

# Spectral Analysis

# Agenda

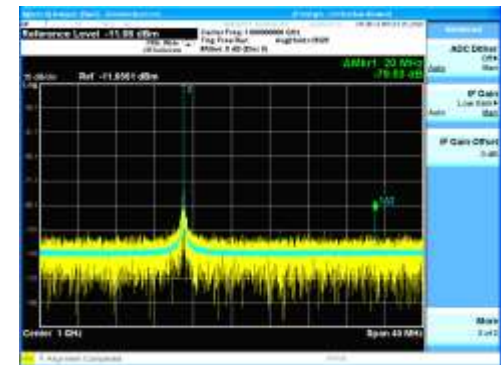
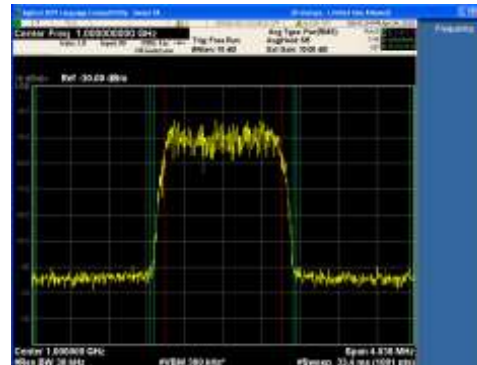
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- Overview
- Theory of Operation
  - Traditional Spectrum Analyzers
  - Modern Signal Analyzers
- Specifications
- Features
- Wrap-up

# Overview

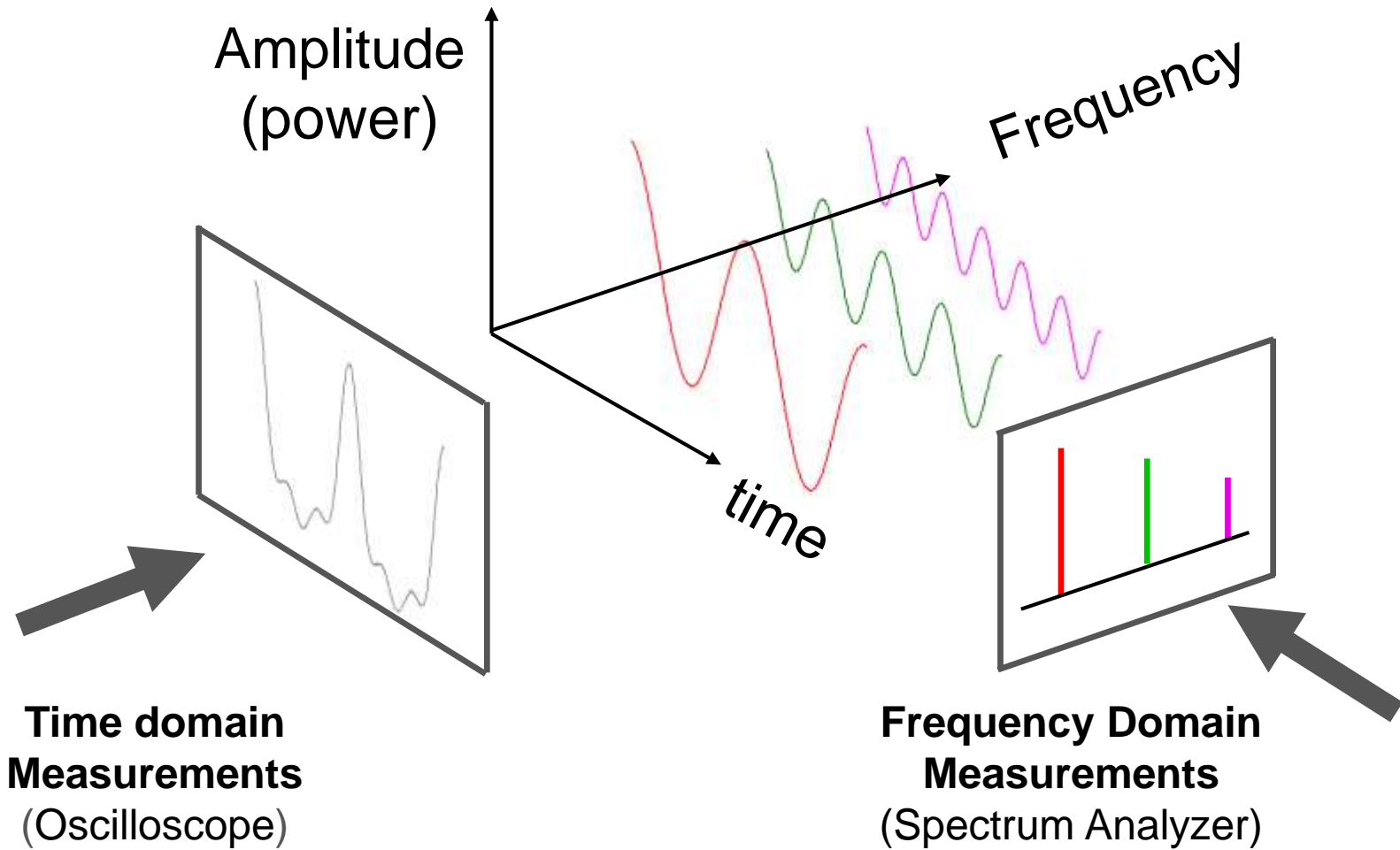
## What is Spectrum Analysis

- Passive Receiver
- Display and measure amplitude versus frequency
- Separate or demodulate complex signals into their base components (sine waves)



# Overview

## Frequency vs Time Domain



# Overview

## Types of Measurements Available

### – Frequency, power, modulation, distortion, and 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

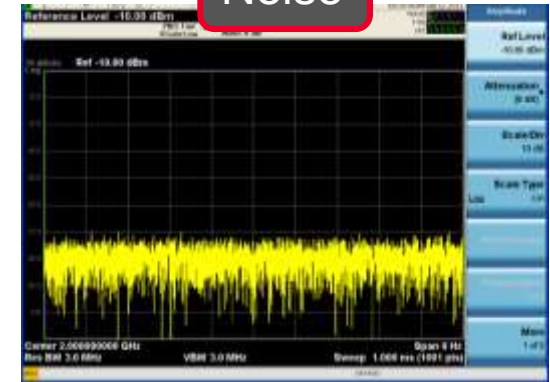
– **Measurement range:** -172 dBm to +30 dBm

– **Frequency range:** 3 Hz to 1.1 THz

Modulation



Noise



Spur Search



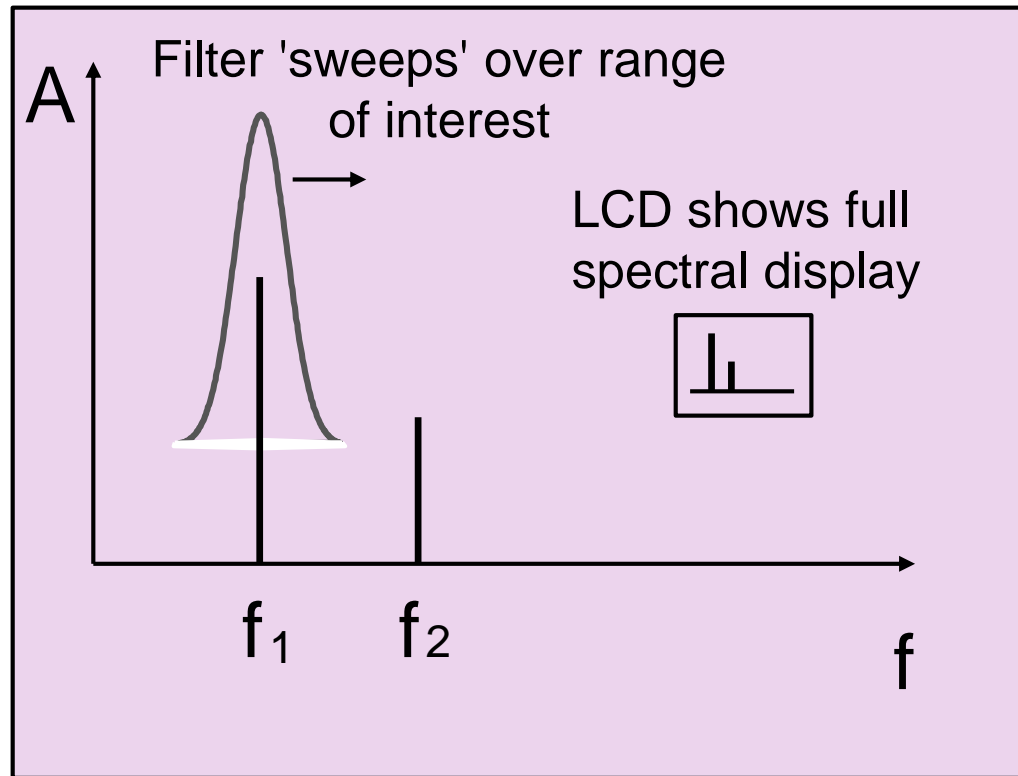
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# Overview

## Different Types of Analyzers

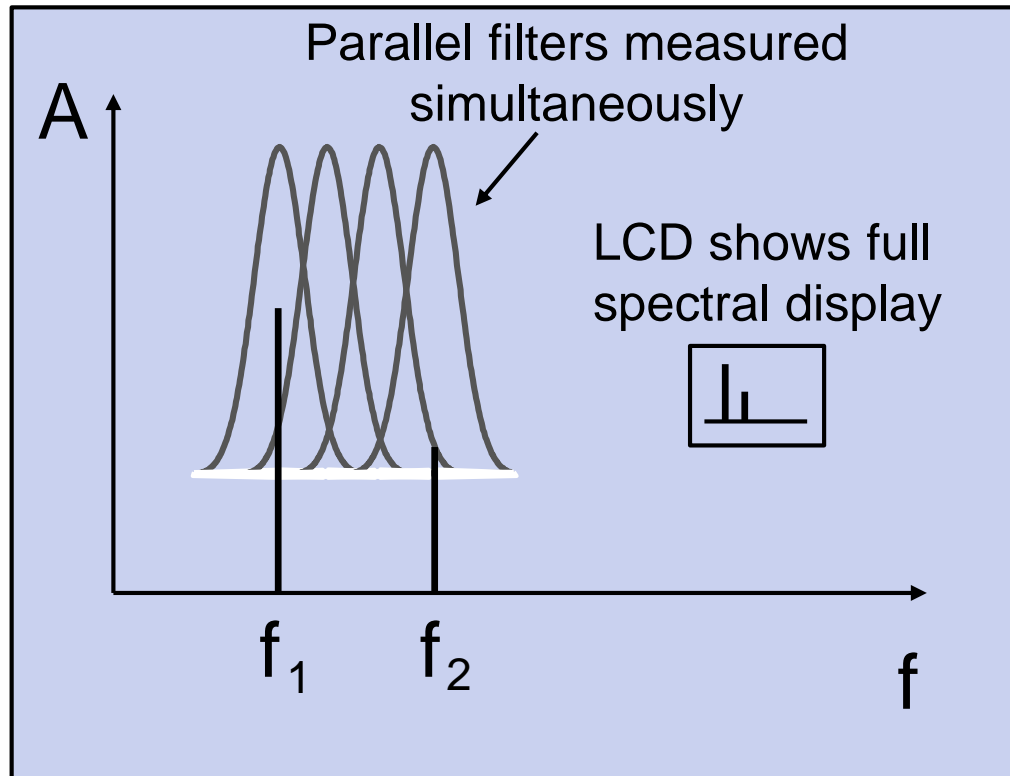
### Swept Analyzer



# Overview

## Different Types of Analyzers

### FFT Analyzer



# 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 display and measure Amplitude vs. Frequency of known and unknown RF and Microwave signals.





# Analyzer Definitions

- **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.



# Analyzer Definitions

- **Signal Analyzer:** A signal analyzer provides the functions of a spectrum analyzer and a vector signal analyzer.

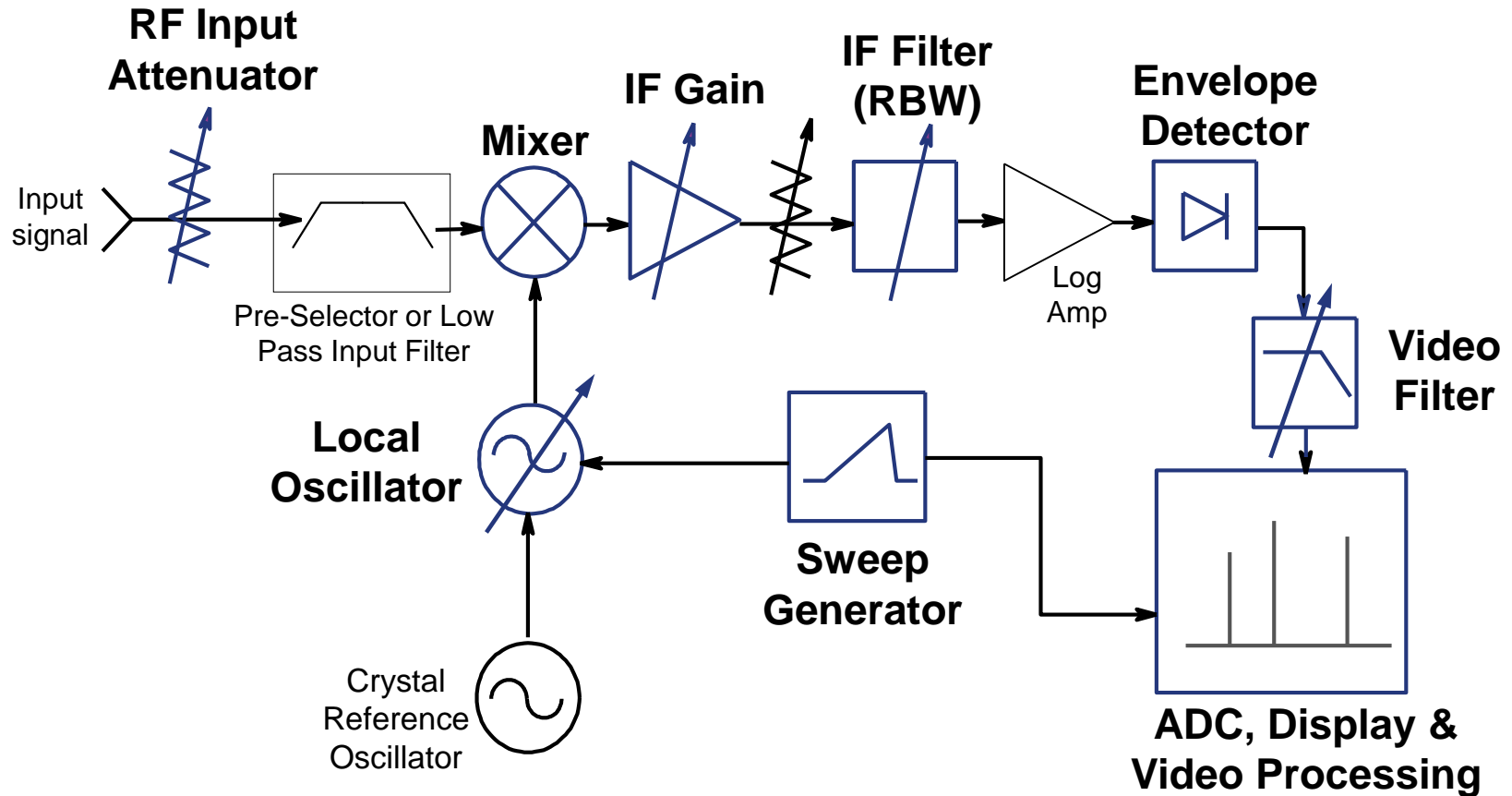


# Agenda

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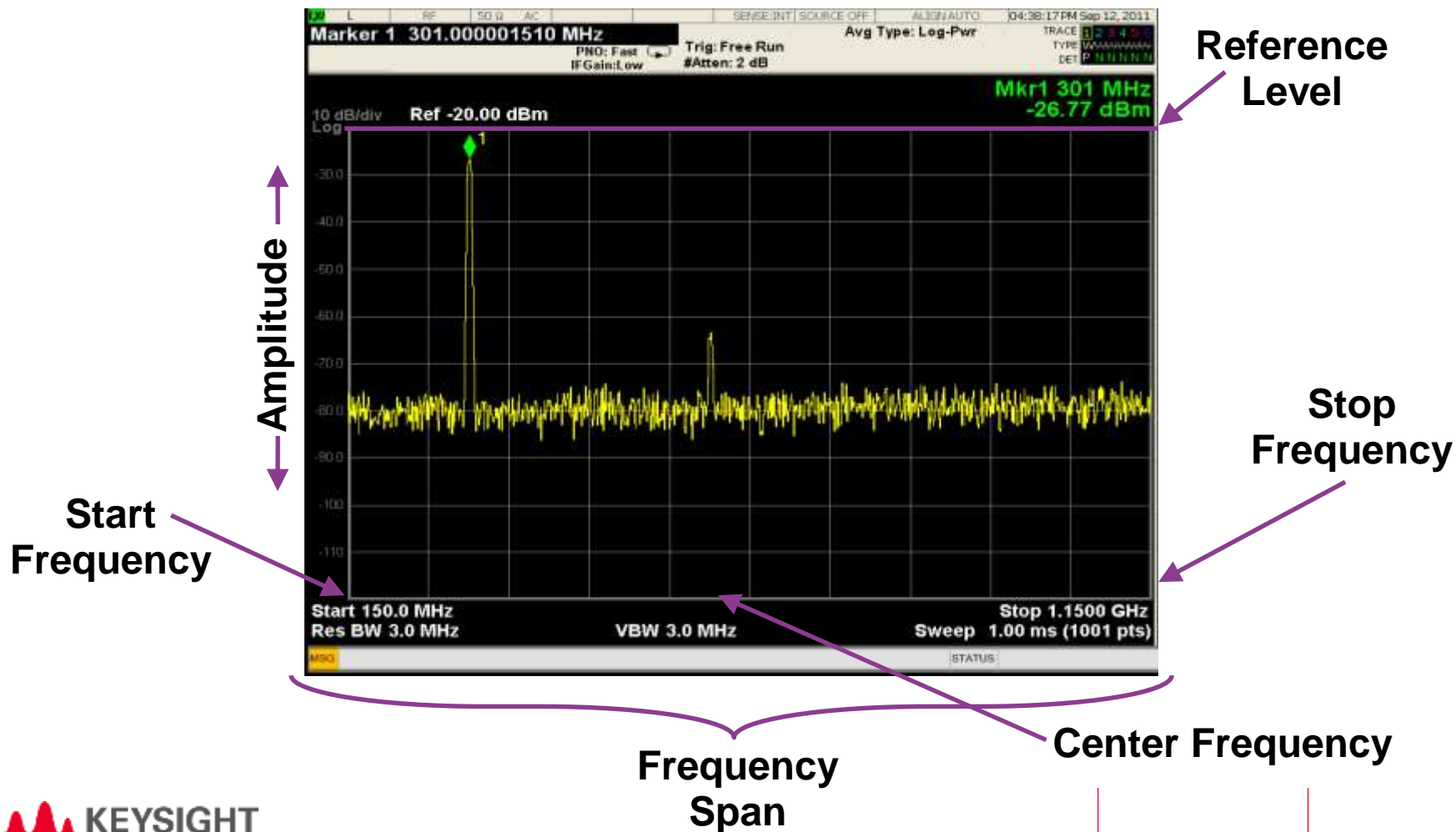
# Theory of Operation

## Swept Spectrum Analyzer Block Diagram



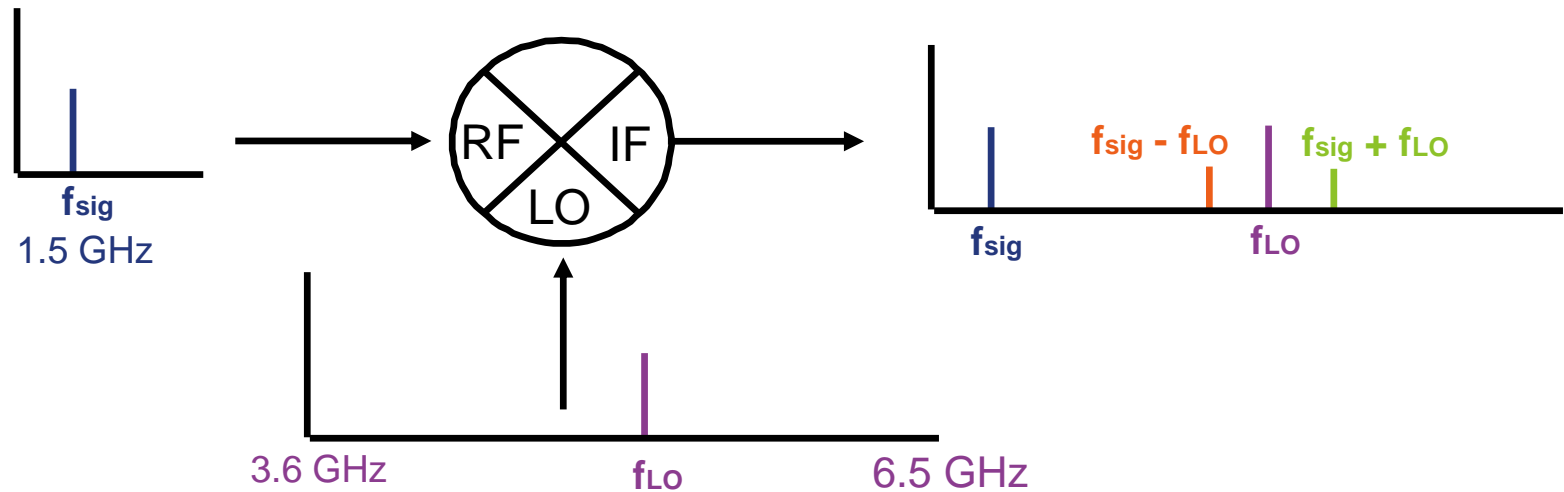
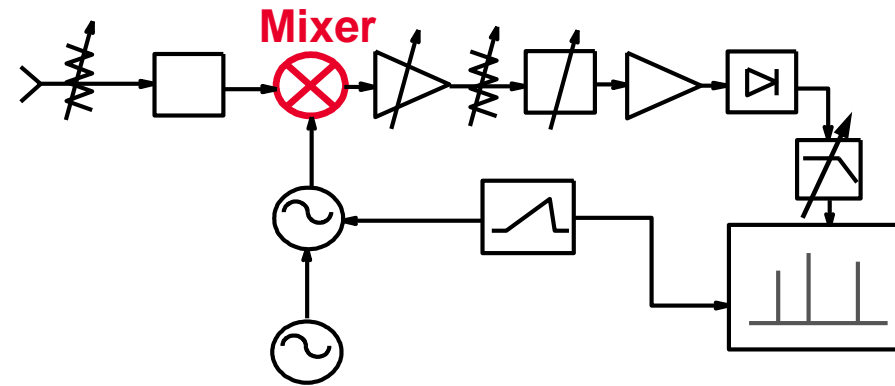
# Theory of Operation

## Display Terminology



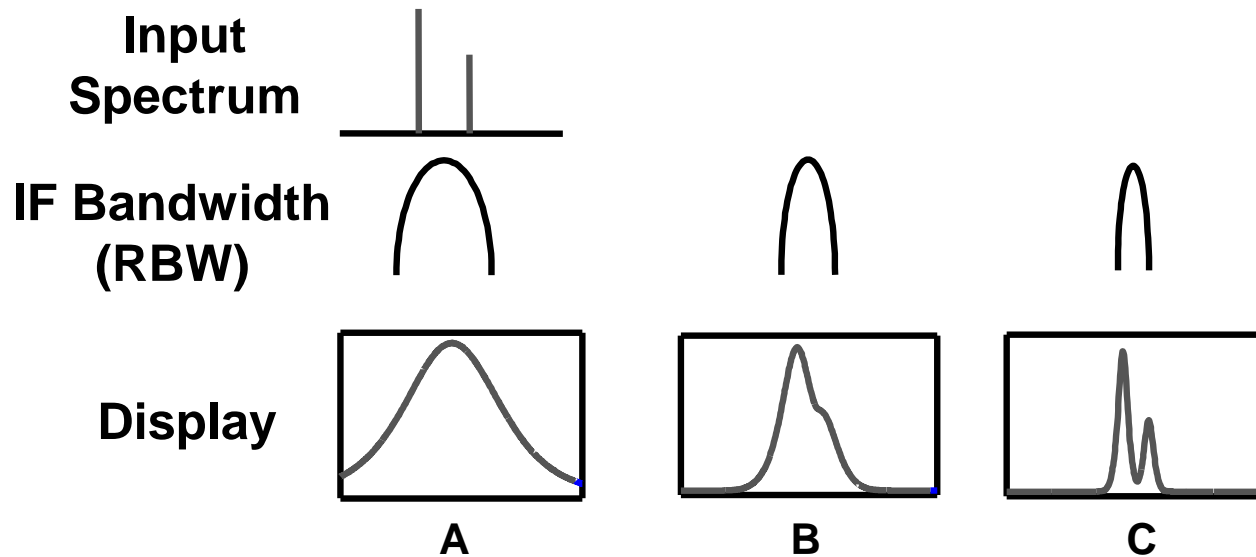
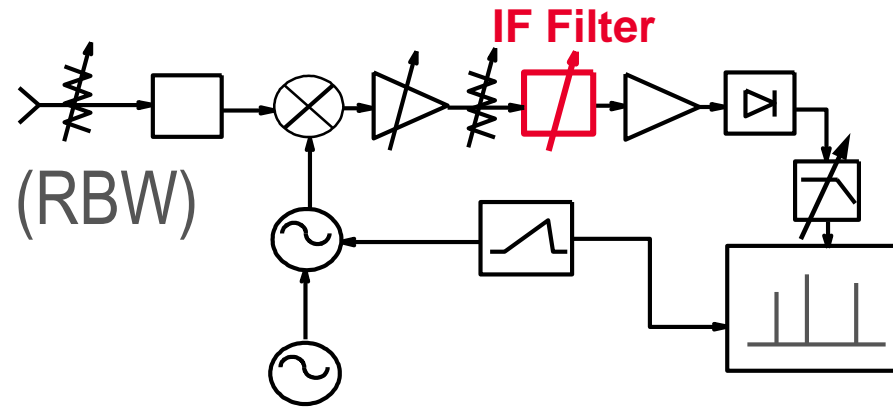
# Theory of Operation

## Mixer



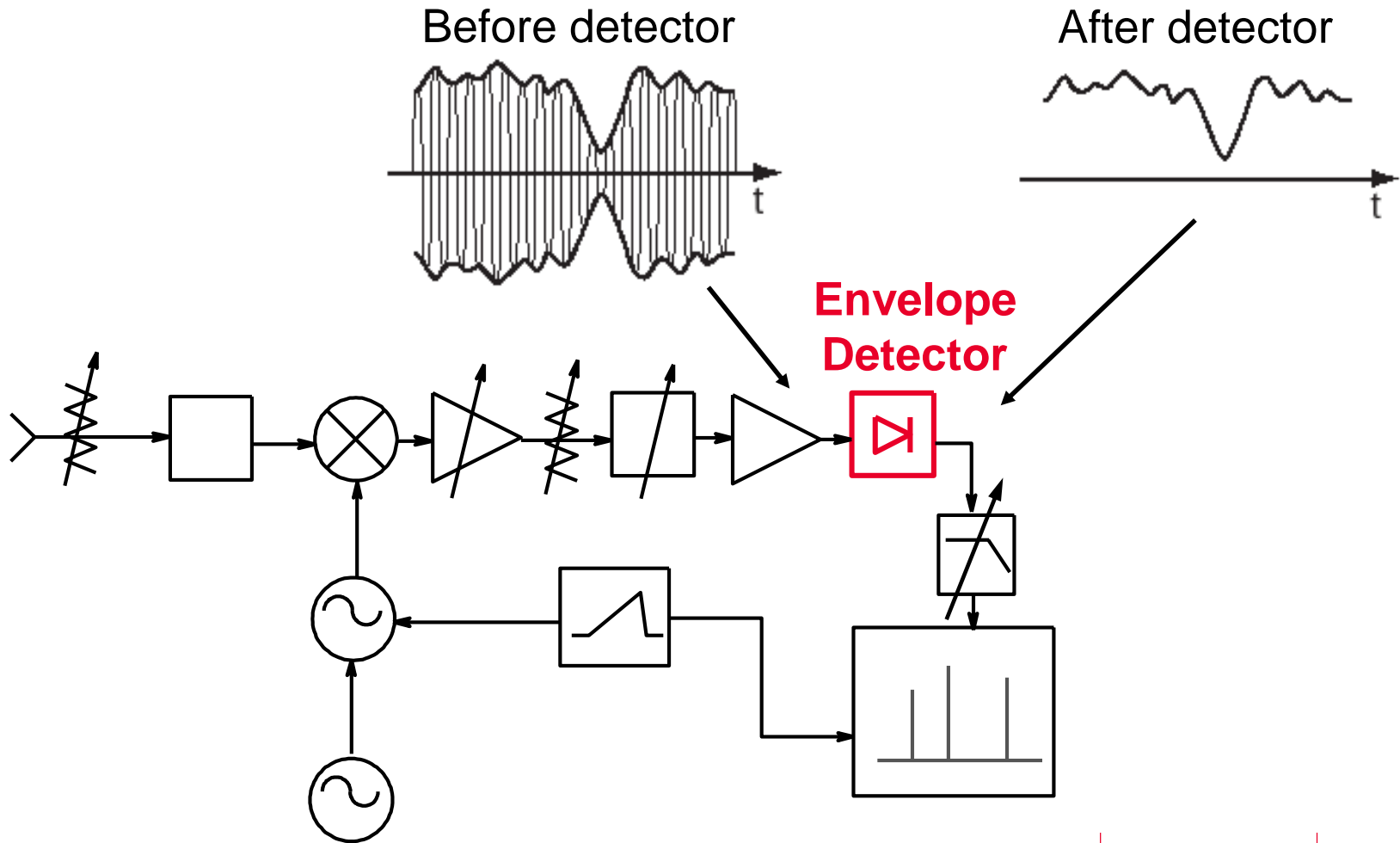
# Theory of Operation

## IF Filter (Resolution Bandwidth (RBW))



# Theory of Operation

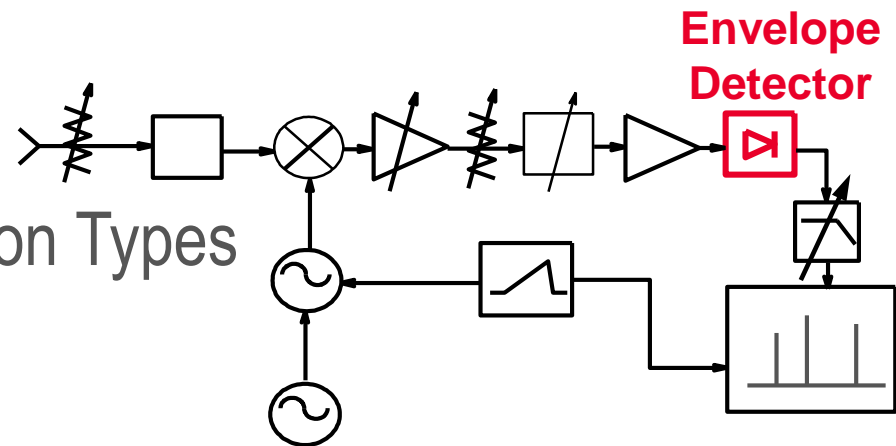
## Envelope Detector



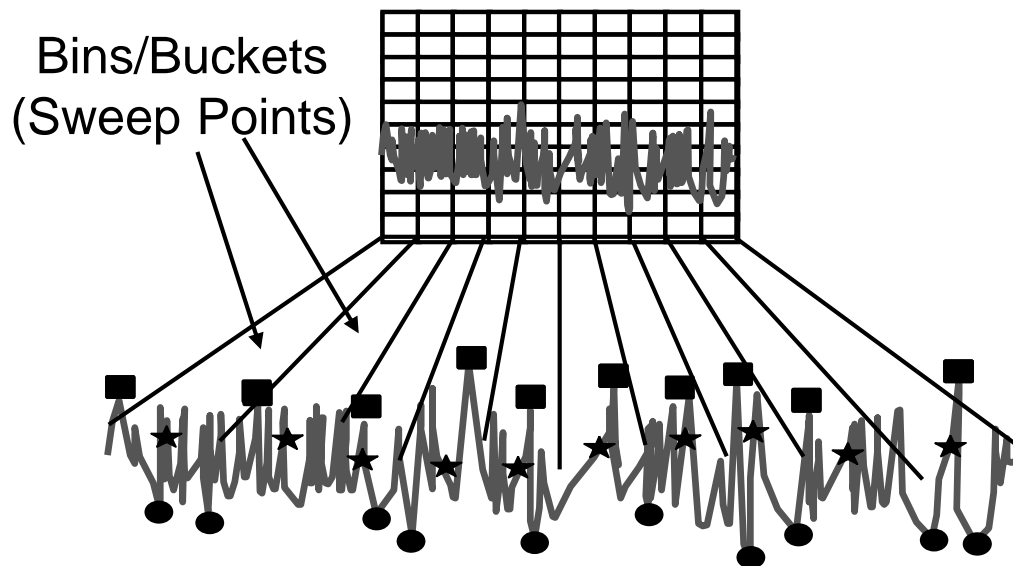


# Theory of Operation

## Envelope Detector and Detection Types



## Digitally Implemented Detection Types

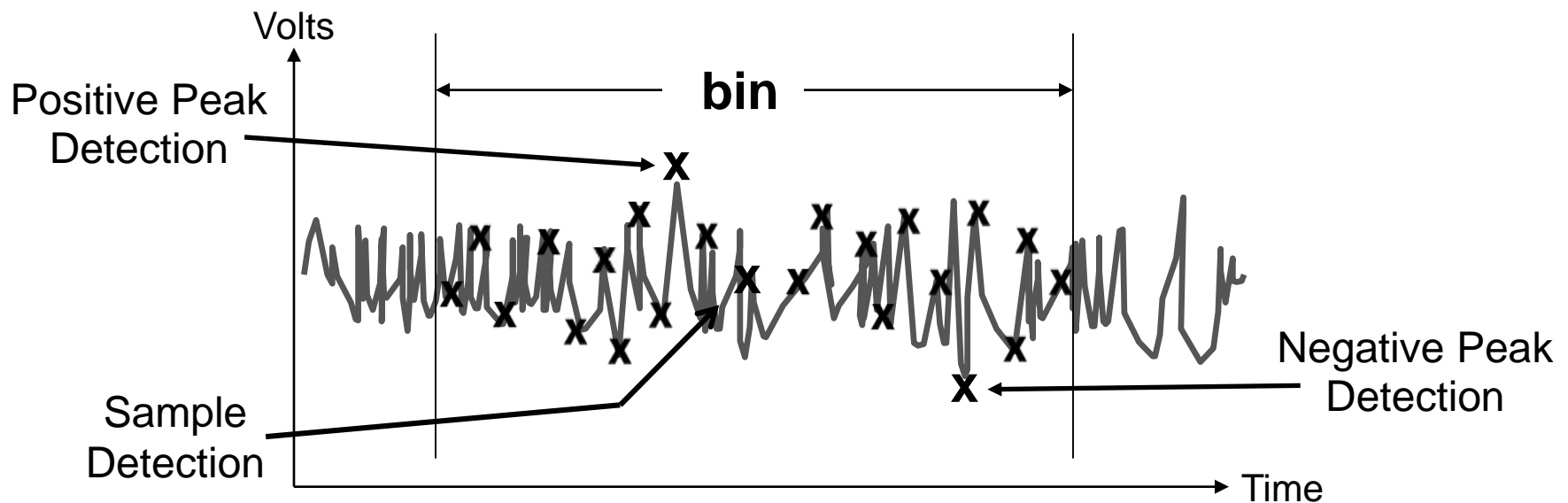
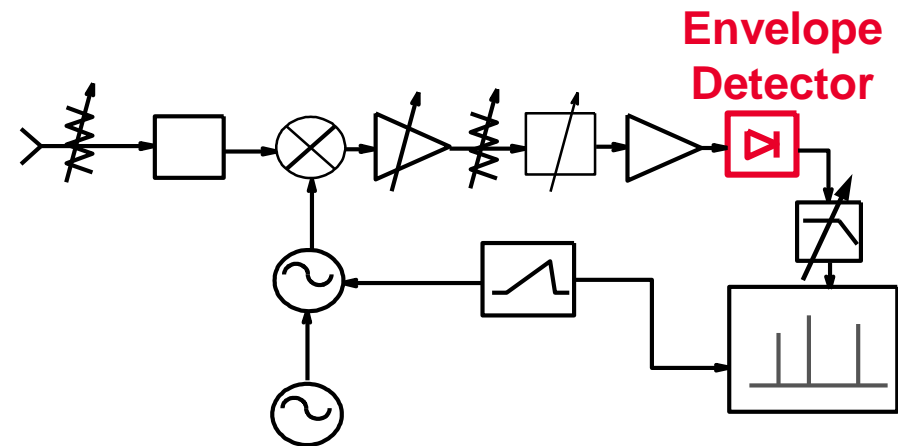


- **Positive Detection:** largest value in bin displayed
- **Negative detection:** smallest value in bin displayed
- ★ **Sample detection:** middle value in bin displayed

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

# Theory of Operation

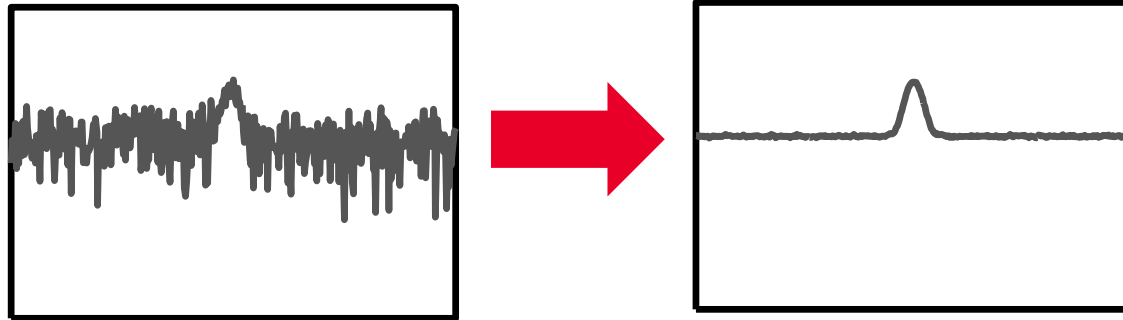
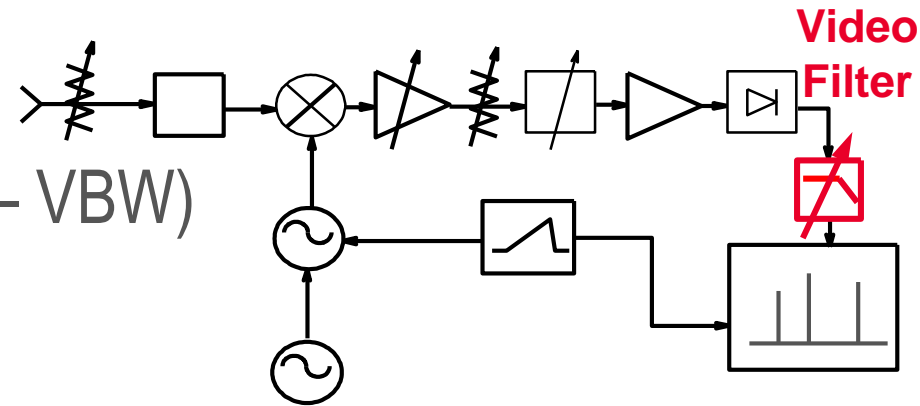
## Average Detector Type



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

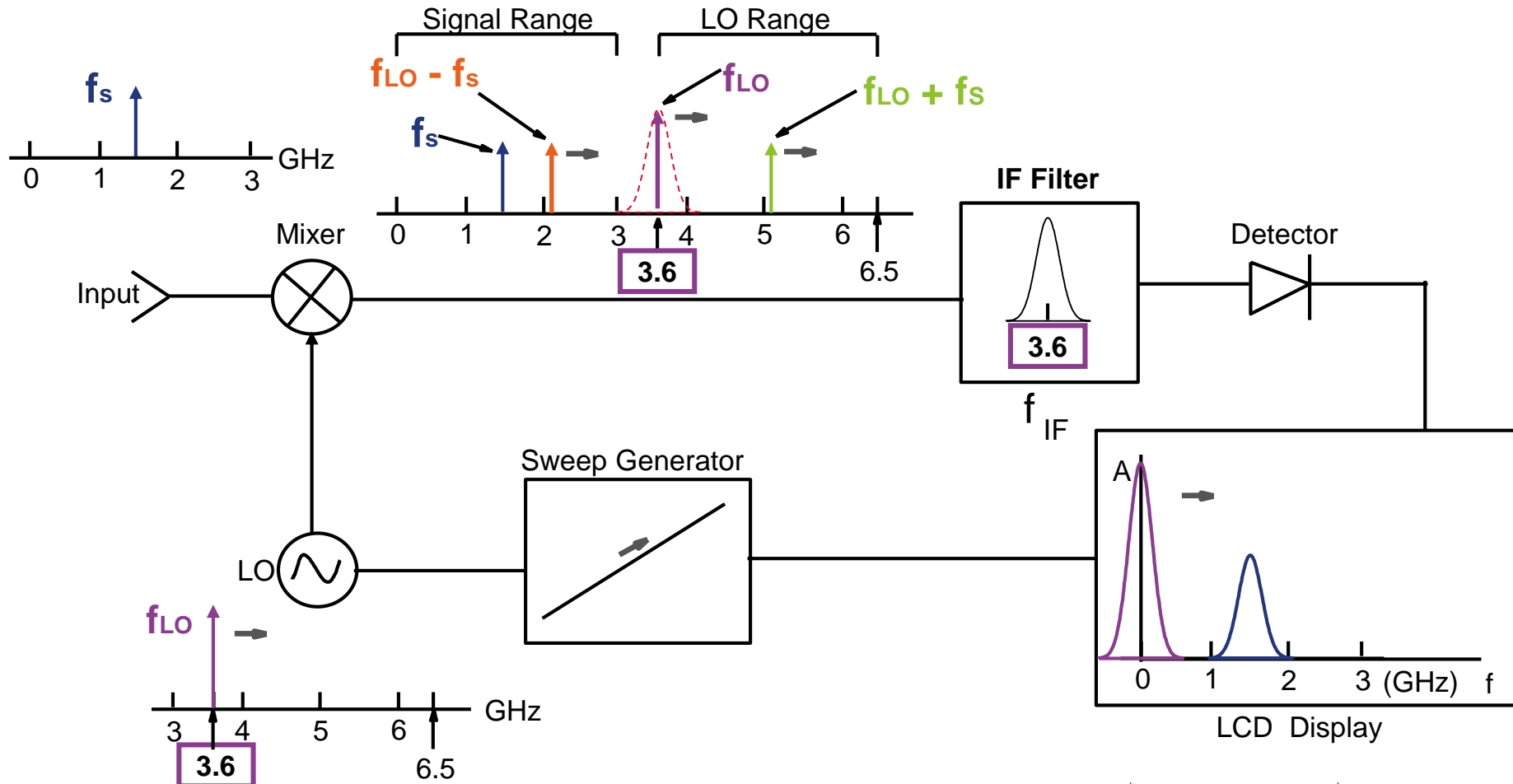
# Theory of Operation

Video Filter (Video Bandwidth – VBW)



# Theory of Operation

## How it All Works Together – 3 GHz Spectrum Analyzer

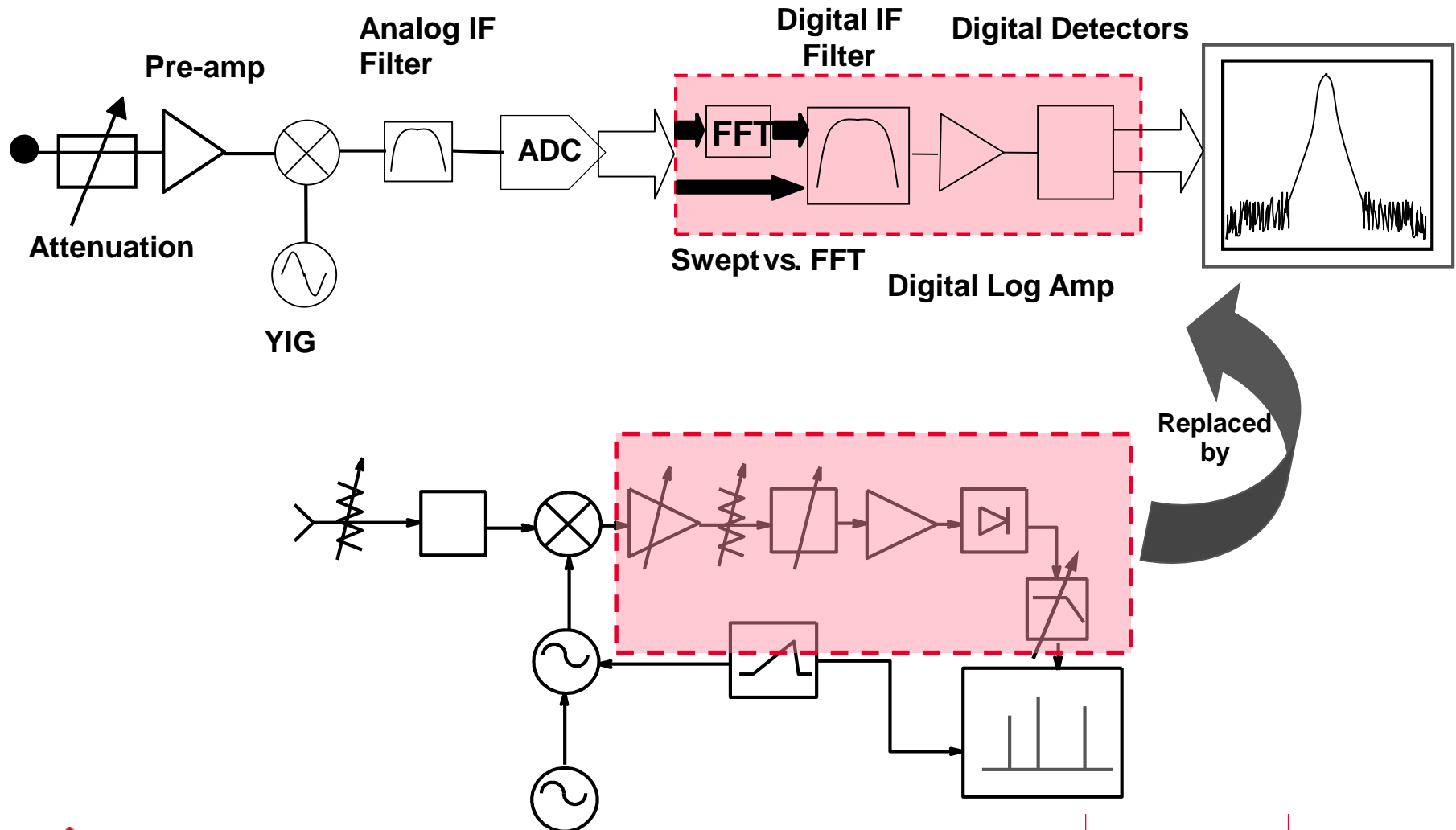


# Demonstration

Show Spectrum Analyzer animation of sweep

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# Modern Signal Analyzer Block Diagram

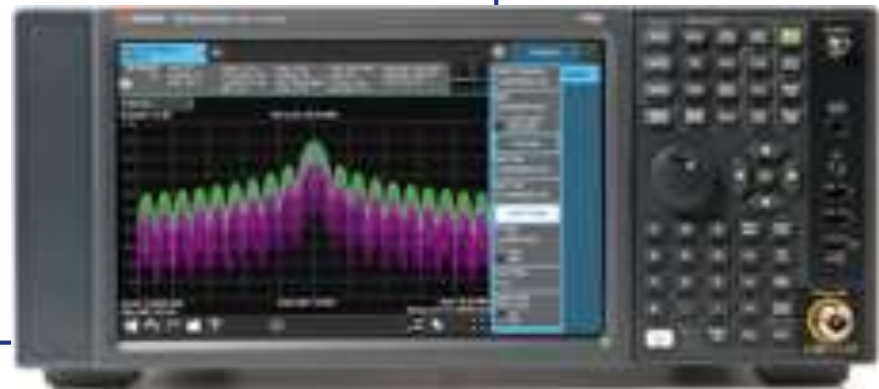


# Agenda

- Overview
- Theory of Operation
  - Traditional Spectrum Analyzers
  - Modern Signal Analyzers
- Specifications
- Features
- Wrap-up

# Key Specifications

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





# Specifications

## Definitions

- **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.

# Specifications

## Practicing Safe Spectrum Analysis - Safe Hookups to RF

- 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 exceeding what the analyzer can tolerate while DC coupled!



# Specifications

## Frequency Range

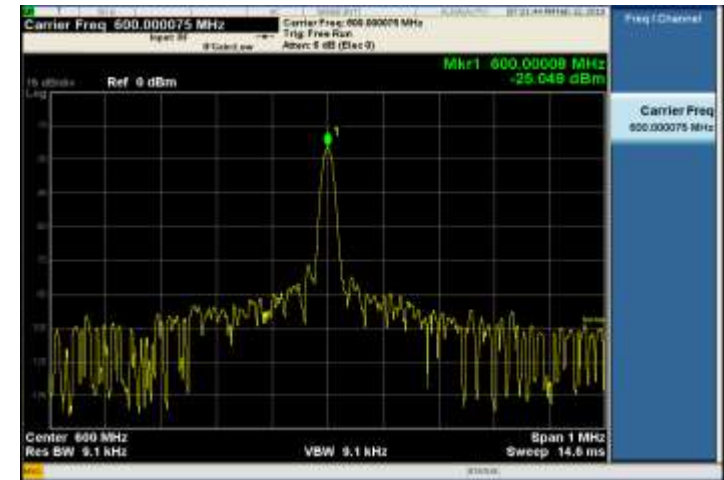
### Description

### 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

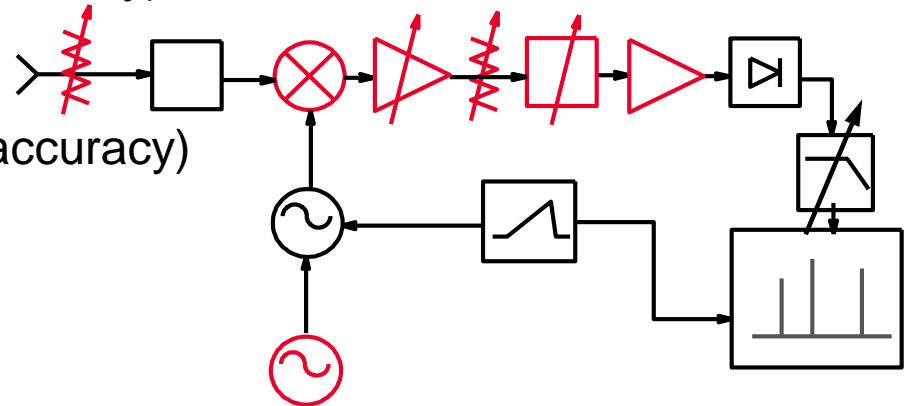


# Specifications

## Accuracy: Frequency & Amplitude

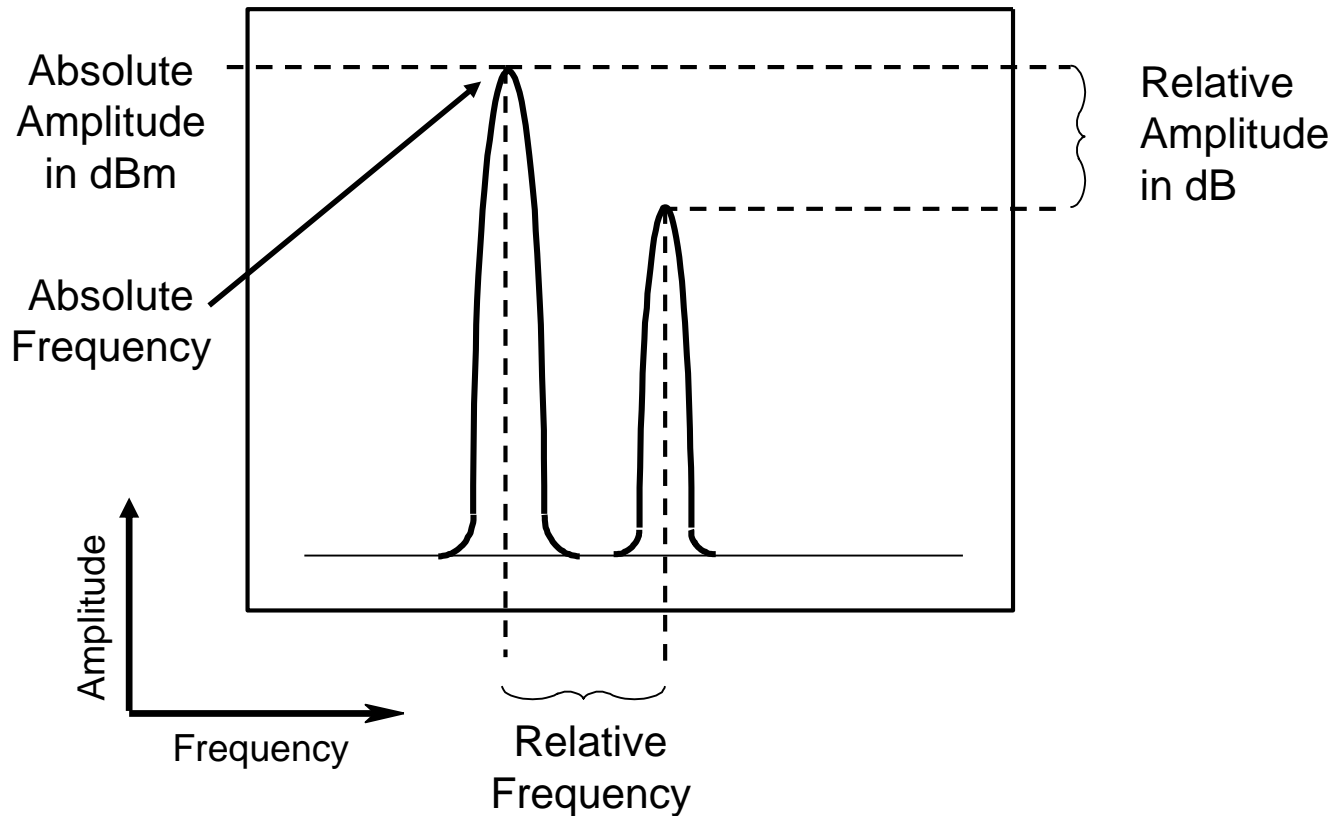
- Components which contribute to uncertainty are:

- 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

## Accuracy: Absolute vs Relative

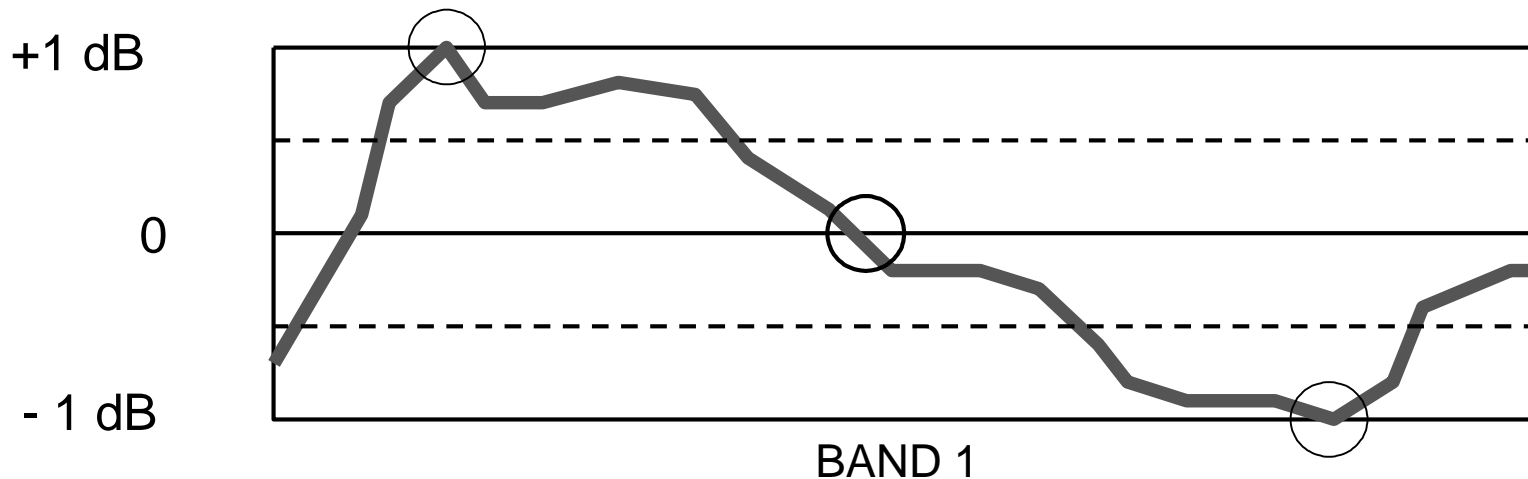


Note: Absolute accuracy is also “relative” to the calibrator reference point

# Specifications

## Accuracy: Frequency Response

Signals in the Same Harmonic Band



Absolute amplitude accuracy – Specification:  $\pm 1$  dB

Relative amplitude accuracy – Specification:  $\pm 2$  dB

# Specifications

## Accuracy: Frequency Readout Accuracy

Frequency Readout Accuracy =

$$\pm [(\text{Marker Frequency} \times \text{Frequency Reference Accuracy}) + (\text{0.1\%} \times \text{Span}) + (\text{5\%} \times \text{RBW}) + 2\text{Hz} + (0.5 \times \text{Horizontal Resolution})]$$

$$= \pm [(\text{time since last adjustment} \times \text{aging rate}) + \text{temperature stability} + \text{calibration accuracy}] = 1.55 \times 10^{-7} / \text{year}$$

$$= \text{span} / (\text{sweep points} - 1)$$

**Example:** 1 GHz Marker Frequency, 400 kHz Span, 3 kHz RBW, 1000 Sweep Points

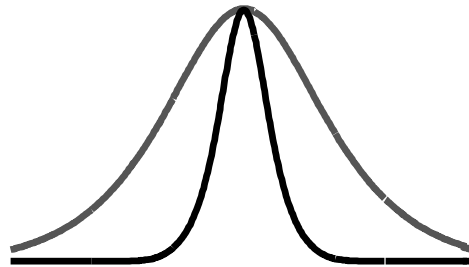
<b>Calculation:</b> $(1 \times 10^9 \text{Hz}) \times (\pm 1.55 \times 10^{-7} / \text{Year})$	= 155Hz
400kHz Span x 0.1%	= 400Hz
3kHz RBW x 5%	= 150Hz
2Hz + $0.5 \times 400\text{kHz} / (1000 - 1)$	= 202Hz
<b>Total uncertainty</b>	<b>= ±907Hz</b>

- Utilizing internal frequency counter improves accuracy to ±155 Hz
- The maximum number of sweep points for the X-Series Analyzers is 40,001 which helps to achieve the best frequency readout accuracy

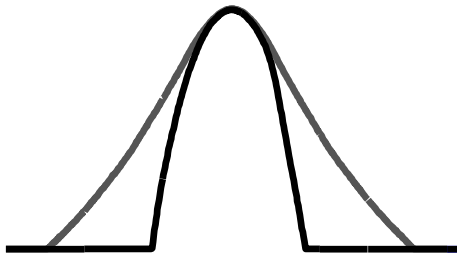
# Specifications

## Resolution

What Determines Resolution?



Resolution  
Bandwidth



RBW Type and  
Selectivity

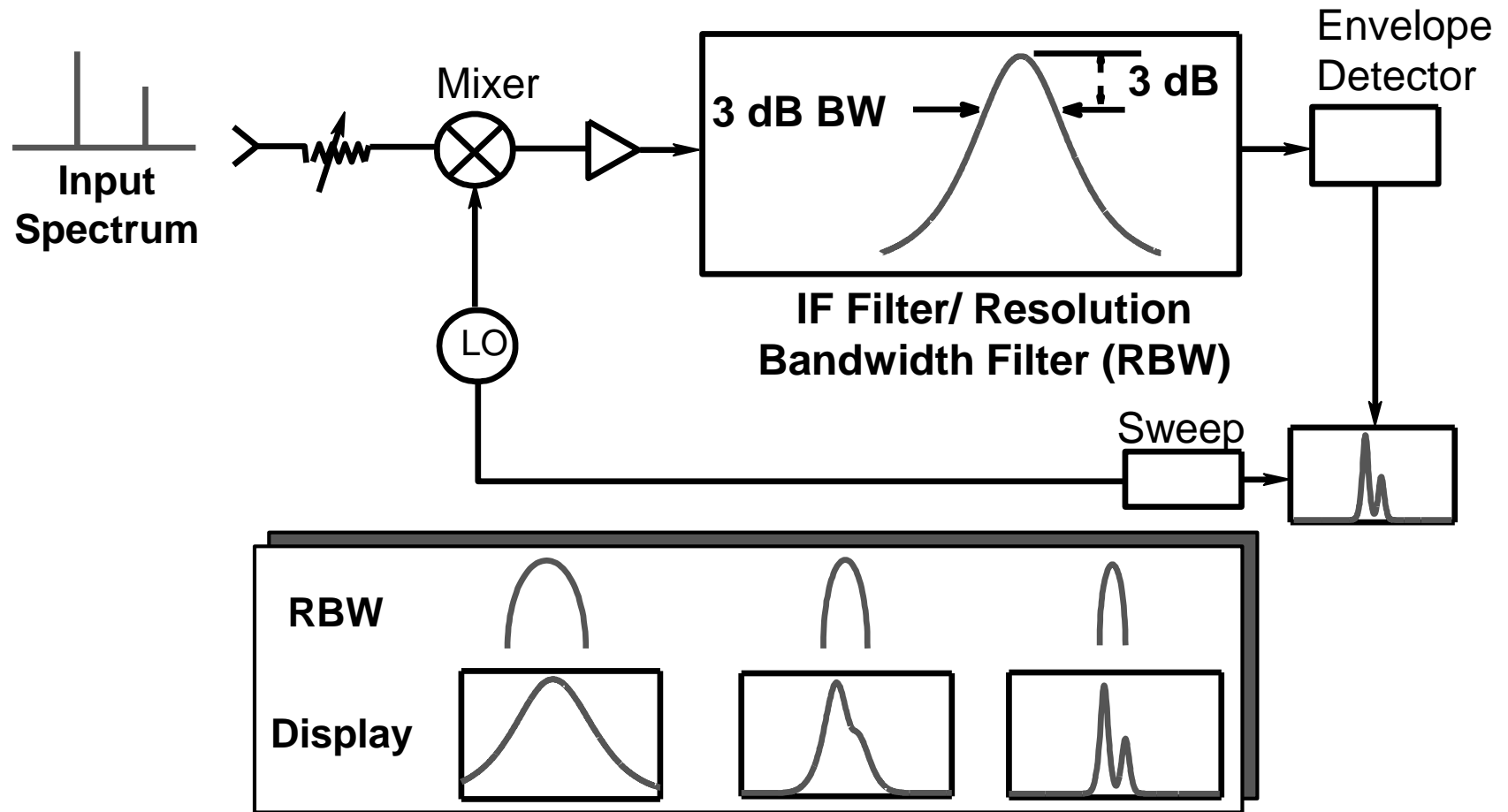


Noise Sidebands



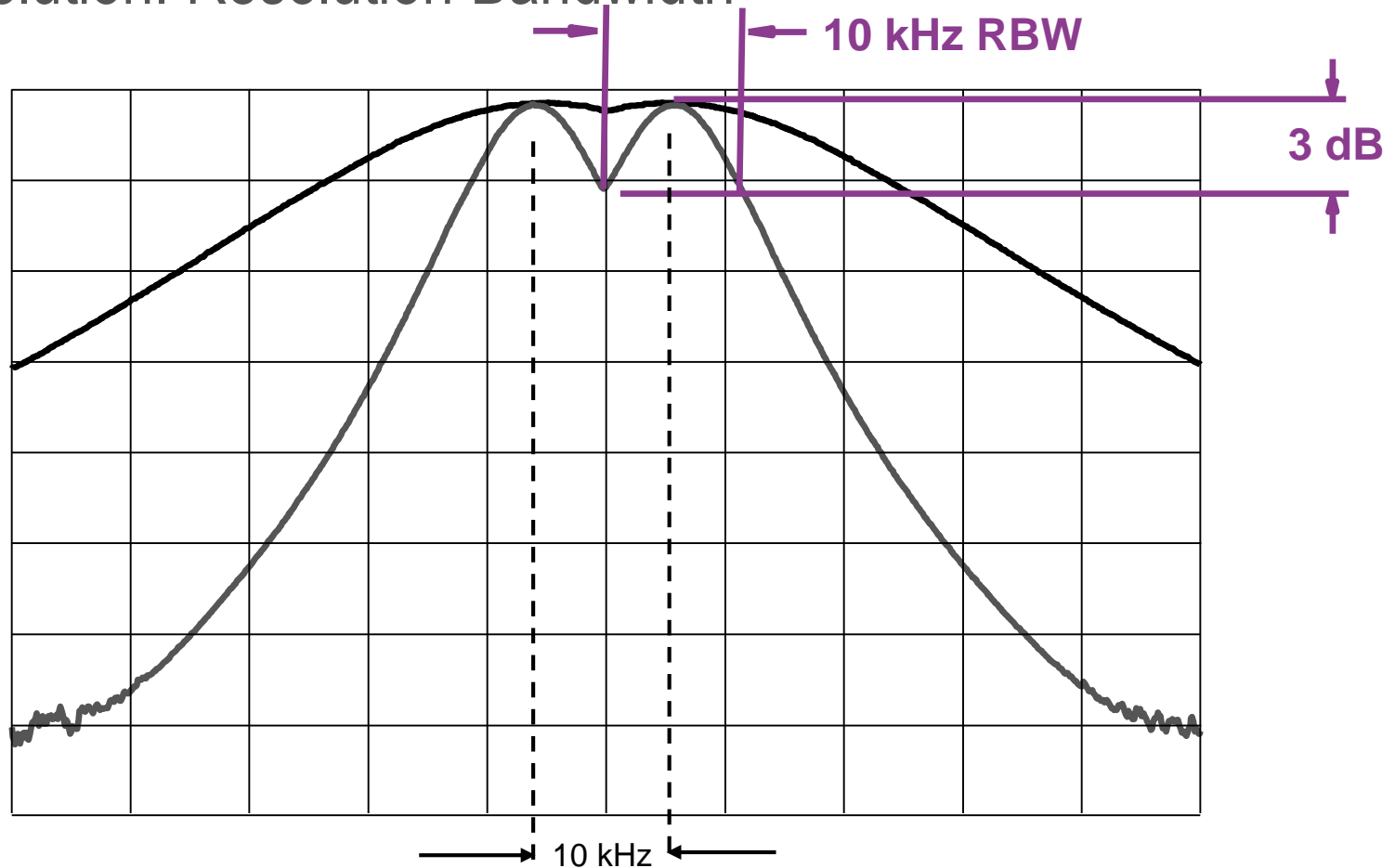
# Specifications

Resolution: Resolution Bandwidth



# Specifications

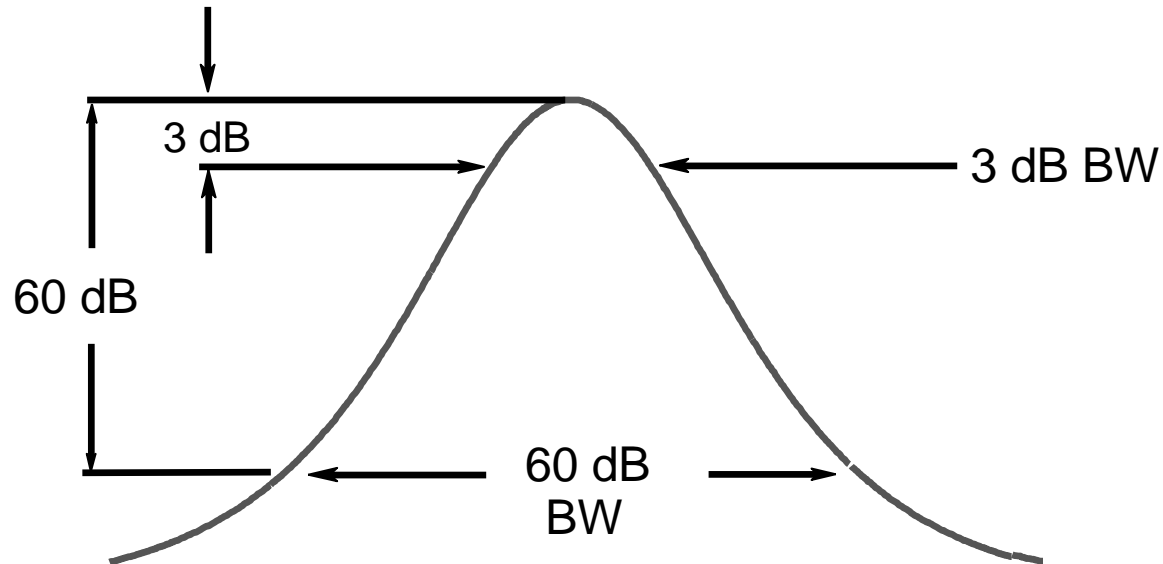
Resolution: Resolution Bandwidth



Determines resolvability of **equal** amplitude signals

# Specifications

Resolution: RBW Selectivity or Shape Factor



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

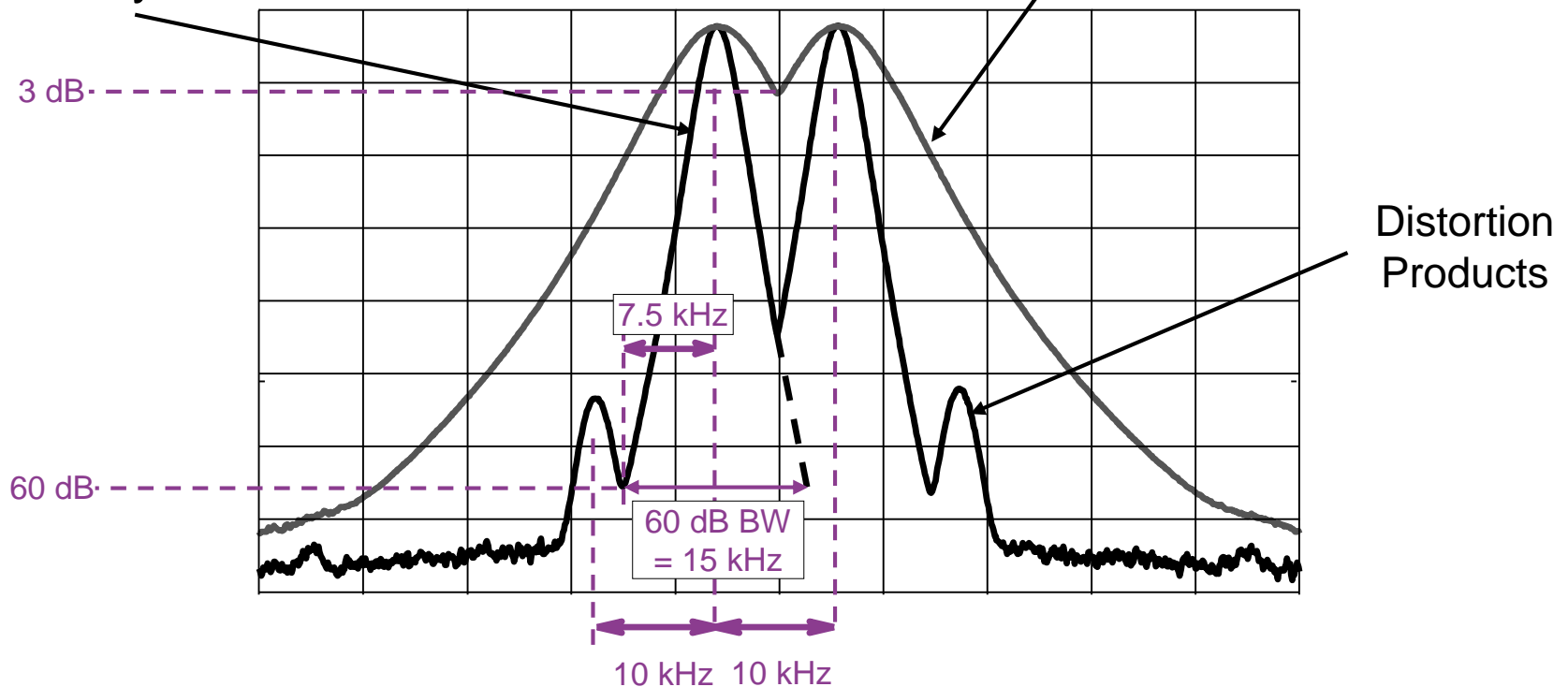
Determines resolvability of **unequal** amplitude signals

# Specifications

Resolution: RBW Selectivity or Shape Factor

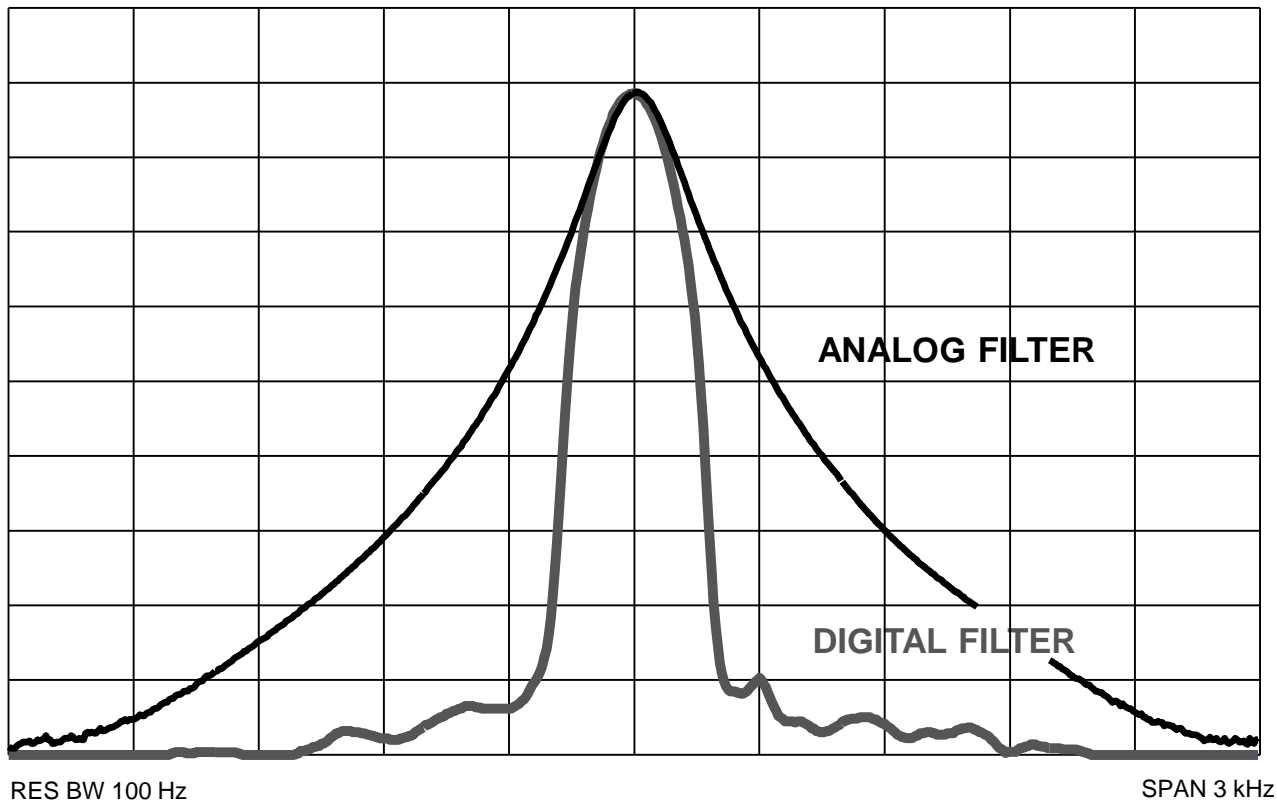
RBW = 1 kHz  
Selectivity 15:1

RBW = 10 kHz



# Specifications

## Resolution: RBW Type and Selectivity



### Typical Selectivity

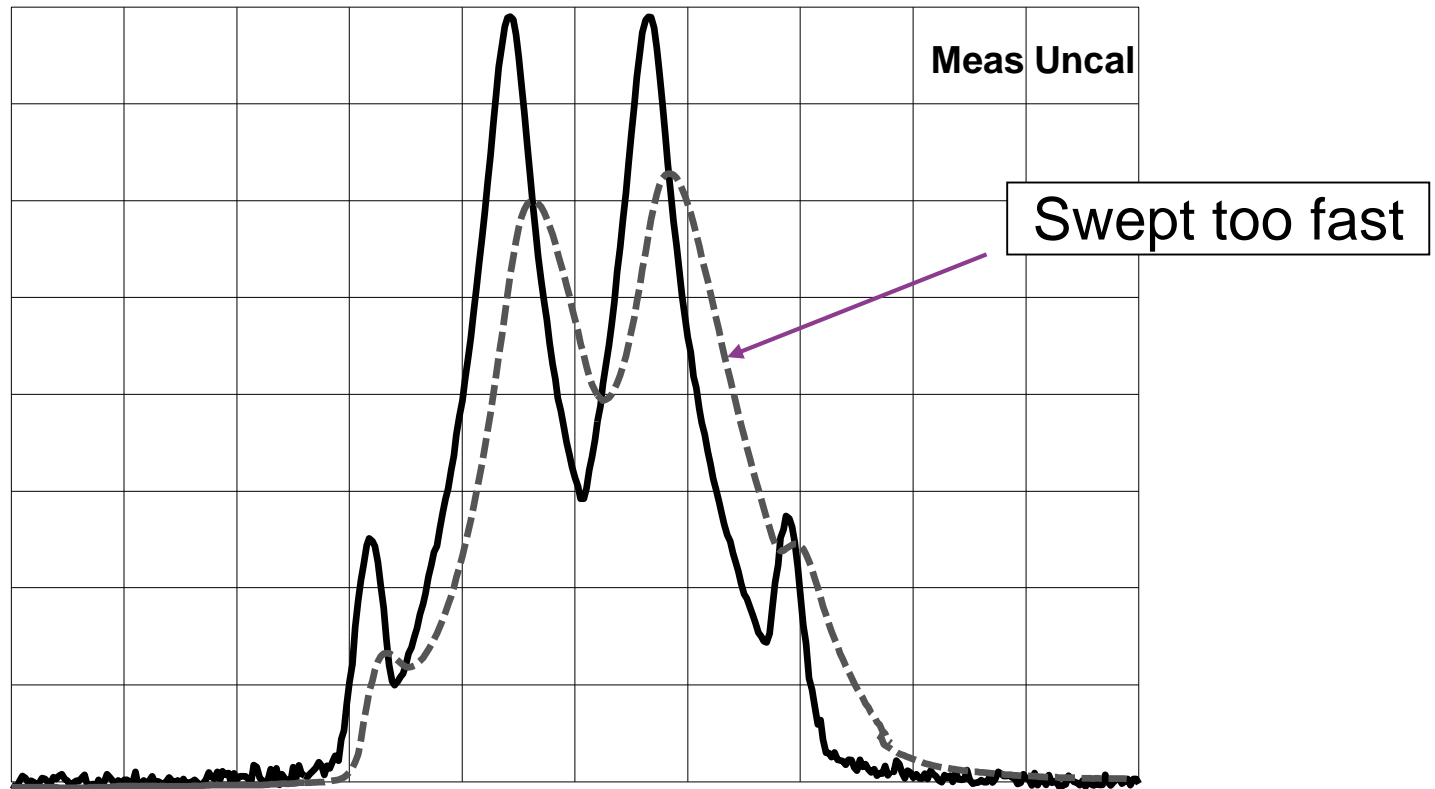
Analog 15:1

Digital  $\leq 5:1$

The X-series RBW shape factor is 4.1:1

# Specifications

Resolution: RBW Determines Sweep Time



The penalty for sweeping too fast is an uncalibrated display.

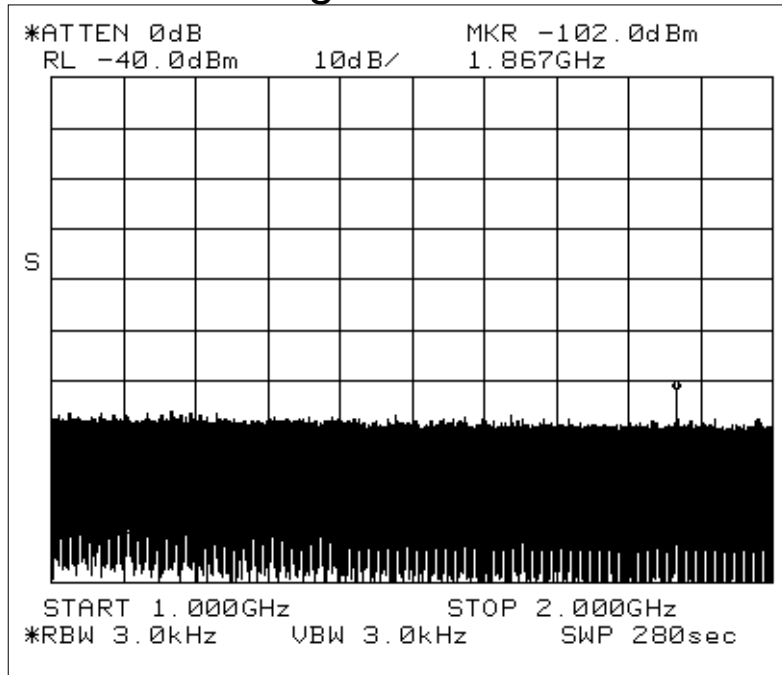
# Demonstration

Show 2 equal amplitude signals, 10kHz apart with RBW set high enough that both signals cannot be seen. Reduce RBW until both signals can be seen.

Show 2 unequal amplitude signals and reduce RBW until both can be seen. Set analyzer to sweep too fast and show errors (if possible).

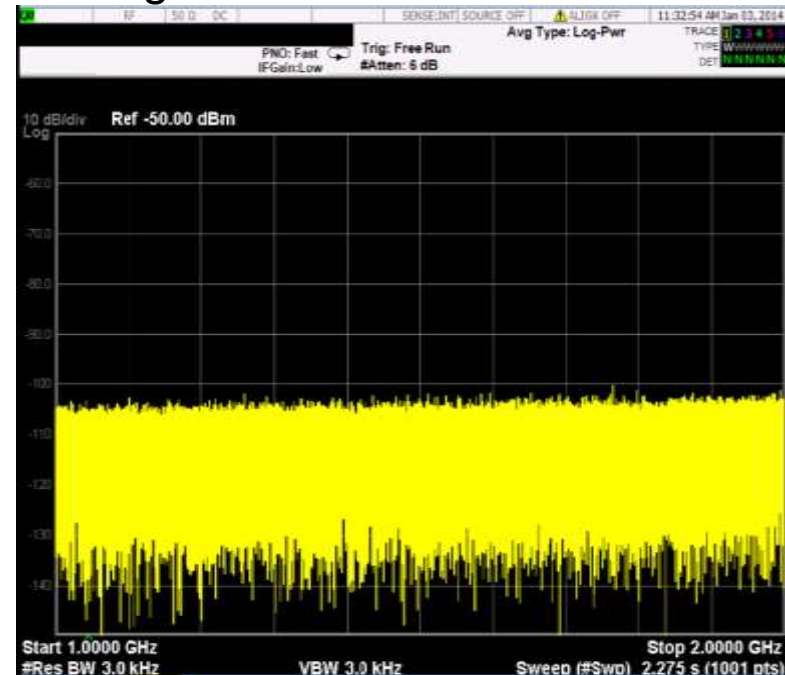
# Resolution: RBW Type Determines Sweep Time

## Analog RBW



280 sec

## Digital RBW

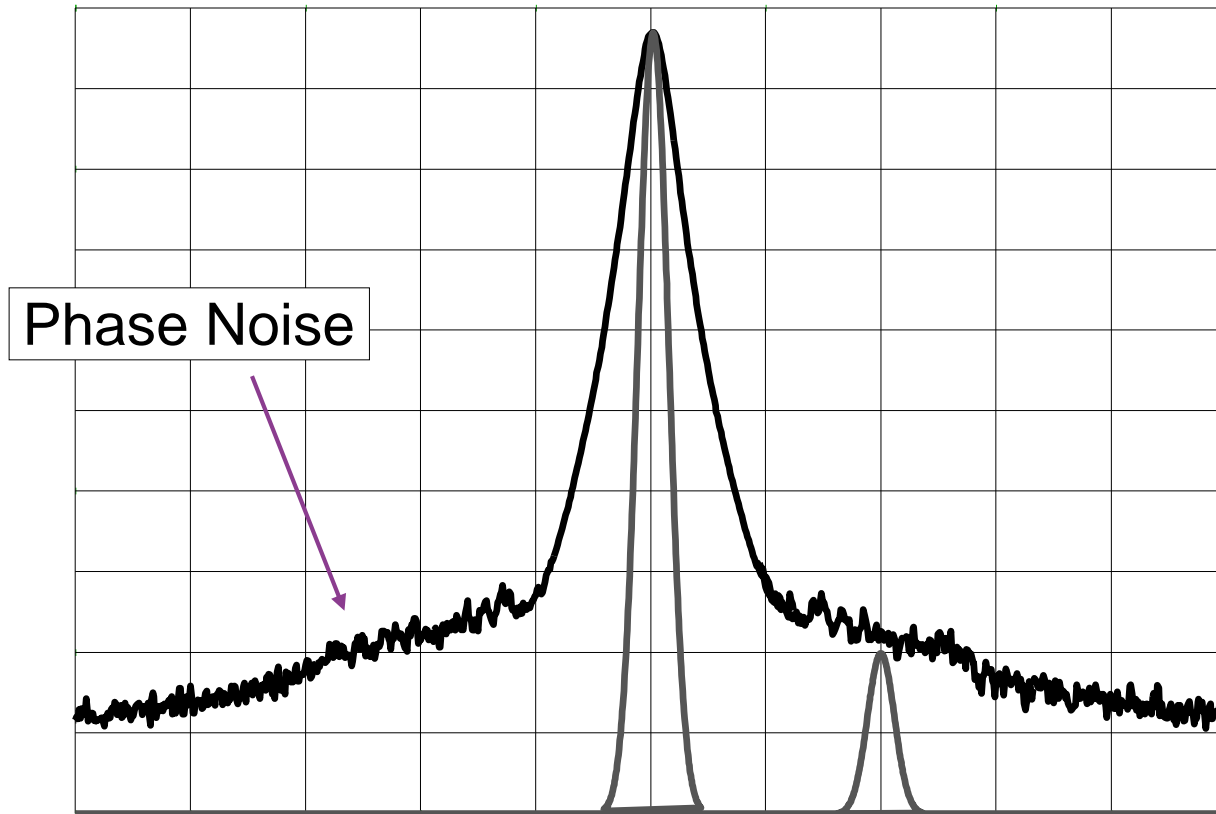


2.3 sec



# Specifications

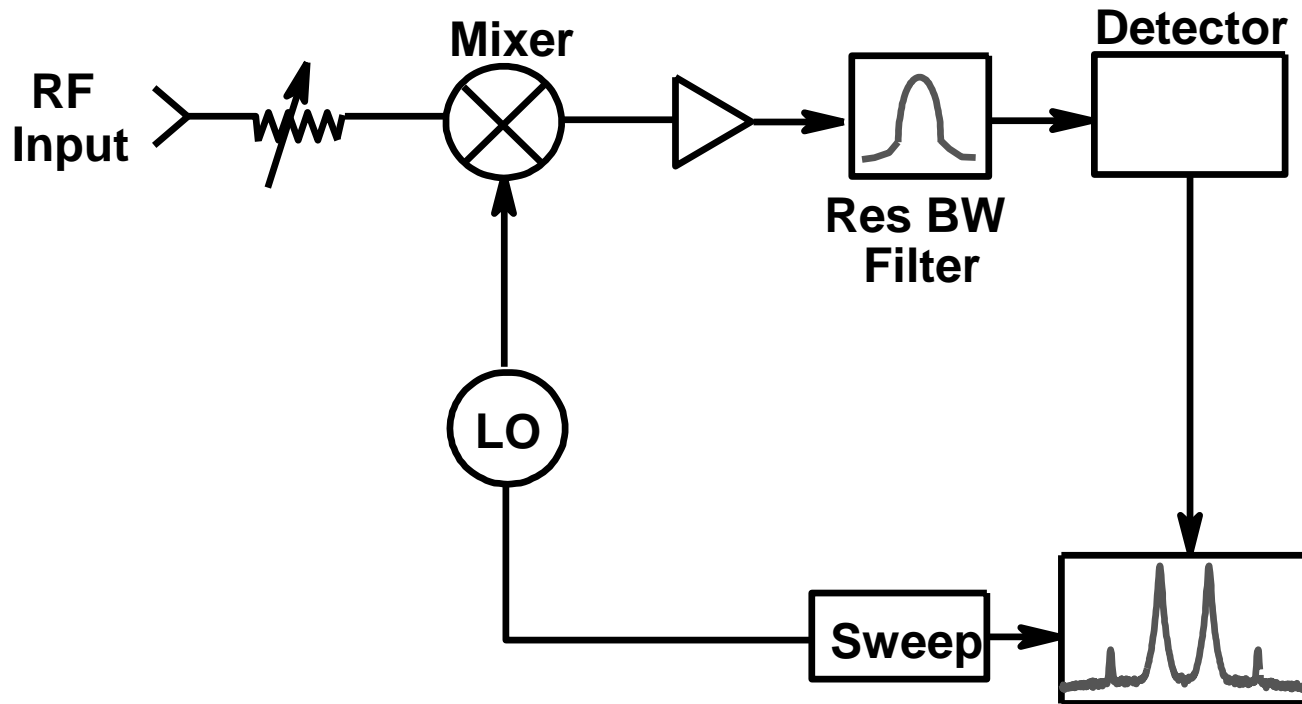
## Resolution: Noise Sidebands



Noise sidebands can prevent resolution of unequal signals.

# Specifications

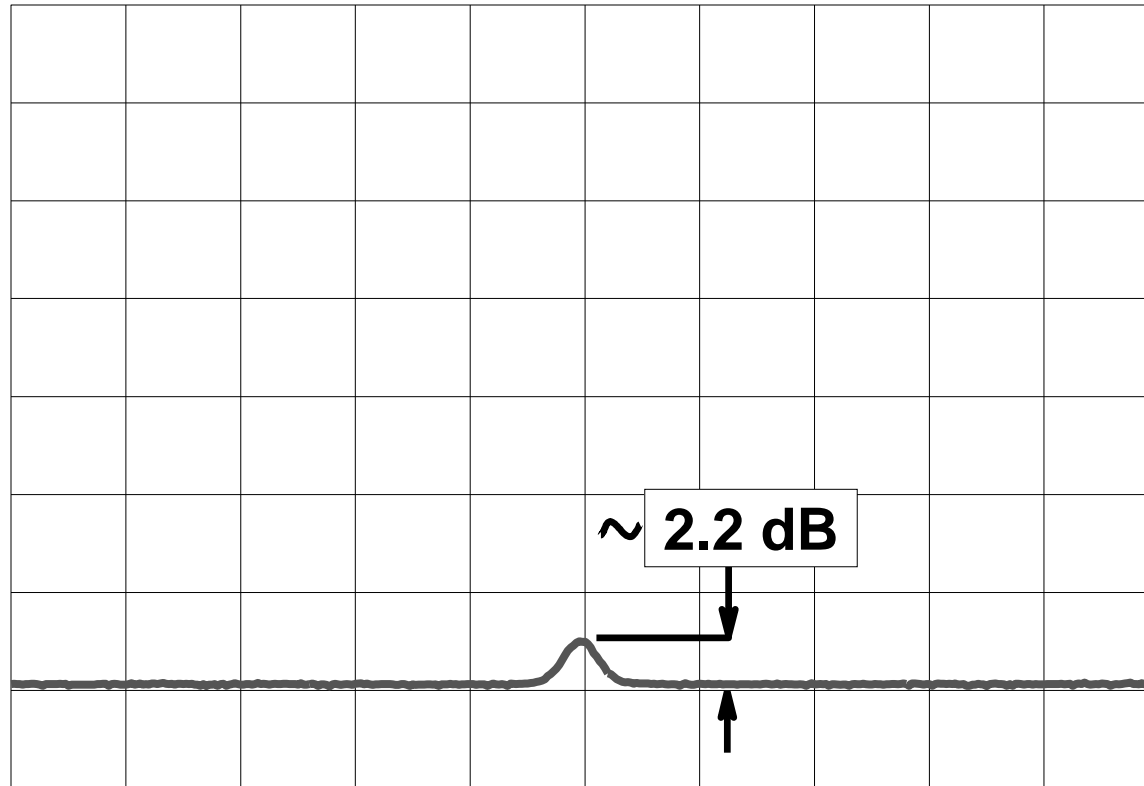
## Sensitivity/DANL



A spectrum analyzer generates and amplifies noise just like any active circuit.

# Specifications

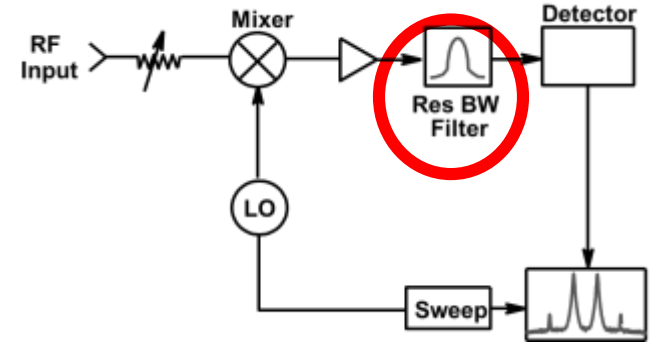
## Sensitivity/DANL



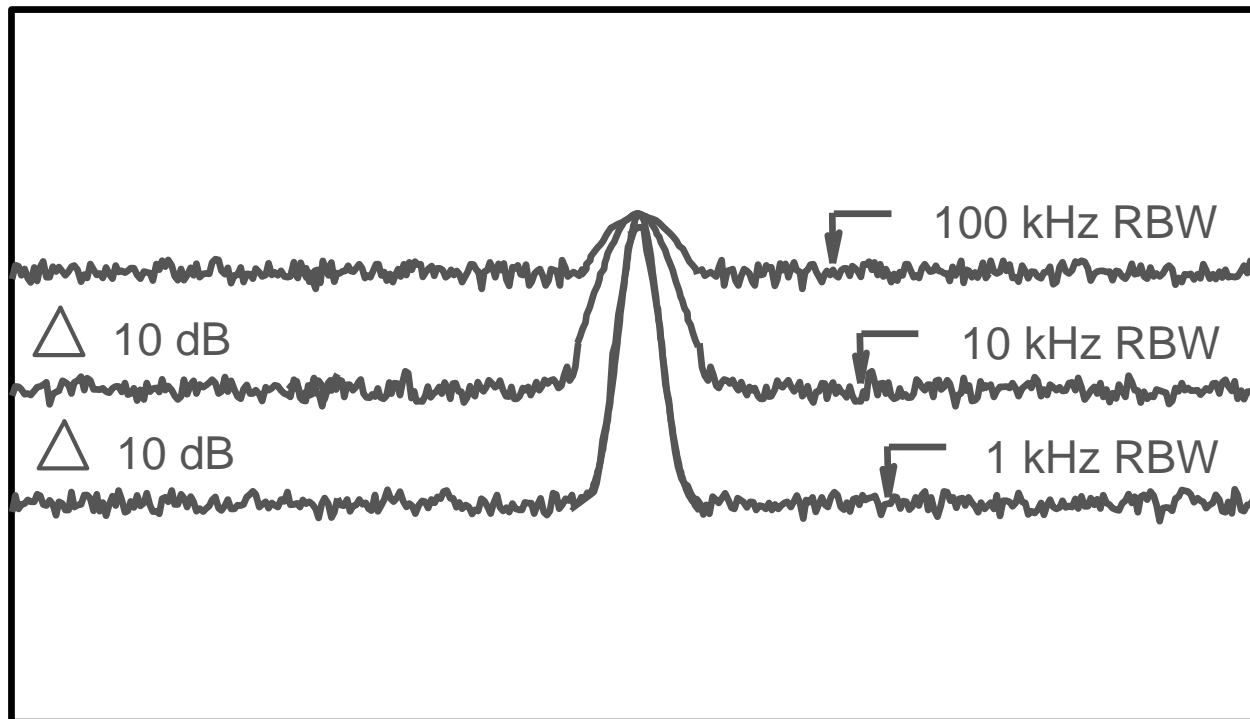
Sensitivity is the smallest signal that can be measured.

# Specifications

## Sensitivity/DANL: IF Filter (RBW)



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

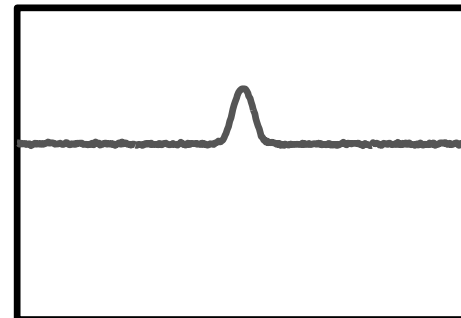
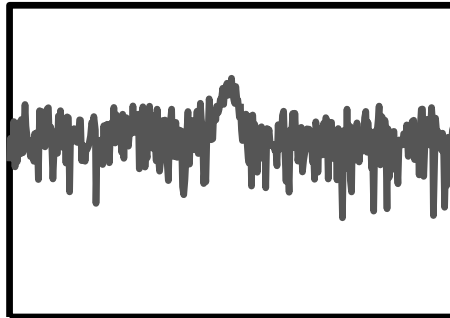
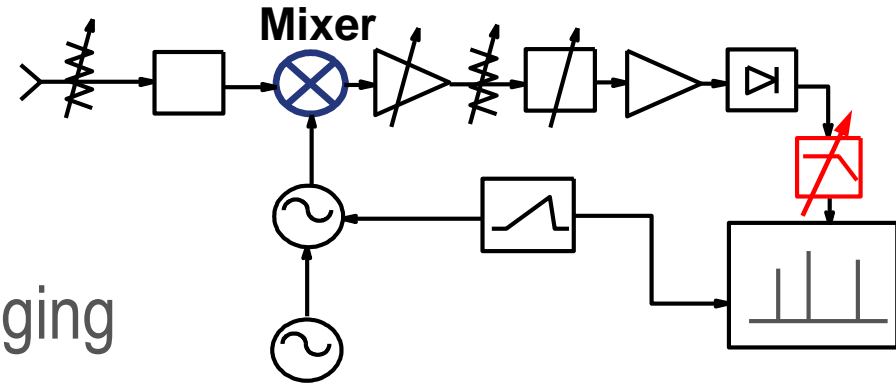


# Specifications

Sensitivity/DANL:

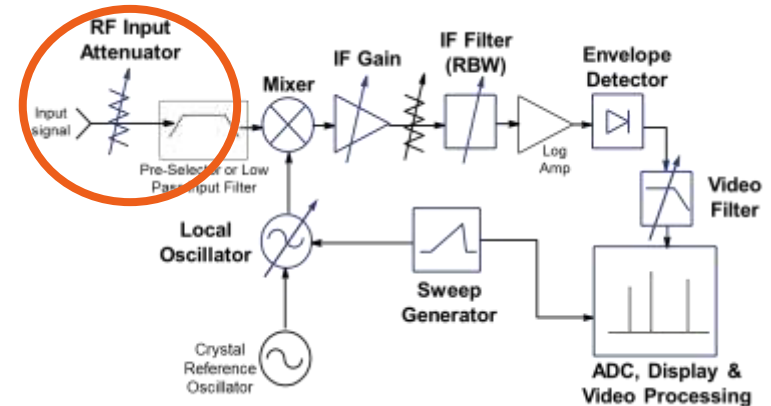
Video BW Filter or Trace Averaging

Video BW or trace averaging smoothes noise for easier identification of low level signals.

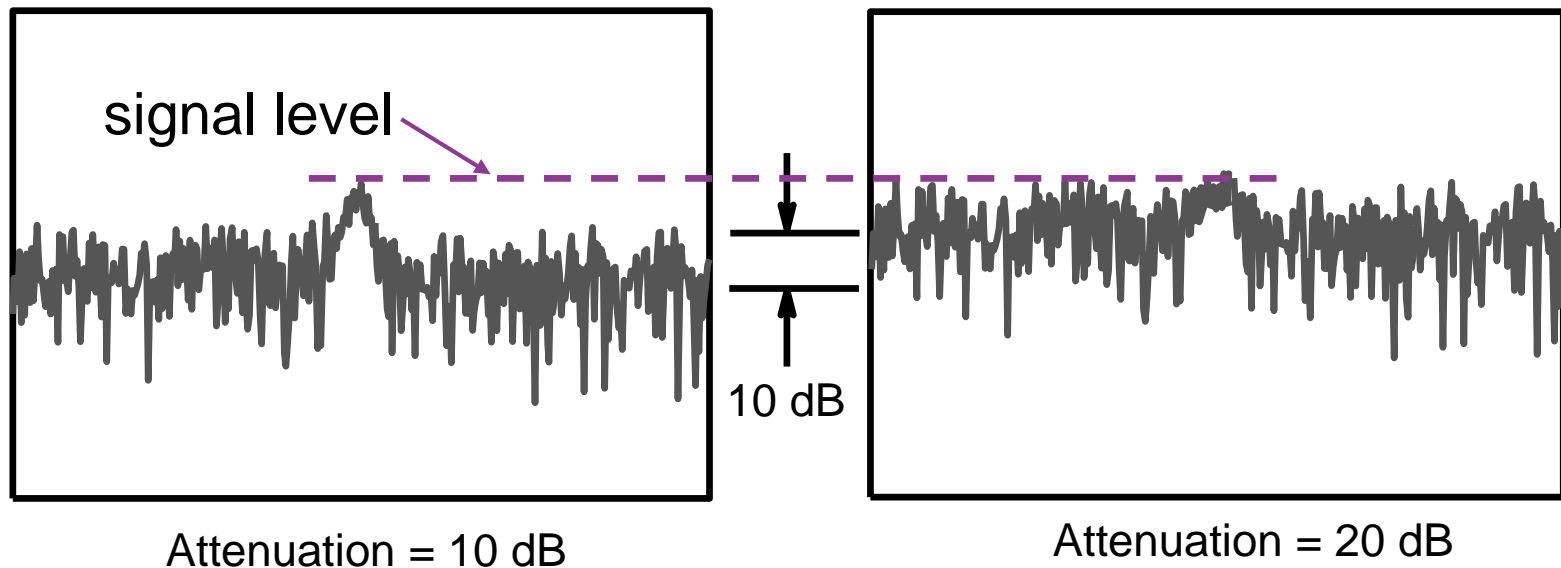


# Specifications

## Sensitivity/DANL: Input Attenuation



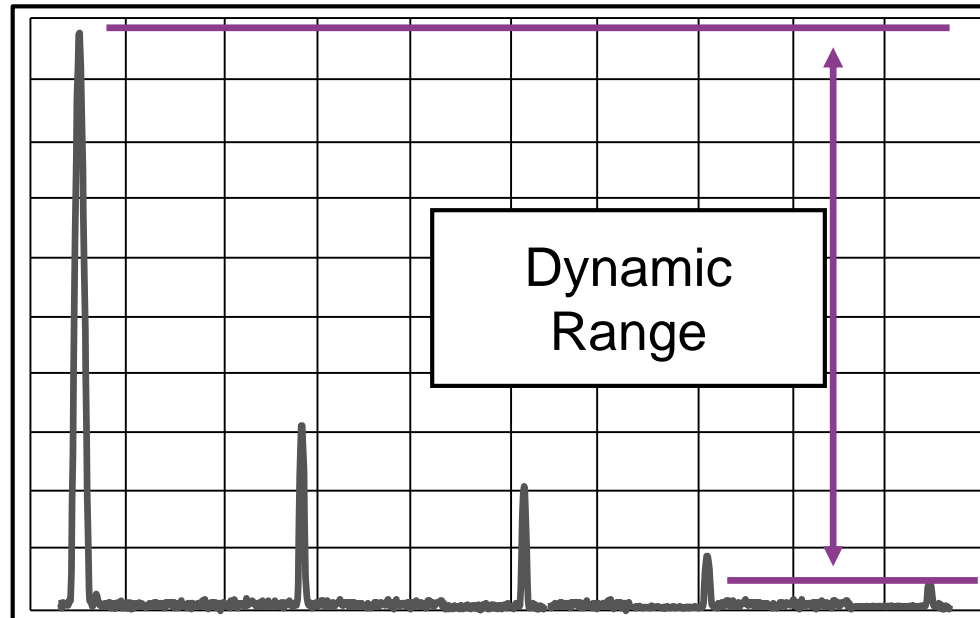
Effective level of displayed noise is a function of RF input attenuation: signal to noise ratio decreases as RF input attenuation increases.



# Specifications

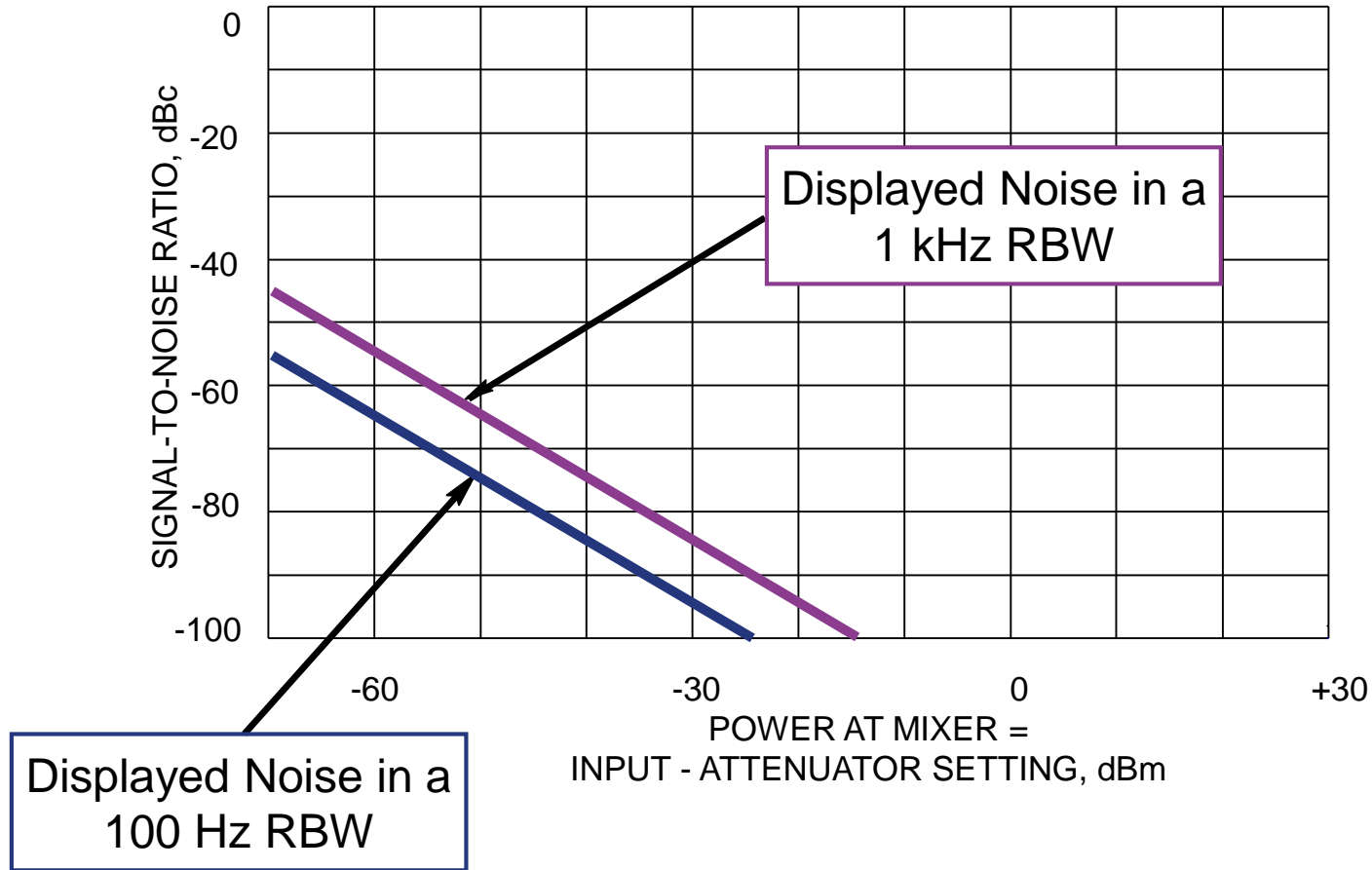
## Dynamic Range

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

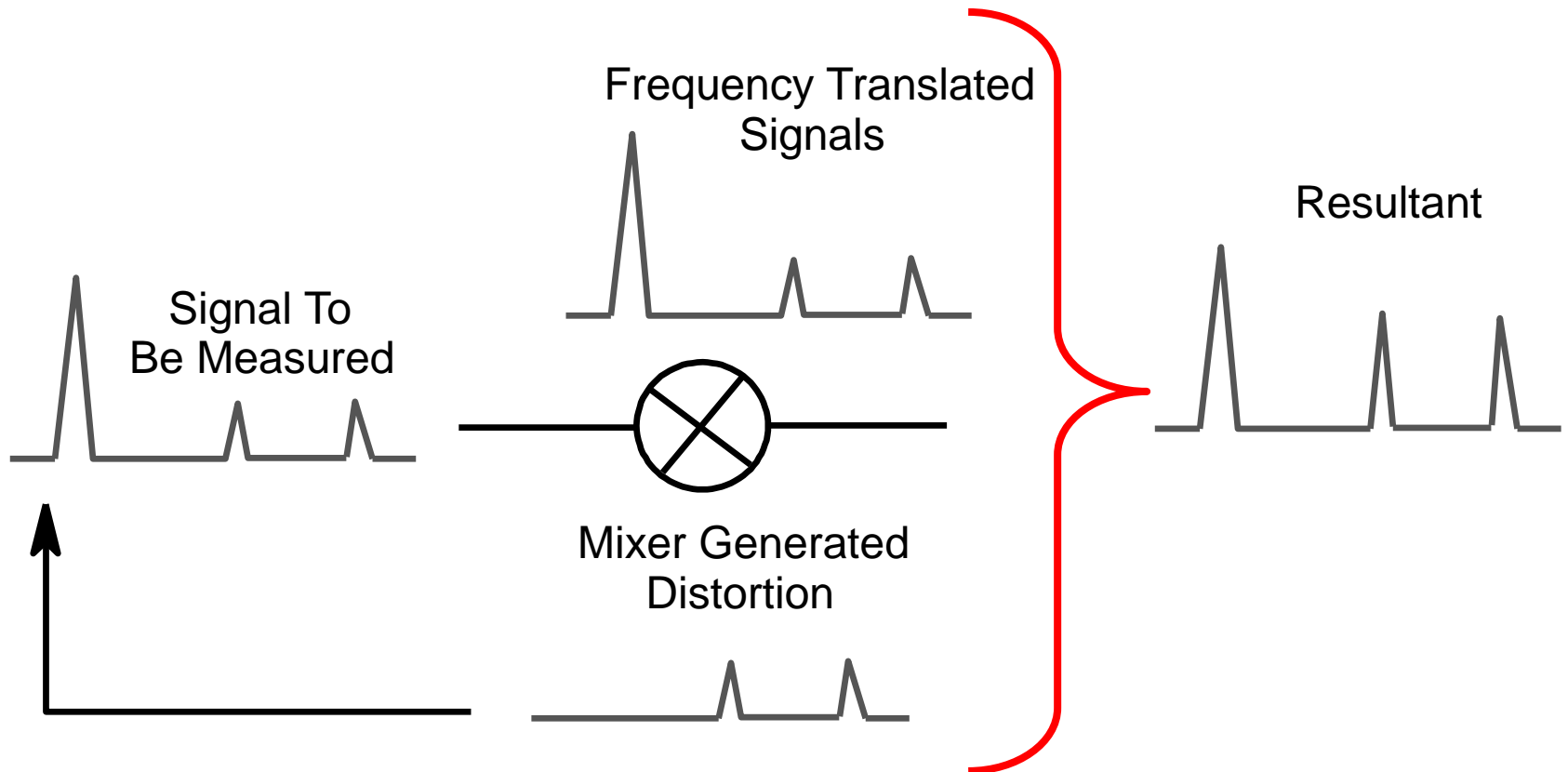
## Displayed DANL per RBW and Mixer Input Power





# Specifications

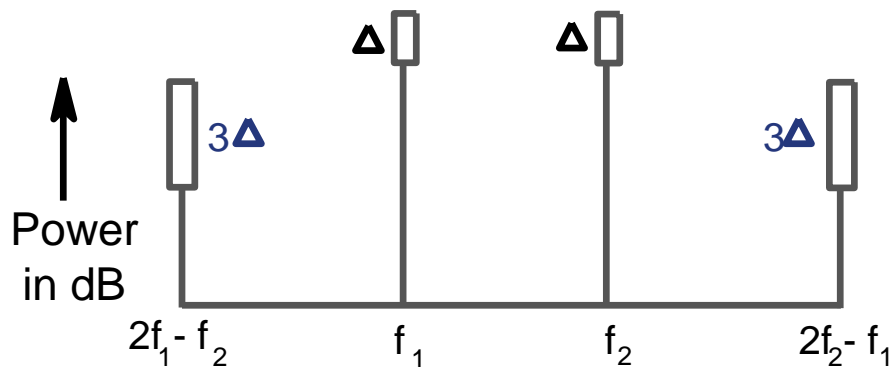
## Distortion: Mixers



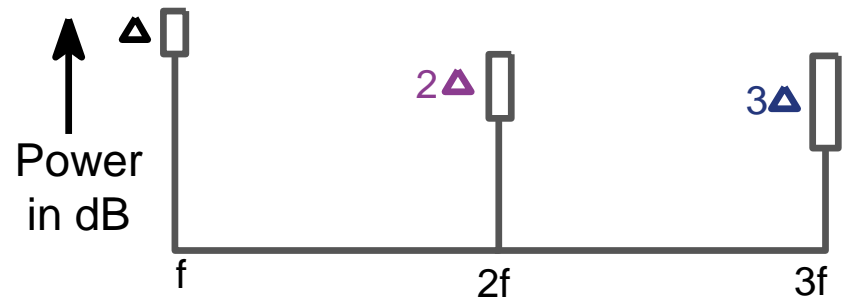
# Specifications

## Distortion: Second and Third Order

Distortion products increase as a function of fundamental's power.



Two-Tone Intermod

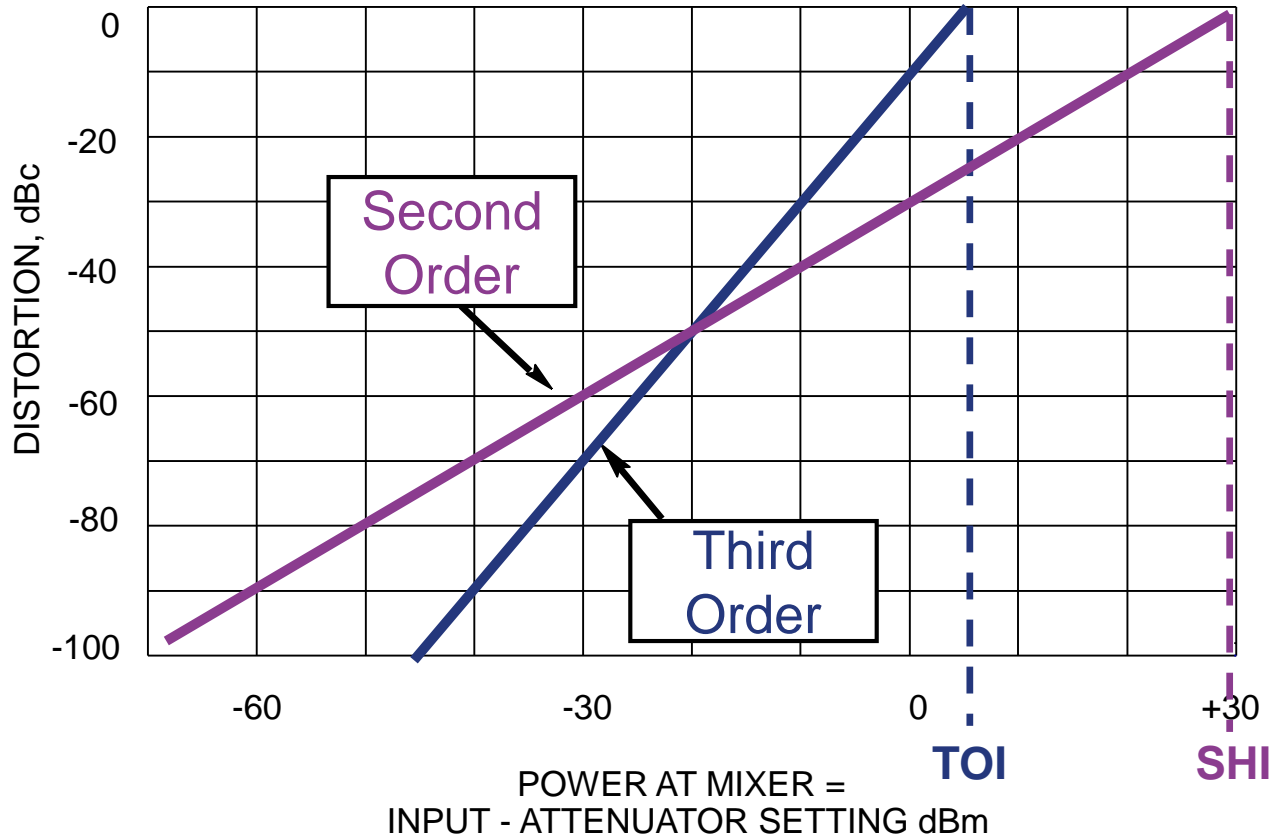


Harmonic Distortion

Third Order:  $\Delta 3$  dB/dB of Fundamental  
Second Order:  $\Delta 2$  dB/dB of Fundamental

# Specifications

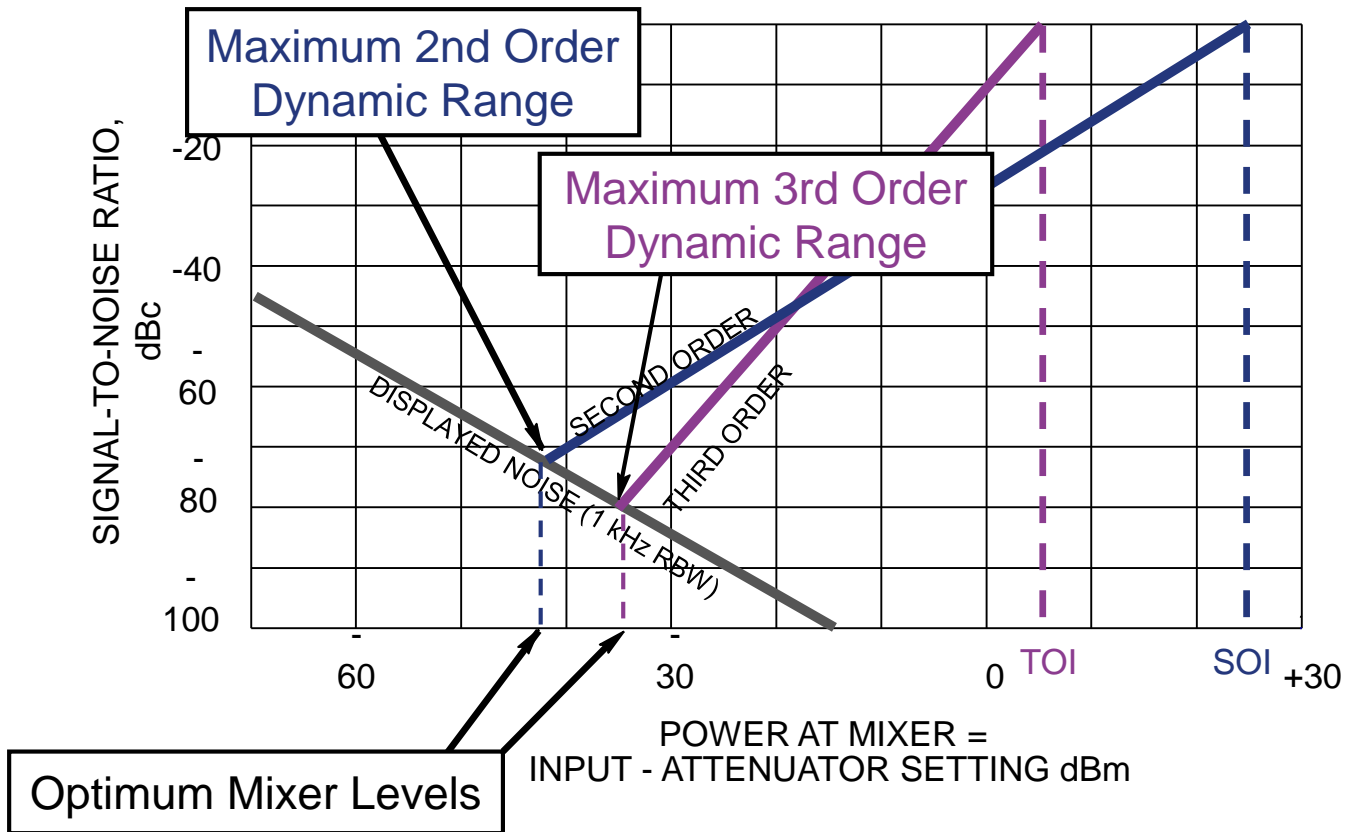
## Distortion: A Function of Mixer Level



# Specifications

## Dynamic Range (DANL, RBW, Distortion)

Dynamic range can be presented graphically.



# Demonstration

## Distortion – Internal or External?

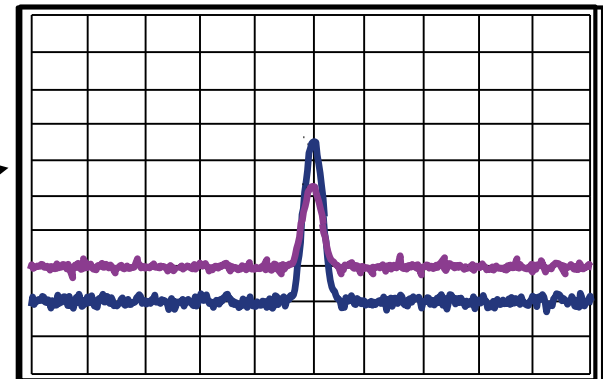
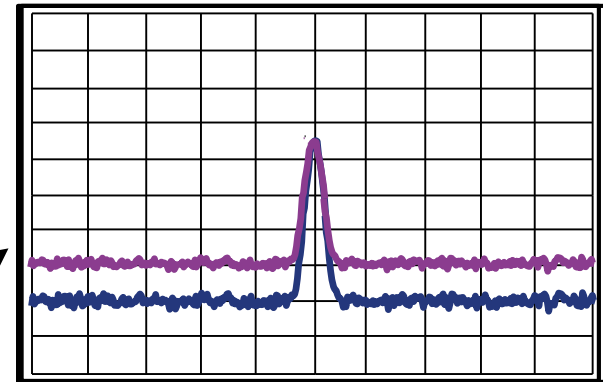
■ Original distortion signal  
■ Signal with 10dB input attenuation

**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).

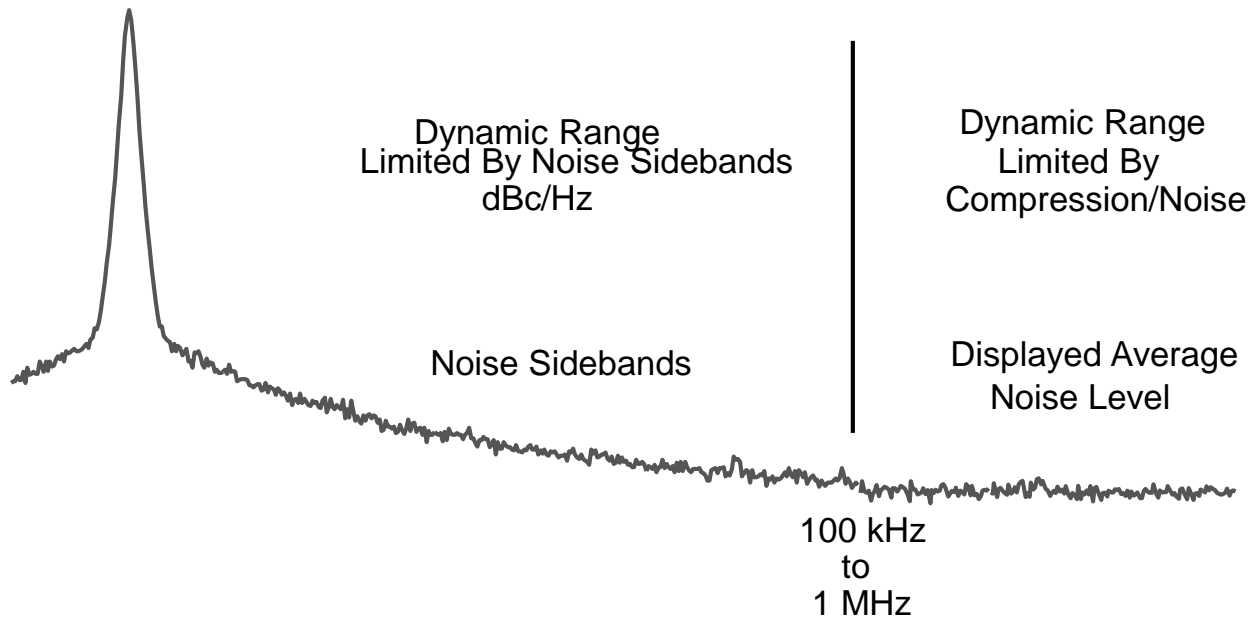
**Change in amplitude:**  
At least some of the distortion is being generated inside the analyzer (internal).



# Specifications

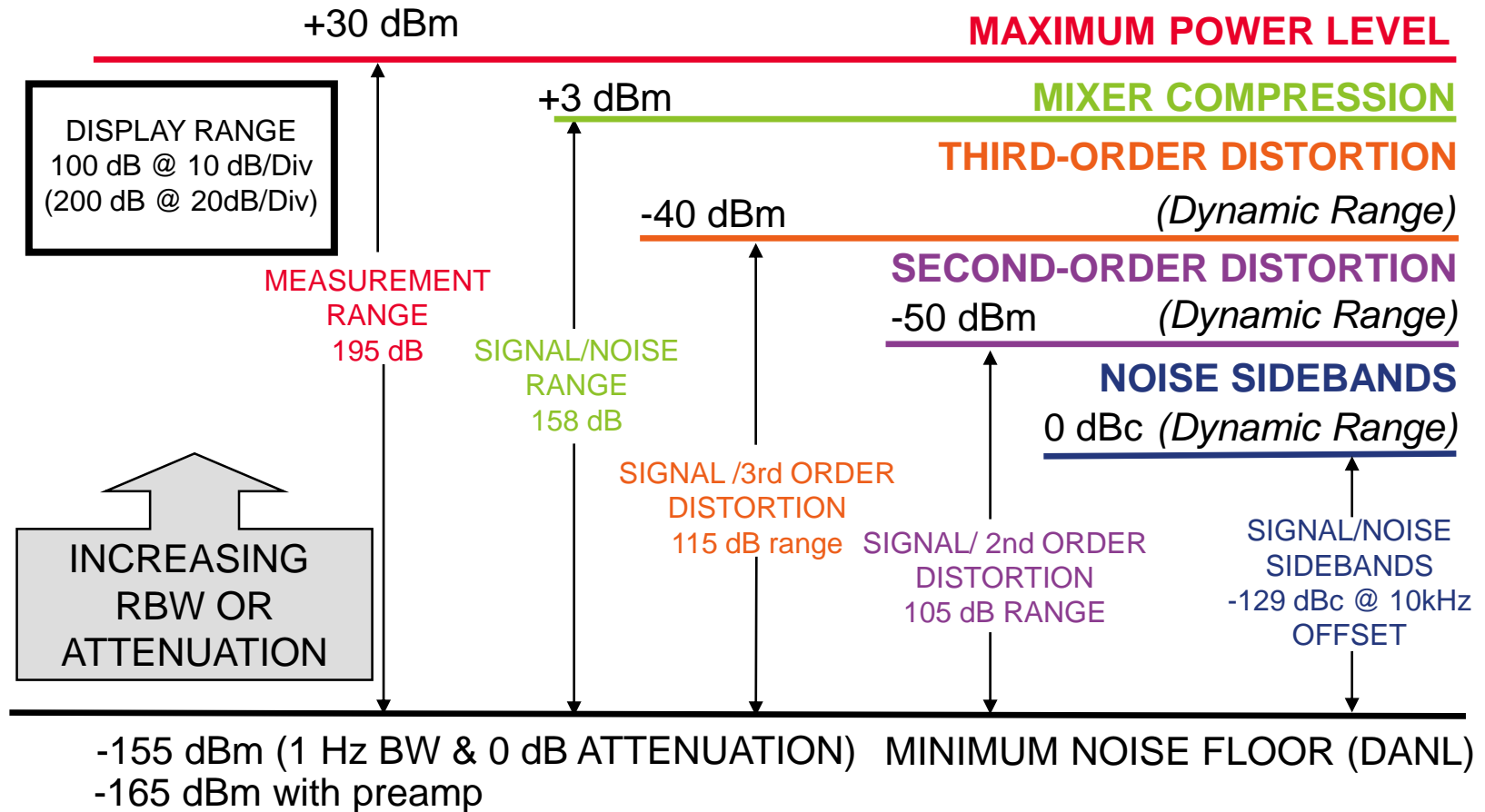
## Dynamic Range

Dynamic range for spur search depends on closeness to carrier.



# Specifications

## Dynamic Range vs Measurement Range



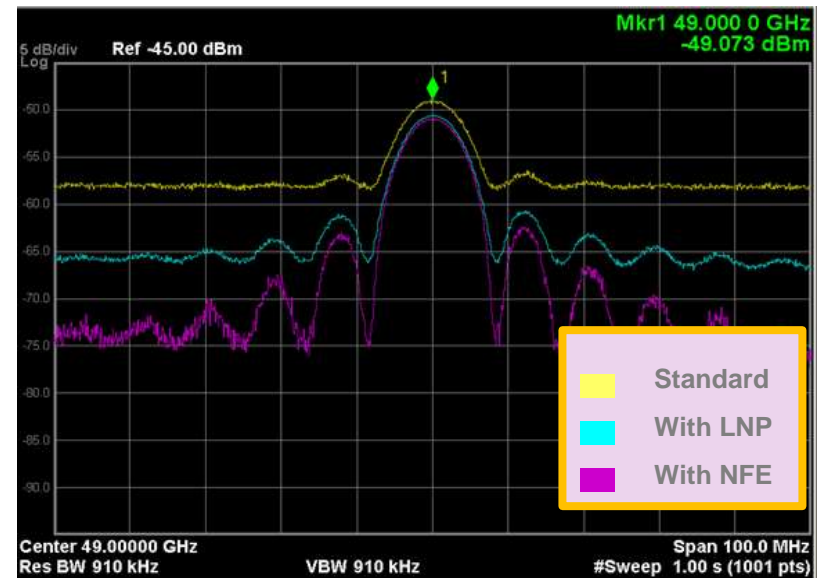
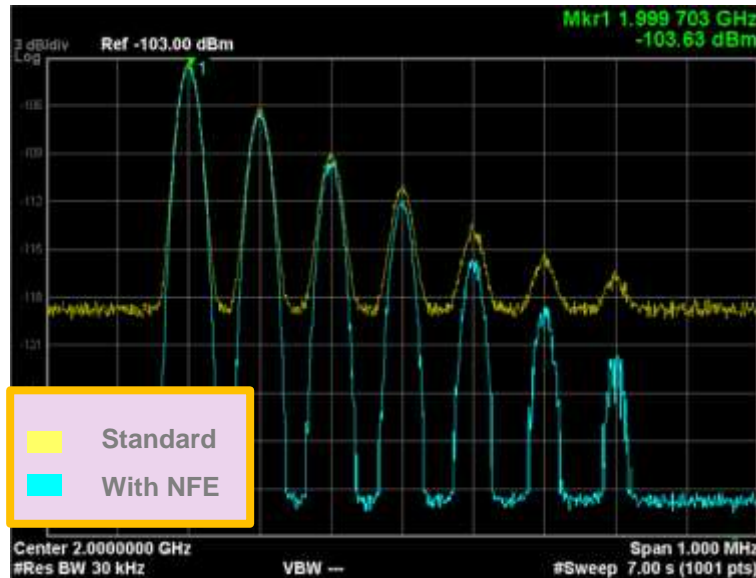
# Agenda

- Overview
- Theory of Operation
  - Traditional Spectrum Analyzers
  - Modern Signal Analyzers
- Specifications
- **Features**
- Wrap-up



# Features

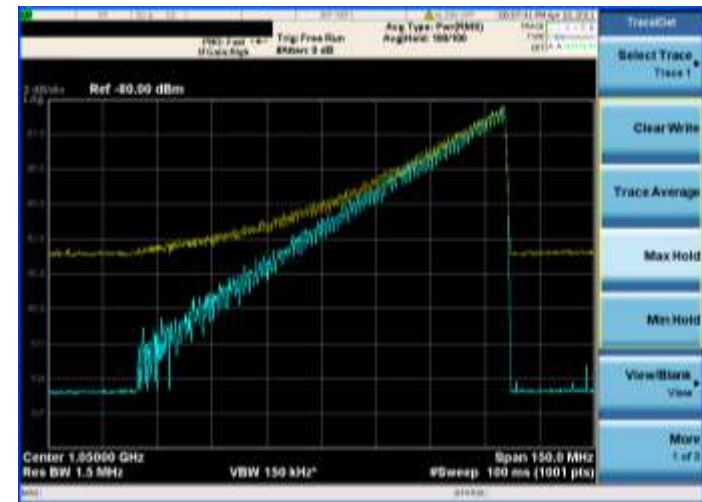
## Sensitivity/DANL: Noise Floor Extension



- The PXA combines 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 RF to millimeter wave. At RF, 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.

# Features

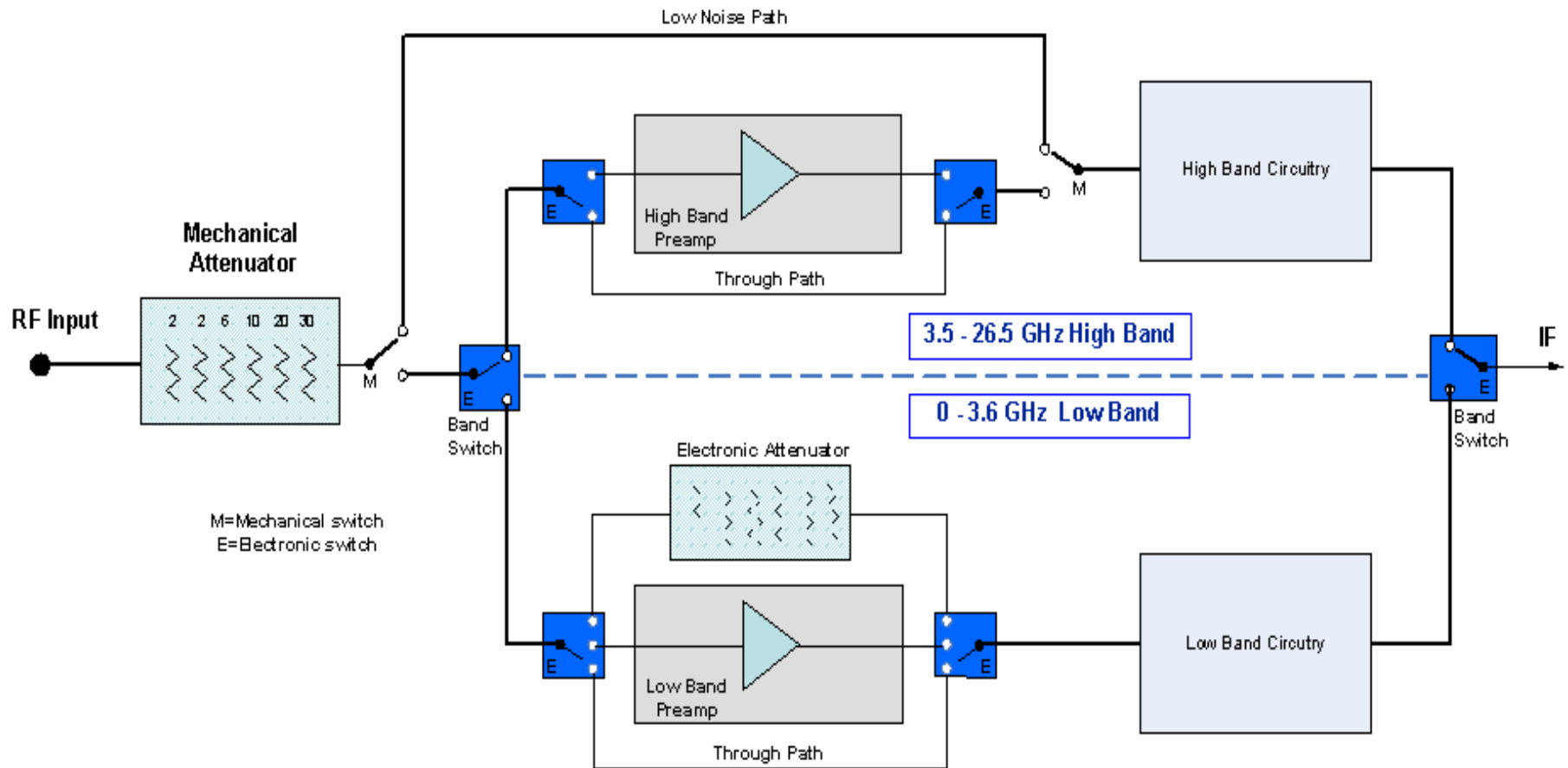
## Sensitivity/DANL: Low Noise Path (LNP)



- At microwave frequencies any sort of signal routing or switching results in signal path loss.
- Preamplifiers can compensate for this loss and improve signal/noise for small signals, but they can cause distortion in the presence of larger signals
- LNP allows the “lossy” elements normally found in the RF input chain to be completely bypassed for highest sensitivity without a preamplifier
- LNP allows measurements of small spurs w/o speed penalty imposed by narrow RBW that would otherwise be needed for adequate noise level

# Features

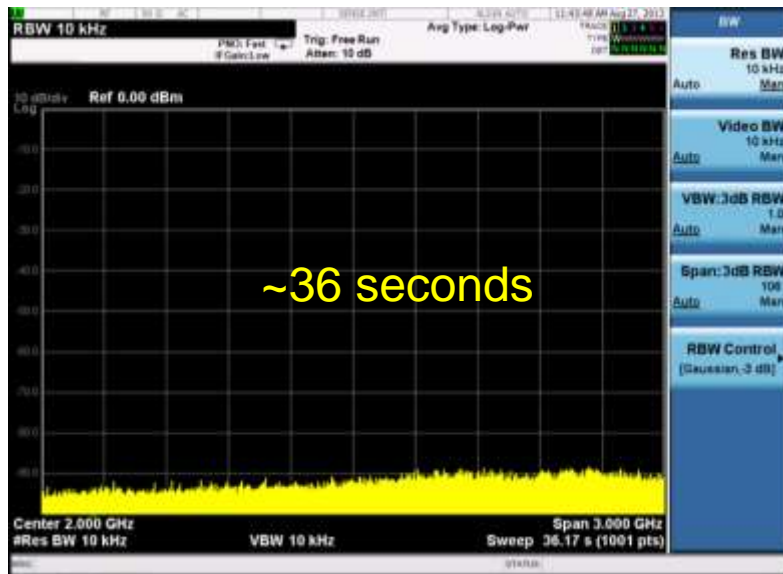
## Sensitivity/DANL: Low Noise Path Block Diagram



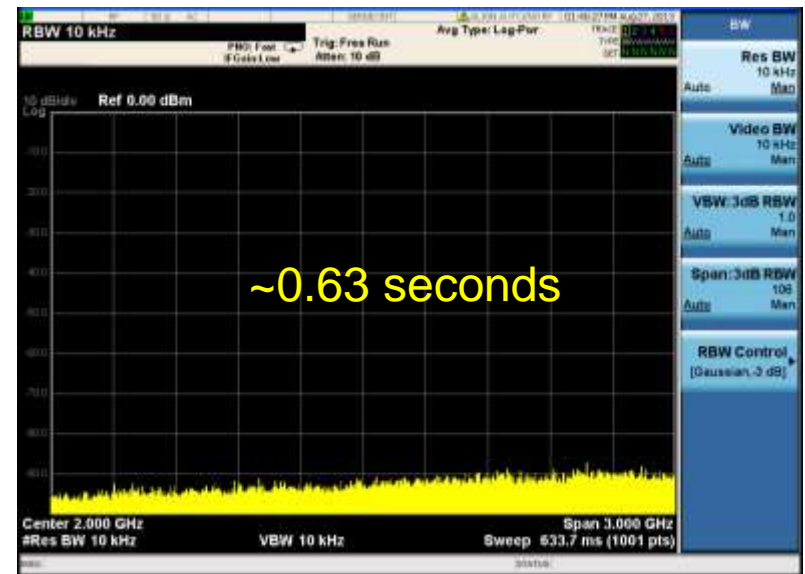
# Features

## Fast Sweep Processing

By adjusting the phase response of the RBW filters, the LO can be swept at a faster rate without creating errors.



Sweep without fast sweep enabled

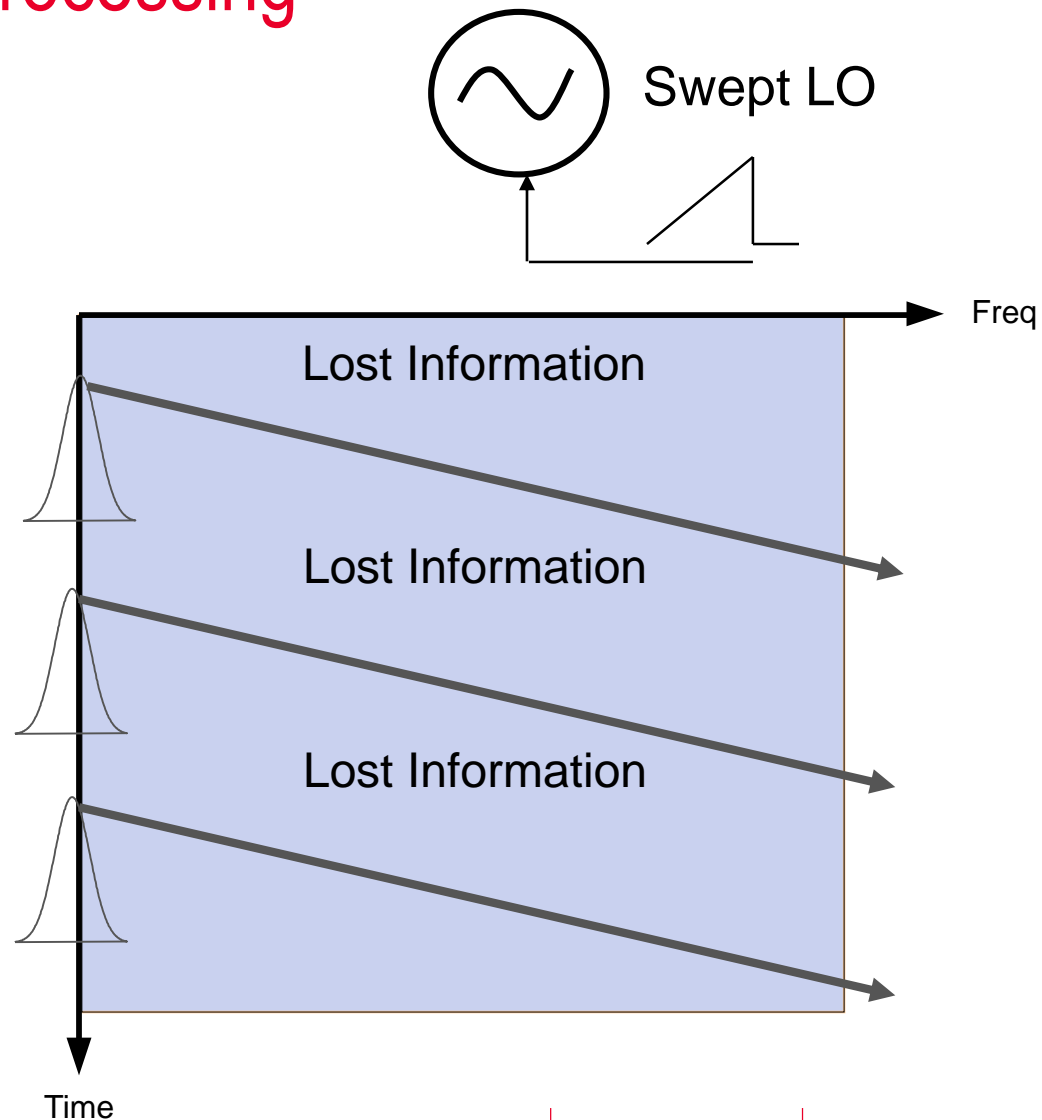


Sweep with fast sweep enabled

# Data Acquisition and Processing

## Swept Mode

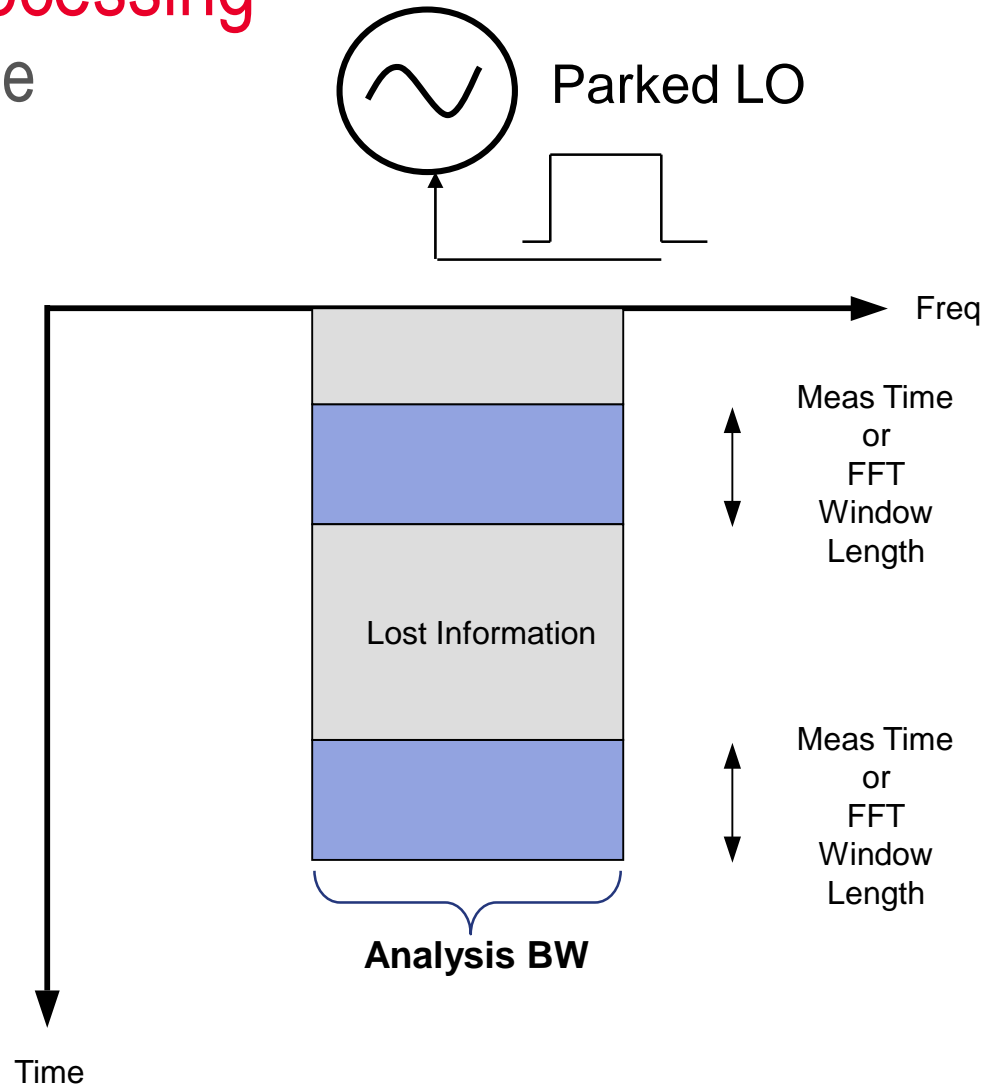
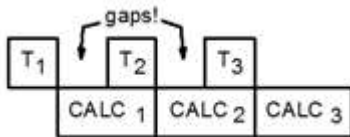
- A swept LO w/ an assigned RBW.
- Covers much wider span.
- Good for events that are stable in the frequency domain.
- Magnitude ONLY, no phase information (scalar info).
- Captures only events that occur at right time and right frequency point.
- Data (info) loss when LO is “not there”.



# Data Acquisition and Processing

## Vector Signal Analyzer Mode

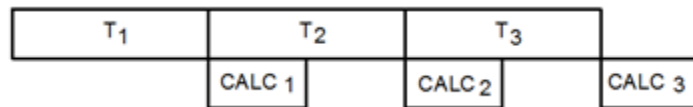
- A parked LO w/ a given IF BW
- Collects IQ data over an interval of time.
- Performs FFT for time- freq-domain conversion
- Captures both magnitude and phase information (vector info).
- Data is collected in bursts with data loss between acquisitions.



# Data Acquisition and Processing

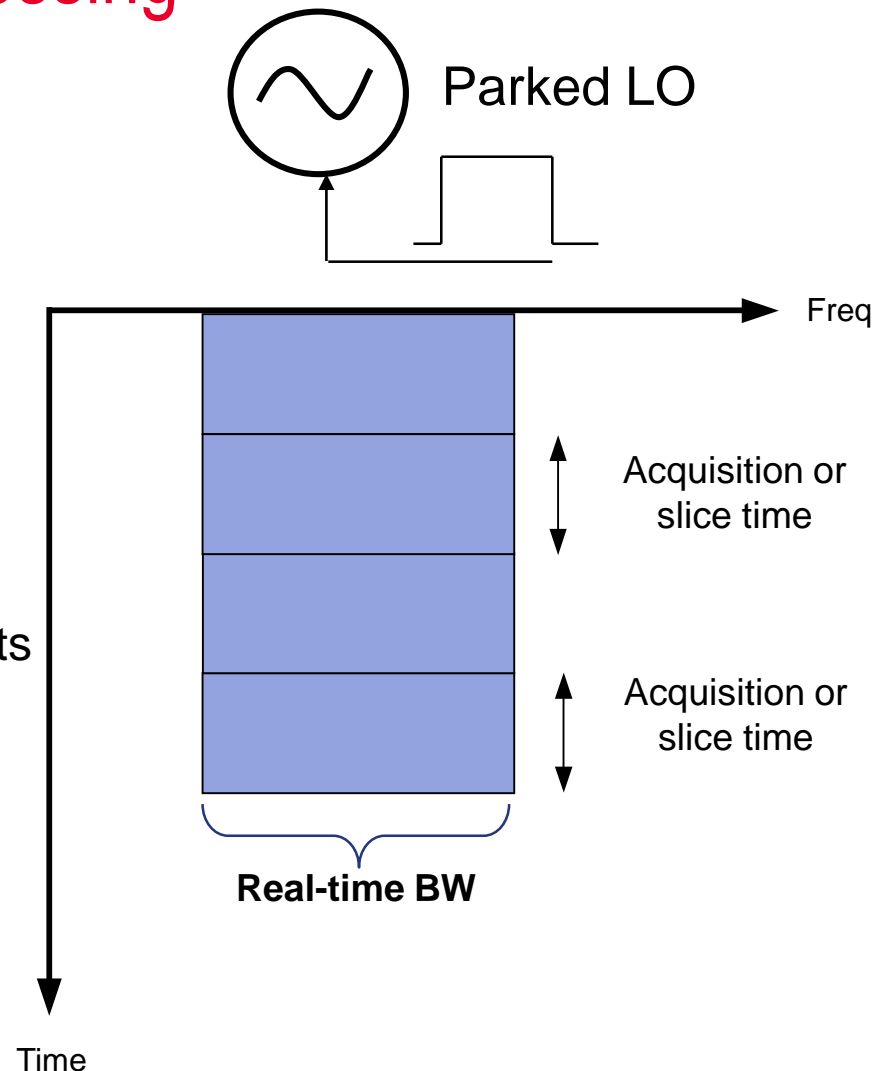
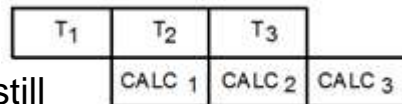
## Real-Time Mode

- A parked LO w/ a given IF BW
- Collects IQ data over an interval of time.
- Data is corrected and FFT'd in parallel
- Vector information is lost
- Advanced displays for large amounts of FFT's



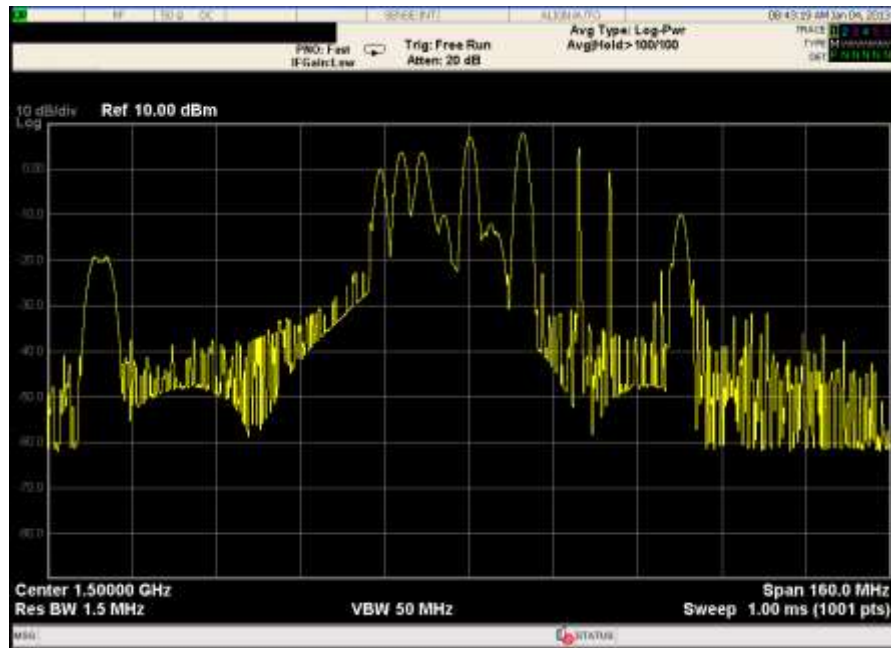
### Real Time Processing

Some data may still be "lost"

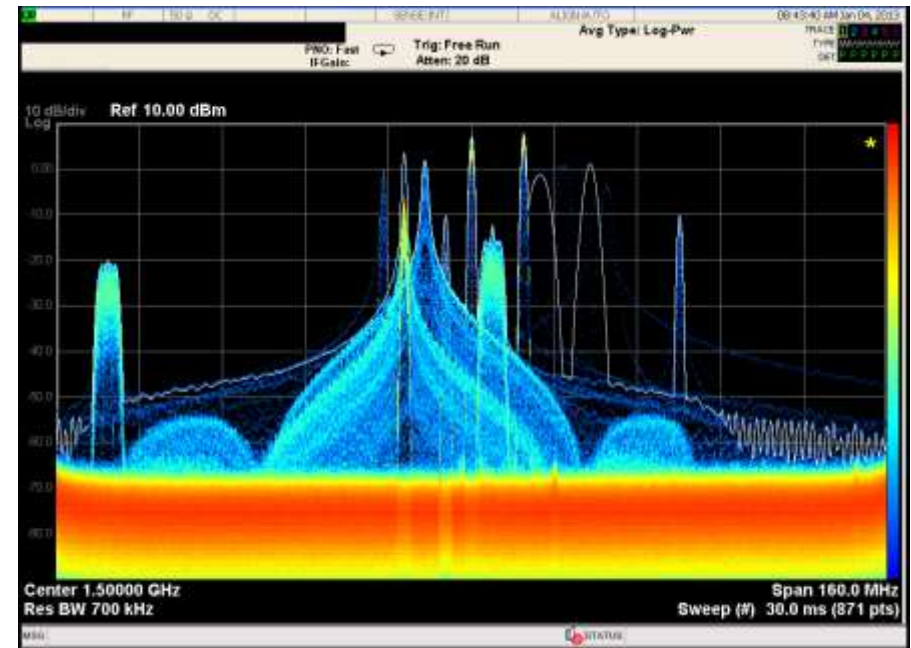


# Real-Time Spectrum Analysis

## Swept vs RTSA



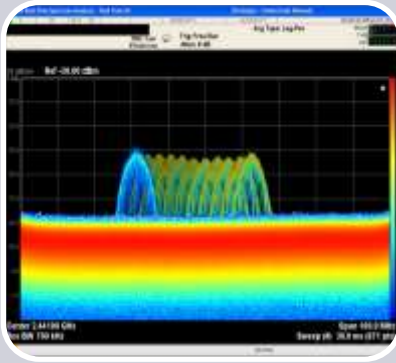
From this...



...to this

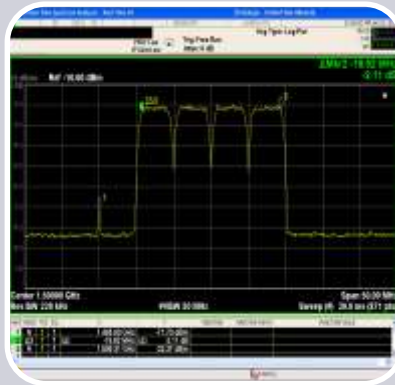


# Real-Time Displays



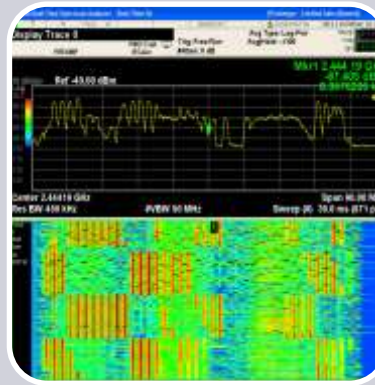
## Density

- Also known as Histogram Persistence
- Color indicates number of hits
- Screen typically updates every 30 ms
- Persistence can be manual



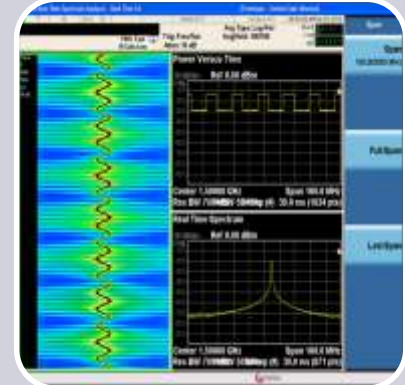
## Spectrum

- Accumulate all FFT's to a single trace
- Apply detector
- Superimposed on the density display
- Used for marker operations



## Spectrogram

- Real-time spectrum slices – no gaps
- 10,000 spectrogram traces available
- Scroll through stored traces
- Use markers on and between traces



## Power vs Time

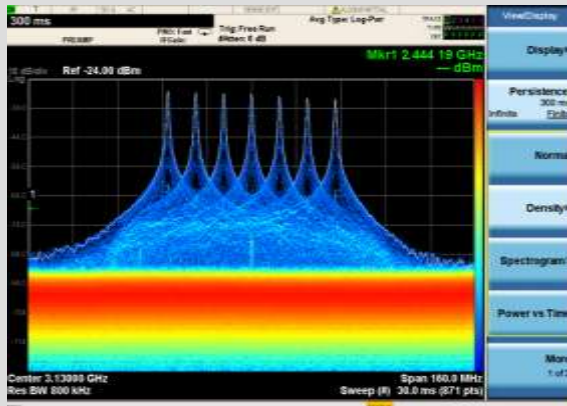
- PvT over configurable range
- Gapless time data transformed to frequency domain
- Different displays available
- Level based trigger available

# Real-Time Spectrum Analysis

Application: Detect Low Level Signals with Precision



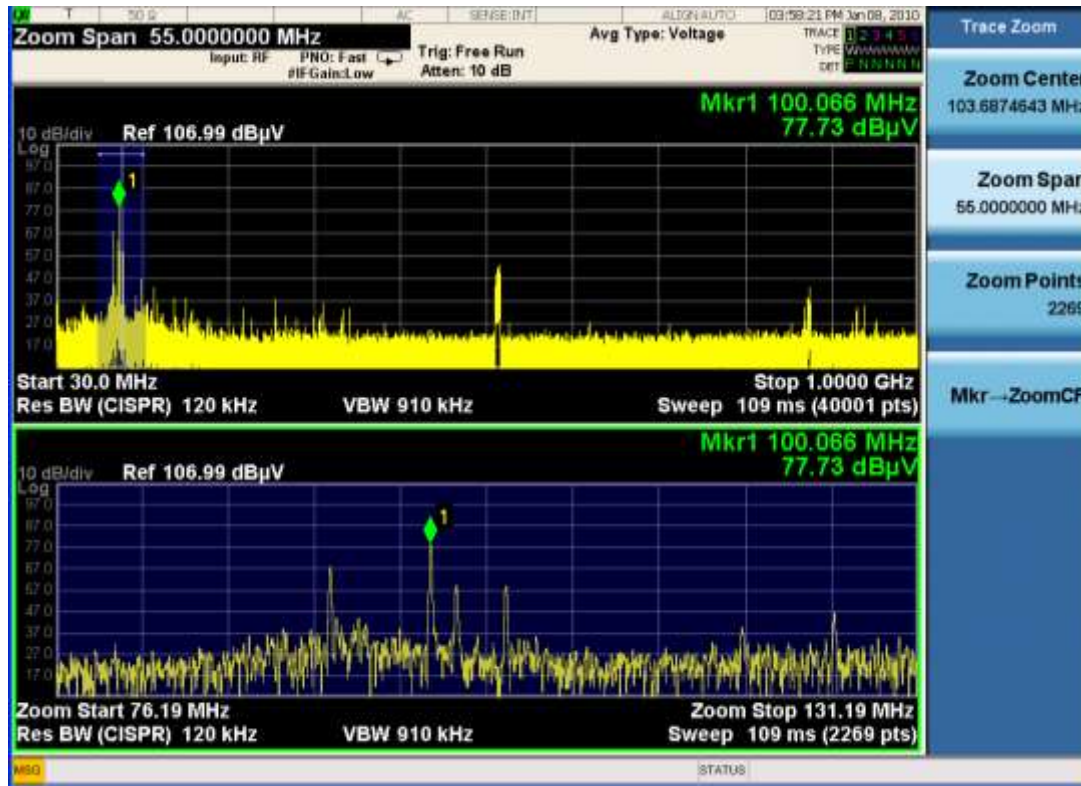
- Short burst comms, LPI radar systems make it very difficult to analyze jamming & interference
- Communication jamming needs to be done very quickly for adaptive threats



- POI of 3.57us for 100% POI with full amplitude accuracy to catch the most elusive signals
- Excellent noise performance at X-band further improves POI

# Features

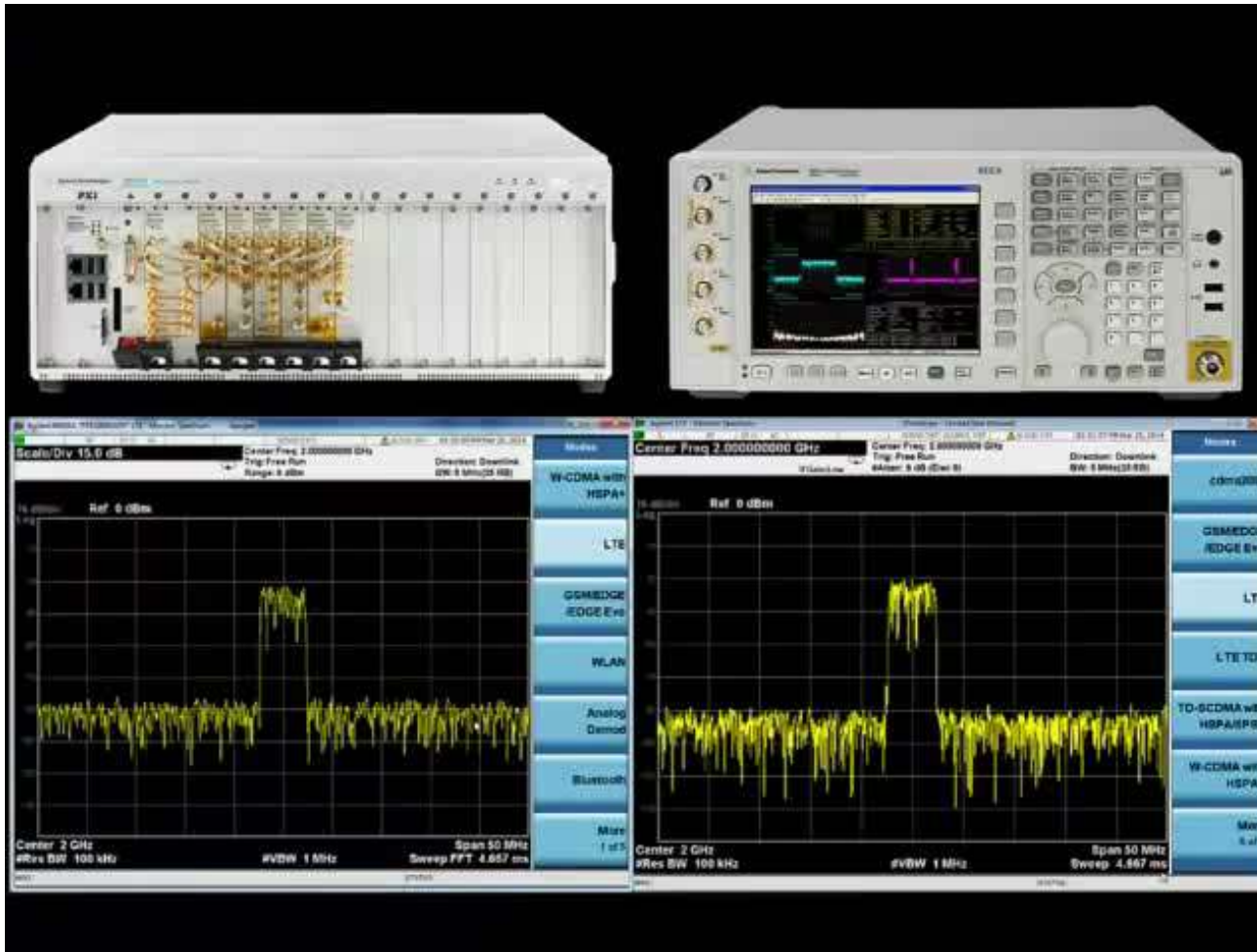
## Trace Zoom



- 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

# Scalability

Multi-Channel, Higher Speed/Throughput, Smaller Footprint



# Extend Frequencies to 325GHz and Beyond



## Supported measurements:

- Spectrum analysis
- PowerSuite one-button power measurements
- N9068A phase noise measurement application
- 89600A VSA

## Supported external mixers:

- M1970V/E/W
- 11970 Series
- OML Inc.
- VDI





# Wide Analysis Bandwidth

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 BWs with high data rates
- Military Communications: capture high data rate digital comms & measure EVM



## Emerging Communications

- WLAN, 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 3<sup>rd</sup> order distortion for 4 carrier pre-distortion algorithms

# Additional Resources

- Keysight RF Learning Center [www.keysight.com/find/klc](http://www.keysight.com/find/klc)
  - Webcast Recordings
  - Application Notes
    - AN 150 – Spectrum Analysis Basics
    - 8 Hints for Better Spectrum Analysis
    - 10 Hints for Making Better Noise Figure Measurements
  - Videos
  - Register for Future Webcasts



# The End