Spectrum Analysis

KEYSIGHT TECHNOLOGIES

Agenda

– Overview

– Theory of Operation

  • Traditional Spectrum Analyzers

  • Modern Signal Analyzers

– Specifications

– Features

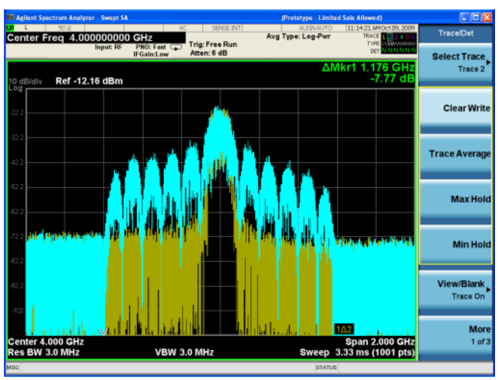
– Wrap-up

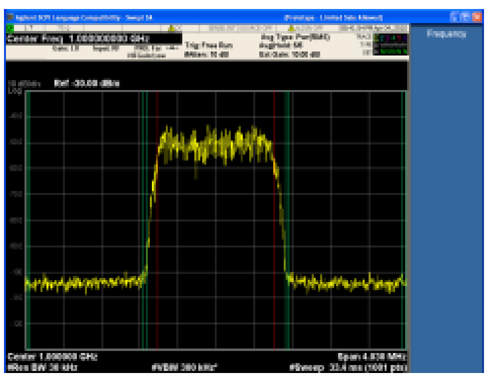
KEYSIGHT TECHNOLOGIES

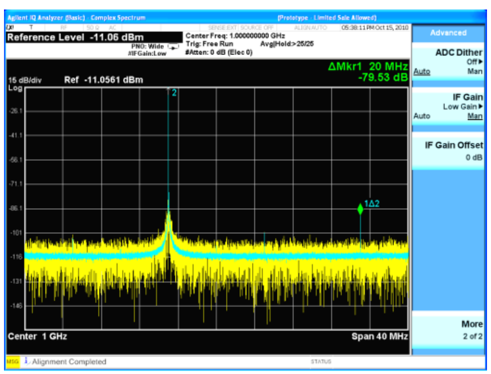
Overview

What is Spectrum Analysis

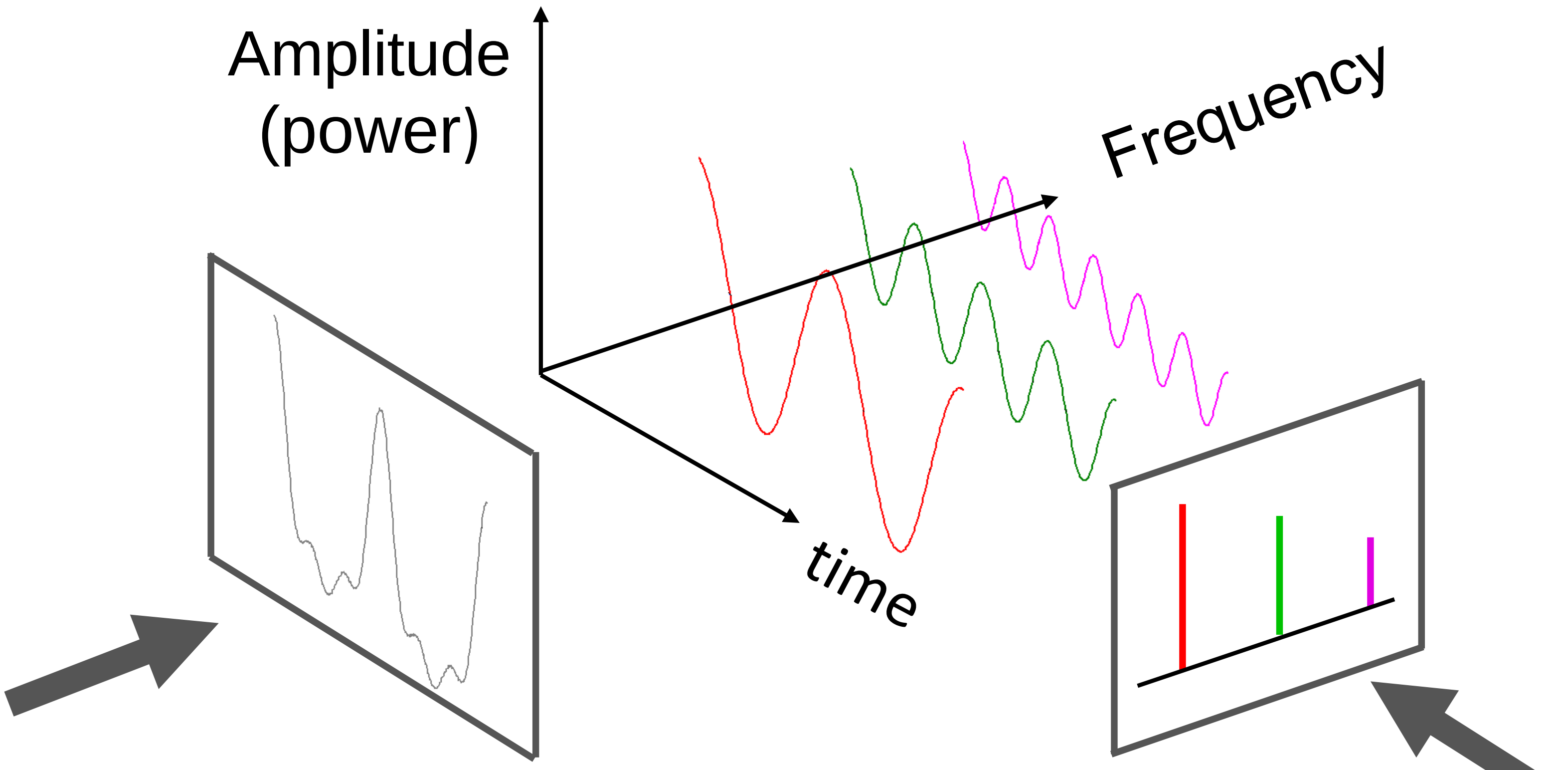
- Passive Receiver
- Display and measure amplitude versus frequency
- Separate or demodulate complex signals into their base components (sine waves)







Overview
Frequency vs Time Domain



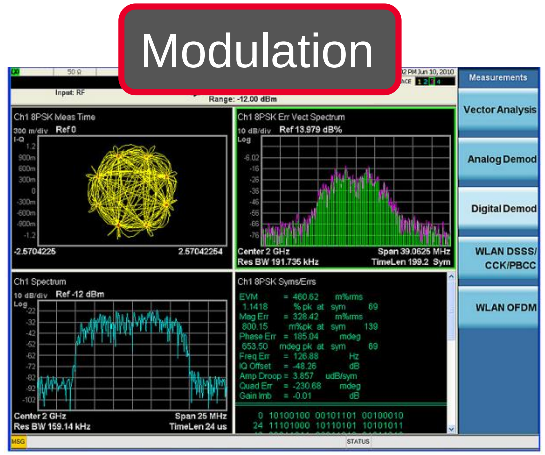
Time domain Measurements
(Oscilloscope)

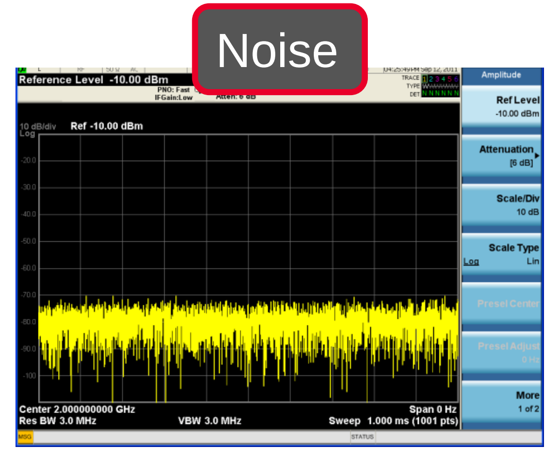
Frequency Domain Measurements
(Spectrum Analyzer)

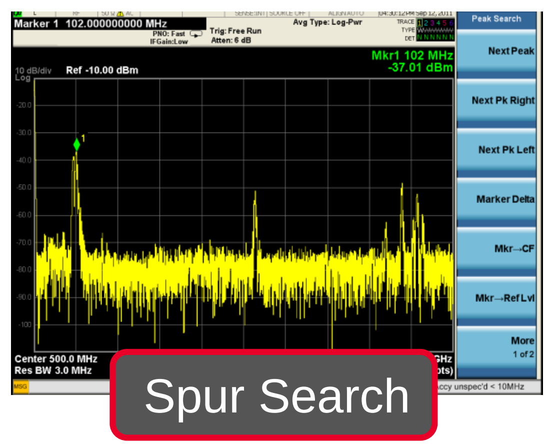
Overview

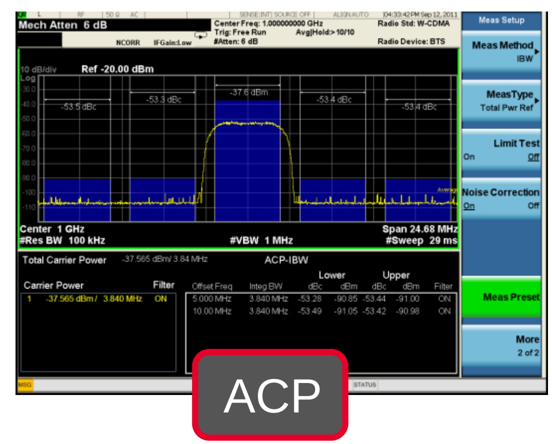
Types of Measurements Available

- **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



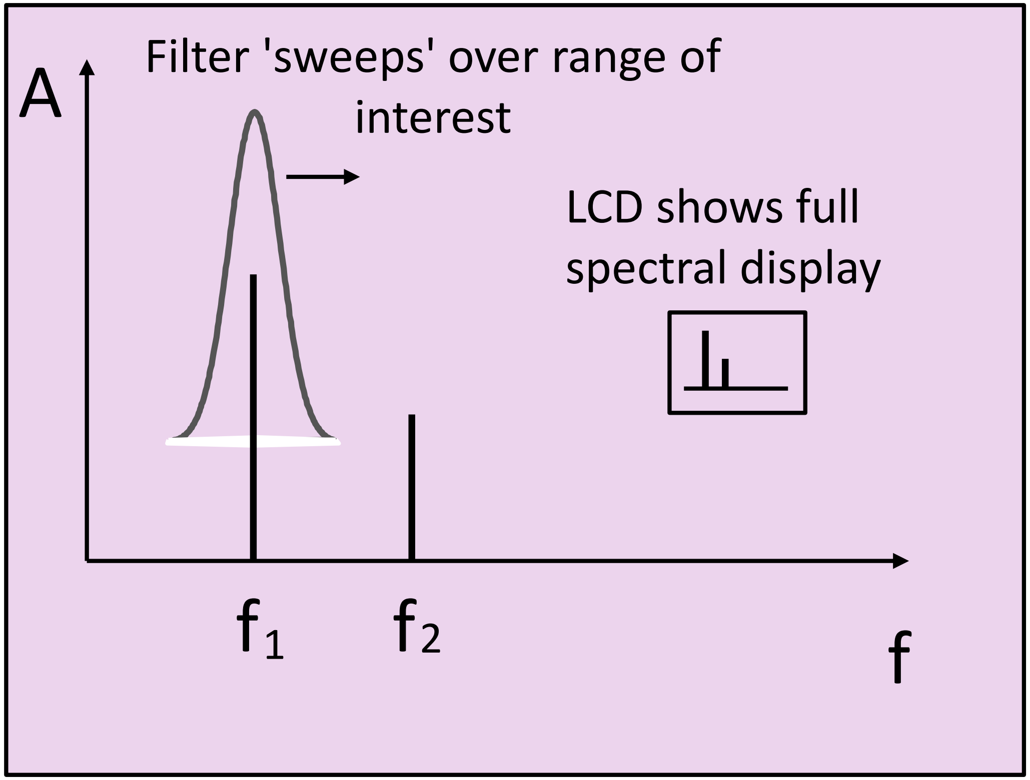






Overview
Different Types of Analyzers

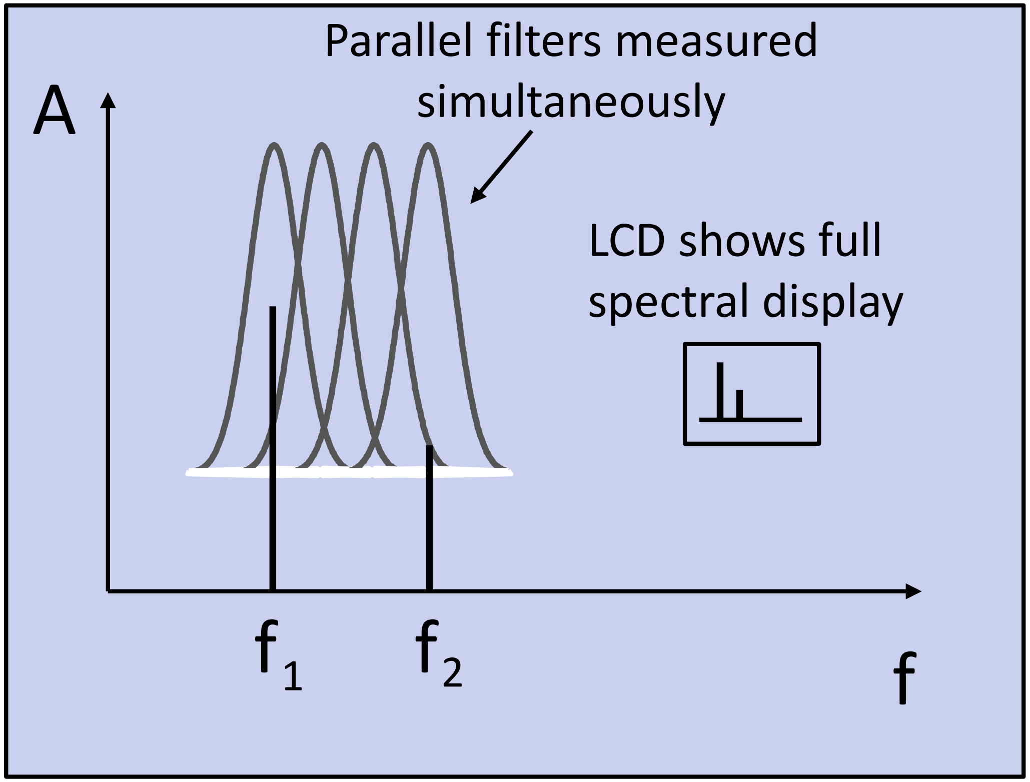
Swept Analyzer



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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– Features

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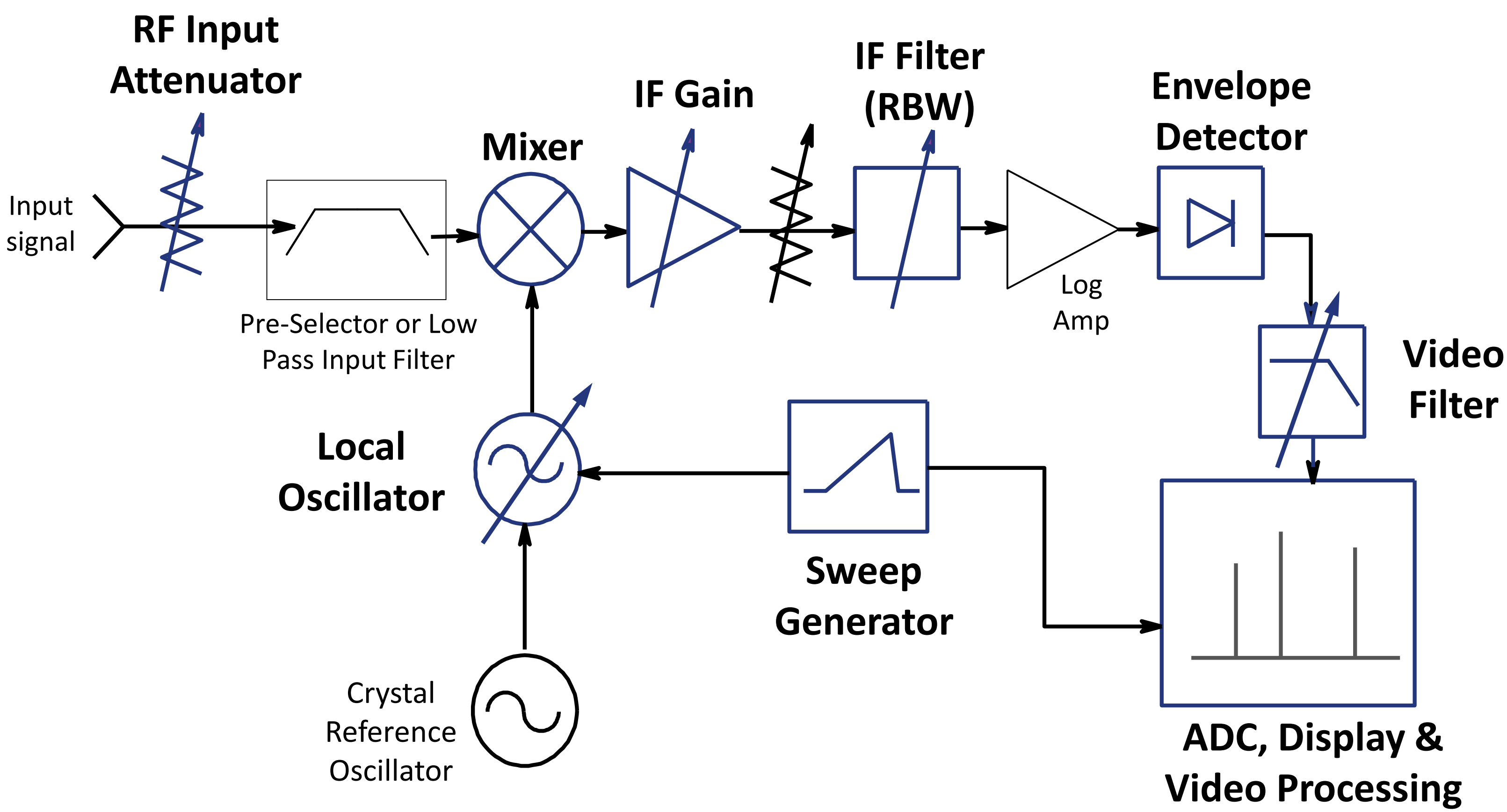
Theory of Operation

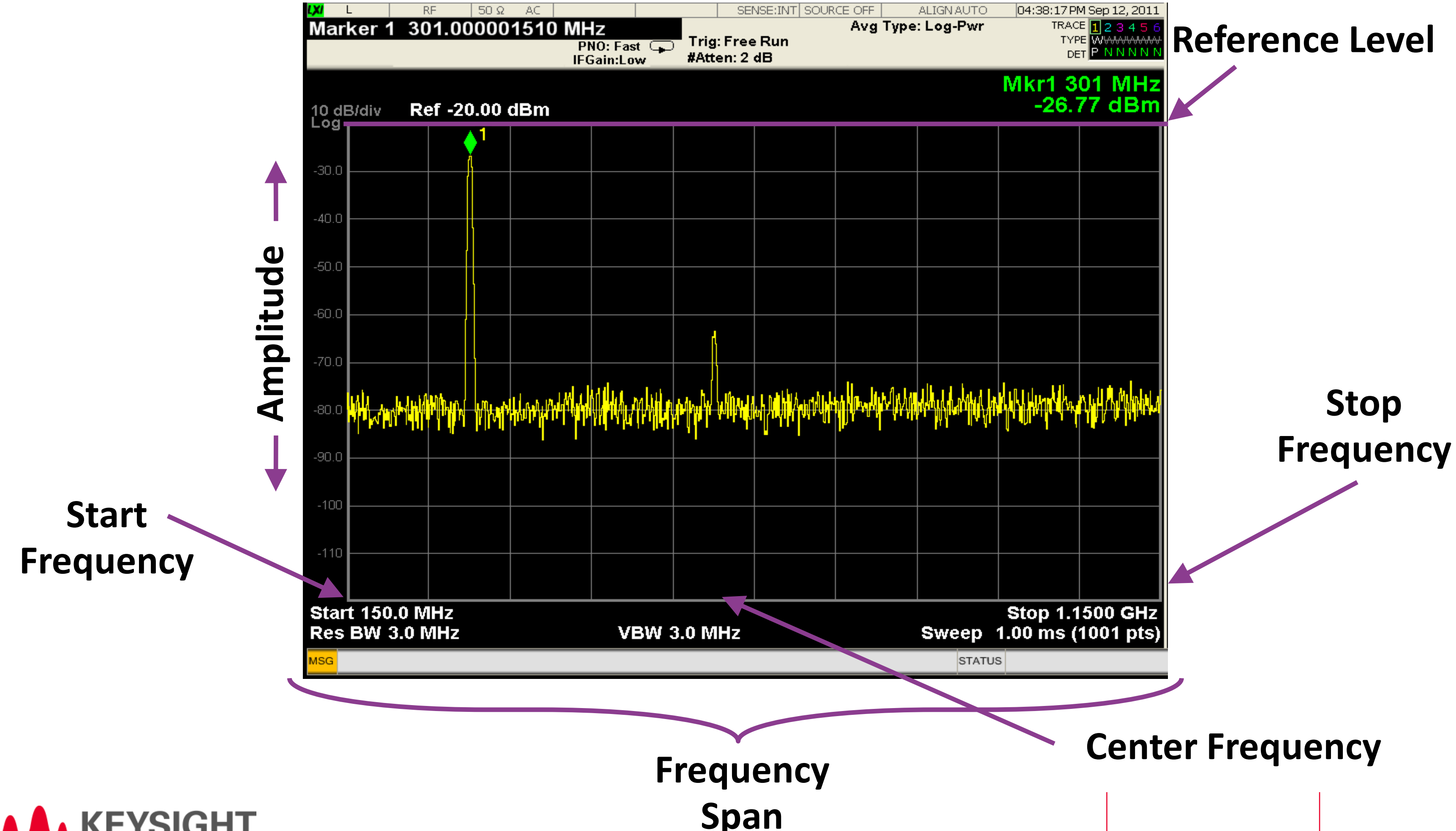
Swept Spectrum Analyzer Block Diagram



KEYSIGHT TECHNOLOGIES

Theory of Operation

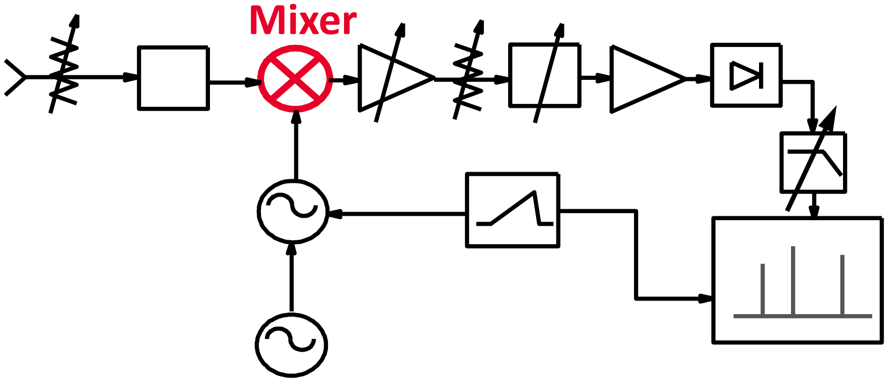
Display Terminology

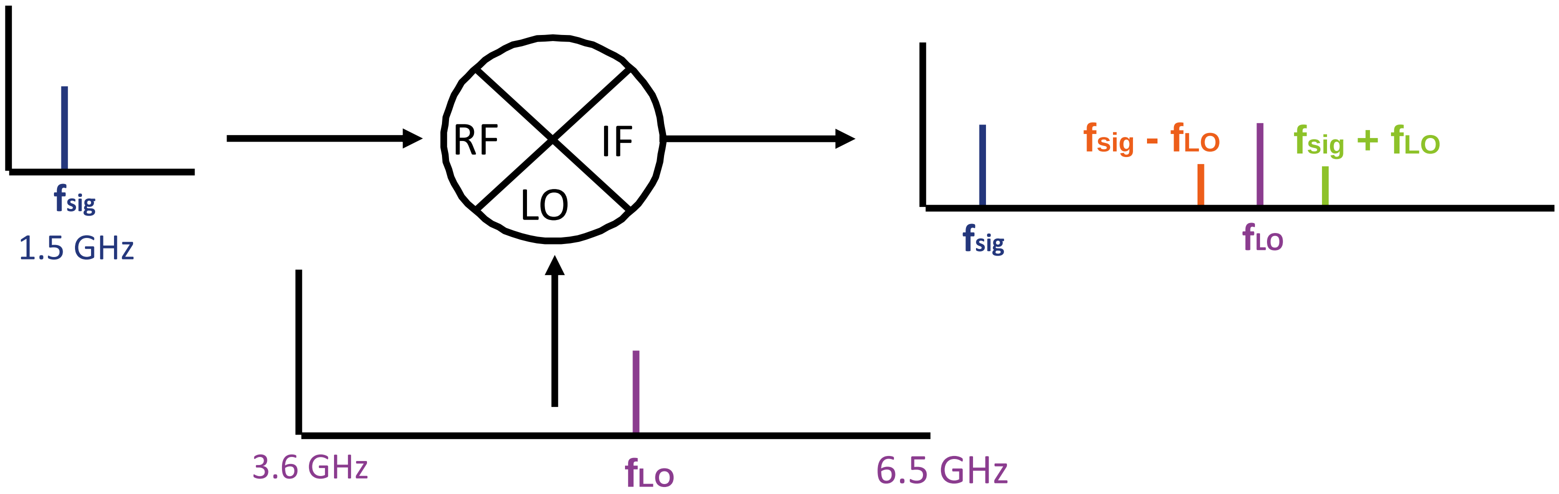


KEYSIGHT TECHNOLOGIES

Theory of Operation

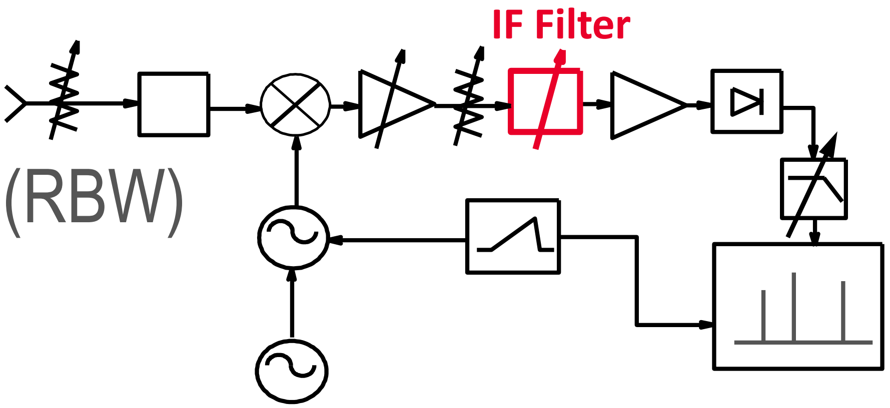
Mixer

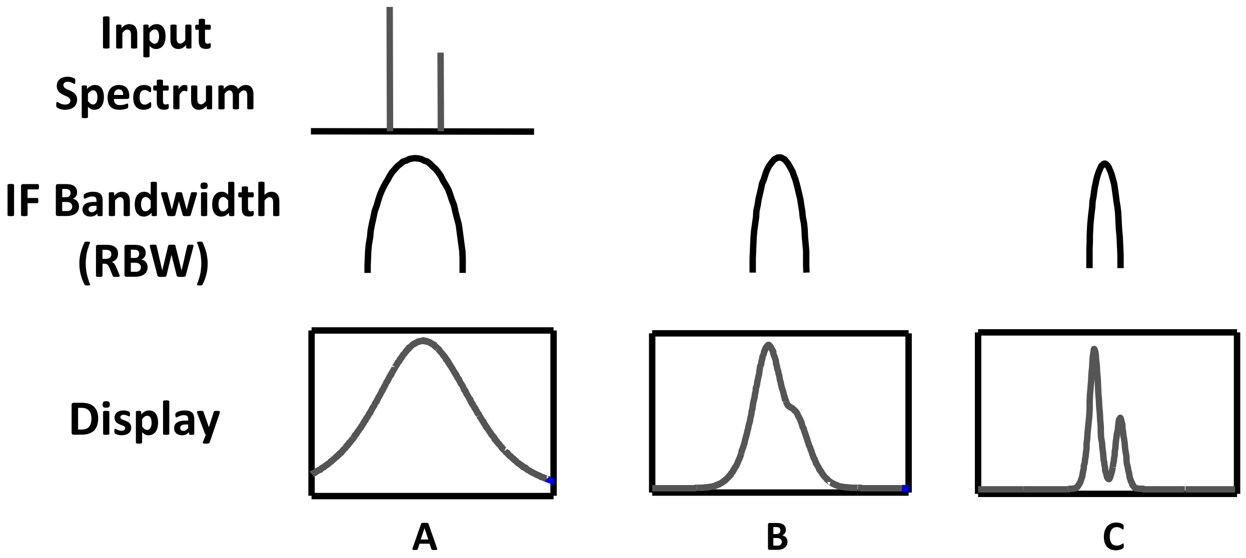




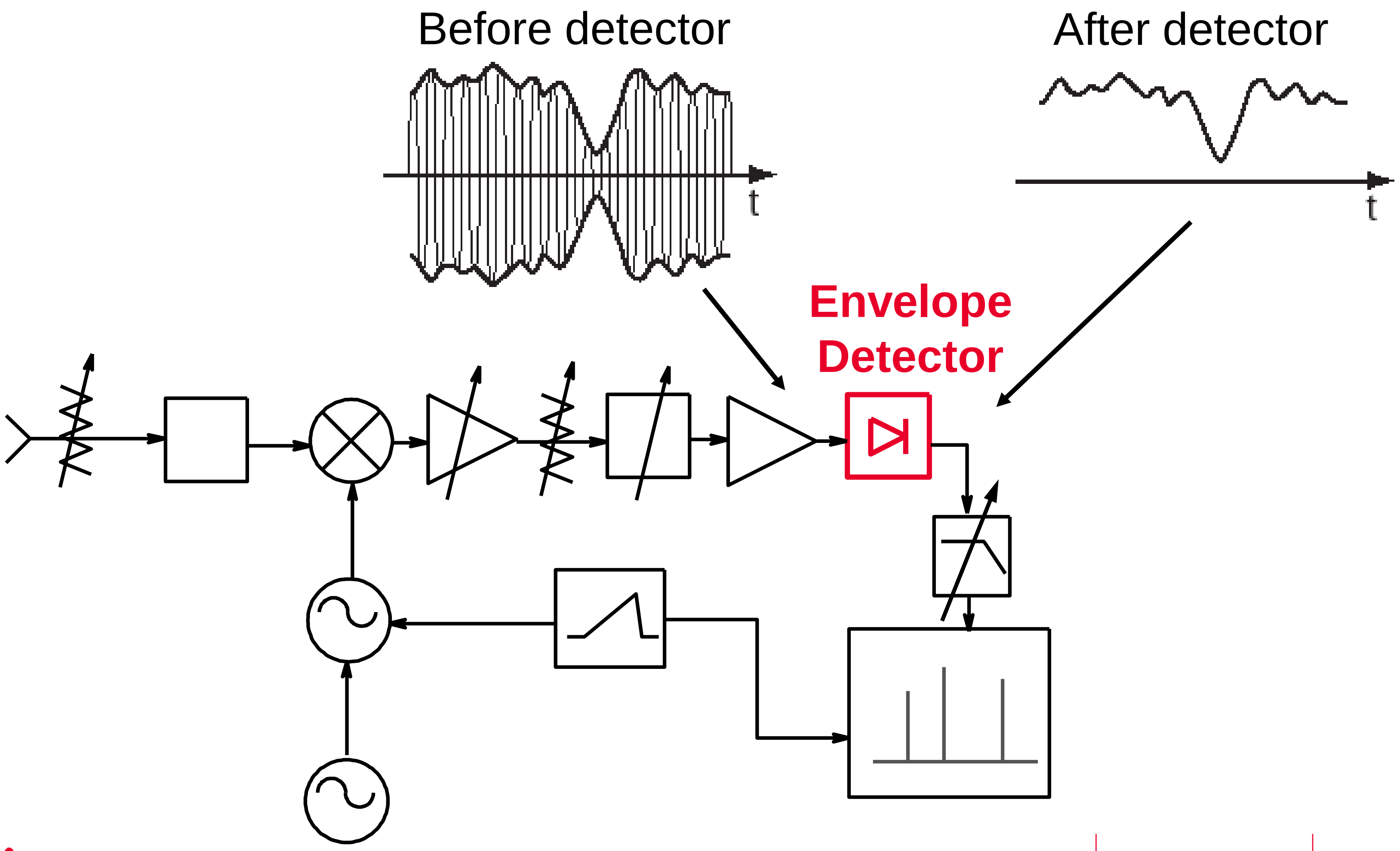
Theory of Operation

IF Filter (Resolution Bandwidth (RBW)



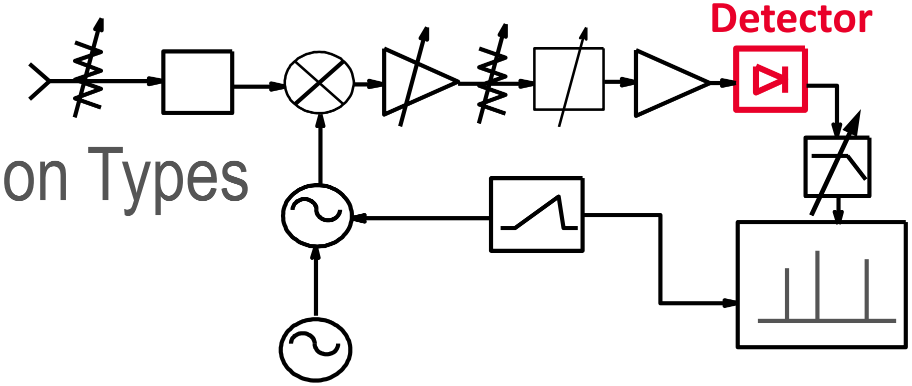


Theory of Operation
Envelope Detector

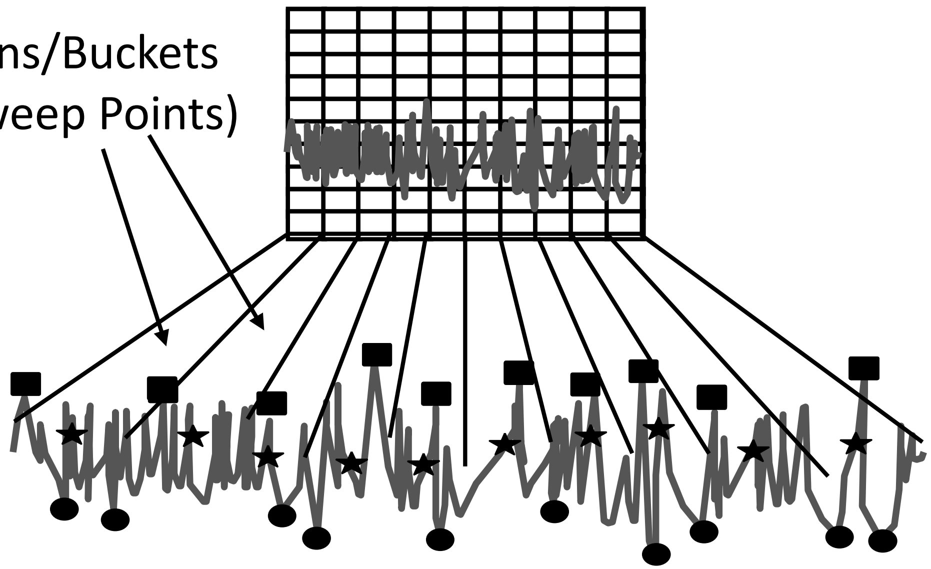


Theory of Operation

Envelope Detector and Detection Types



Digitally Implemented Detection Types



■ **Positive Detection:** largest value in bin displayed

● **Negative detection:** smallest value in bin displayed

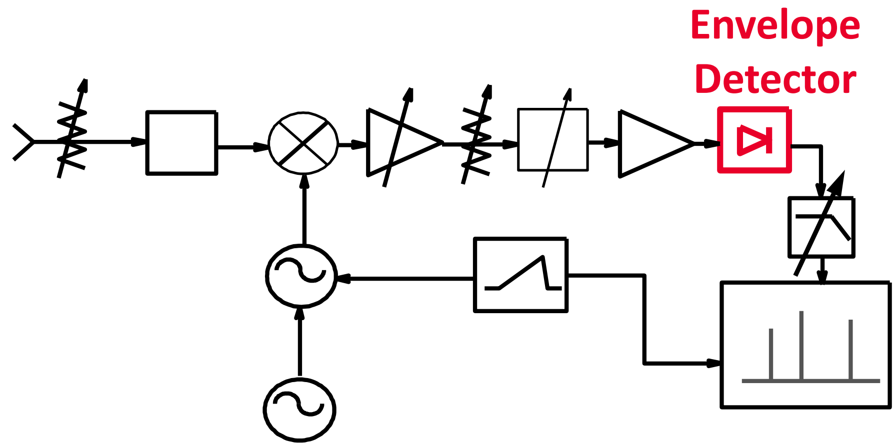
★ **Sample detection:** middle value in bin displayed

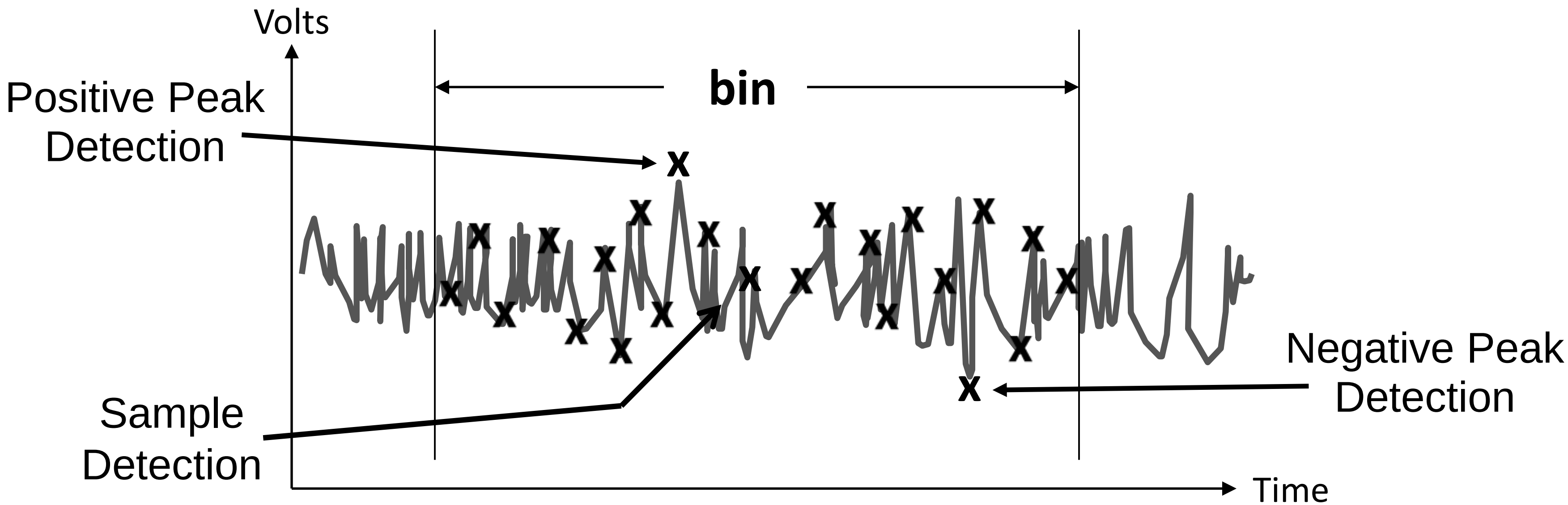
Other Detectors: Normal (Rosenfell), Average (RMS Power)

KEYSIGHT TECHNOLOGIES

Theory of Operation

Average Detector Type

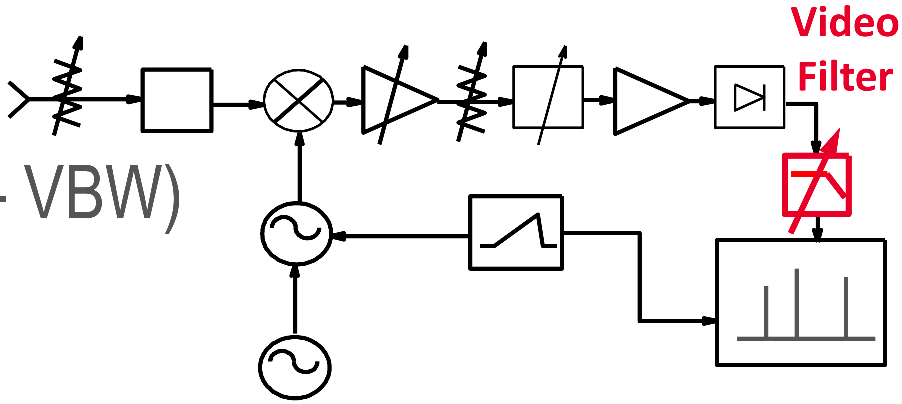


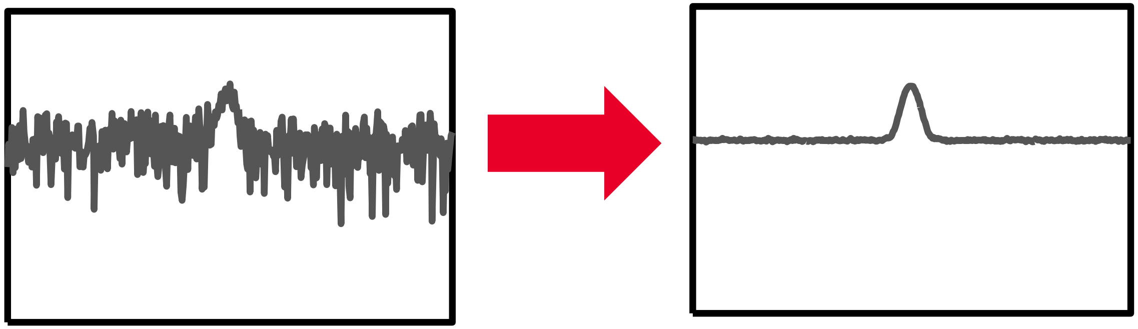


Power Average Detection (rms): Square root of the sum of the squares of ALL of the voltage data values in the bin divided by 50Ω

Theory of Operation

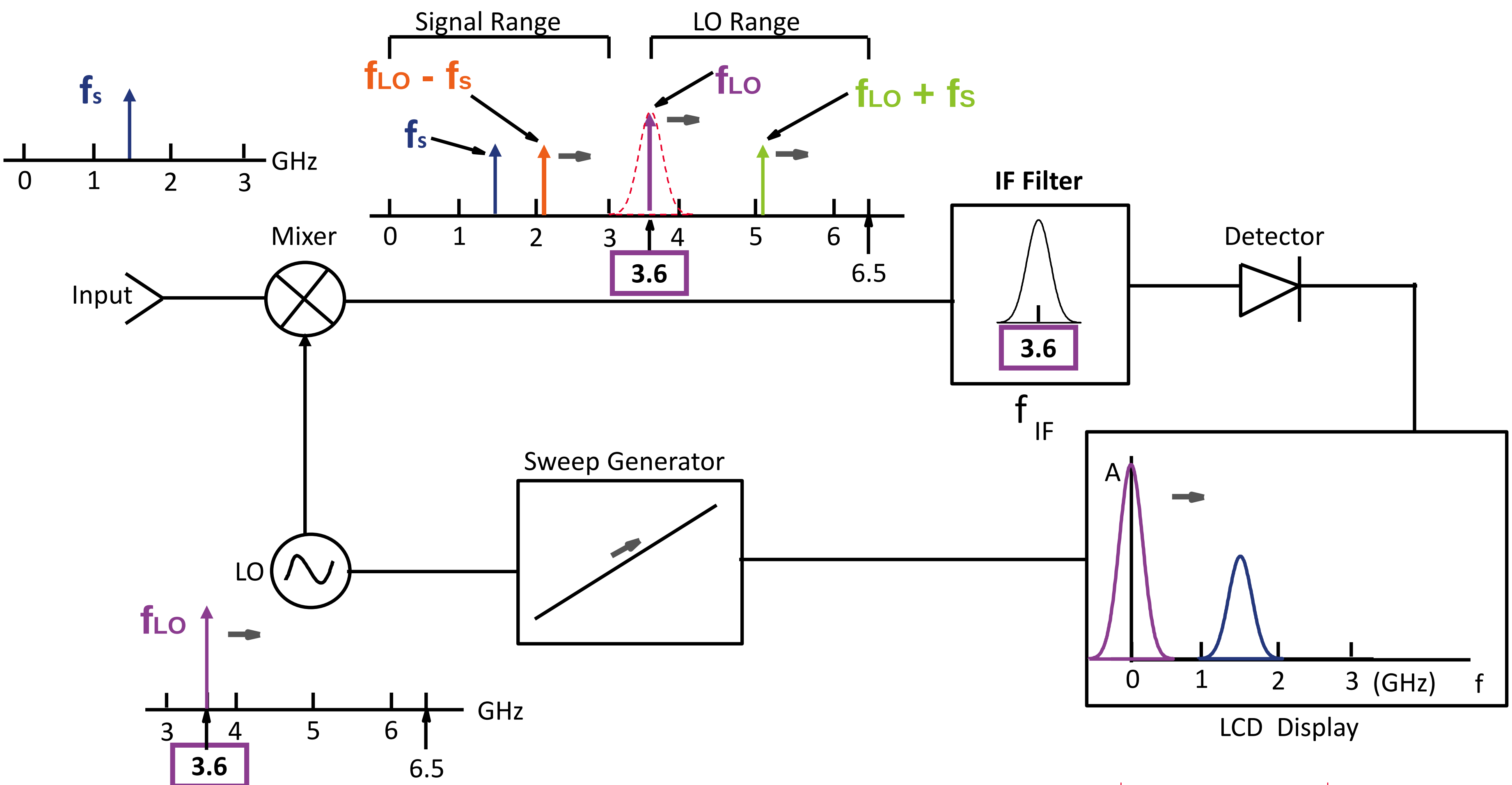
Video Filter (Video Bandwidth – VBW)





Theory of Operation

How it All Works Together – 3 GHz Spectrum Analyzer

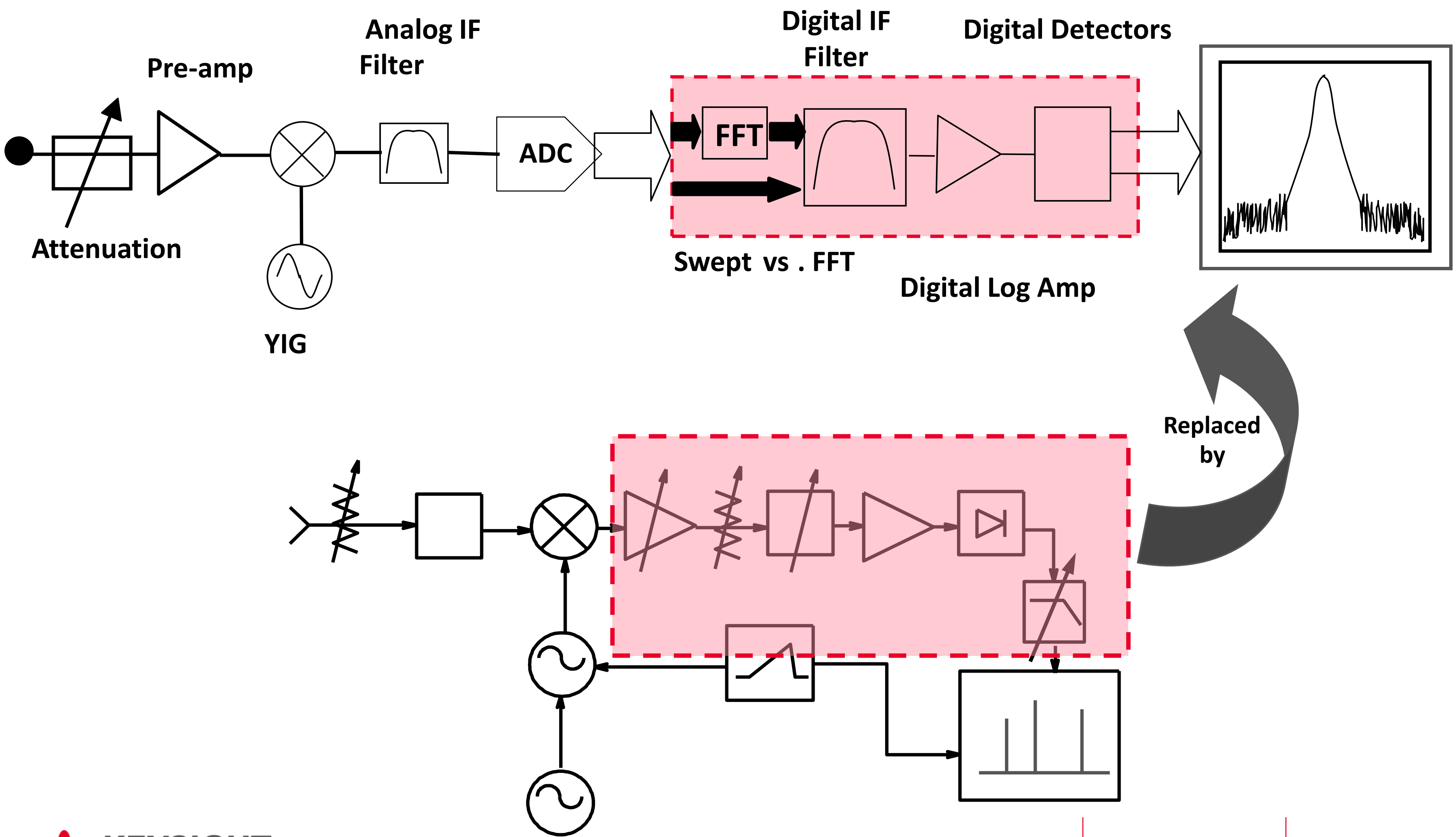


KEYSIGHT TECHNOLOGIES

Demonstration

Show Spectrum Analyzer animation of sweep

Modern Signal Analyzer Block Diagram



Agenda

– Overview

– Theory of Operation

- Traditional Spectrum Analyzers
- Modern Signal Analyzers

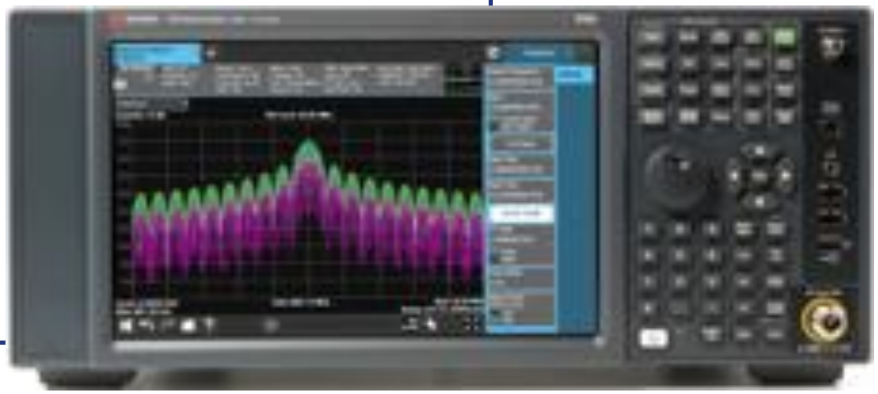
– Specifications

– 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).

- **Typica**l 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.

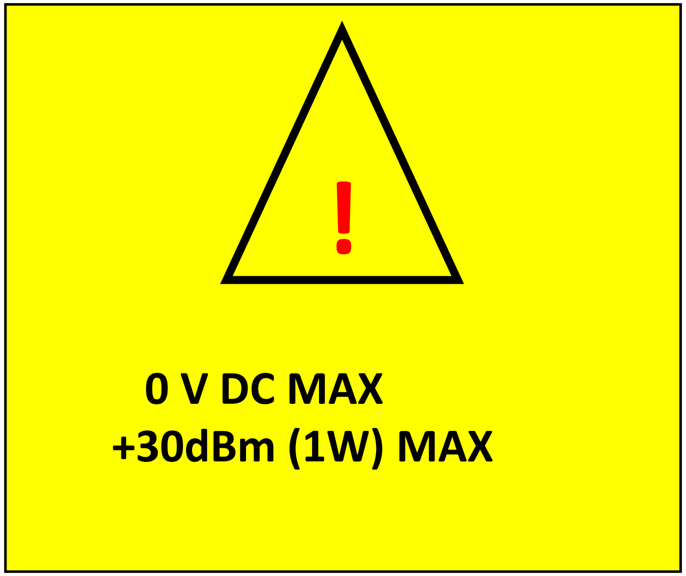
Specifications

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!

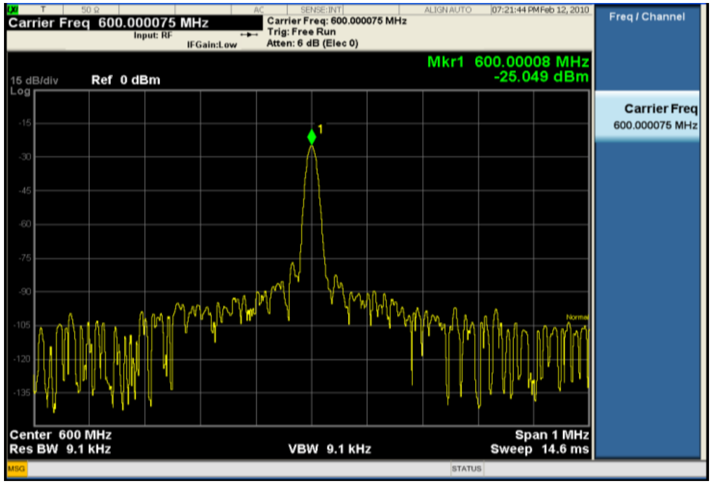
– Do not input signals with DC bias exceeding what the analyzer can tolerate while DC coupled!



KEYSIGHT TECHNOLOGIES

Specifications
Frequency Range

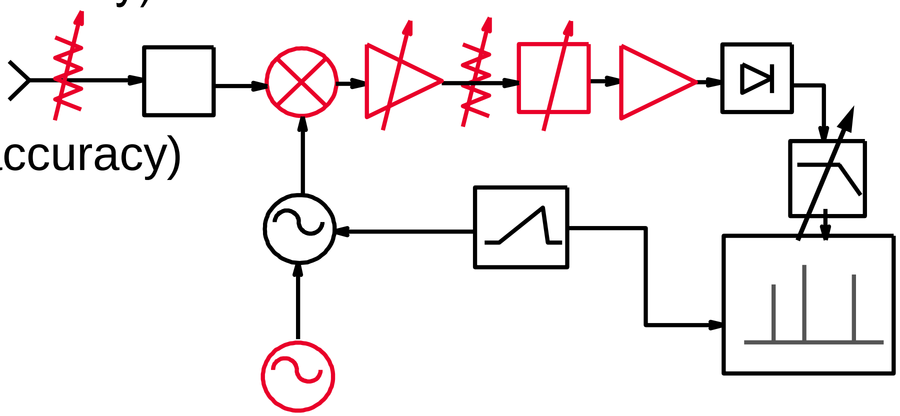
Description	Specifications
Internal Mixing	
Bands	
0	**3 Hz to 3.6 GHz**
1	**3.5 to 8.4 GHz**
2	**8.3 to 13.6 GHz**
3	**13.5 to 17.1 GHz**
4	**17 to 26.5 GHz**
5	**26.4 to 34.5 GHz**
6	**34.4 to 50 GHz**



Specifications

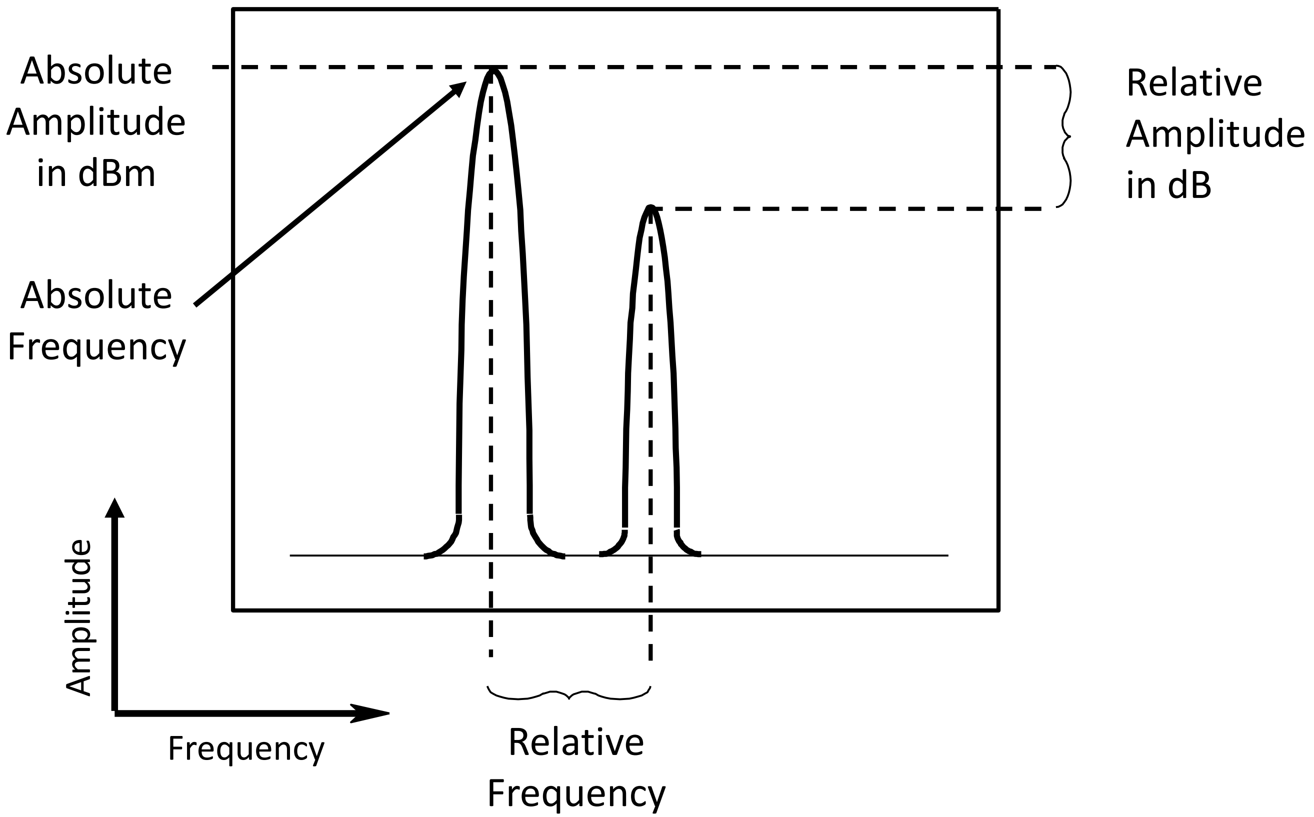
Accuracy: Frequency & Amplitude

- 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

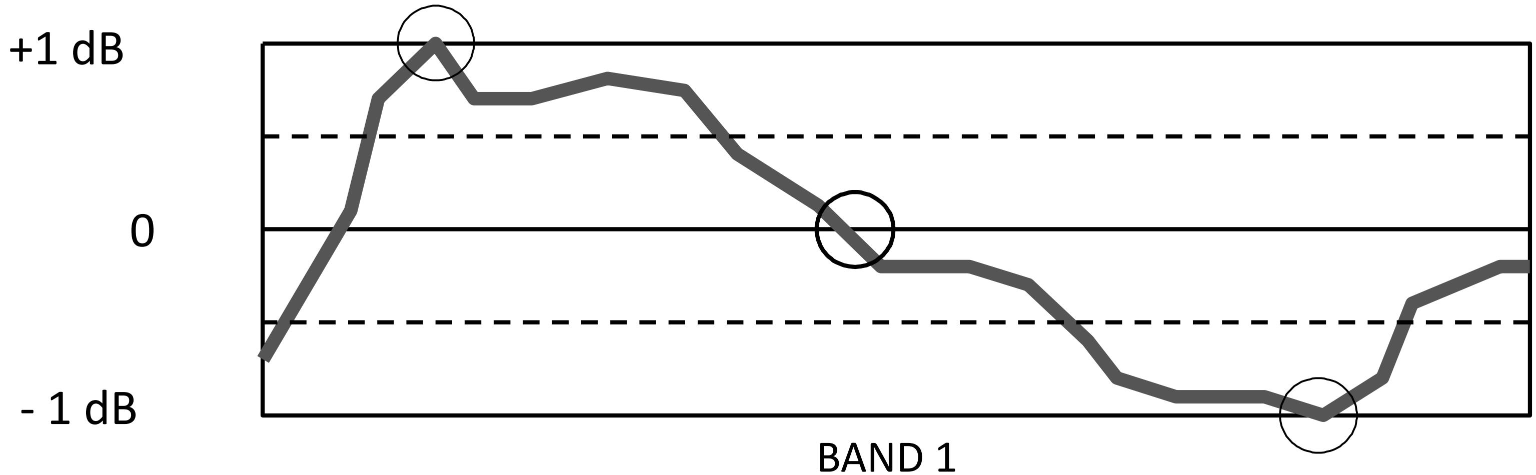


Note: Absolute accuracy is also “relative” to the calibrator reference point

Specifications

Accuracy: Frequency Response

Signals in the Same Harmonic Band



Absolute amplitude accuracy – Specification: ± 1 dB
Relative amplitude accuracy – Specification: ± 2 dB

Specifications

Accuracy: Frequency Readout Accuracy

Frequency Readout Accuracy =

± [(Marker Frequency x Frequency Reference Accuracy) + (0.1% x Span) + (5% x RBW) + 2Hz + (0.5 x Horizontal Resolution)]

= ± [(time since last adjustment **x** aging rate) + temperature stability + calibration accuracy] = **1.55 x 10^{-7}/ year**

= span / (sweep points – 1)

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

Calculation:	(1×10^{9}Hz) x (±1.55×10^{-7}/Year)	= 155Hz
	400kHz Span x 0.1%	= 400Hz
	3kHz RBW x 5%	= 150Hz
	2Hz + 0.5 x 400kHz/(1000-1)	= 202Hz
	Total uncertainty	**= ±907Hz**

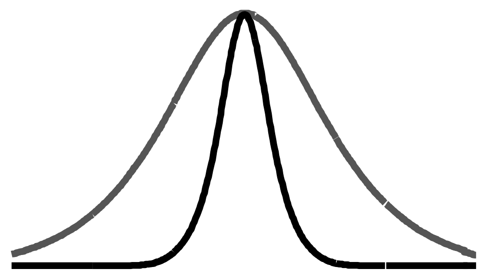
– Utilizing internal frequency counter improves accuracy to ±155 Hz

– The maximum number of sweep points for the X-Series Analyzers is 40,001 which helps to achieve the best frequency readout accuracy

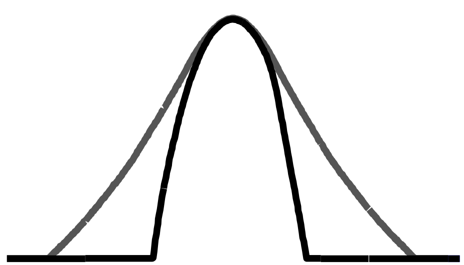
Specifications

Resolution

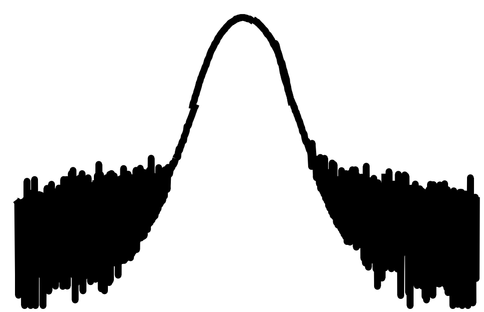
What Determines Resolution?



Resolution Bandwidth



RBW Type and Selectivity

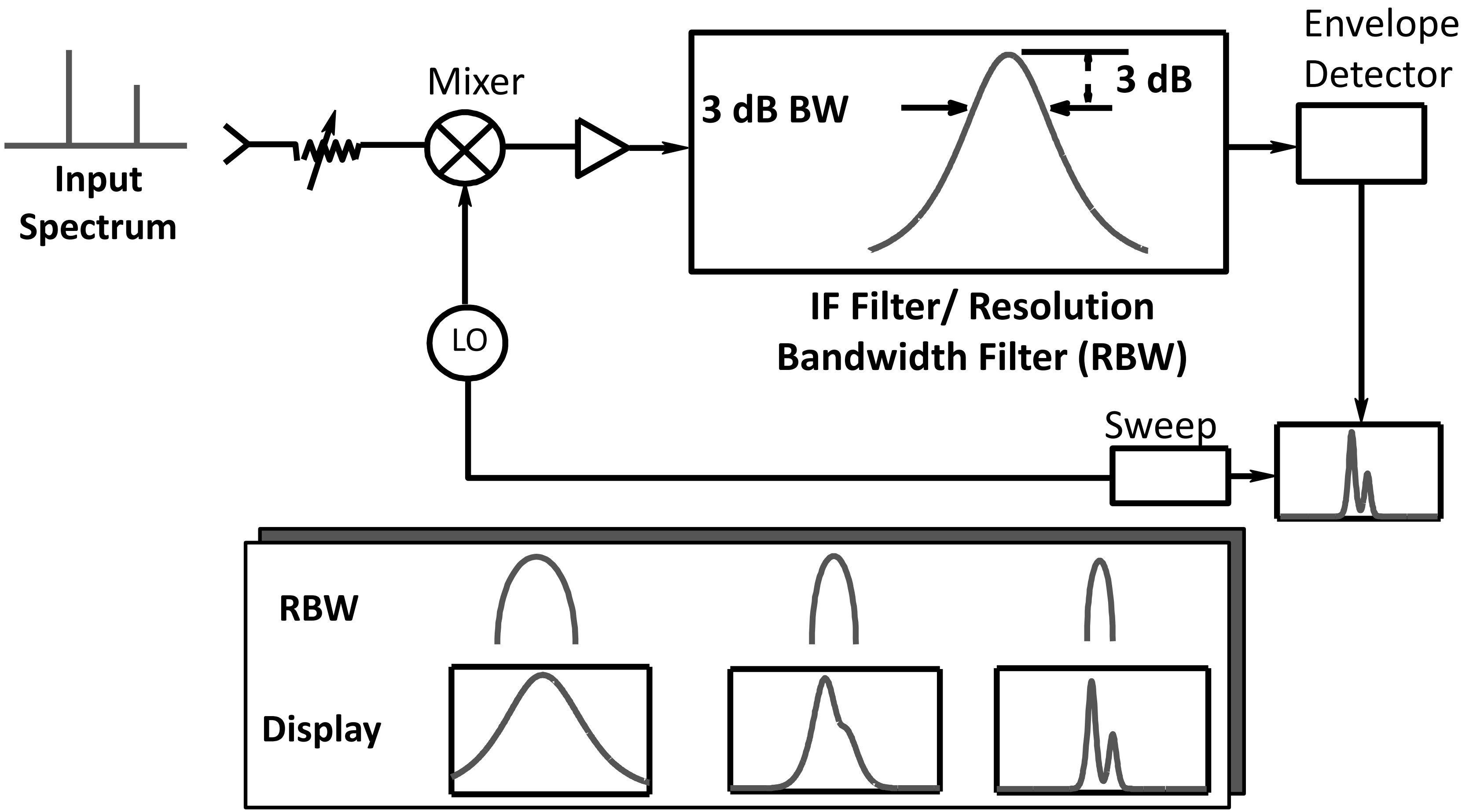


Noise Sidebands

KEYSIGHT TECHNOLOGIES

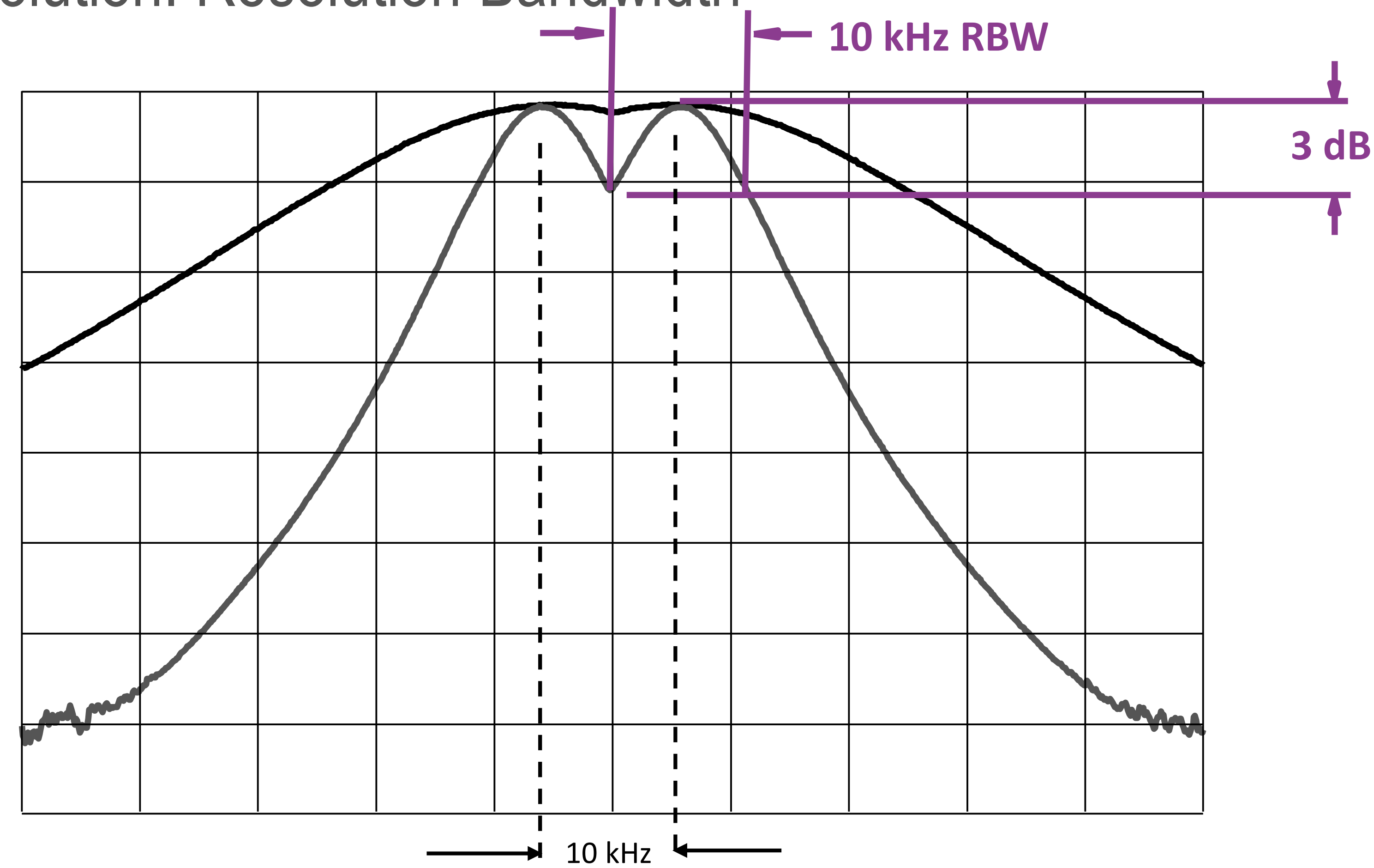
Specifications

Resolution: Resolution Bandwidth



Specifications

Resolution: Resolution Bandwidth

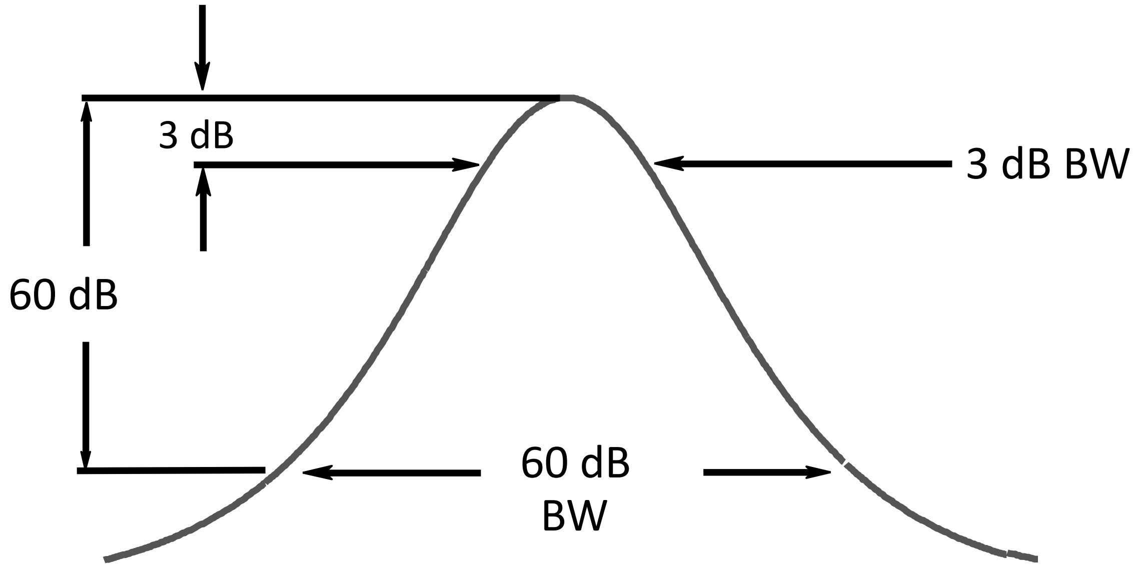


Determines resolvability of equal amplitude signals

KEYSIGHT TECHNOLOGIES

Specifications

Resolution: RBW Selectivity or Shape Factor

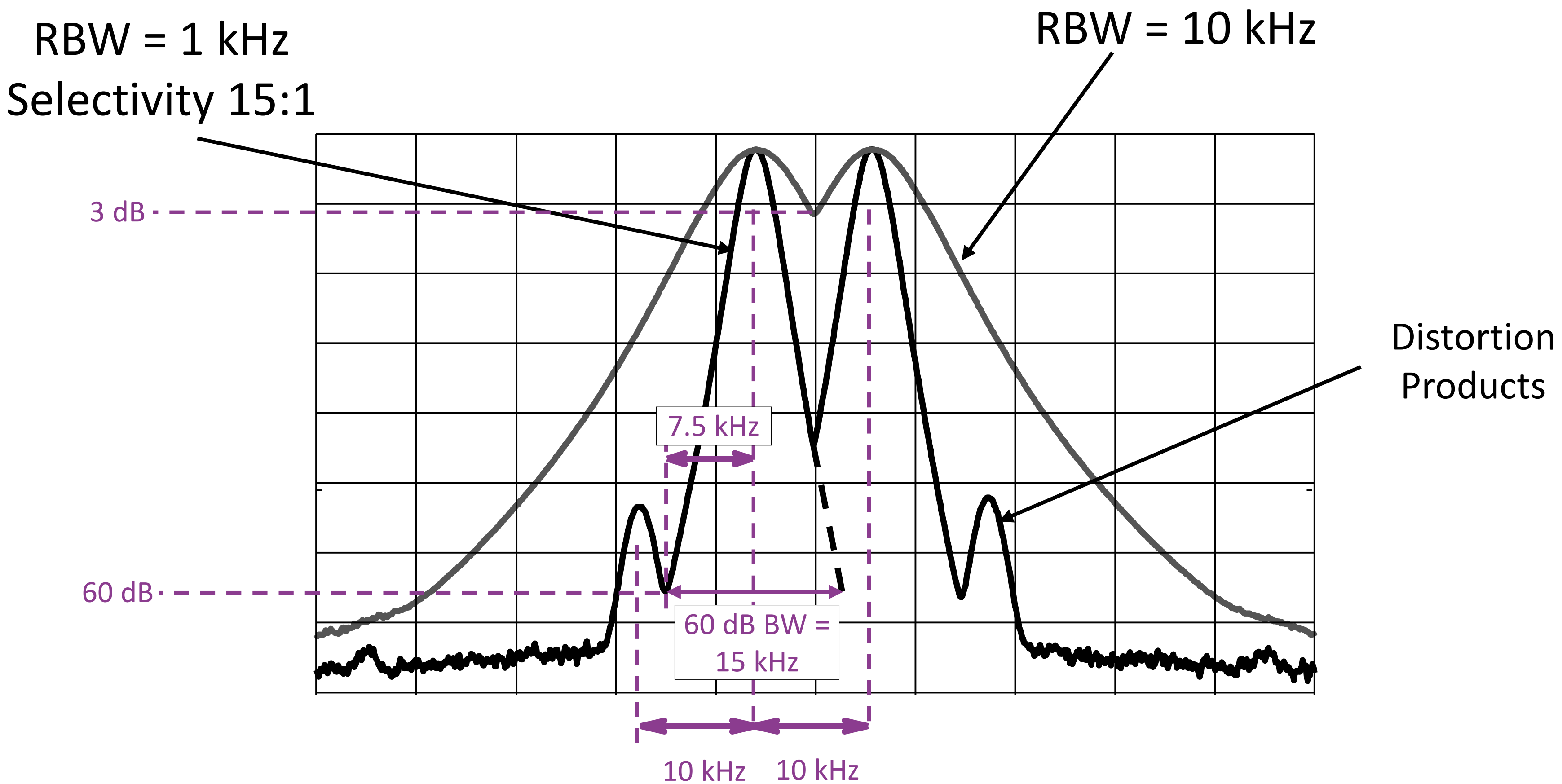


Selectivity $=$ $\dfrac{\text{60 dB BW}}{\text{3 dB BW}}$

Determines resolvability of unequal amplitude signals

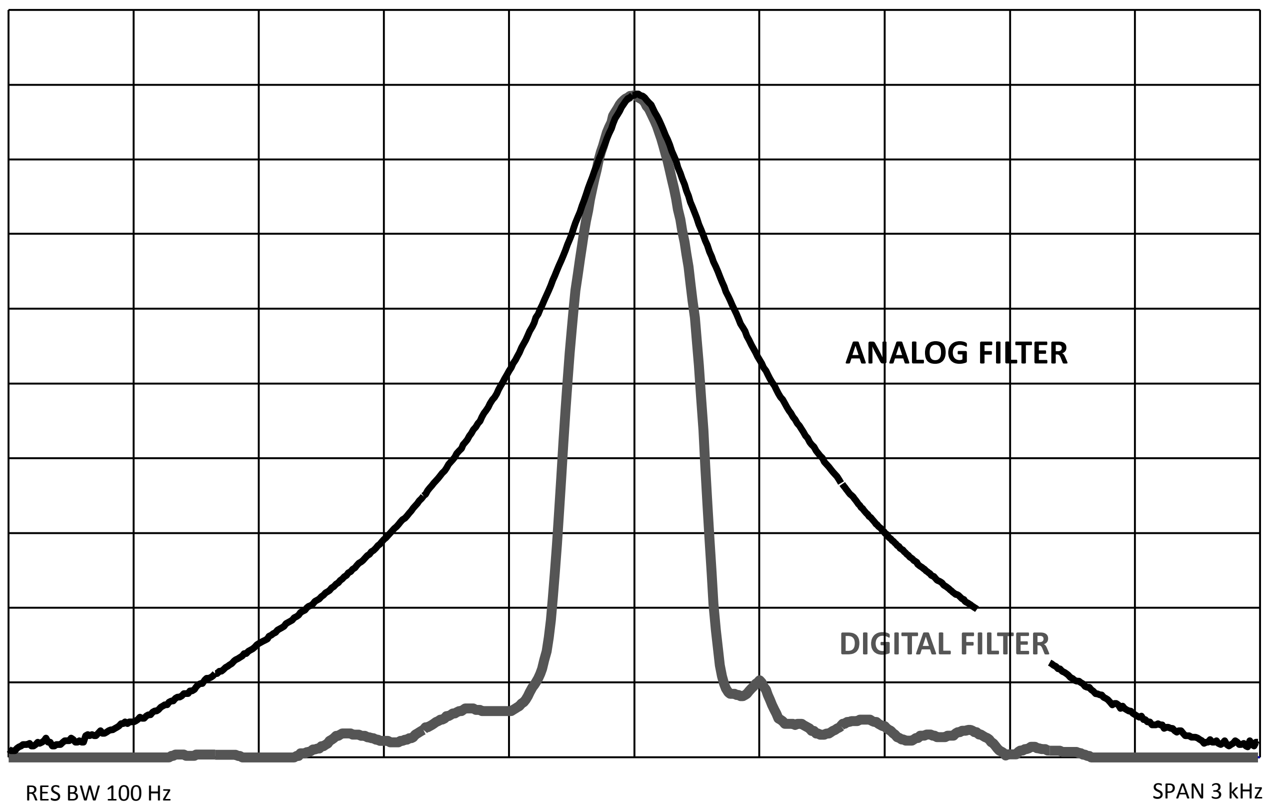
Specifications

Resolution: RBW Selectivity or Shape Factor



Specifications

Resolution: RBW Type and Selectivity



Typical Selectivity

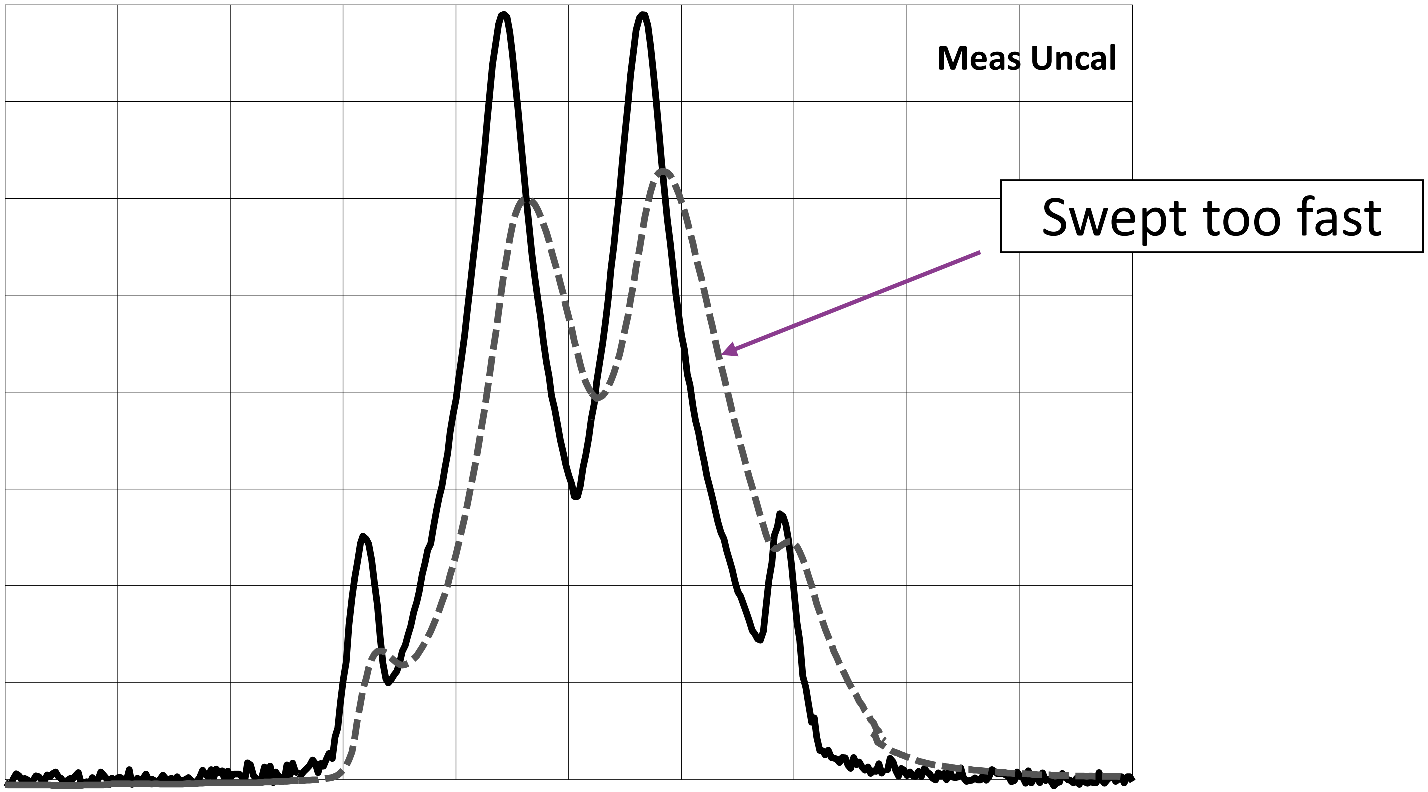
Analog 15:1

Digital ≤5:1

The X-series RBW shape factor is 4.1:1

Specifications

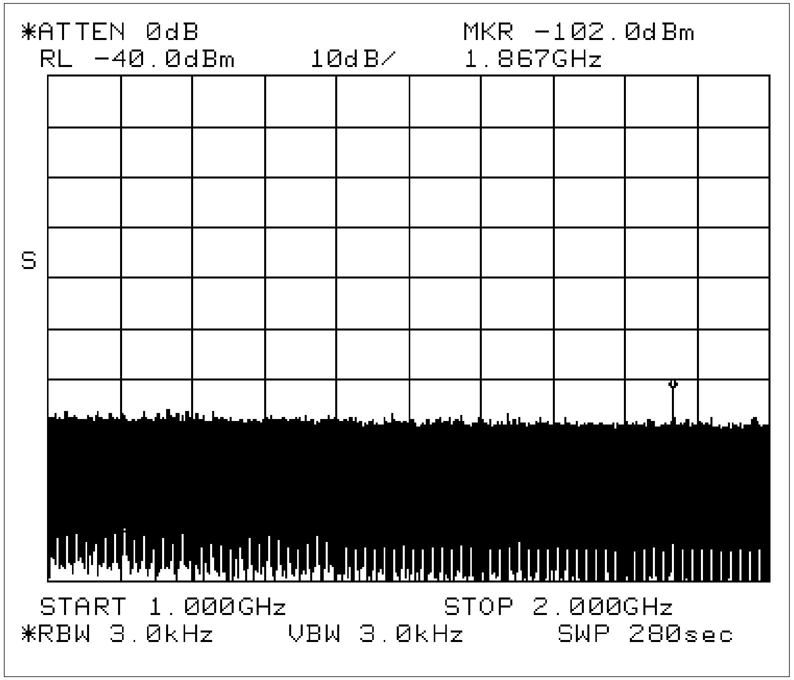
Resolution: RBW Determines Sweep Time



The penalty for sweeping too fast is an uncalibrated display.

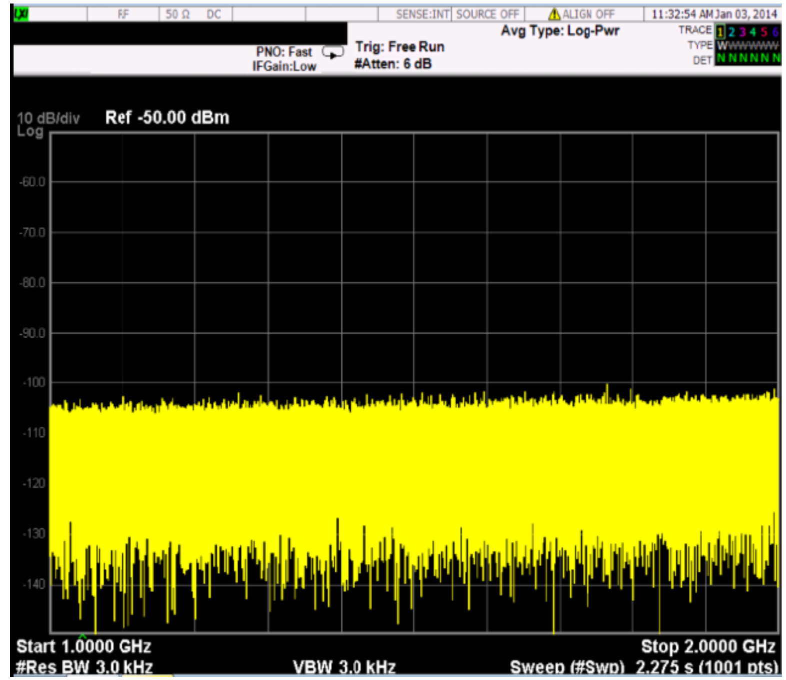
Resolution: RBW Type Determines Sweep Time

Analog RBW



280 sec

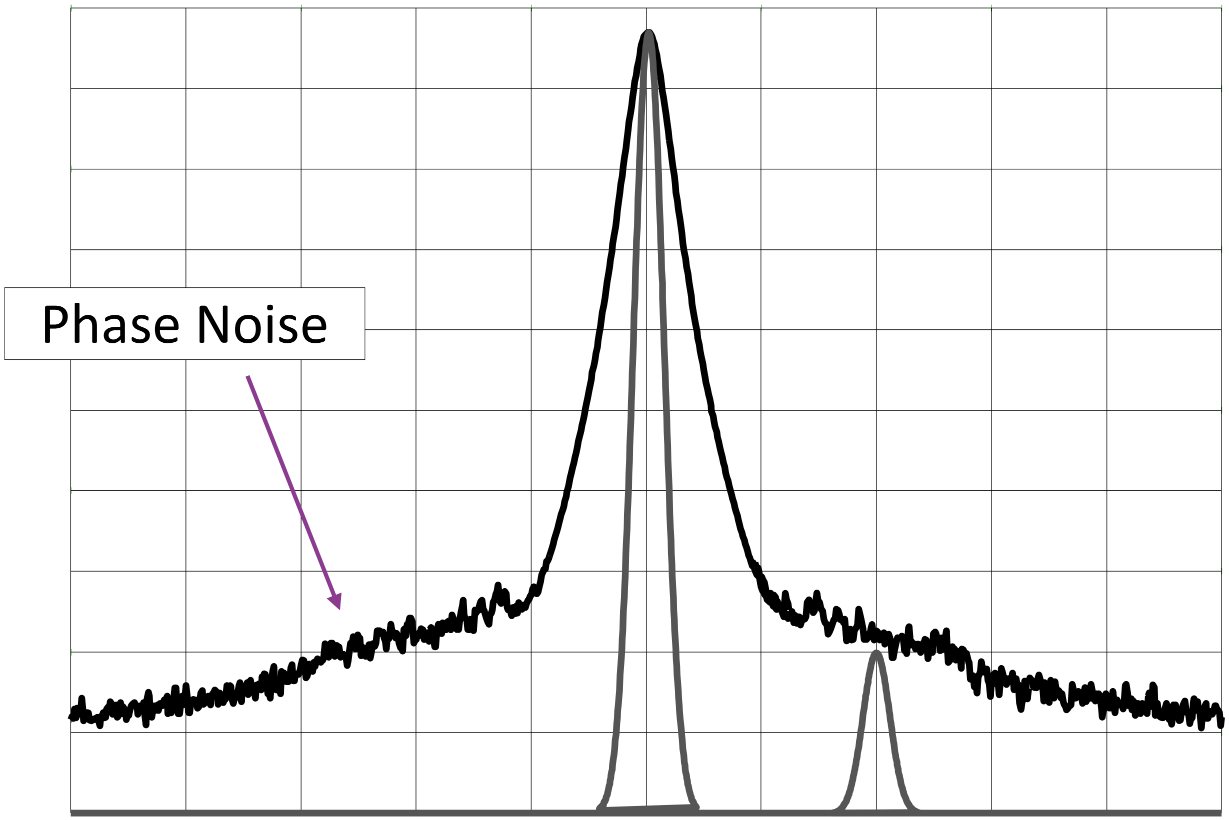
Digital RBW



2.3 sec

Specifications

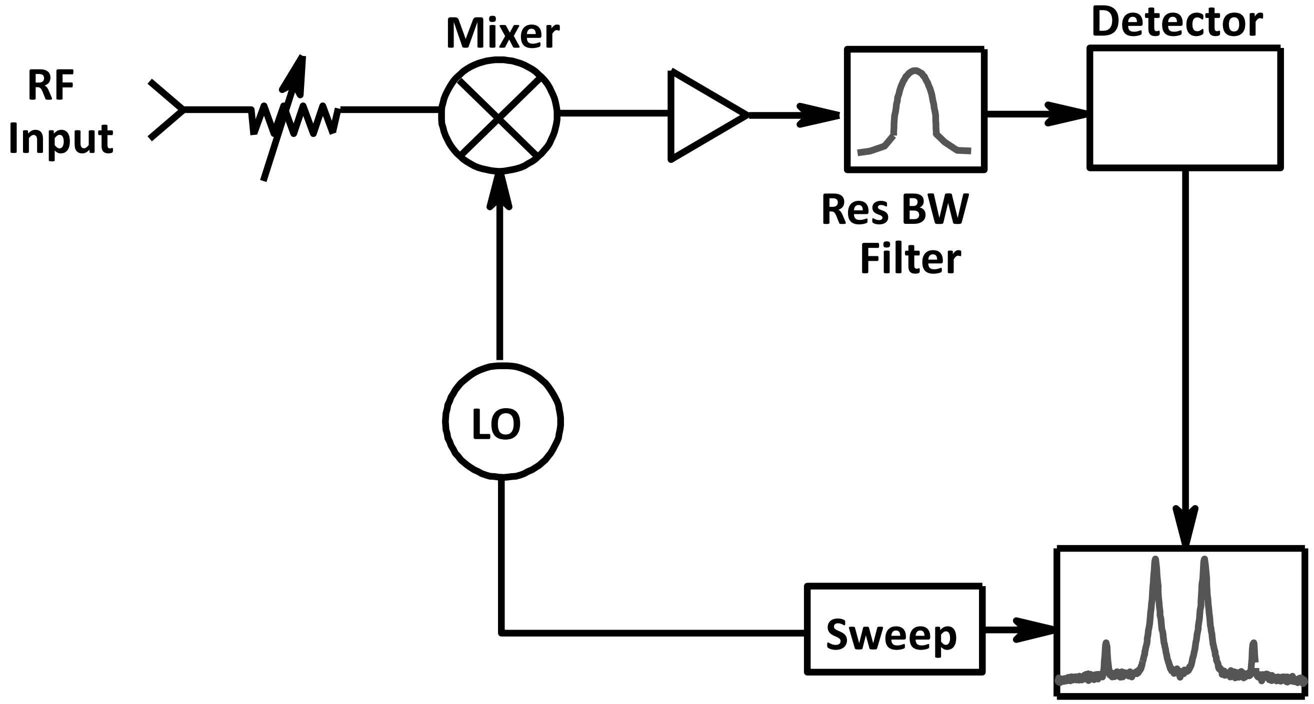
Resolution: Noise Sidebands



Noise sidebands can prevent resolution of unequal signals.

Specifications

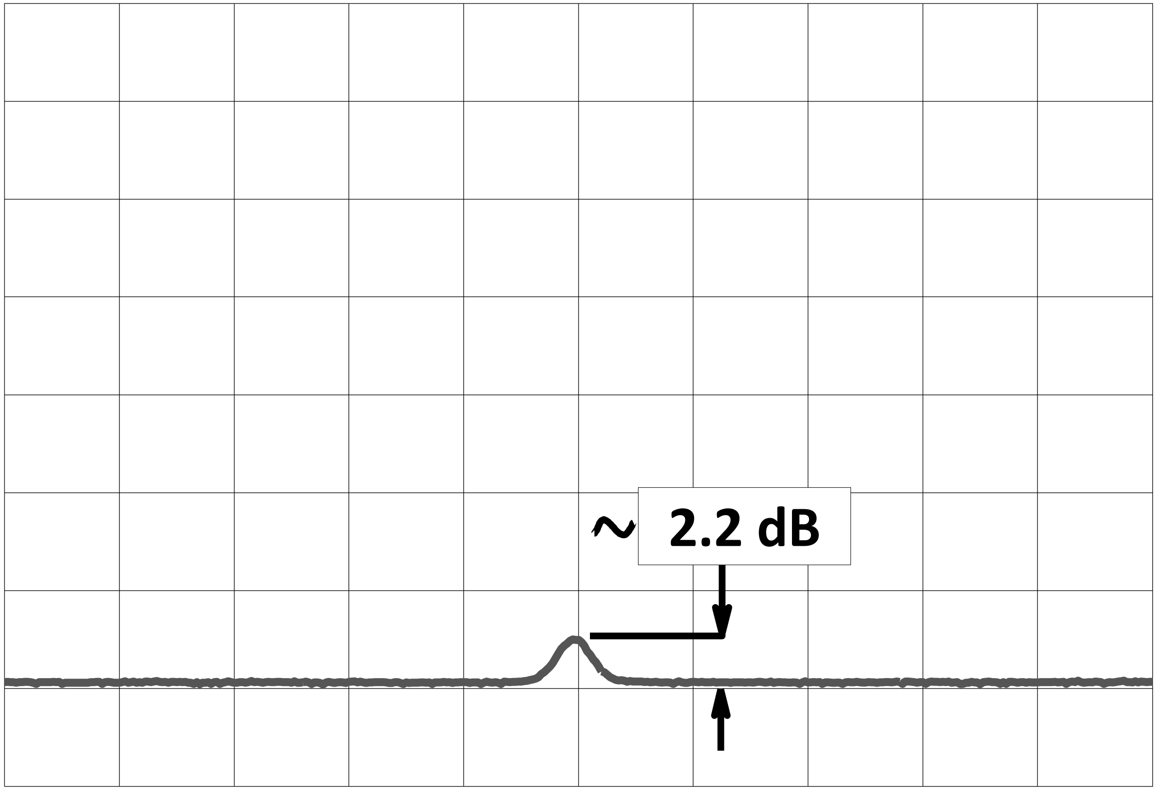
Sensitivity/DANL



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

Specifications

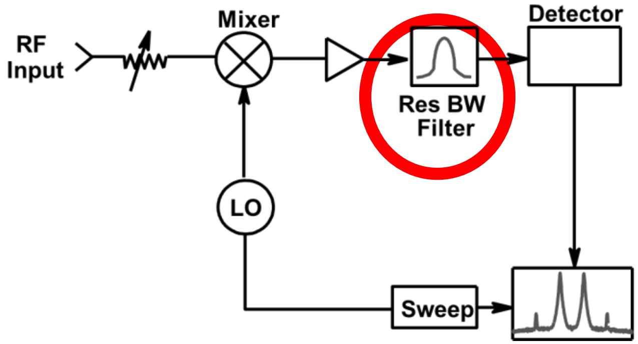
Sensitivity/DANL



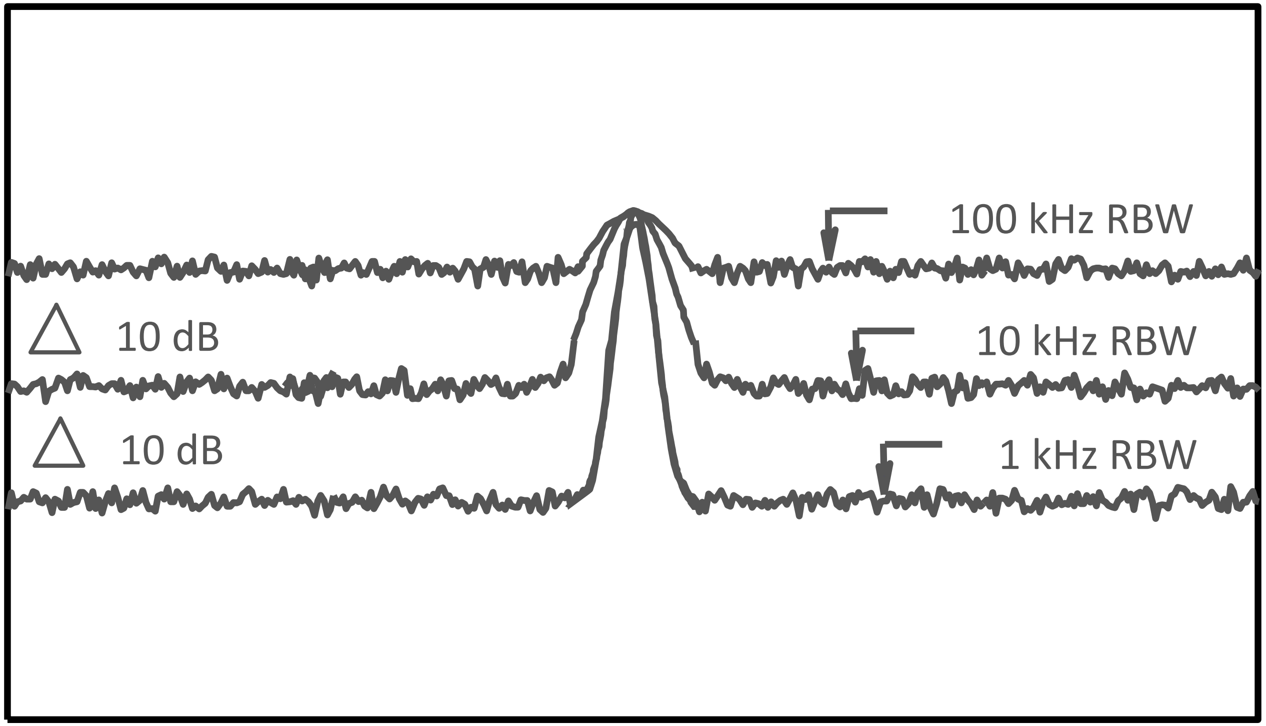
Sensitivity is the smallest signal that can be measured.

Specifications

Sensitivity/DANL: IF Filter (RBW)

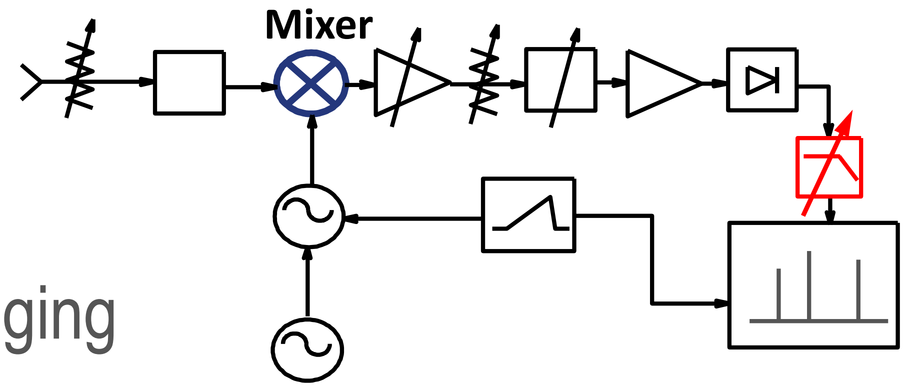


Displayed noise is a function of IF filter bandwidth: noise decreases as bandwidth decreases.



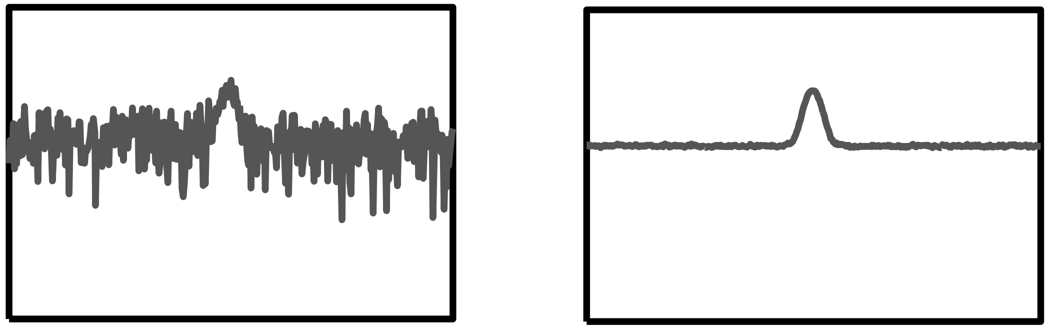
Specifications

Sensitivity/DANL:



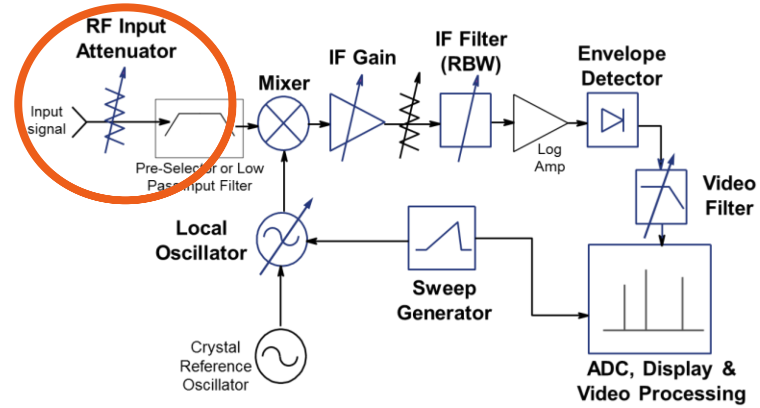
Video BW Filter or Trace Averaging

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

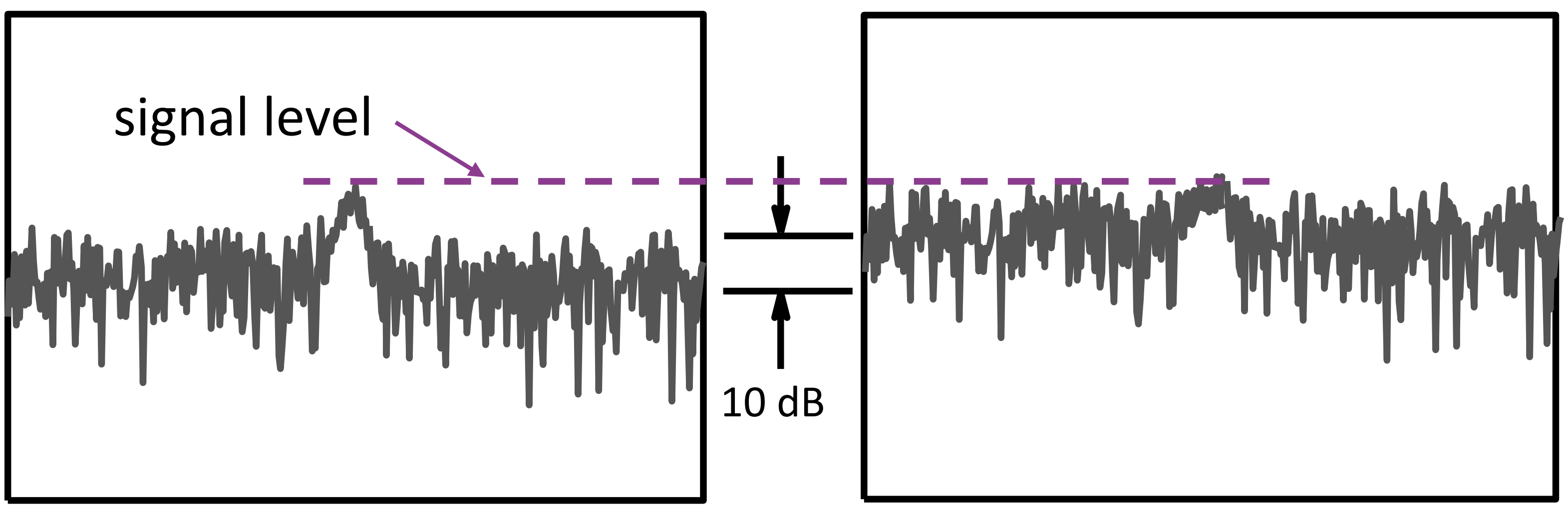


Specifications

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.

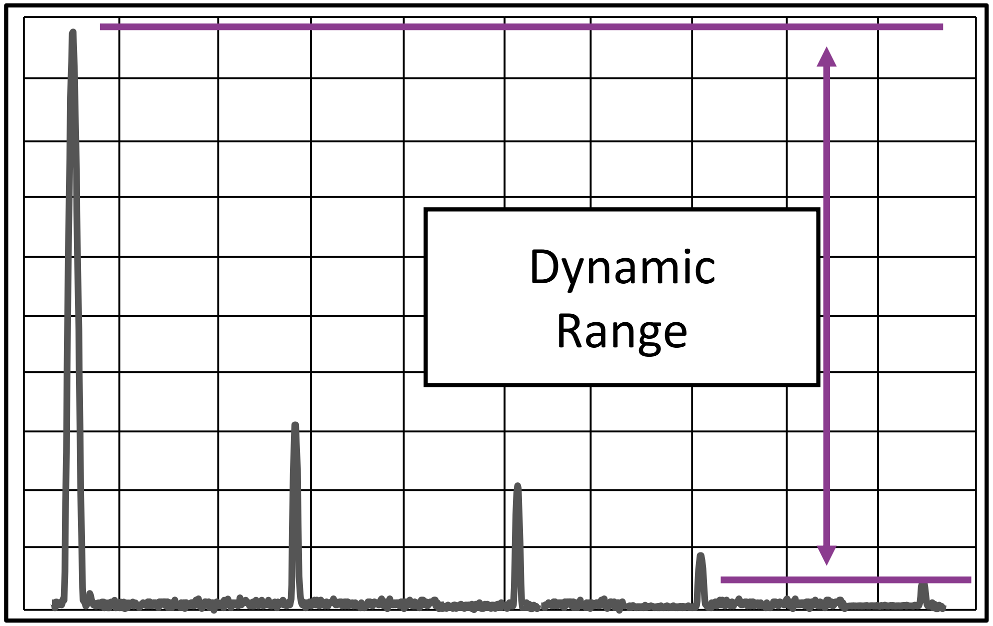


Attenuation = 10 dB

Attenuation = 20 dB

Specifications
Dynamic Range

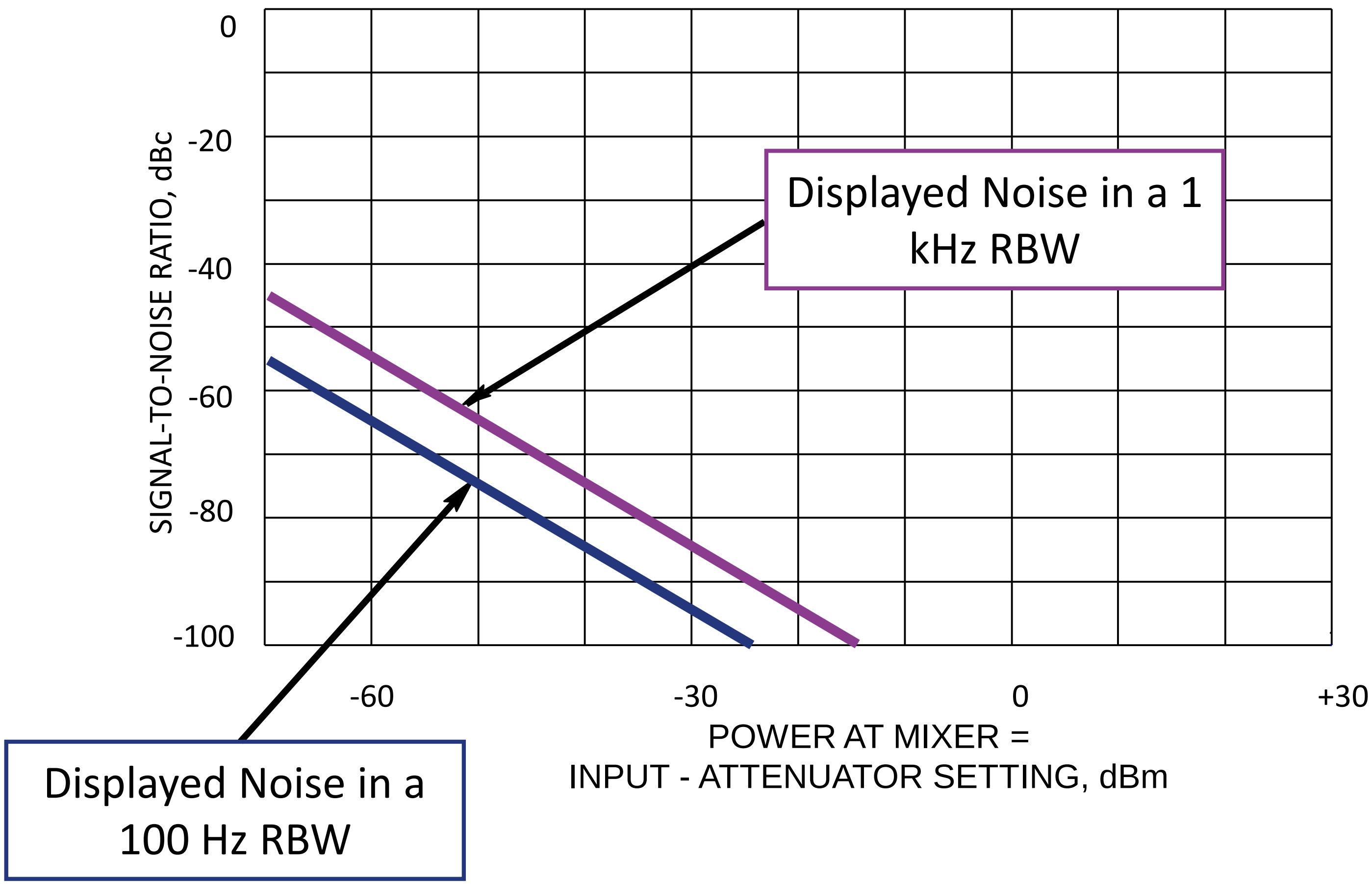
The ratio, expressed in dB, of the largest to the smallest signals simultaneously present at the input of the spectrum analyzer that allows measurement of the smaller signal to a given degree of uncertainty.



KEYSIGHT TECHNOLOGIES

Specifications

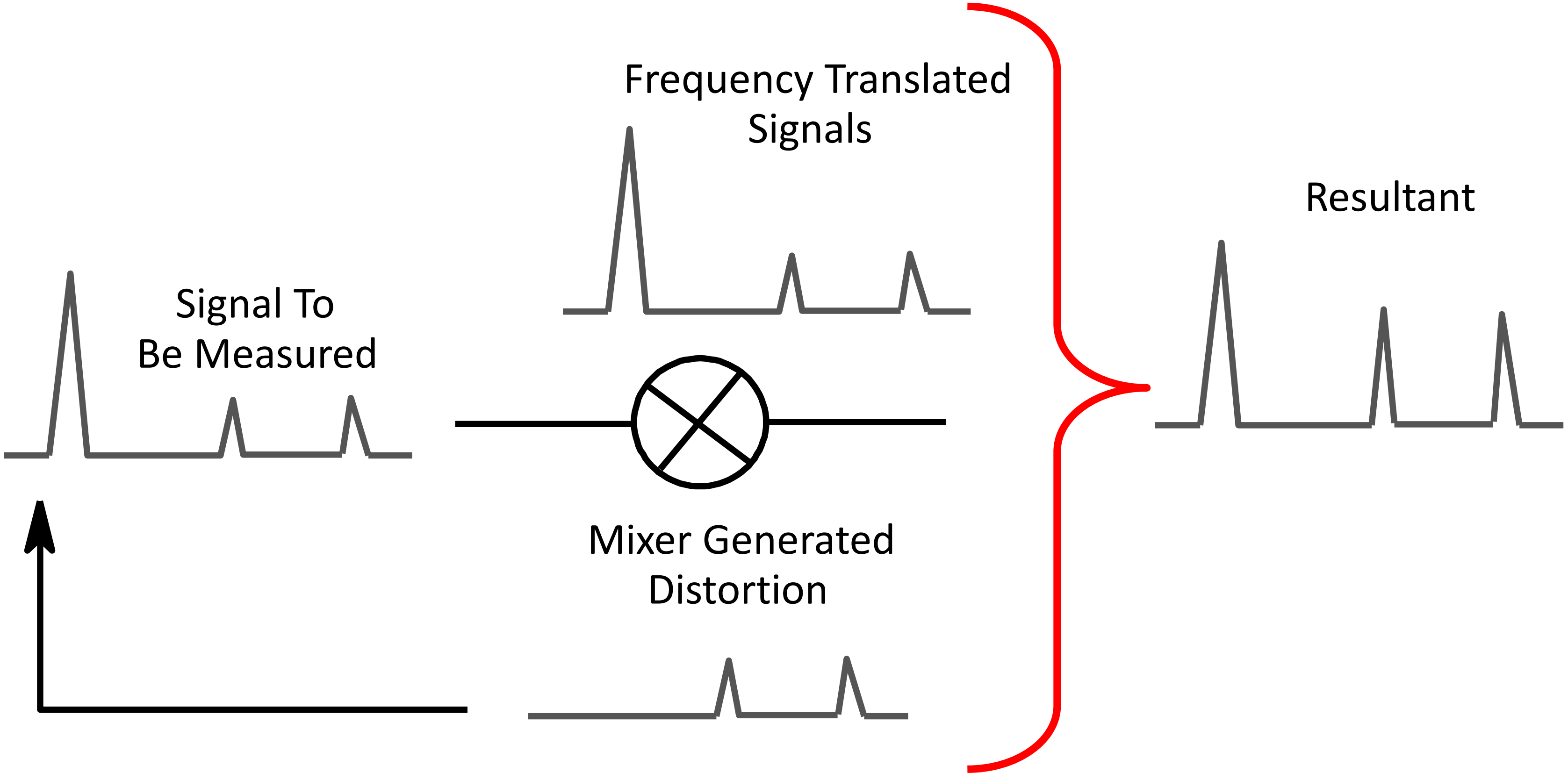
Displayed DANL per RBW and Mixer Input Power



KEYSIGHT TECHNOLOGIES

Specifications

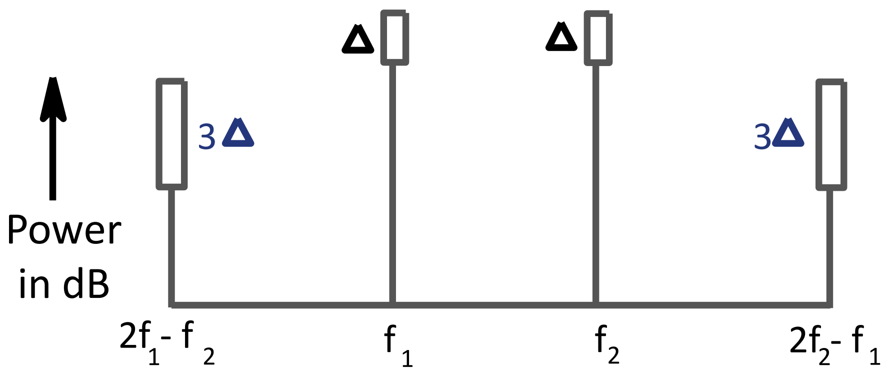
Distortion: Mixers



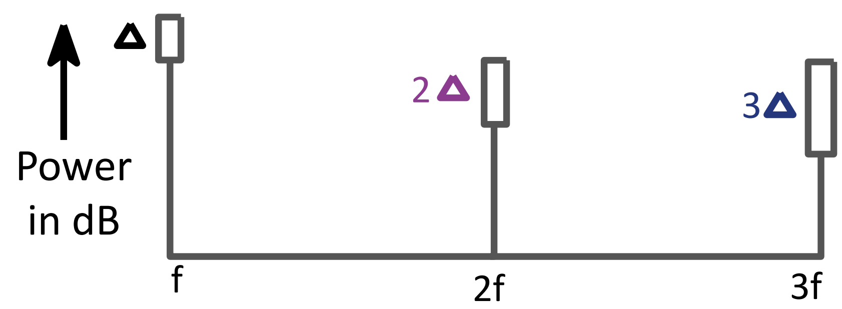
Specifications

Distortion: Second and Third Order

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



Two-Tone Intermod



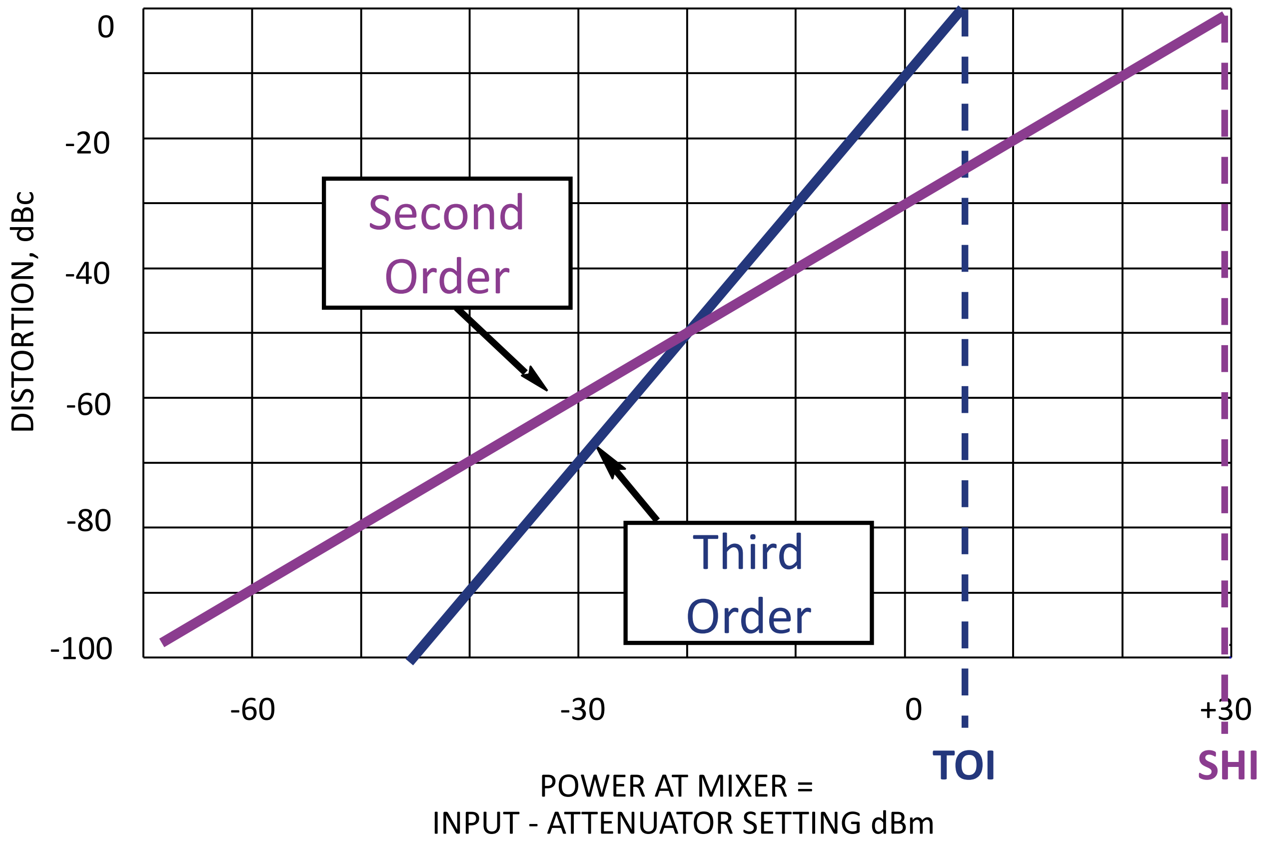
Harmonic Distortion

Third Order: △3 dB/dB of Fundamental

Second Order: △2 dB/dB of Fundamental

Specifications

Distortion: A Function of Mixer Level

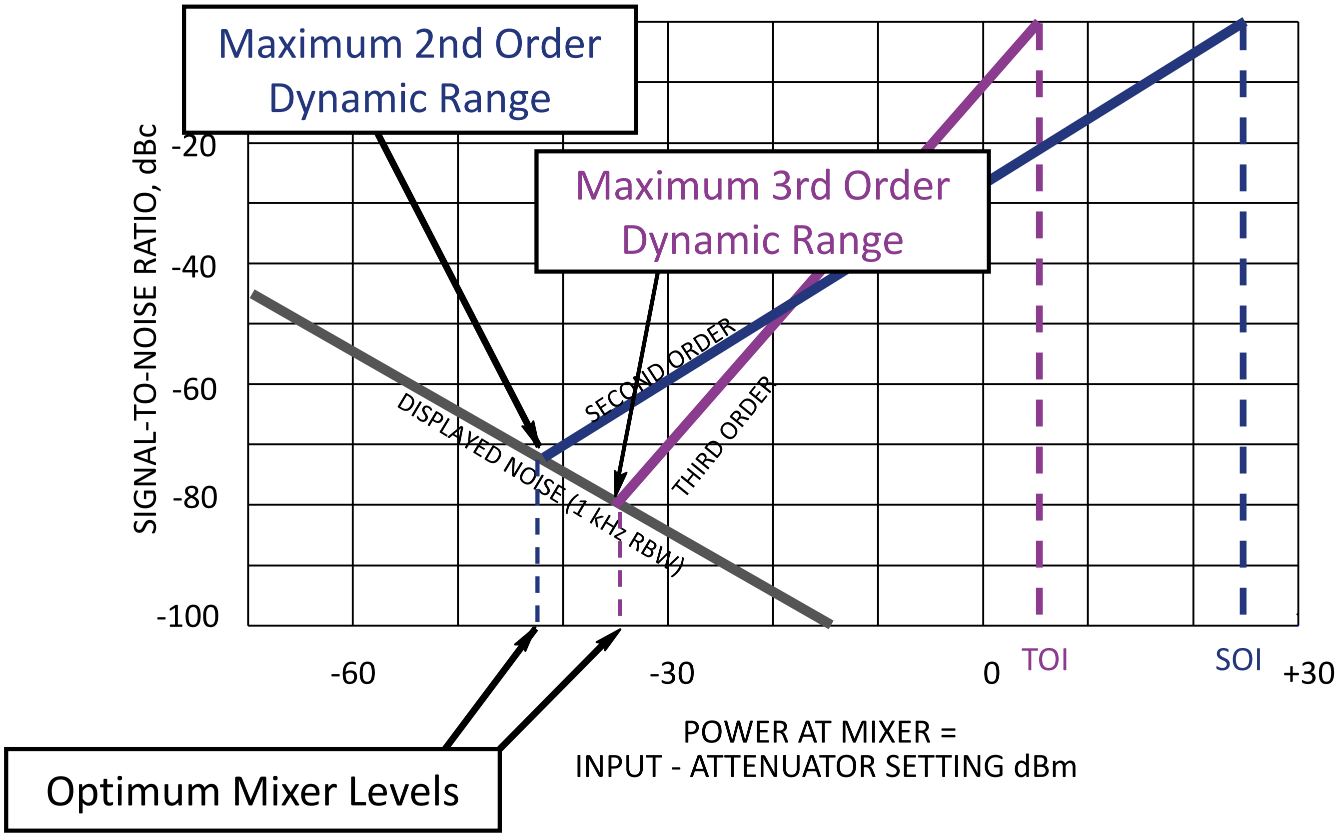


KEYSIGHT TECHNOLOGIES

Specifications

Dynamic Range (DANL, RBW, Distortion)

Dynamic range can be presented graphically.



Demonstration

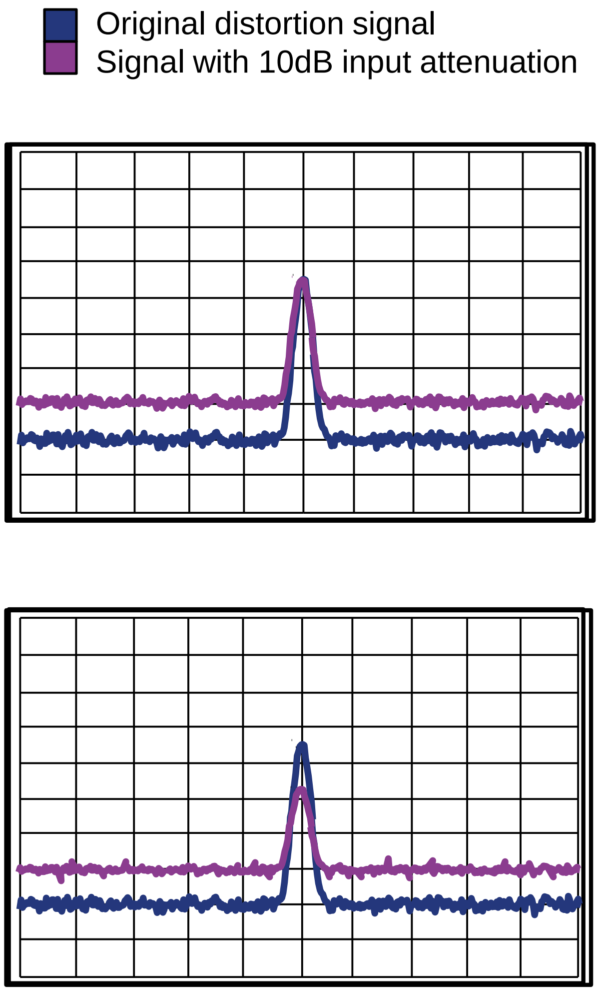
Distortion – Internal or External?

Attenuator Test: Change power to the mixer

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

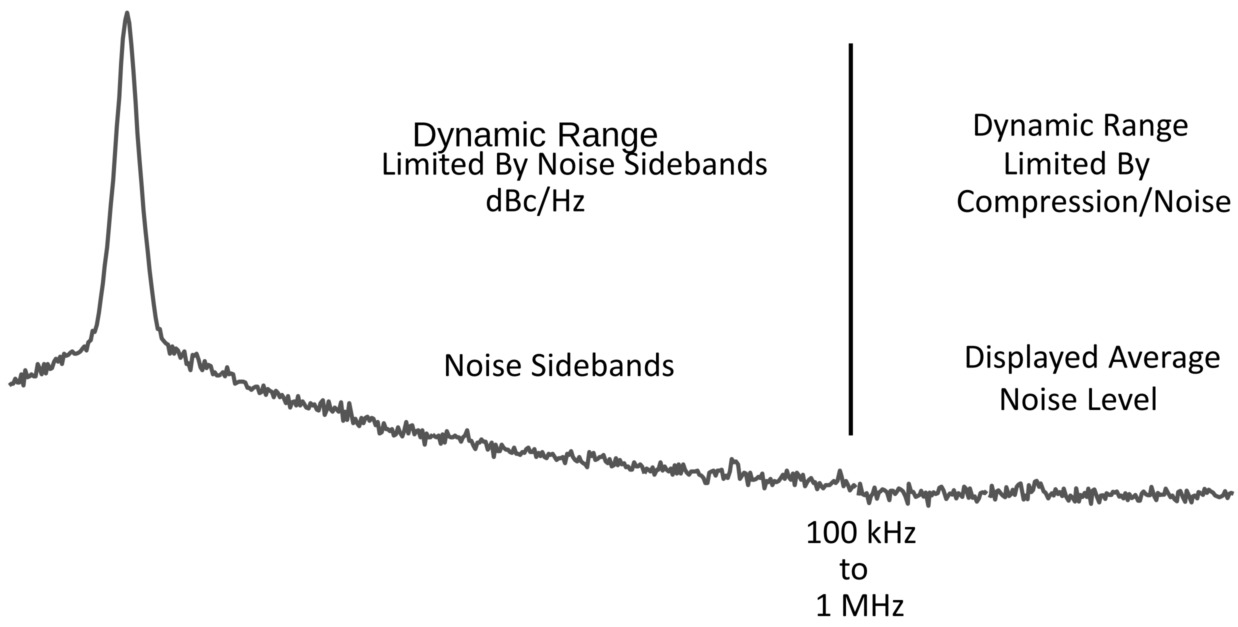
No change in amplitude:
Distortion is part of input signal (external).

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



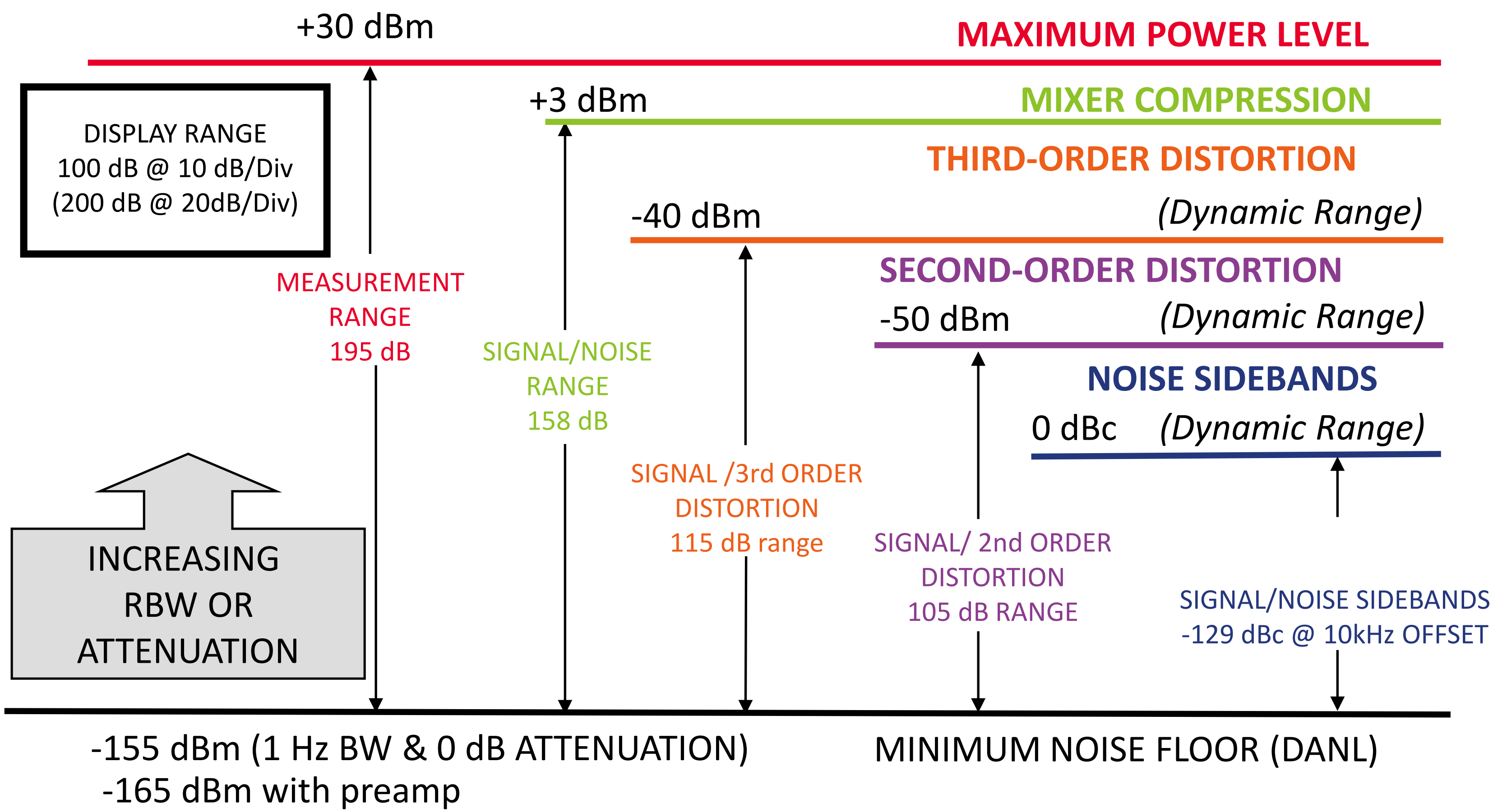
Specifications
Dynamic Range

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

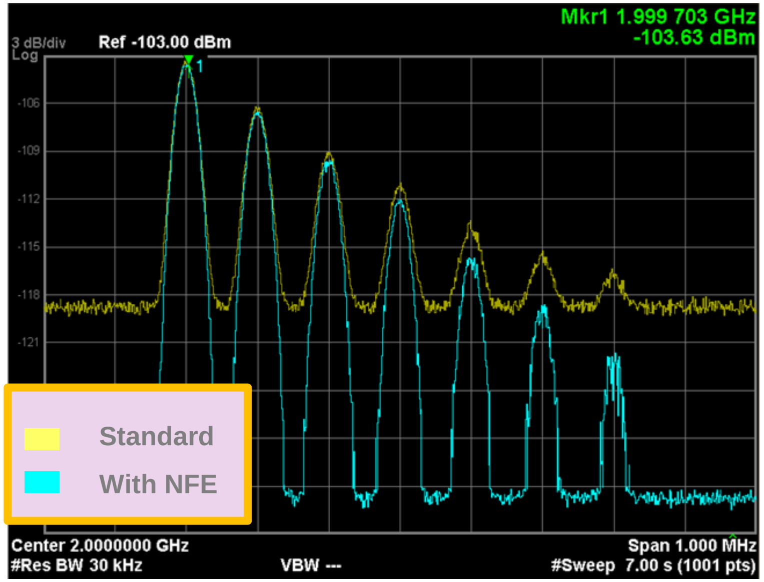
– Specifications

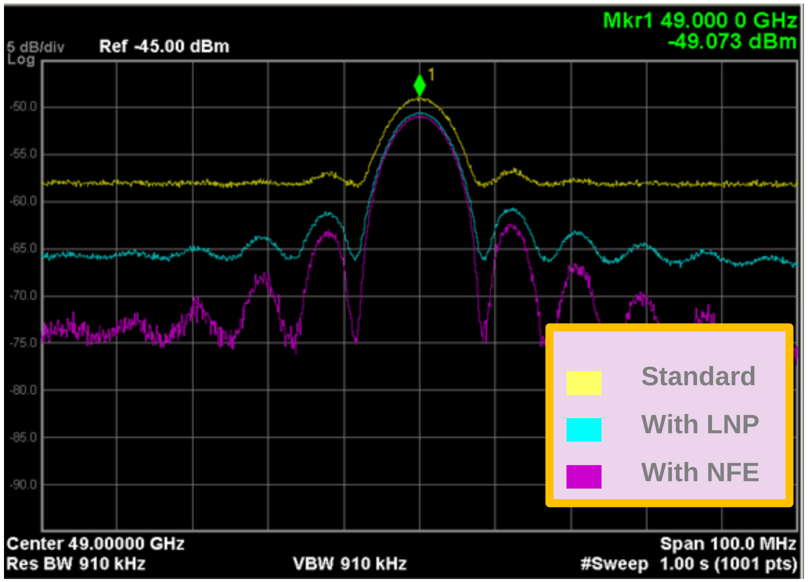
– Features

– Wrap-up

Features

Sensitivity/DANL: Noise Floor Extension

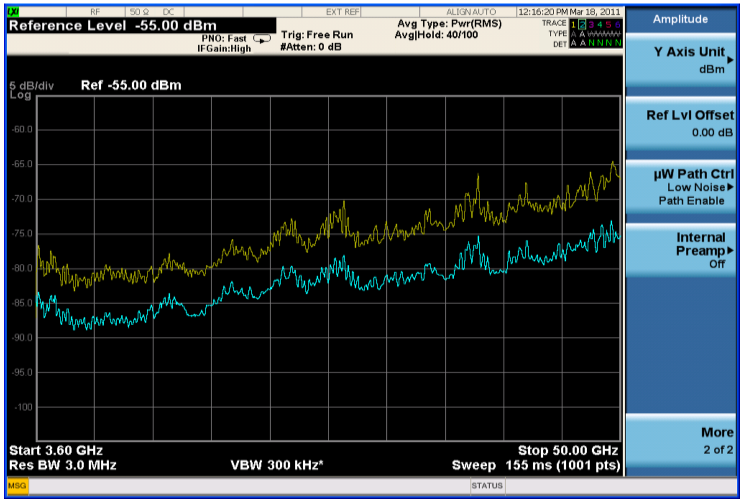


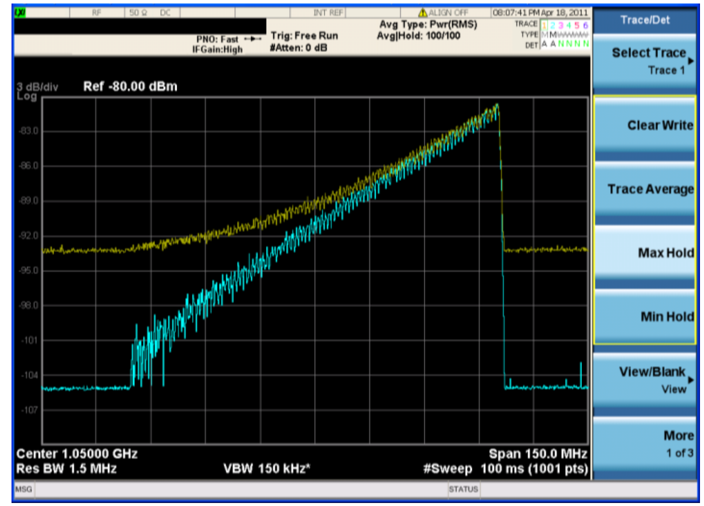


- The PXA combines real-time measurement processing with an unprecedented characterization of the analyzer’s own noise to allow that noise to be accurately removed from measurements.
- The improvement from *noise floor extension* varies from RF to millimeter wave. At RF, from about 3.5 dB for CW and 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)

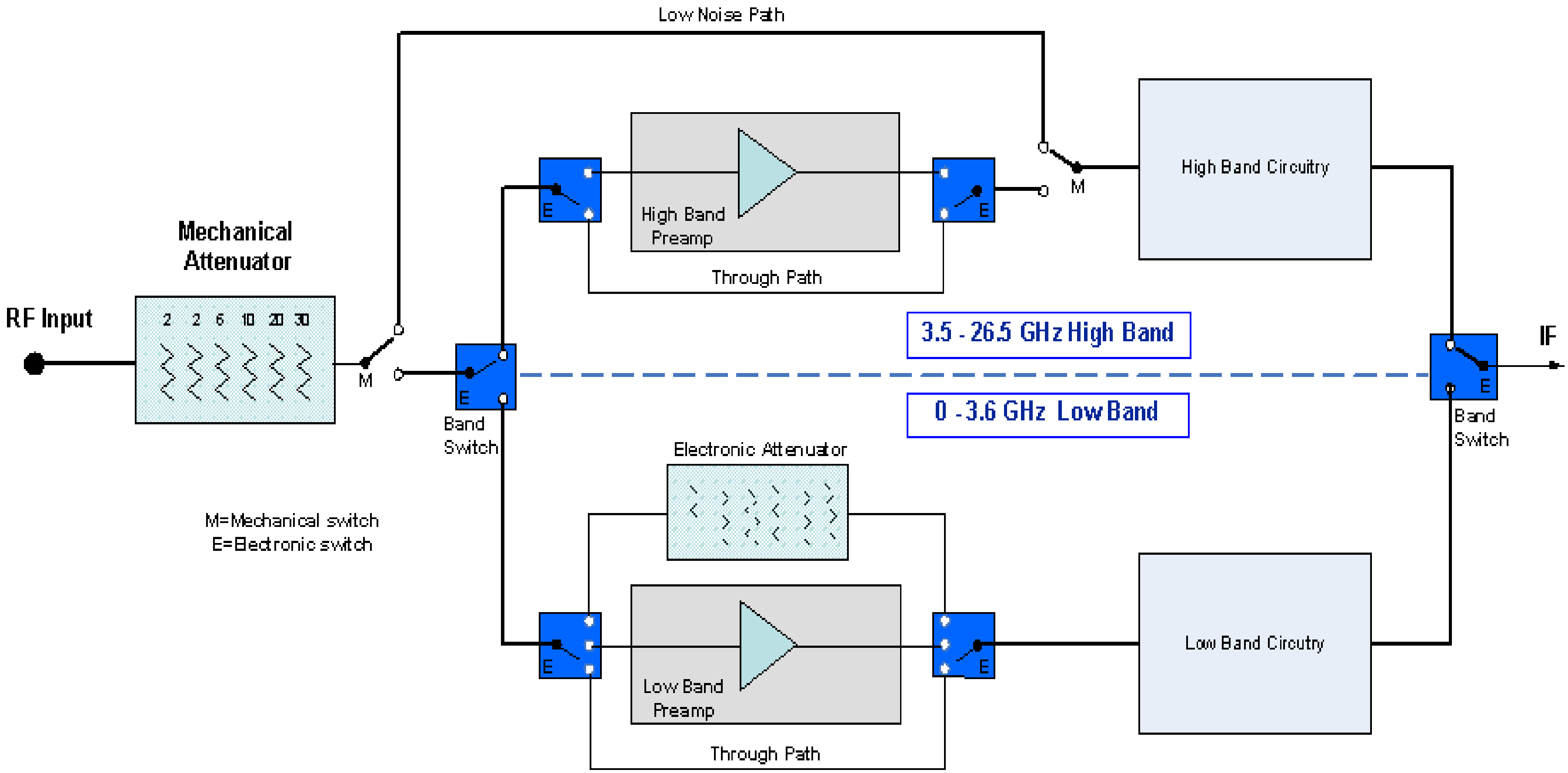




- At microwave frequencies any sort of signal routing or switching results in signal path loss.
- Preamplifiers can compensate for this loss and improve signal/noise for small signals, but they can cause distortion in the presence of larger signals
- LNP allows the “lossy” elements normally found in 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

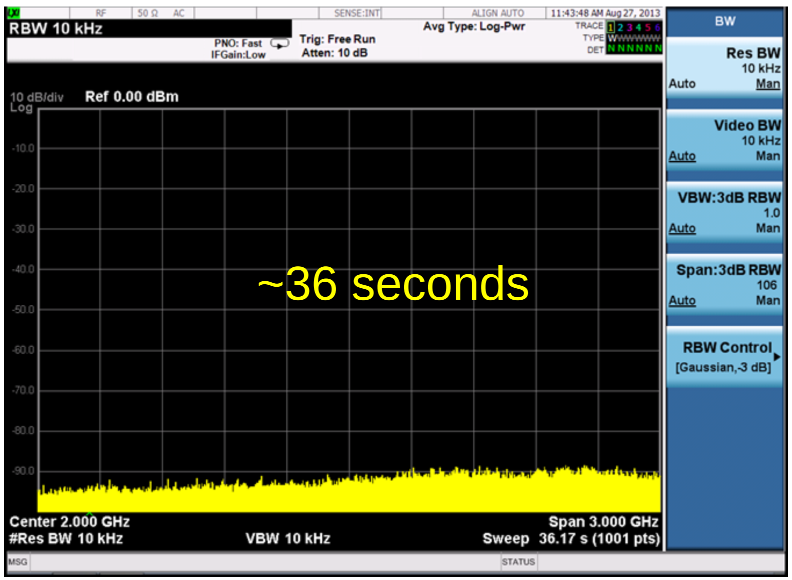
Sensitivity/DANL: Low Noise Path Block Diagram



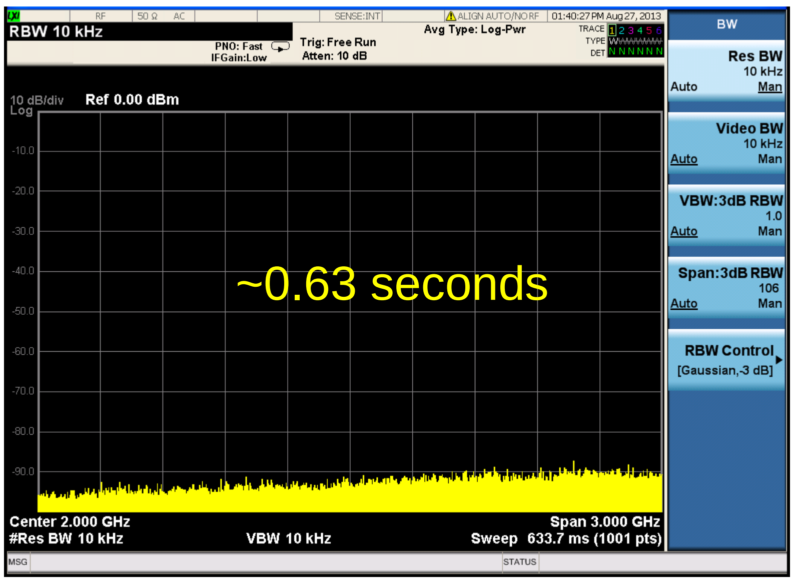
Features

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

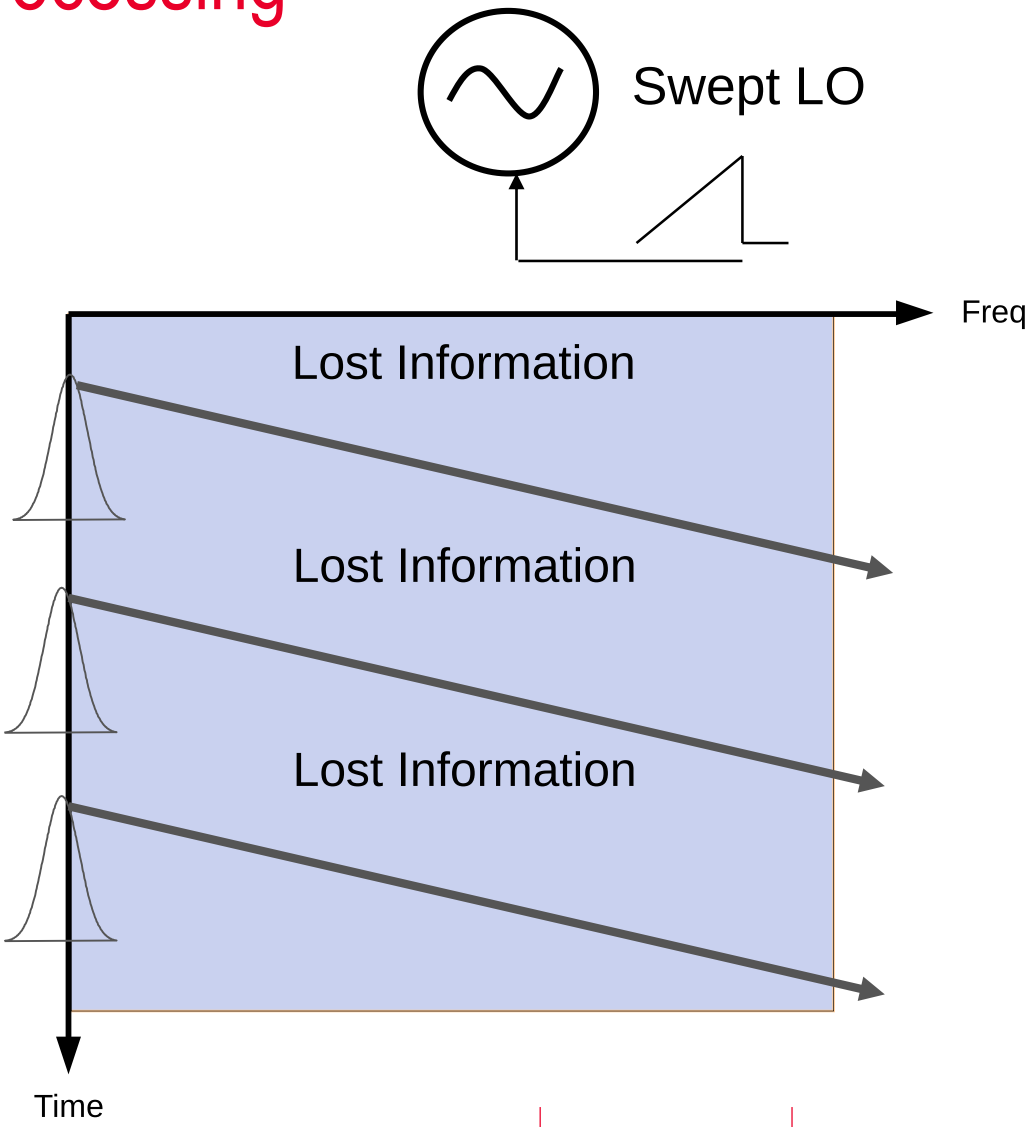


Sweep with fast sweep enabled

Data Acquisition and Processing

Swept Mode

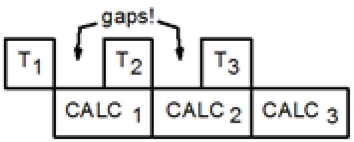
- A swept LO w/ an assigned RBW.
- Covers much wider span.
- Good for events that are stable in the frequency domain.
- Magnitude ONLY, no phase information (scalar info).
- Captures only events that occur at right time and right frequency point.
- Data (info) loss when LO is "not there".

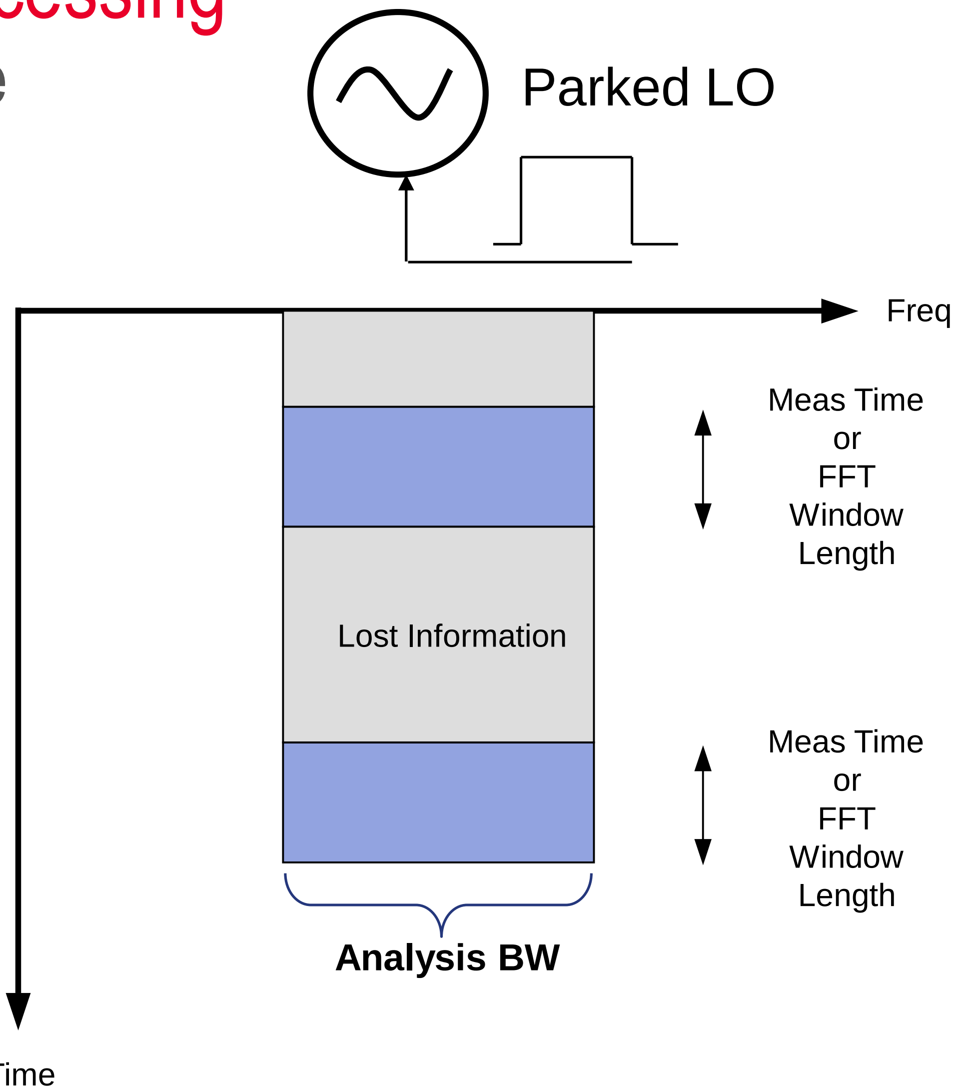


Data Acquisition and Processing

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.

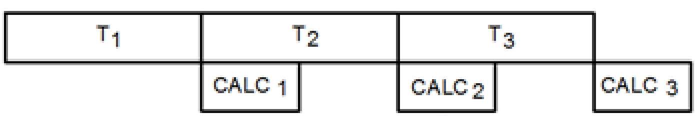




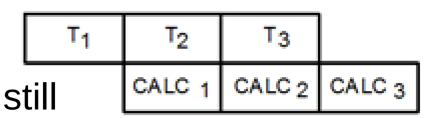
Data Acquisition and Processing

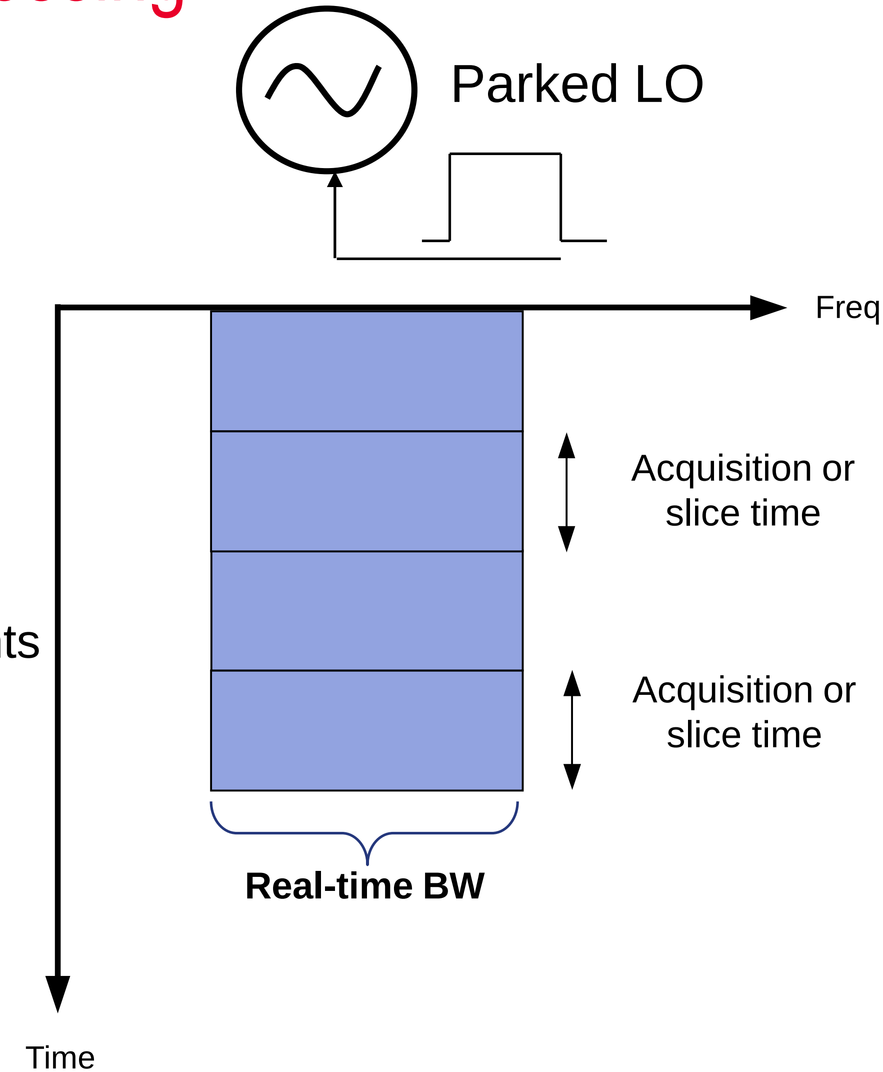
Real-Time Mode

- 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



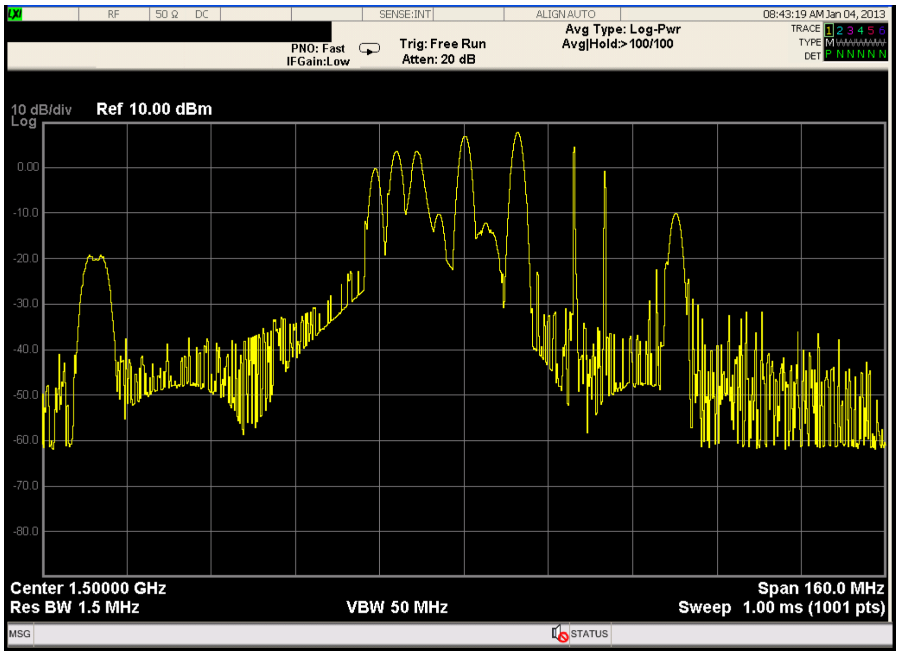
Real Time Processing
Some data may still be “lost”



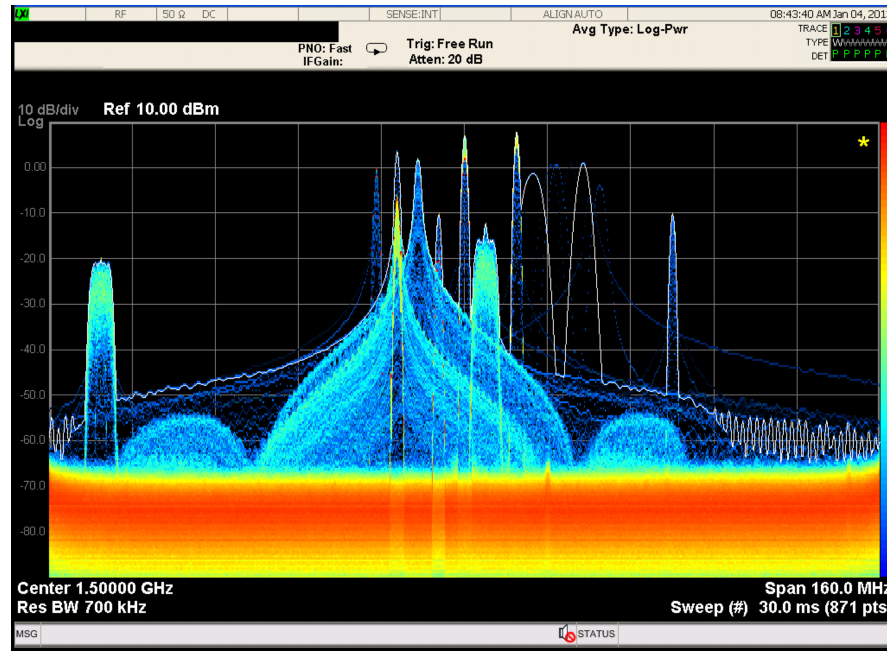


Real-Time Spectrum Analysis

Swept vs RTSA



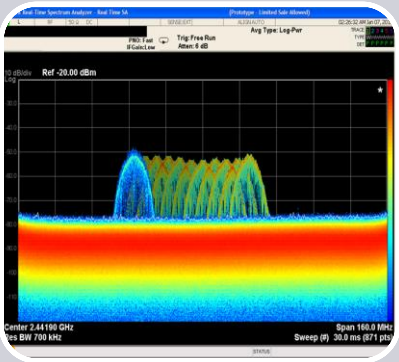
From this…

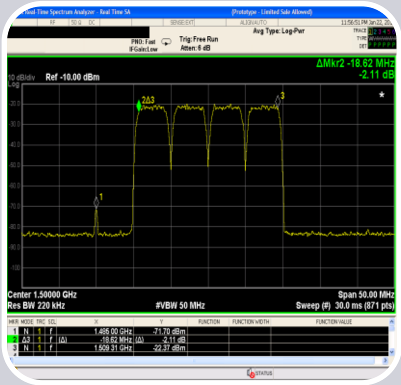


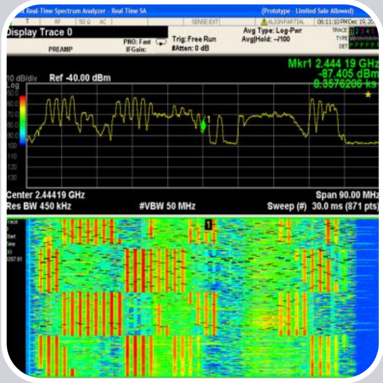
...to this

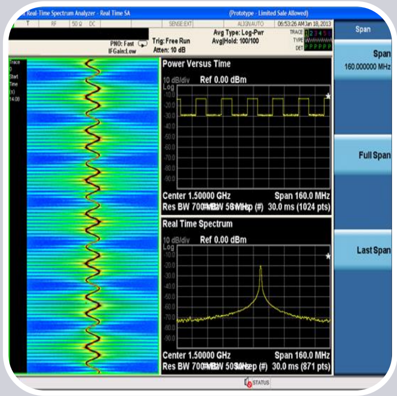
KEYSIGHT TECHNOLOGIES

Real-Time Displays









Density

- Also know 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

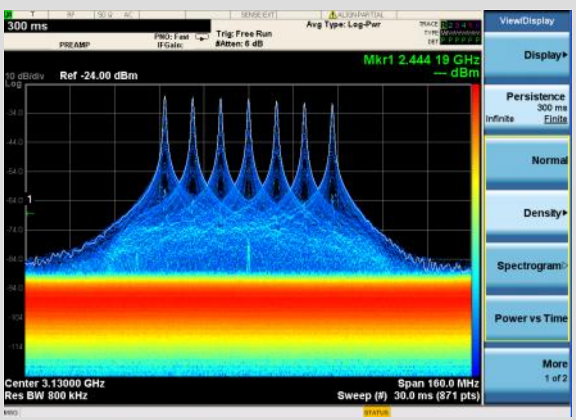
- PvT over configurable range
- Gapless time data transformed to frequency domain
- Different displays available
- Level based trigger available

KEYSIGHT TECHNOLOGIES

Real-Time Spectrum Analysis

Application: Detect Low Level Signals with Precision

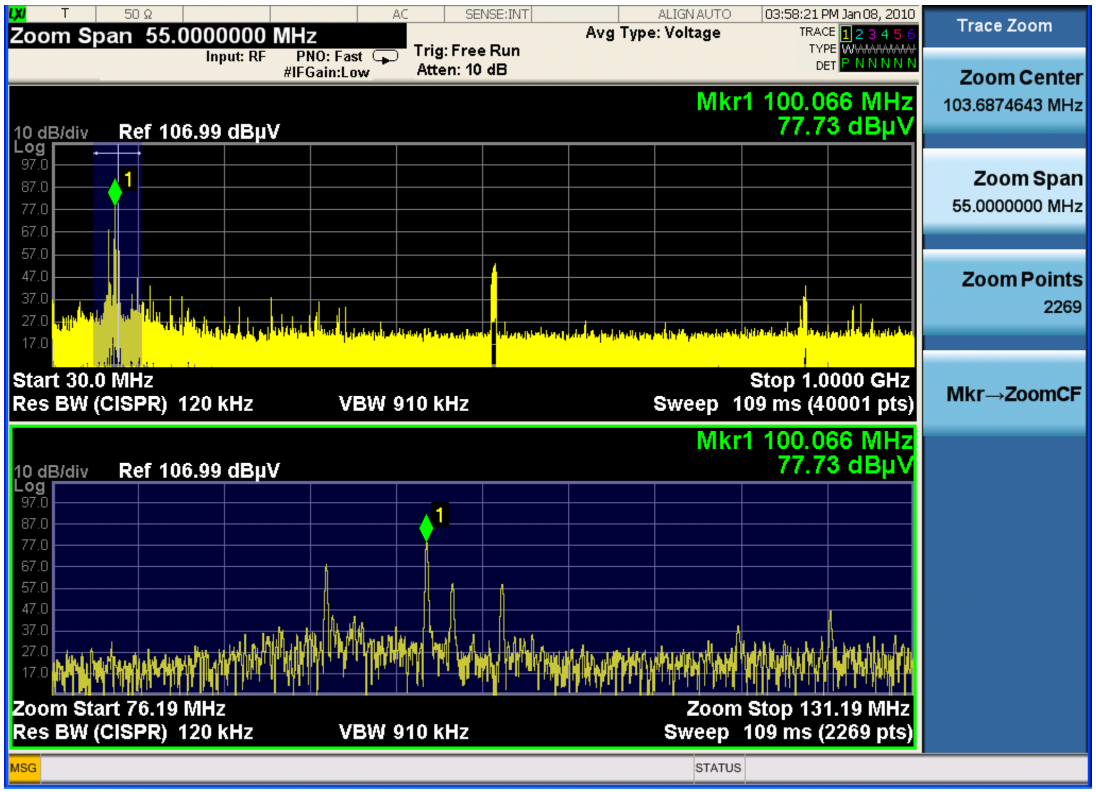
- Short burst comms, LPI radar systems make it very difficult to analyze jamming & interference
- Communication jamming needs to be done very quickly for adaptive threats



- 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

KEYSIGHT TECHNOLOGIES

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 3rd order distortion for 4 carrier pre-distortion algorithms

Additional Resources

- Keysight RF Learning Center 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