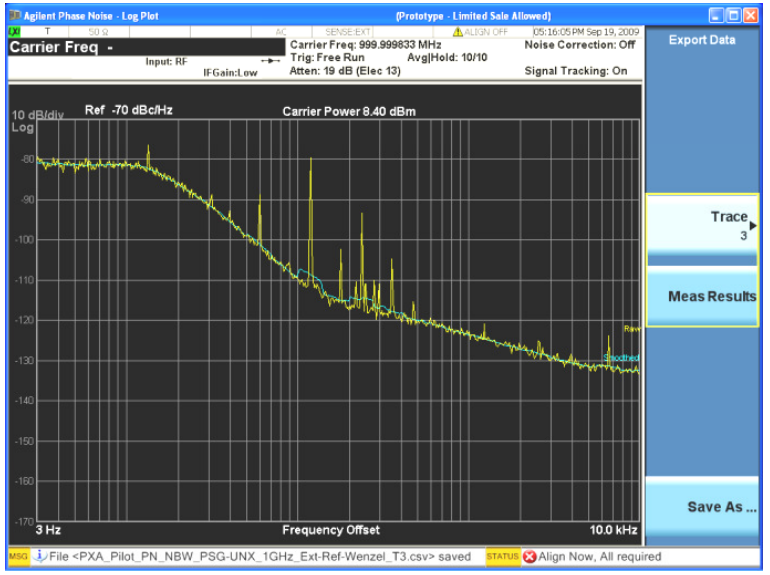


- Better PN of the LO improves sub-channel resolution

Direct Spectrum Measurement Method



- Easy to configure and use
- Quick phase noise check
- Log pot
- Spot frequency (PN change vs. time)
- rms PN, rms Jitter, residual FM
- X-Series phase noise application automates the PN measurements
- Limited by SA internal PN floor
- Caution: Direct Spectrum method requires AM << PM



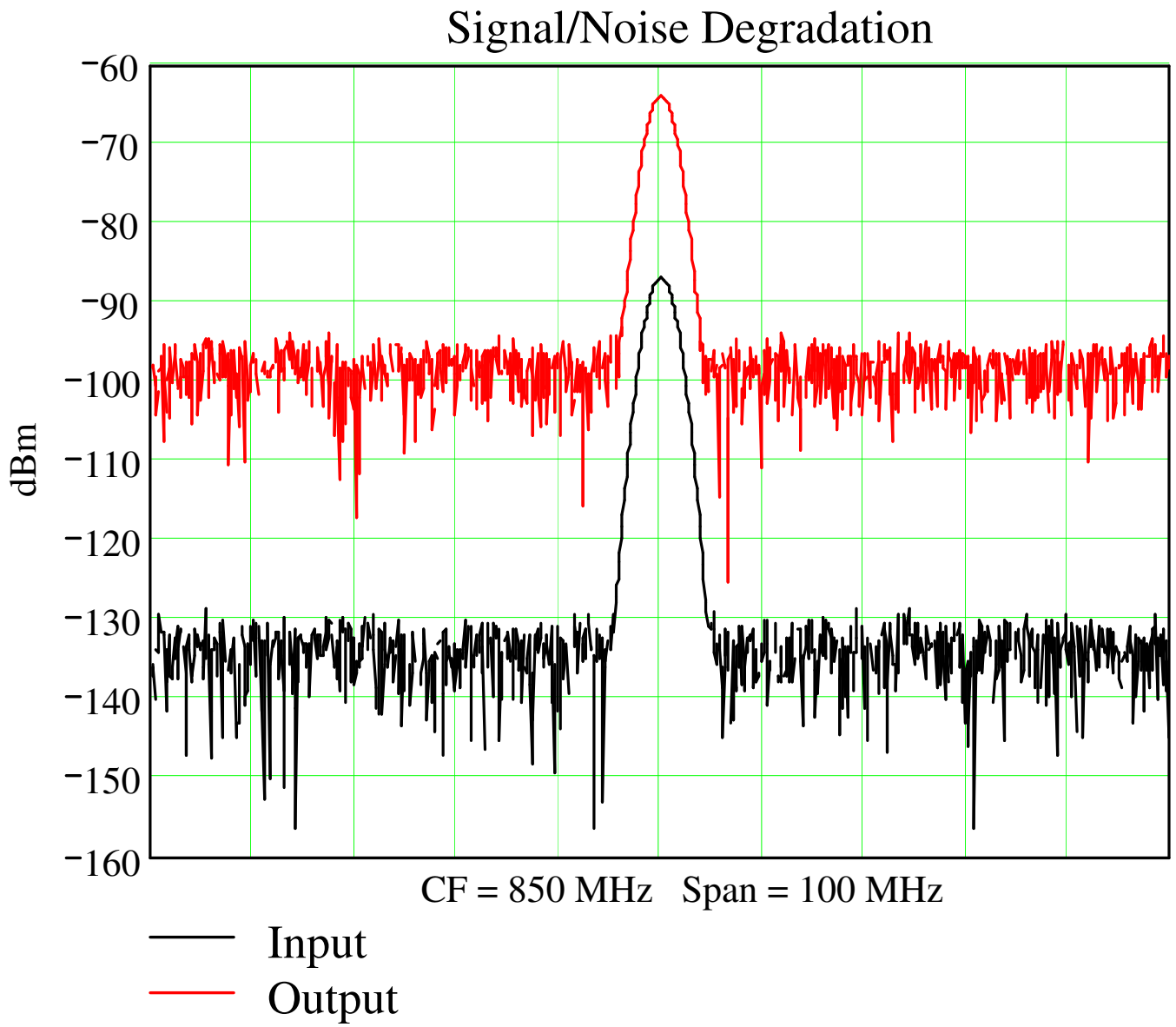
Phase noise result in Log Plot

What is Noise Figure ?

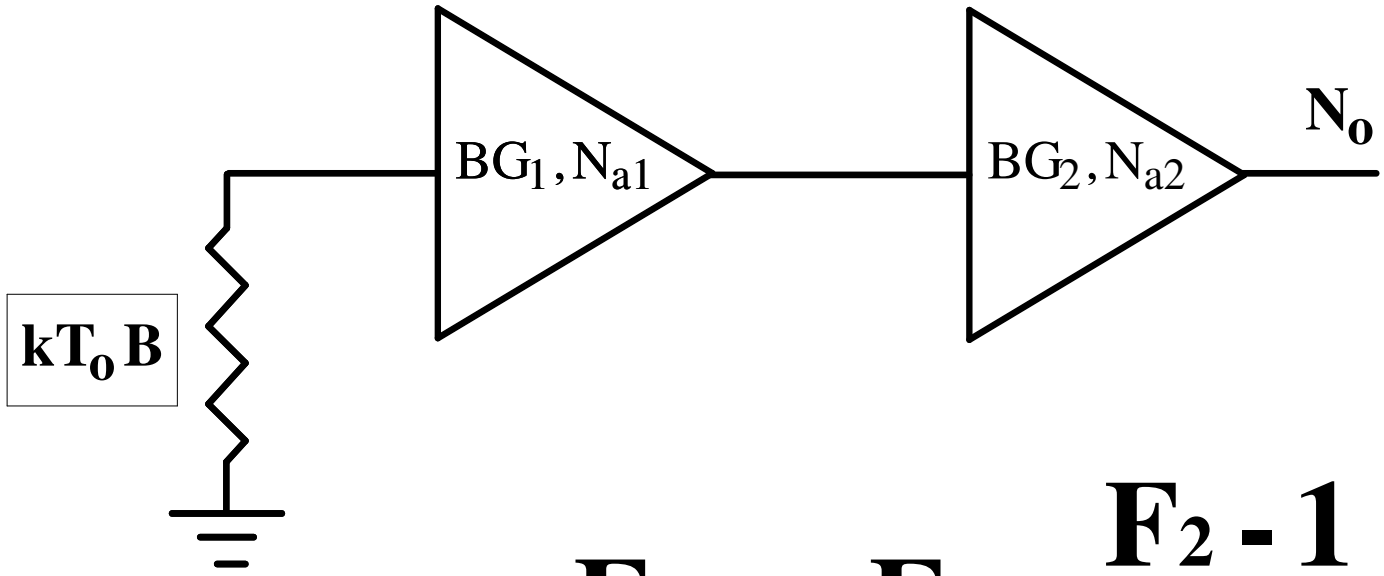
$$F = \frac{\frac{S_i}{N_i}}{\frac{S_o}{N_o}}$$

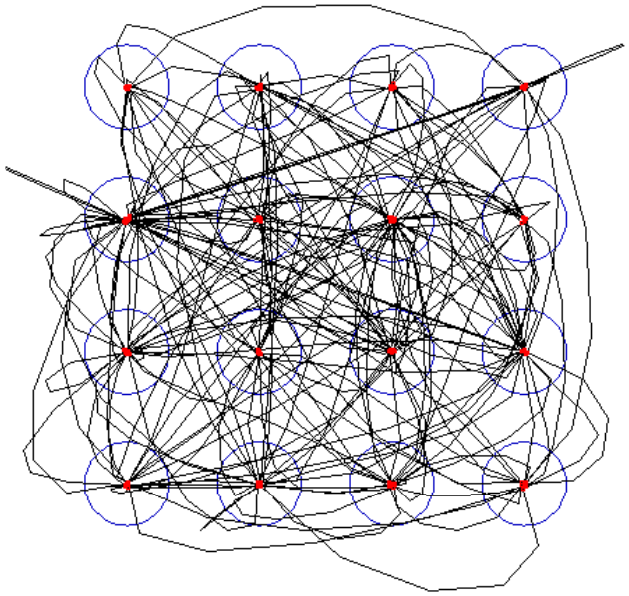
$$= \frac{\frac{Si}{Ni}}{\frac{GSi}{(N_a + GN_i)}}$$

$$= \frac{N_a + GN_i}{GN_i} \quad (1)$$



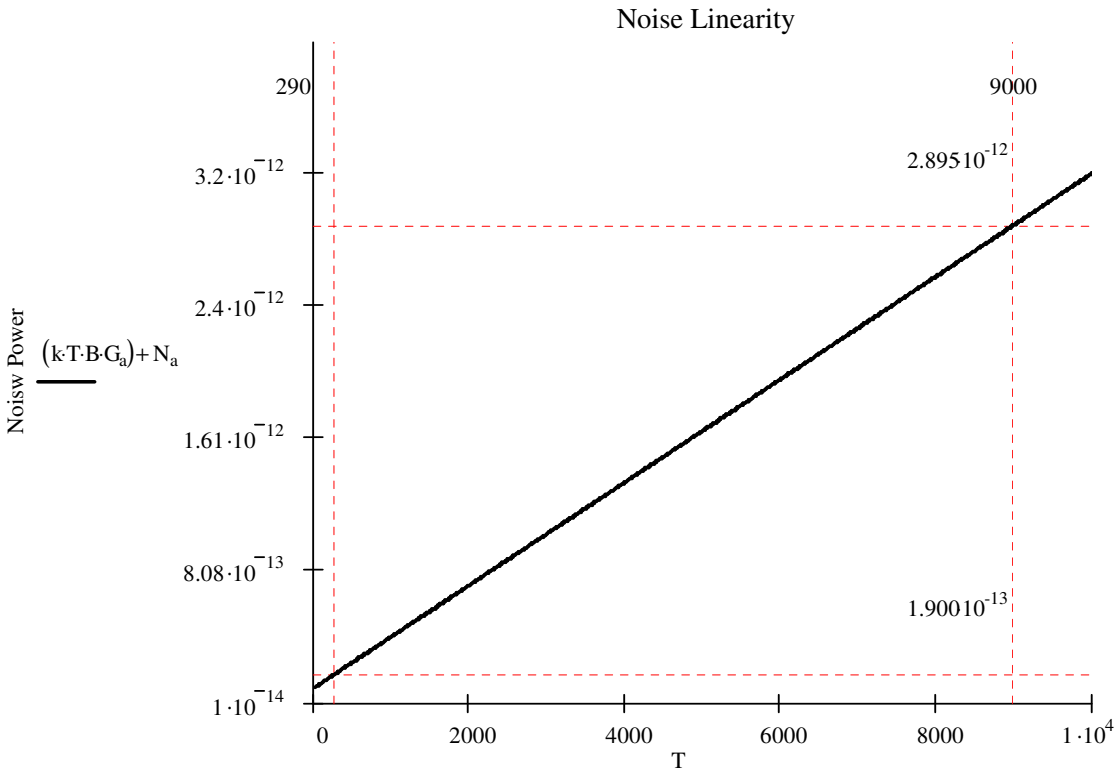
Noise in Cascaded Two Port Networks

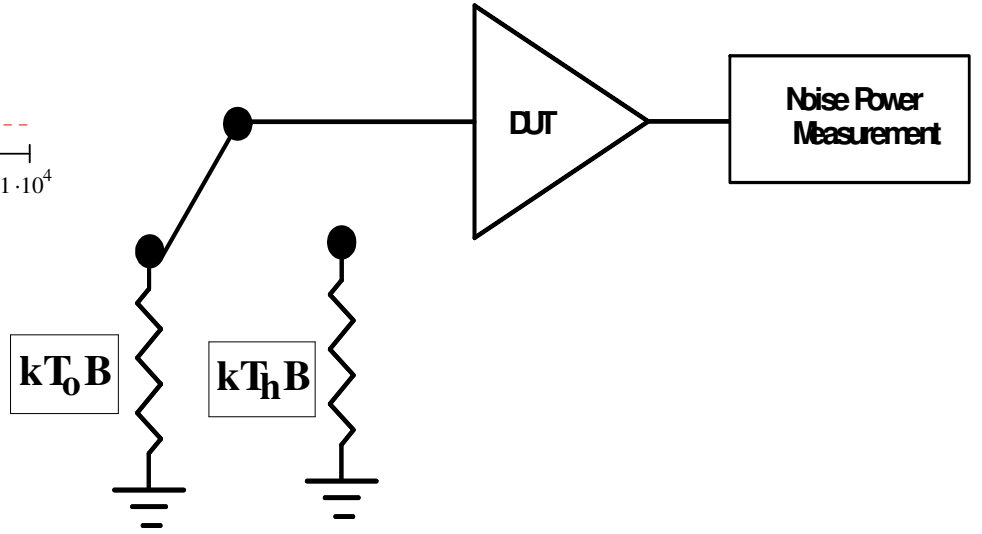




$$F_{sys} = F_1 + \frac{F_2 - 1}{G_1}$$

How to Measure Noise Figure:



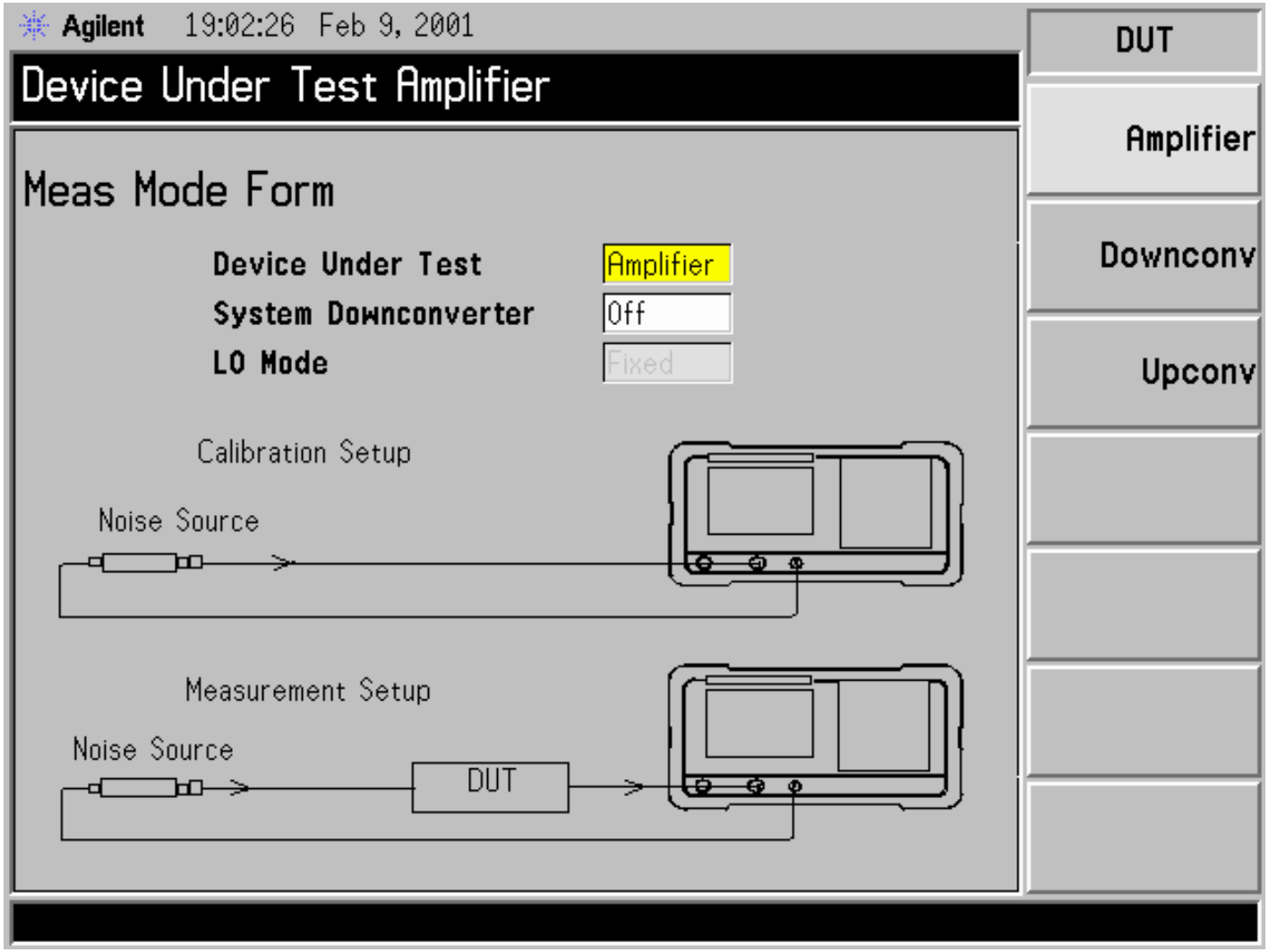


Corrected Noise Figure

$$F_{sys} = F_1 + \frac{F_2 - 1}{G_1}$$

$$F_1 = F_{sys} - \frac{F_2 - 1}{G_1} \quad (13)$$

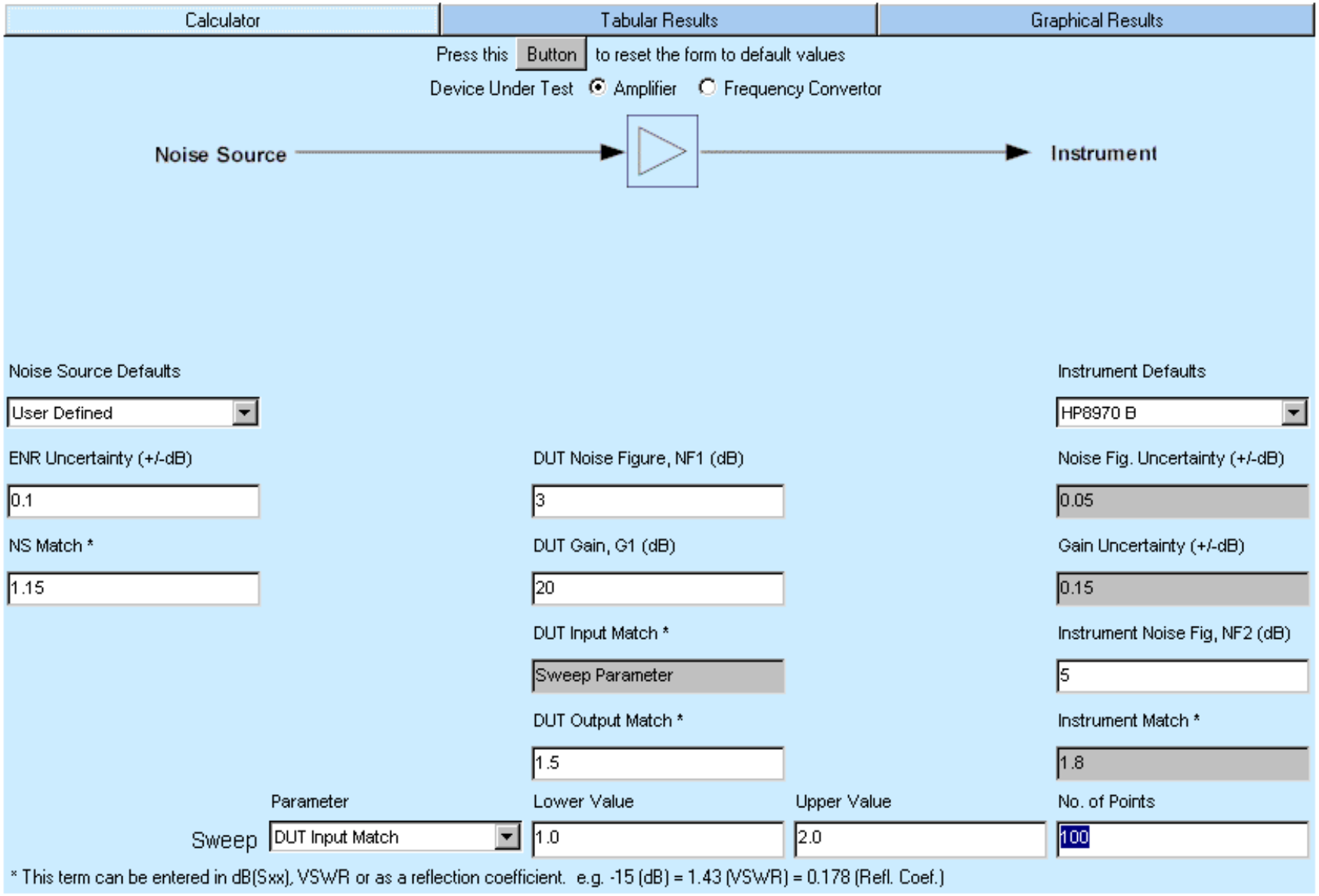
$$G_1 = \frac{N'_2 - N'_1}{N_2 - N_1} \quad (14)$$



$N_2 \rightarrow$ noise source on

$N_1 \rightarrow$ noise source off

Noise Figure Uncertainty Calculator



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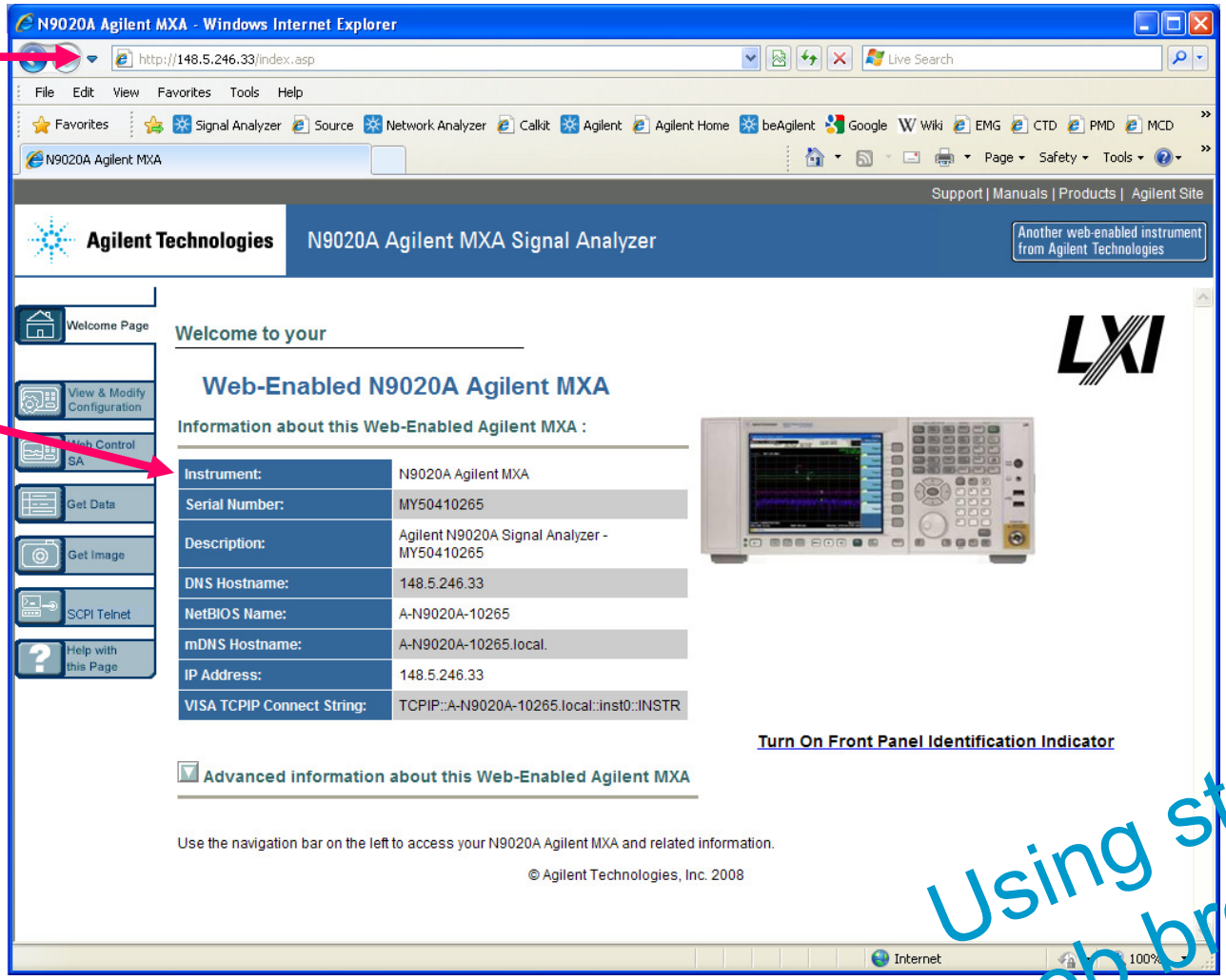
LAN eXtension for Instrumentation

LXI devices serve a web page

IP Address

- Manufacturer
- Model #
- Serial #
- Firmware rev.
- IP Address
- Domain name
- etc.

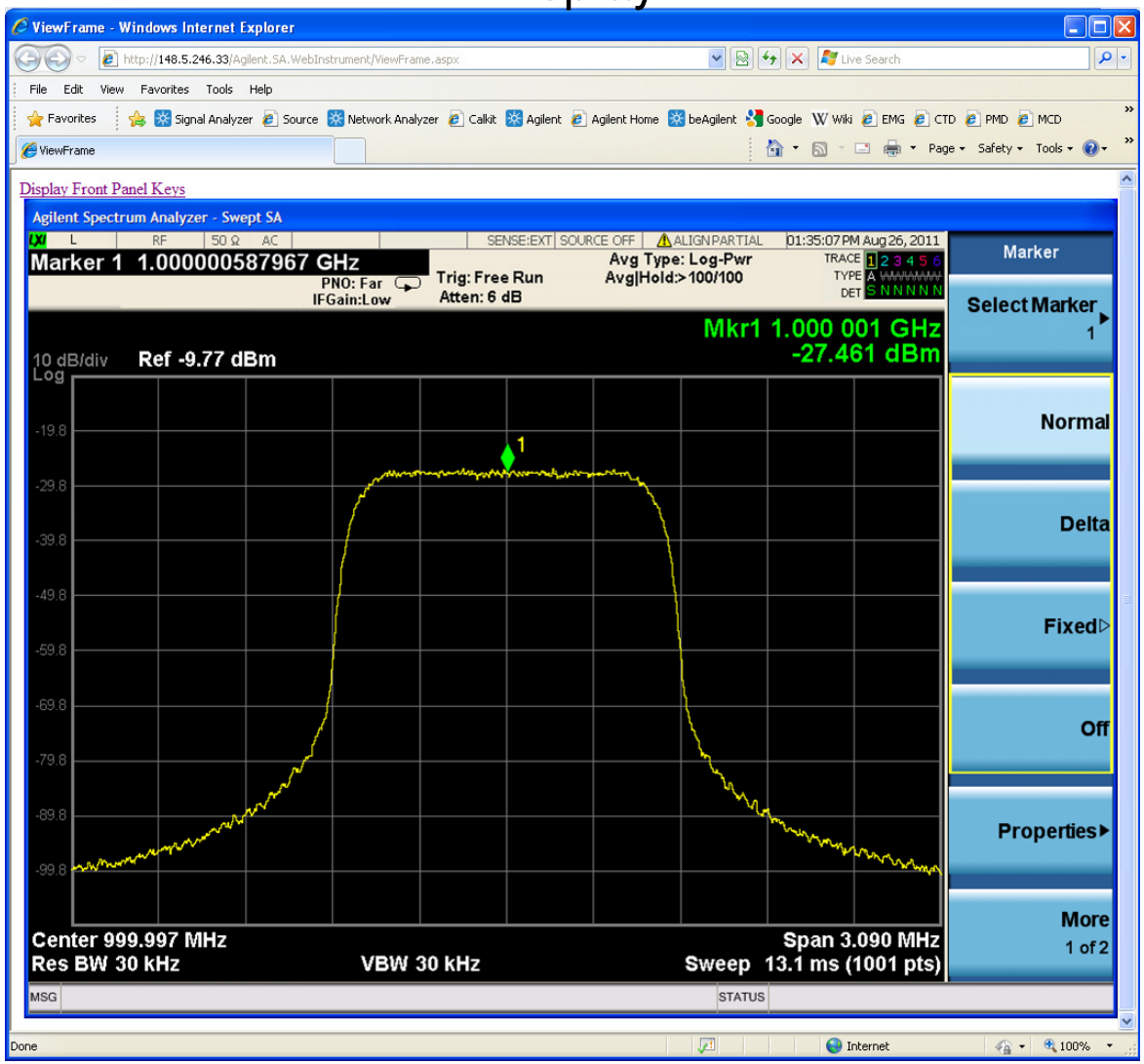
Ability to change the IP address



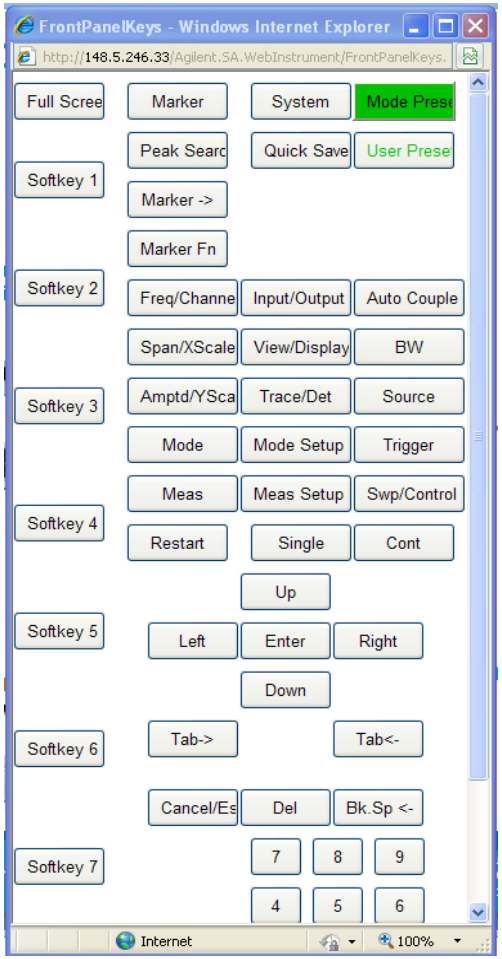
Using standard web browser

X-Series LXI Web control example

Display

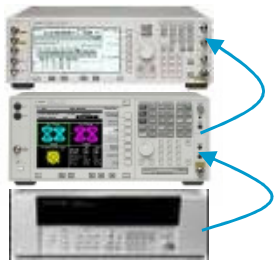


Keypad



LXI Possibilities

Long distance operations

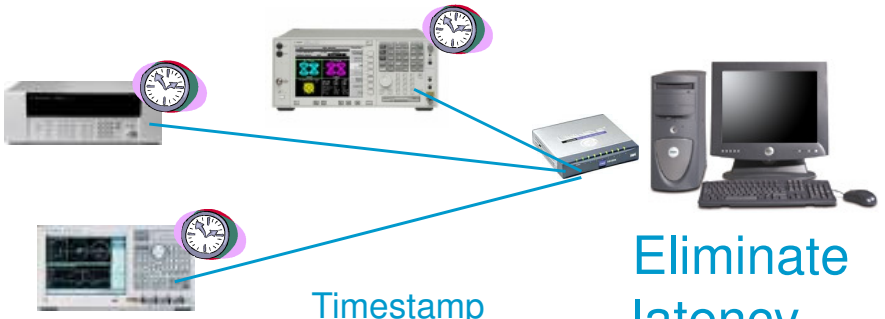


Higher throughput

No trigger wires

Flexible triggering

Expert Troubleshooting

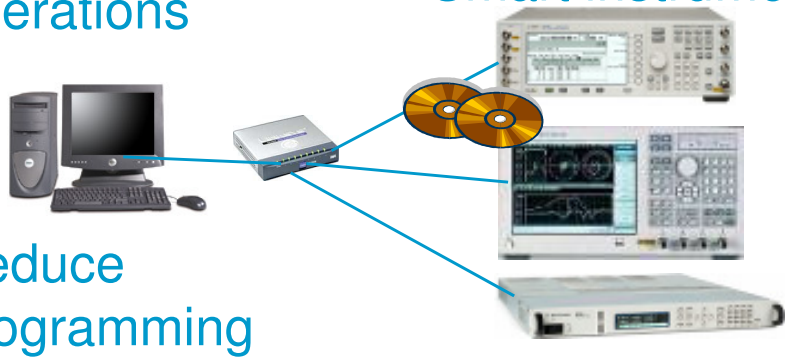


Timestamp all data

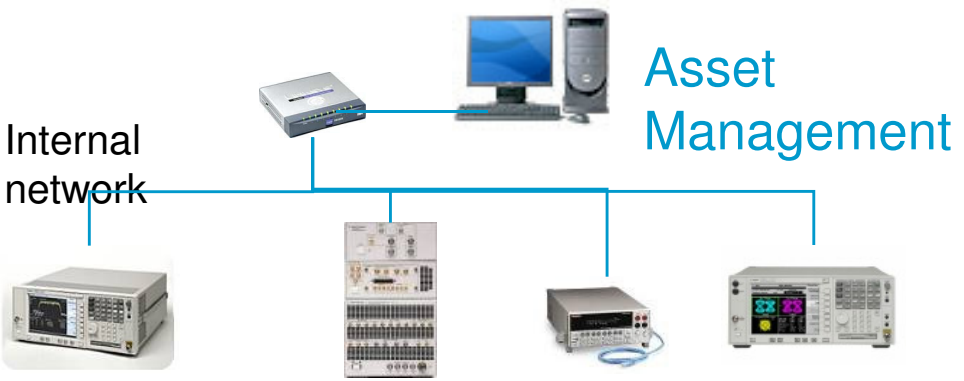
Eliminate latency

Parallel operations

Smart instruments



Reduce programming



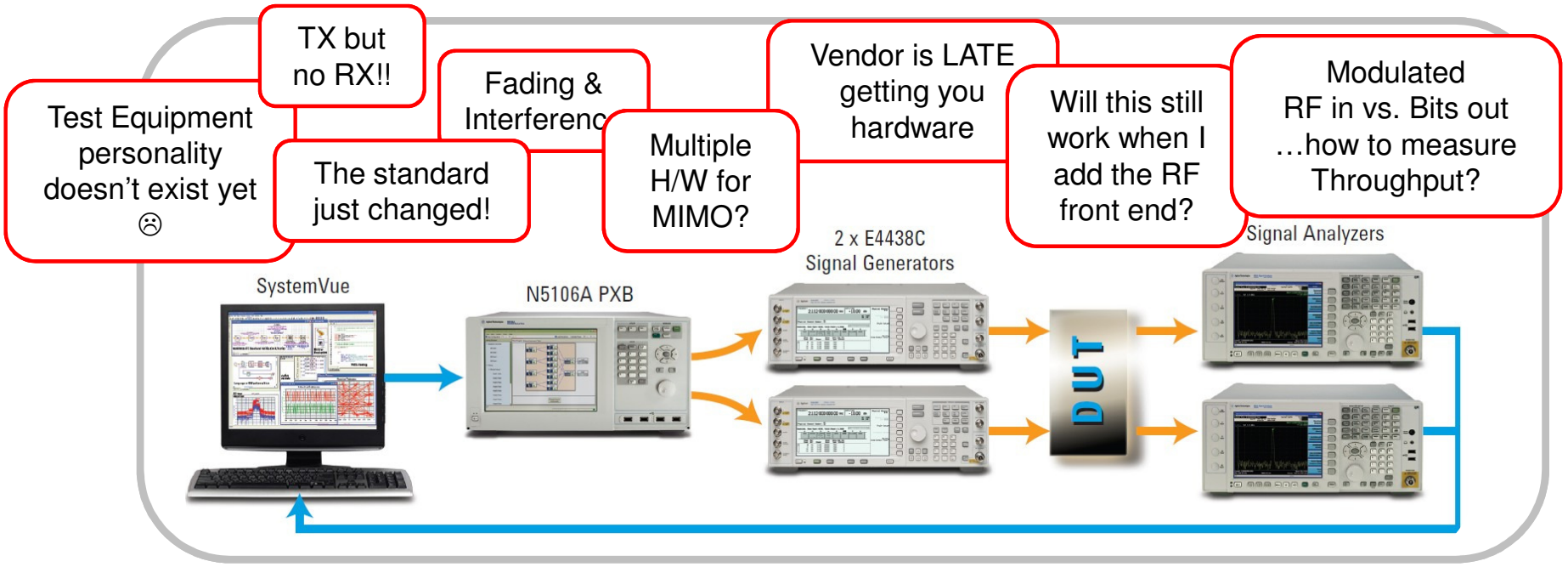
Internal network

Asset Management

SystemVue

Overcome early R&D measurement holes using simulation

If any of these pieces is missing….

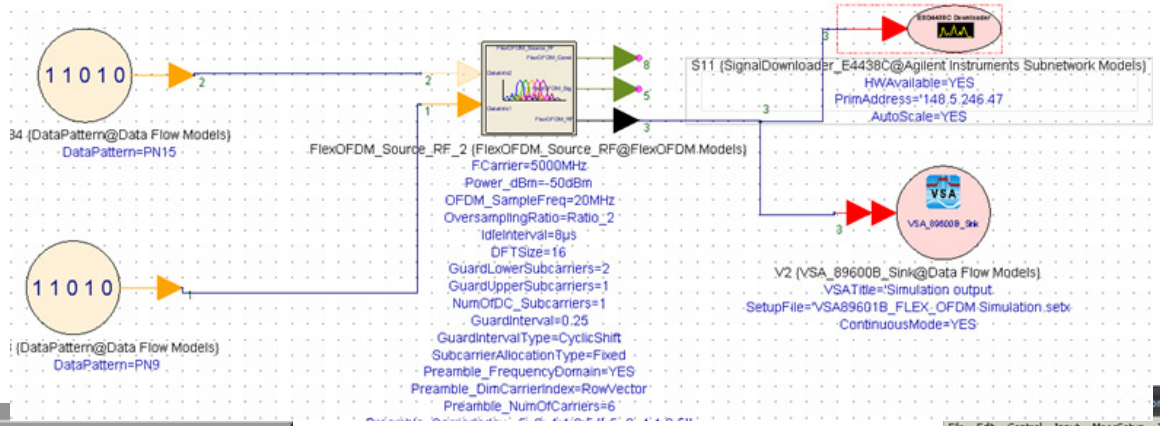


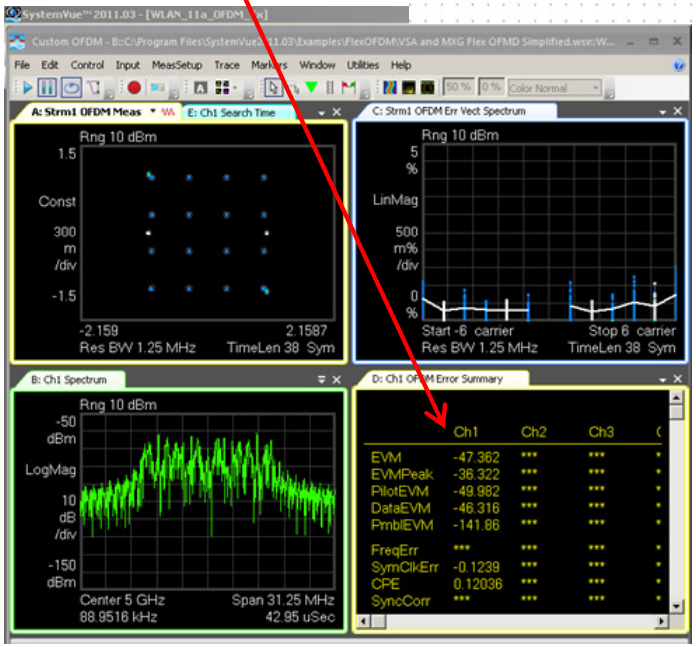
….Use SystemVue to complete a working PHY

- Finish create superior algorithms
- Make new or challenging link-level measurements, such as BER, Throughput
- Verify critical system-level performance, despite missing IP, Equip, or H/W

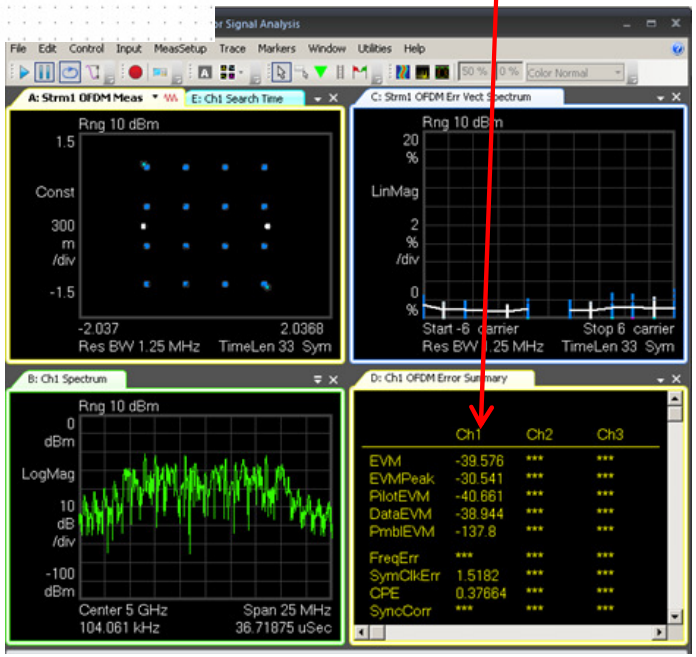
SystemVue Example

Simulated
EVM= -47 dB





Measured
EVM= -39 dB



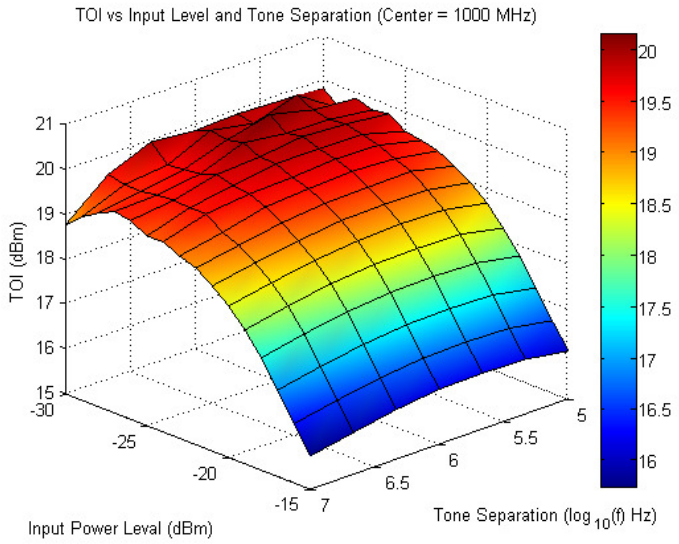
Signal Generator

Signal Analyzer

MATLAB Software Control

- MATLAB software can now be installed directly on the signal analyzers.
- Key uses:
  1. Create, modify, and execute your own applications
  2. Analyze, filter, and visualize data
  3. Execute and test custom modulation schemes
  4. Generate arbitrary waveforms
  5. Automate measurements
  6. Configuration and control instruments

```
% Example:MATLAB/MXA program
% TCPIP parameters of the MXA box
mxa_ip = '141.121.92.157';
mxa_port = 5025;
% MXA connection opening
mxa = tcpip(mxa_ip,mxa_port);
fopen(mxa);
% Intrument identification
idn = query(mxa,'*IDN?');
fprintf('Hello from %s', idn);
% Set the center frequency to 1 GHz
fprintf(mxa,':FREQ:CENT 1 GHz');
% Set the span to 20 MHz
fprintf(mxa,':FREQ:SPAN 20 MHz');
```



www.agilent.com/find/n6171a

Agenda

Introduction

Overview

Theory of Operation

Specifications

Modern spectrum analyzer designs & capabilities

Applications

Automation Tools

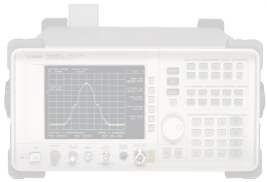
Wrap-up

Agilent X-Series Signal Analysis

An evolutionary approach to signal analysis
that spans instrumentation, measurements and software

PXA
Sep 09
X-Series
High-performance
3 Hz to 26.5 GHz

856xEC
Mid- performance



PSA
Market leading performance
3 Hz to 50 GHz

X-Series Signal Analysis Just got better…..

MXA
Sep 06
X-Series
Mid-performance
20 Hz to 26.5 GHz

NEW

89600B VSA software
Feb 11
Premier analysis & troubleshooting

EXA
Sep 07
X-Series
Economy-class
9 kHz to 26.5 GHz

ESA
World's most popular
100 Hz to 26.5 GHz

CXA
X-Series
Sep 09
Low-cost
9 kHz to 7.5 GHz

Expanded backward code compatibility with 856xE/EC, 66/68 on PXA/MXA/EXA
Sep 09

Price

Performance

Agilent Spectrum Analyzer Families (Handhelds)

N9342C Handheld Spectrum Analyzer

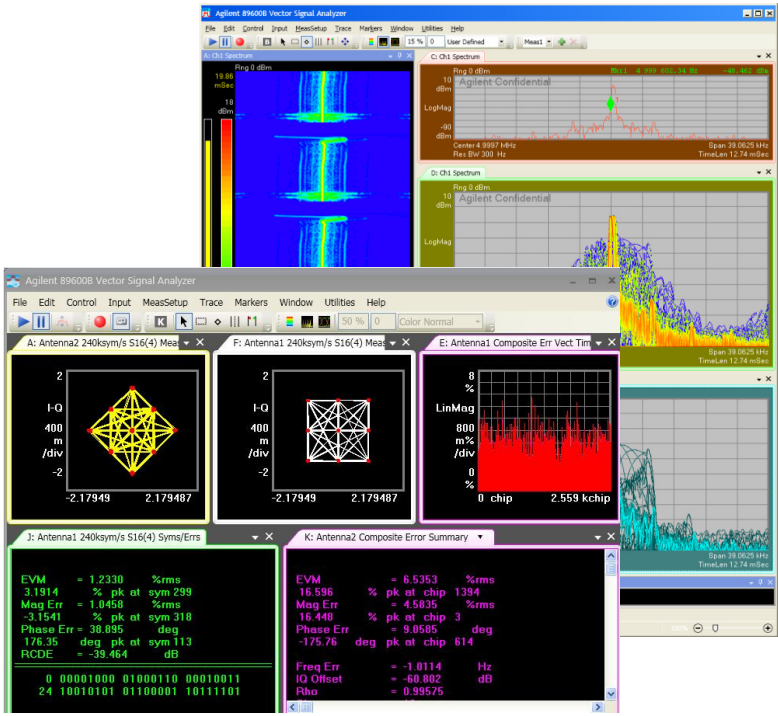
- Handheld SA -- 100kHz to 7.0 GHz
- Fastest sweep – minimum sweep time < 2ms
- –164 dBm displayed average noise level (DANL) typical
- +10 dBm third order intercept (TOI)
- Light weight, rugged and portable
- four hours battery life

N9340B Handheld Spectrum Analyzer

- Handheld SA -- 100kHz to 3.0 GHz
- 10 ms non-zero span sweep time
- –144 dBm displayed average noise level (DANL) with pre-amplifier
- +10 dBm third order intercept (TOI)
- Light weight, rugged and portable
- four hours battery life

Agilent Vector Signal Analysis Software

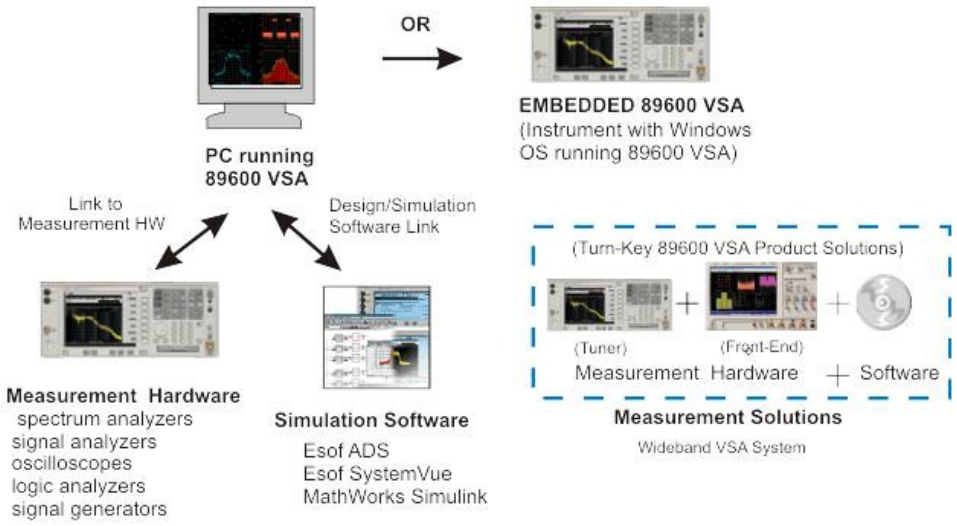
89600B VSA Software



- FFT-based spectrum, time-domain & bit-level modulation analysis
- Support for more than 70 signal standards and modulation types
- 20:20 trace/marker capability and arbitrary window arrangement
- Digital persistence and cumulative history displays

- Wireless networking: 802.11a/b/g/n, 802.16 OFDMA, WiMAX...
- Cellular: LTE (FDD/TDD), W-CDMA HSPA+, GSM/EDGE Evolution
- Custom OFDM modulation analysis for proprietary signals

- Links to over 30 hardware platforms including: *X-series signal analyzers, 16800 logic analyzers, 90000 X-series scopes, Infiniium scopes, VXI*
- Runs on external PC linked to hardware or embedded operation on instruments with Windows OS



Basic Spectrum Analyzer Application & Product Notes

A.N. 150 – Spectrum Analysis Basics: #5952-0292EN

A.N. 150-15 - Vector Signal Analysis Basics: #5989-1121EN

Spectrum Analyzer & Signal Analyzer Selection Guide: #5968-3413E

PXA Brochure: 5990-3951EN

MXA Brochure: 5989-5047EN

EXA Brochure: 5989-6527EN

CXA Brochure: 5990-3927EN

N9342B Brochure: 5990-5586EN

89600B Brochure: 5990-6553EN

www.agilent.com/find/sa

The End

THANK YOU!