# 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 Signal Analyzer Designs & Capabilities

- Wide Bandwidth Vector Measurements

Wrap-up

# Analyzer Definitions

## Spectrum Analyzer

– "A spectrum analyzer measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. The primary use is to measure the power of the spectrum of known and unknown signals."

## Vector Signal Analyzer

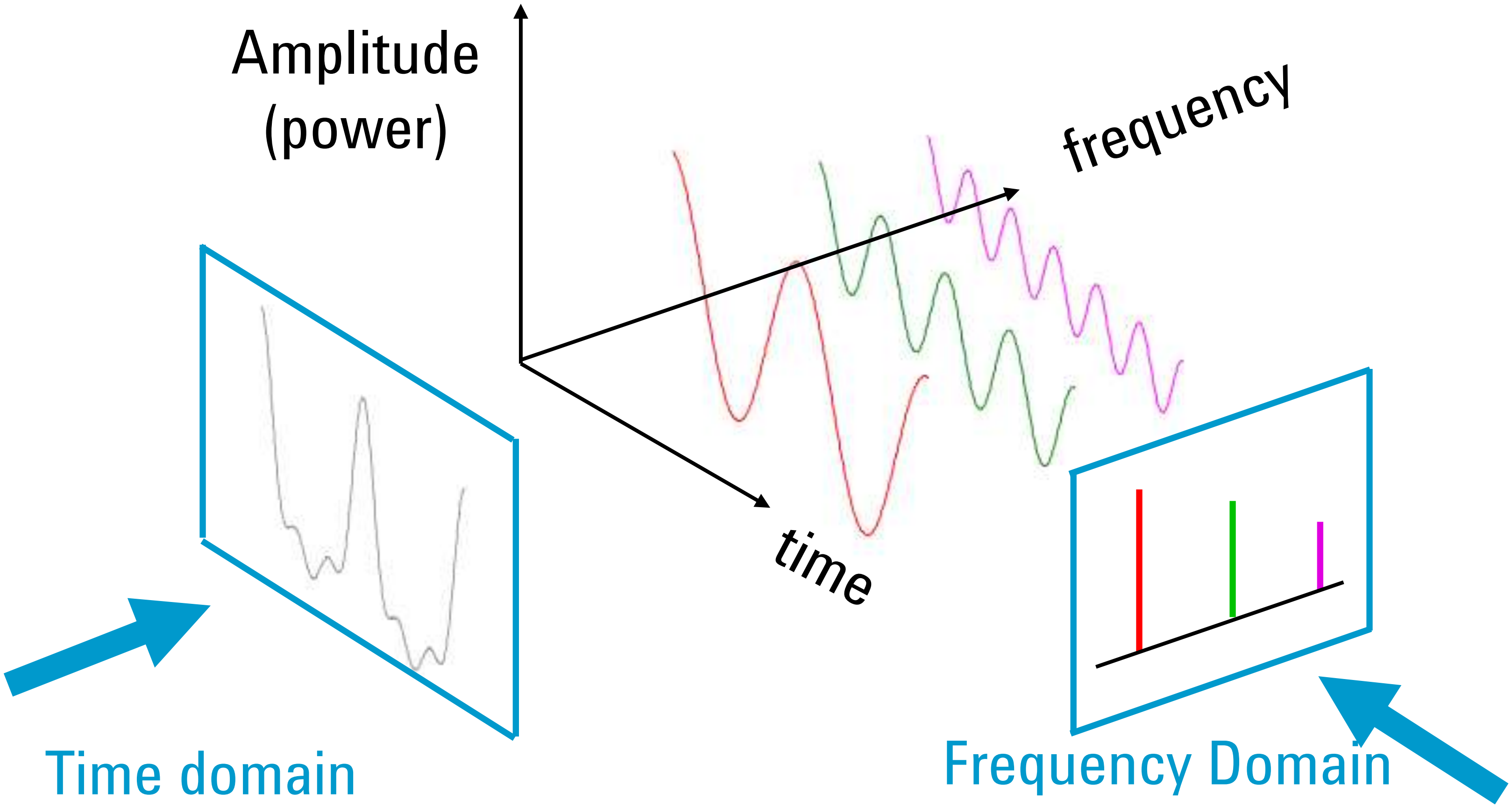
– "A vector signal analyzer measures the magnitude and phase of an input signal at a single frequency within the IF bandwidth of the instrument. The primary use is to make in-channel measurements, such as error vector magnitude, code domain power, and spectral flatness, on known signals."

## Signal Analyzer

– "A signal analyzer provides the functions of a spectrum analyzer and a vector signal analyzer."

# Overview

## Frequency versus Time Domain



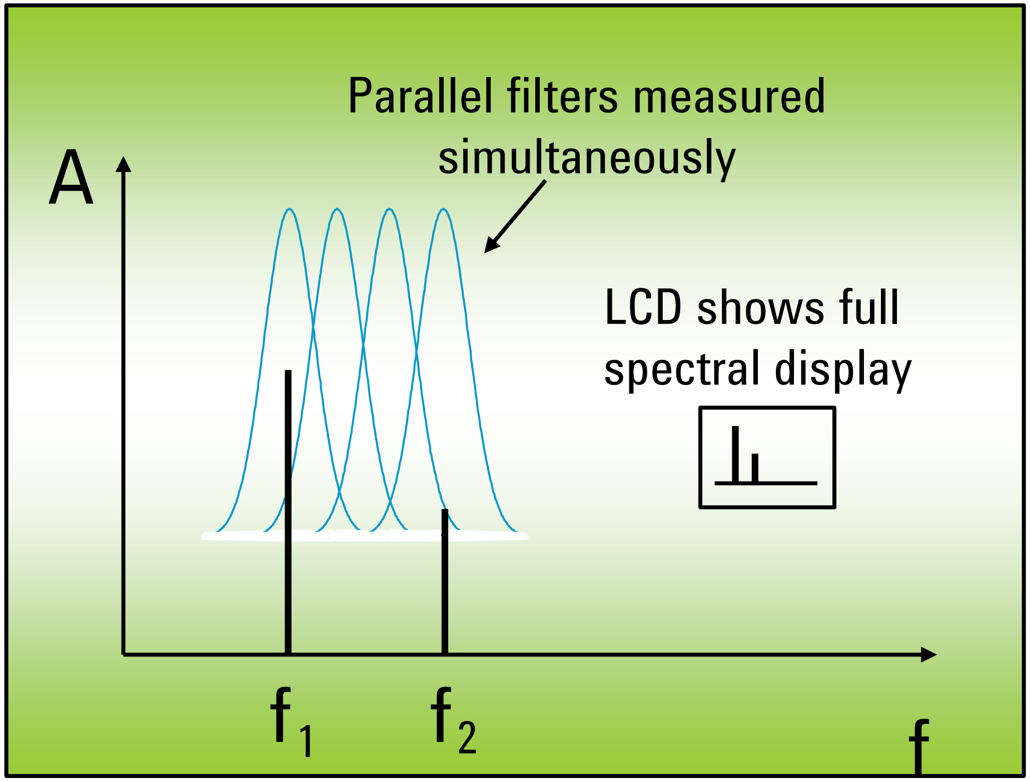

Time domain Measurements (Oscilloscope)

Frequency Domain Measurements (Spectrum Analyzer)

# Overview

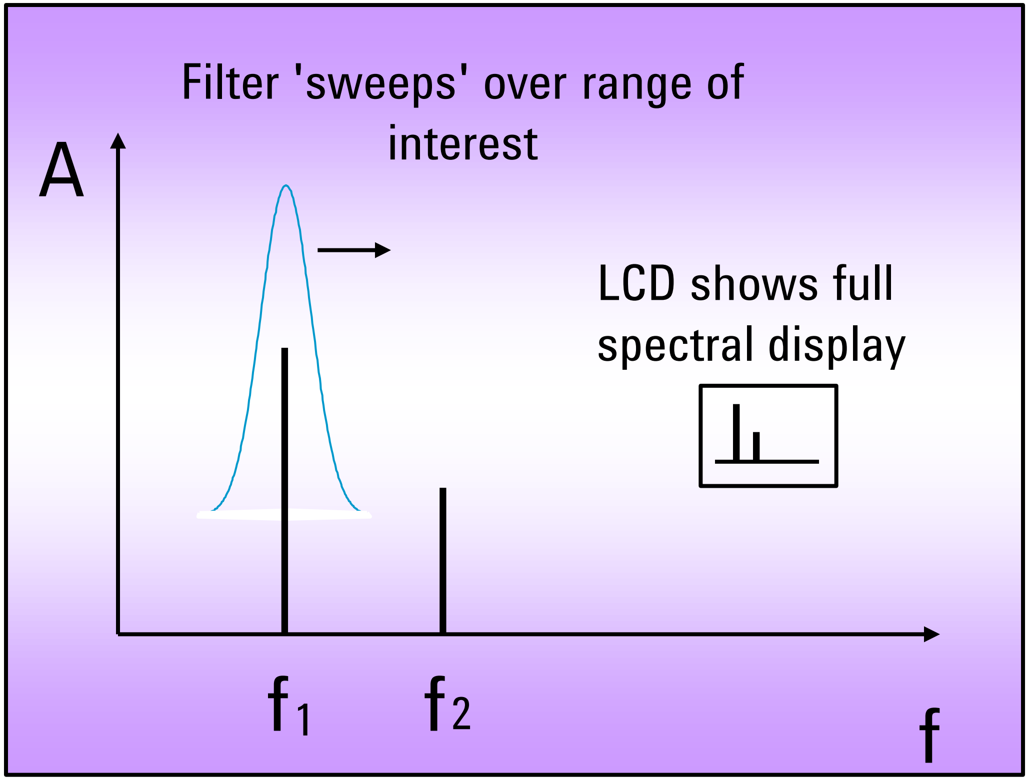
## Different Types of Analyzers

### FFT Analyzer



# Overview
## Different Types of Analyzers

### Swept Analyzer



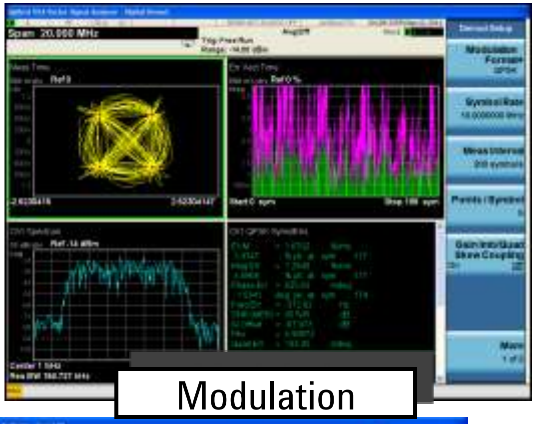
# Overview

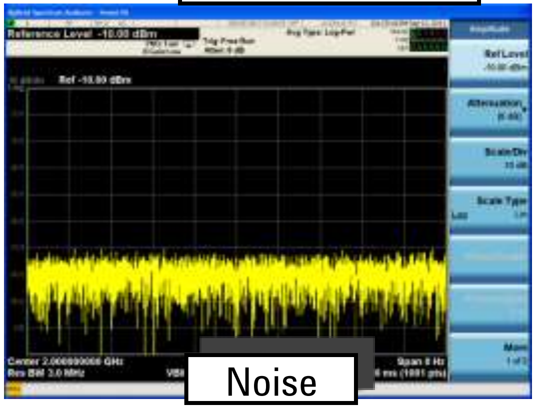
## Types of Measurements Available

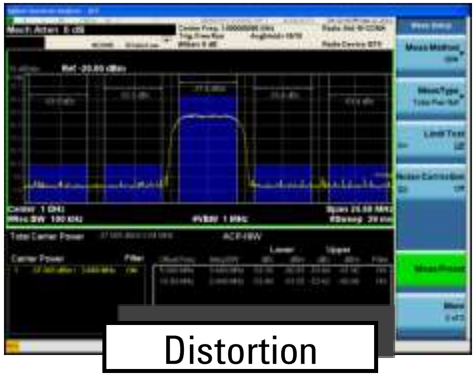
Frequency, power, modulation, distortion & noise

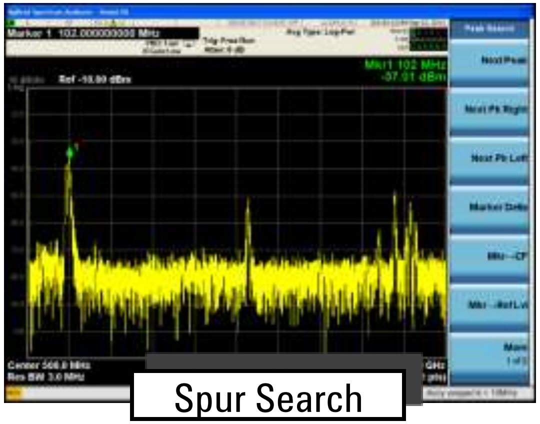
- Spectrum monitoring
- Spurious emissions
- Scalar network analysis
- Noise figure & phase noise
- Harmonic & intermodulation distortion
- Analog, digital, burst & pulsed RF Modulation
- Wide bandwidth vector analysis
- Electromagnetic interference

- *Measurement range (-172 dBm to +30 dBm)*
- *Frequency range (3 Hz to >>325 GHz)*



# Agenda

Introduction

Overview

Theory of Operation:

- Swept Spectrum Analyzer Hardware

Specifications

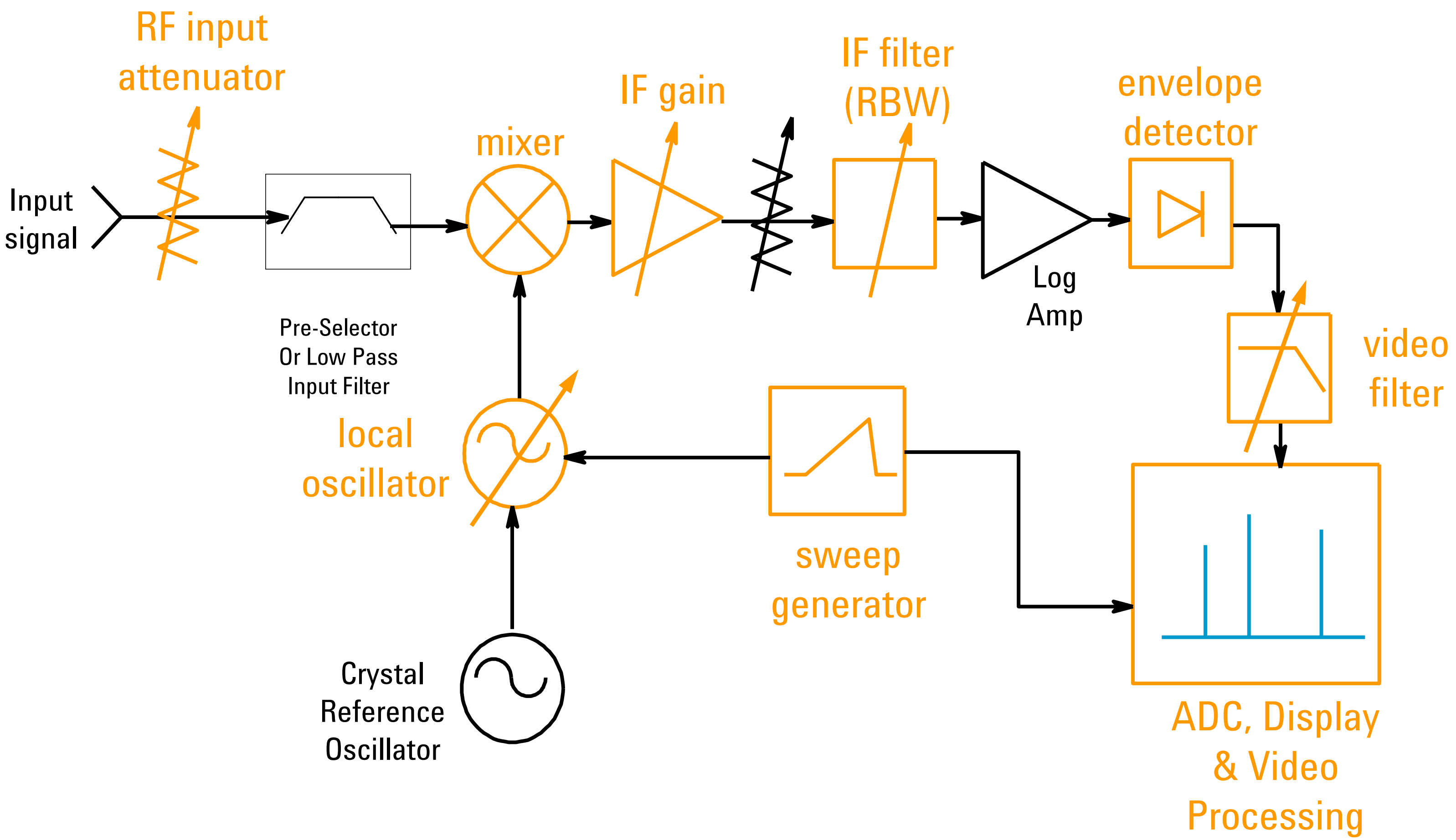
Modern spectrum analyzer designs & capabilities

  – Wide Bandwidth Vector Measurements

Wrap-up

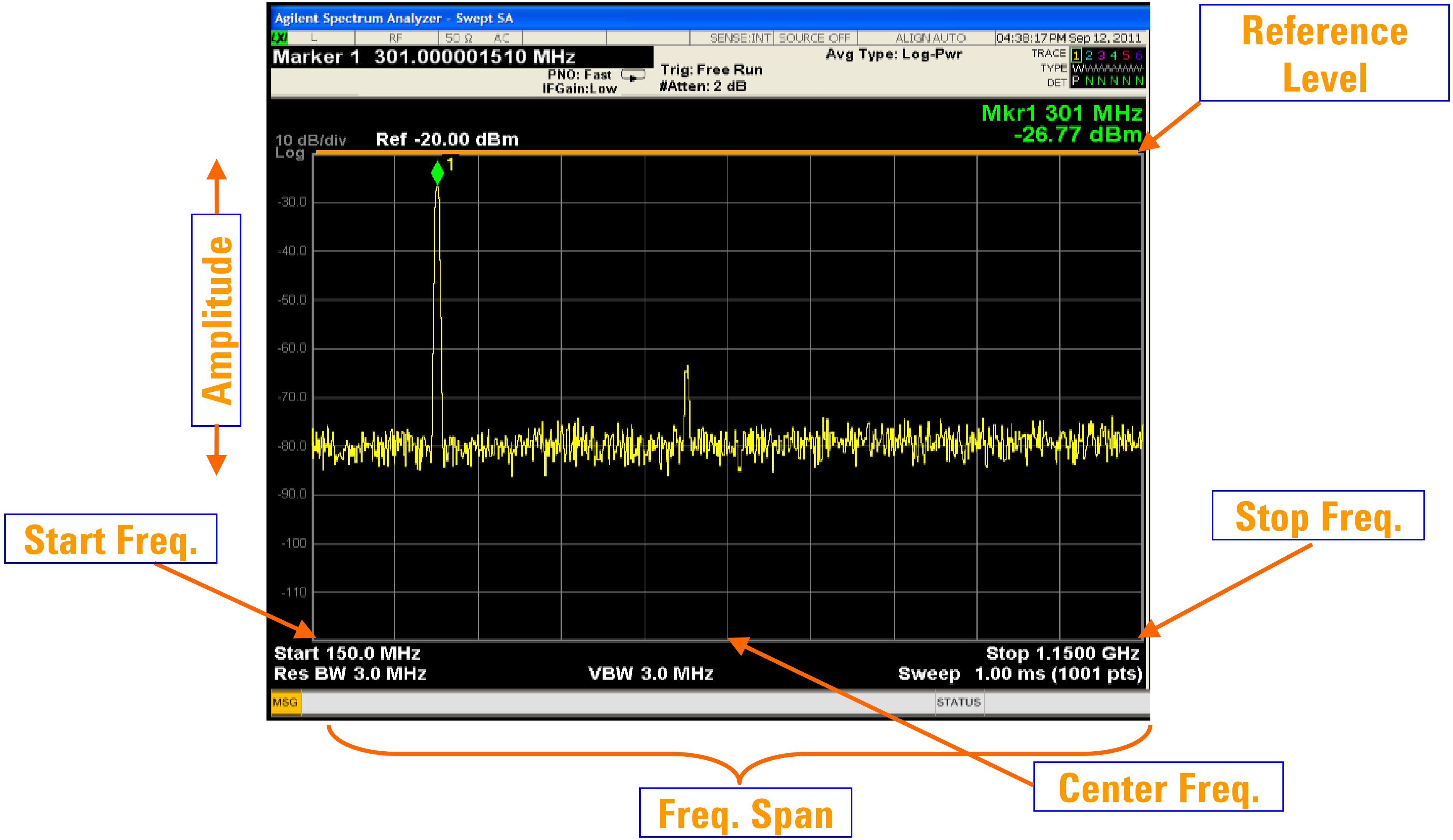
# Theory of Operation

## Traditional Swept Spectrum Analyzer Block Diagram



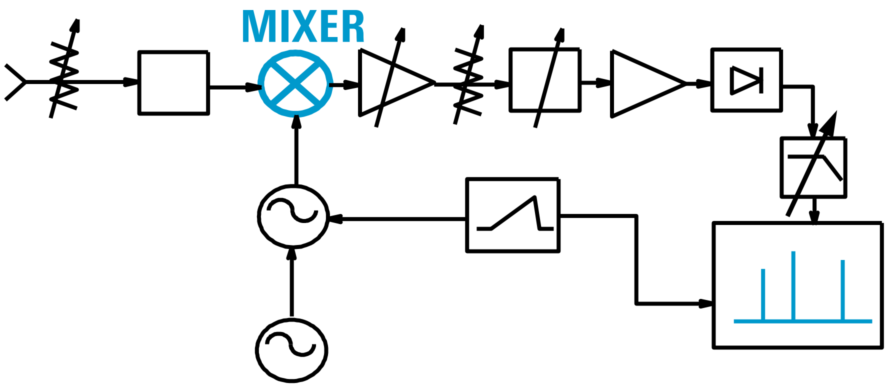
# Theory of Operation

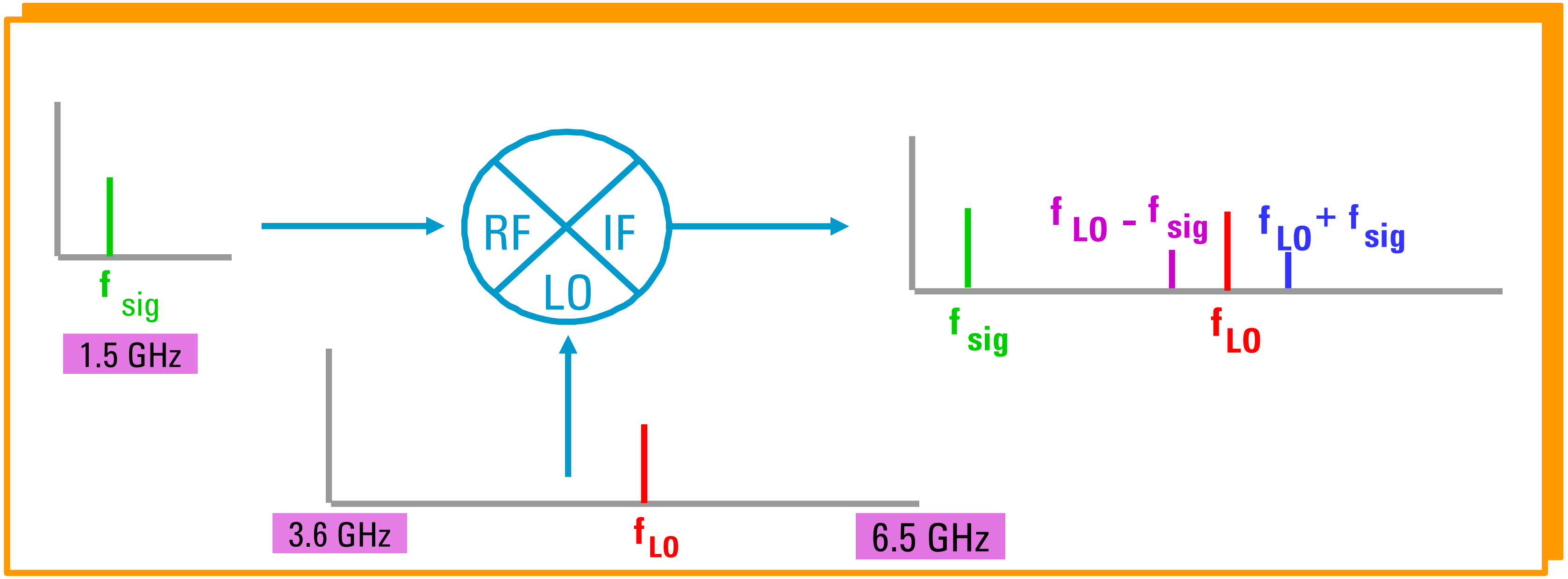
## Display terminology



# Theory of Operation

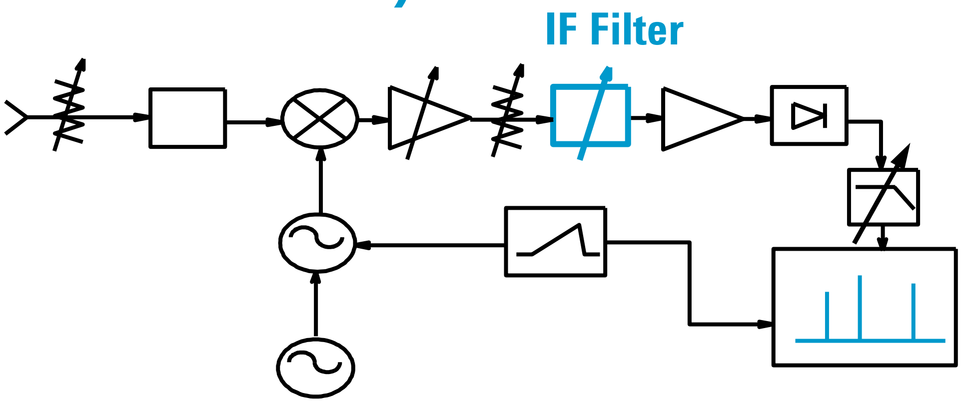
## Mixer

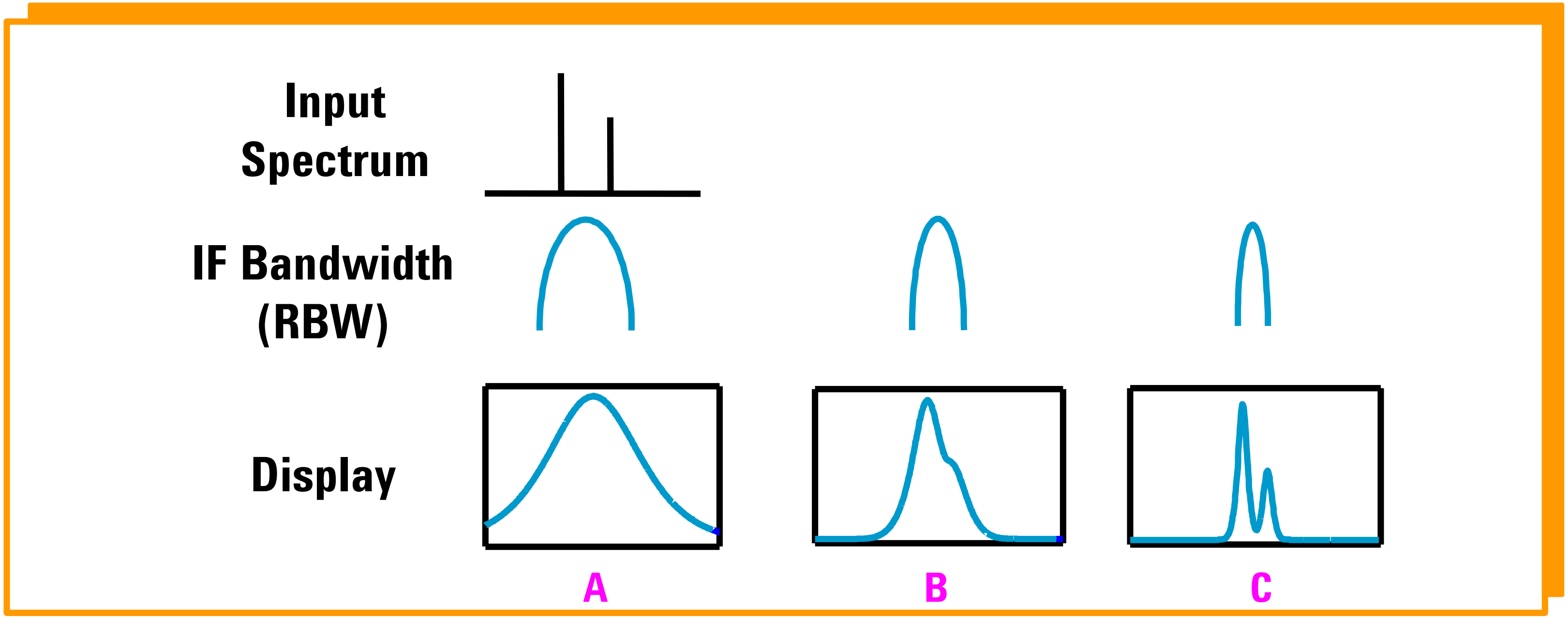


# Theory of Operation

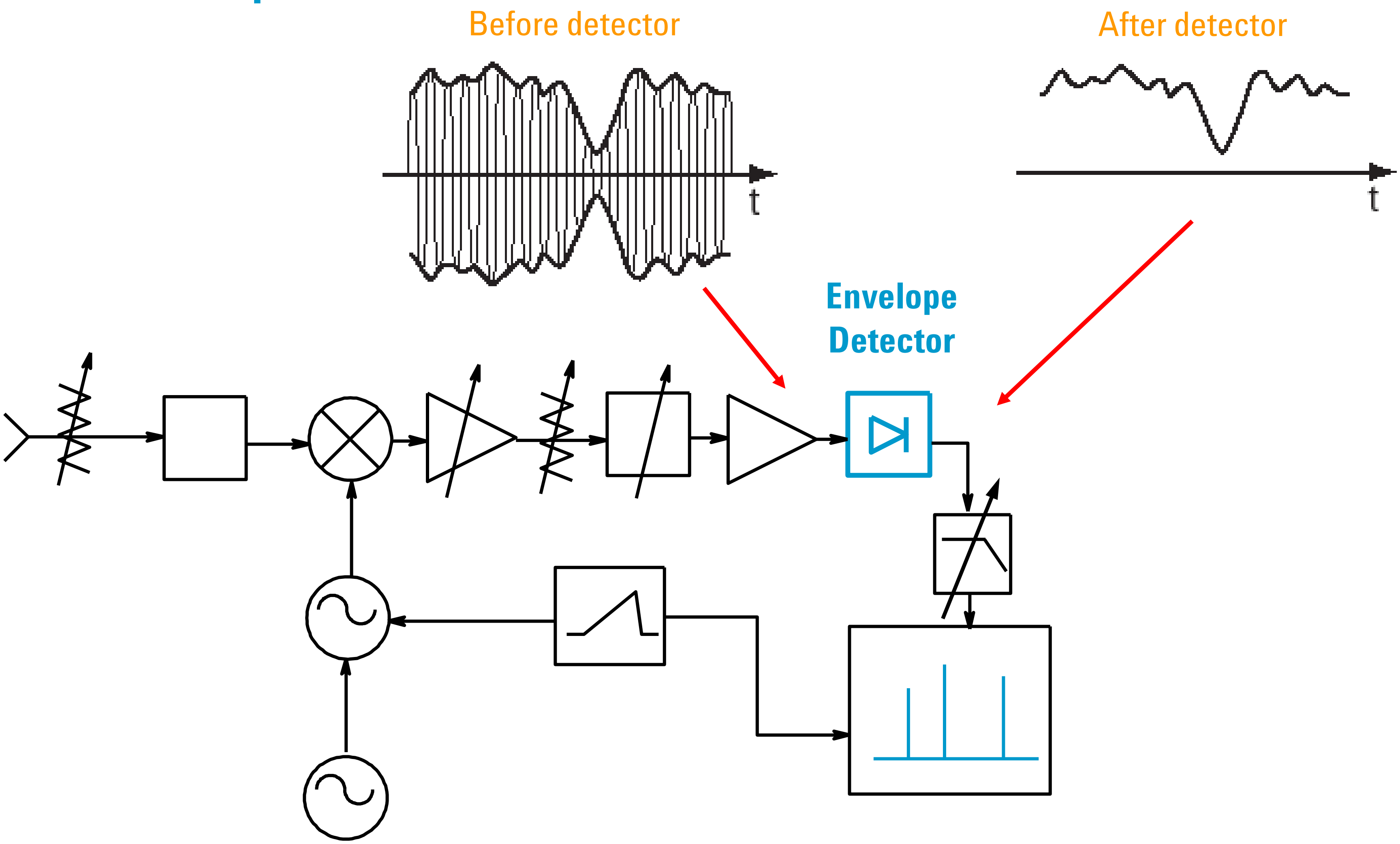
## IF Filter (Resolution Bandwidth – RBW)



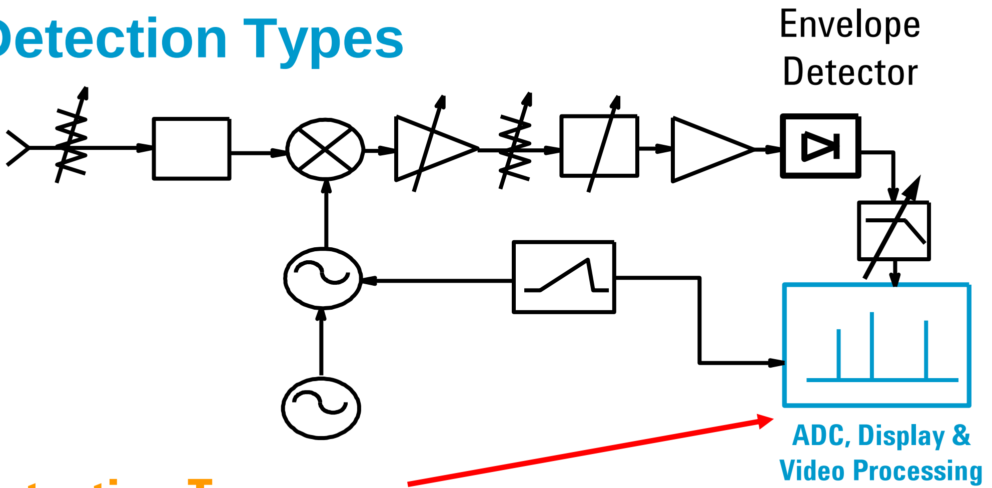
# Theory of Operation

## Envelope Detector

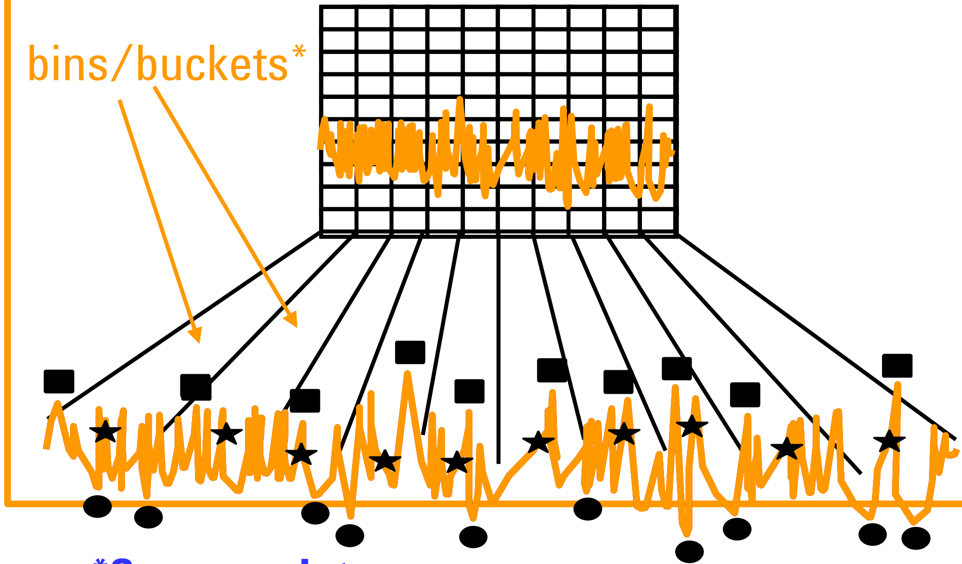


# Theory of Operation

## Envelope Detector and Detection Types




### Digitally Implemented Detection Types



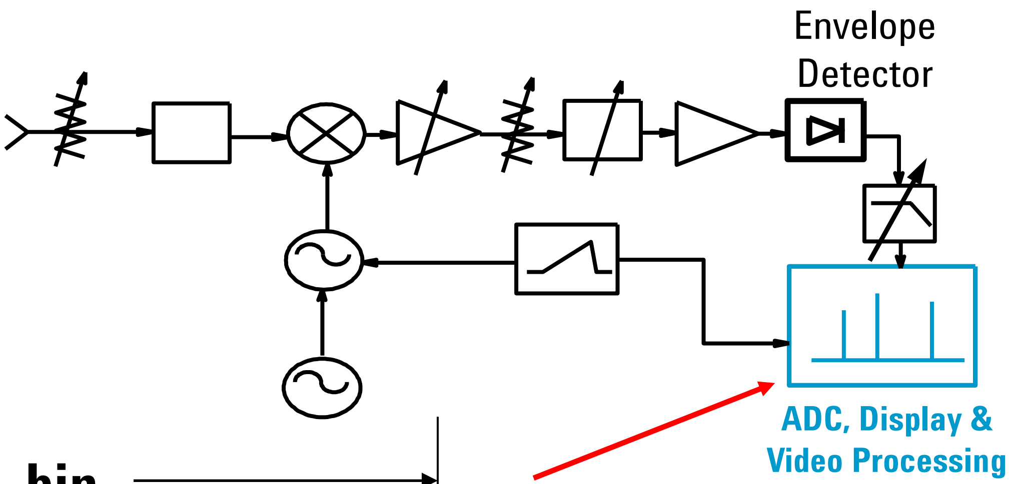

- ■ Positive detection: largest value in bin displayed
- ● Negative detection: smallest value in bin displayed
- ★ Sample detection: middle value in bin displayed

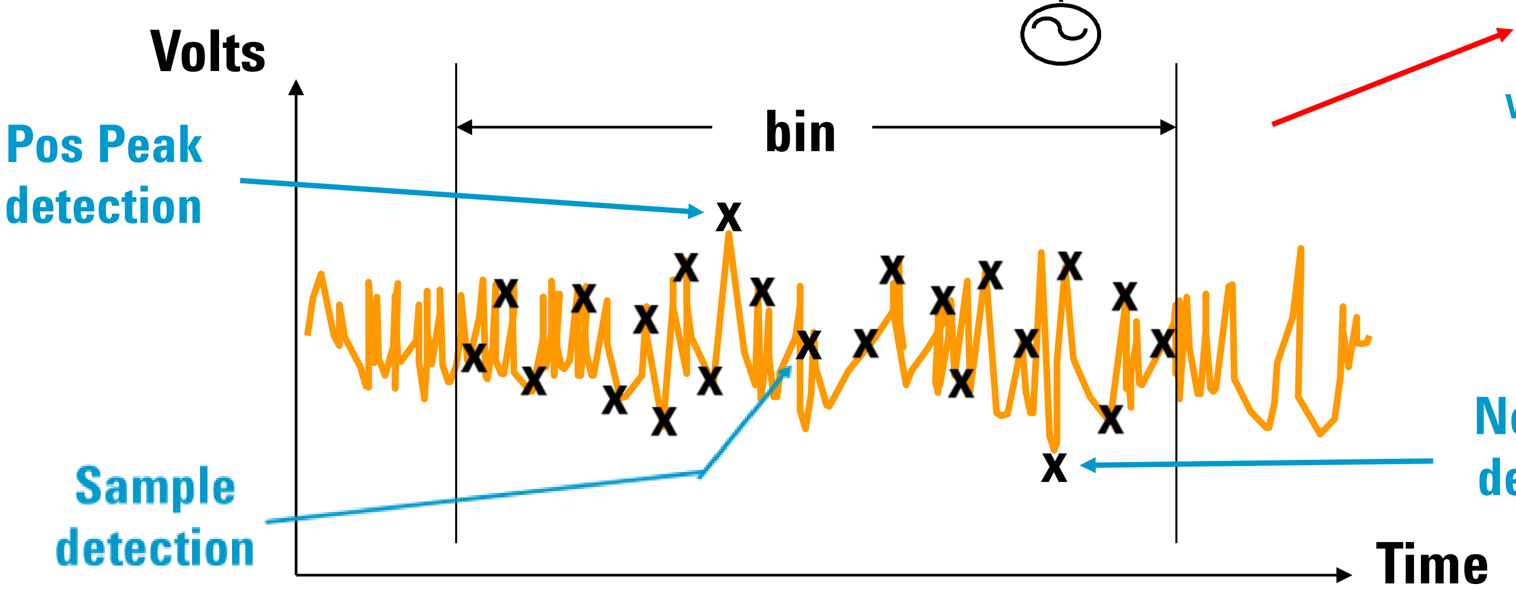
Other Detectors: Normal (Rosenfell), Average (RMS Power)

*Sweep points

# Theory of Operation

## Average Detector Type

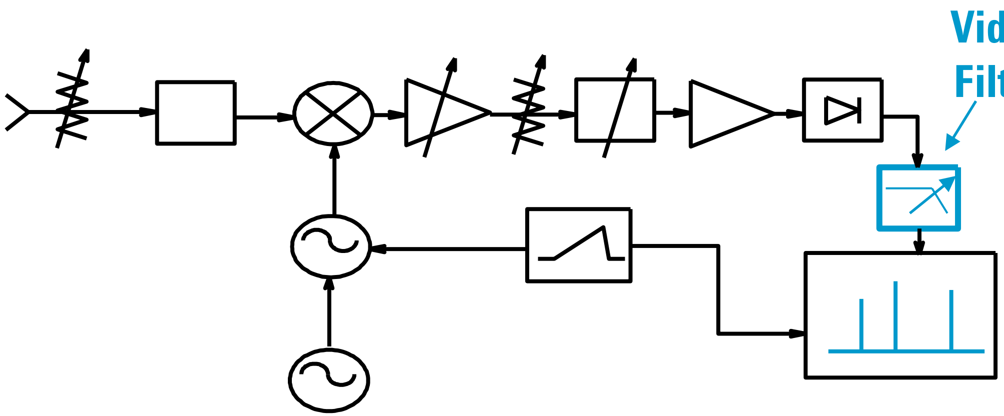


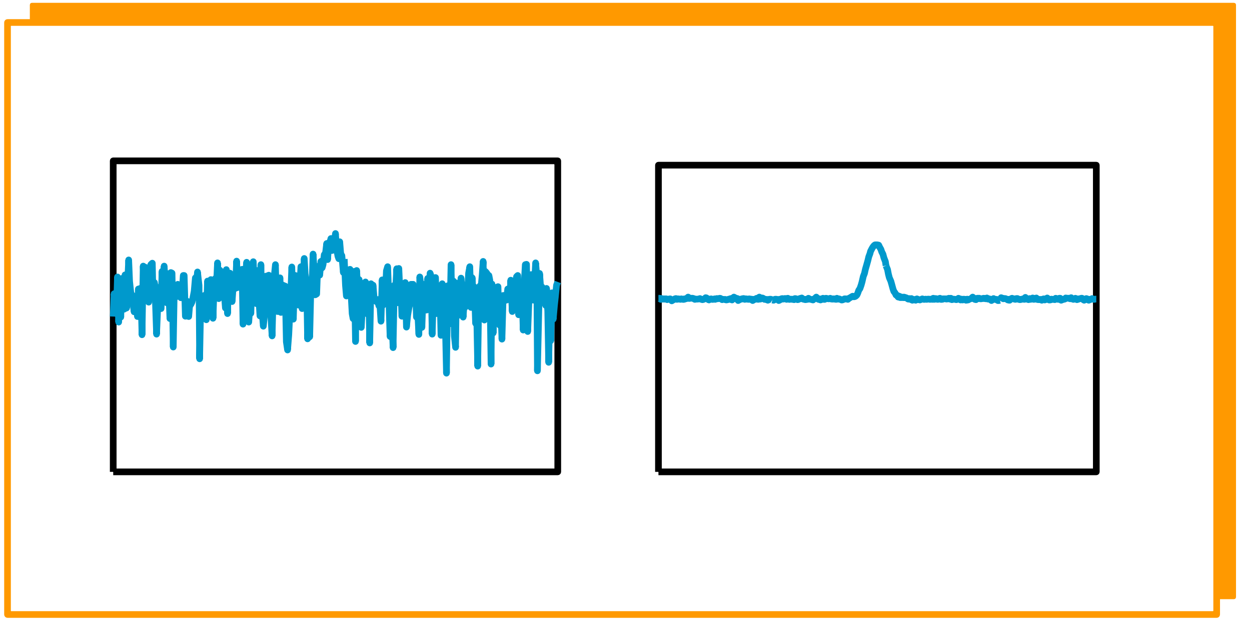




**Power Average Detection (rms) = Square root of the sum of the squares of ALL of the voltage data values in the bin /50Ω**

# Theory of Operation

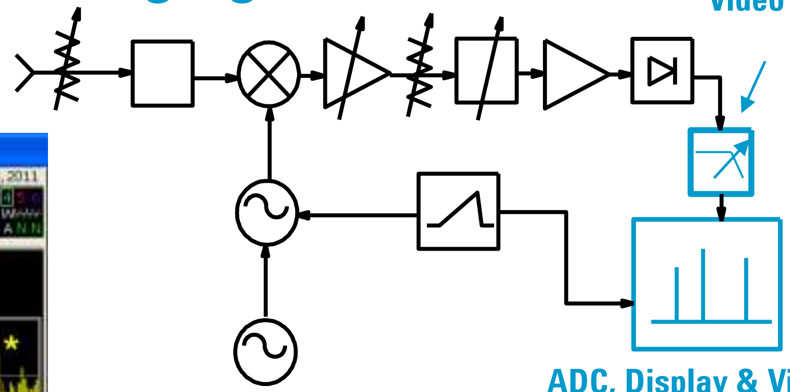
## Video Filter (Video Bandwidth – VBW)



# 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)

- 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

# Agenda

Overview

Theory of Operation

Specifications:

- Which are important and why?

Modern spectrum analyzer designs & capabilities

  – Wide Bandwidth Vector Measurements

Wrap-up

# Specifications?

## Agilent Terminology

Specifications **describe the performance of parameters covered by the product warranty (temperature = 0 to 55°C, unless 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 measurement uncertainty.**

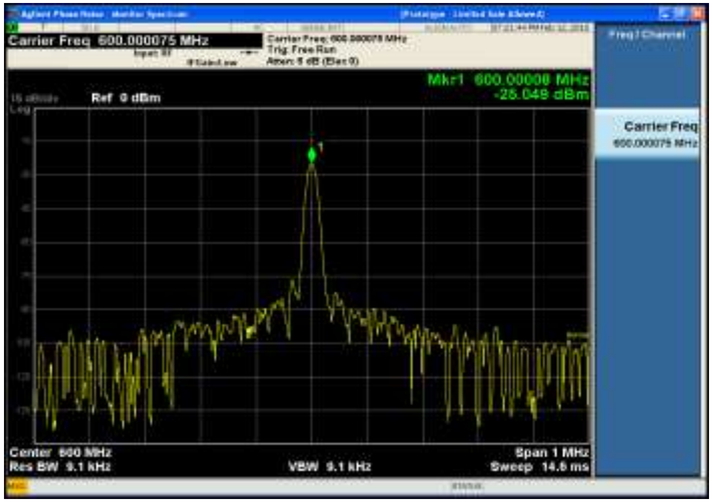
Nominal **values indicate expected performance, or describe product performance that is useful in the application of the product, but is not covered by the product warranty.**

# Key Specifications

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

# Specifications
## Frequency Range

| Description | Specifications |
|---|---|
| **Internal Mixing** | |
| **Bands** | |
| **0** | **3 Hz to 3.6 GHz** |
| **1** | **3.5 to 8.4 GHz** |
| **2** | **8.3 to 13.6 GHz** |
| **3** | **13.5 to 17.1 GHz** |
| **4** | **17 to 26.5 GHz** |
| **5** | **26.4 to 34.5 GHz** |
| **6** | **34.4 to 50 GHz** |



# Specifications

## 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

## Frequency Readout Accuracy Example

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

**Calculation :**

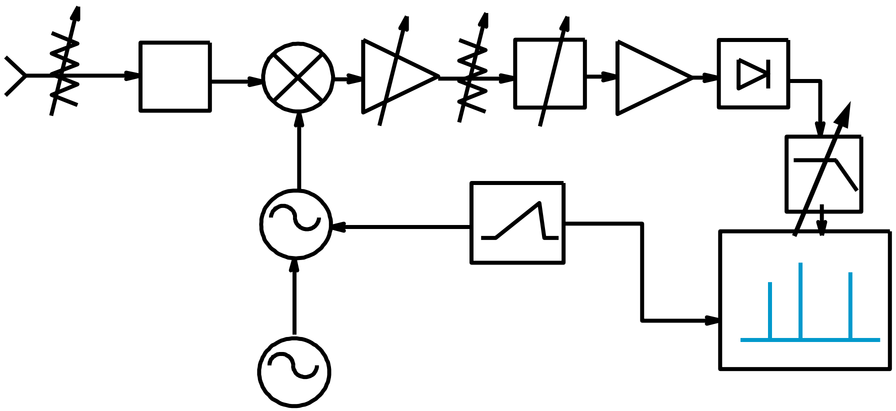
| | |
|---|---|
| $(1 \times 10^9 Hz) \times (\pm 1.55 \times 10^{-7}$/Year ref. Error) | = **155Hz** |
| 400kHz Span x 0.1% | = **400Hz** |
| 3kHz RBW x 5% | = **150Hz** |
| 2Hz + 0.5 x 400kHz/(1000-1) | = **202Hz** |
| **Total uncertainty** | = **±907Hz** |

*Utilizing internal frequency counter improves accuracy to ±155Hz

** The Maximum # of sweep points for the X-Series is 40,001 which helps to achieve the best frequency readout accuracy

# Specifications

## Amplitude accuracy

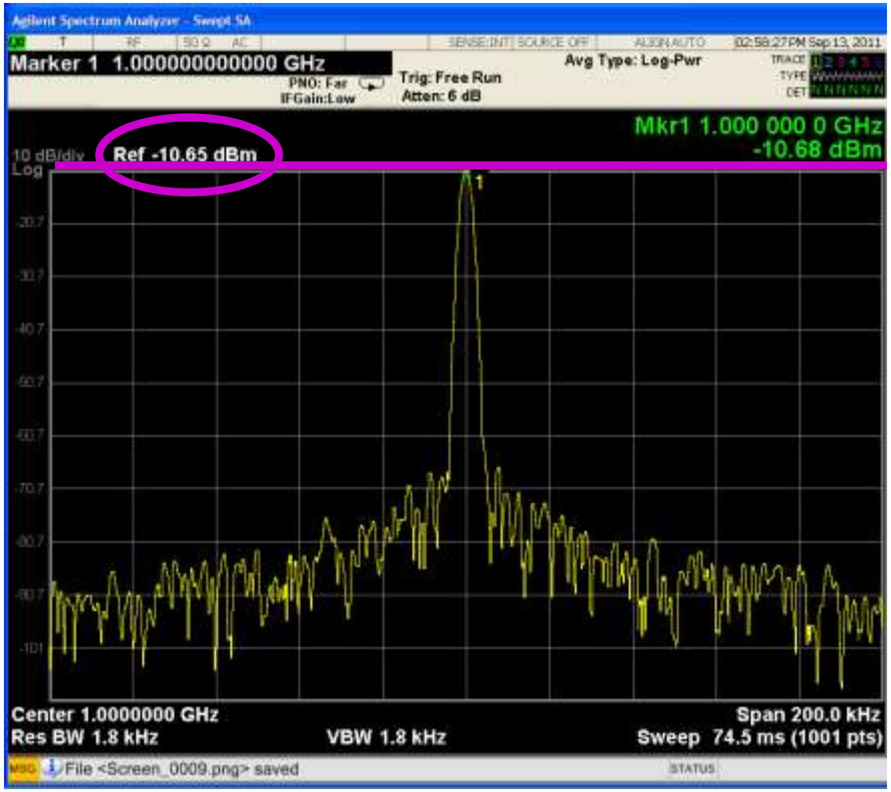


Components which contribute to amplitude uncertainty are:

- 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)
- Calibrator (amplitude accuracy)

# Specifications

## Amplitude Accuracy: Reference Level Switching




Uncertainty applies when changing the Ref. Level

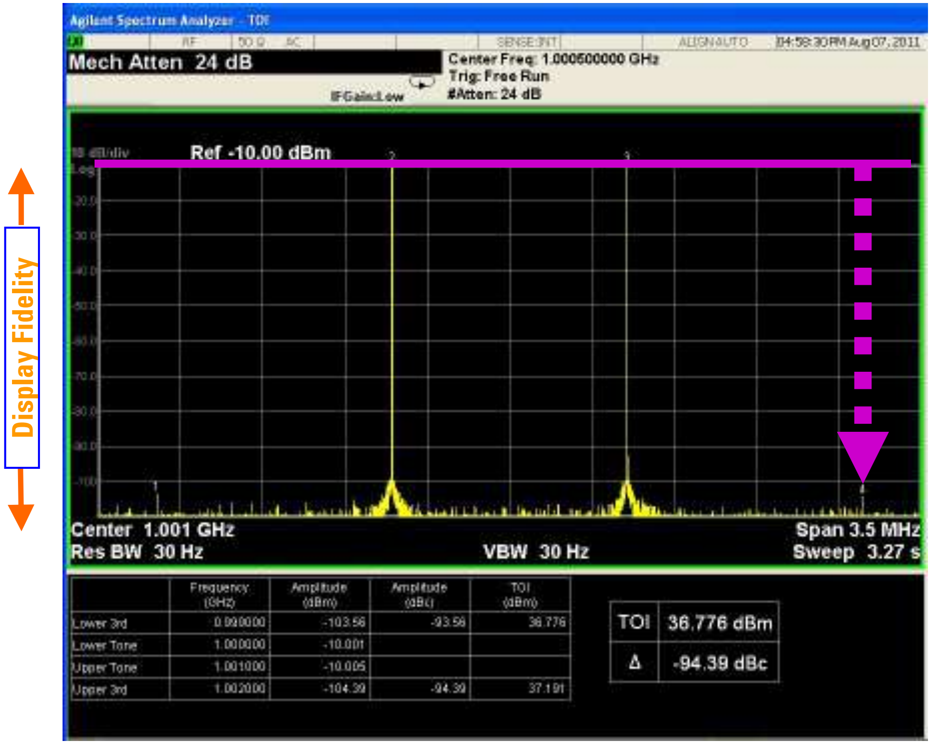
Also called IF Gain Uncertainty

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

However with today's X-series analyzers, provided the attenuation remains unchanged, the signal no longer needs to be at the reference level for the most accurate measurement.

# Specifications

## Accuracy: Display Fidelity




Display Fidelity includes:

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

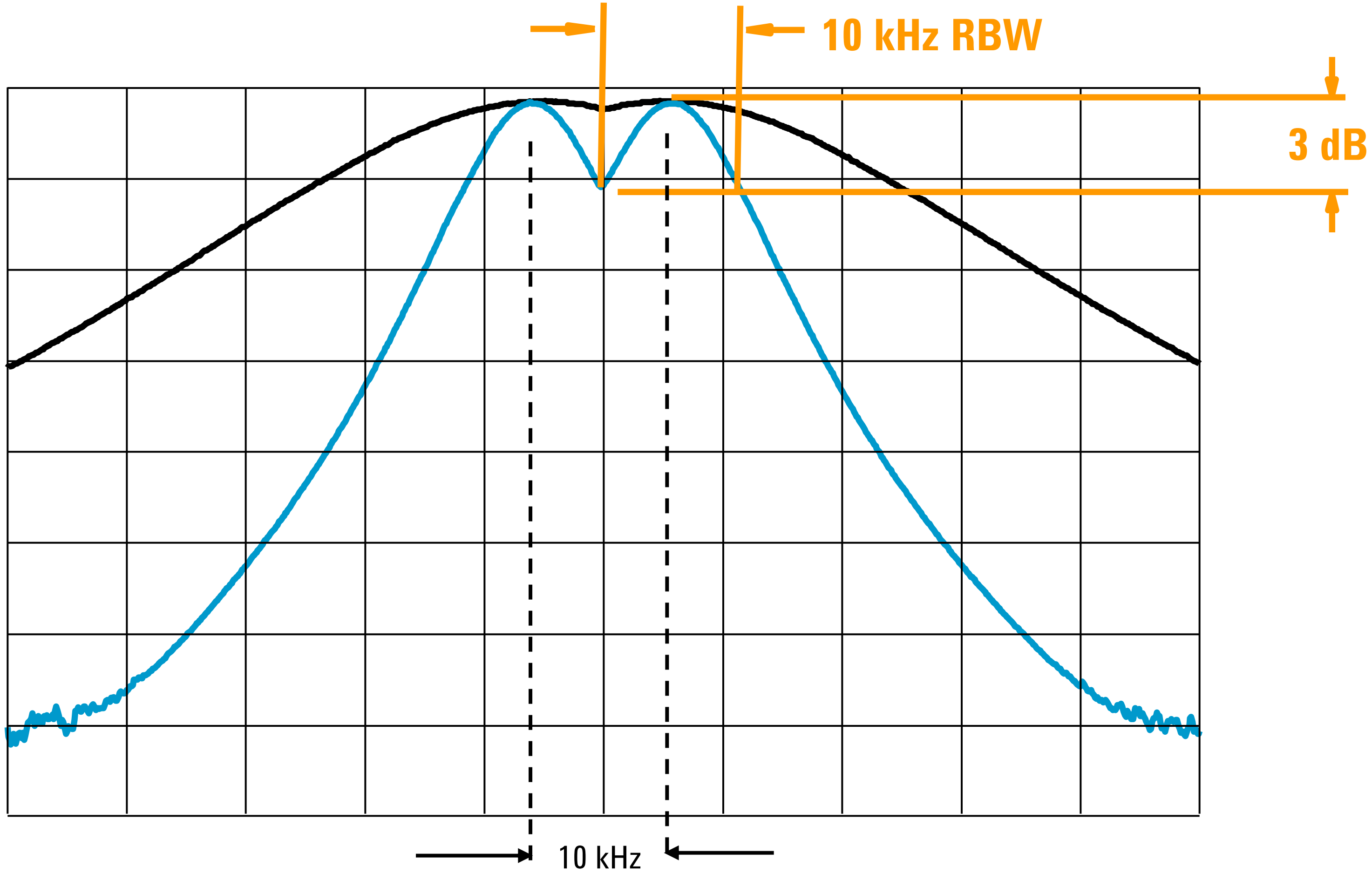
Display fidelity error applies when signals are not at the same reference level amplitude when measured

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

Display Scale Fidelity of analyzers with digital IF are superior to those with analog IF i.e. X-series analyzers have +/- 0.1 db vs. ESA, 856xEC +/- 1.0 db

# Specifications

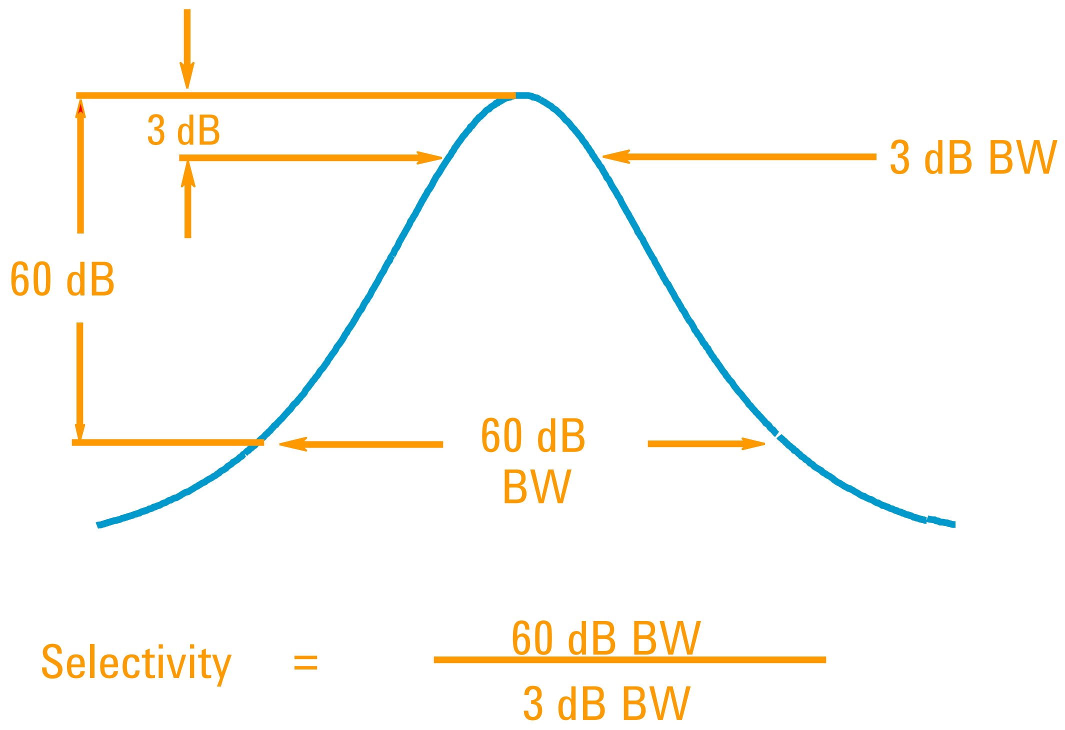
## Resolution: Resolution BW




**Determines resolvability of equal amplitude signals**

# Specifications

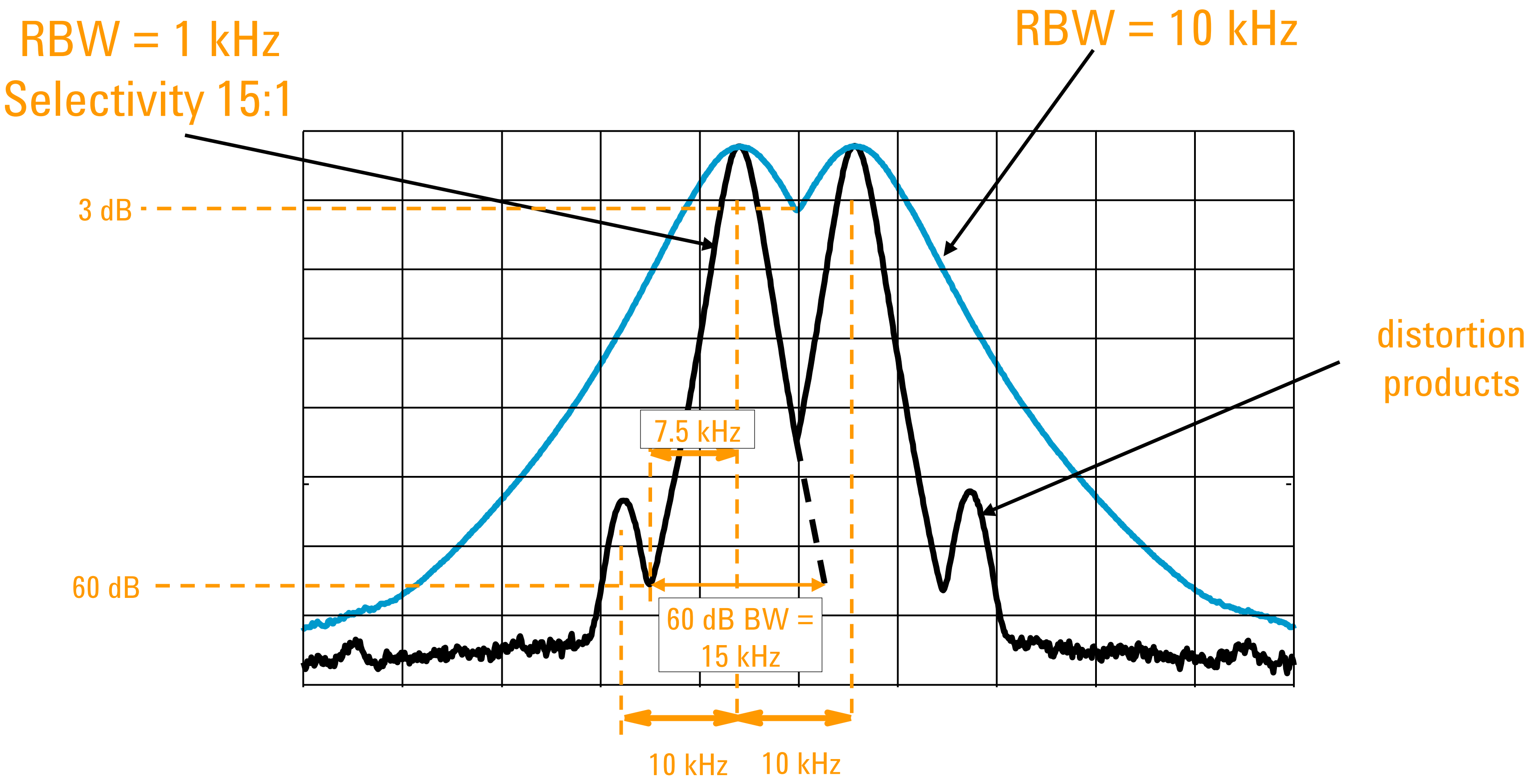
## Resolution BW Selectivity or Shape Factor




**Determines resolvability of unequal amplitude signals**

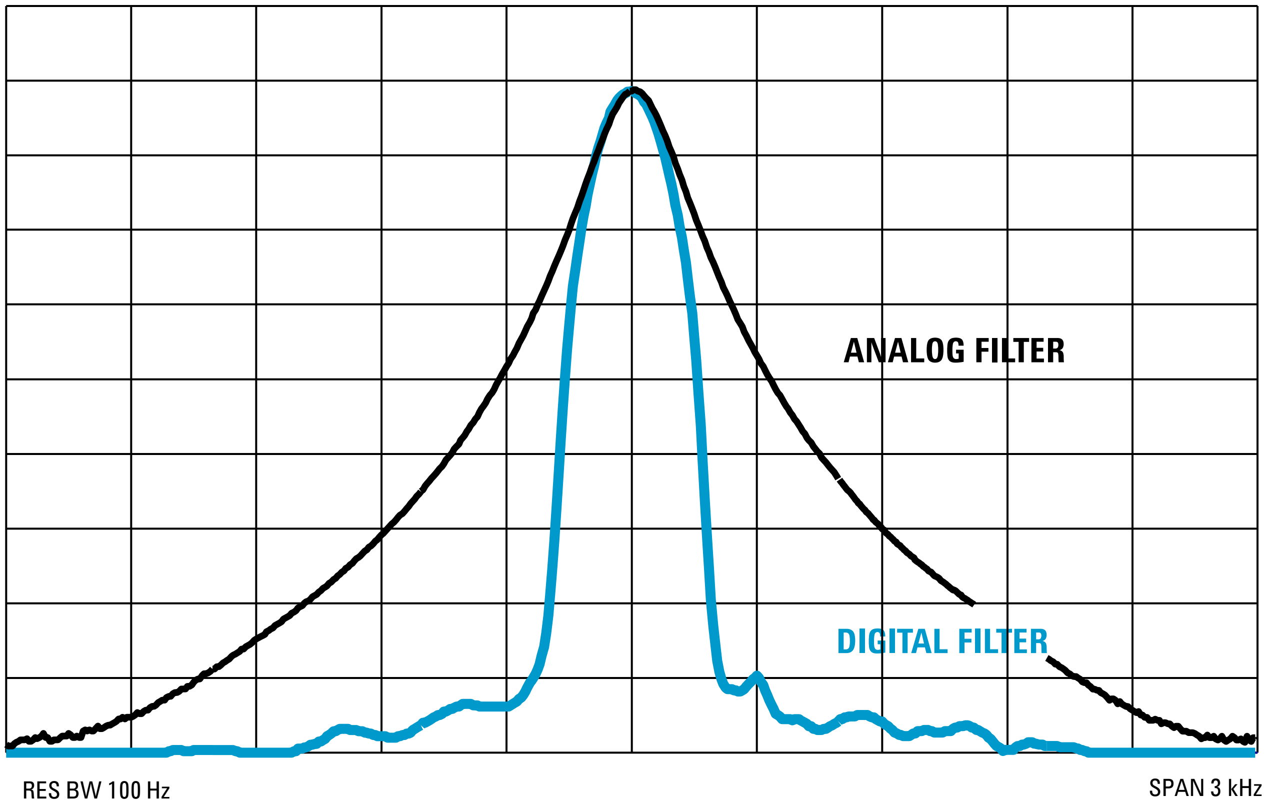
# Specifications

## Resolution BW Selectivity or Shape Factor



# Specifications

## Resolution: RBW Type and Selectivity




Typical Selectivity

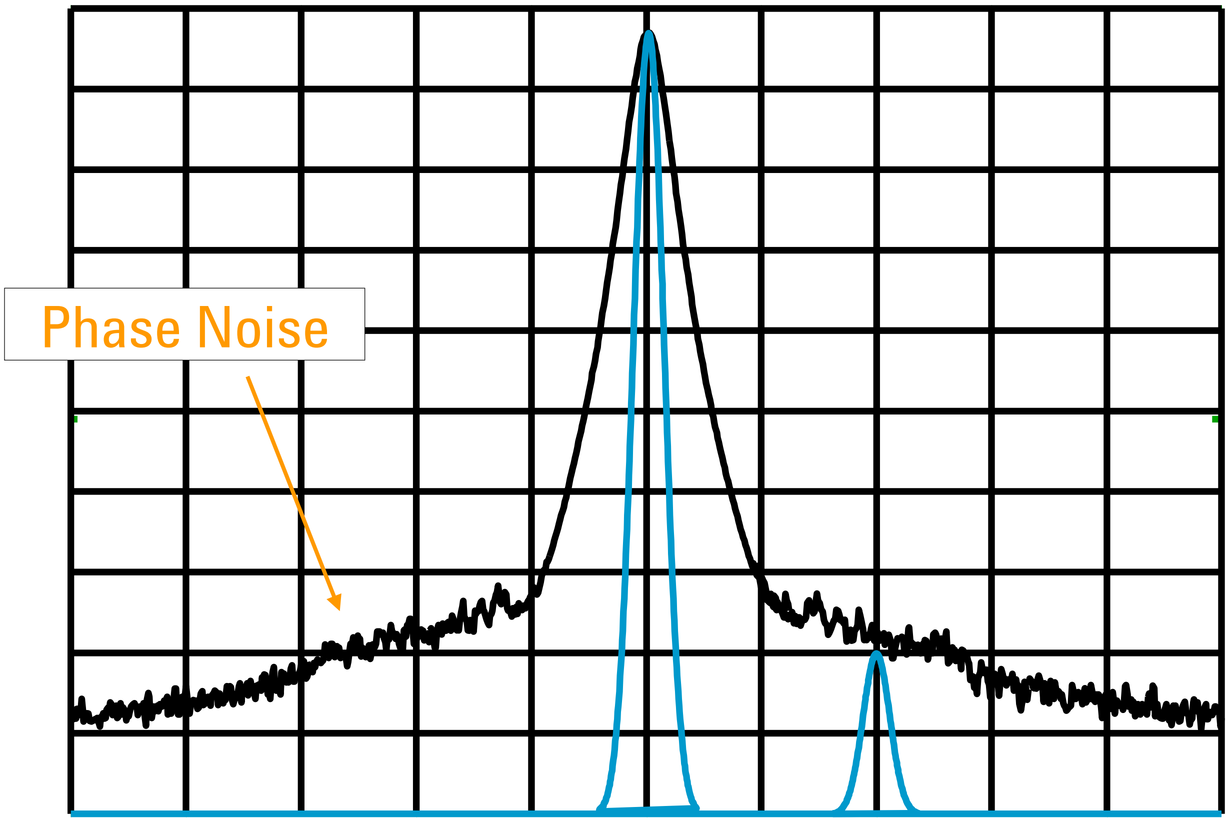
Analog 15:1

Digital ≤5:1

*** The X-series RBW shape factor is 4.1:1**

# Specifications

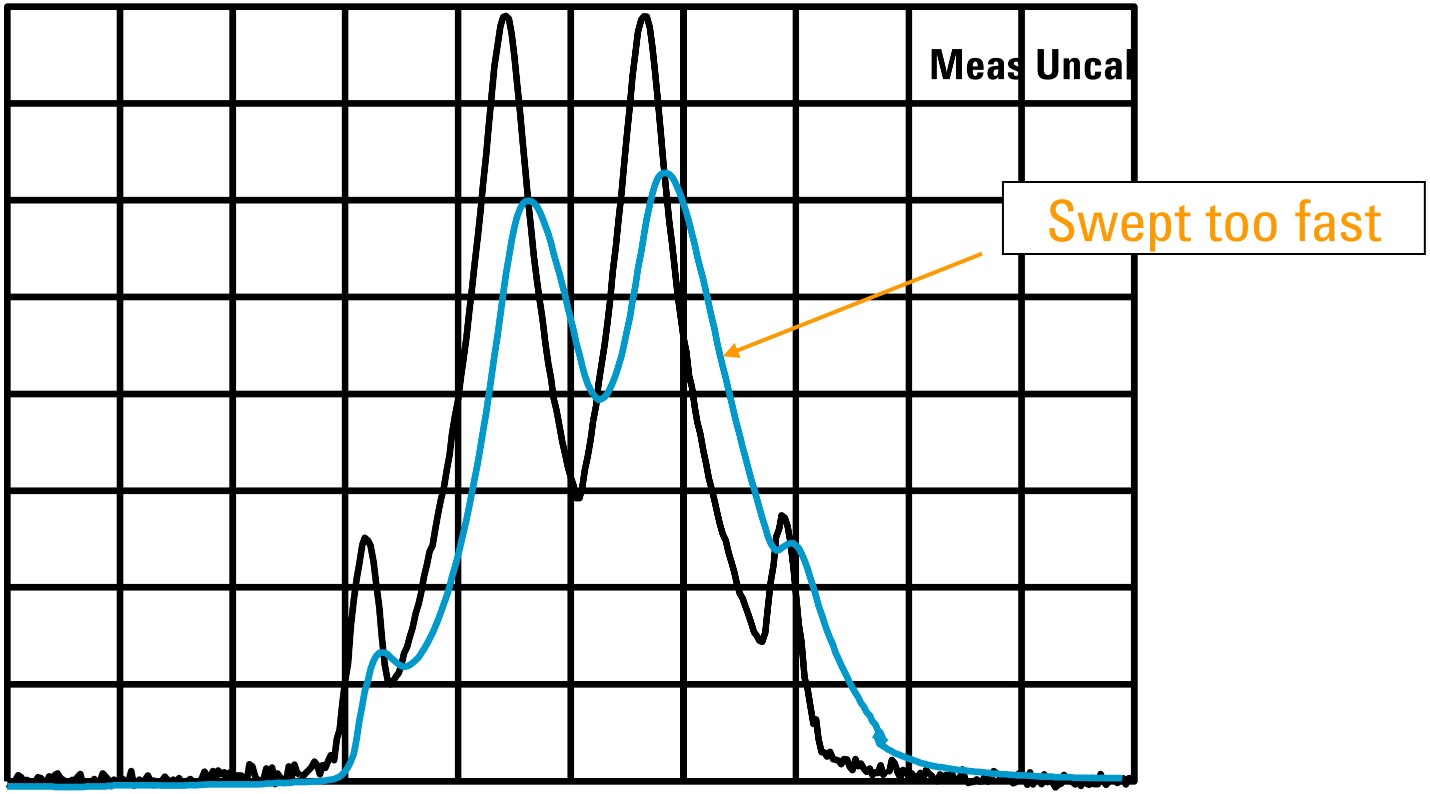
## Resolution: Noise Sidebands




Noise Sidebands can prevent resolution of unequal signals

# Specifications

## Resolution: RBW Determines Sweep Time

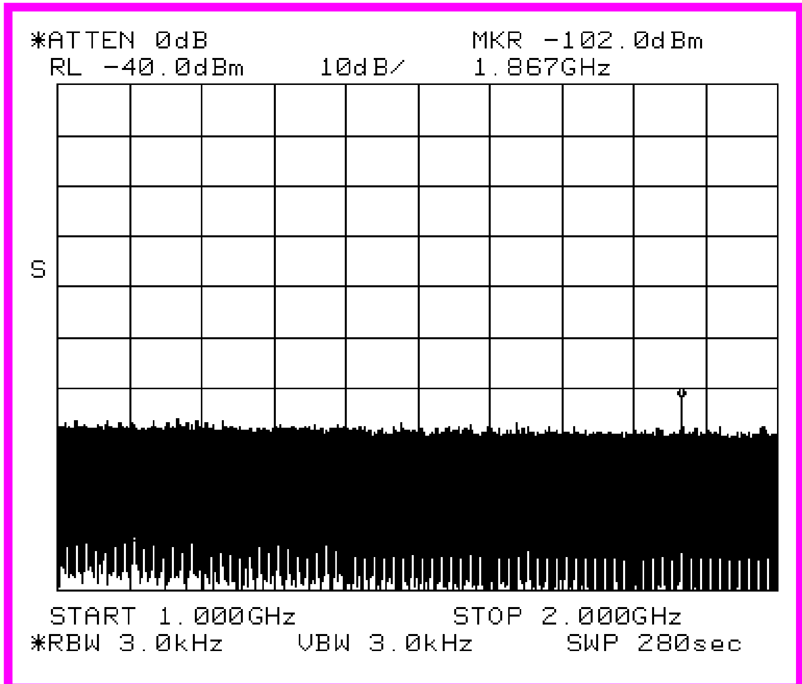



**Penalty For Sweeping Too Fast**
**Is An Uncalibrated Display**

# Specifications

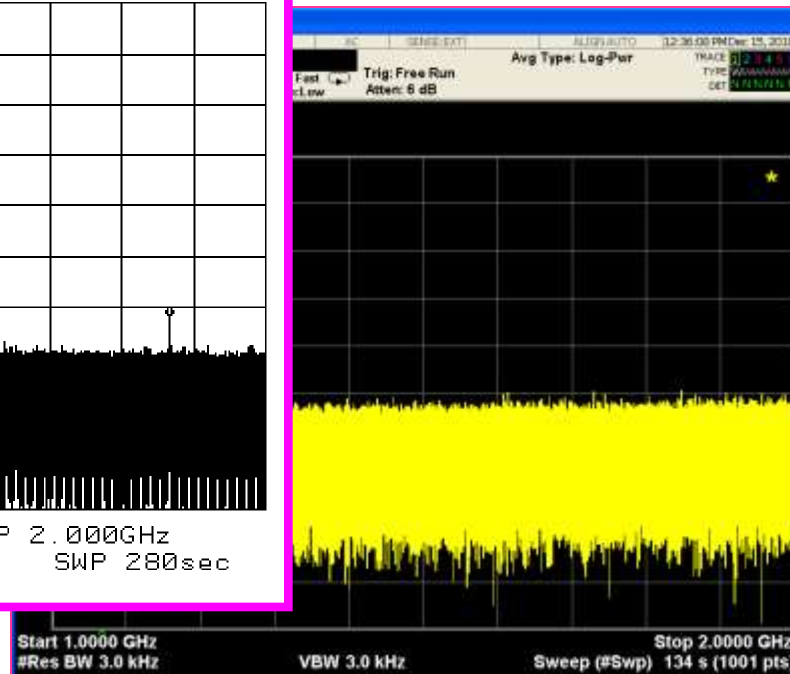
## Resolution: RBW Type Determines Sweep Time

8563E Analog RBW



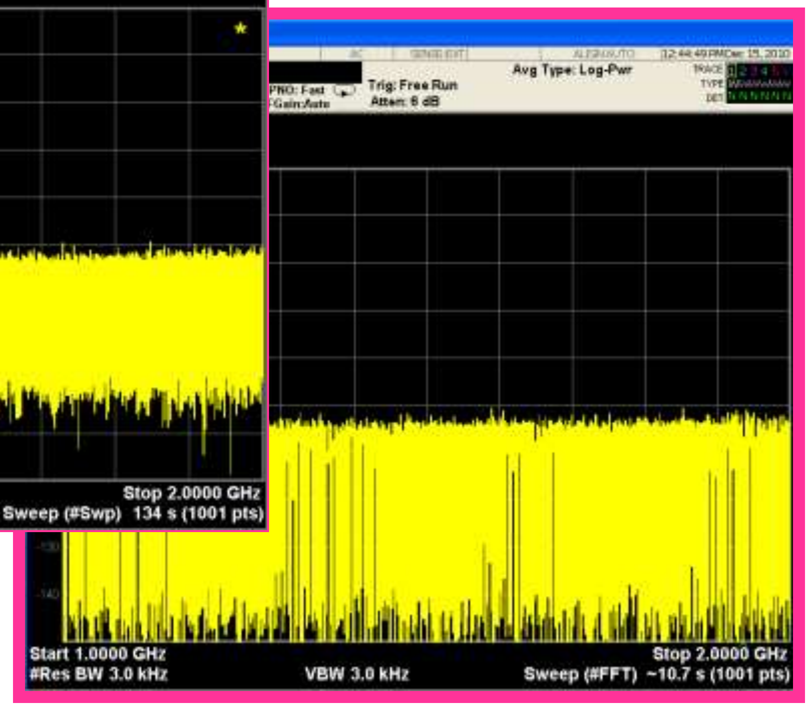

280 sec

PXA Swept RBW



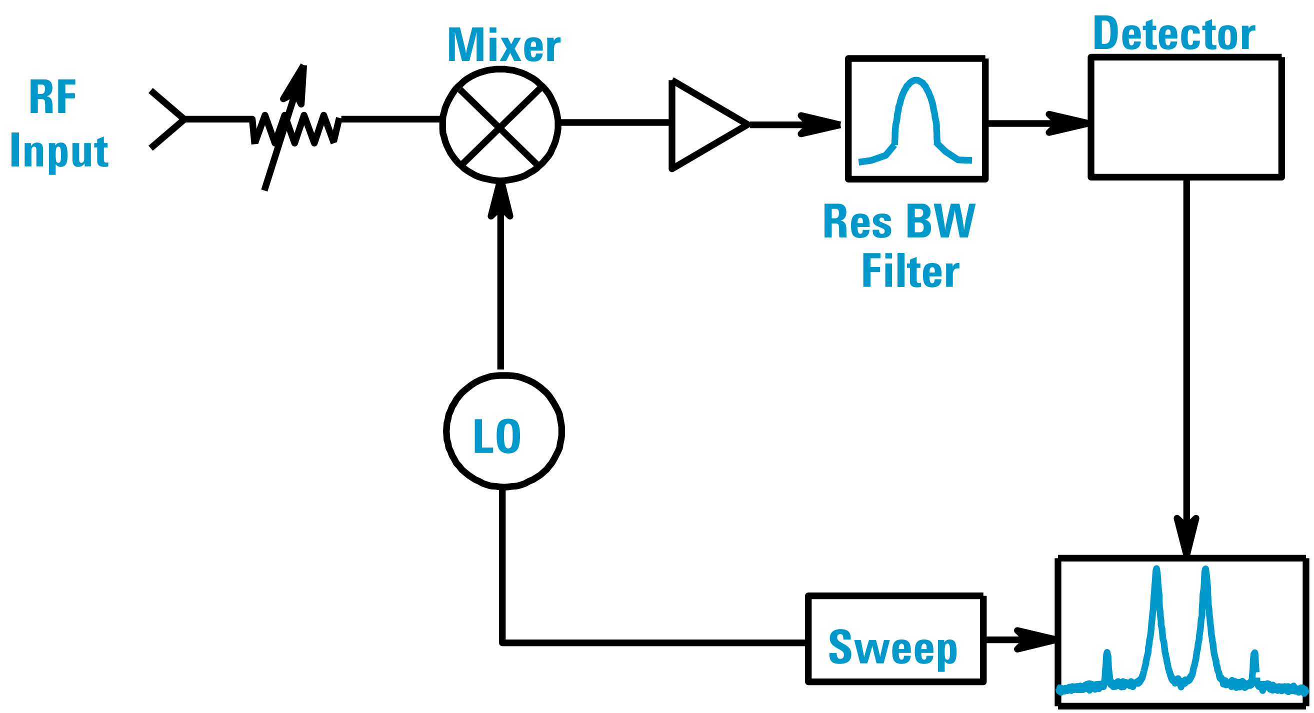

134 sec

PXA FFT RBW




10.7 sec

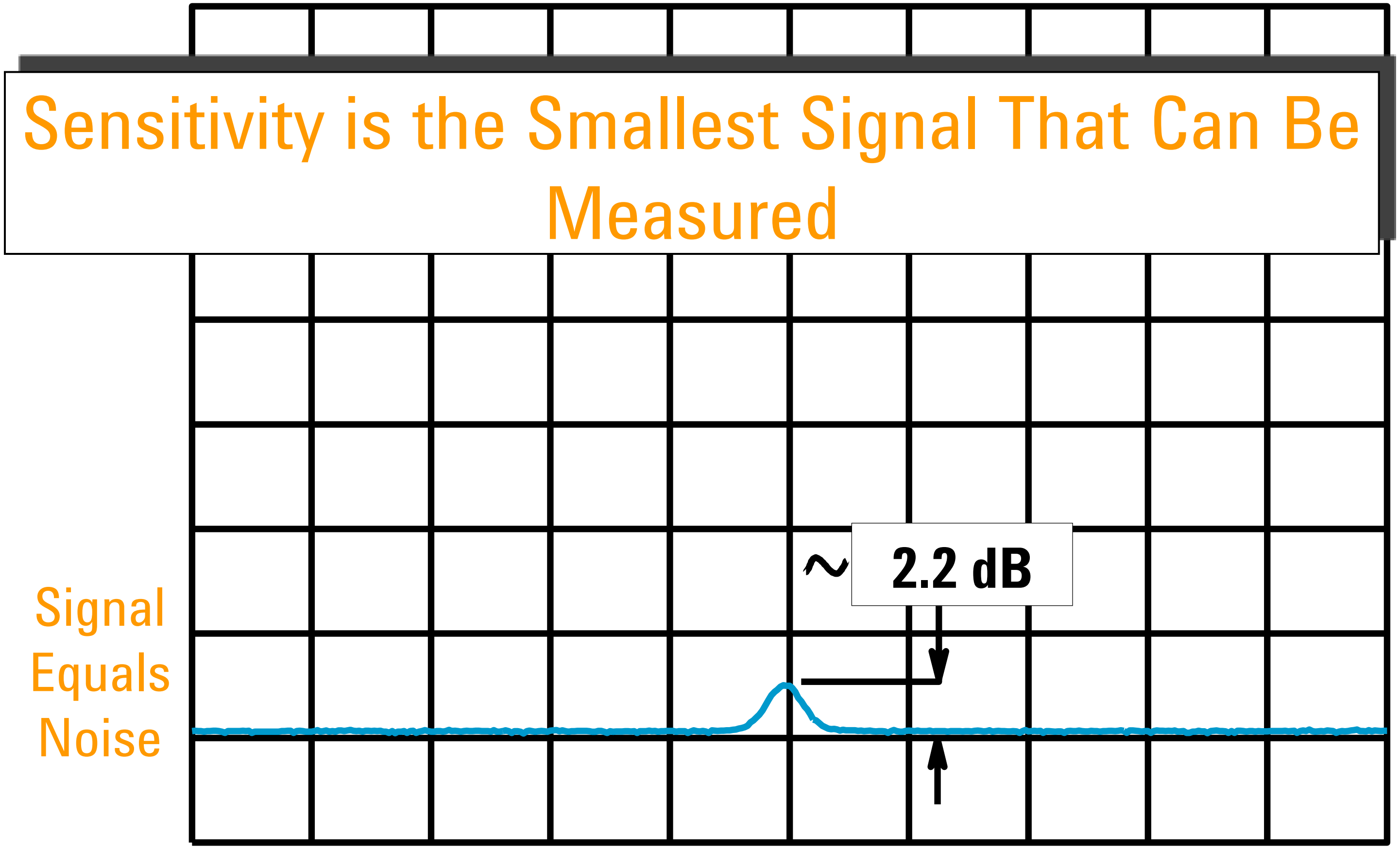
# Specifications
## Sensitivity/DANL




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

# Specifications

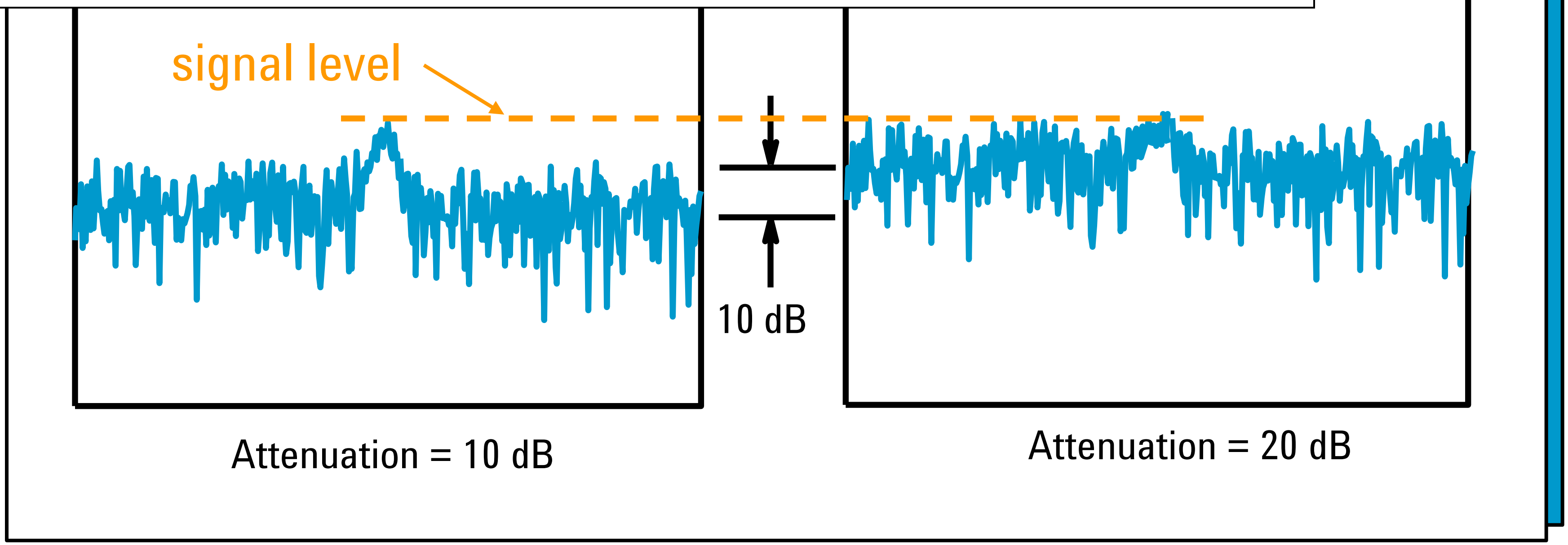
## Sensitivity/DANL



# Specifications

## Sensitivity/DANL

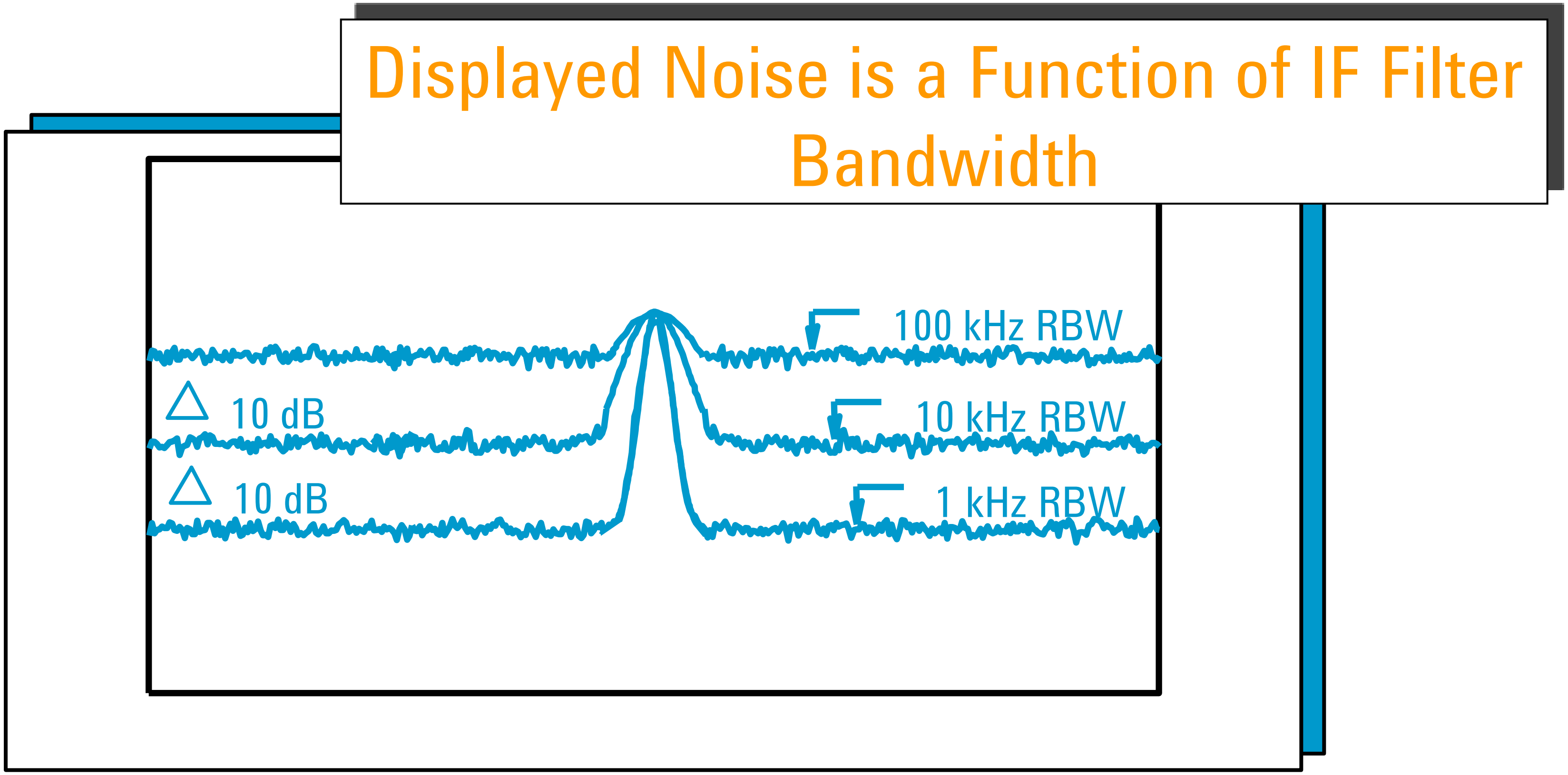
Effective Level of Displayed Noise is a Function of RF Input Attenuation




Signal To Noise Ratio Decreases as RF Input Attenuation is Increased

# Specifications

## Sensitivity/DANL: IF Filter(RBW)

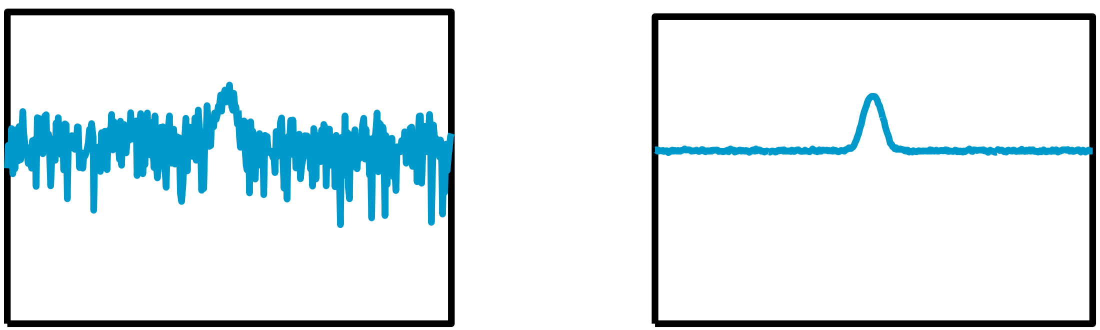



Decreased BW = Decreased Noise

# Specifications

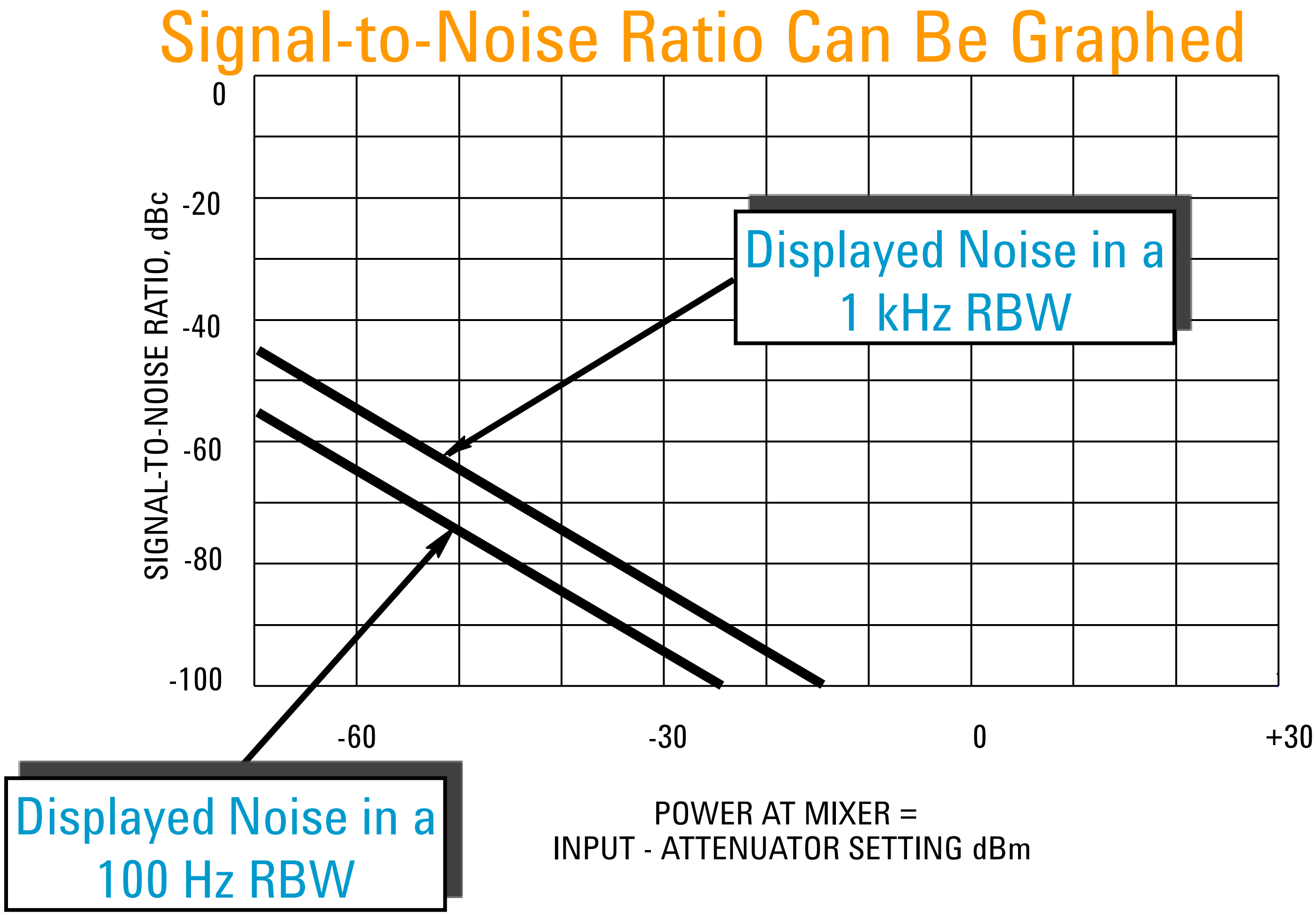
## Sensitivity/DANL: Video BW filter (or Trace Averaging)

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



# Specifications

## Sensitivity/DANL:



# Specifications

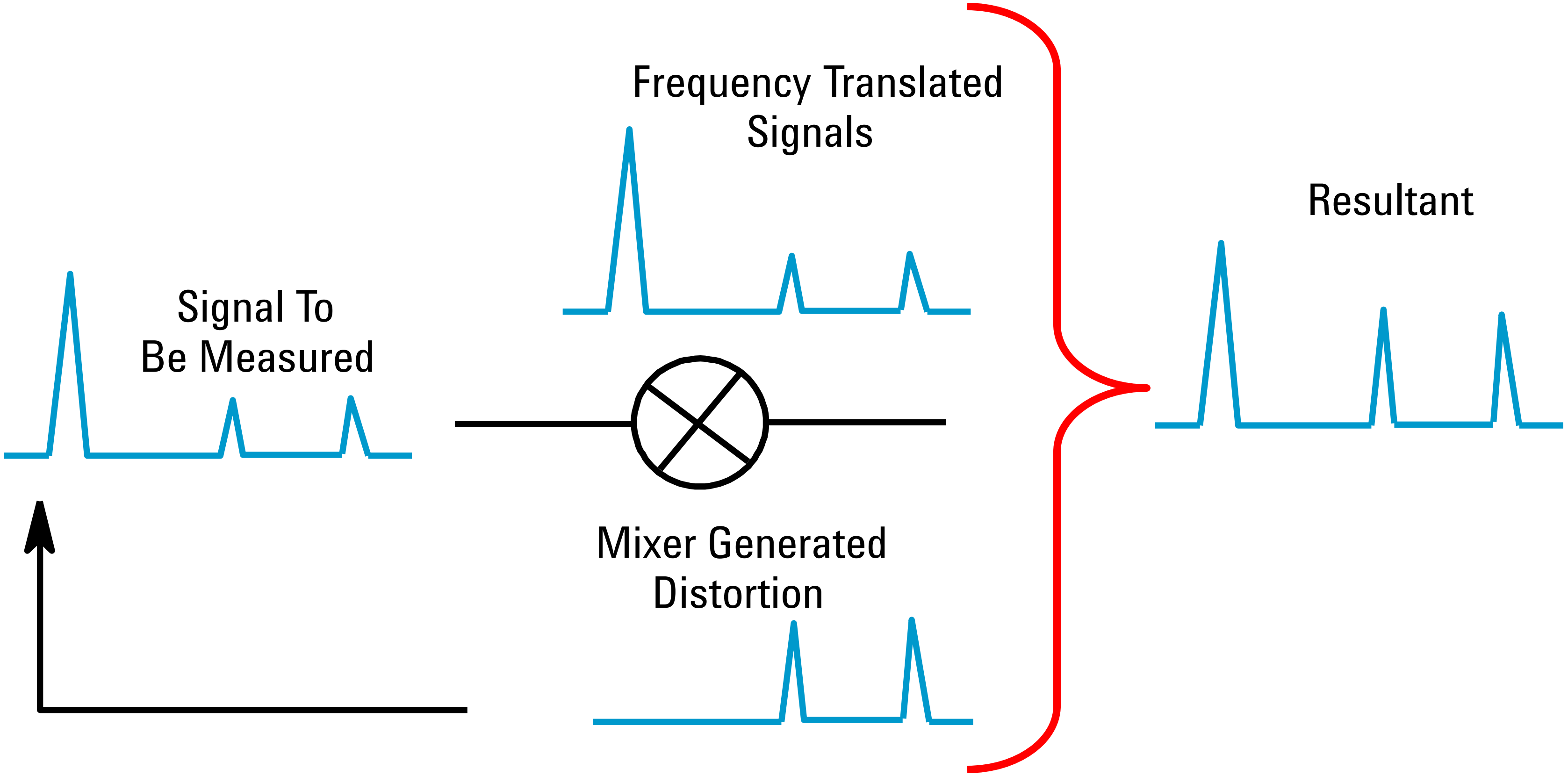
## Sensitivity/DANL: Summary

### For Best Sensitivity Use:

- Narrowest Resolution BW
- Minimum RF Input Attenuation
- Sufficient Averaging (video or trace)
- Using the Preamp also improves sensitivity
- Low Noise Path (PXA only)
- Noise Floor Extension (PXA only)

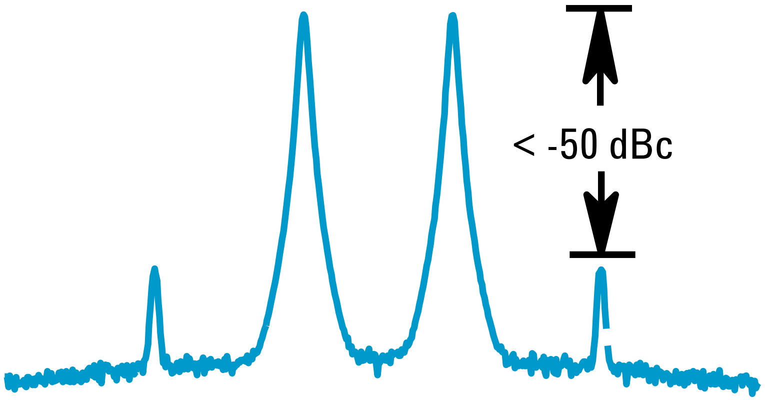
# Specifications
## Distortion

### Mixers Generate Distortion

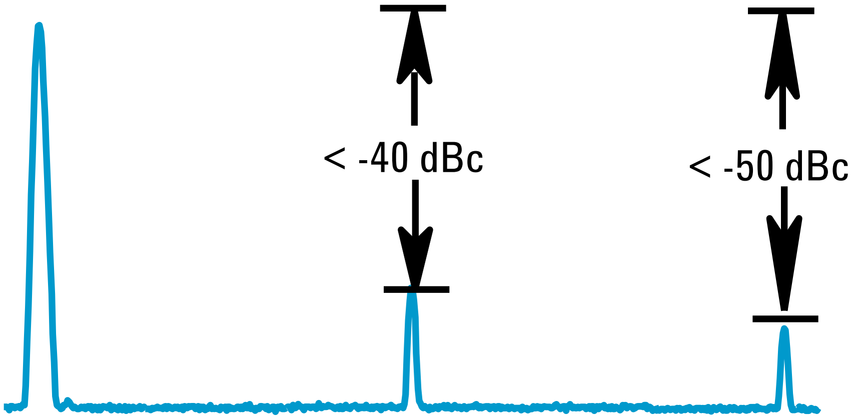


# Specifications
## Distortion

Most Influential Distortion is the Second and Third Order



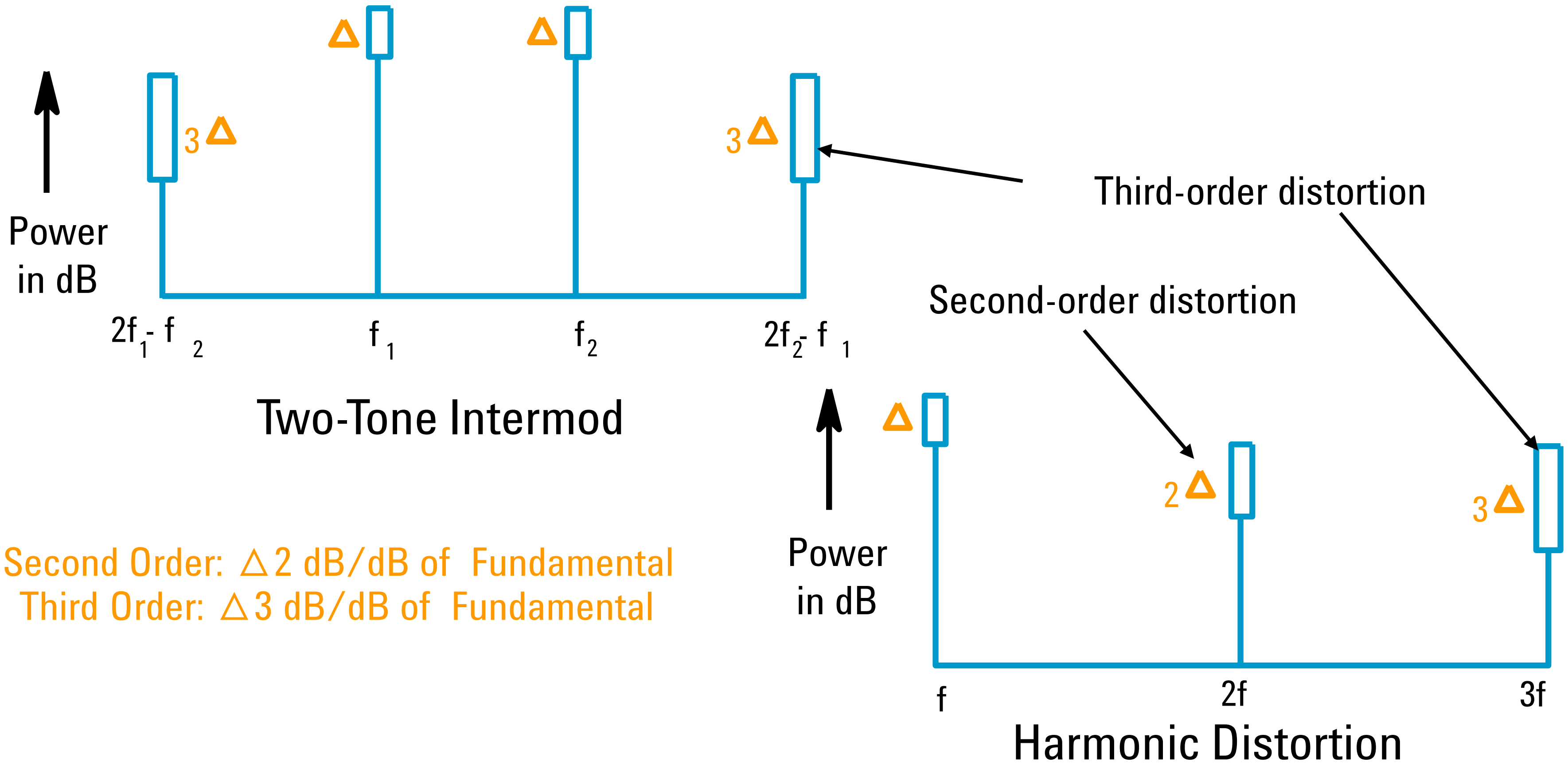

Two-Tone Intermod




Harmonic Distortion

# Specifications
## Distortion

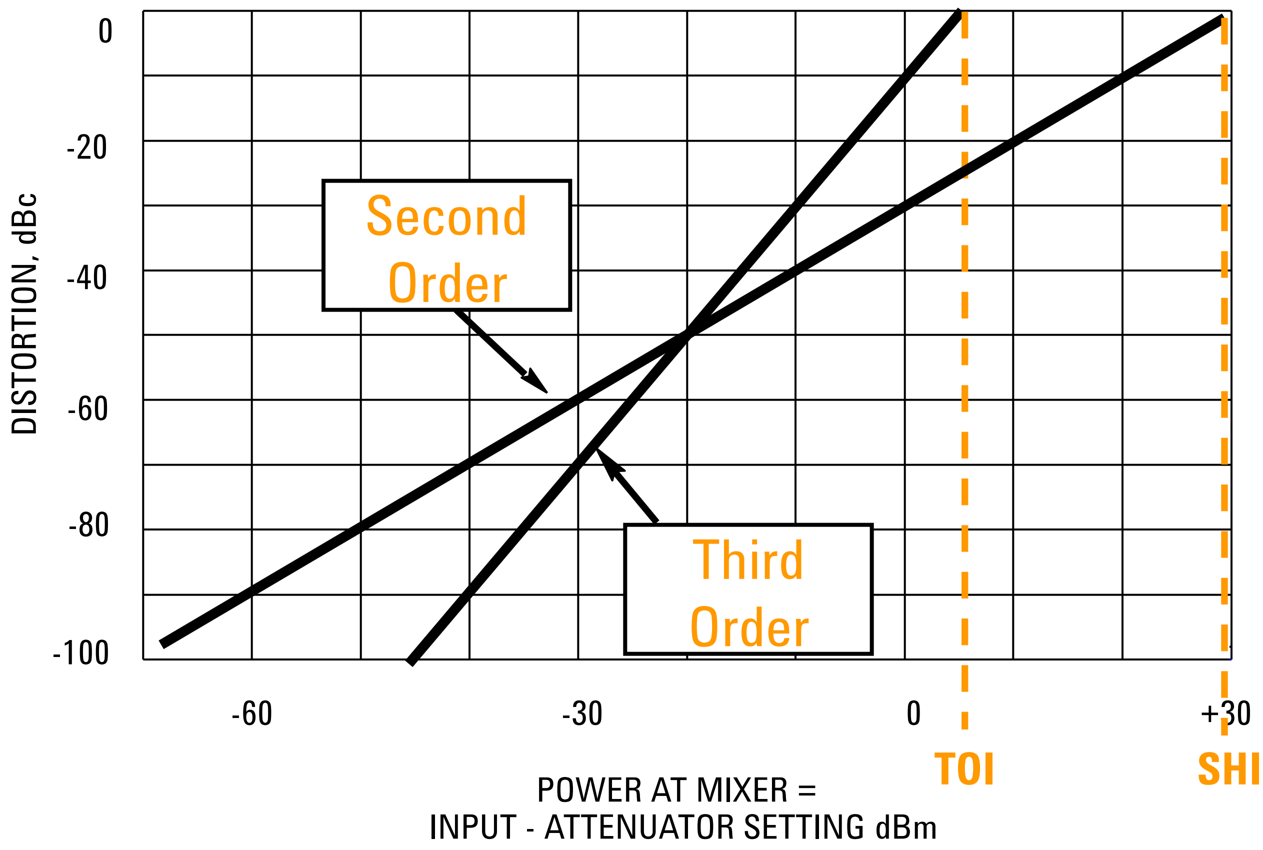
Distortion Products Increase as a Function of Fundamental's Power




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

# Specifications
## Distortion

Distortion is a Function of Mixer Level



# Specifications

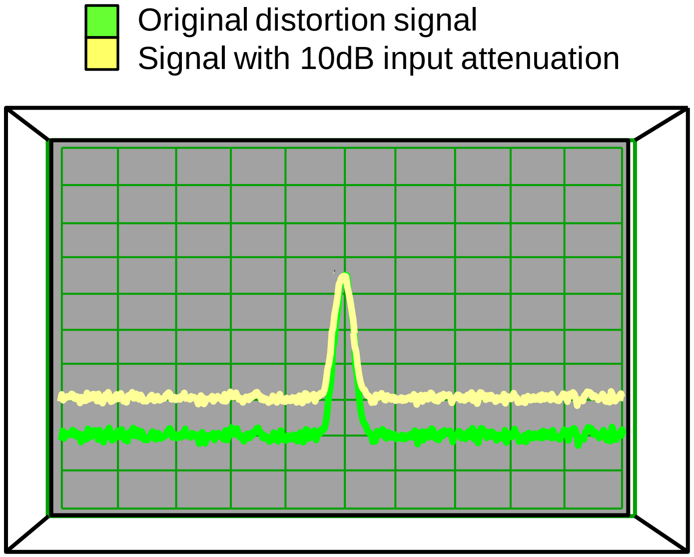
## Distortion – Internal or External?

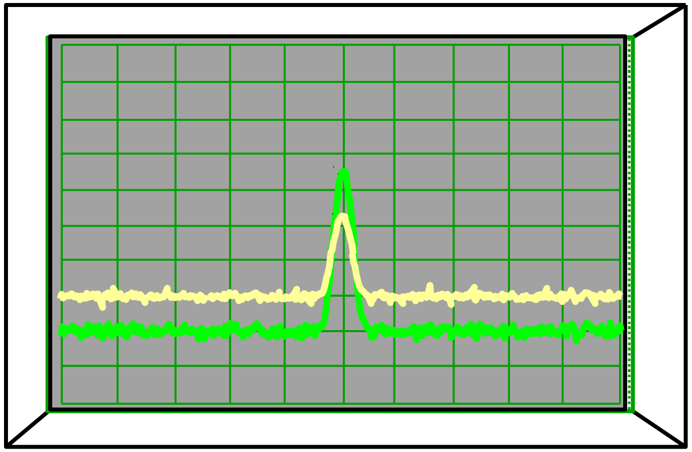
**Attenuator Test:**
**Change power to the mixer**

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

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

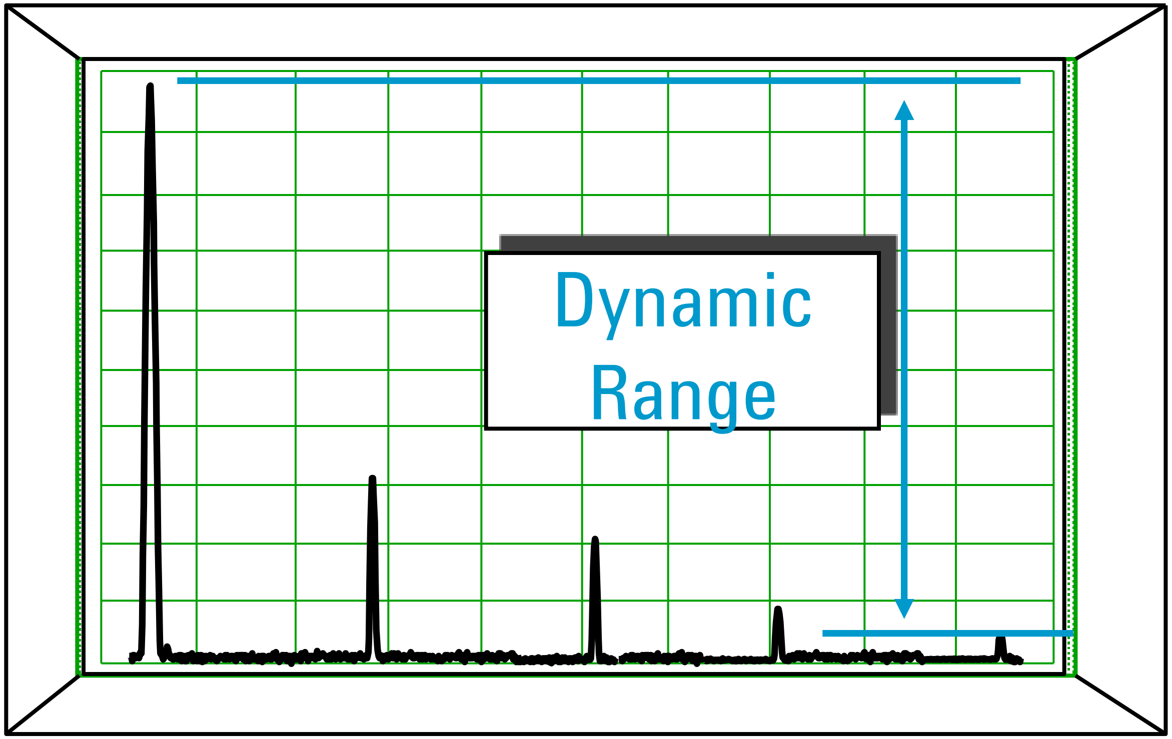
***Change in amplitude***: at least some of the distortion is being generated inside the analyzer (internal)



# Specifications

## Spectrum Analyzer Dynamic Range

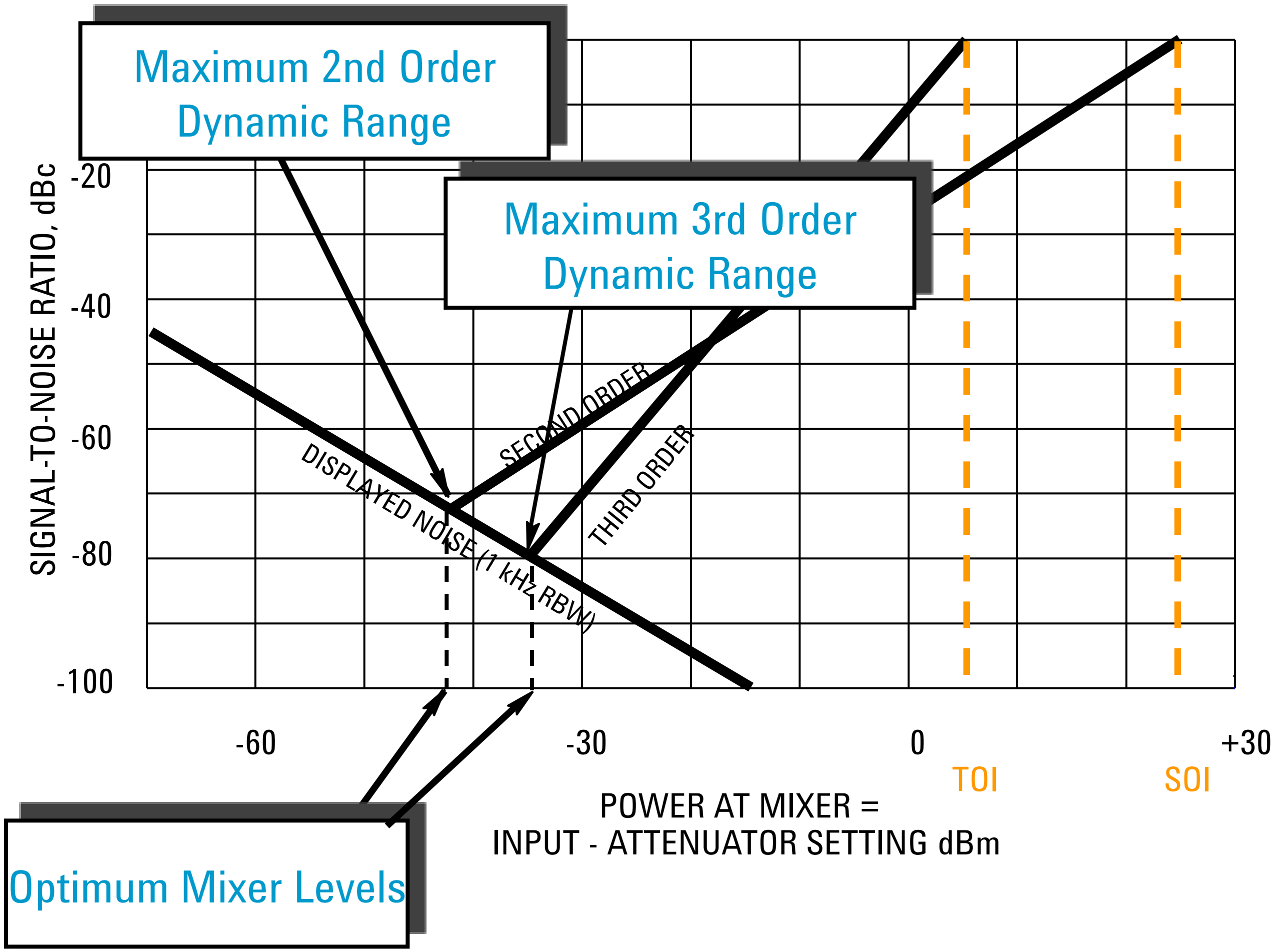



The ratio, expressed in dB, of the largest to the smallest signals simultaneously present at the input of the spectrum analyzer that allows measurement of the smaller signal to a given degree of uncertainty.

# Specifications

## Dynamic Range

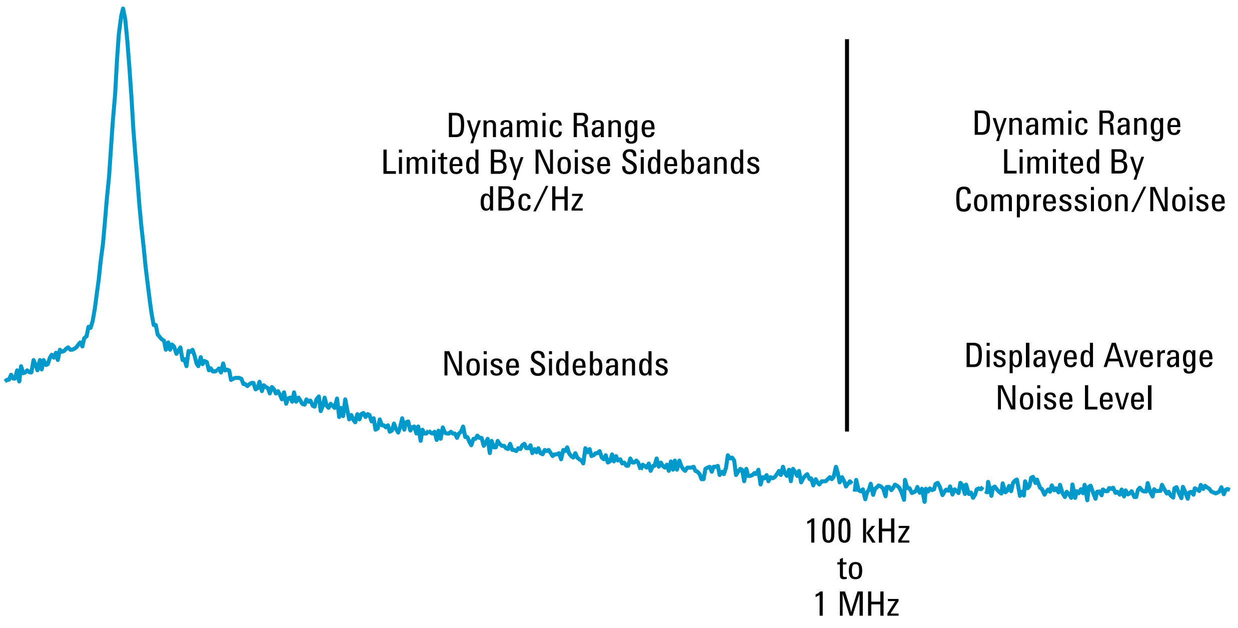
Dynamic Range Can Be Presented Graphically



# Specifications

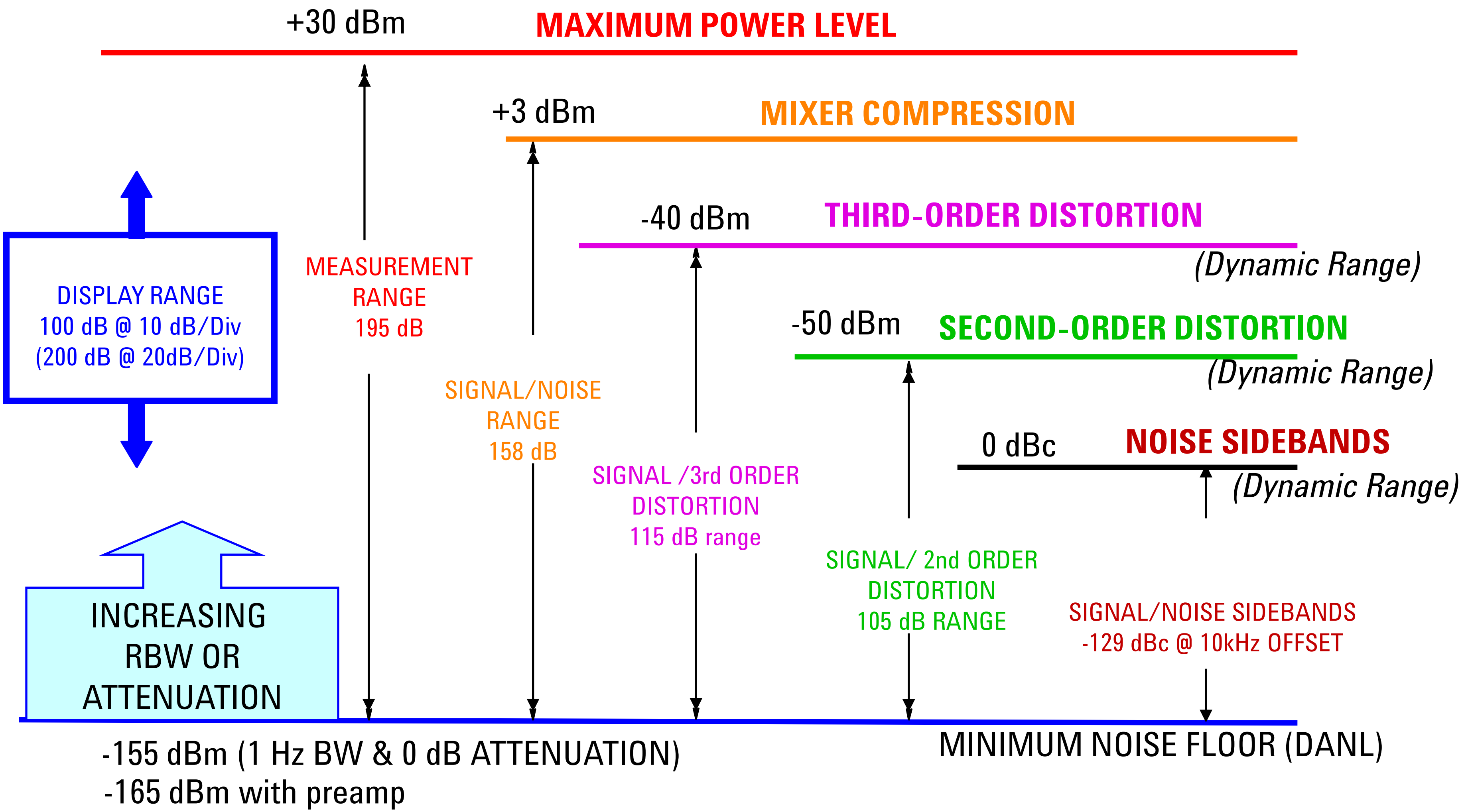
## Dynamic Range

### 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

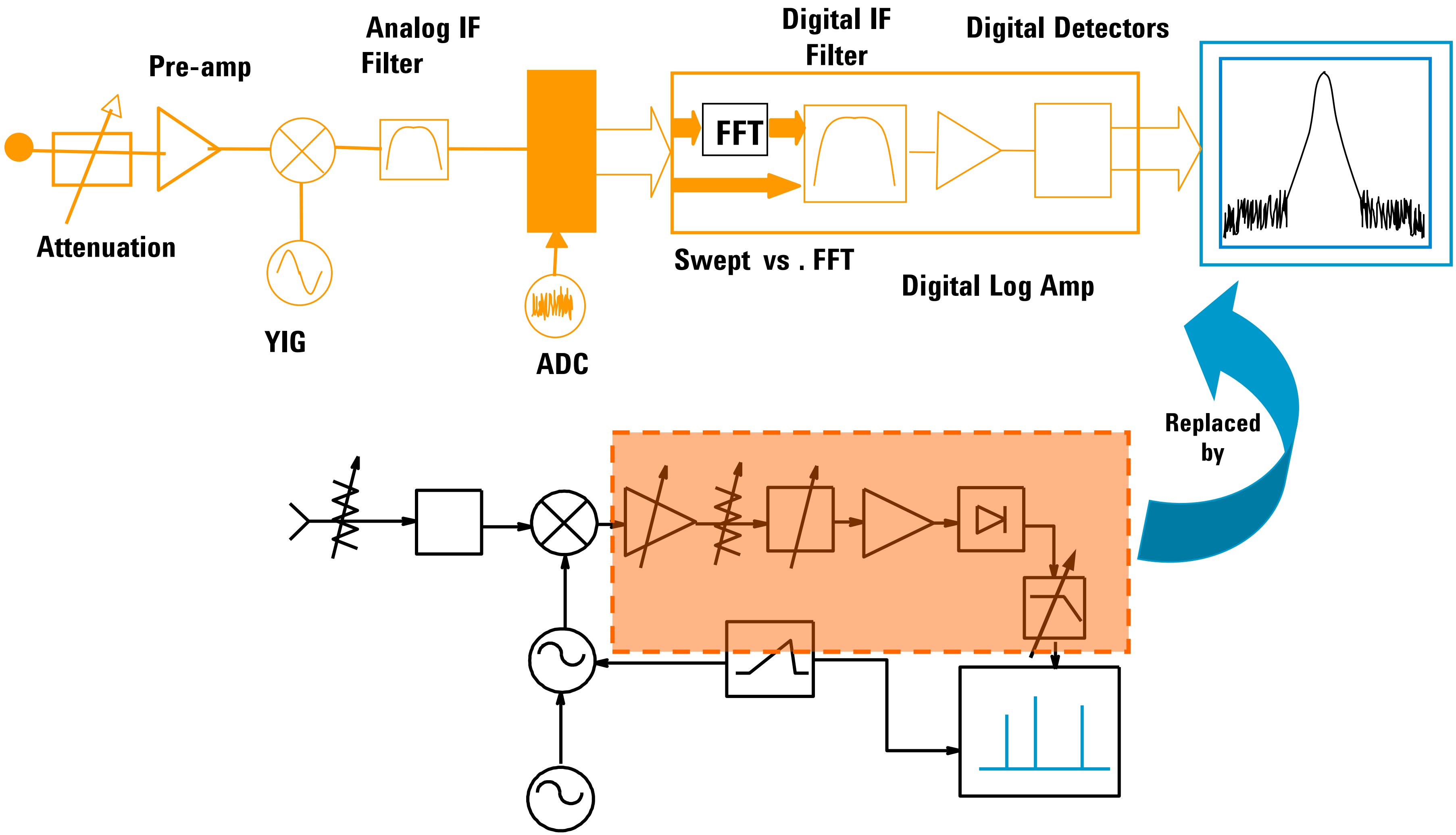
Modern spectrum analyzer designs & capabilities

- Wide Analysis Bandwidth Measurements

Wrap-up

# Modern Signal Analyzer Block Diagram

## Digital IF



# Modern Signal 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**

# Modern Signal Analyzer Features

## Built-in One-Button Power Measurements

### Power Measurements:

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

### Format Setups include:

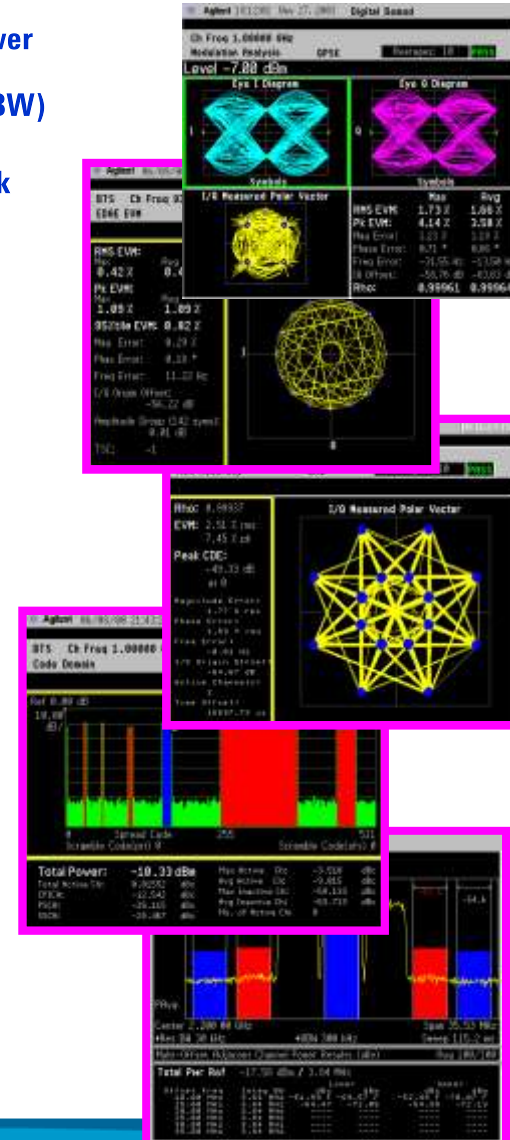
- cdma2000 1x
- IS-95A
- DVB-T L/SECAM/NICAM
- NADC
- J-STD-008
- FCC Part 15 Subpart F
- PDC
- IS-97D/98D
- S-DMB System E
- Bluetooth DH1
- GSM/EDGE
- UWB Indoor
- TETRA
- 3GPP W-CDMA
- W-LAN 802.11a

# Modern Signal Analyzer Features

## Application Focused Internal Software (one-button measurements)

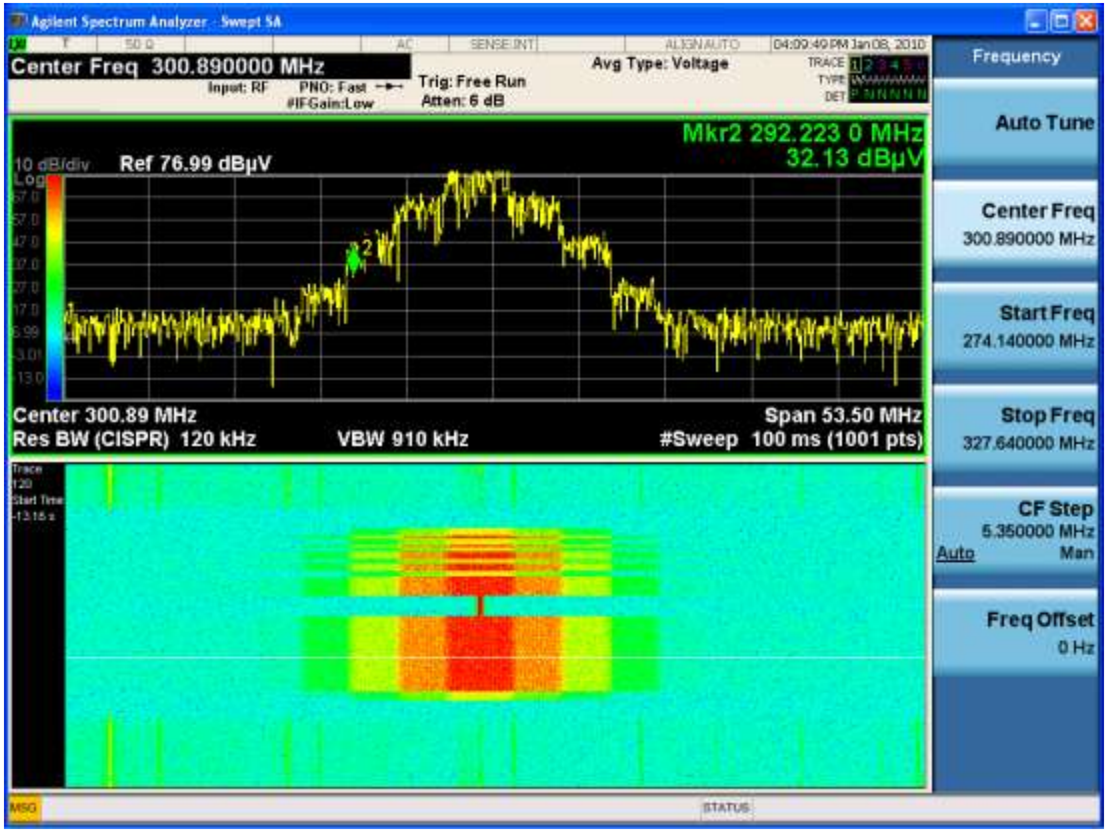
| | |
|---|---|
| General purpose applications | Phase noise |
| | Ext. source control |
| | Noise figure |
| | Code compatibility suite |
| | EMI pre-compliance |
| | Analog demod |
| Flexible digital modulation analysis | Flexible demod |
| Power & digital modulation measurements for wireless comms formats | 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 |

- 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



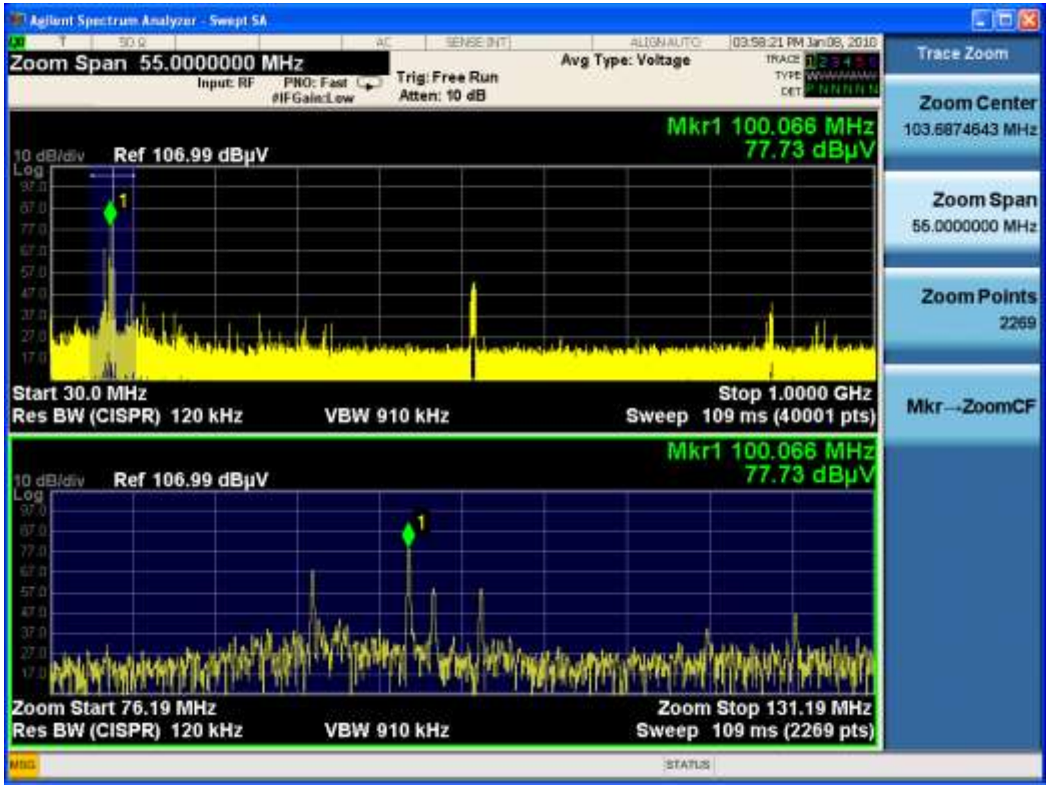
# Enhanced Display Capabilities
# Spectrogram

- Allows you to see time history in bottom window
- Amplitude displayed using color
- Great for finding intermittent signals



# Enhanced Display Capabilities
## Trace Zoom

- Allows you to zoom in on your trace data
- Same trace in both screens but bottom screen shows “close up” view with fewer points
- Great to look more closely at high-density traces



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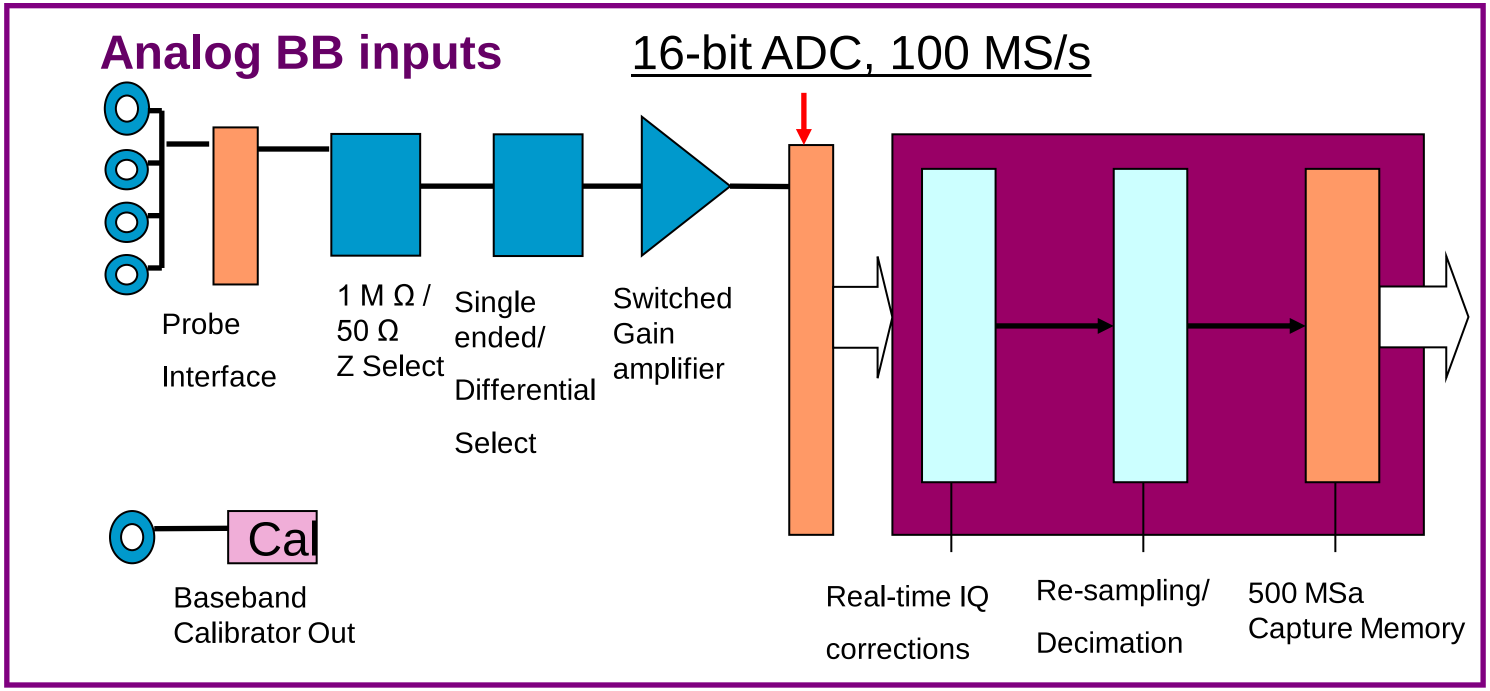
# PXA/MXA Baseband and RF




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

**10, 25 or 40 MHz BW**

**500 MSa memory**

# 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

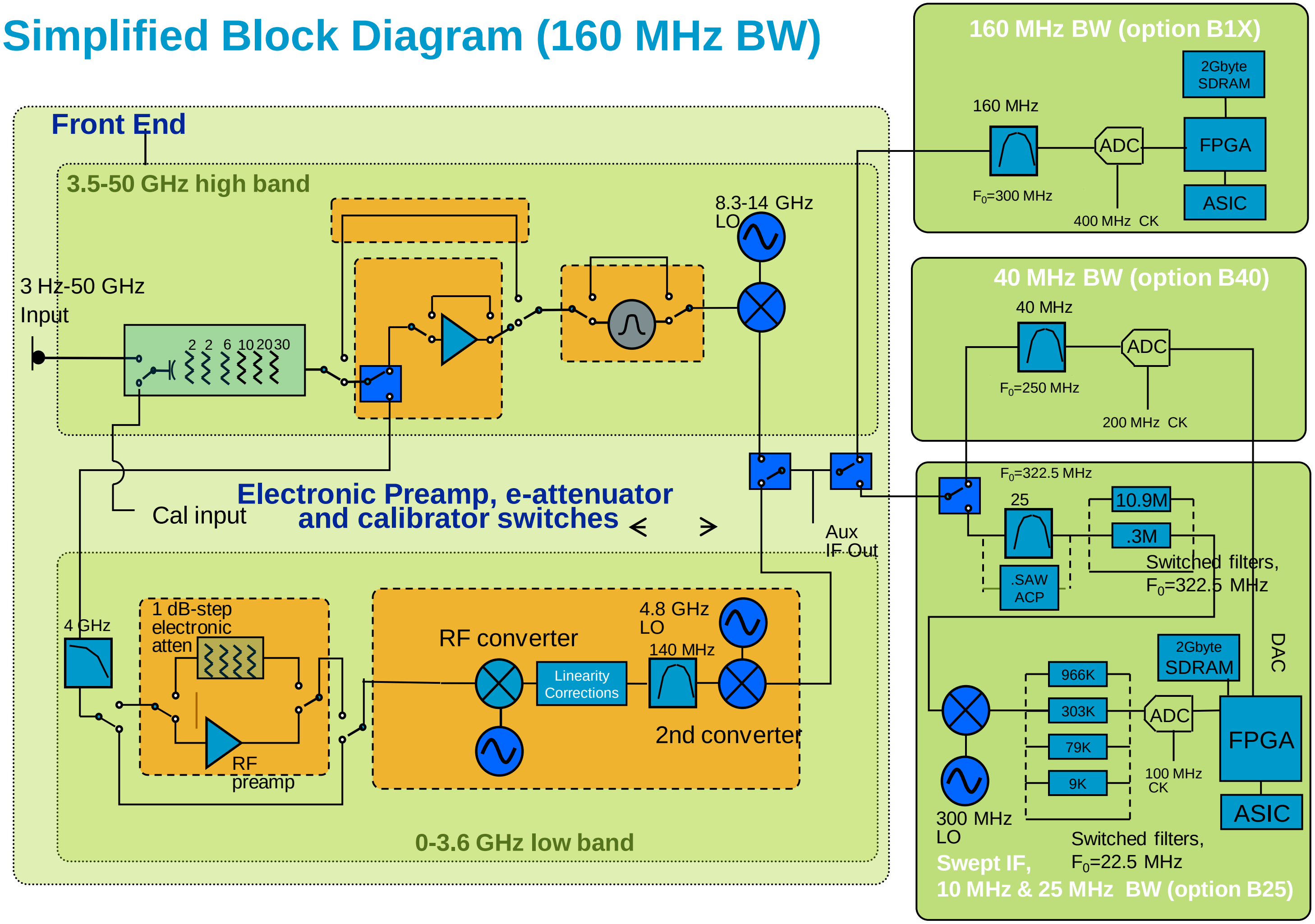
Cellular Communications

- 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

# PXA Wideband analysis

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

## PXA Simplified Block Diagram (160 MHz BW)



# Agenda

Introduction

Overview

Theory of Operation

Specifications

Modern spectrum analyzer designs & capabilities

- Wide Analysis Bandwidth Measurements

Wrap-up

# Agilent Technologies' Signal Analysis Portfolio


**PXA**
X-Series
High-performance
3 Hz to 26.5 GHz
Apr 11
3 Hz to 43/44/50 GHz

**PSA**
Market leading performance
3 Hz to 50 GHz


**MXA**
X-Series
Mid-performance
20 Hz to 26.5 GHz

**8560EC**
Mid-performance


**EXA**
X-Series
Economy-class
9 kHz to 26 GHz

**ESA**
World's most popular
100 Hz to 26 GHz


**CXA**
Low-cost
9 kHz to 7.5 GHz

**CSA**
Low cost portable
100 Hz to 7 GHz

**N9320B**
9KHz to 3 GHz
Basic performance, bench top

**N9340B**
100KHz to 3 GHz
Handheld

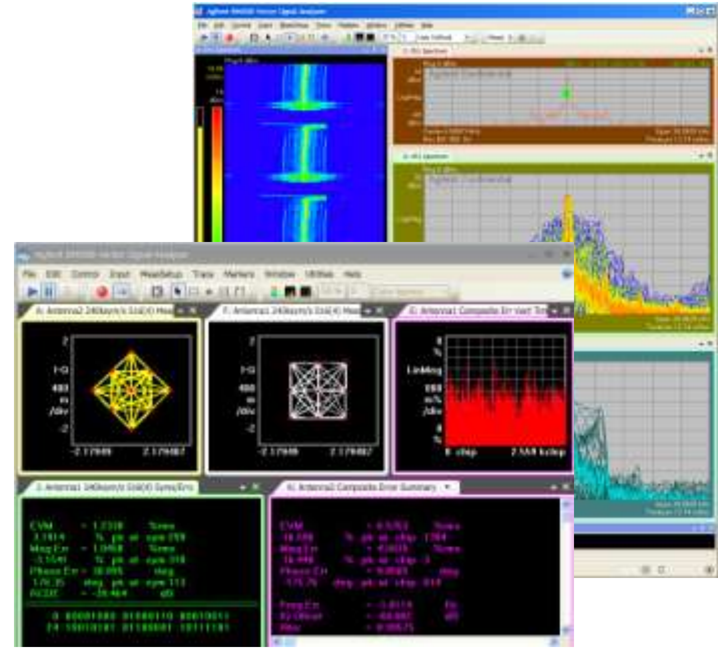
**N9342/43/44C**
100KHz to 7/13.6/20 GHz
Handhelds

**X-Series Code Compatibility**

- ✓ Backward CC with legacy
- ✓ Inherent X-Series CC

# Agilent Vector Signal Analysis Software

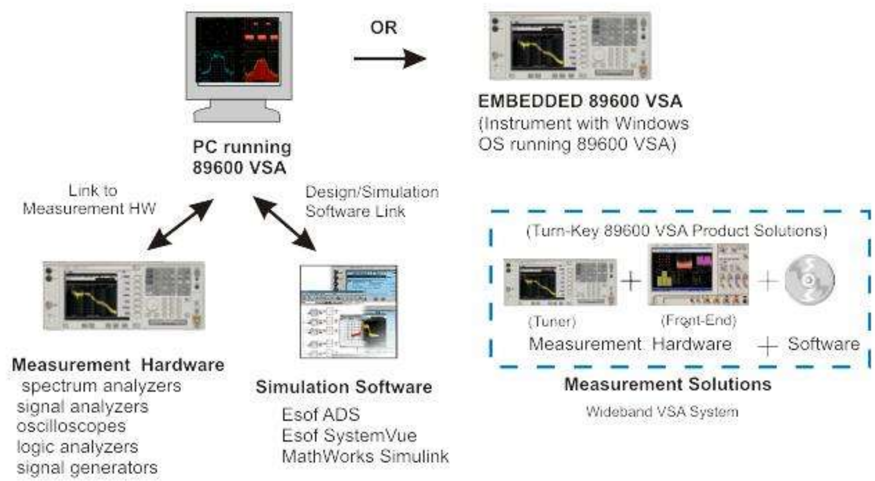
## 89600B VSA Software



- 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





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# 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**

**HSA Brochure: 5990-8024EN**

**89600B VSA Brochure: 5990-6553EN**

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# The End

*THANK YOU!*