Spectrum Analysis Back to Basics

Presented by:

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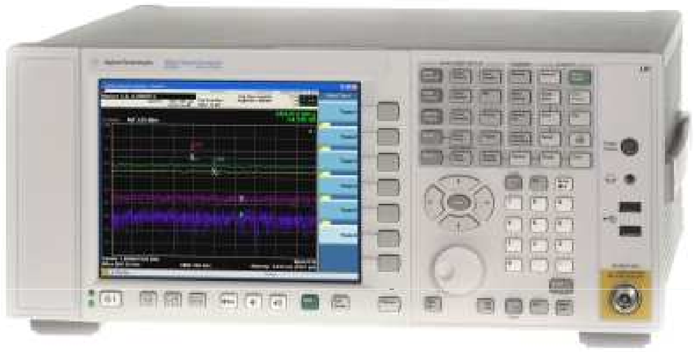
Agilent Technologies

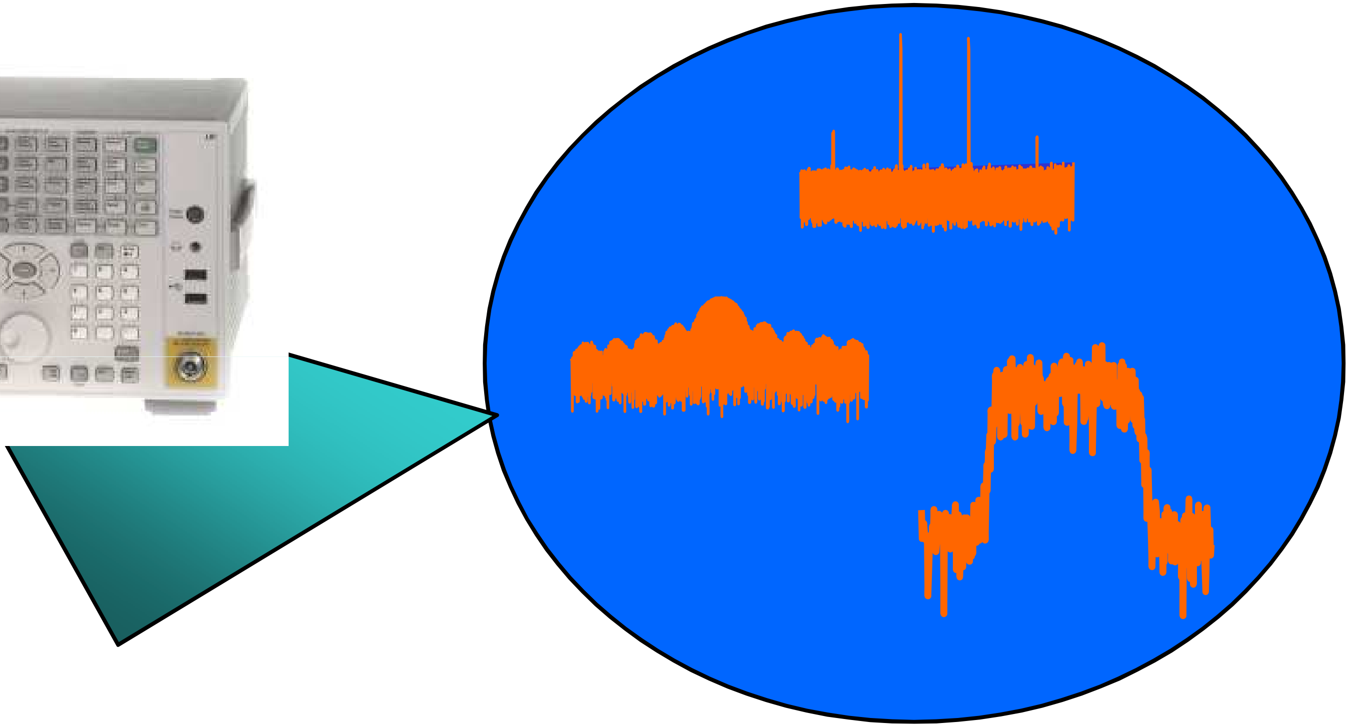
Agenda

- Introduction
- Overview:
  - What is Signal Analysis?
  - What Measurements are available?
- Theory of Operation
- Specifications
- Modern Signal Analyzer Designs & Capabilities
  - Wide Bandwidth Vector Measurements
- Wrap-up
- Appendix

Overview

What is Signal, Vector and Spectrum Analysis?

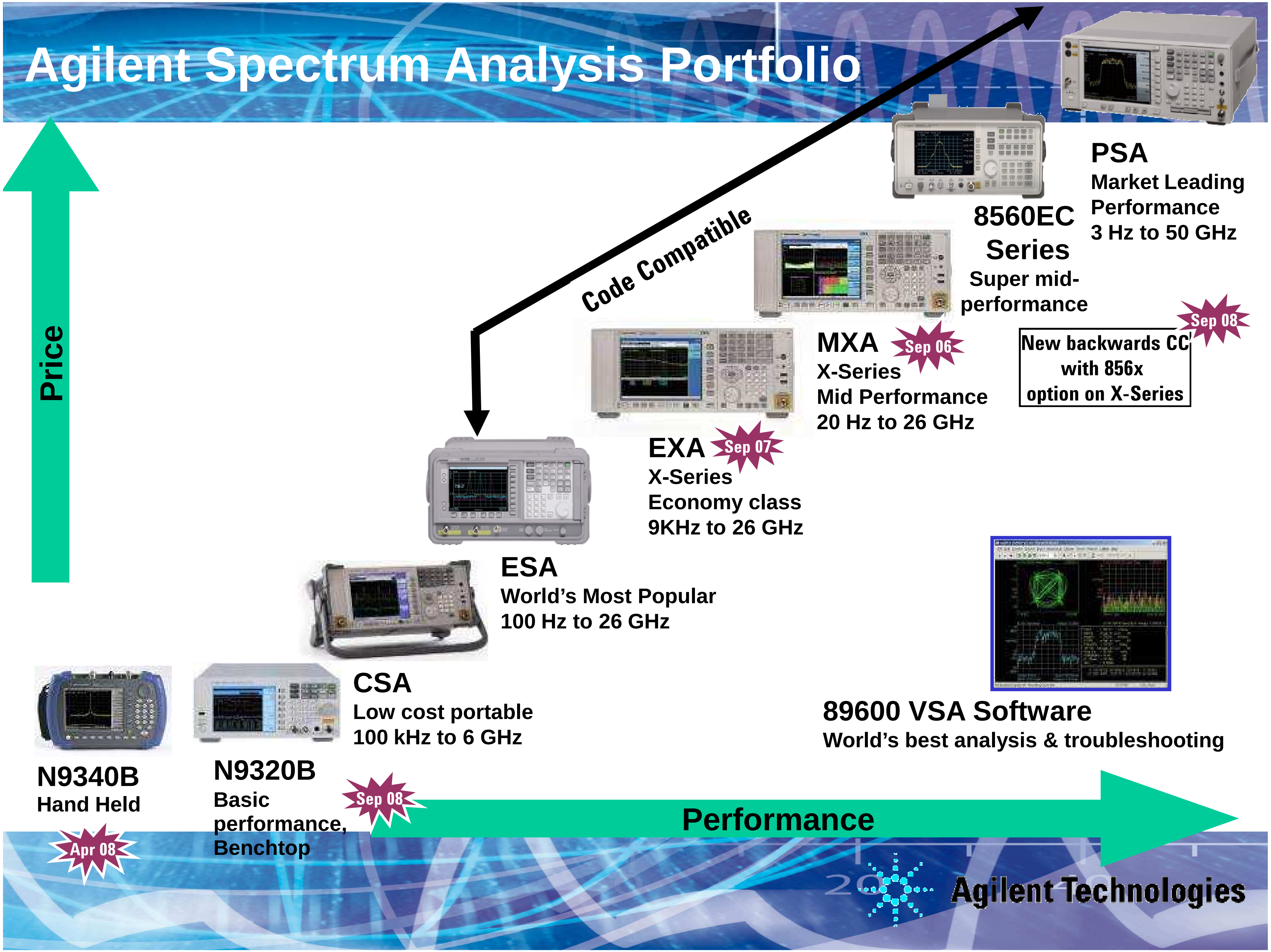




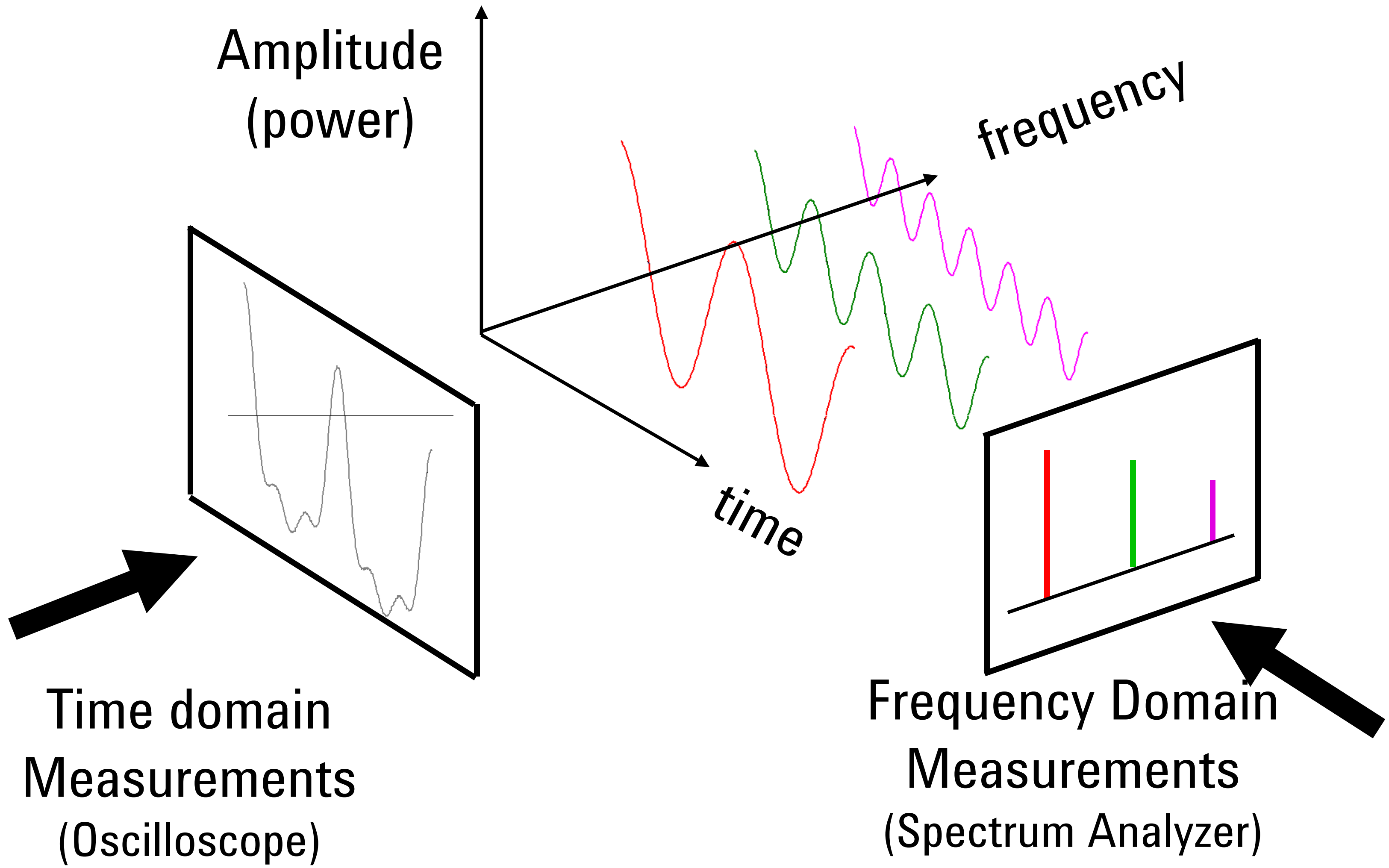
Spectrum Analysis

- **Display and measure amplitude versus frequency for RF & MW signals**
- **Separate or demodulate complex signals into their base components (sine waves)**

Agilent Spectrum Analysis Portfolio



Overview
Frequency versus Time Domain

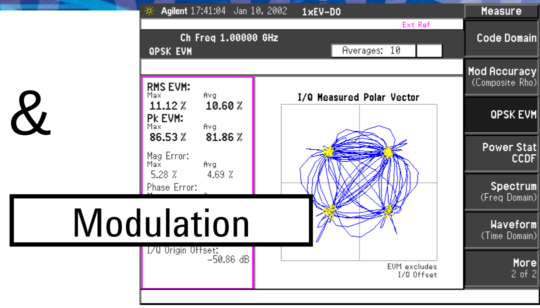


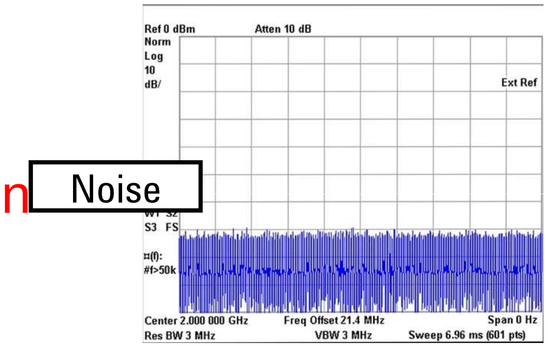
Overview

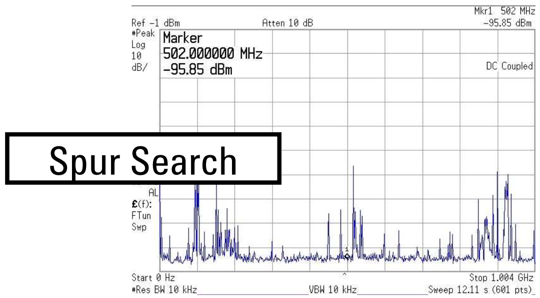
Types of Measurements Available

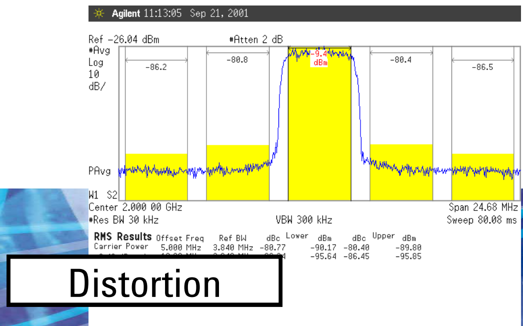
- Frequency, power, modulation, distortion & noise
  - Spectrum monitoring
  - Spurious emissions
  - Scalar network analysis
  - Noise figure & phase noise
  - Harmonic & intermodulation distortion
  - Analog, digital, burst & pulsed RF Modulation
  - Wide bandwidth vector analysis
  - Electromagnetic interference

  - *Measurement range (-168 dBm to +30 dBm)*
  - *Frequency range (3 Hz to 325 GHz)*

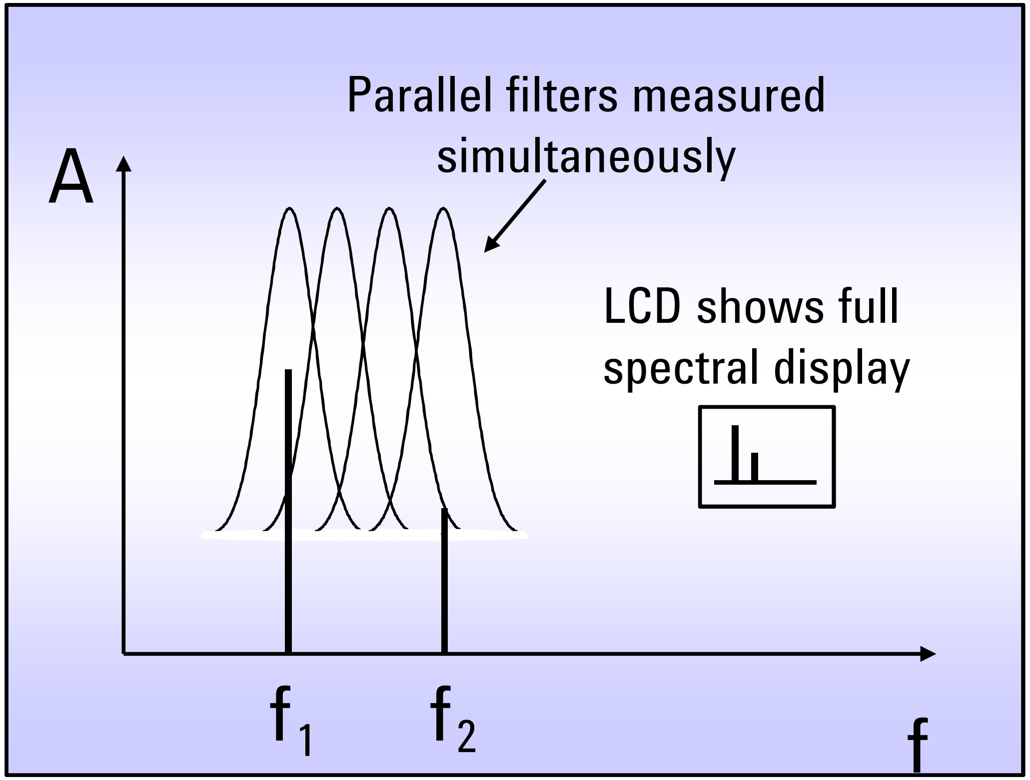




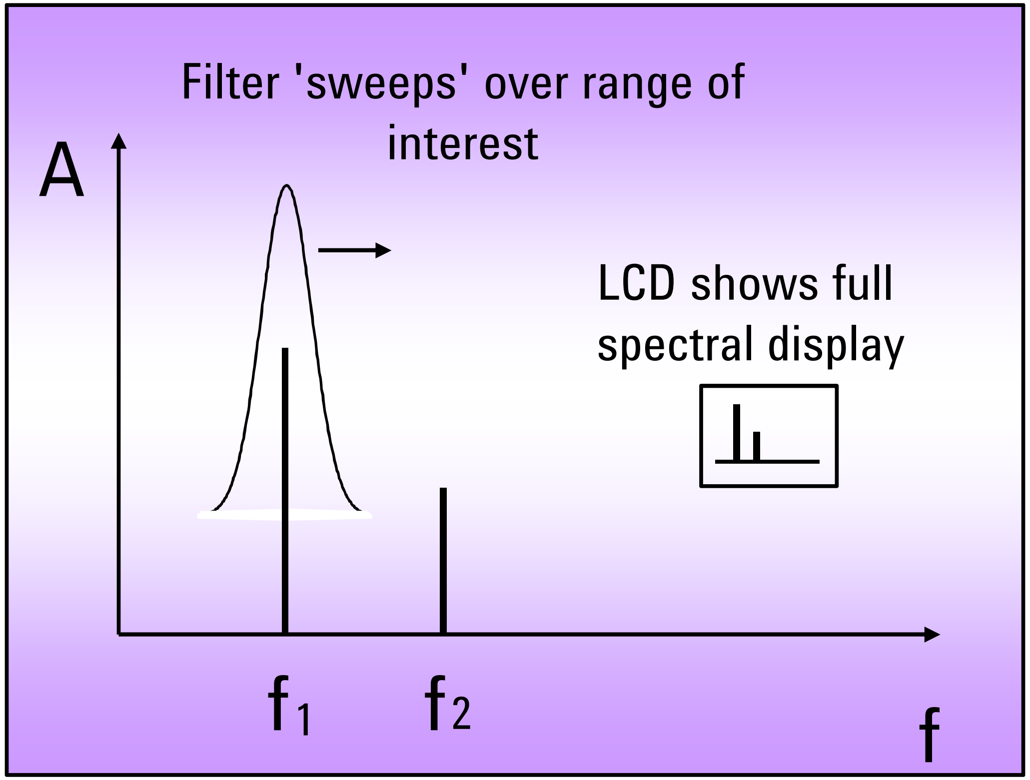




FFT Analyzer



Swept Analyzer

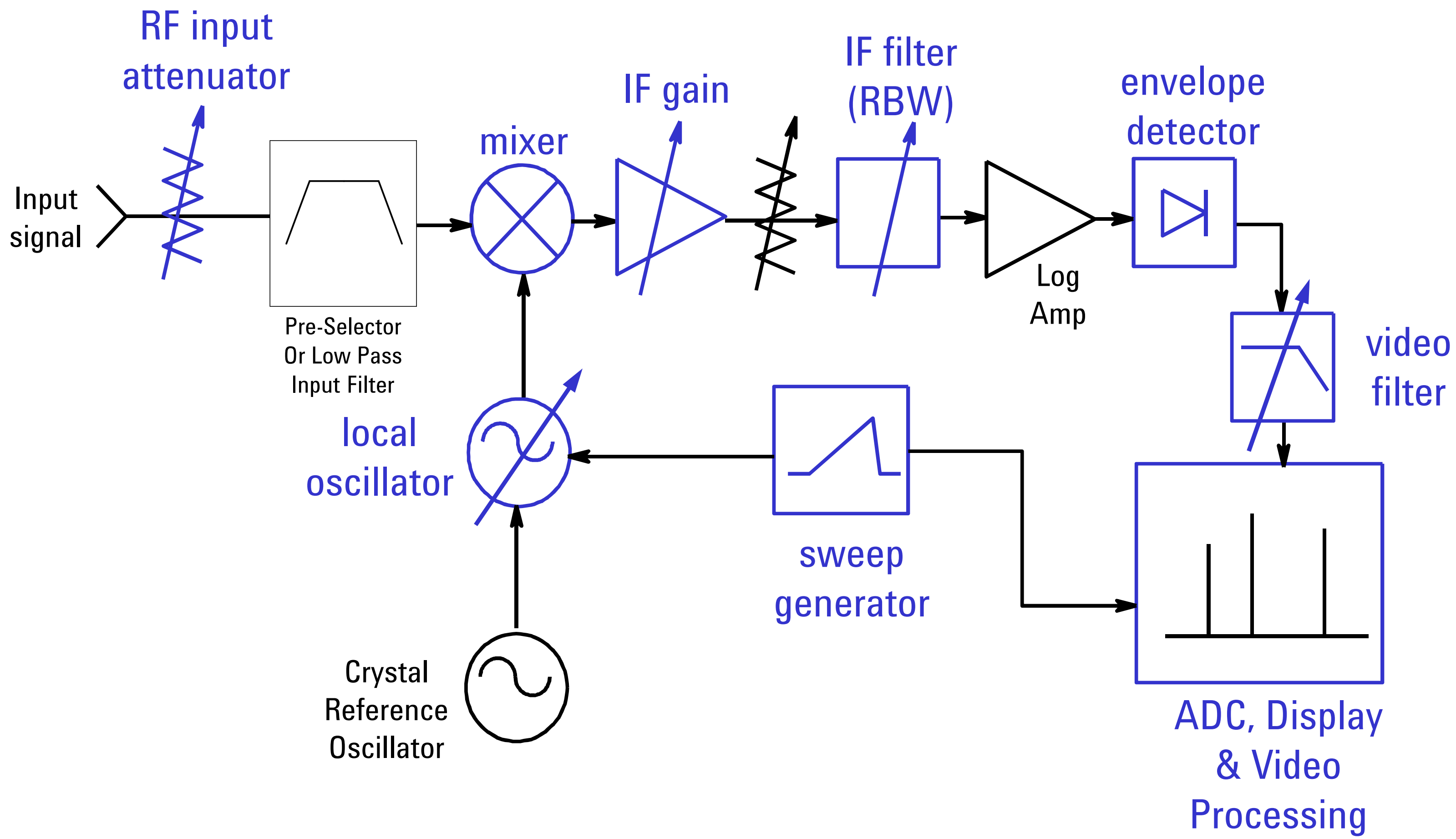


Agenda

- Introduction
- Overview
- Theory of Operation:
  - Swept Spectrum Analyzer Hardware
- Specifications
- Modern spectrum analyzer designs & capabilities
  - » Wide Bandwidth Vector Measurements
- Wrap-up
- Appendix

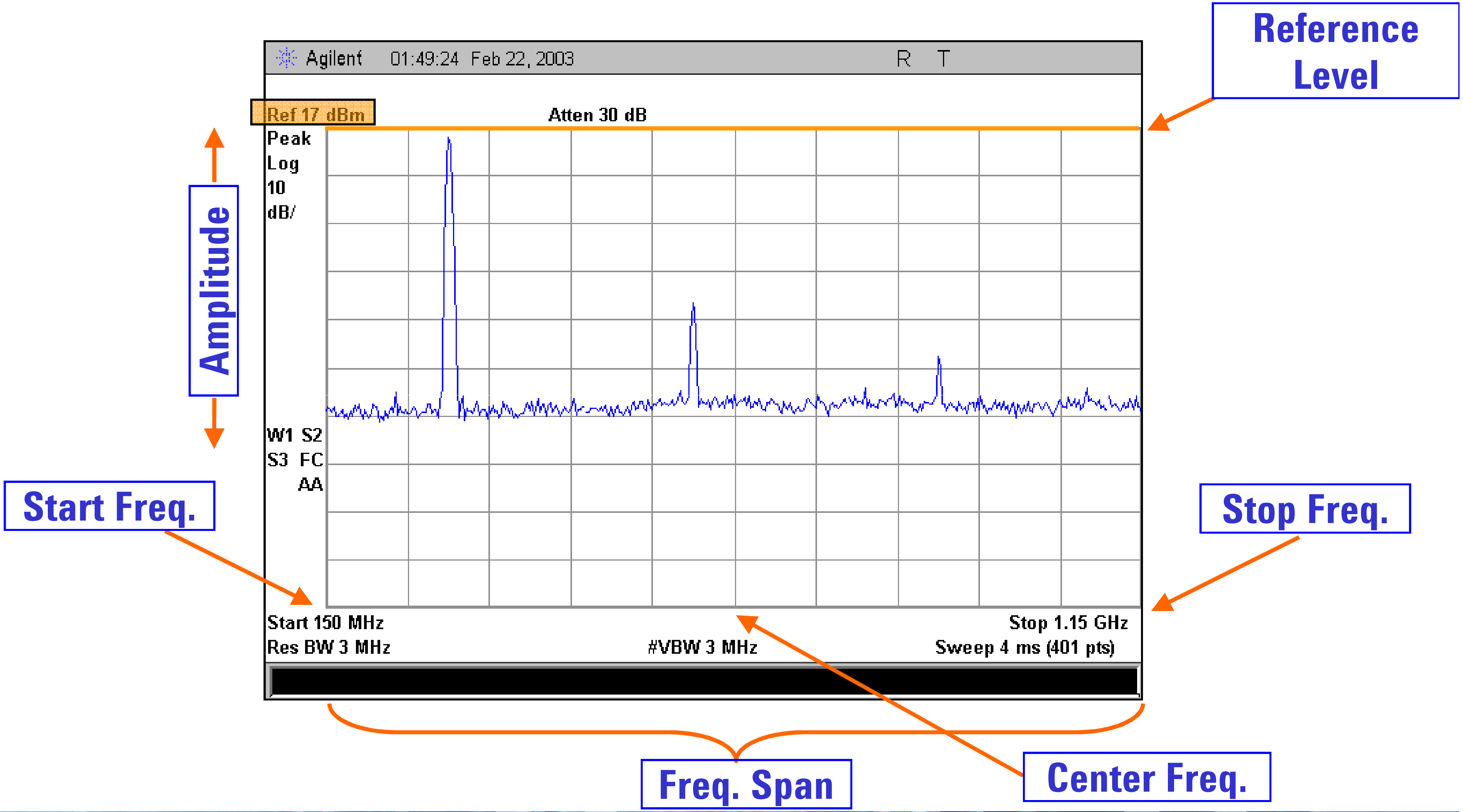
Theory of Operation

Swept Spectrum Analyzer Block Diagram



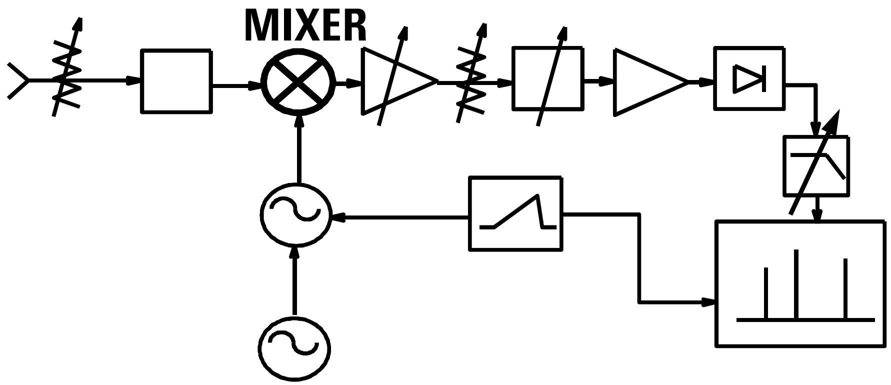
Theory of Operation

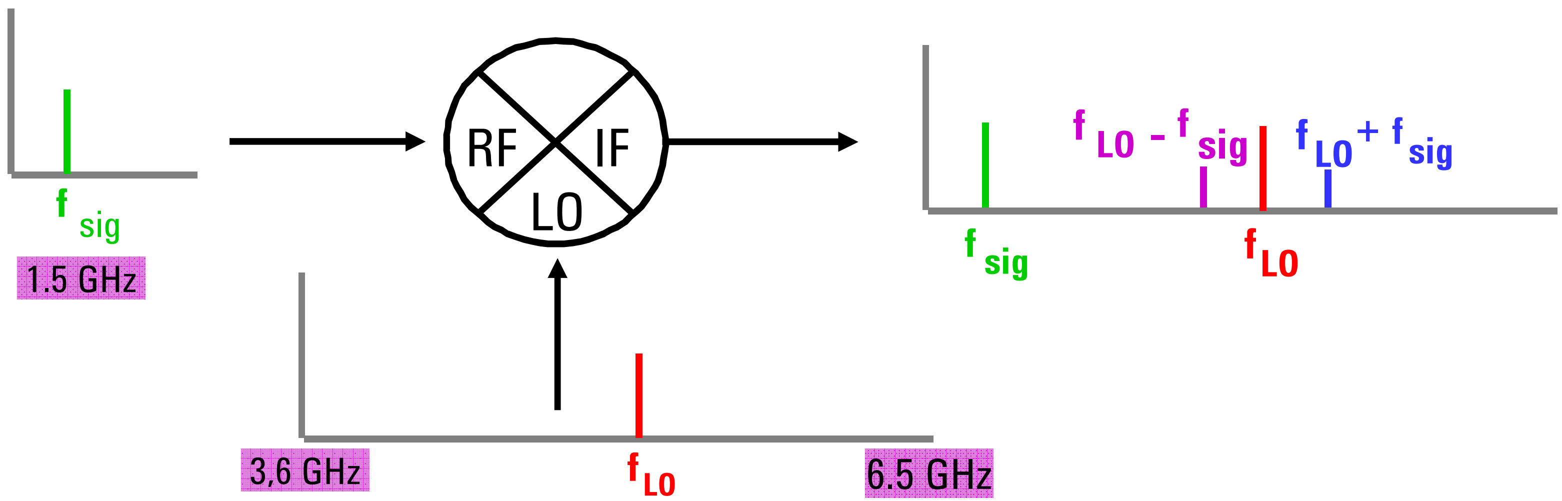
Display terminology



Theory of Operation

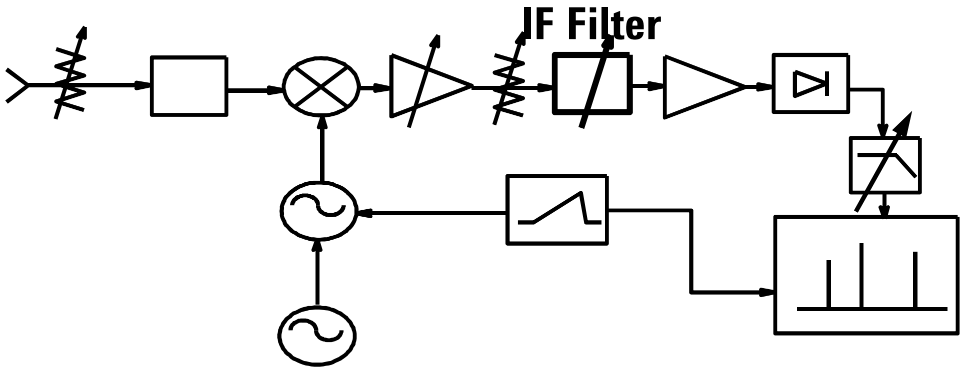
Mixer

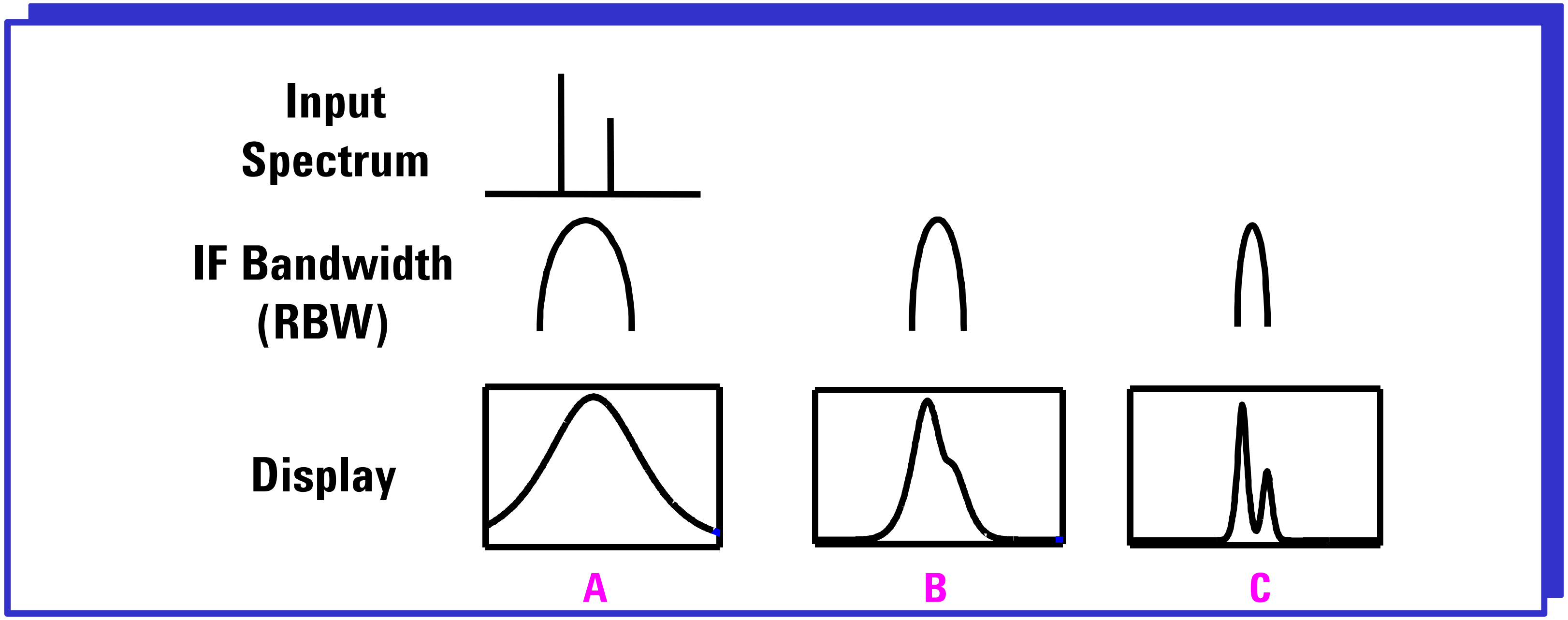




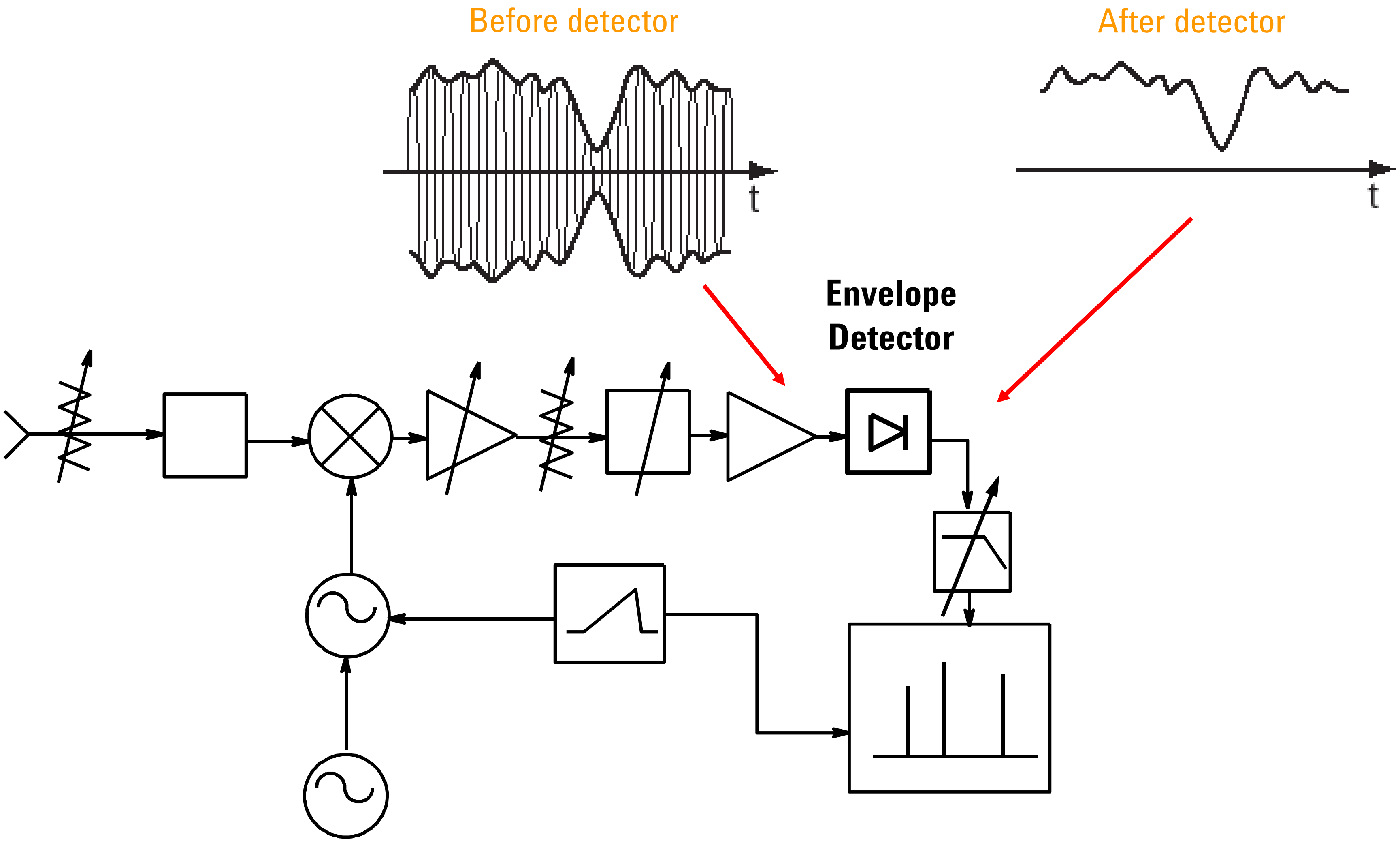
Theory of Operation

IF Filter (Resolution Bandwidth – RBW)



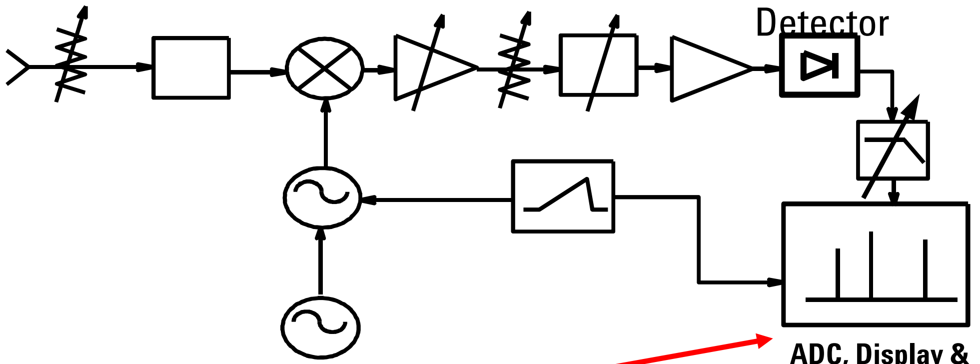


Theory of Operation
Envelope Detector

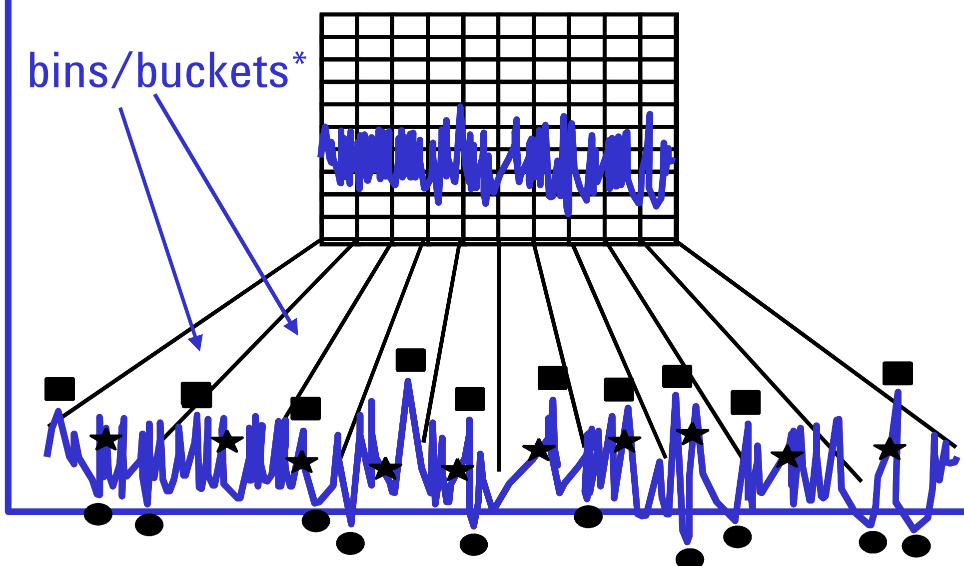


Theory of Operation

Envelope Detector and Detection Types



Digitally Implemented Detection Types



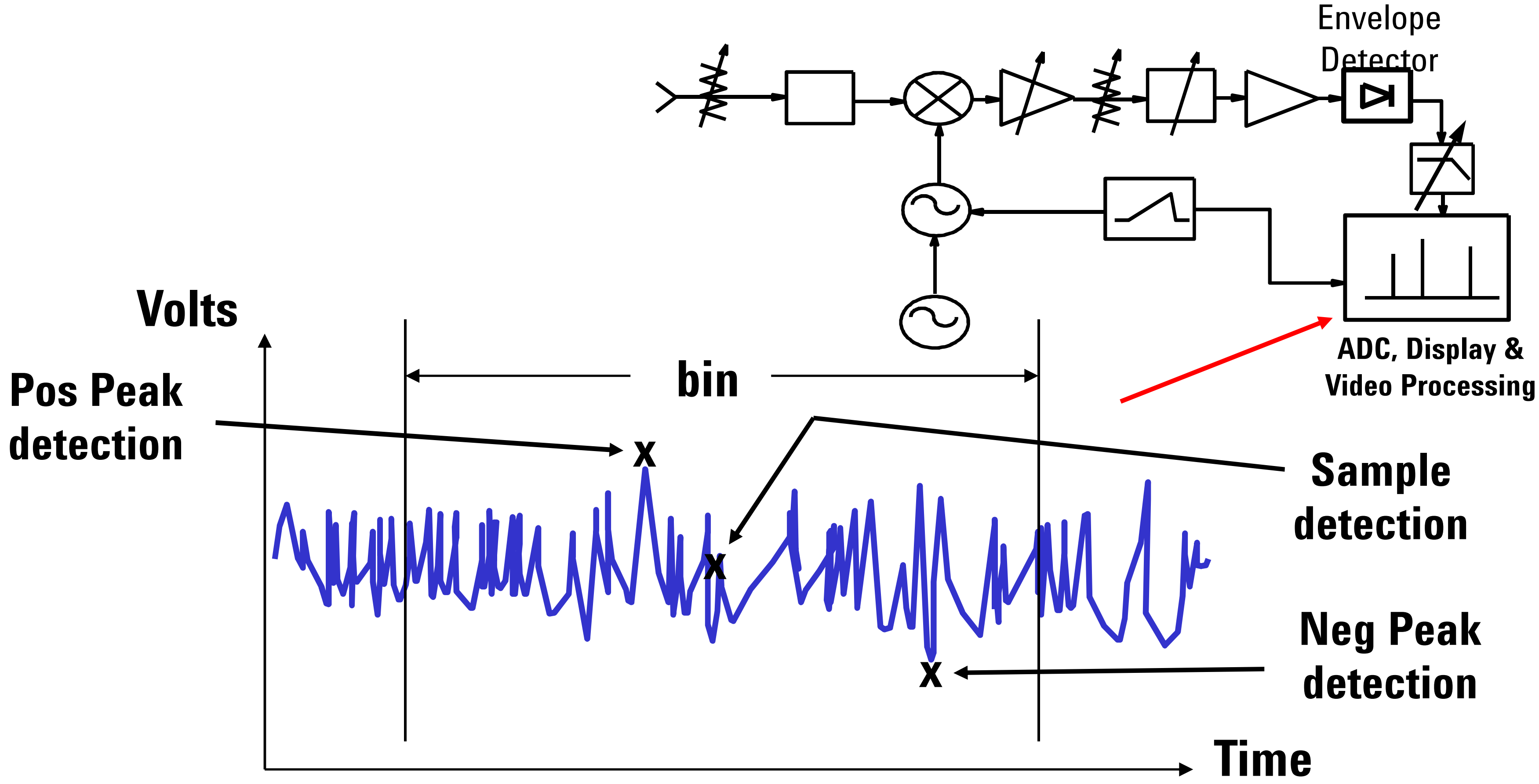
- ■ Positive detection: largest value in bin displayed
- ● Negative detection: smallest value in bin displayed
- ★ Sample detection: middle value in bin displayed

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

*Sweep points

Theory of Operation

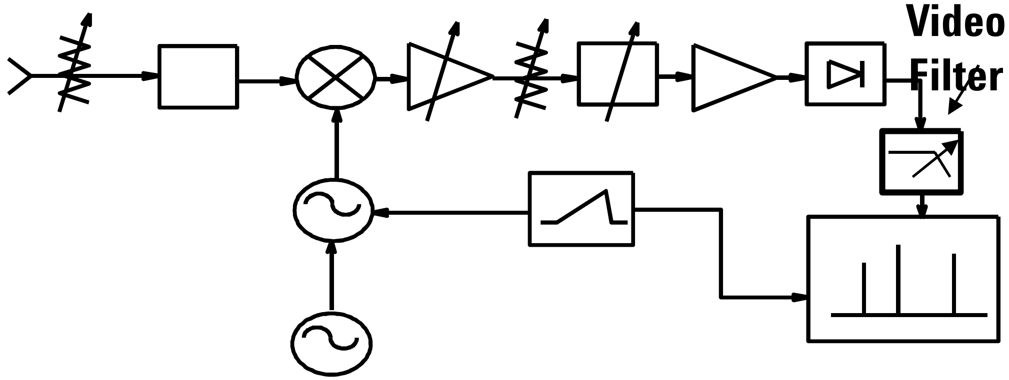
Average Detector Type

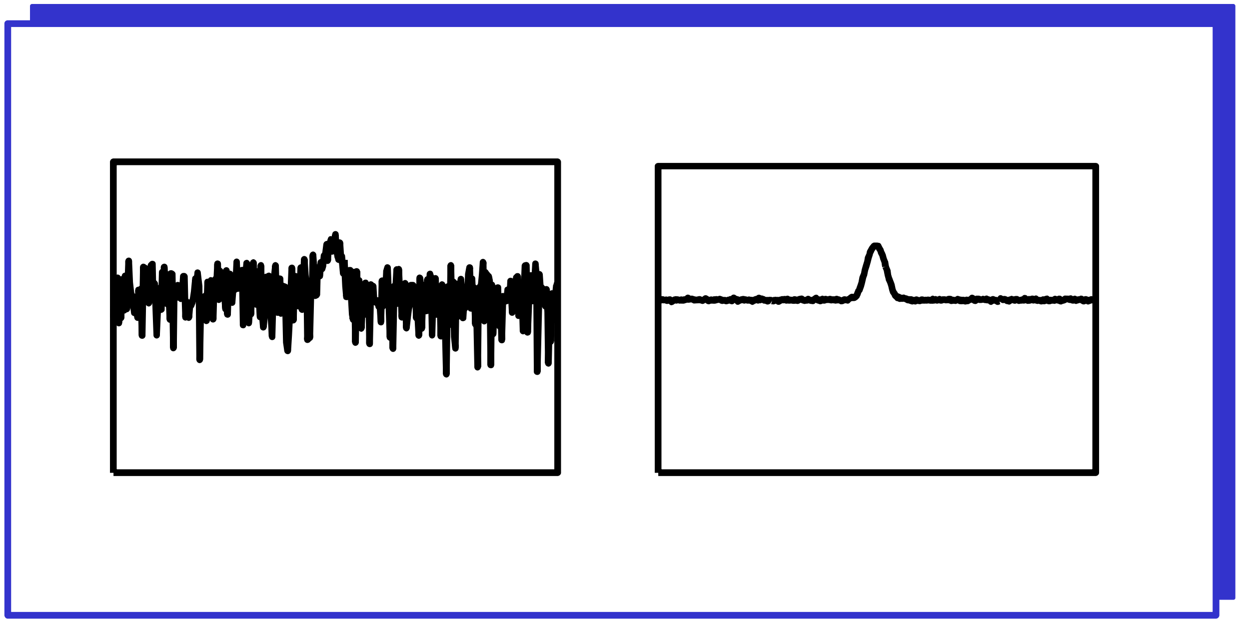


Power Average Detection (rms) = Square root of the sum of the squares of ALL of the voltage data values in the bin /50Ω

Theory of Operation

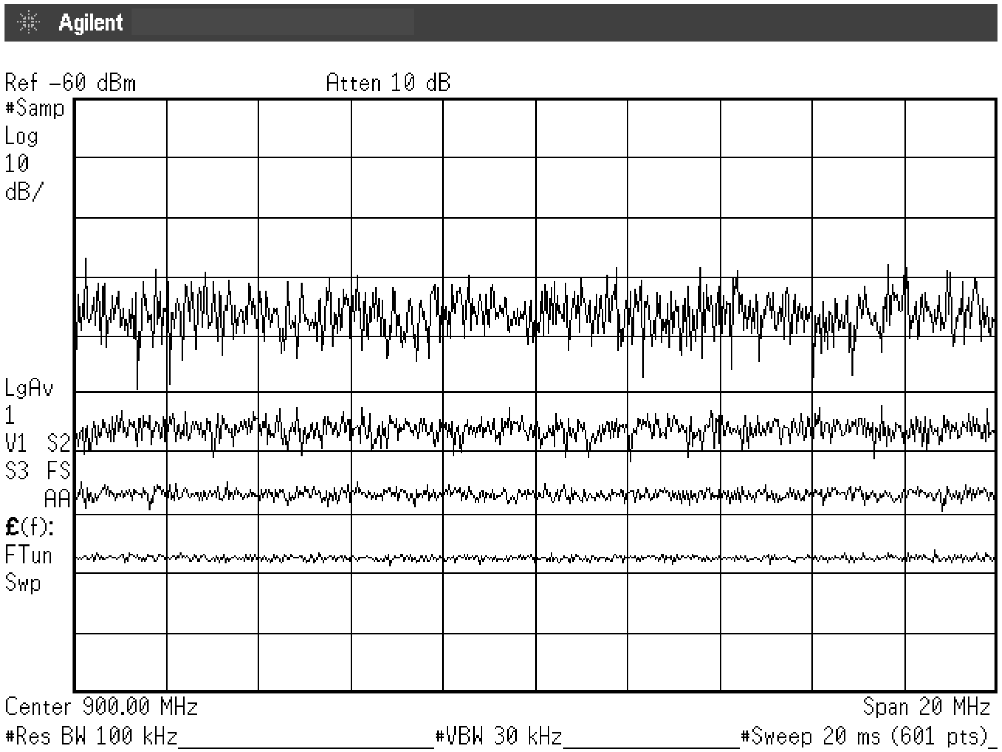
Video Filter (Video Bandwidth – VBW)



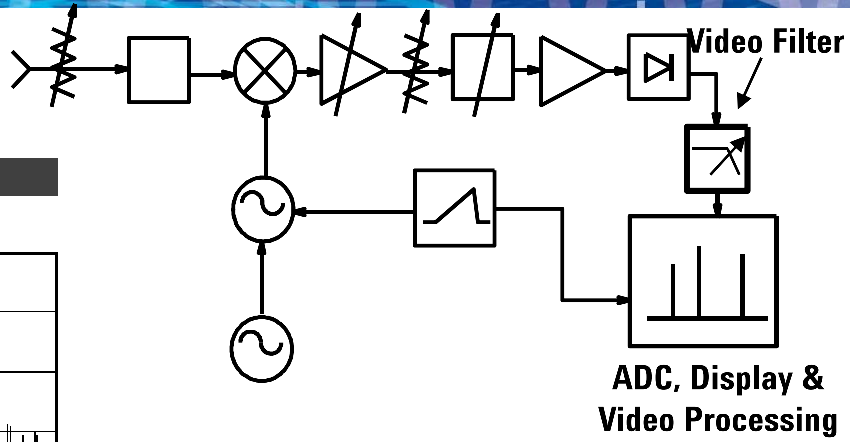


Theory of Operation

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)

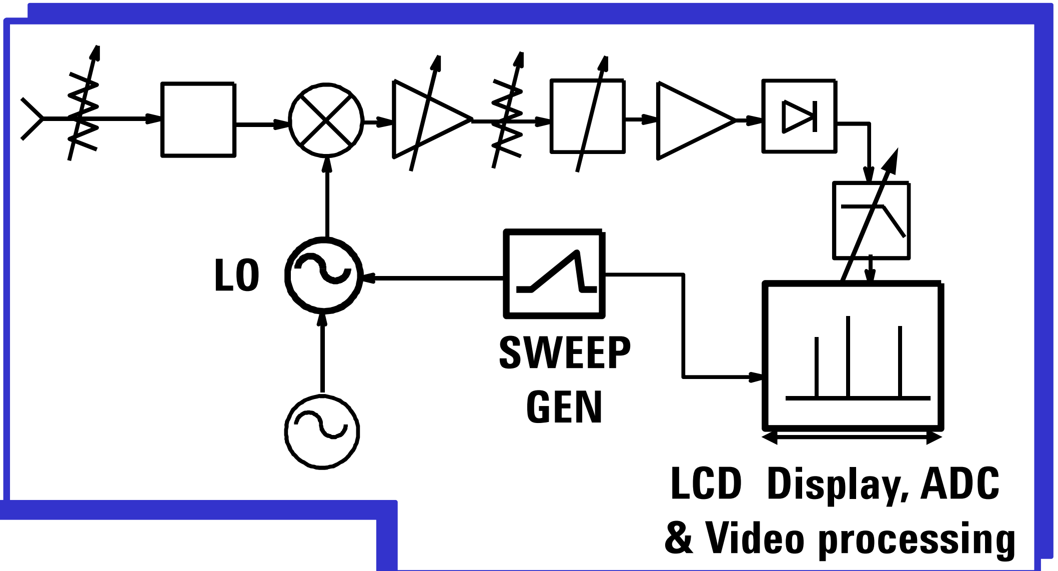


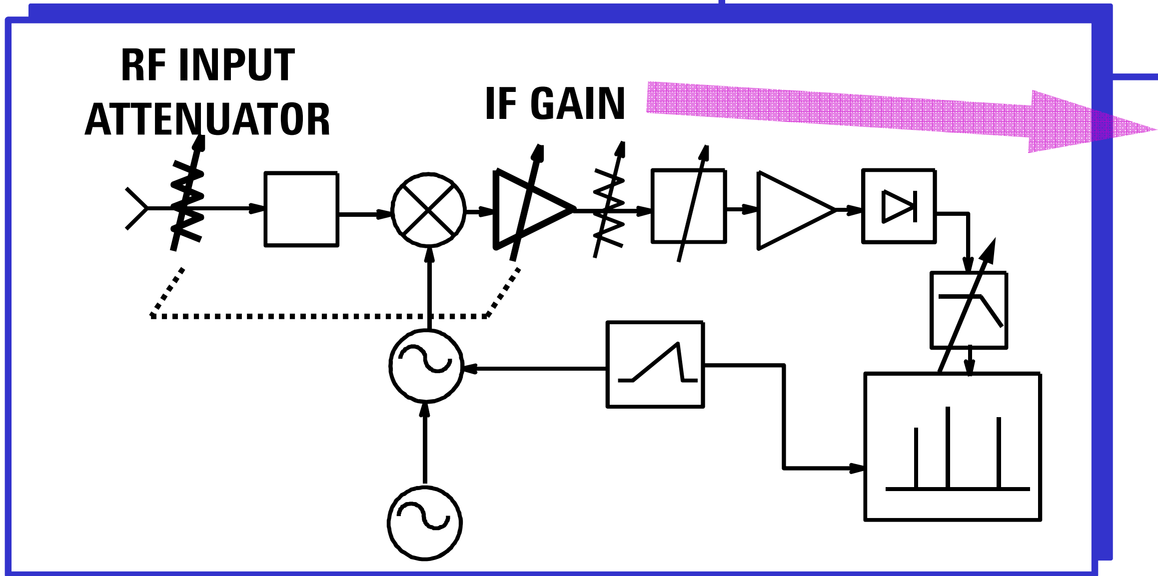
- **<u>Video Filter</u> operates as the sweep progresses, sweep time may be required to slow down by the transient response of the VBW filter.**

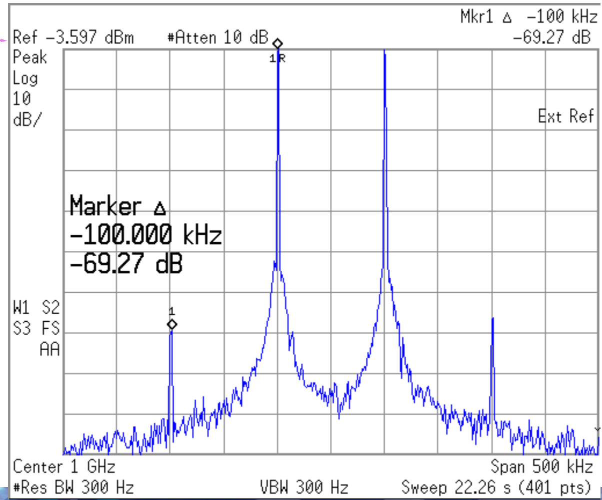
- **<u>Trace/Video Average</u> takes multiple sweeps, sweep time for each sweep is not affected**

- **Many signals give the same results with either video filtering or trace averaging**

Theory of Operation
Other Components

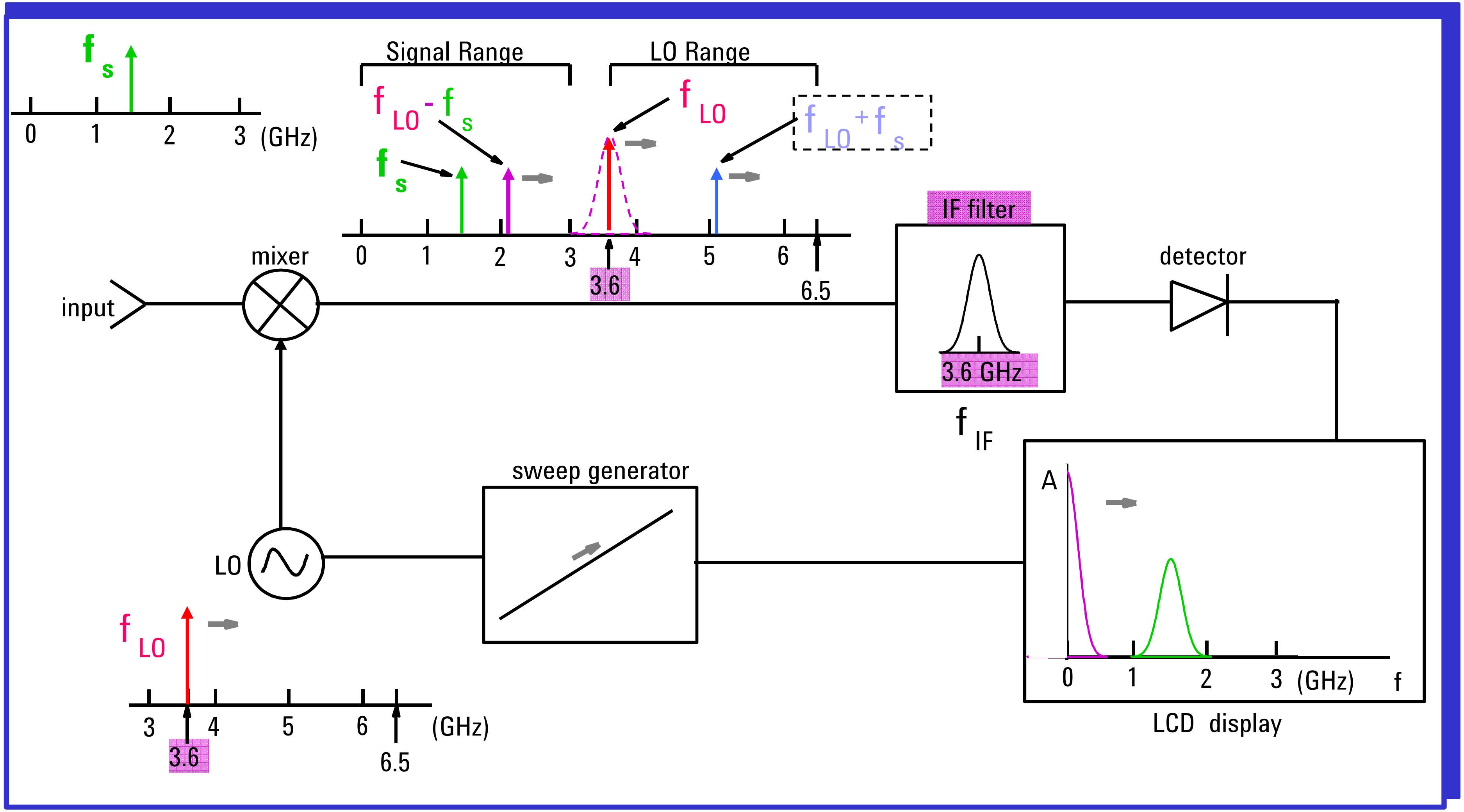






Theory of Operation

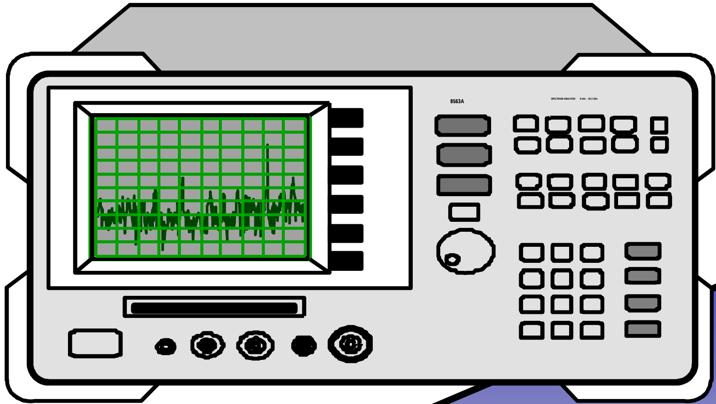
How it All Works Together - 3 GHz spectrum analyzer



Agenda

- Overview
- Theory of Operation
- Specifications:
  - Which are important and why?
- Modern spectrum analyzer designs & capabilities
  - » Wide Bandwidth Vector Measurements
- Wrap-up
- Appendix

Key Specifications



- Safe spectrum analysis
- Frequency Range
- Accuracy: Frequency & Amplitude
- Resolution
- Sensitivity
- Distortion
- Dynamic Range

Specifications?
A Definition

- Specifications **describe the performance of parameters covered by the product warranty (temperature = 0 to 55℃, u nless otherwise noted).**

- Typical **values describe additional product performance information that is not covered by the product warranty. It is performance beyond specification that 80 % of the units exhibit with a 95 % confidence level over the temperature range 20 to 30°C. Typical performance does not include measurem ent uncertainty.**

- Nominal **values indicate expected performance, or describe product performance that is useful in the application of the product, but is not covered by the product warranty.**

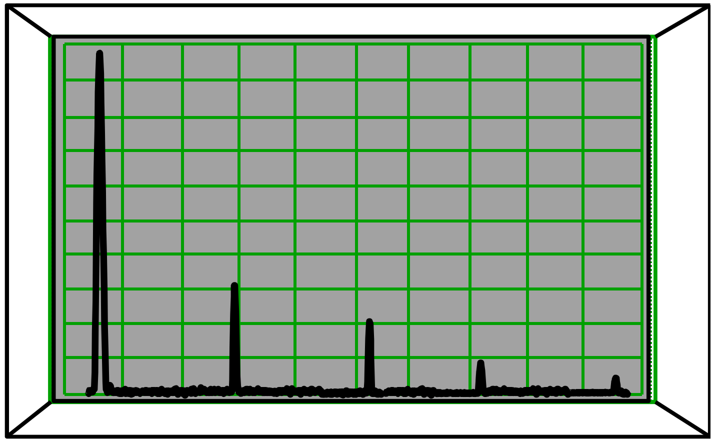
Specifications

Practicing safe spectrum analysis - *Safe Hookups to RF Input*

- **Use best practices to eliminate static discharge to the RF input!**
- **Do not exceed the Damage Level on the RF Input!**
- **Do not input signals with DC bias!**

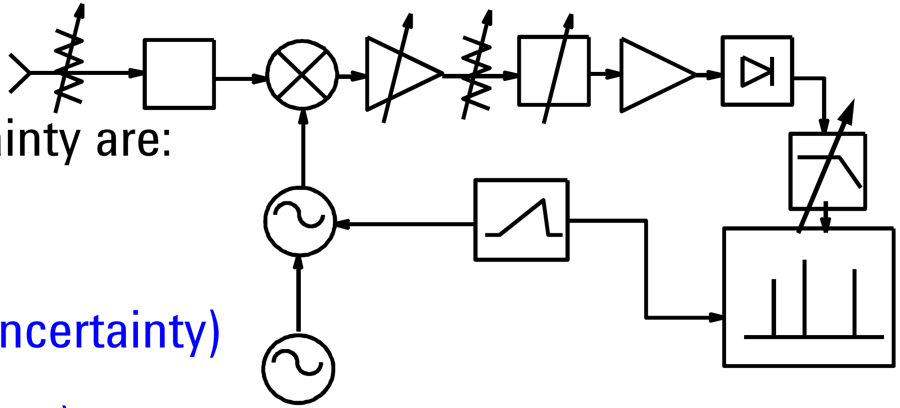
0 V DC MAX
+30dBm (1W) MAX

Description	Specifications
Internal Mixing	
Bands	
• **0**	**3 Hz to 3.0 GHz**
• **1**	**2.85 to 6.6 GHz**
• **2**	**6.2 to 13.2 GHz**
• **3**	**12.8 to 19.2 GHz**
• **4**	**18.7 to 26.8 GHz**
• **5**	**26.4 to 31.15 GHz**
• **6**	**31.0 to 50.0 GHz**
External mixing	**18 to 325 GHz**



Specifications

Accuracy: Frequency & amplitude

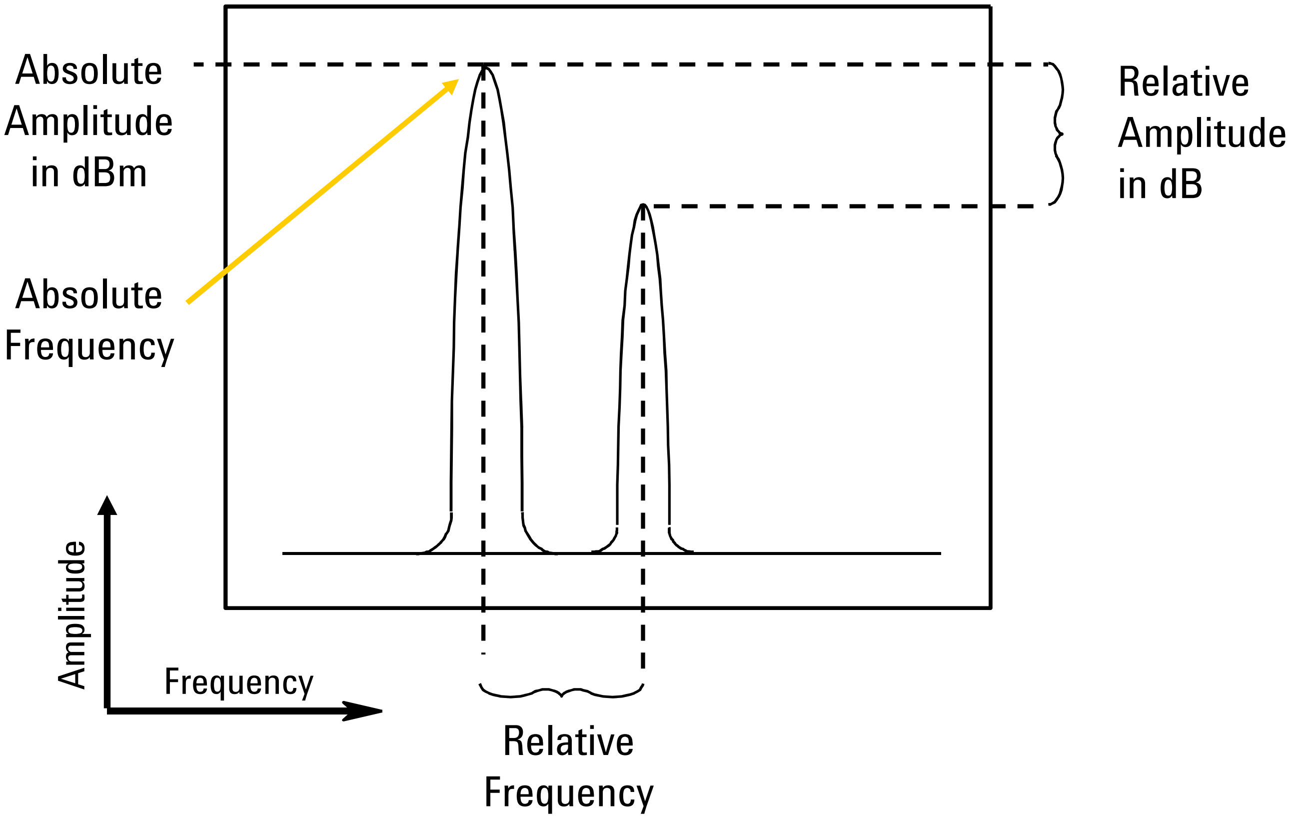


Components which contribute to uncertainty are:

- 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 PSA Data Sheet:

$\pm$ (freq readout x freq reference error + 0.25%*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 :	$(1\text{x}10^{9}\text{Hz}) \text{ x } (\pm 1.8\text{x}10{-}7/\text{Year ref. Error})$	= **180Hz**
	400kHz Span x 0.25%	= **1000Hz**
	3kHz RBW x 5%	= **150Hz**
	2Hz + 0.5 x 400kHz/1000-1	= **202Hz**
	Total uncertainty	= **±1532Hz**

Utilizing internal frequency counter improves accuracy to ±180Hz

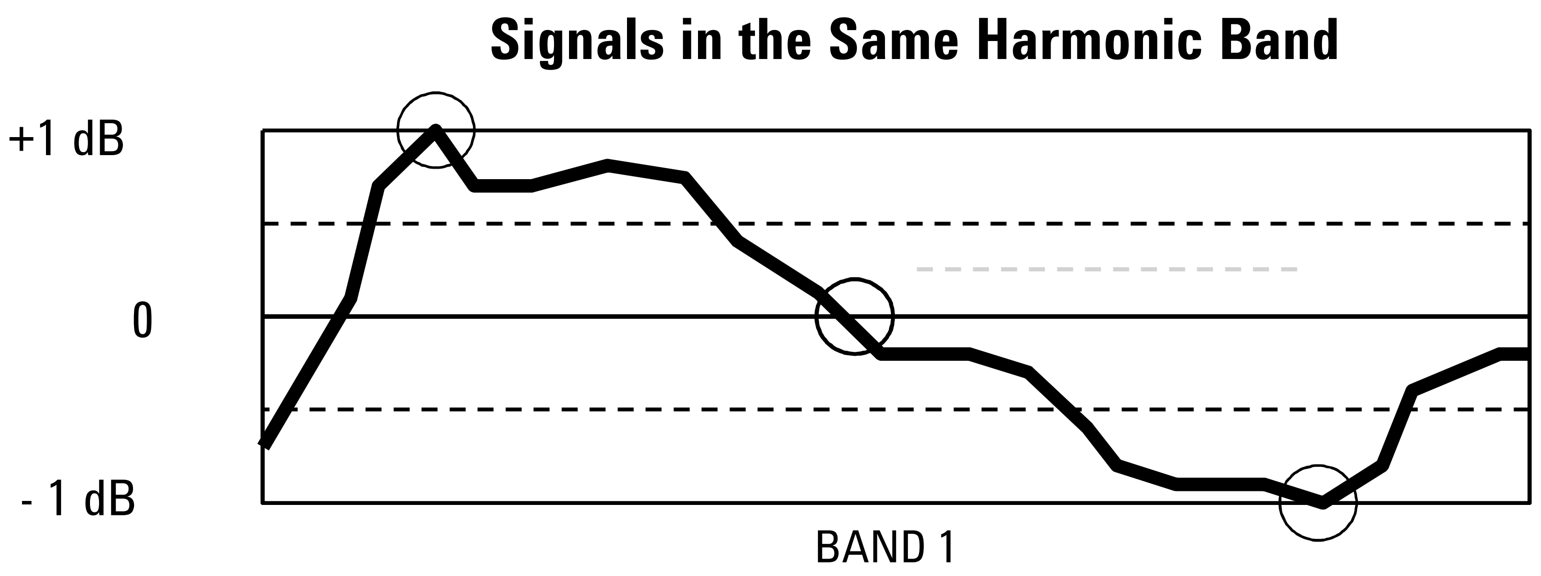
Specifications

Accuracy: Key amplitude uncertainty contributions

Relative and absolute:	Sample Uncertainties
• Input impedance mismatch	(±0.13 dB)
• Input attenuator switching uncertainty	(±0.6 dB)
• Frequency response	(±1.8 dB)
• Reference level accuracy	(±1.0 dB)
• RBW switching uncertainty	(±0.5 dB)
• Display scale fidelity	(±0.85 dB)
Absolute only:	
• Calibrator accuracy	(±0.34 dB)

Specifications

Accuracy: Frequency Response

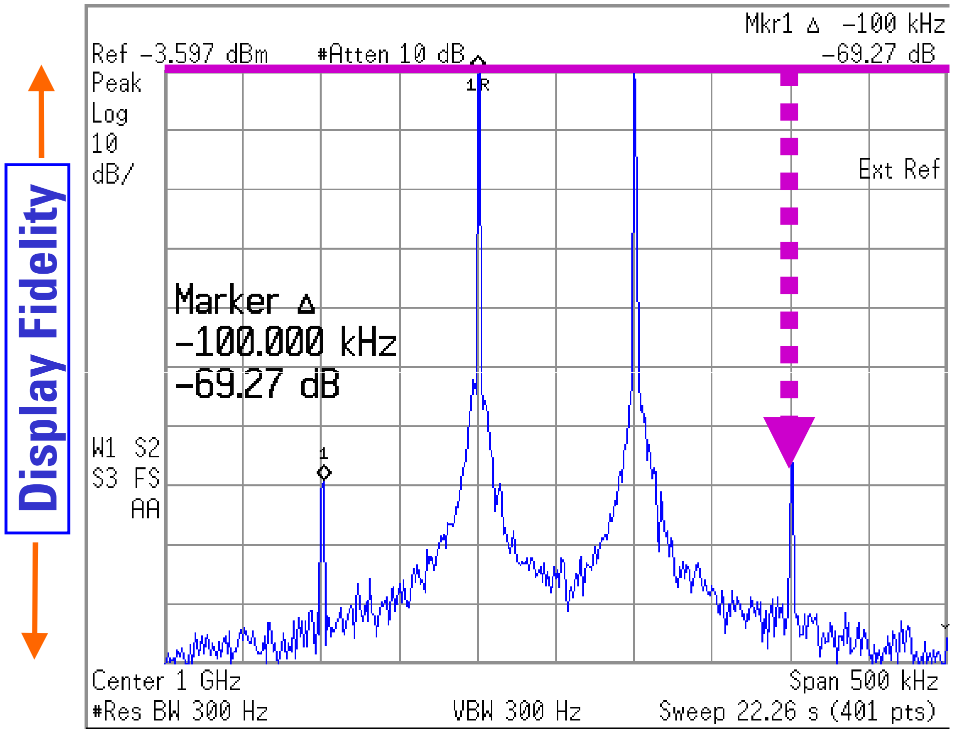


Absolute amplitude accuracy – Specification: ± 1 dB

Relative amplitude accuracy – Specification: ± 2 dB

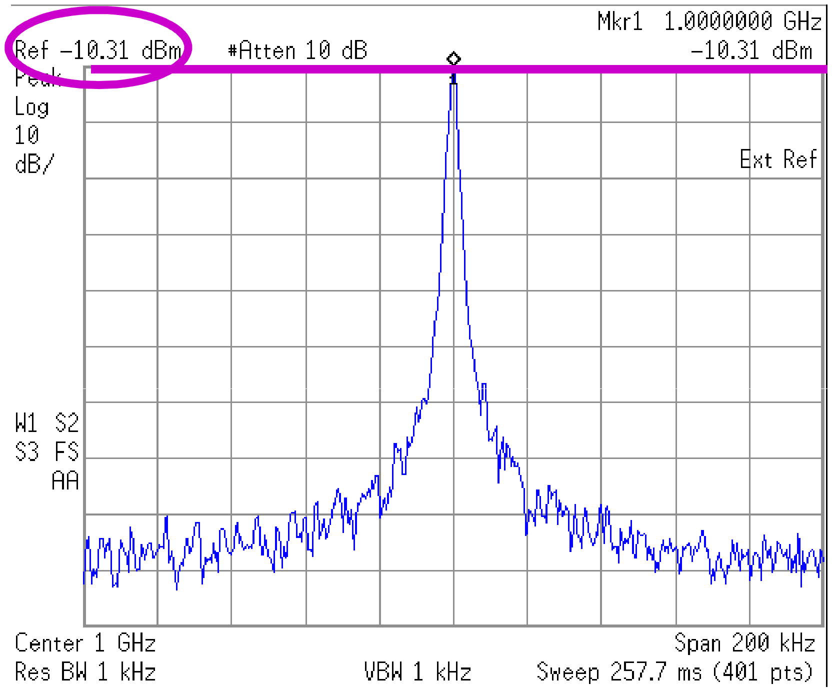
Specifications

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.

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

Amplitude Accuracy - Summary

Optimize measurement setup & techniques for best accuracy

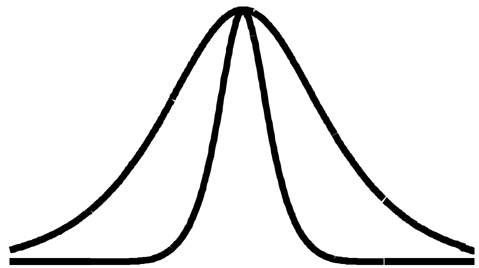
- **Minimize changes to uncertainty contributors**
  - **Or change contributor with least error impact**
  - **Or stay within the optimum accuracy envelope parameters that modern auto-alignment calibration techniques provide**

- **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.**

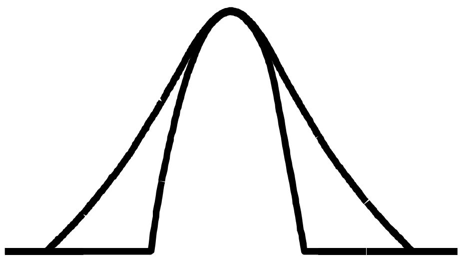
- **Except for freq. response, uncertainty contributors that impact both signals equally in a relative measurement can be ignored.**

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

What Determines Resolution?



Resolution Bandwidth

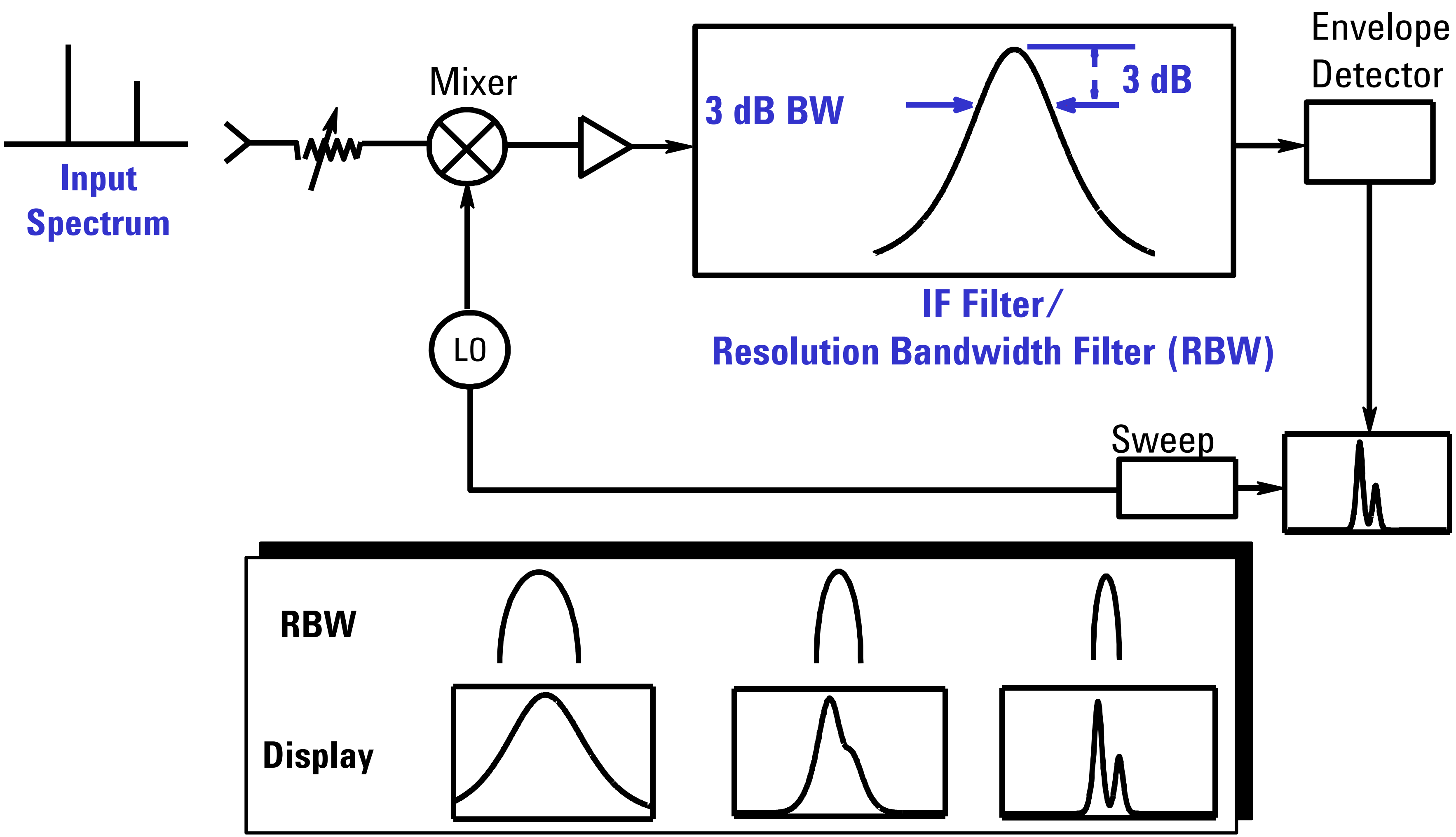


RBW Type and Selectivity

Noise Sidebands

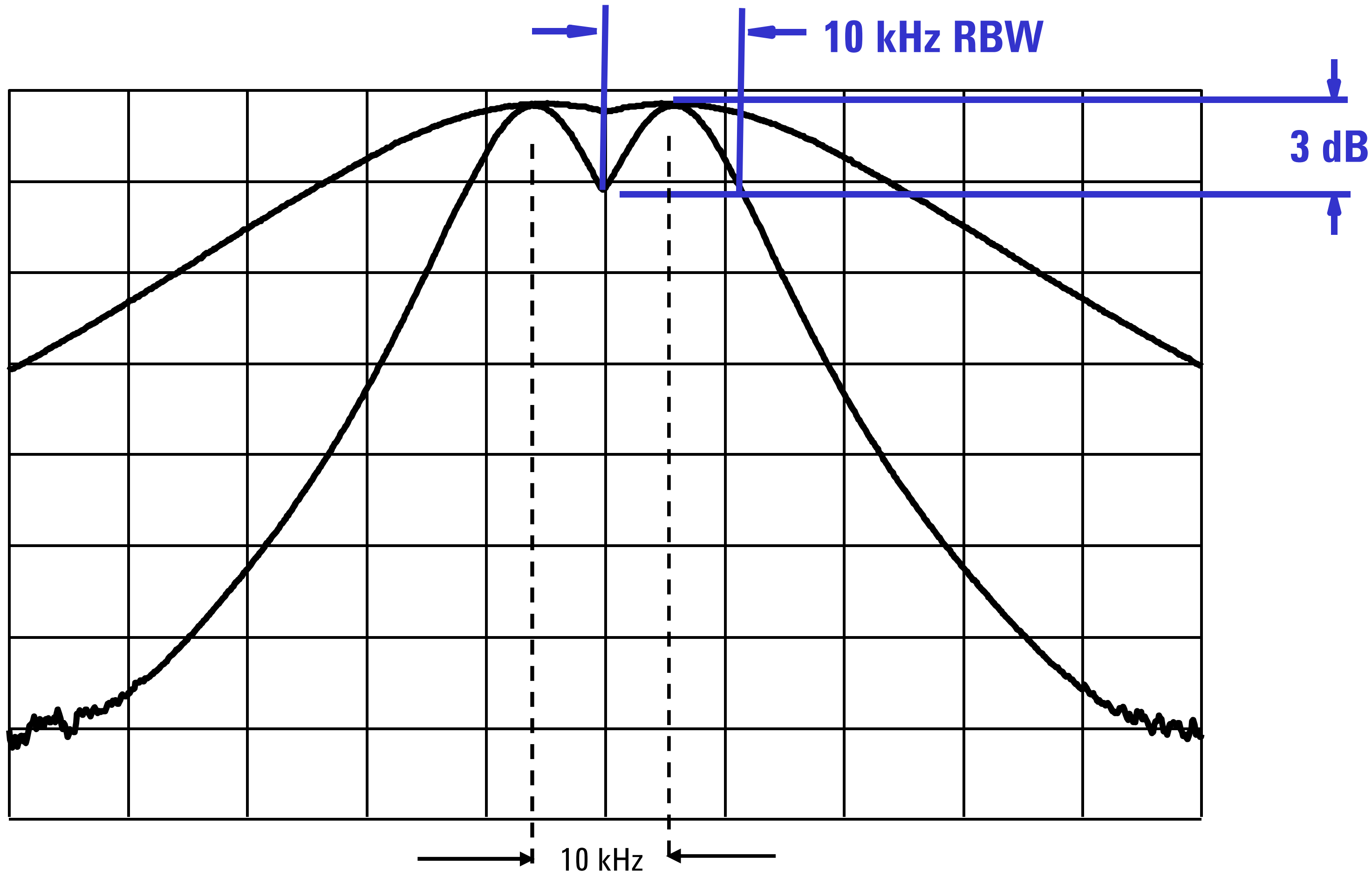
Specifications

Resolution: Resolution Bandwidth



Specifications

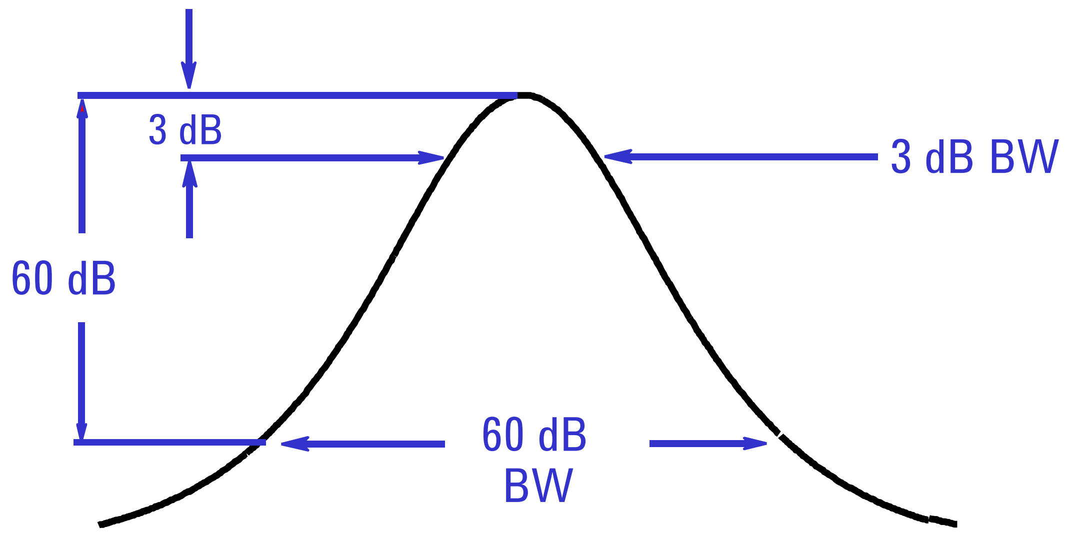
Resolution: Resolution BW



Determines resolvability of equal amplitude signals

Specifications

Resolution BW Selectivity or Shape Factor

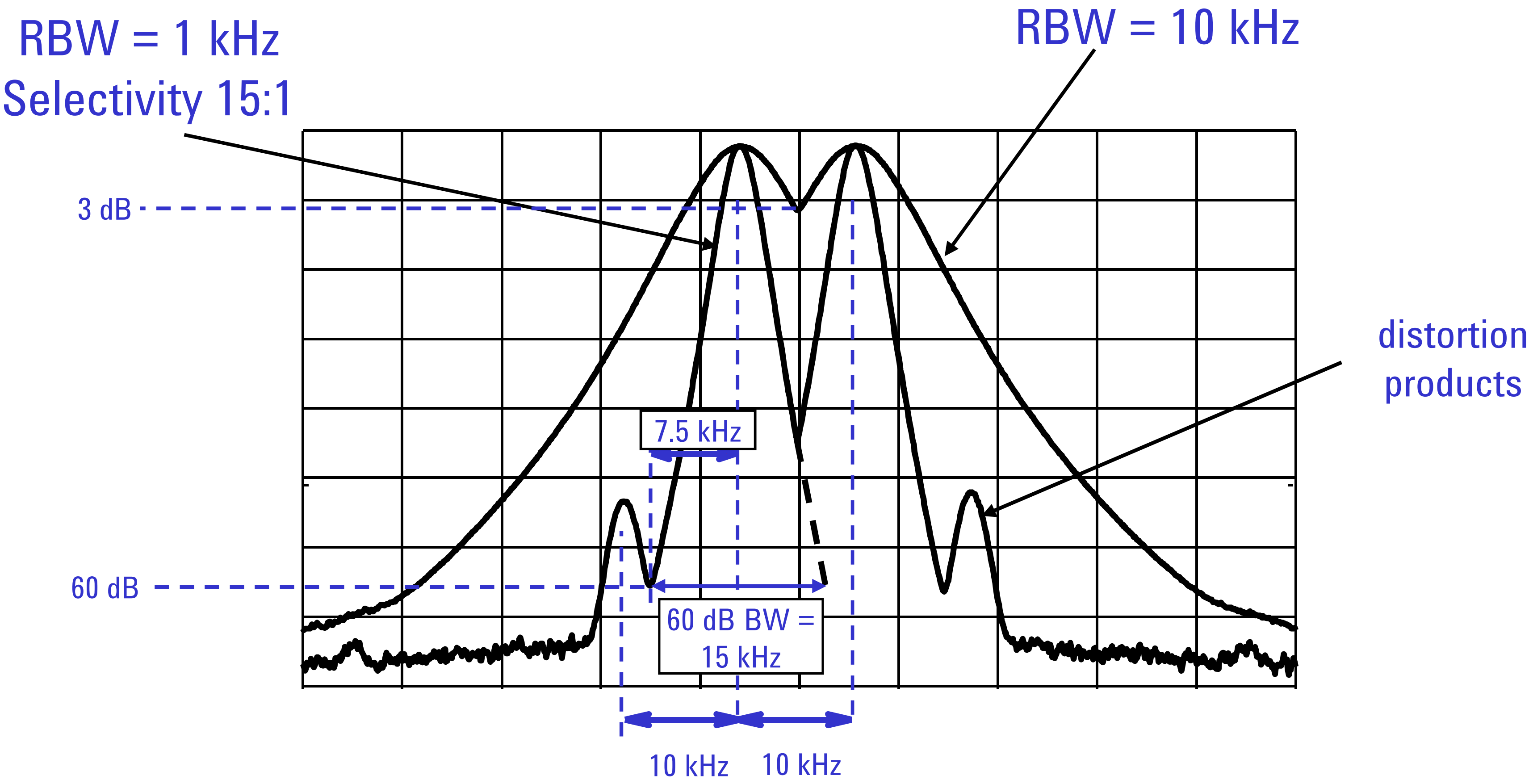


$$\text{Selectivity} = \frac{\text{60 dB BW}}{\text{3 dB BW}}$$

Determines resolvability of unequal amplitude signals

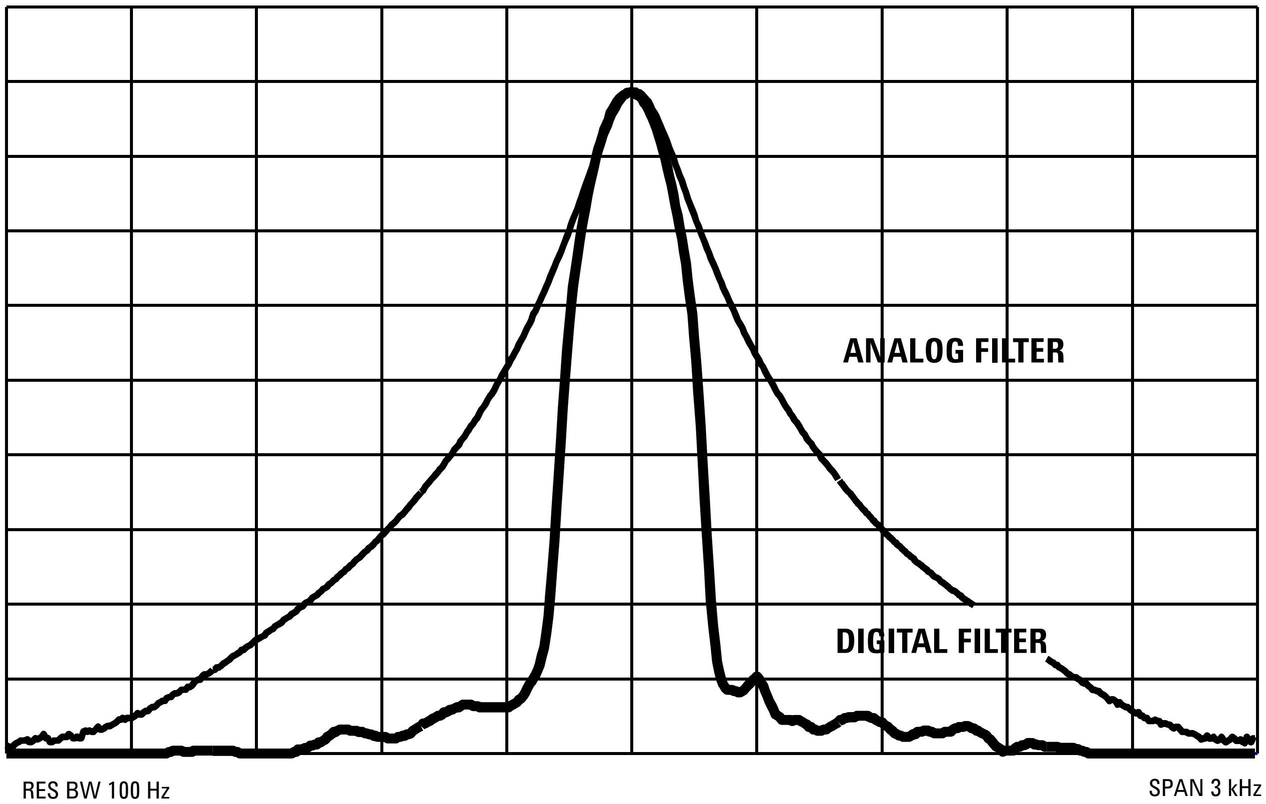
Specifications

Resolution BW Selectivity or Shape Factor



Specifications

Resolution: RBW Type and Selectivity



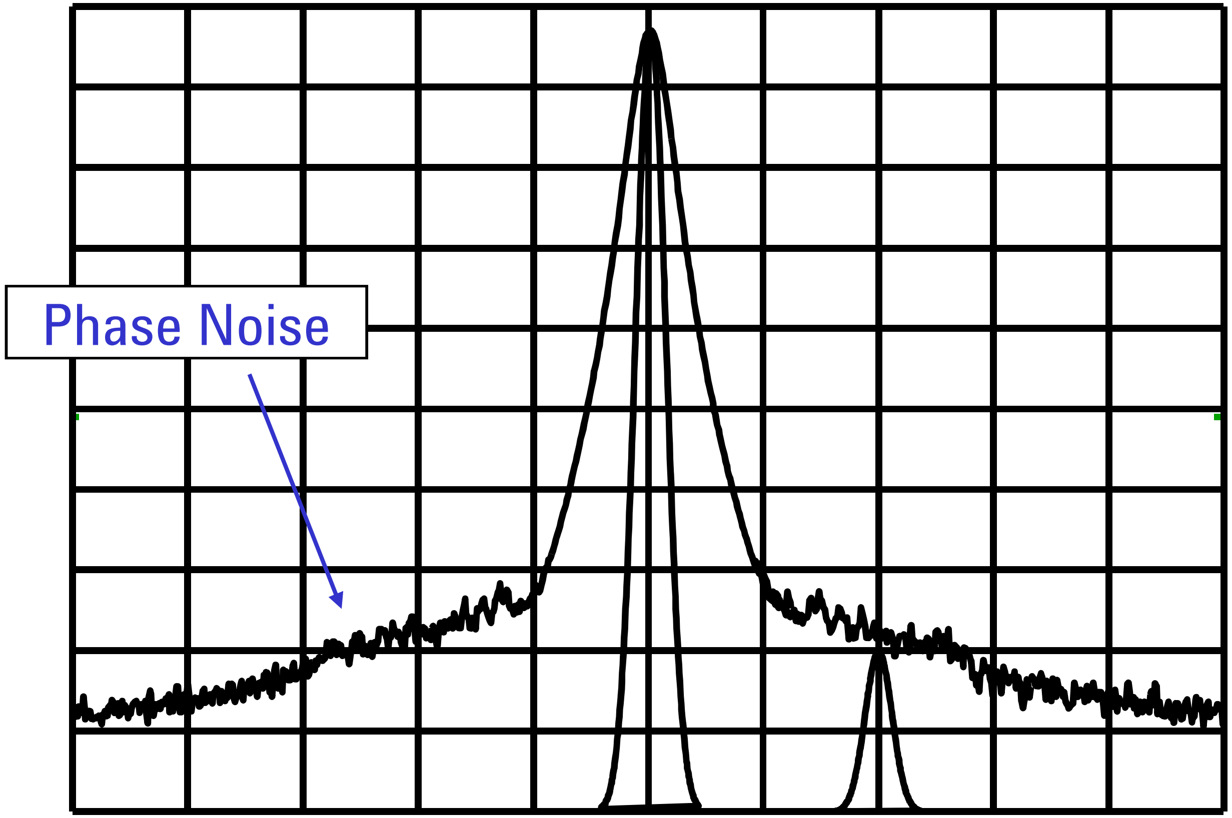
Typical Selectivity

Analog 15:1

Digital ≤5:1

Specifications

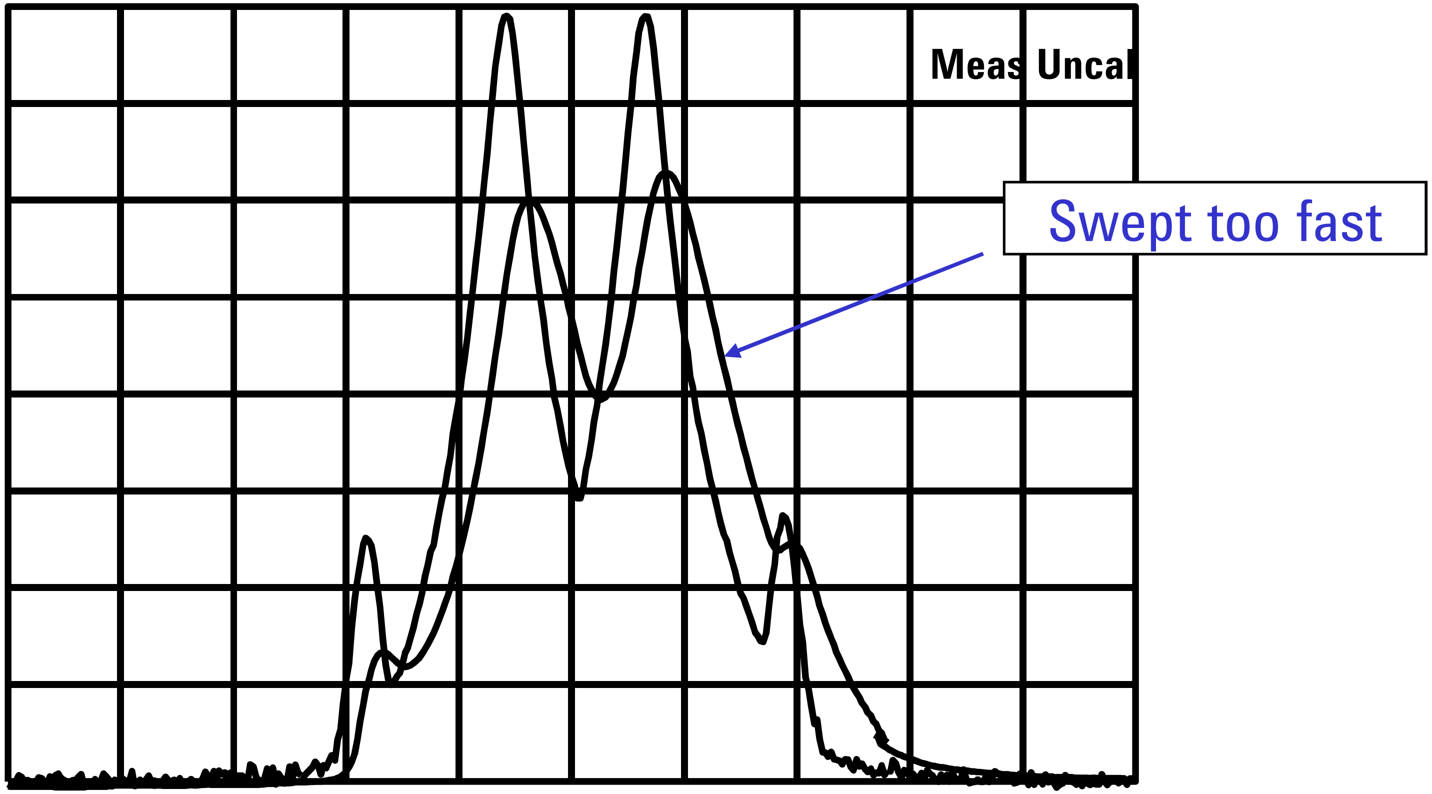
Resolution: Noise Sidebands



Noise Sidebands can prevent resolution of unequal signals

Specifications

Resolution: RBW Determines Sweep Time



Penalty For Sweeping Too Fast
Is An Uncalibrated Display

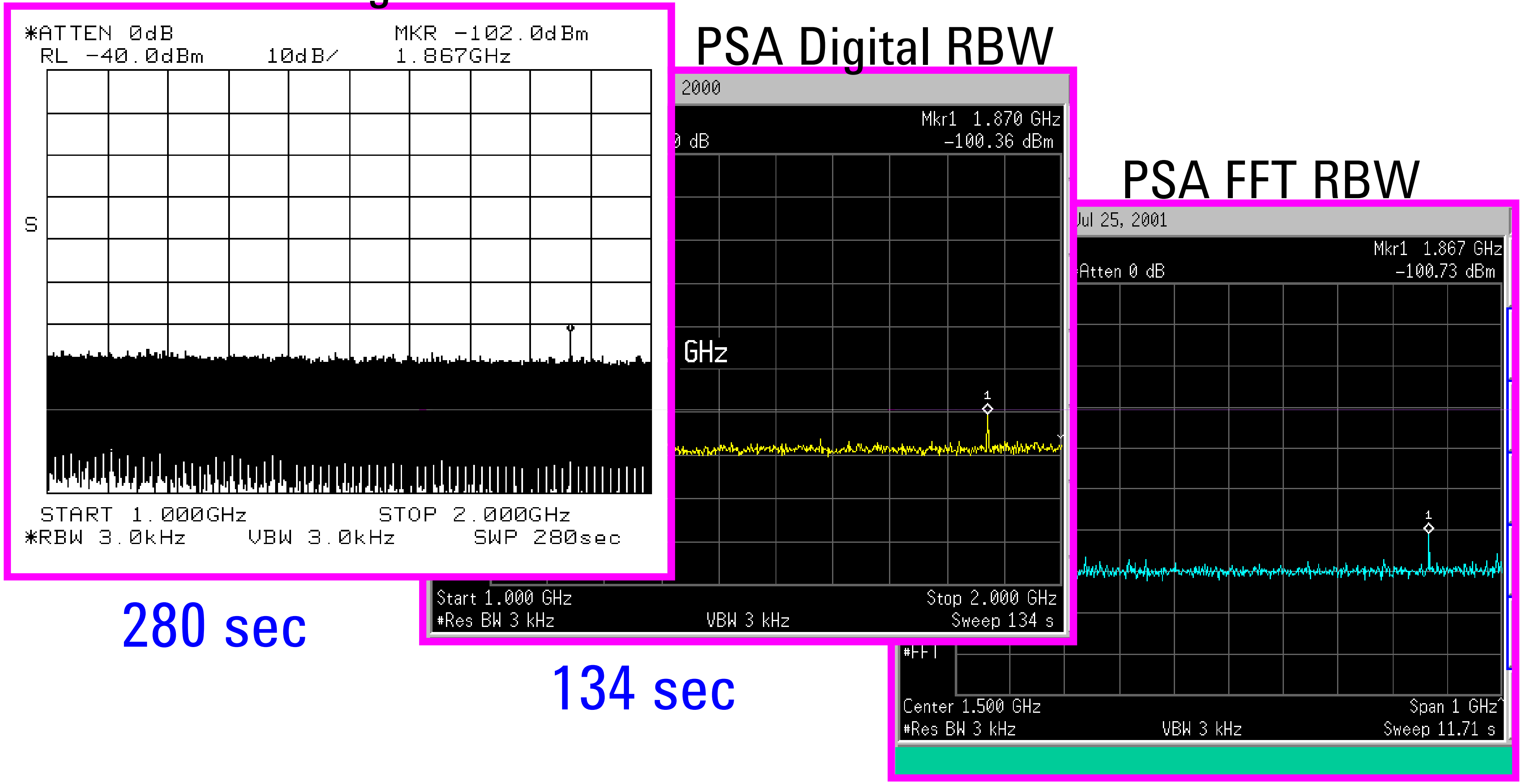
Specifications

Resolution: RBW Type Determines Sweep Time

8563E Analog RBW

PSA Digital RBW

PSA FFT RBW



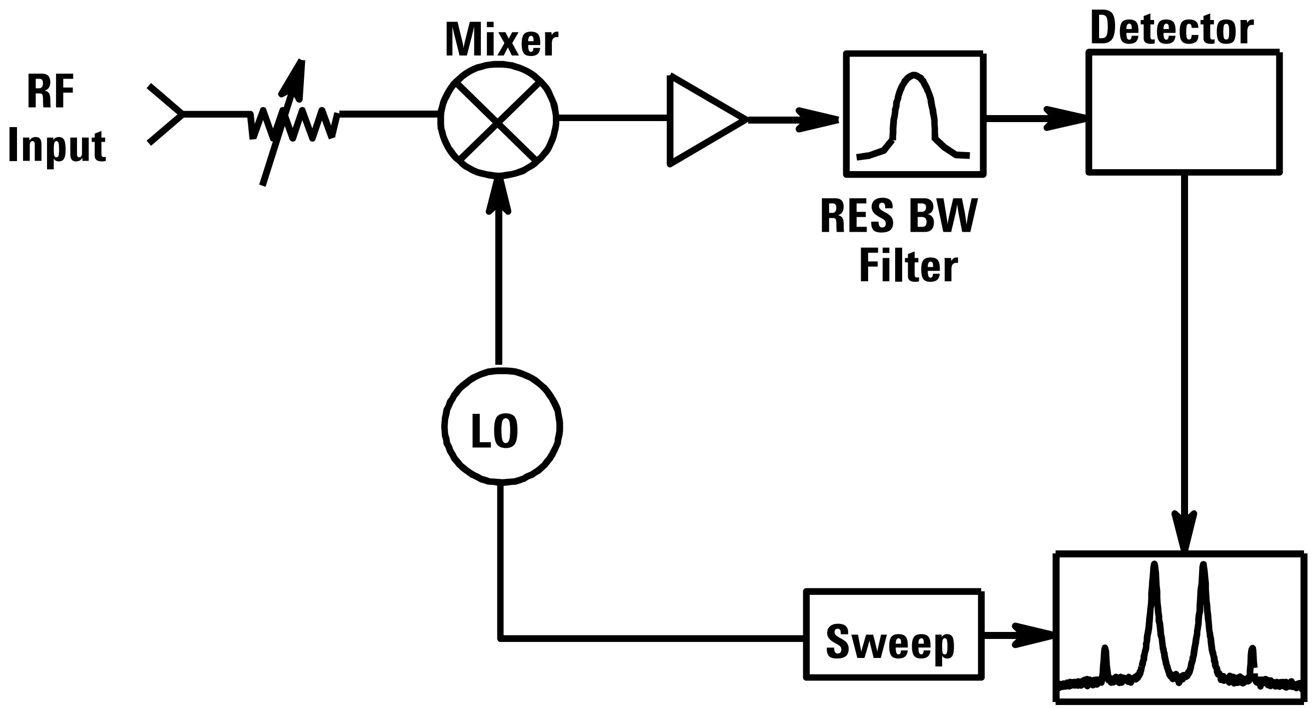
280 sec

134 sec

13.5 sec

Specifications

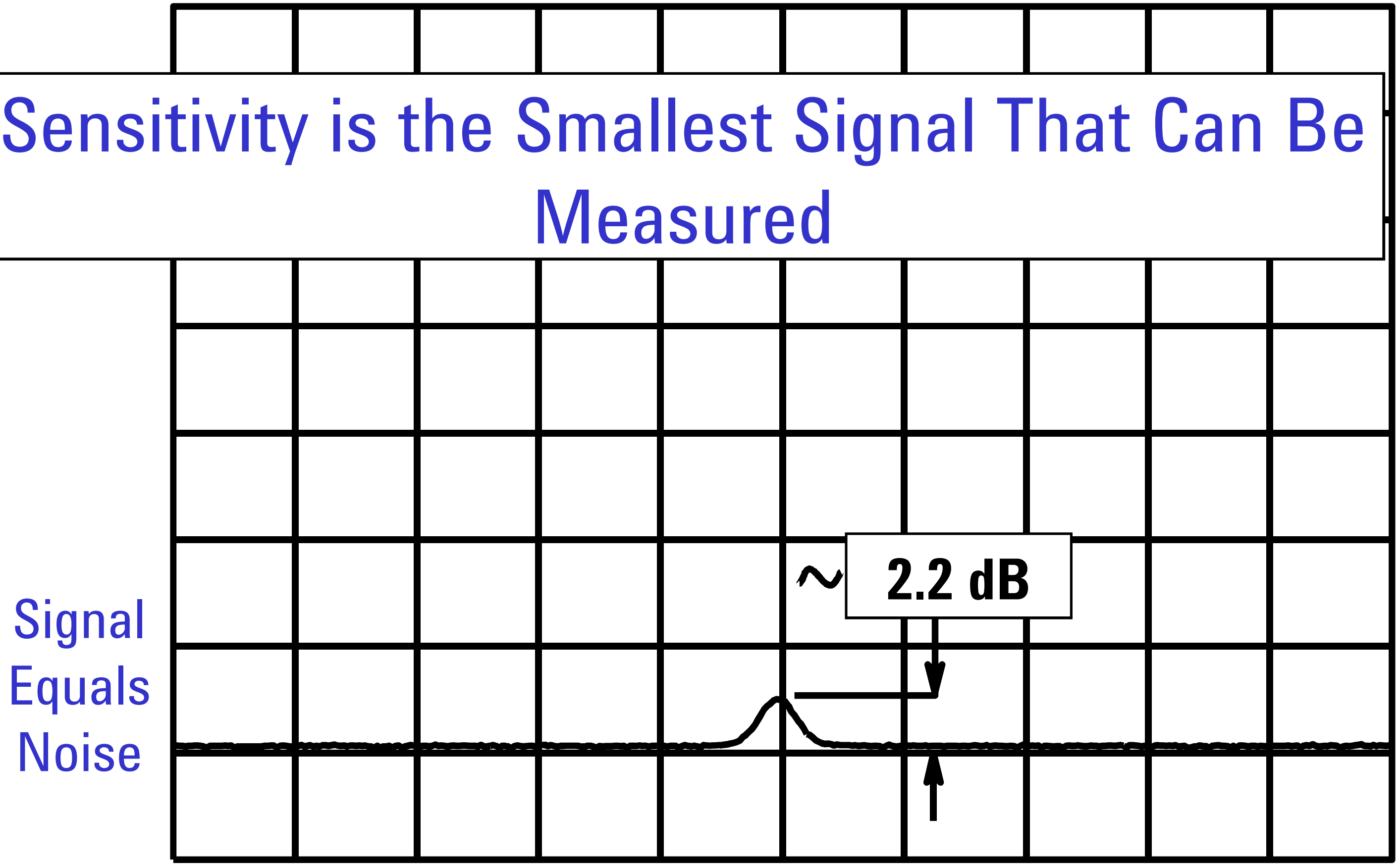
Sensitivity/DANL

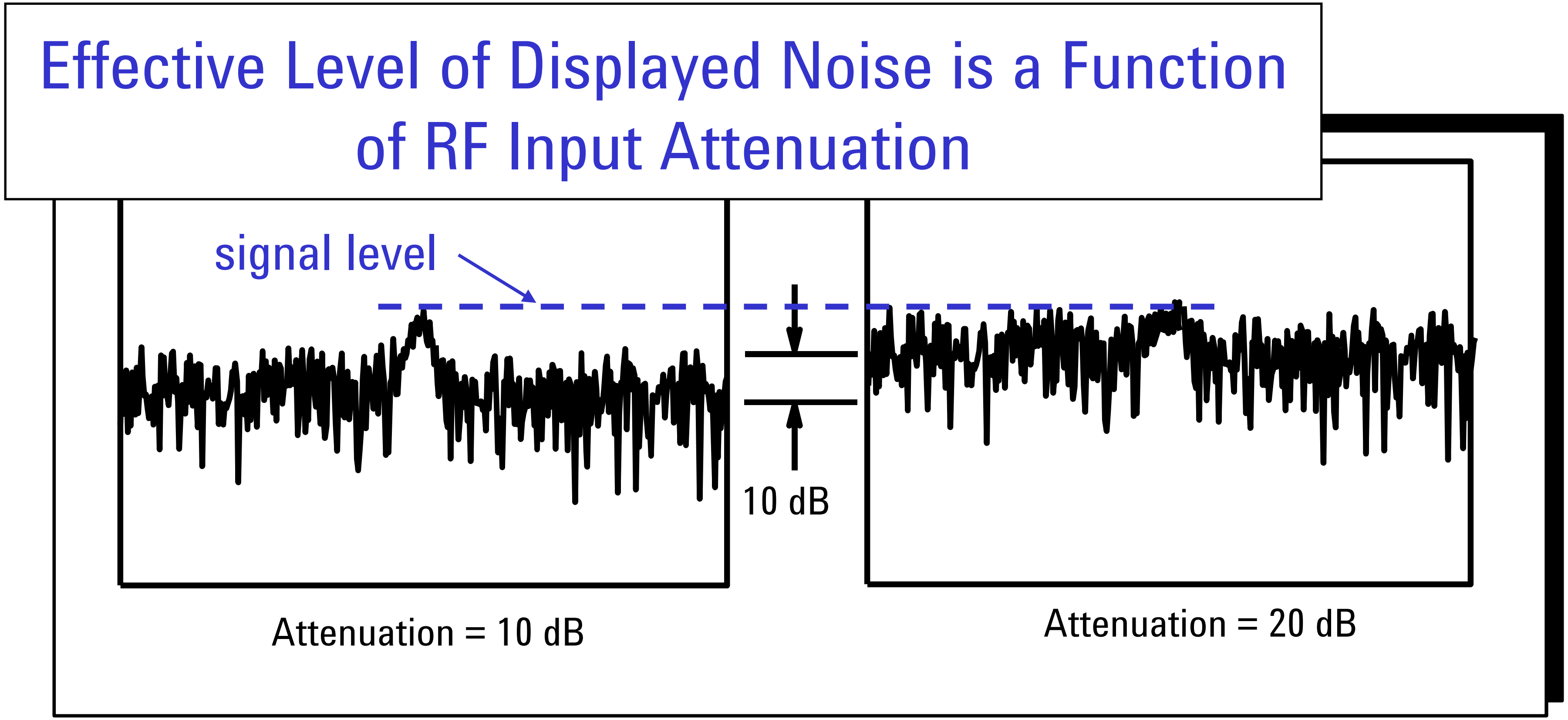


A Spectrum Analyzer Generates and Amplifies Noise Just Like Any Active Circuit

Specifications
Sensitivity/DANL

Sensitivity is the Smallest Signal That Can Be Measured

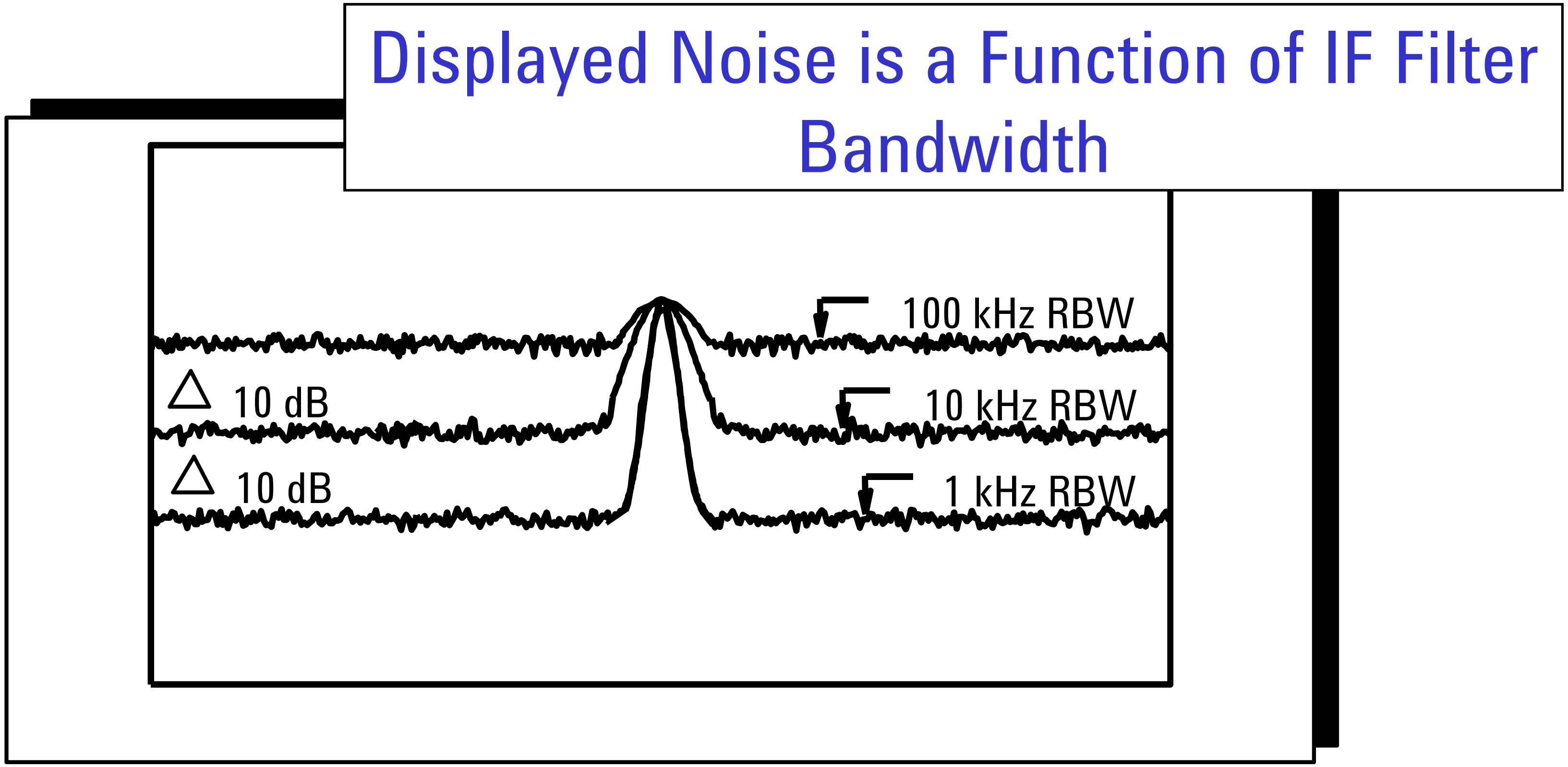




Signal To Noise Ratio Decreases as
RF Input Attenuation is Increased

Specifications

Sensitivity/DANL: IF Filter(RBW)

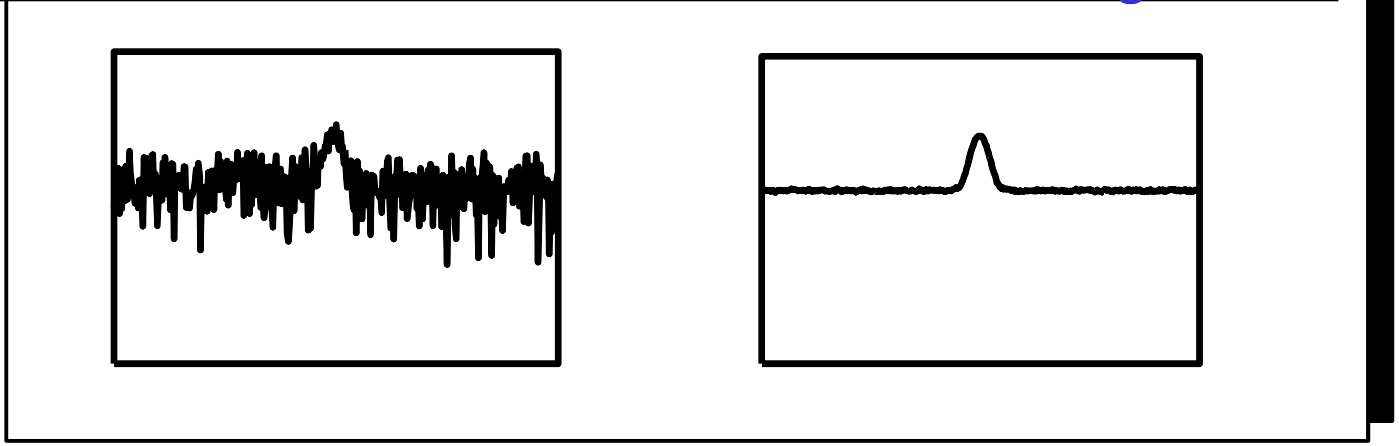


Decreased BW = Decreased Noise

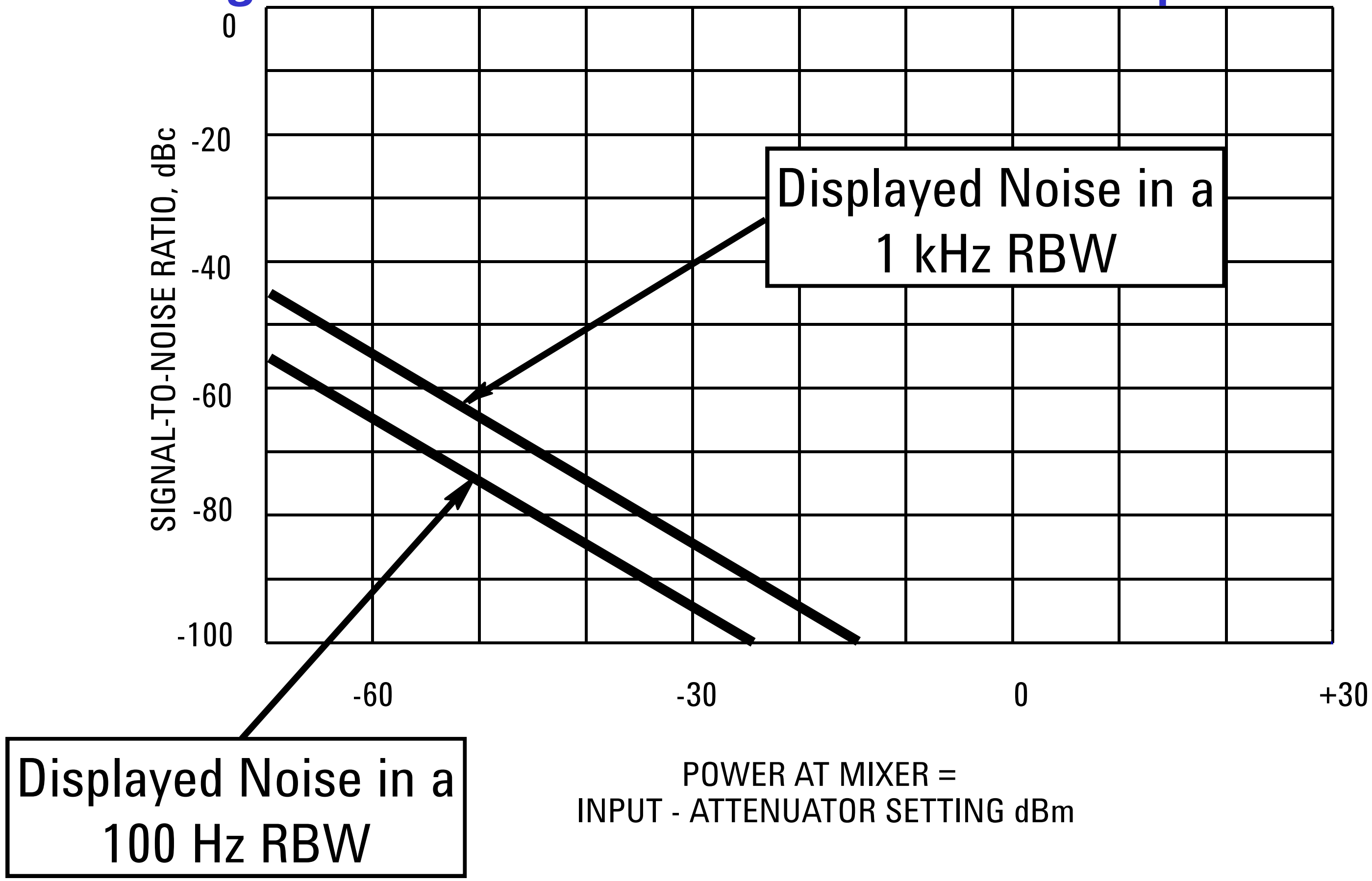
Specifications

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

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



Signal-to-Noise Ratio Can Be Graphed

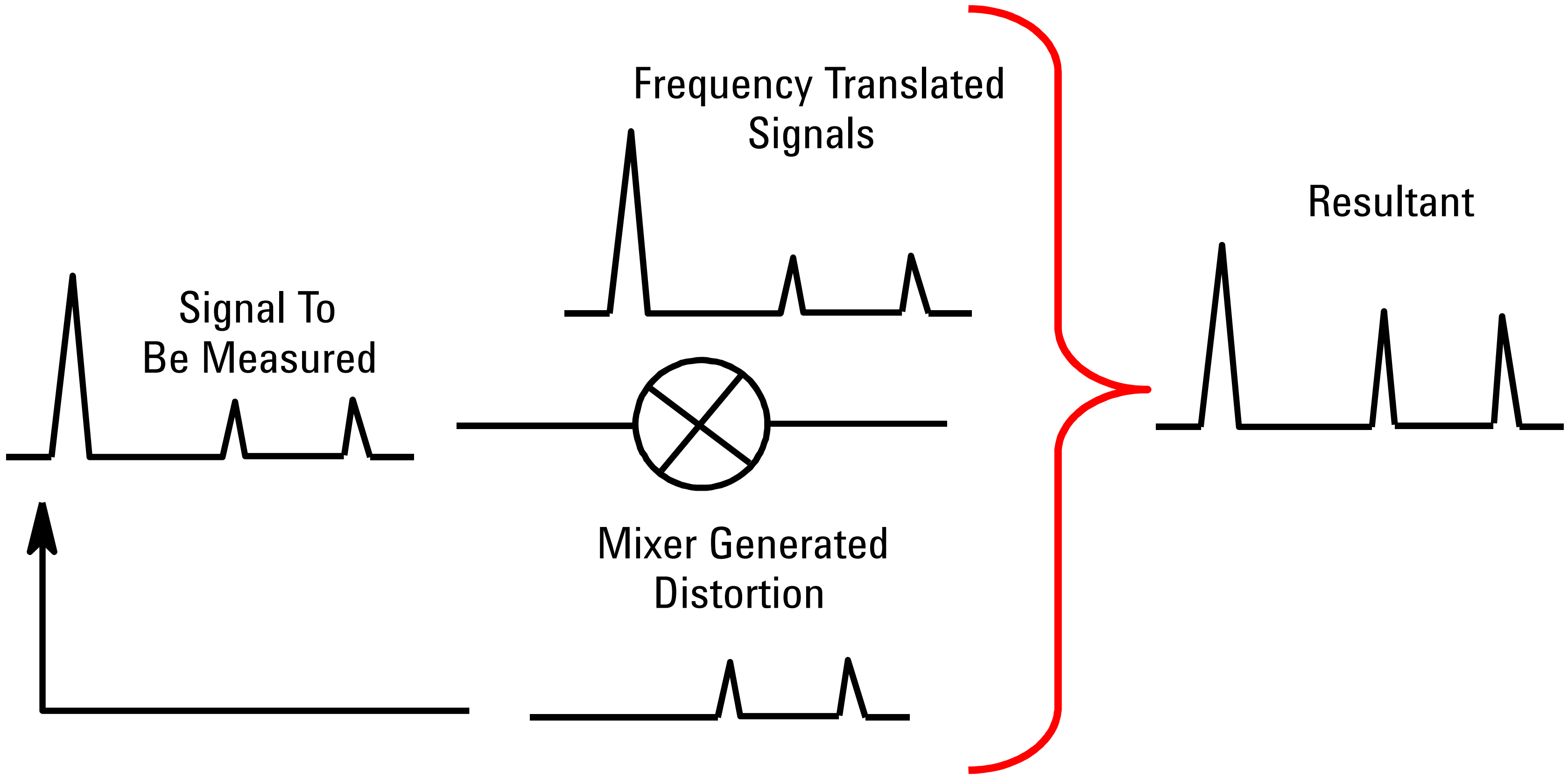


Sensitivity/DANL: Summary

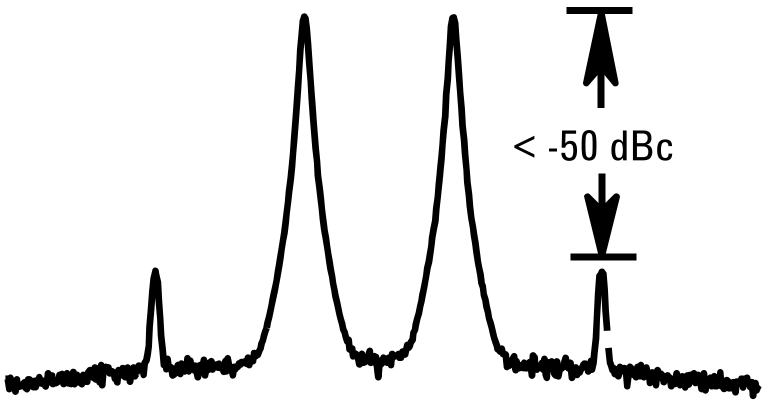
For Best Sensitivity Use:

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

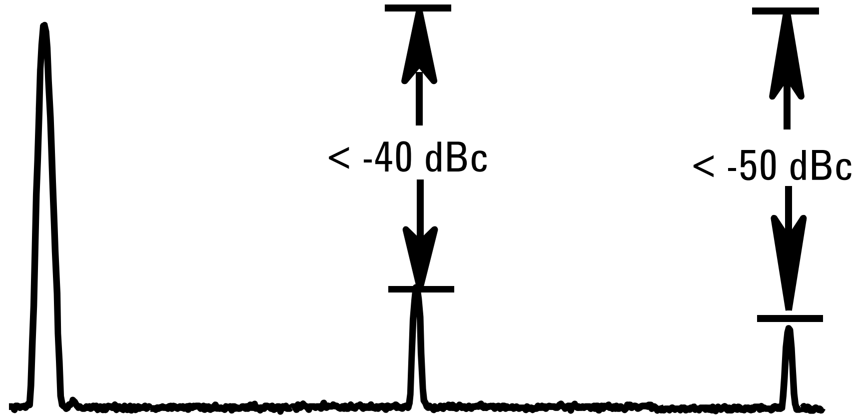
Mixers Generate Distortion



Most Influential Distortion is the Second and Third Order

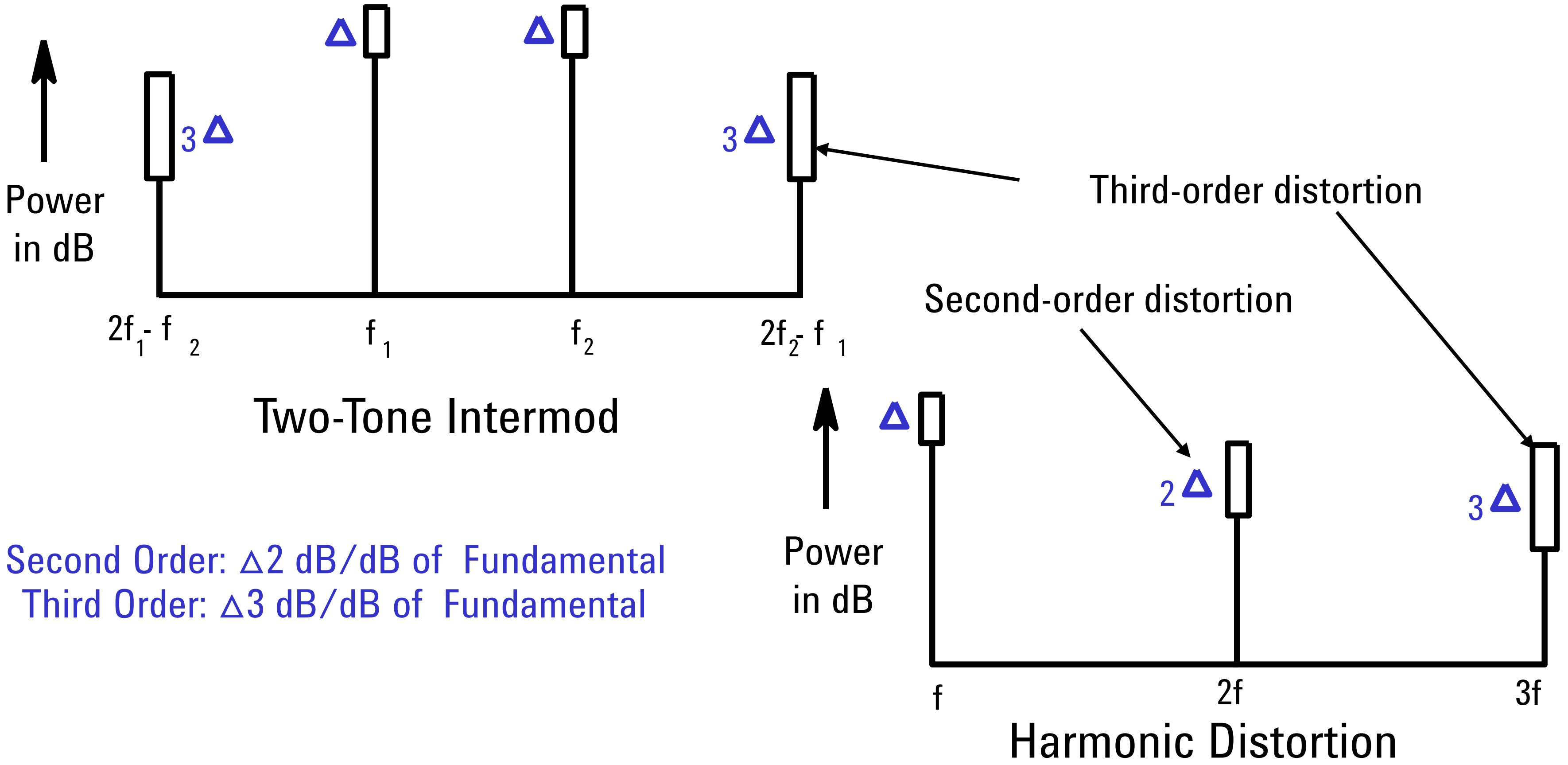


Two-Tone Intermod



Harmonic Distortion

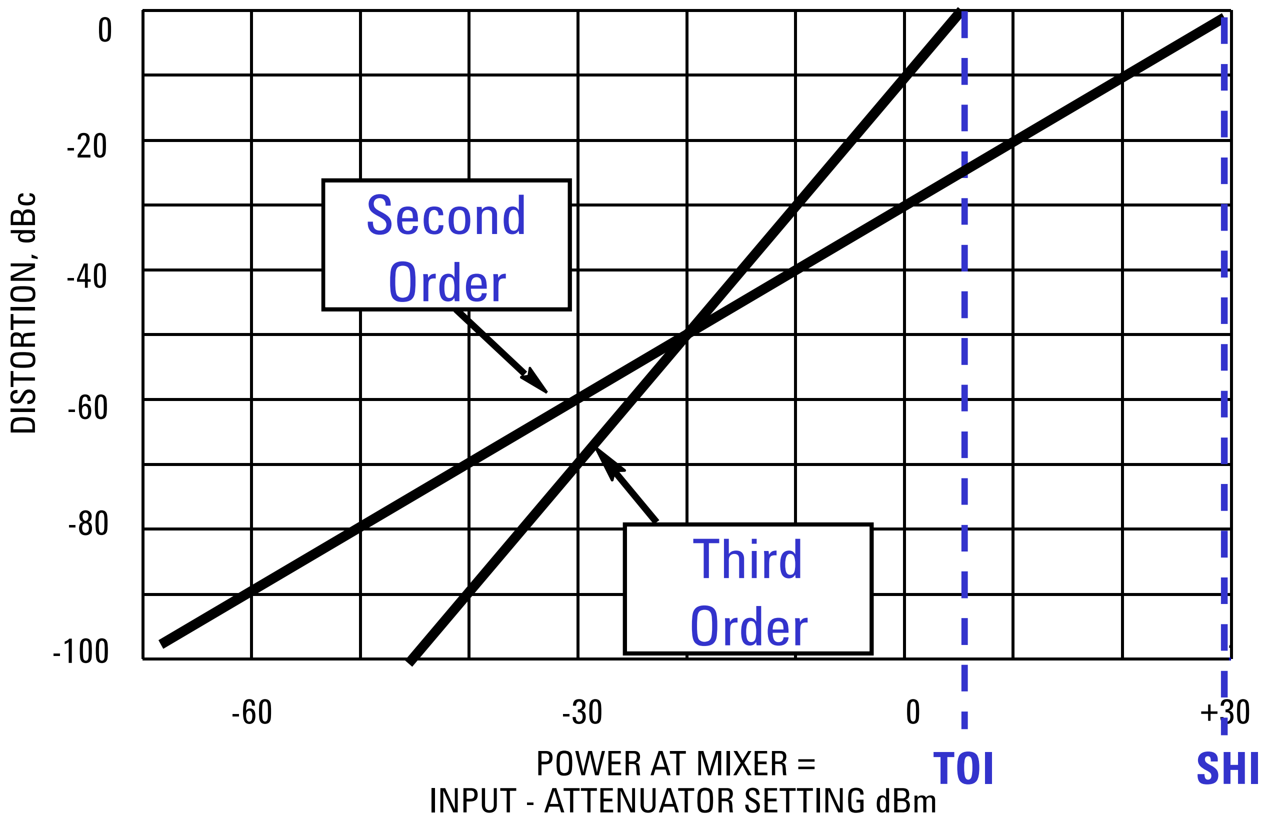
Distortion Products Increase as a Function of Fundamental's Power



Second Order: Δ2 dB/dB of Fundamental
Third Order: Δ3 dB/dB of Fundamental

Specifications
Distortion

Distortion is a Function of Mixer Level

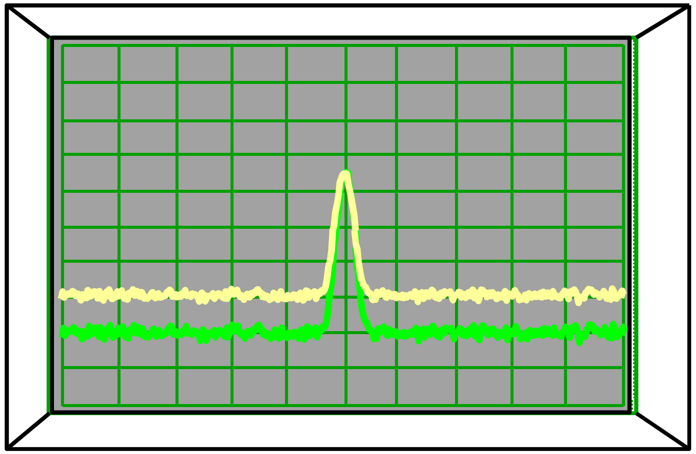


Attenuator Test: Change power to the mixer

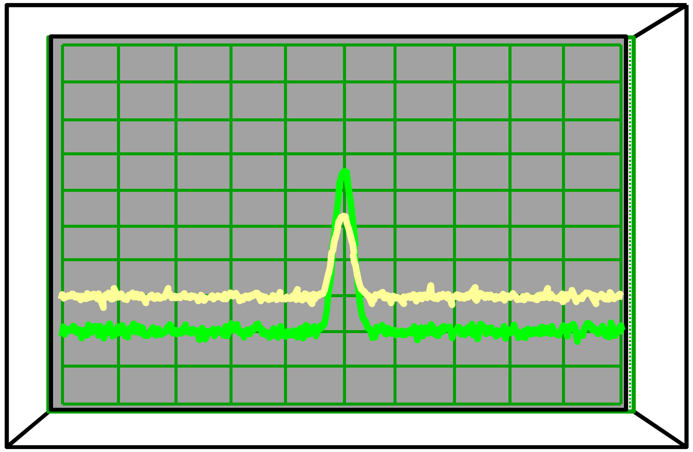
1. Change input attenuator by 10 dB

2. Watch distortion amplitude on screen

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

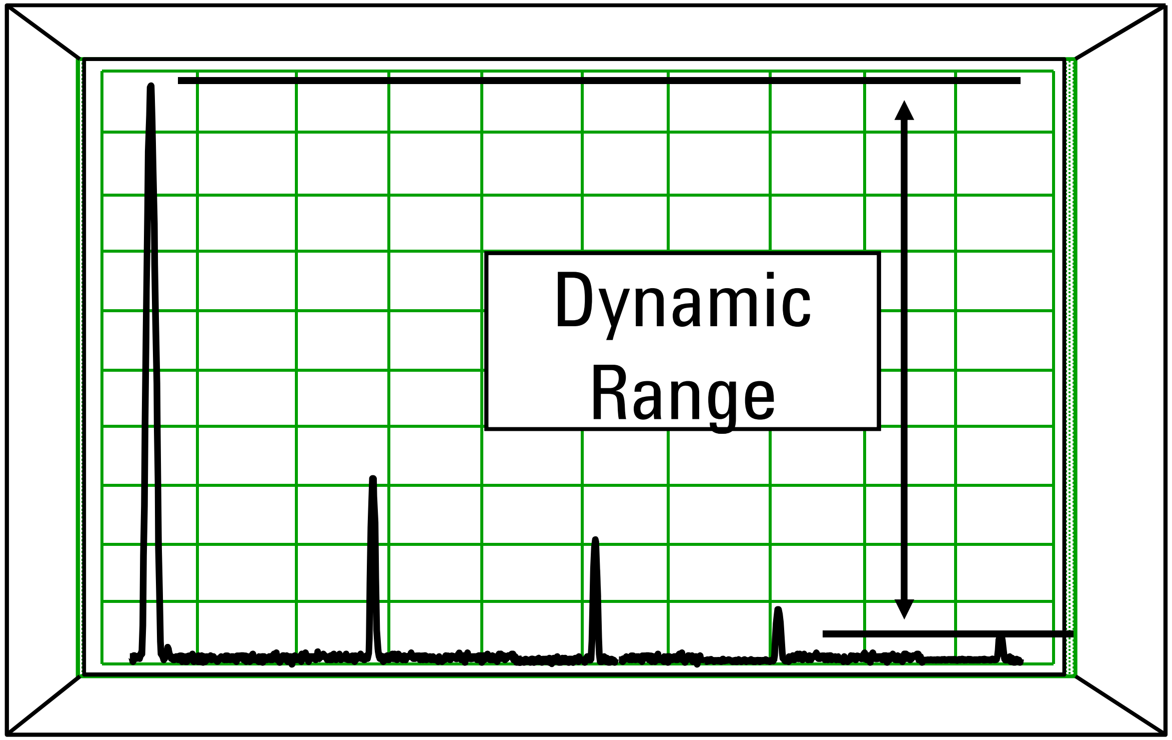


Change in amplitude:
at least some of the distortion is being generated inside the analyzer (internal)



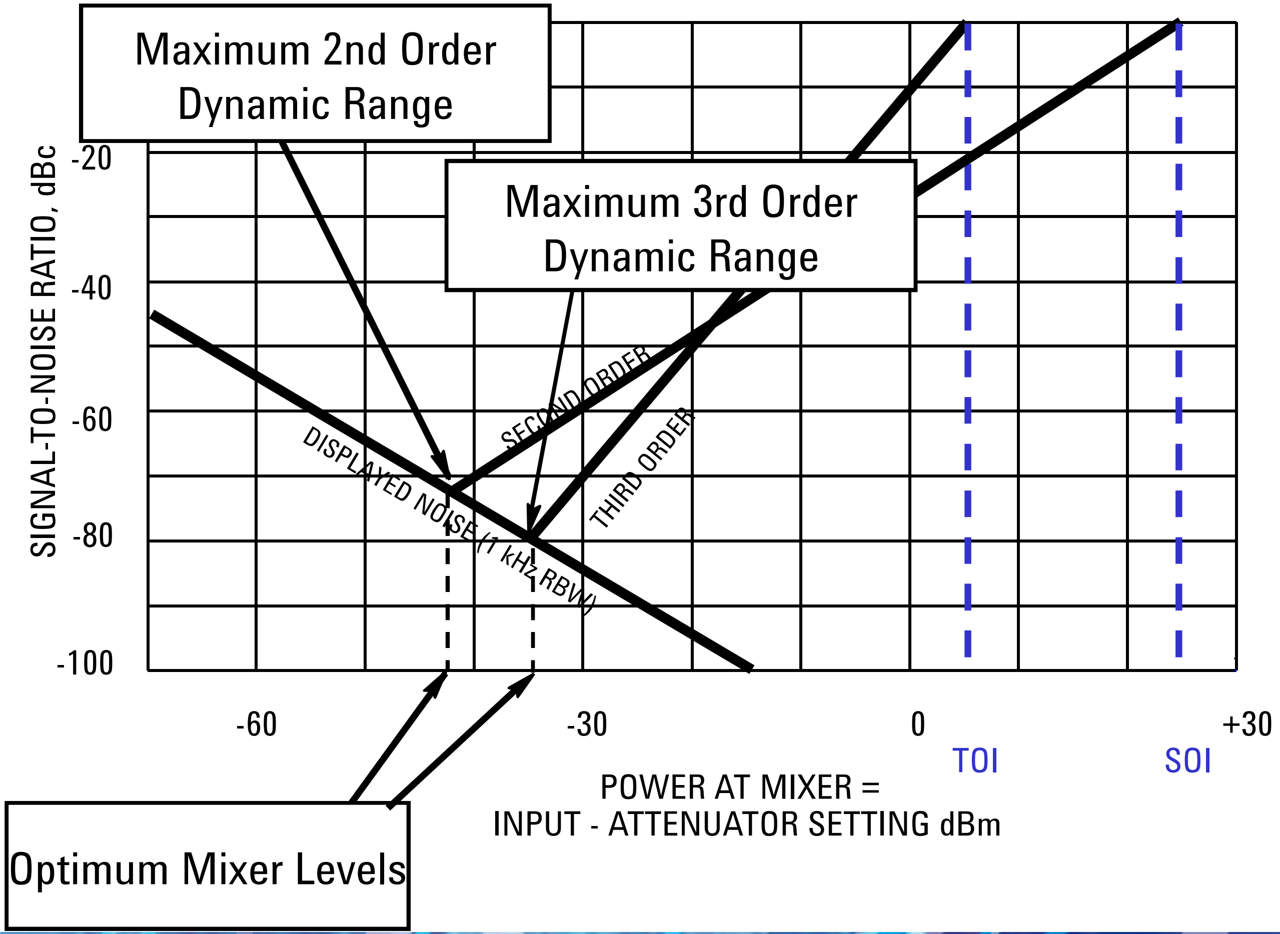
Specifications

Spectrum Analyzer Dynamic Range

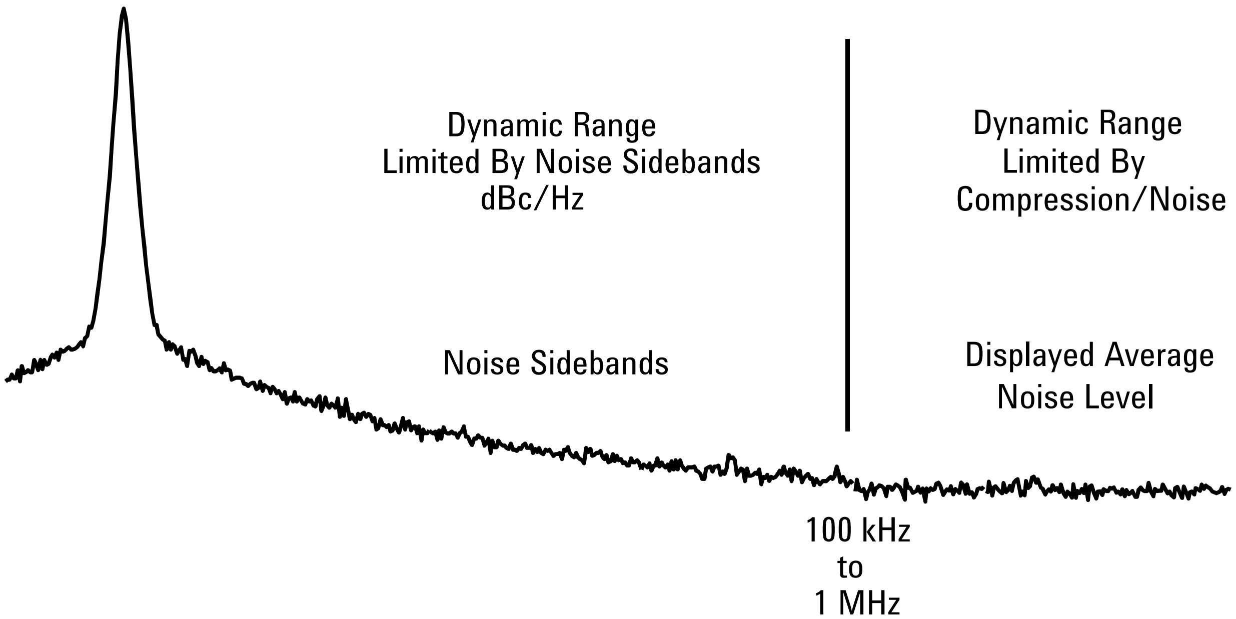


The ratio, expressed in dB, of the largest to the smallest signals simultaneously present at the input of the spectrum analyzer that allows measurement of the smaller signal to a given degree of uncertainty.

Dynamic Range Can Be Presented Graphically



Dynamic Range for Spur Search Depends on Closeness to Carrier



Dynamic Range is actually:

Maximum dynamic range calculation

Calculated from distortion products and sensitivity/DANL

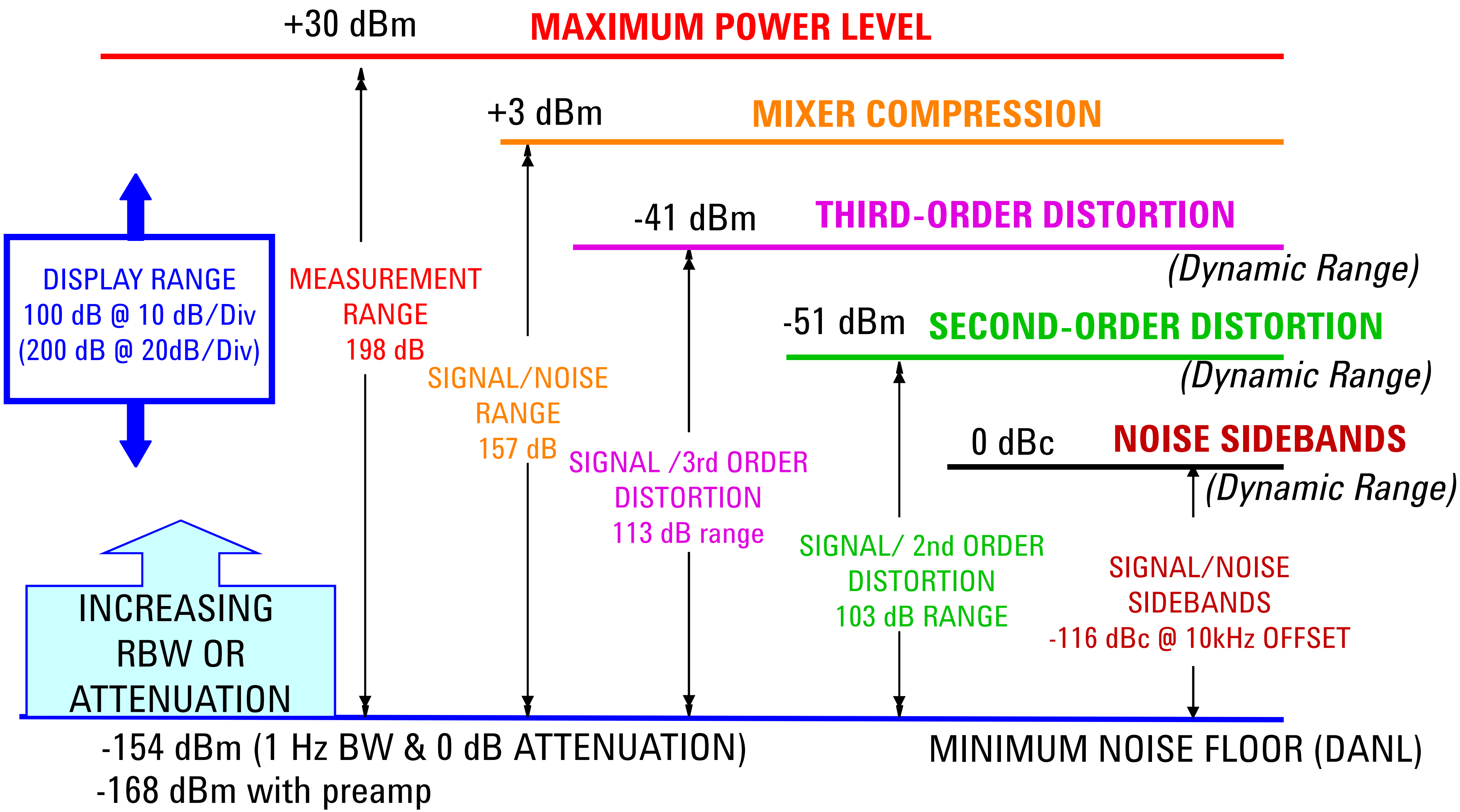
bounded by

-dBc/Hz Phase Noise sidebands @ close-in offset frequencies

Determined by the phase noise specifications of the SA

Specifications

Dynamic Range vs. Measurement Range



Specifications

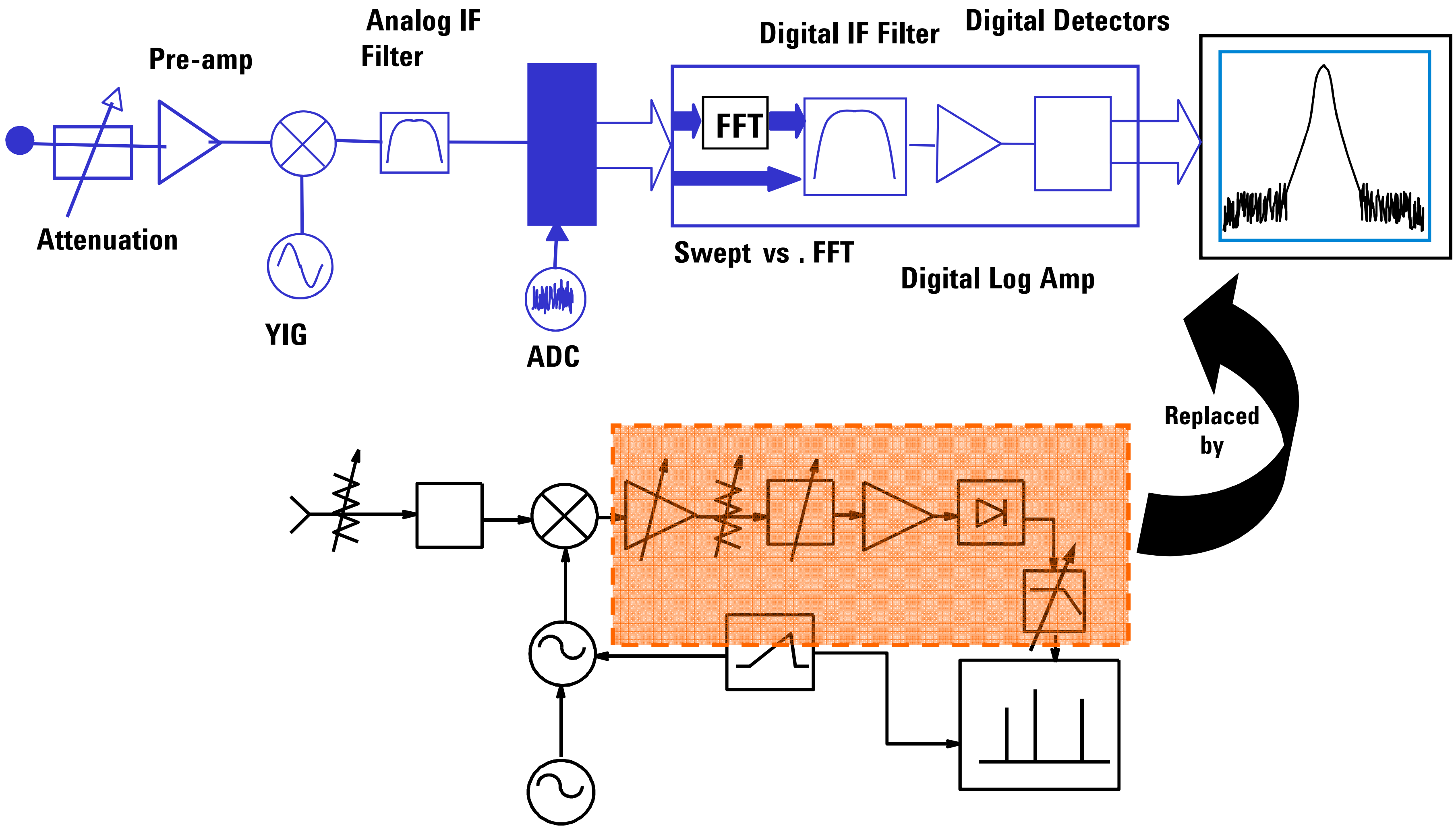
Summary: Optimizing Dynamic Range

- **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**

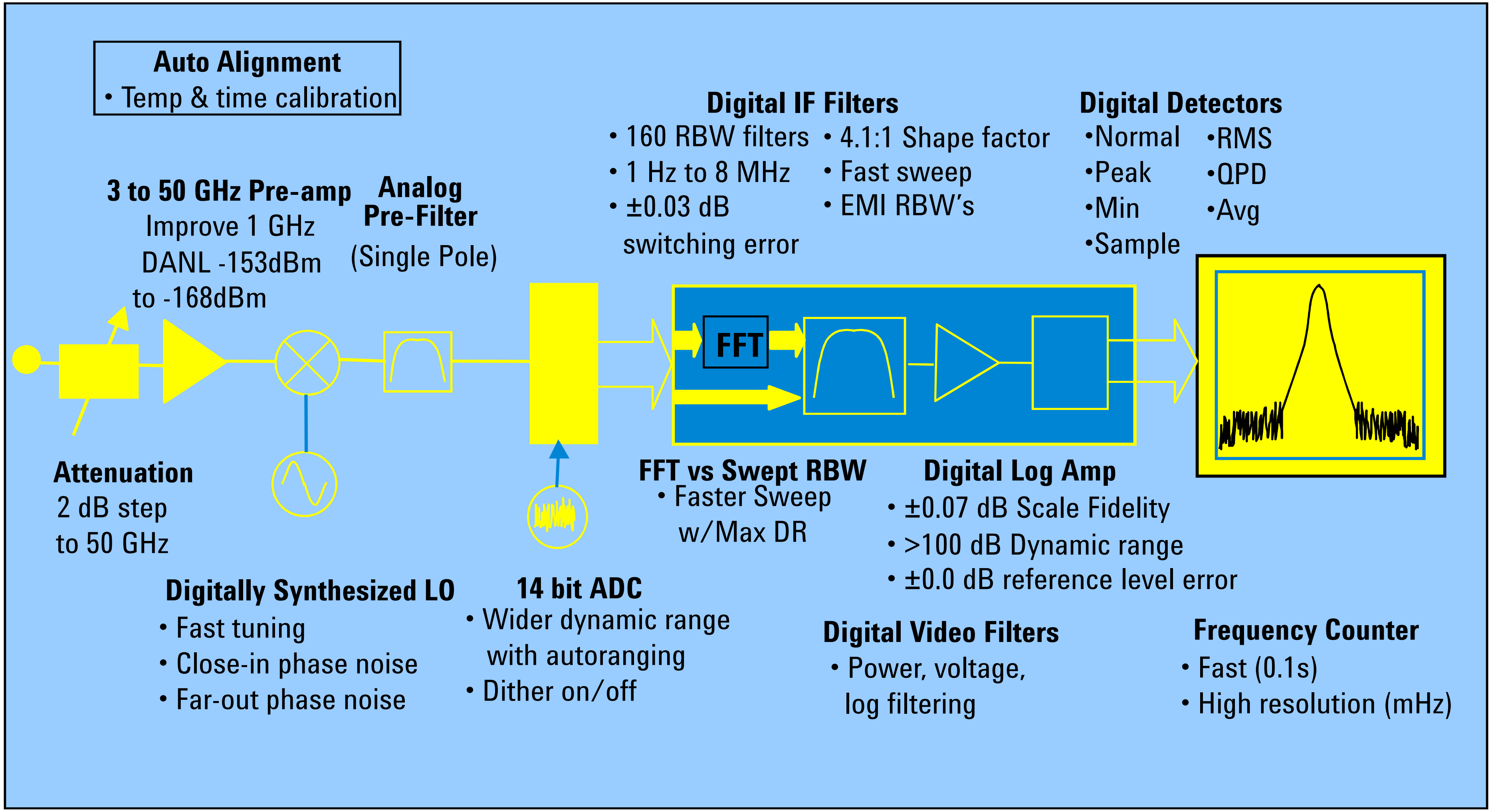
Agenda

- Introduction
- Overview
- Theory of Operation
- Specifications
- Modern spectrum analyzer designs & capabilities
    - – Wide Analysis Bandwidth Measurements
- Wrap-up
- Appendix

Modern Spectrum Analyzer Block Diagram



Modern Spectrum Analyzer Block Diagram



Modern Spectrum Analyzer - Specifications

Digital IF provides improved accuracy

	PSA	vs. Traditional
• Input impedance mismatch	±0.13	~~±0.29 dB~~
• Input attenuator switching uncertainty	±0.18	~~±0.6 dB~~
• Frequency response	±0.38	~~±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) **±0.62 dB** vs. ~~**±1.8 dB**~~

95% Confidence **±0.24 dB**

Typical **±0.17 dB**

Modern Spectrum Analyzer Features

Built-in One-Button Power Measurements

Power Measurements

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

Format Setups

- GSM/EDGE
- cdma2000
- W-CDMA
- cdmaOne
- NADC/PDC
- Bluetooth
- Tetra (Ch. Pwr, ACP)
- 802.11a/b (SEM)
- HiperLAN2 (SEM)
- DVB-T
- UWB
- S-DMB

Modern Spectrum Analyzer Features

Application Focused Internal Software (one-button measurements)

General purpose applications

- Phase noise
- Ext. source control
- Noise figure
- Code compatibility suite

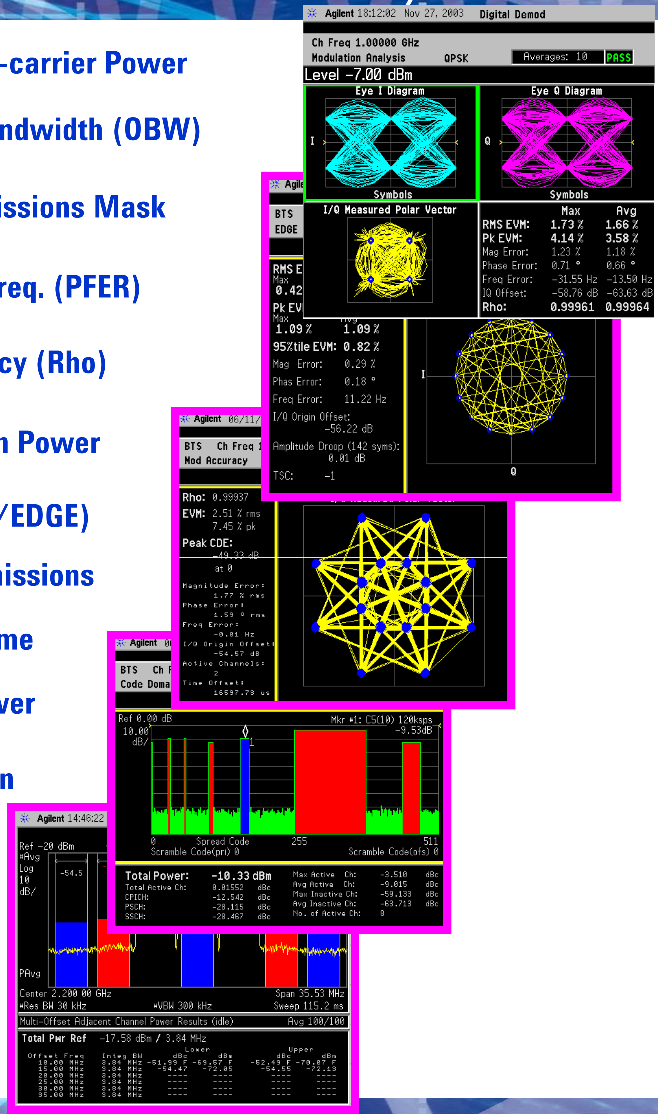
Flexible digital modulation analysis

- Flexible demod

Power & digital modulation measurements for wireless comms formats.

- W-CDMA, HSDPA, HSUPA
- GSM with EDGE
- Cdma2000 & 1xEV-DV
- 1xEV-DO
- cdmaOne
- NADC/PDC
- TD-SCDMA

ACPR, Multi-carrier Power
Occupied Bandwidth (OBW)
Spectral Emissions Mask
Phase and Freq. (PFER)
Mod Accuracy (Rho)
Code Domain Power
ORFS (GSM/EDGE)
Spurious Emissions
Power vs Time
Channel power
IM distortion
CCDF
ACPR
EVM
SEM

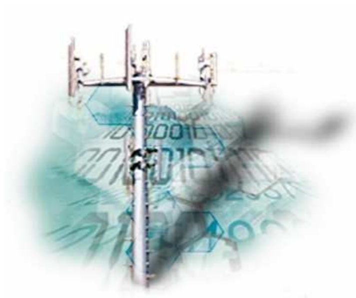


Who needs wide analysis BW?

Modern designs demand more bandwidth for capturing high data rate signals and analyzing the quality of digitally modulated bandwidths

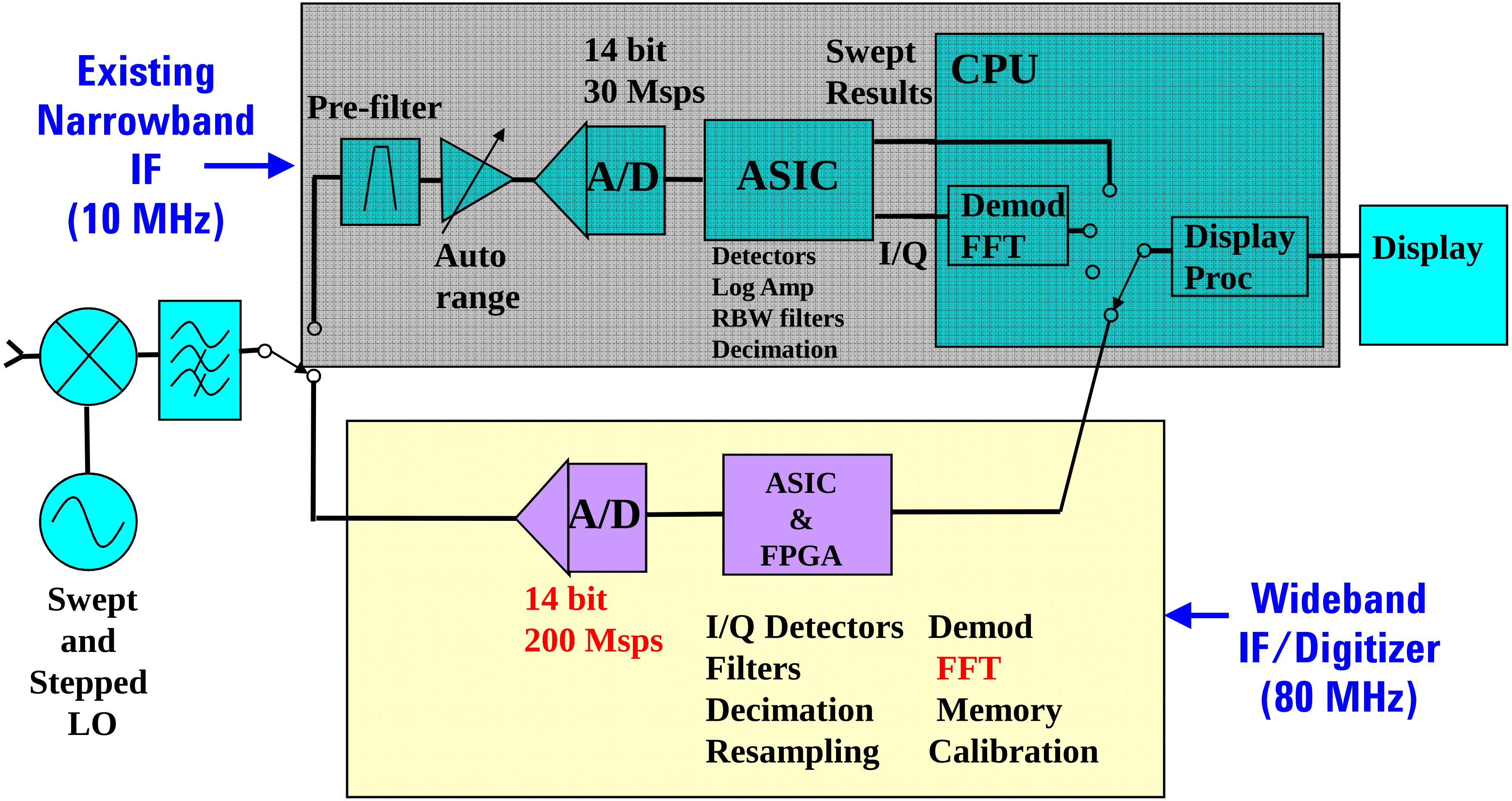
- Aerospace and Defense
  - Radar – Chirp errors & modulation quality
    Satellite – Capture 36/72 MHz BW's w/high data rates
    Military communications – Capture high data rate digital comms & measure EVM

- Emerging communications
  - W-LAN, 802.16 (wireless last mile), mesh networks
    - Measure EVM on broadband, high data rate signals



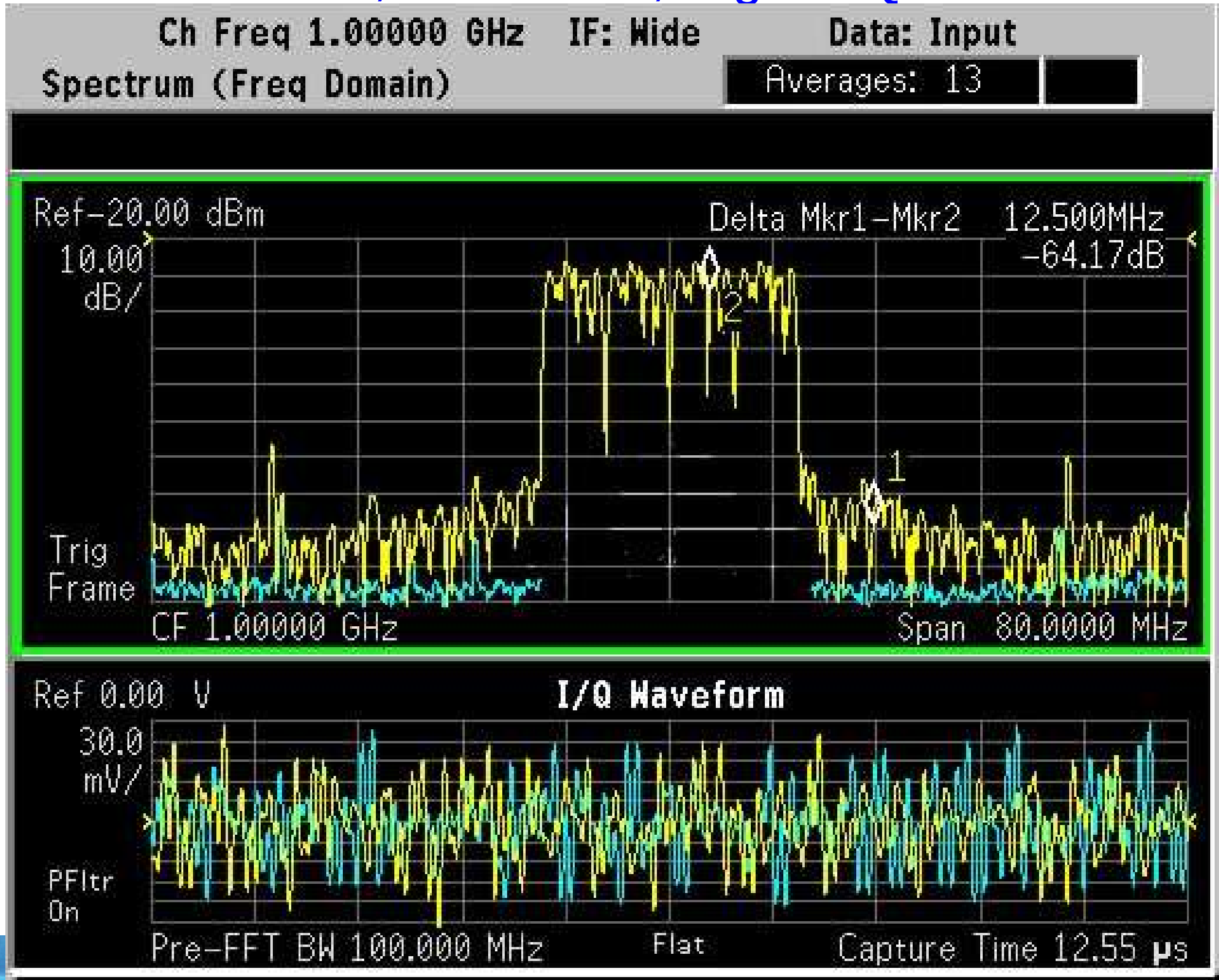
- Cellular Communications
  - W-CDMA ACPR & Multi-carrier Pre-Distortion
    - High dynamic range over 60 MHz BW to see low level 3rd order distortion for 4 carrier pre-distortion algorithms

PSA Wide Analysis Bandwidth

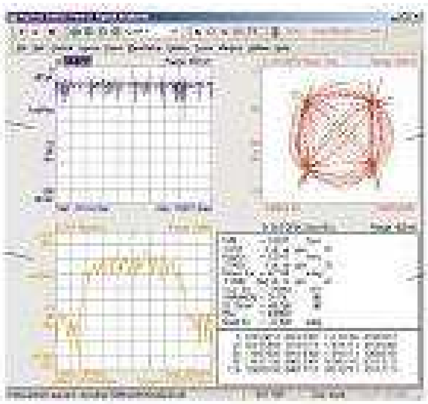


PSA Wide Analysis Bandwidth

80 MHz Analysis Bandwidth Snapshot
w/Real Time, Calibrated, Digital IQ Detection



Measurement of Analog IQ Signals



89601A VSA
Software in both
domains

RF

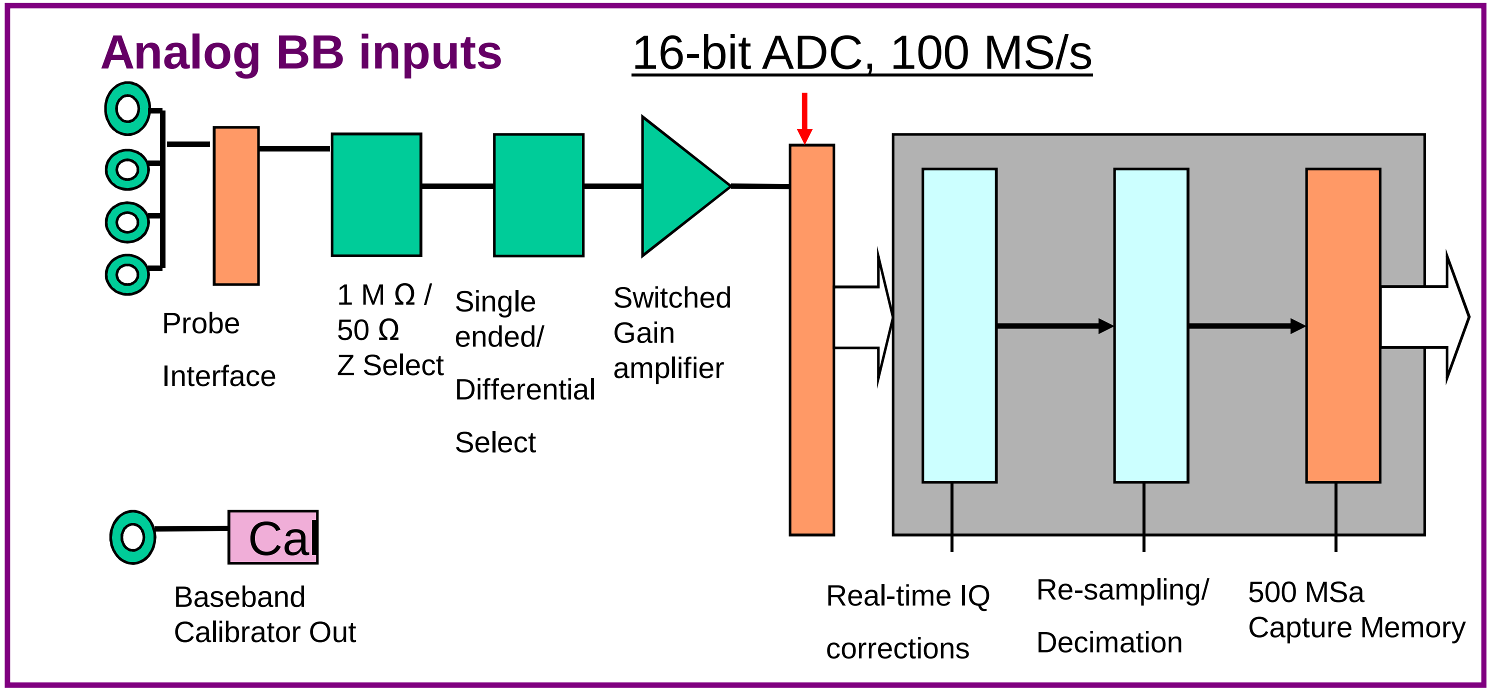
MXA Spectrum Analyzer

Analog Baseband

MXA BBIQ

Oscilloscope for baseband has some limitations

MXA **Baseband** and RF



Baseband to 40 MHz (for 1ch/2ch)

10, 25 or 40 MHz BW

500 MSa memory

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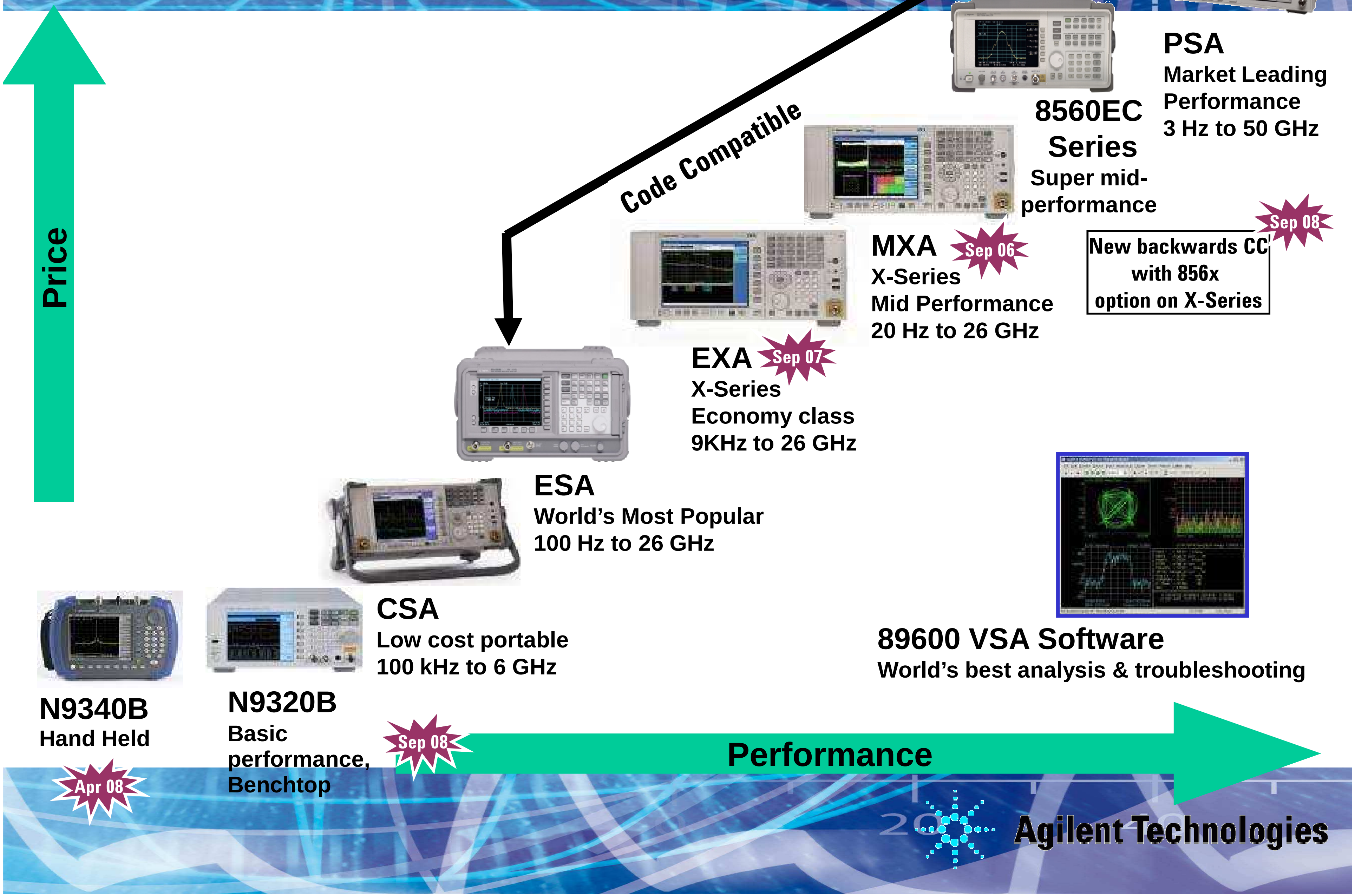
Agilent Spectrum Analysis Portfolio



Agilent Spectrum Analyzer Families

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

N9320A Series

- Basic Performance Benchtop SA -- 9kHz to 3.0 GHz
- Auto Tune — for auto signal search
- 9.2 ms non-zero span sweep time
- RBW from 10Hz to 1MHz
- Displayed Average Noise level of -130 dBm, -148 dBm with pre-amplifier
- One-button power measurements (Channel power, ACPR, SEM, OBW, TOI)

CSA

- Low priced, basic performance SA
- 100 kHz to 3, 6 GHz
- Lightweight portable, optional internal battery
- General purpose for Mfg., bench-top and service environments
- Cable fault, return and insertion loss, built-in TG and VSWR bridge

Agilent Spectrum Analyzer Families

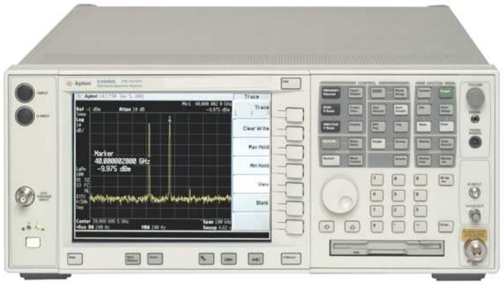
EXA Series

- Economy Performance SA -- 9kHz to 3.6, 7.0, 13.6, 26 GHz
- Industry leading speed
- All digital IF -- 160 RBW settings FFT or swept
- 10 MHz analysis BW
- Optional measurement applications including WiMAX, GSM, W-CDMA & PN
- 89601A VSA software runs inside EXA

MXA Series

- Mid-Performance SA -- 20 Hz to 3.6, 8.4, 13.6, 26 GHz
- Industry leading speed
- All digital IF -- 160 RBW settings FFT or swept
- 25 MHz analysis BW
- Optional measurement applications including WiMAX, GSM, W-CDMA & PN
- 89601A VSA software runs inside MXA

Agilent Spectrum Analyzer Families



PSA Series

- Highest performance SA -- 3 Hz to 6.7, 13.2, 26.5, 44, 50 / 325 GHz
- Industry leading accuracy (±0.62dB)
- All digital IF -- 160 RBW settings FFT or swept
- 40/80 MHz analysis BW with >75 dB dynamic range
- 2G/3.5 G digital demodulation
- 15 Optional measurement personalities

ESA-E Series

- Mid-Performance SA
- 30 Hz to 3, 6.7, 13.2, 26.5 / 325 GHz
- Rugged/Portable with color LCD display
- Fast & Accurate with 5 minute warm-up
- Unparalleled range of performance and application options.
- Express analyzers for fast & easy delivery

856X- EC Series

- Mid-Performance SA
- 30 Hz to 2.9, 13.2, 26.5, 40, 50 / 325 GHz
- Rugged/Portable
- Color LCD Display
- Low Phase Noise
- Digital 1 Hz RBW

Agilent Vector Signal Analyzer Families

89600A Series

- Multi-Format & Flexible vector signal analysis
- DC – 26.5 GHz
- Analysis Bandwidths 36 MHz to 13 GHz
- RF and modulation quality of digital communications signals
- Spectrum & Time (FFT) Analysis
- OFDM Analysis (802.11 and 802.16)
- Links to design software (ADS)
- Analysis software links to PSA, MXA, ESA, VXI, E4406A analyzers & Infiniium scopes.

89600 Ultra-wide VSA bandwidth

- Up to 13 GHz Analysis Bandwidth!
- 89600 Vector Analysis Software runs internal or external to oscilloscope
- Infiniium oscilloscope front-ends for "RF Scope" measurements

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Selection of Basic Spectrum Analyzer Application & Product Notes

- **Selecting the Right Spectrum Analyzer for Your Needs #5968-3413E**

- **A.N. 150 – Spectrum Analysis Basics #5952-0292EN**
- **A.N. 150-15 - Vector Signal Analysis Basics #5989-1121EN**

• **PSA Brochure**	**5980-1283E**
• **MXA Brochure**	**5989-5047EN**
• **EXA Brochure**	**5989-6527EN**
• **ESA Brochure**	**5968-3278E**
• **CSA Tech Overview**	**5989-3678EN**
• **N9320A Tech Overview**	**5989-5521EN**
• **N9340B Tech Overview**	**5989-5971EN**

www.agilent.com/find/sa

The End

THANK YOU!