Radiofrequency Measurements

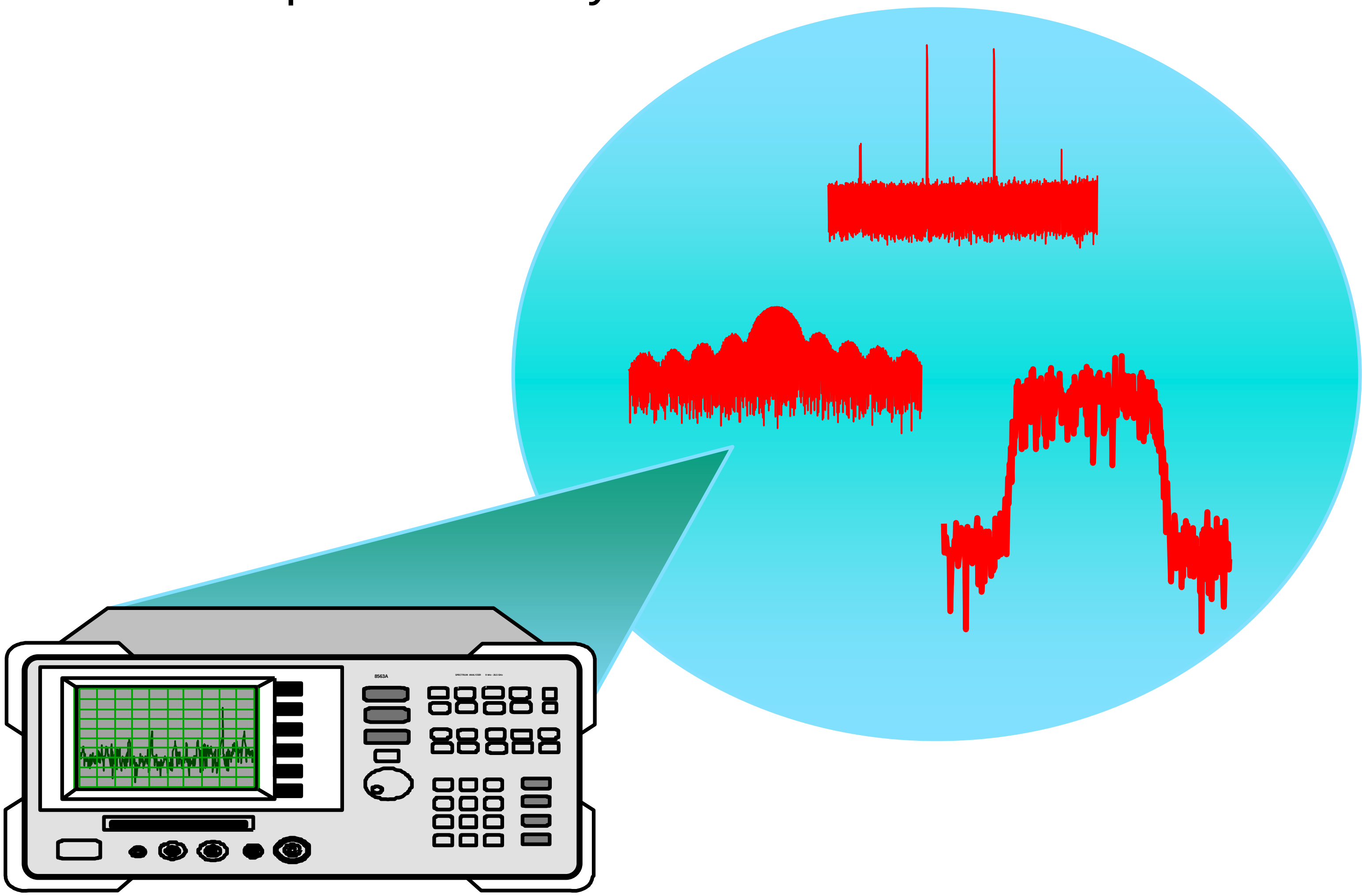
Spectrum Analyzers

The next slides material is taken from

- AGILENT “**Spectrum Analysis Basics”**
- TEKTRONIX’ “**Fundamentals of Real-Time Spectrum Analysis**”
- ROHDE&SCHWARZ “**Key points of real time**”

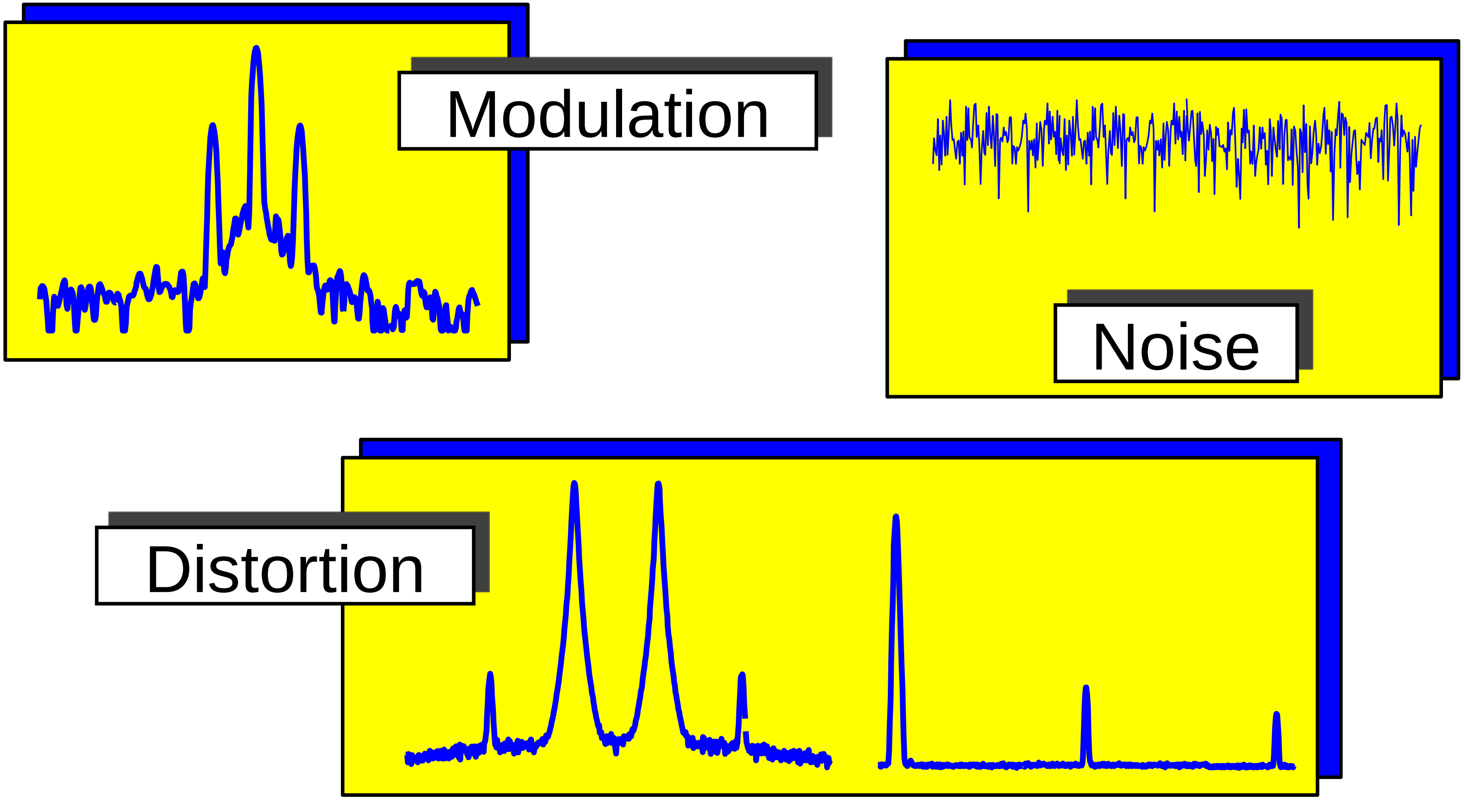
Overview

What is Spectrum Analysis?



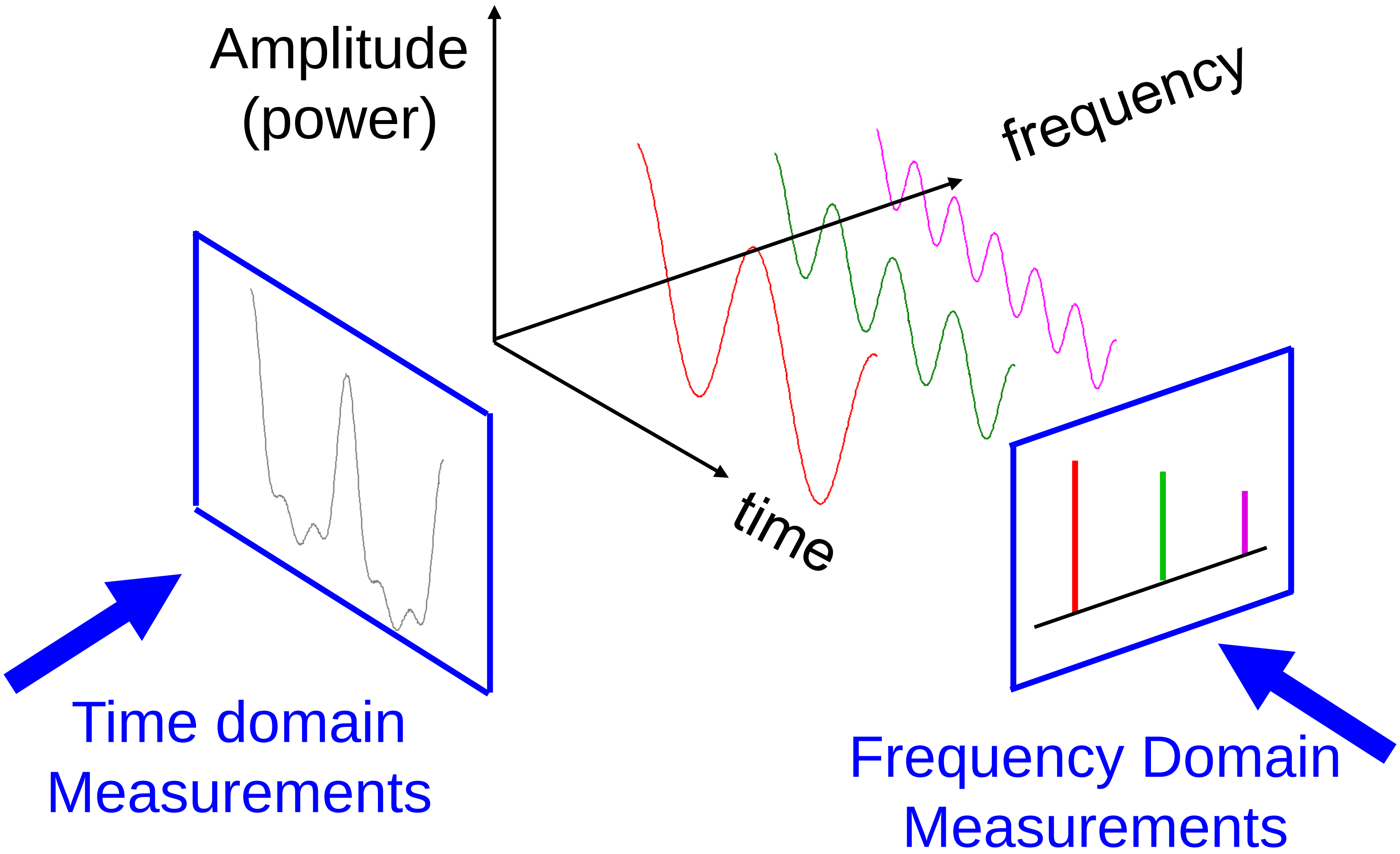
Overview

Types of Tests Made



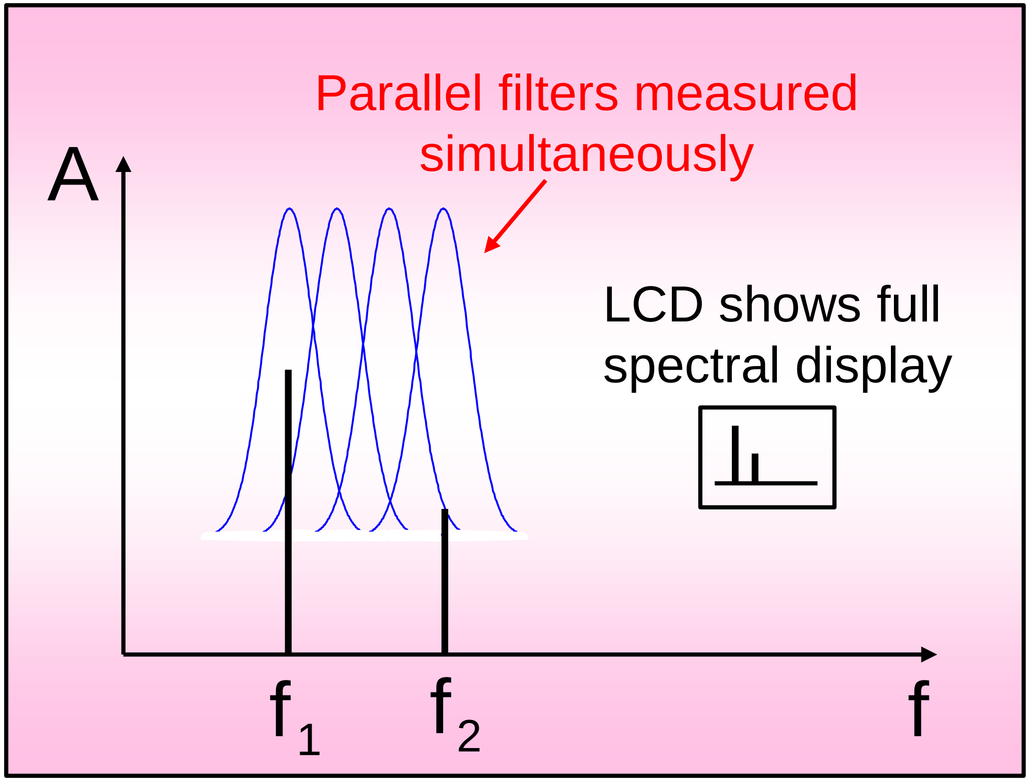
Overview

Frequency versus Time Domain



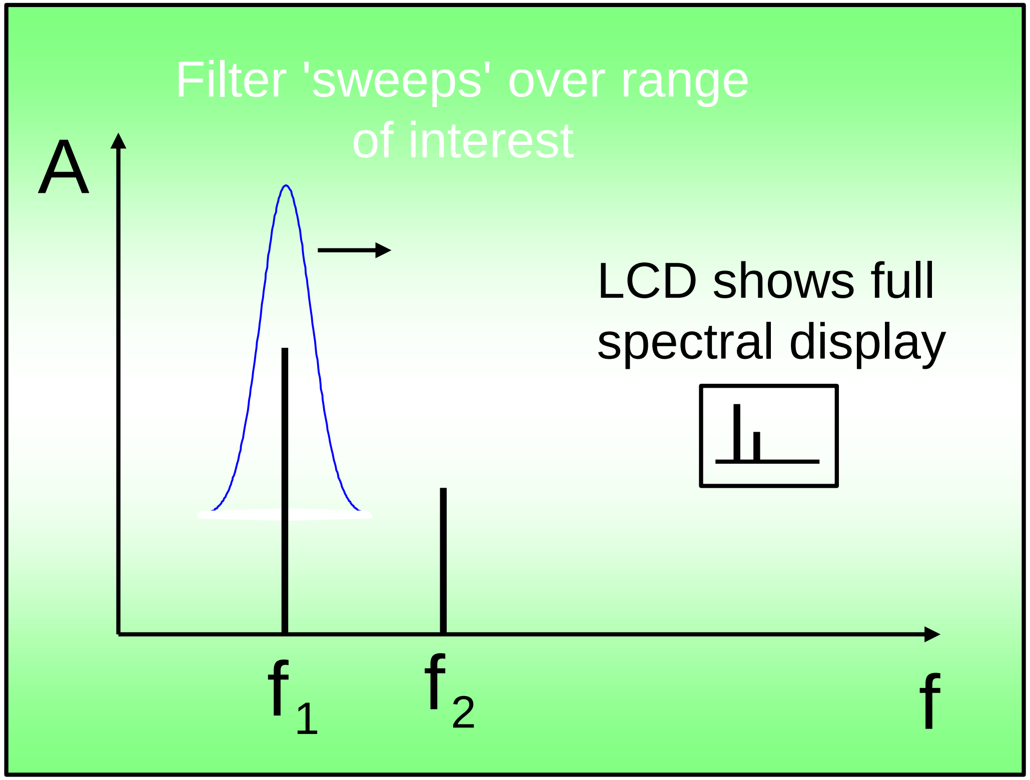
Overview

Different Types of Analyzers

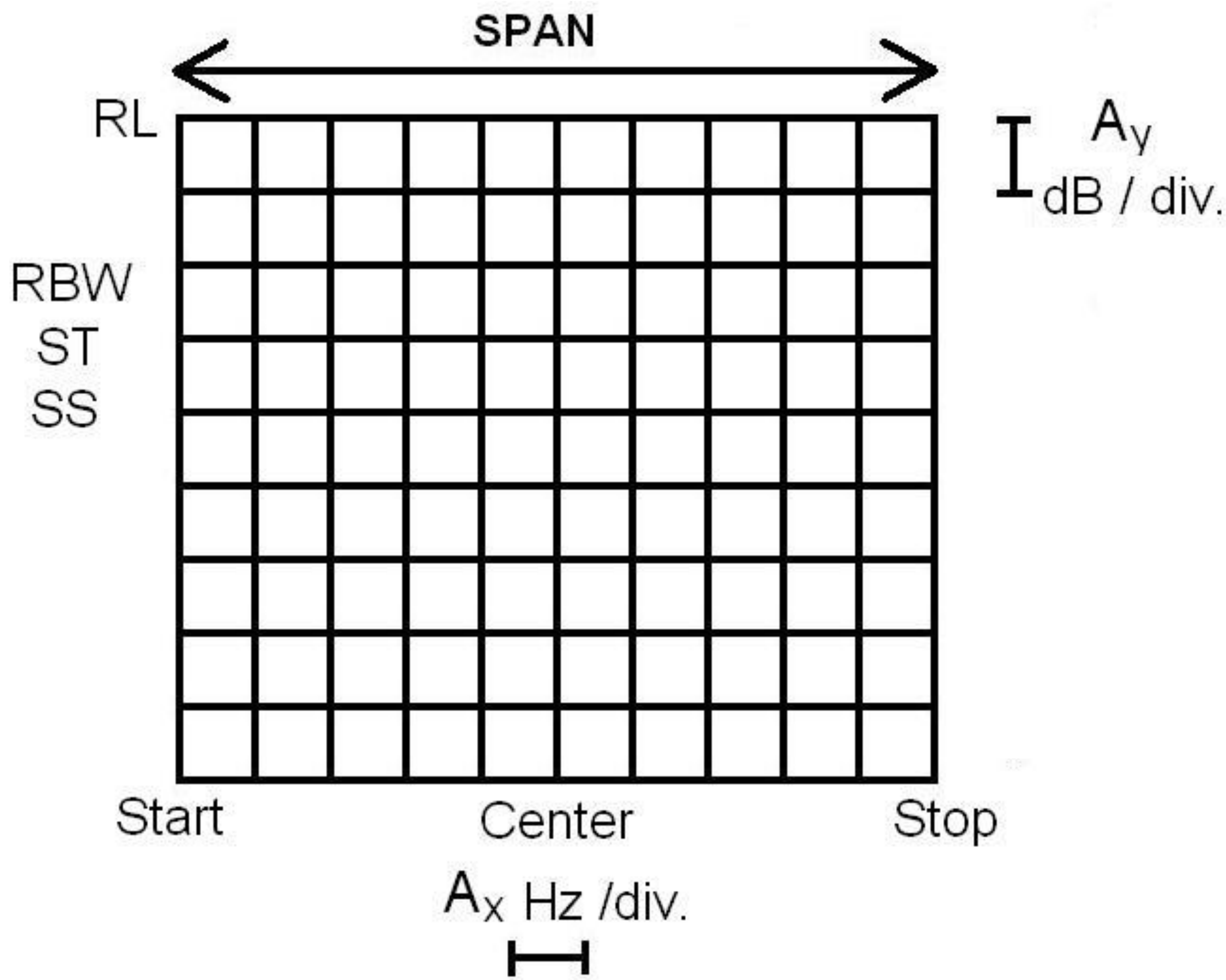


Overview

Different Types of Analyzers

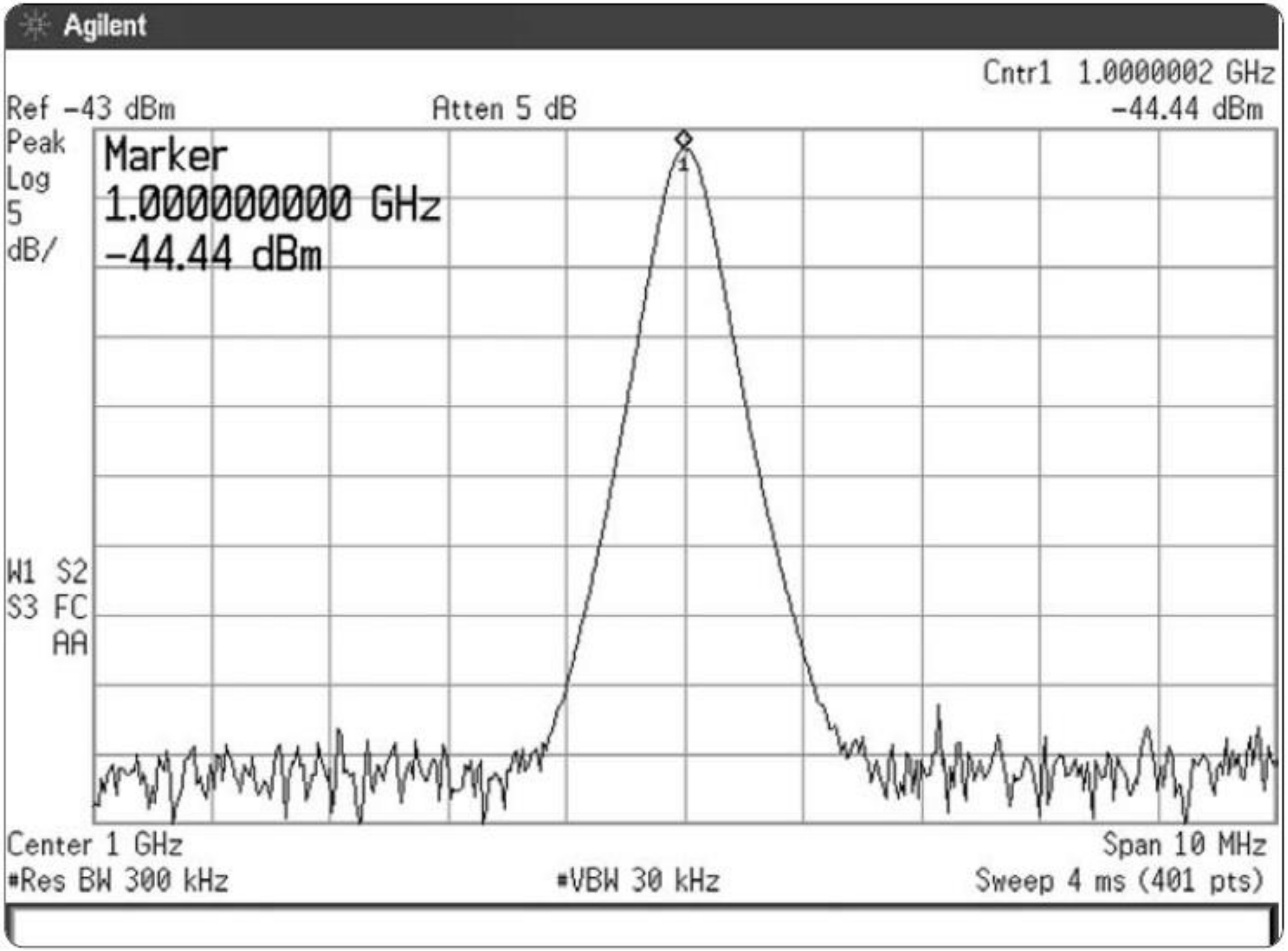


Screen Parameters



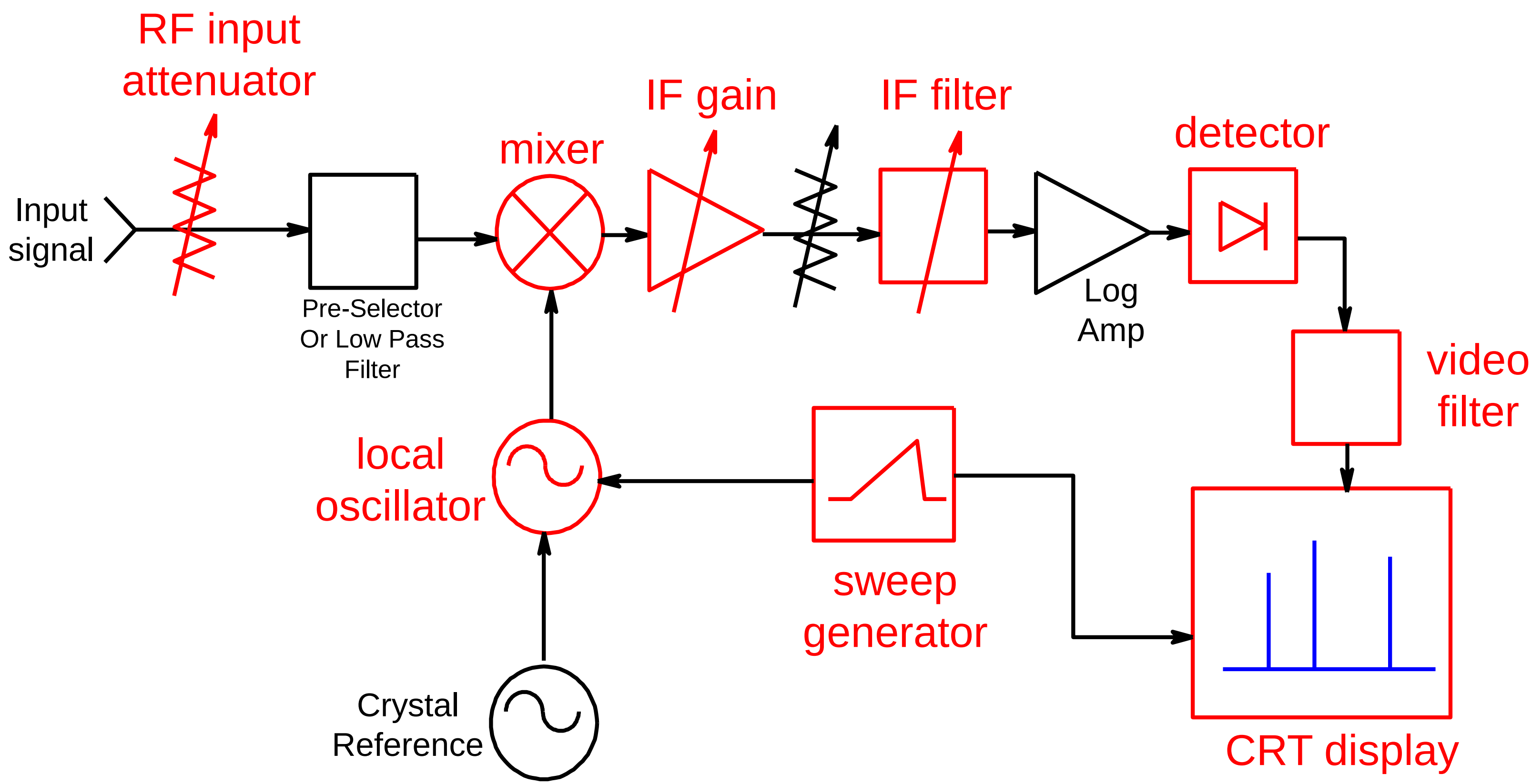
10 DIV vertical: POWER [dBm]
10 DIV horizontal: FREQUENCY [Hz]

Instrument Screen



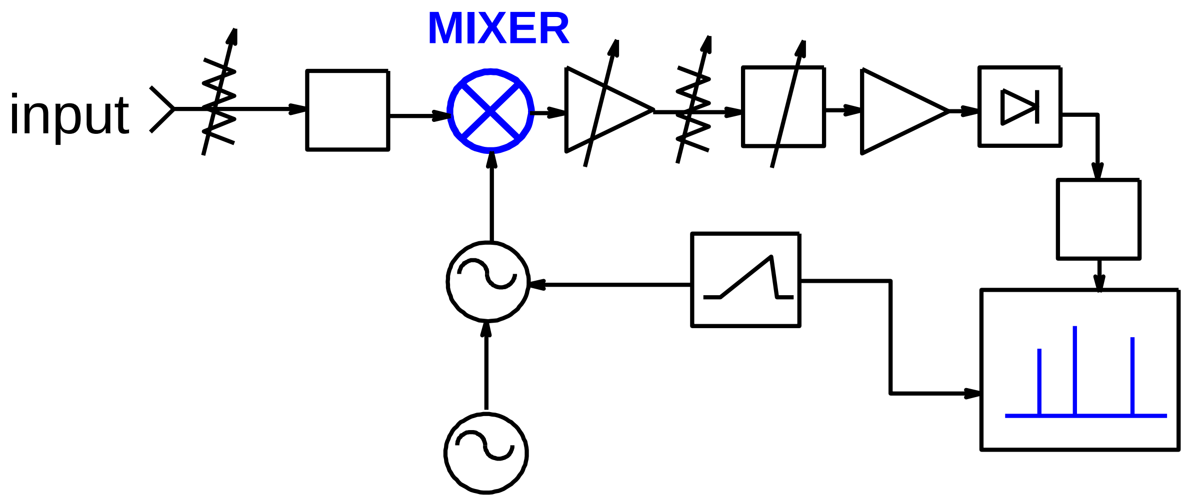
Theory of Operation

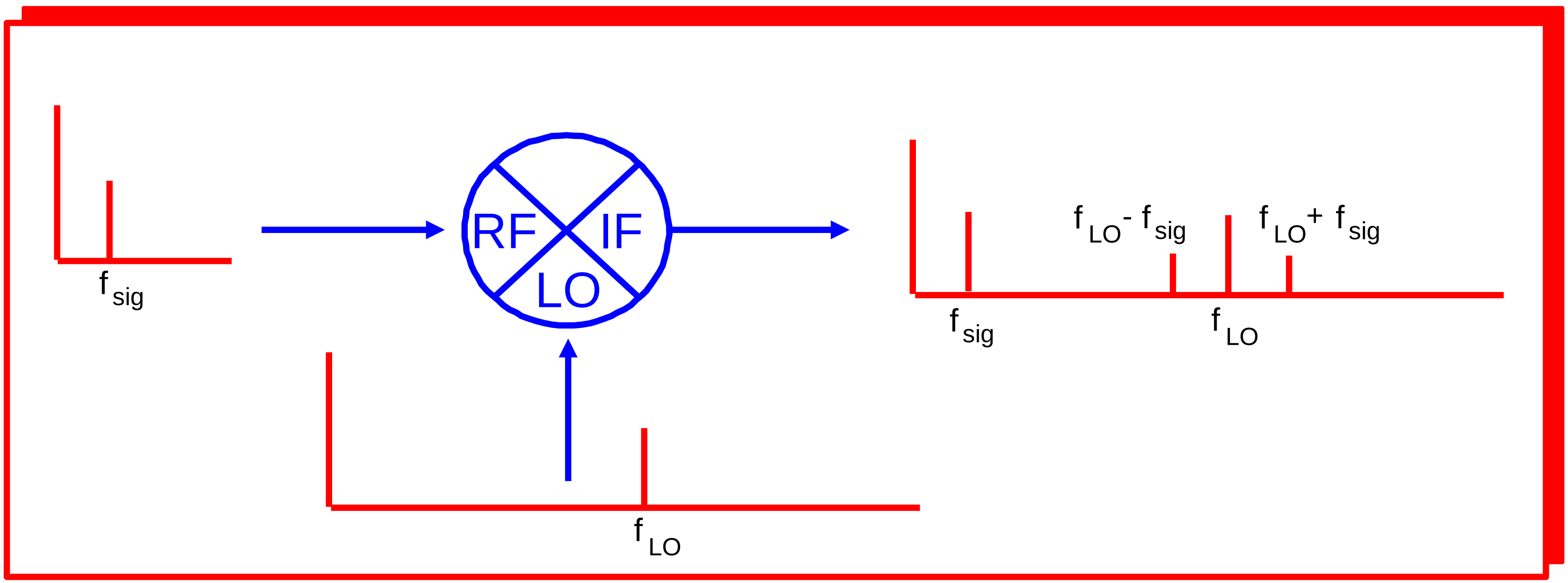
Spectrum Analyzer Block Diagram



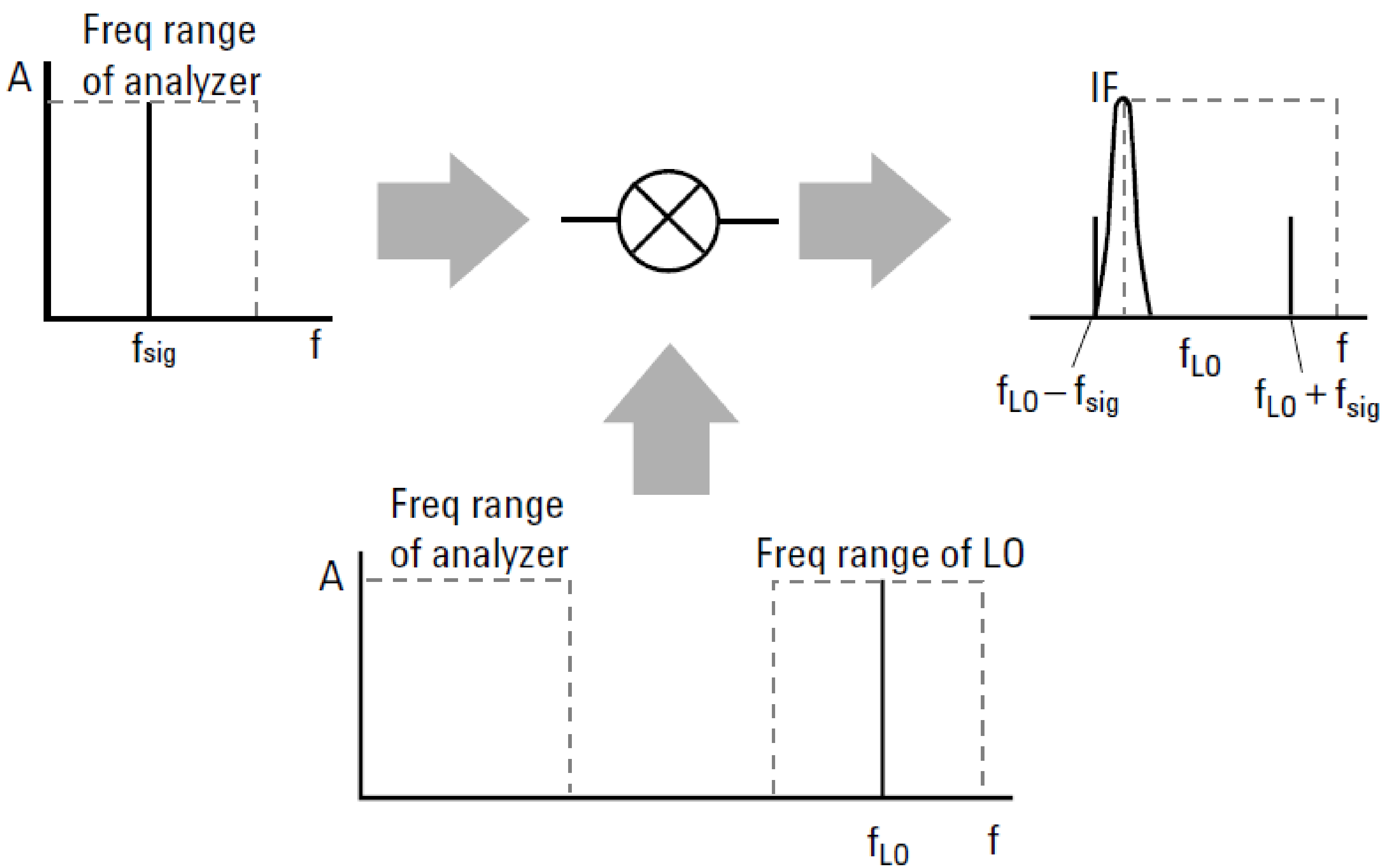
Theory of Operation

Mixer



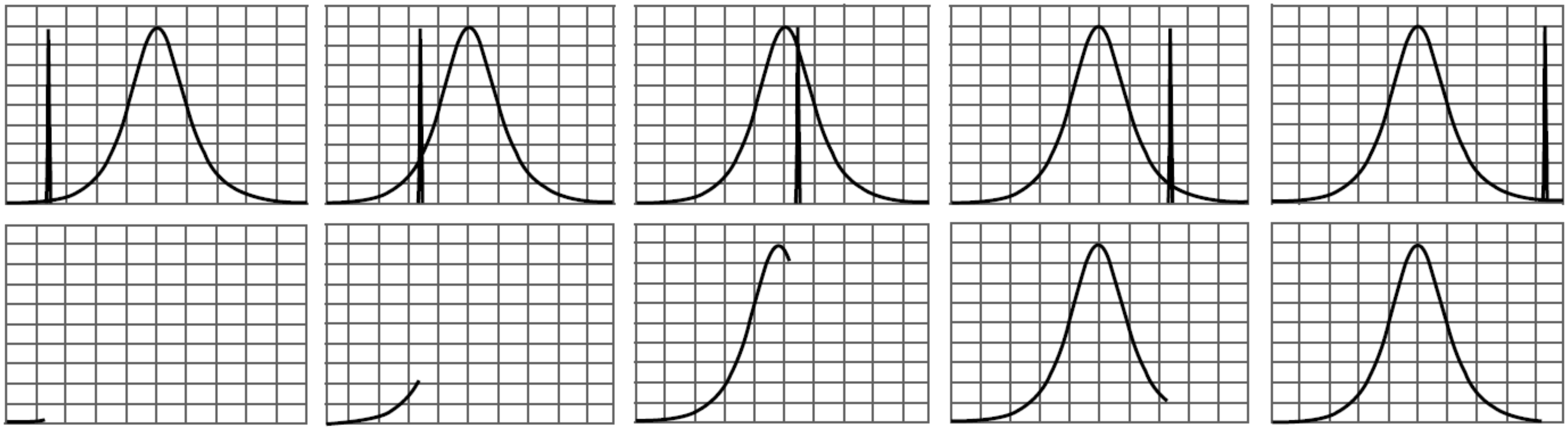


Frequency Scan



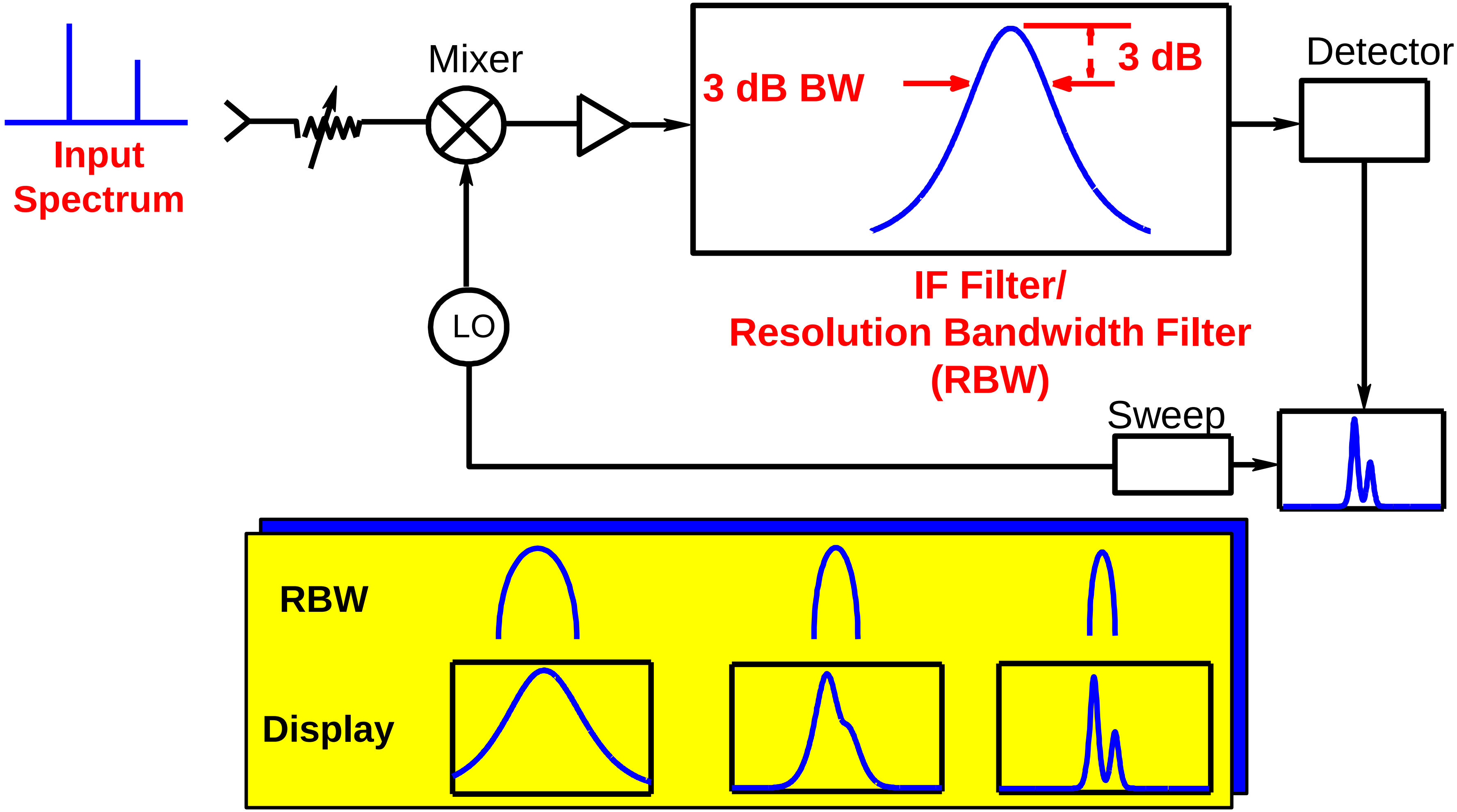
Signal measurement

When a narrowband signal runs beneath the filter, the measured spectrum draws the filter shape (it is a mathematical convolution)



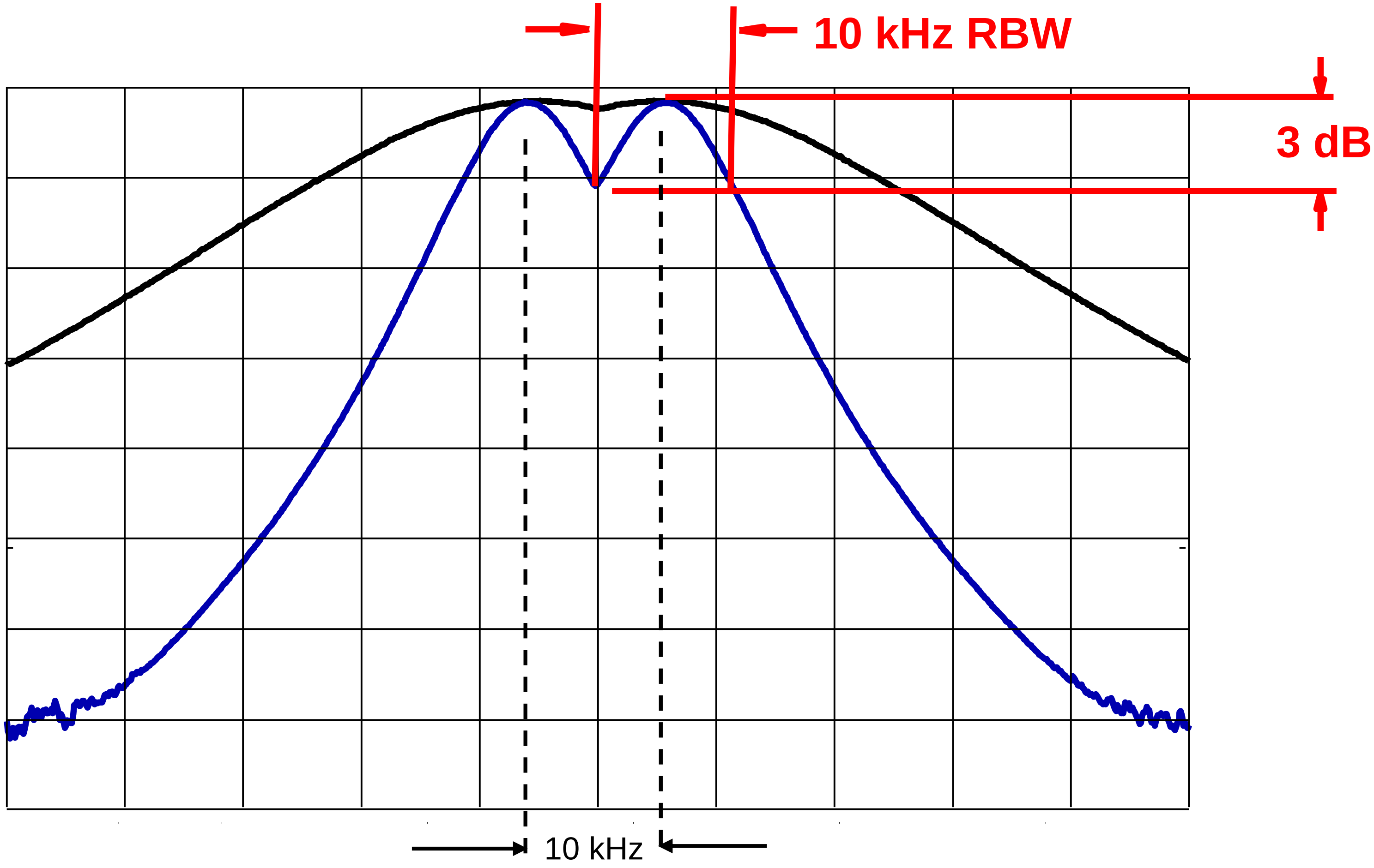
Specifications

Resolution: Resolution Bandwidth



Specifications

Resolution: Resolution Bandwidth



Screen example

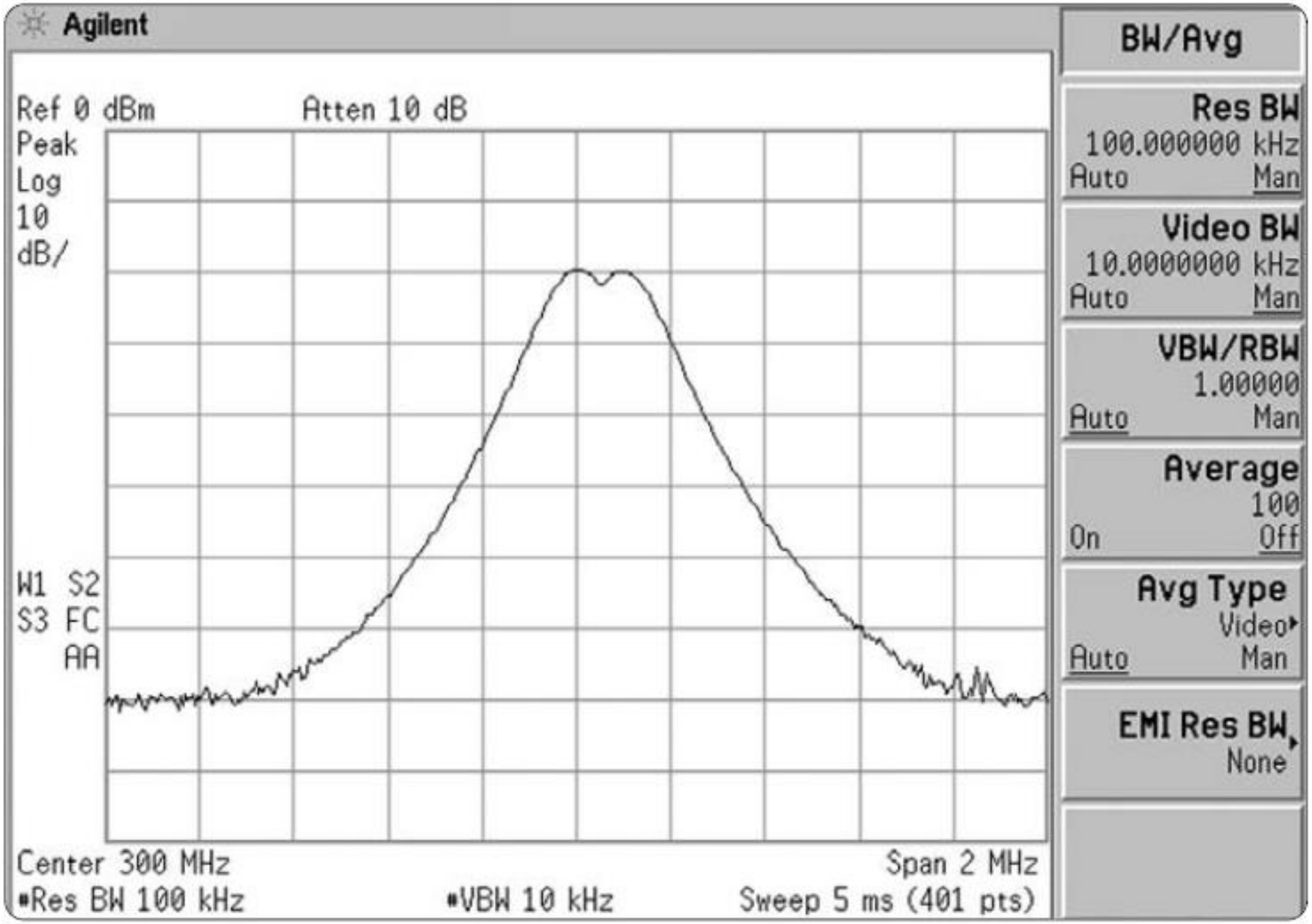


Figure 2-7. Two equal-amplitude sinusoids separated by the 3 dB BW of the selected IF filter can be resolved

Screen example

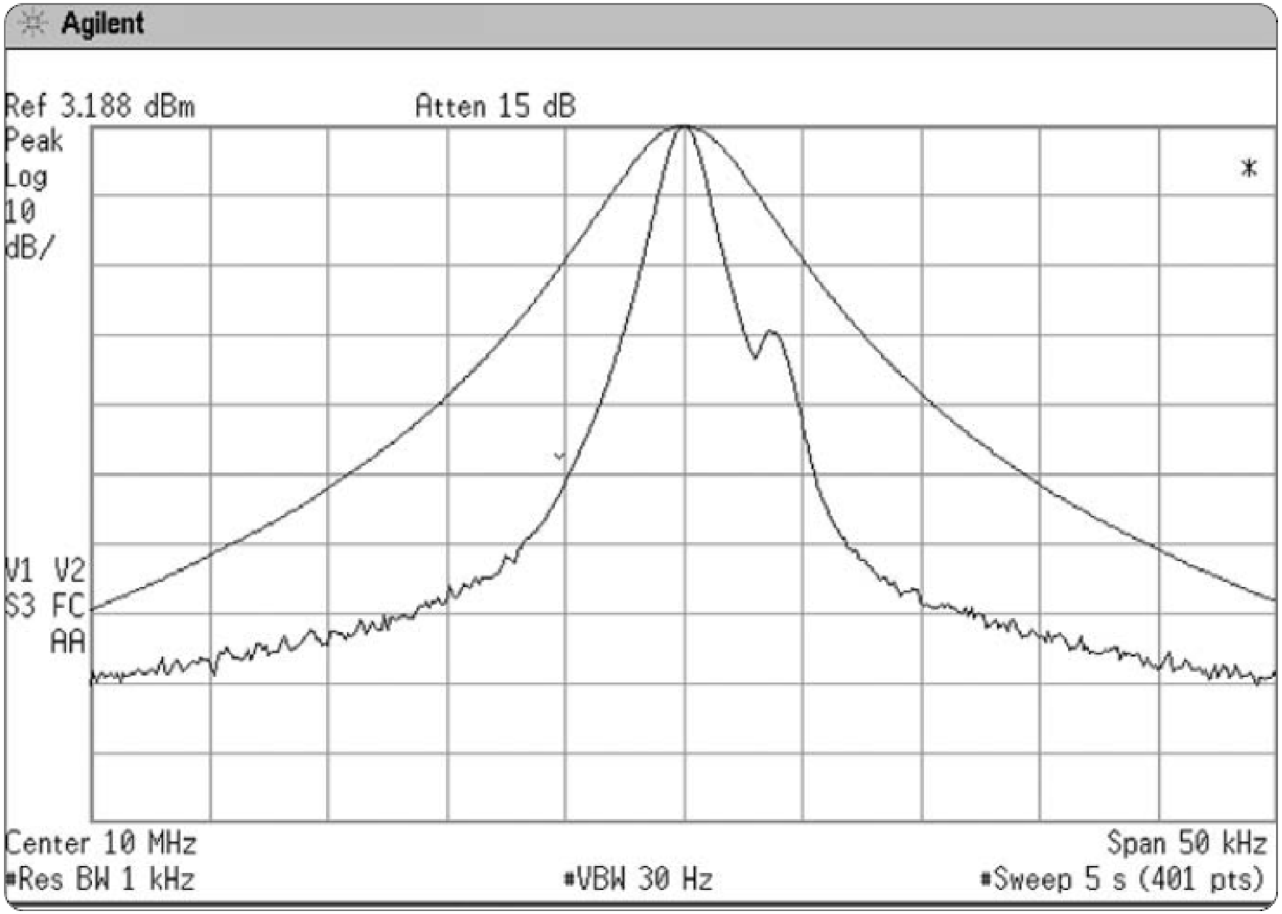
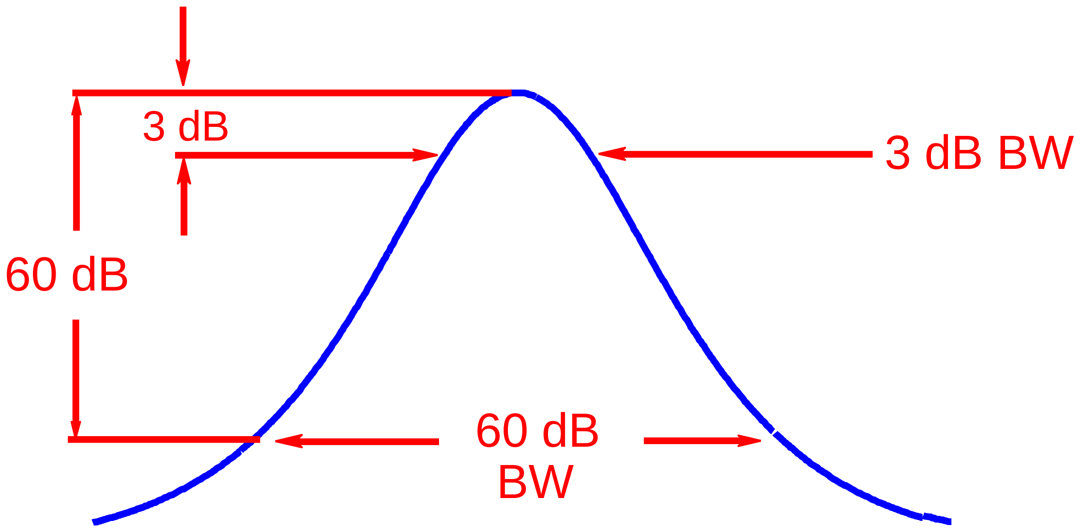


Figure 2-10. The 3 kHz filter (top trace) does not resolve smaller signal; reducing the resolution bandwidth to 1 kHz (bottom trace) does

Specifications

Resolution: RBW Type and Selectivity



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

Filter Selectivity

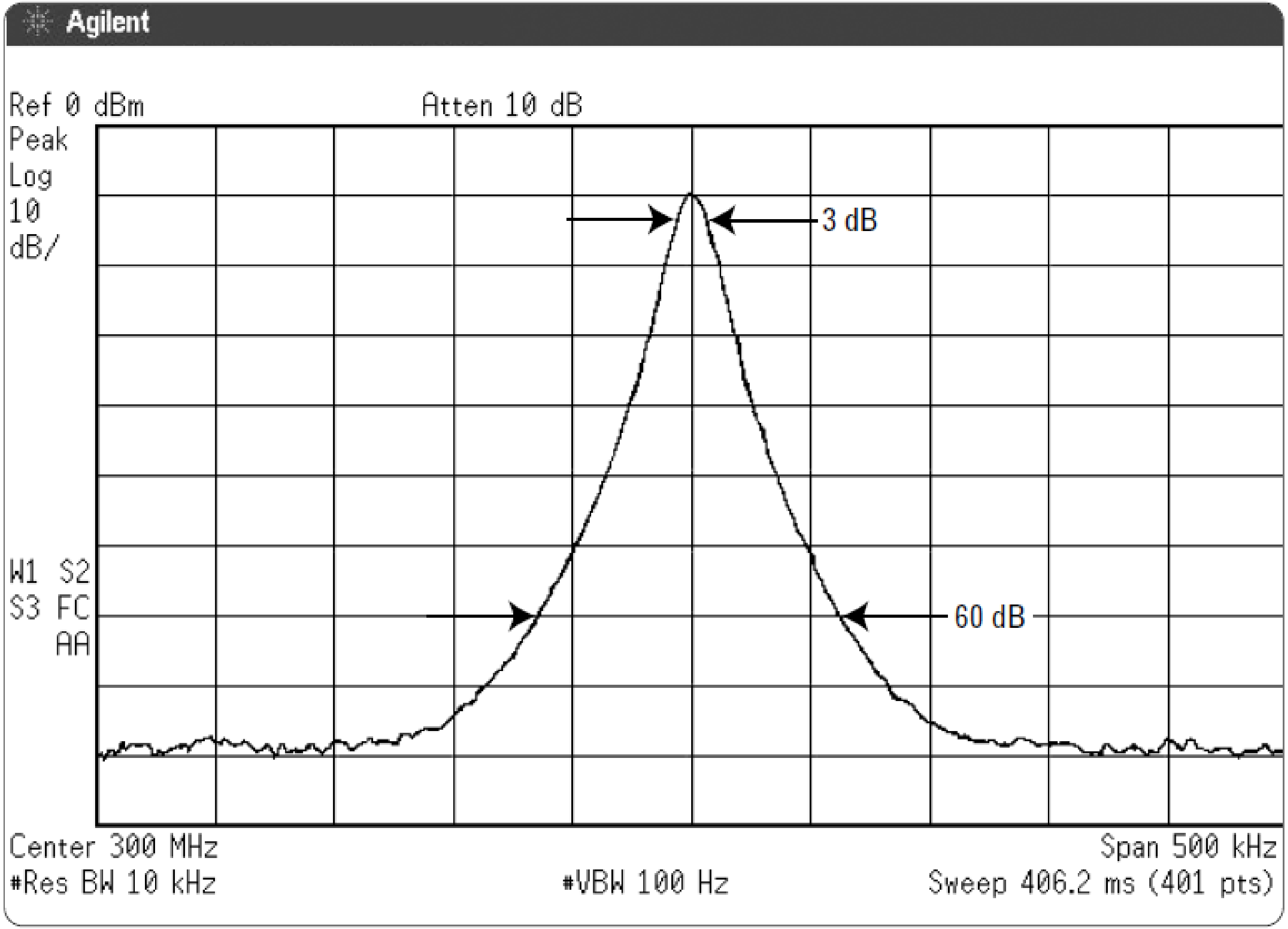
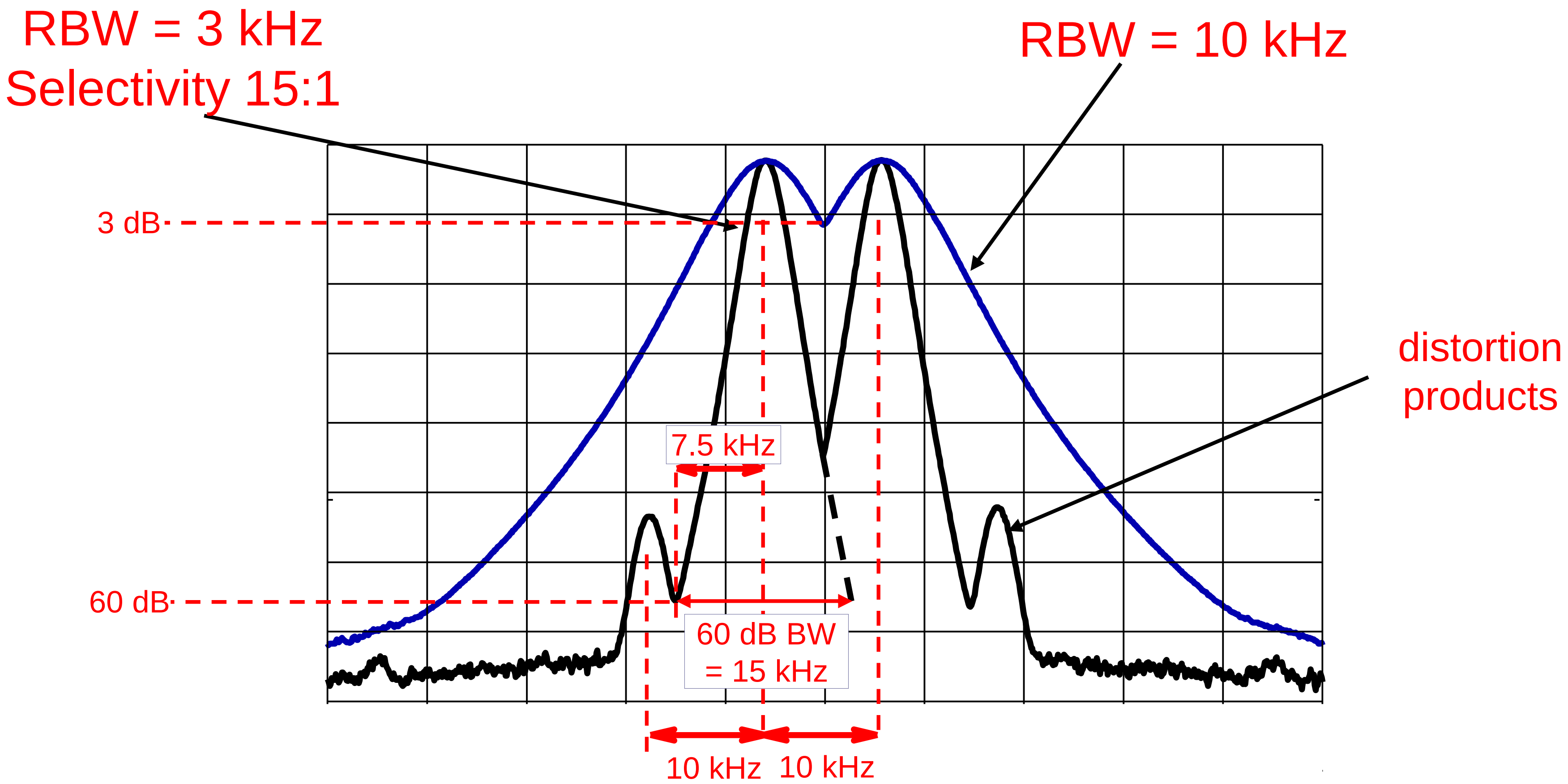


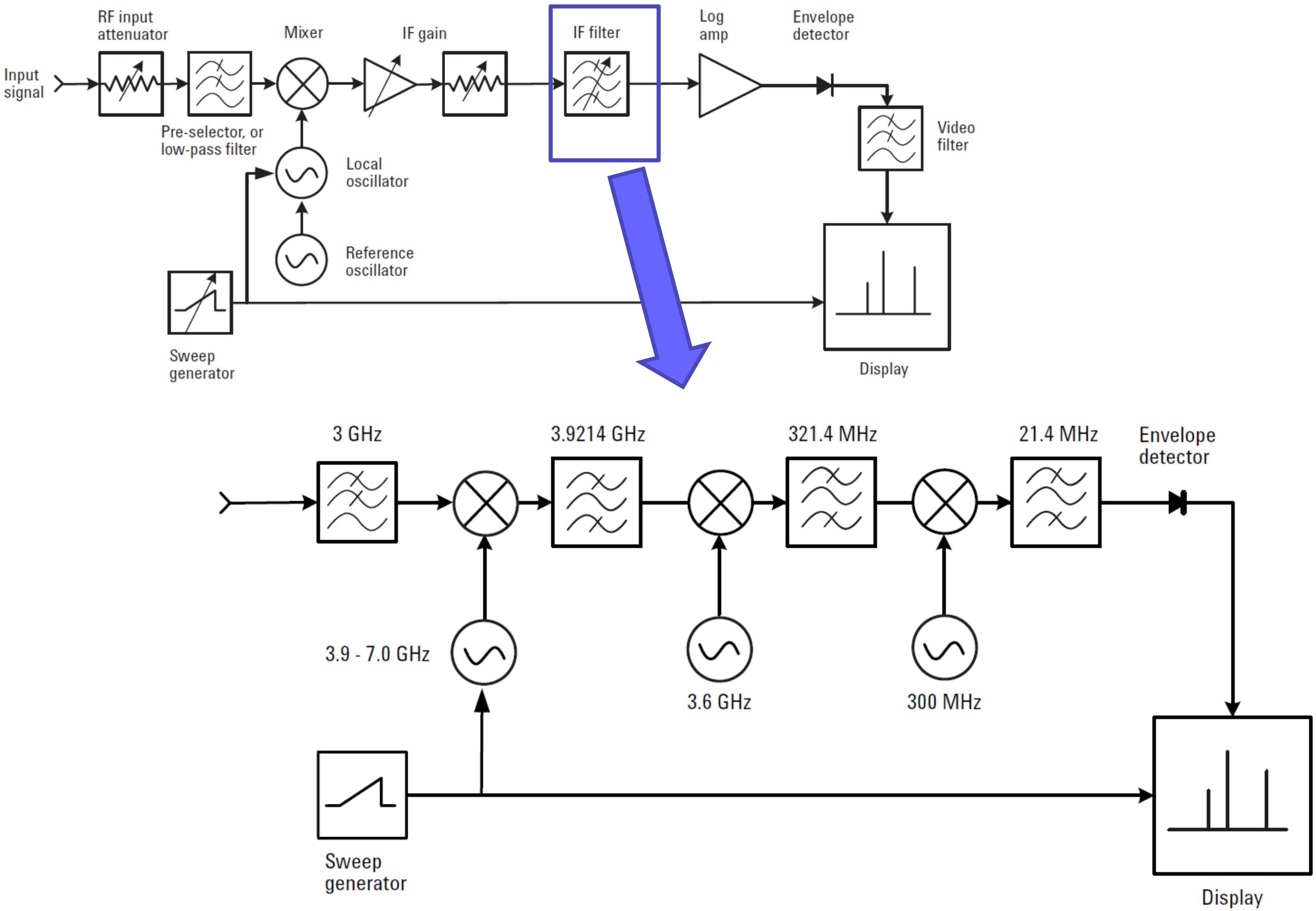
Figure 2-9. Bandwidth selectivity, ratio of 60 dB to 3 dB bandwidths

Specifications

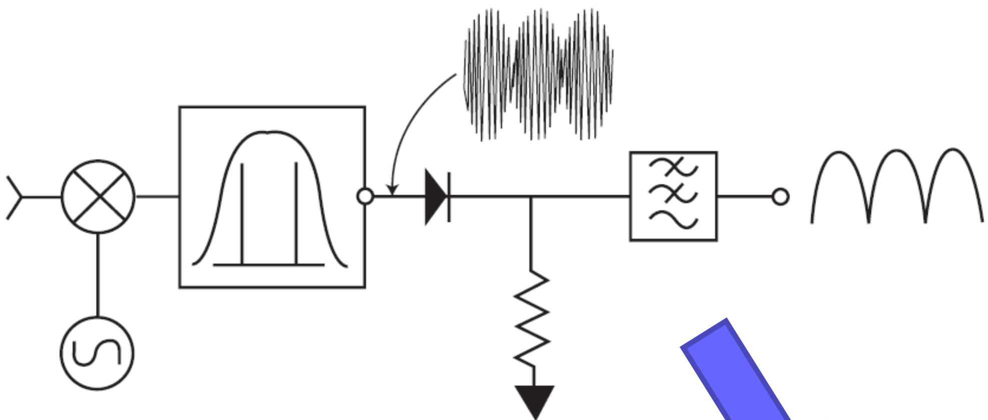
Resolution: RBW Type and Selectivity

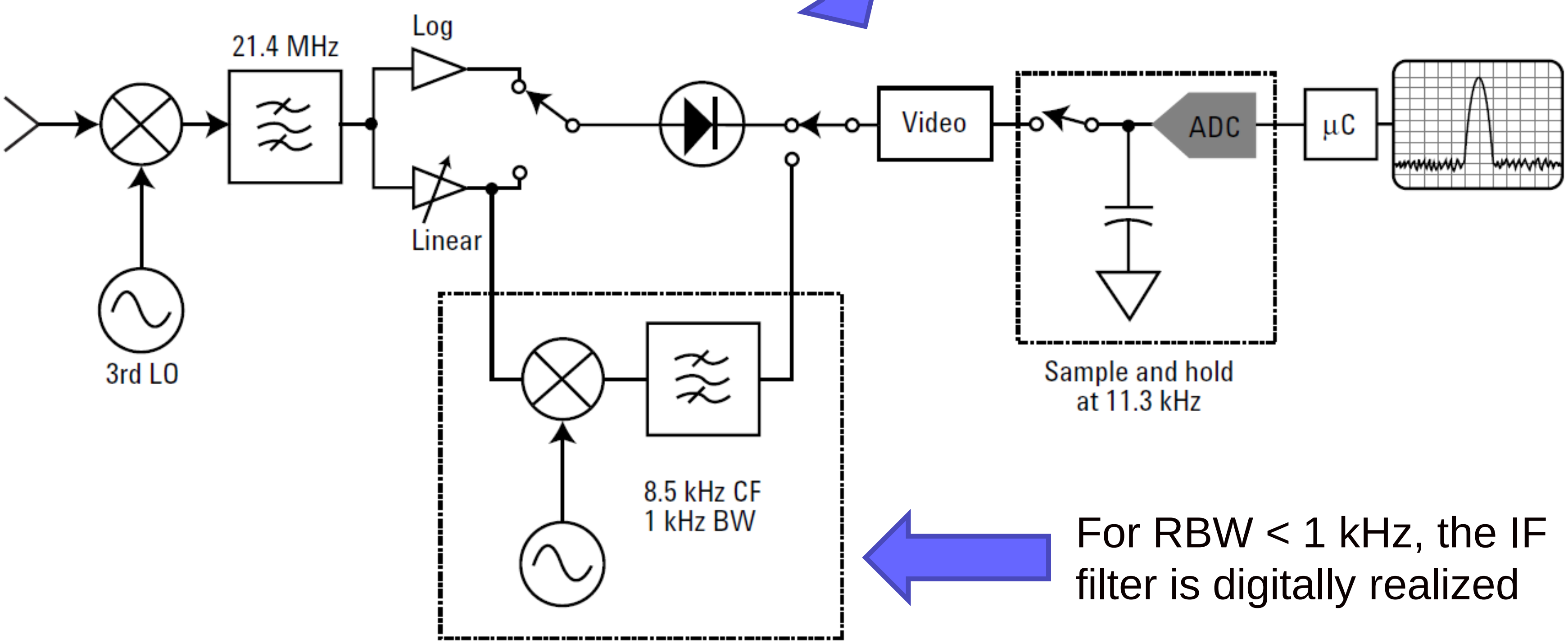


Super-heterodyne detection



Detector – from Analog to Digital

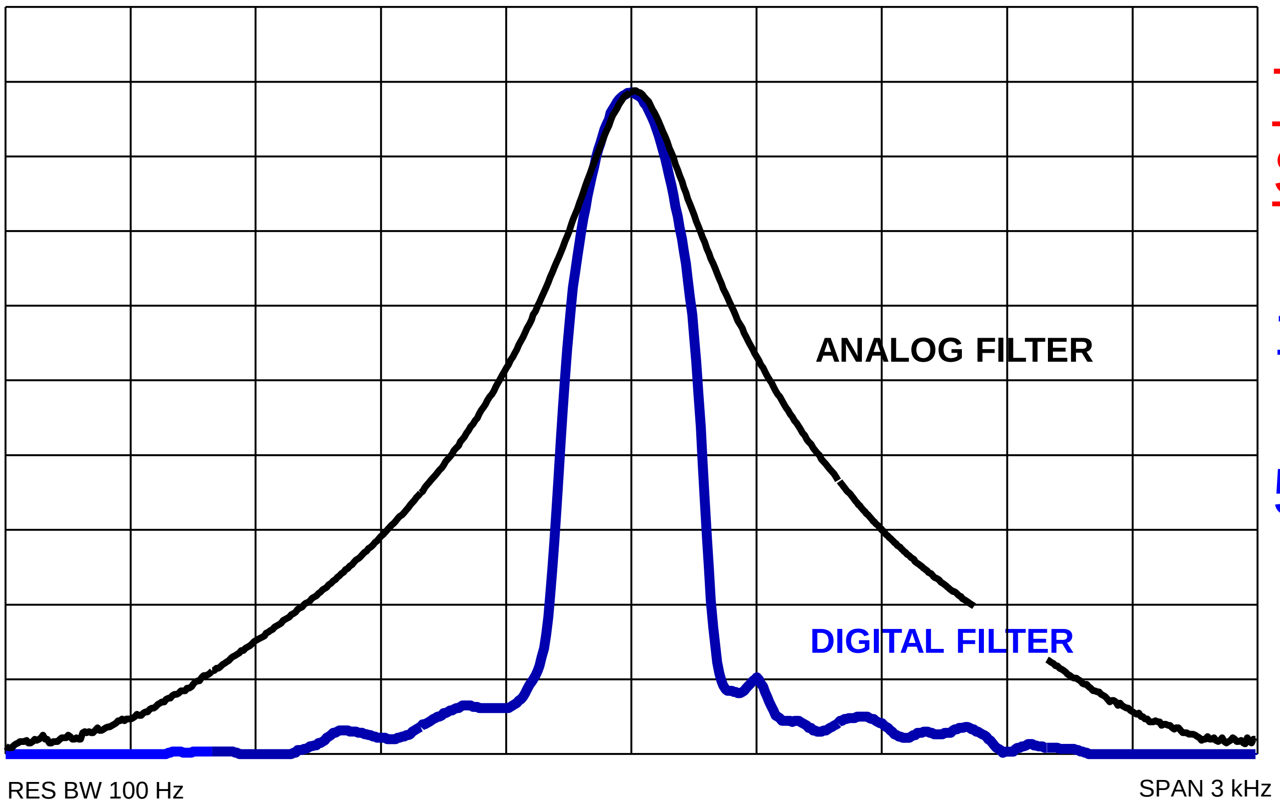




For RBW < 1 kHz, the IF filter is digitally realized

Specifications

Resolution: Digital Resolution Bandwidths



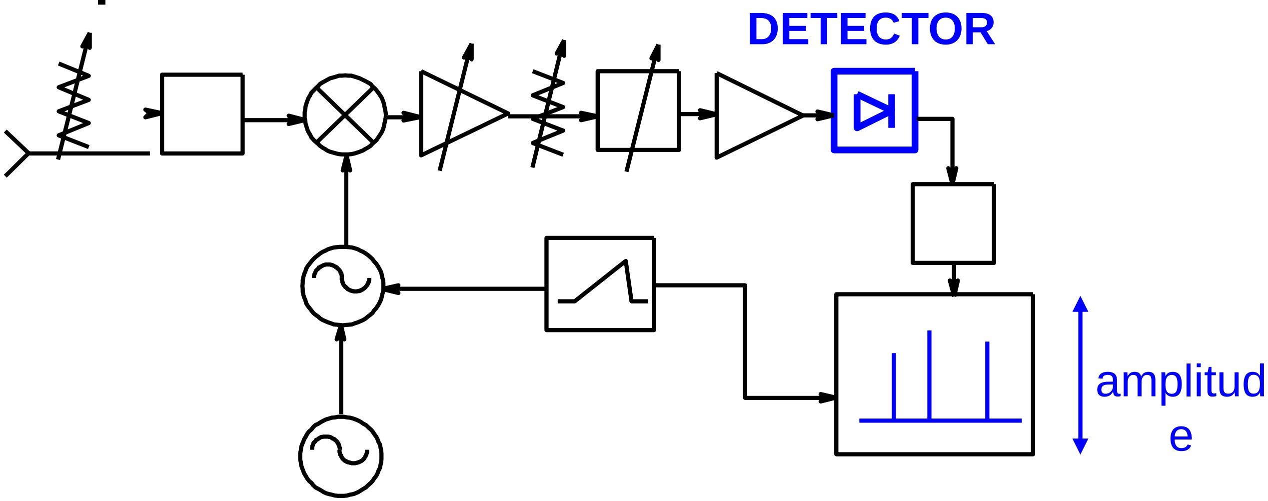
Typical Selectivity

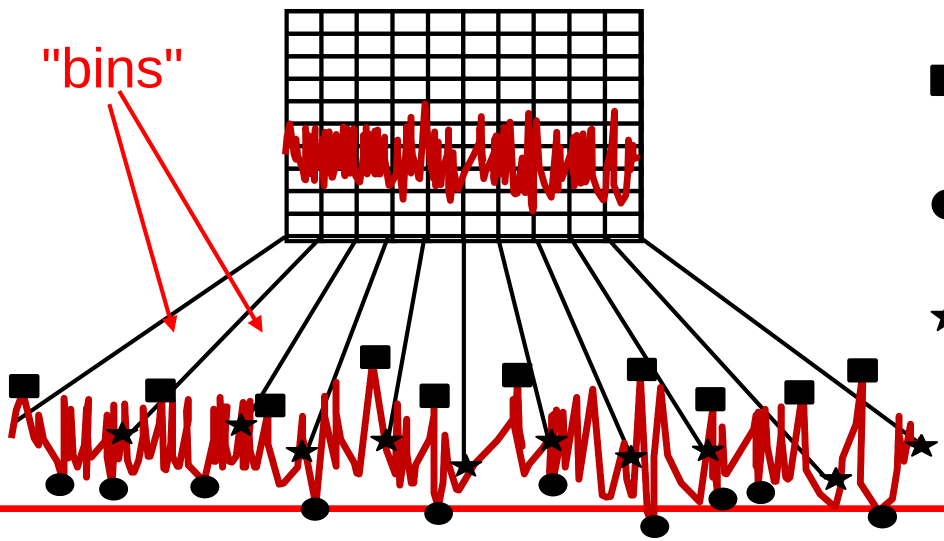
Analog 15:1

Digital 5:1

Theory of Operation

Detector





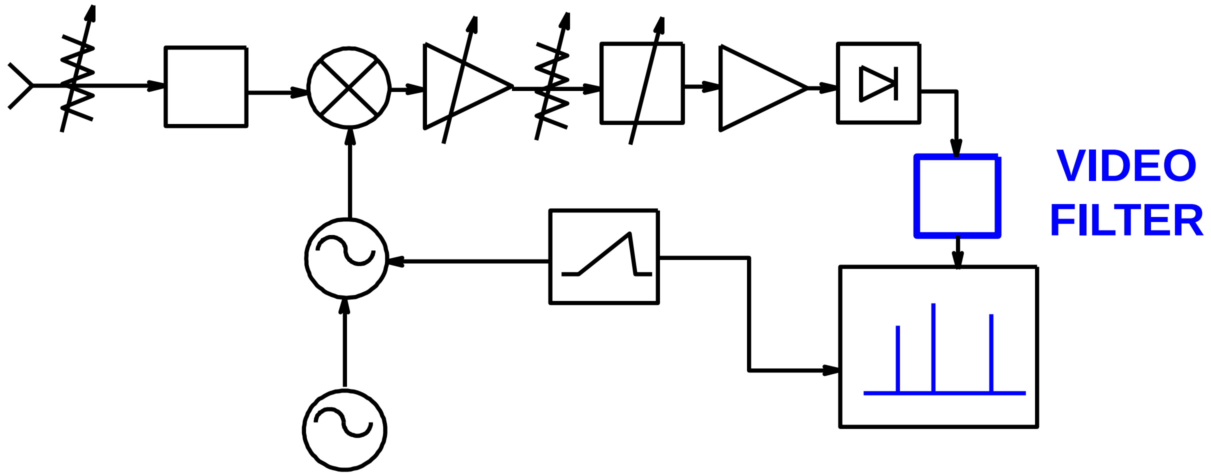
■ Positive detection: largest value in bin displayed

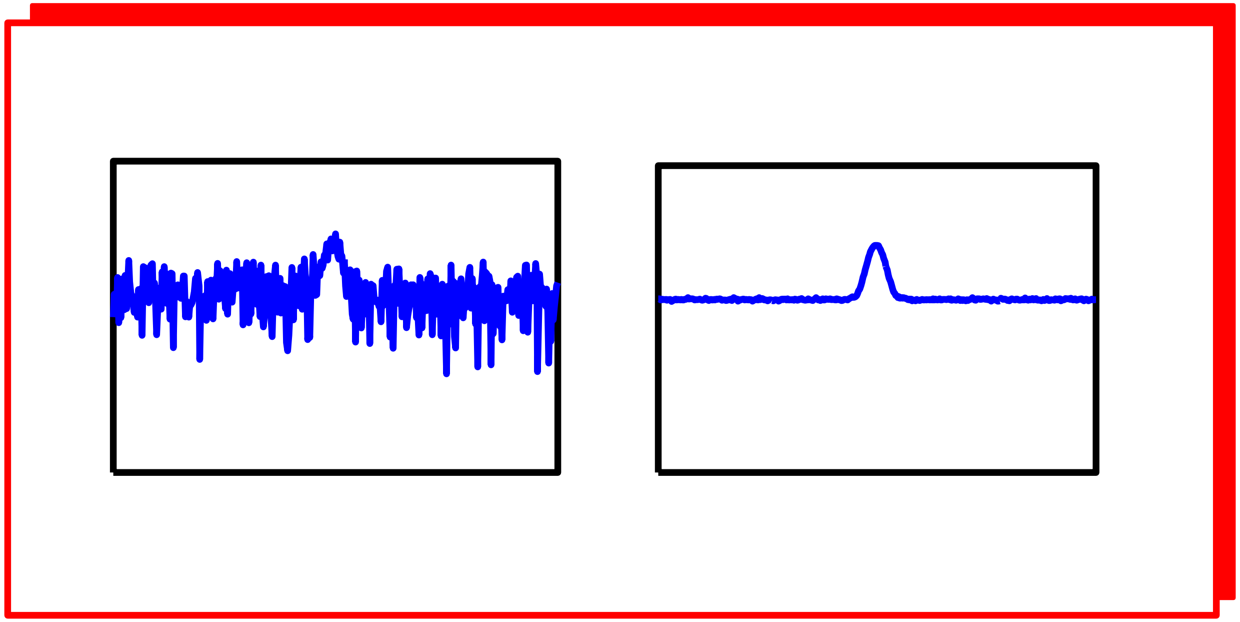
● Negative detection: smallest value in bin displayed

★ Sample detection: last value in bin displayed

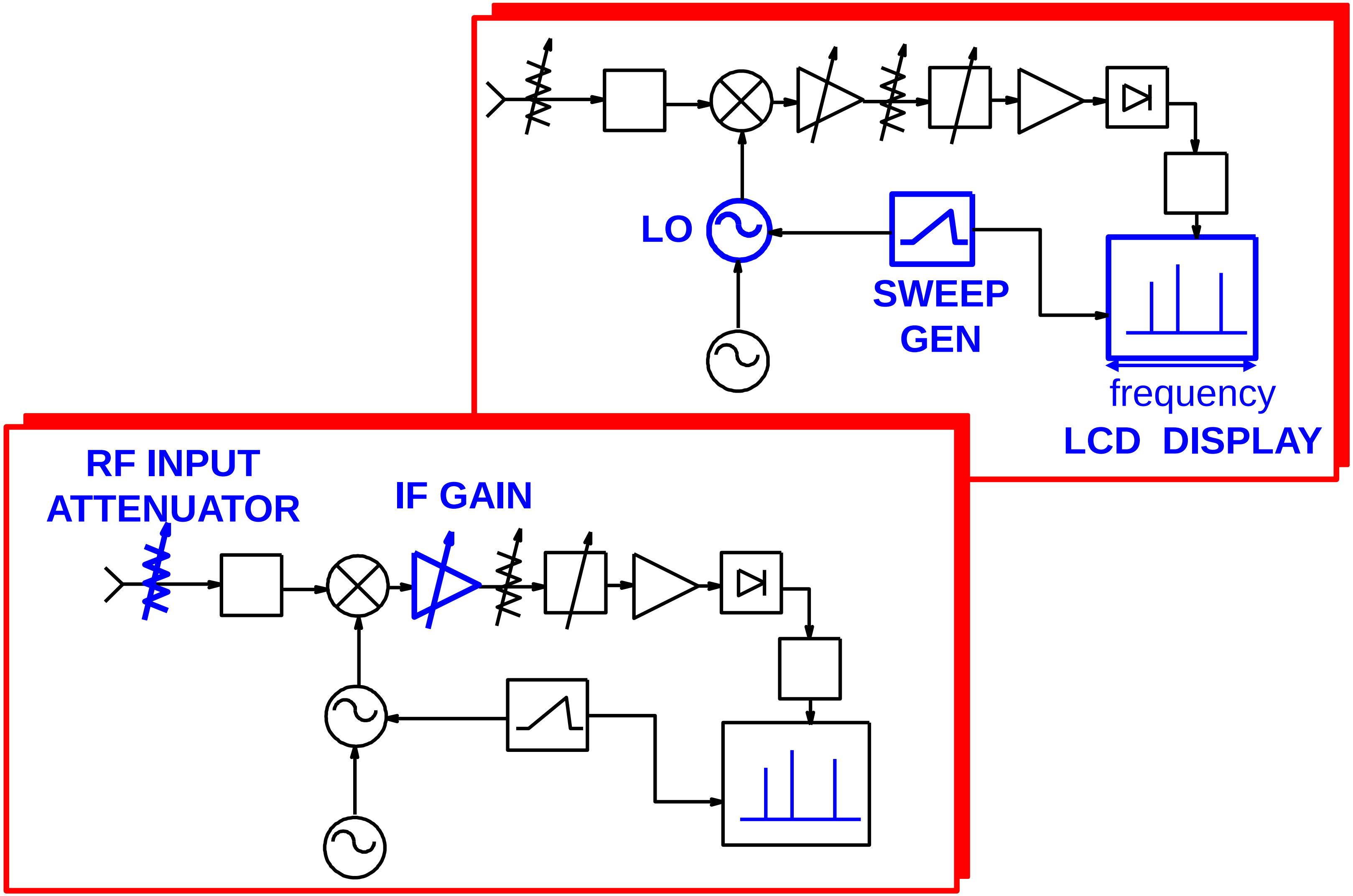
Theory of Operation

Video Filter



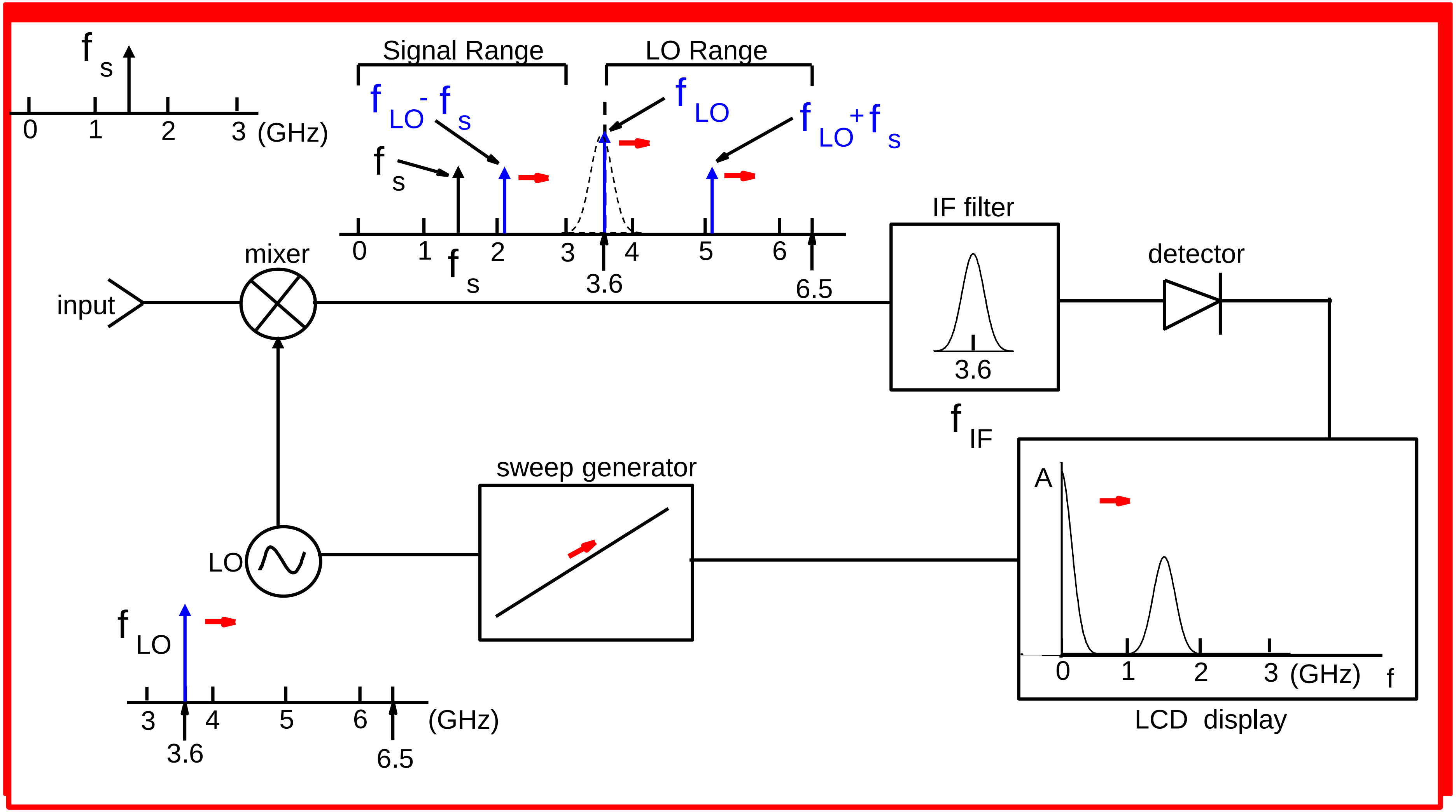


Theory of Operation
Other Components



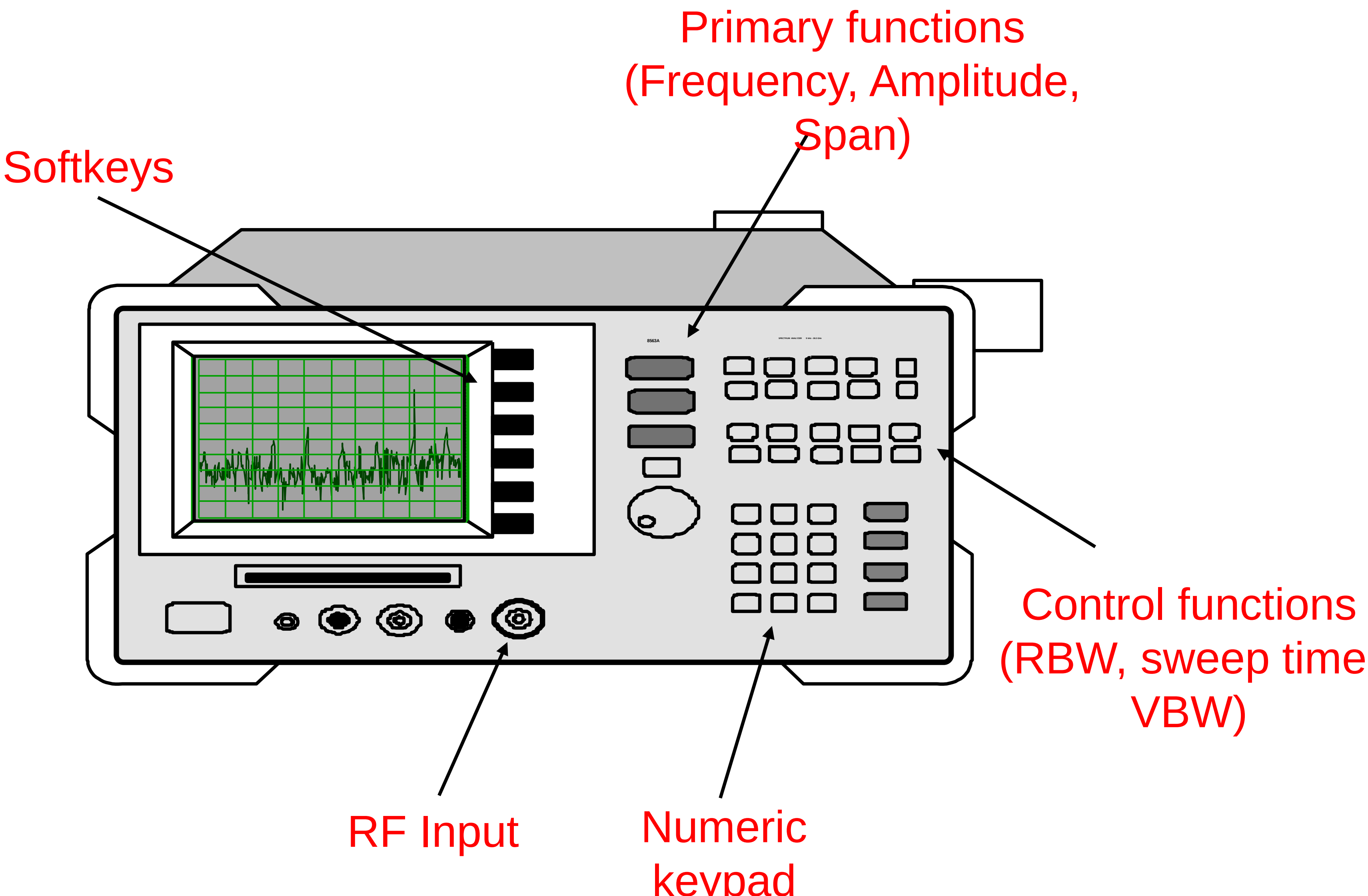
Theory of Operation

How it all works together



Theory of Operation

Front Panel Operation



Swept Spectrum Analyzer: Measurement Time

The rise time of a filter (low-pass, but also band-pass) is inversely proportional to its bandwidth, and if we include a constant of proportionality, *k*, then:

Rise time = *T* = *k* /*RBW*

The value of *k* is in the 2 to 3 range for the synchronously-tuned, near-Gaussian filters used in many analyzers.

The number *N* of “equivalent points” on a screen is given by

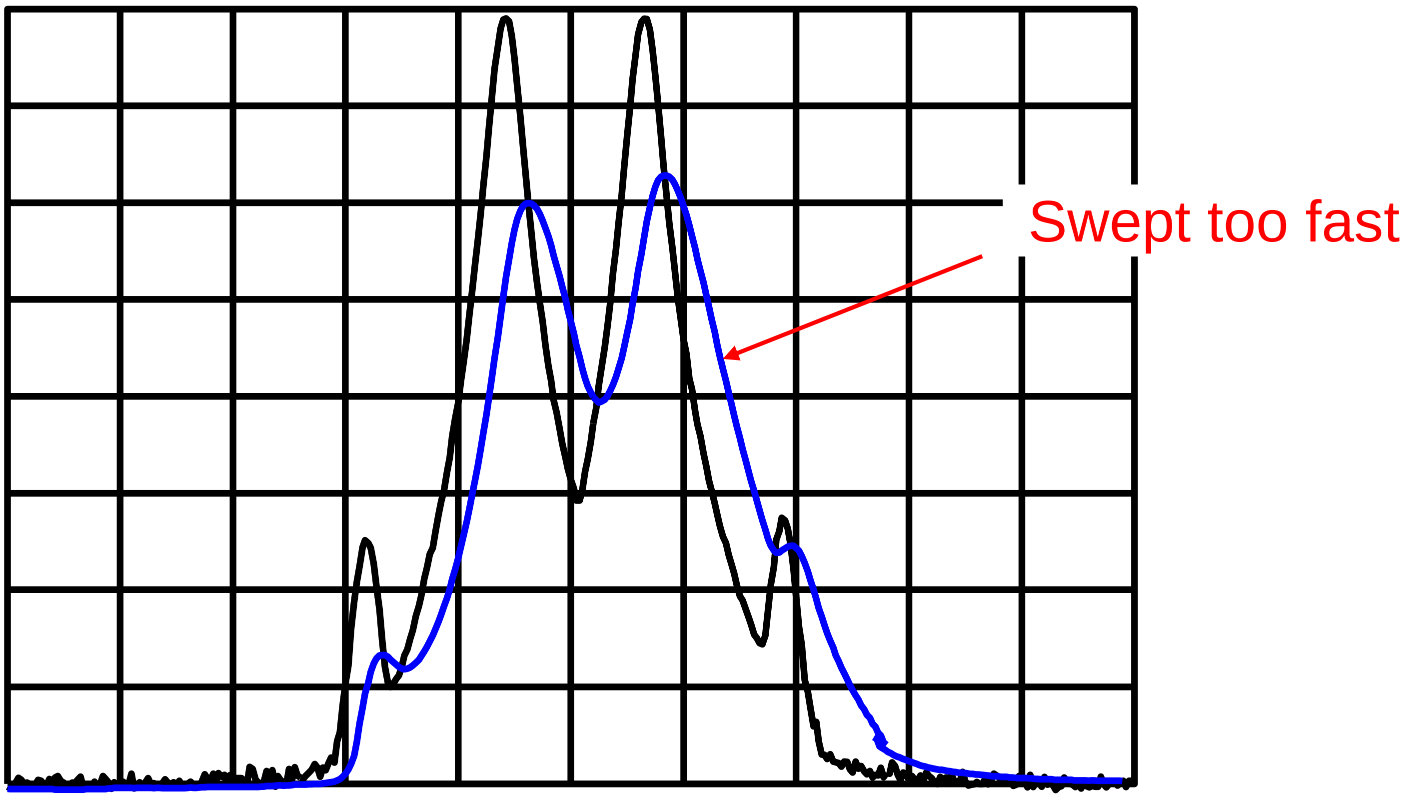
N* = *Span* / *RBW

In conclusion, the minimum sweep time for a correct measurement is

$$ST = N \times T \approx \frac{3Span}{RBW^2}$$

Specifications

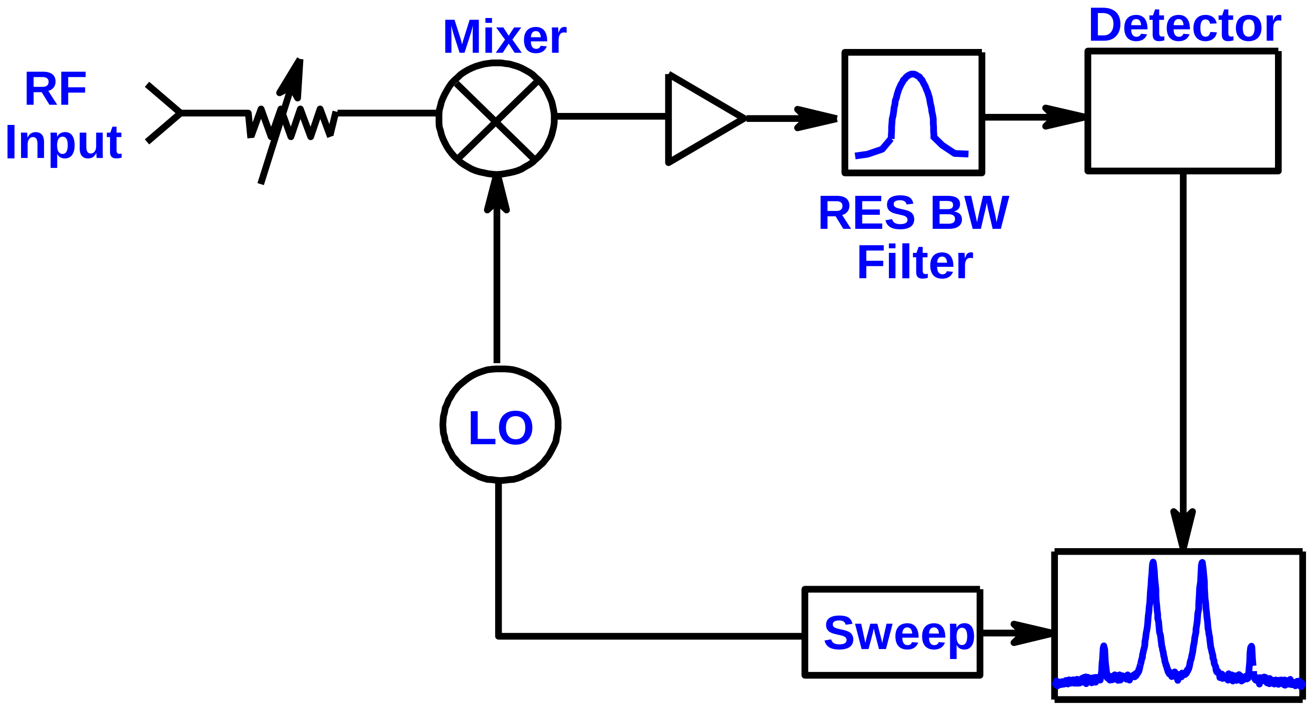
Resolution: RBW Determines Measurement Time



Penalty For Sweeping Too Fast
Is An Uncalibrated Display

Specifications

Sensitivity/DANL

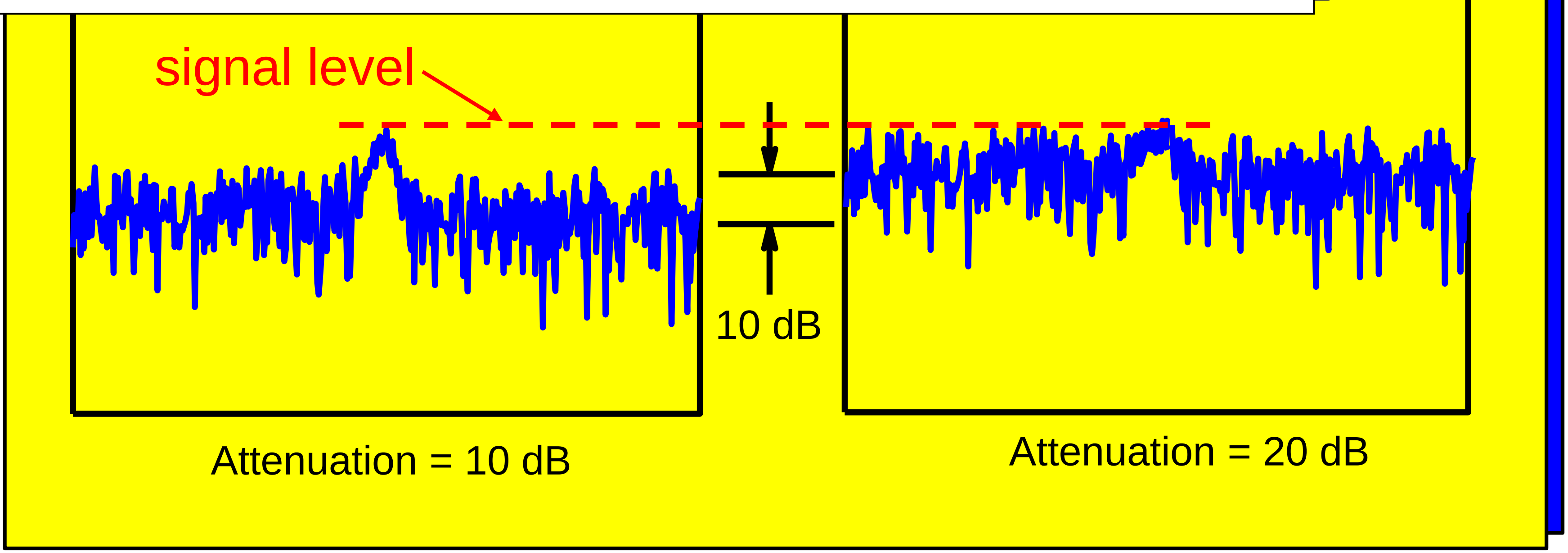


A Spectrum Analyzer Generates and Amplifies Noise Just Like Any Active Circuit

Specifications

Sensitivity/DANL

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



Signal-To-Noise Ratio Decreases as RF Input Attenuation is Increased

Attenuation - Noise Level (DANL)

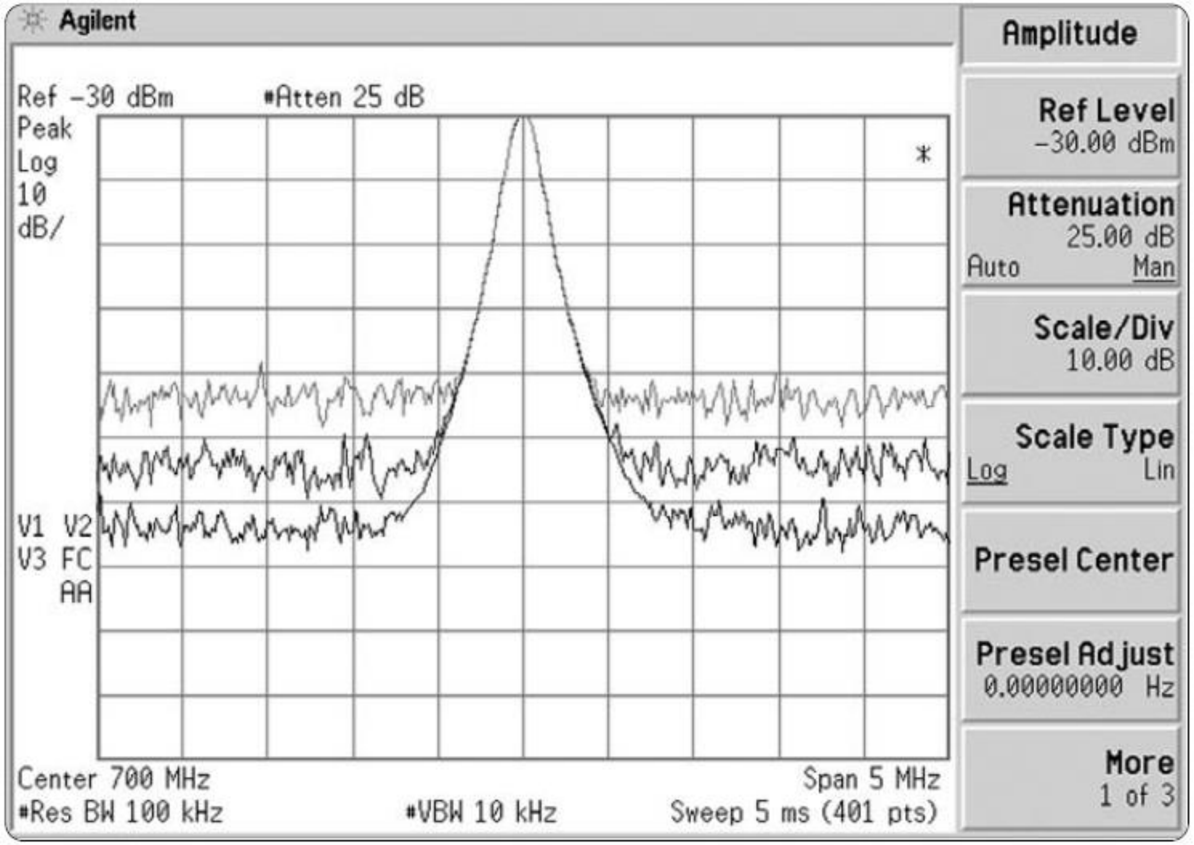


Figure 5-1. Reference level remains constant when changing input attenuation

Noise Figure and DANL

The spectral density of thermal noise is equal to:

$$p_T = kT \cong 4\times10^{-21}\ \mathrm{W/Hz} \cong -174\ \mathrm{dBm/Hz}$$

At ambient temperature, and $k = 1.38\times10^{-23}\left[\frac{\mathrm{W}}{\mathrm{Hz\ K}} = \frac{\mathrm{J}}{\mathrm{K}}\right]$ is the Boltzmann constant

Noise Figure is defined as the ratio between the instrument noise level and the thermal noise:

NF **=** ***DANL*****[measured noise in dBm] – 10 log[*****kT*** **×** ***RBW*****/(1 mW)]**=

= *DANL*[measured noise in dBm] – 10 log(*RBW*/1 Hz) – (-174 dBm/Hz)

(in the approximation of equivalent-noise-bandwidth ≅ *RBW*)

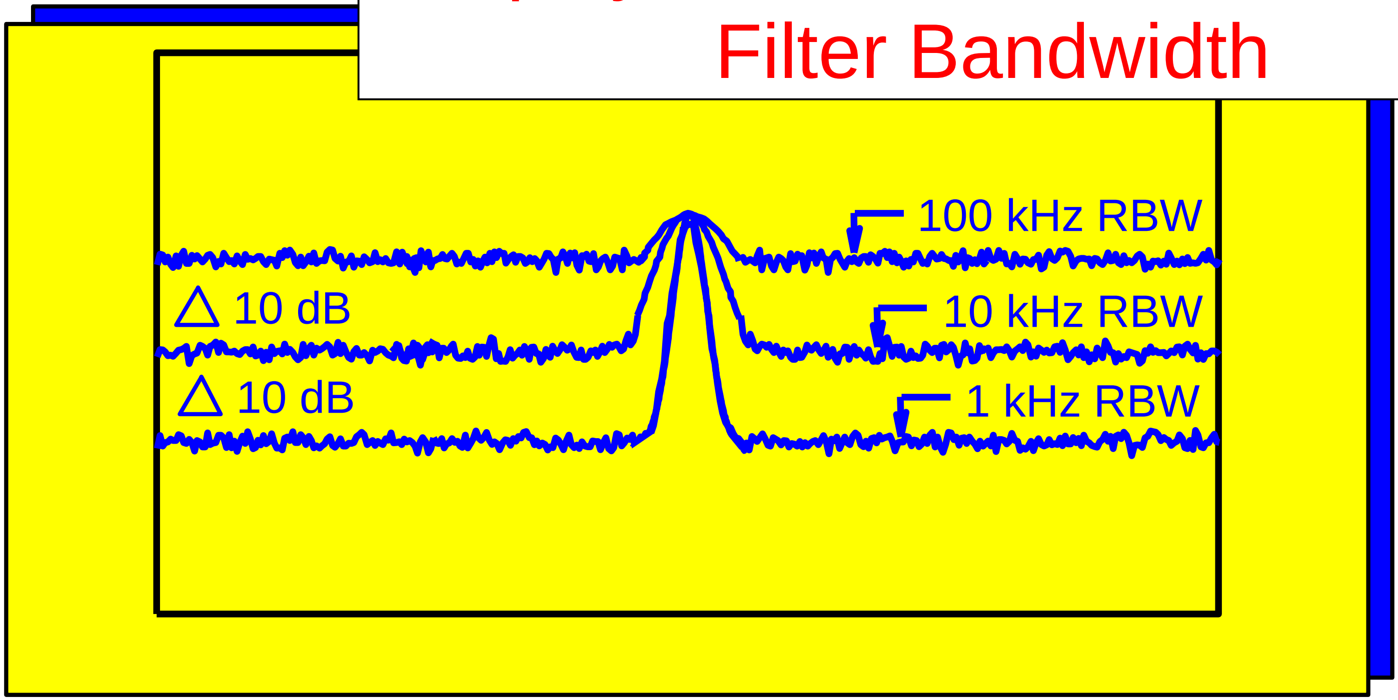
Noise figure is independent of IF-filter bandwidth, while the displayed averaged noise level (DANL) on the analyzer changes with bandwidth.

A typical value for *NF* is 20-24 dB

Specifications

Sensitivity/DANL: IF Filter (RBW)

Displayed Noise is a Function of IF Filter Bandwidth



Decreased BW = Decreased Noise

RBW – Noise Level (DANL)

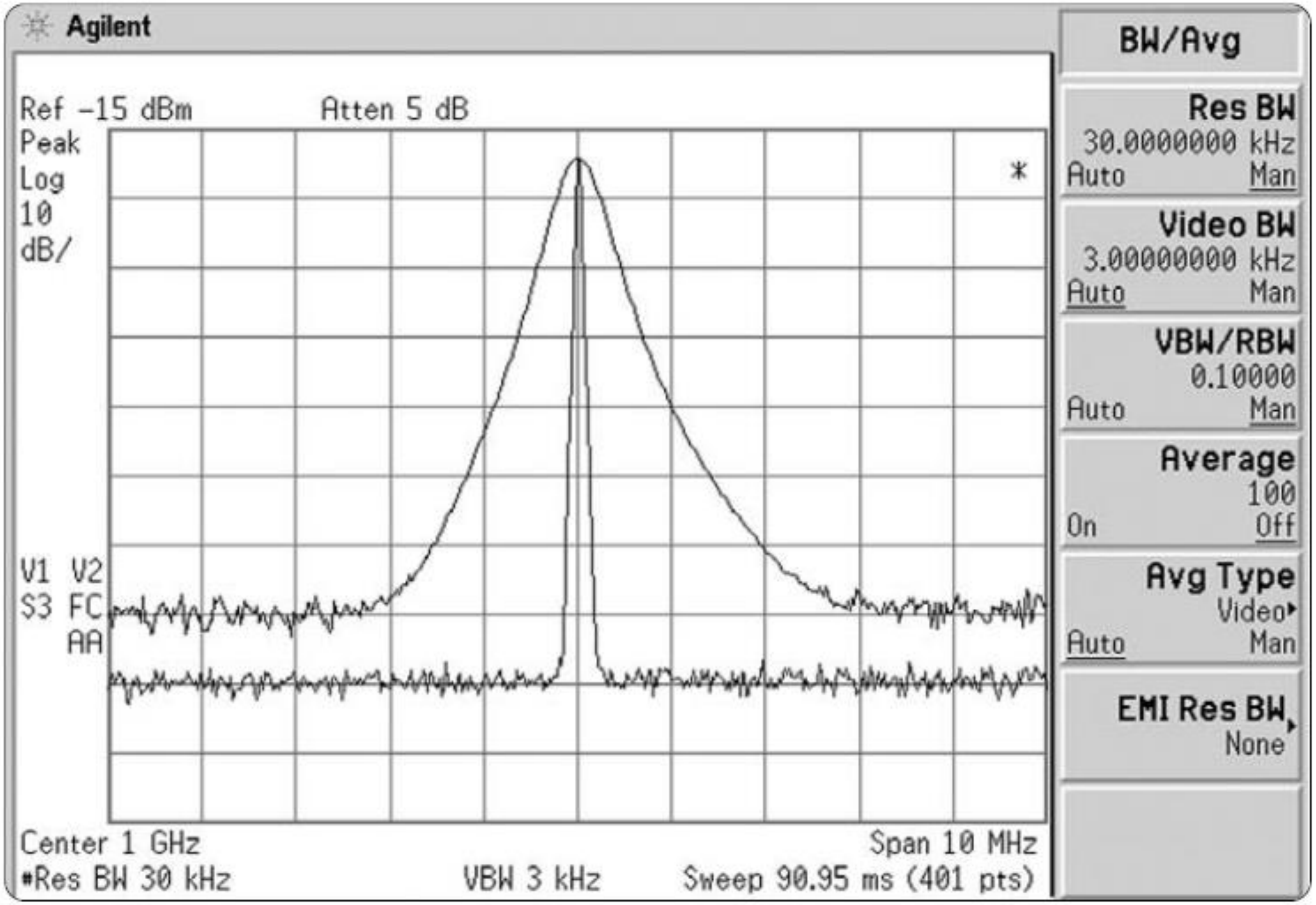
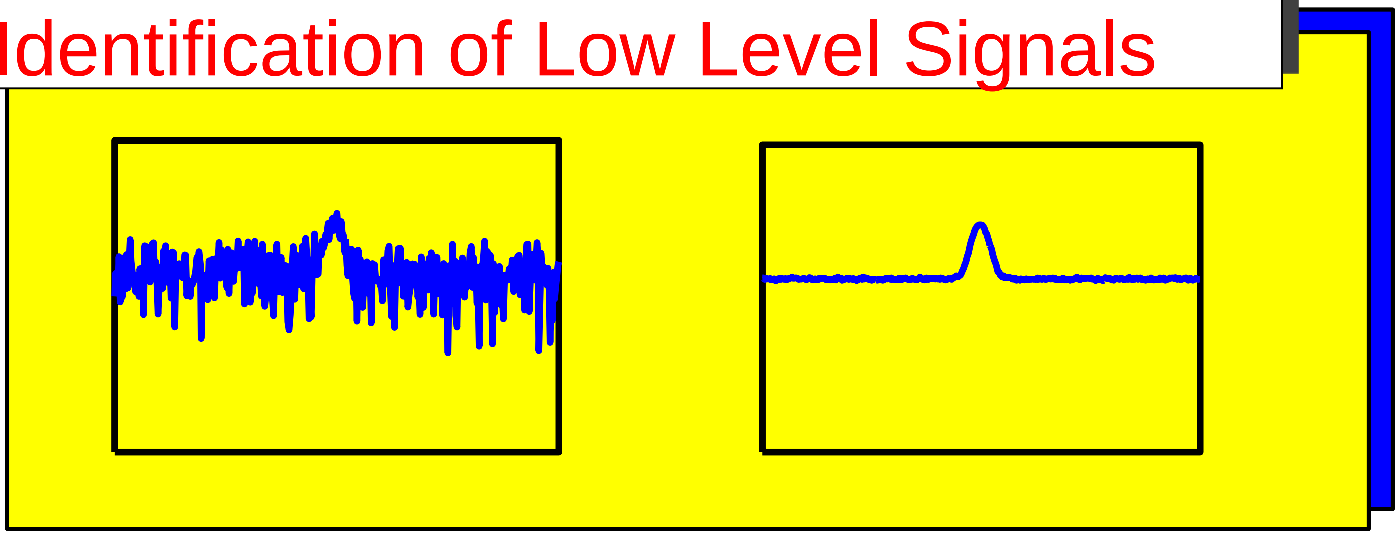


Figure 5-2. Displayed noise level changes as 10 log(BW_2/BW_1)

Specifications

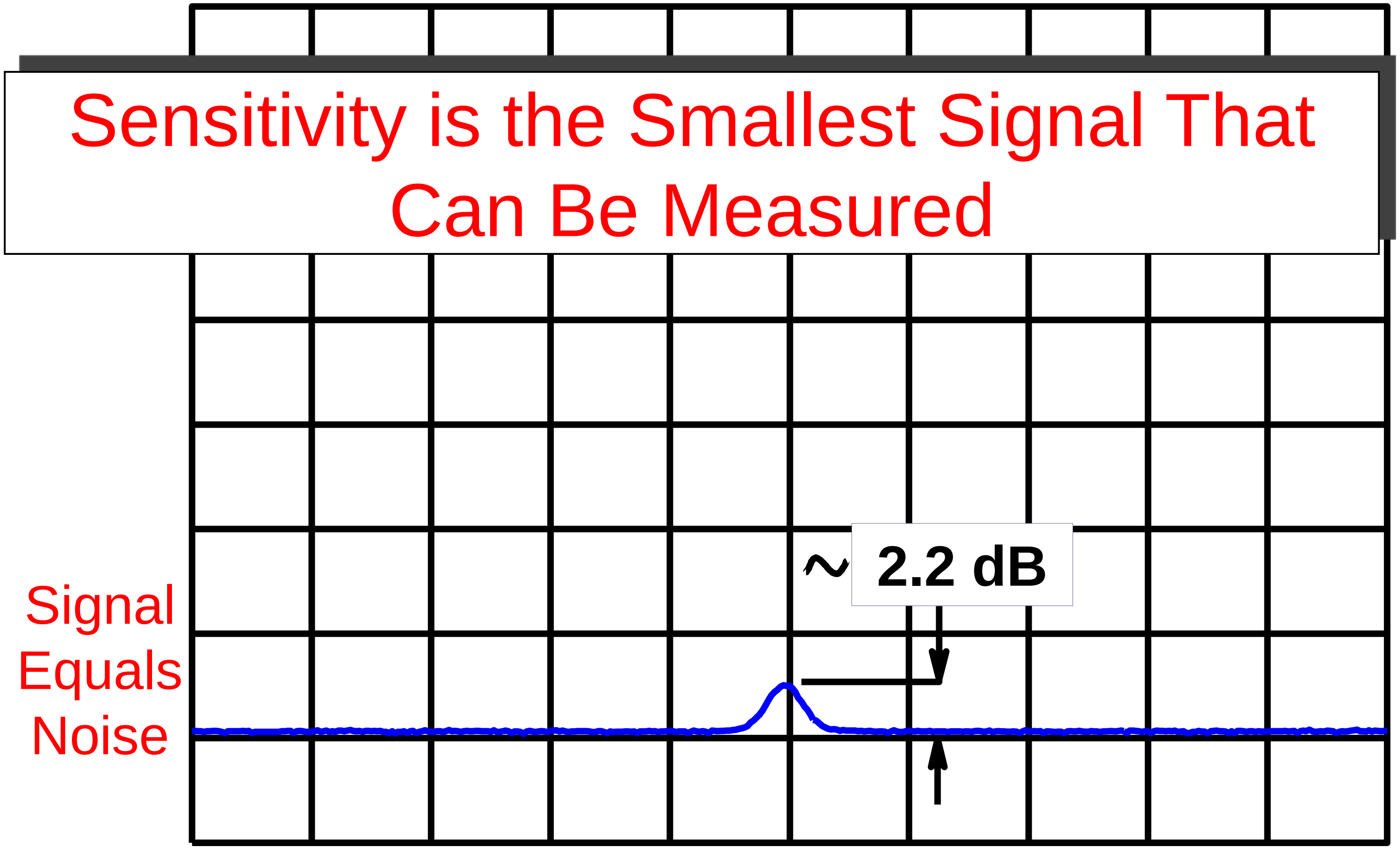
Sensitivity/DANL: VBW

Video BW Smoothes Noise for Easier Identification of Low Level Signals



Specifications

Sensitivity/DANL



Specifications

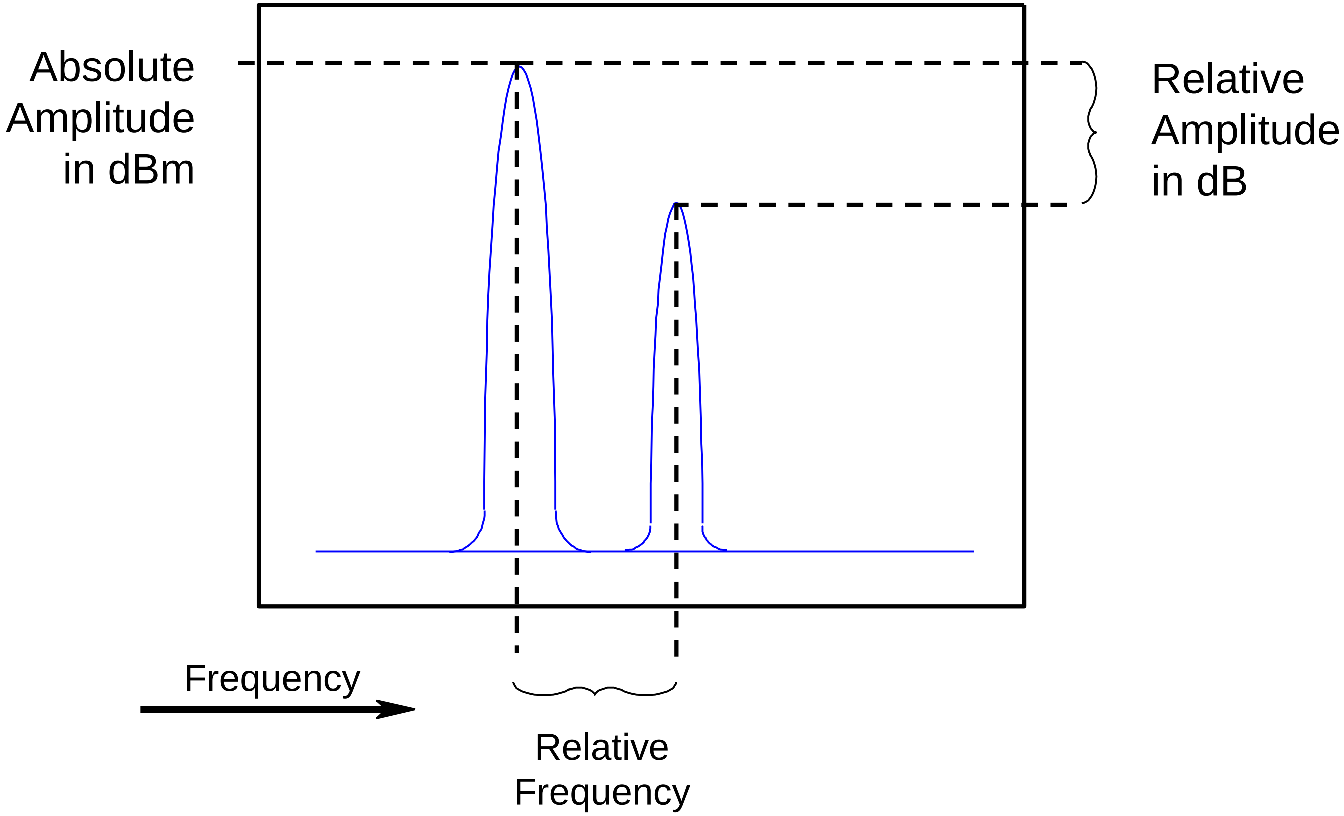
Sensitivity/DANL

For Best Sensitivity Use:

- **Narrowest Resolution BW**
- **Minimum RF Input Attenuation**
- **Sufficient Video Filtering (Video BW < .01 Res BW)**

Specifications

Accuracy



Specifications

Accuracy: Frequency Readout Accuracy

Typical datasheet specification:

Spans < 2 MHz: $\pm$(freq. readout x freq. ref. accuracy
+ 1% of frequency span
+ 15% of resolution bandwidth
+ 10 Hz "residual error")

Specifications

Accuracy: Frequency Readout Accuracy Example

Single Marker Example:

2 GHz
400 kHz span
3 kHz RBW

Calculation:	$(2x10^9$ Hz) x $(1.3x10^{-7}$/yr.ref.error)	=	260 Hz
	1% of 400 kHz span	=	4000 Hz
	15% of 3 kHz RBW	=	450 Hz
	10 Hz residual error	=	10 Hz
		Total =	$\pm$ 4720 Hz

Specifications

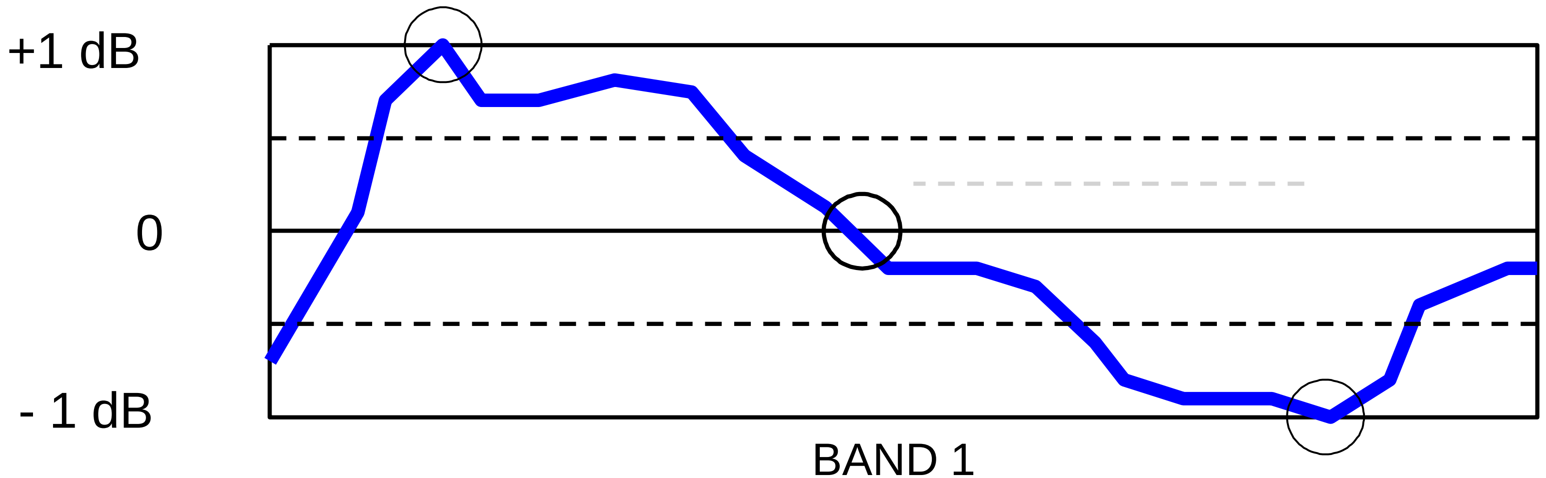
Accuracy: Relative Amplitude Accuracy

- **Display fidelity**
- **Frequency response**
- **RF Input attenuator**
- **Reference level**
- **Resolution bandwidth**
- **Display scaling**

Specifications

Accuracy: Relative Amplitude Accuracy - Freq. Response

Signals in the Same Harmonic Band



Specification: ± 1 dB

Specifications

Accuracy: Relative Amplitude Accuracy

- **RF Input attenuator**
- **Reference level**
- **Resolution bandwidth**
- **Display scaling**

Specifications

Accuracy: Absolute Amplitude Accuracy

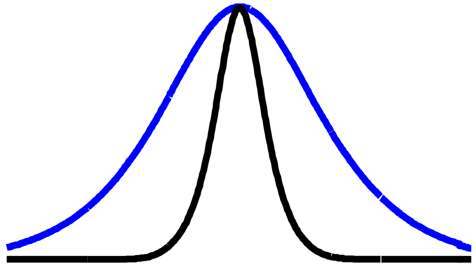
Absolute
Amplitude
in dBm

- **Calibrator accuracy**
- **Frequency response**
- **Reference level uncertainty**

Specifications

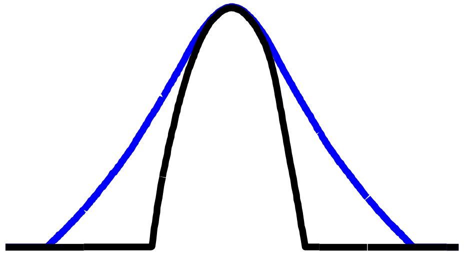
Resolution

What Determines Resolution?



Resolution Bandwidth

Residual FM

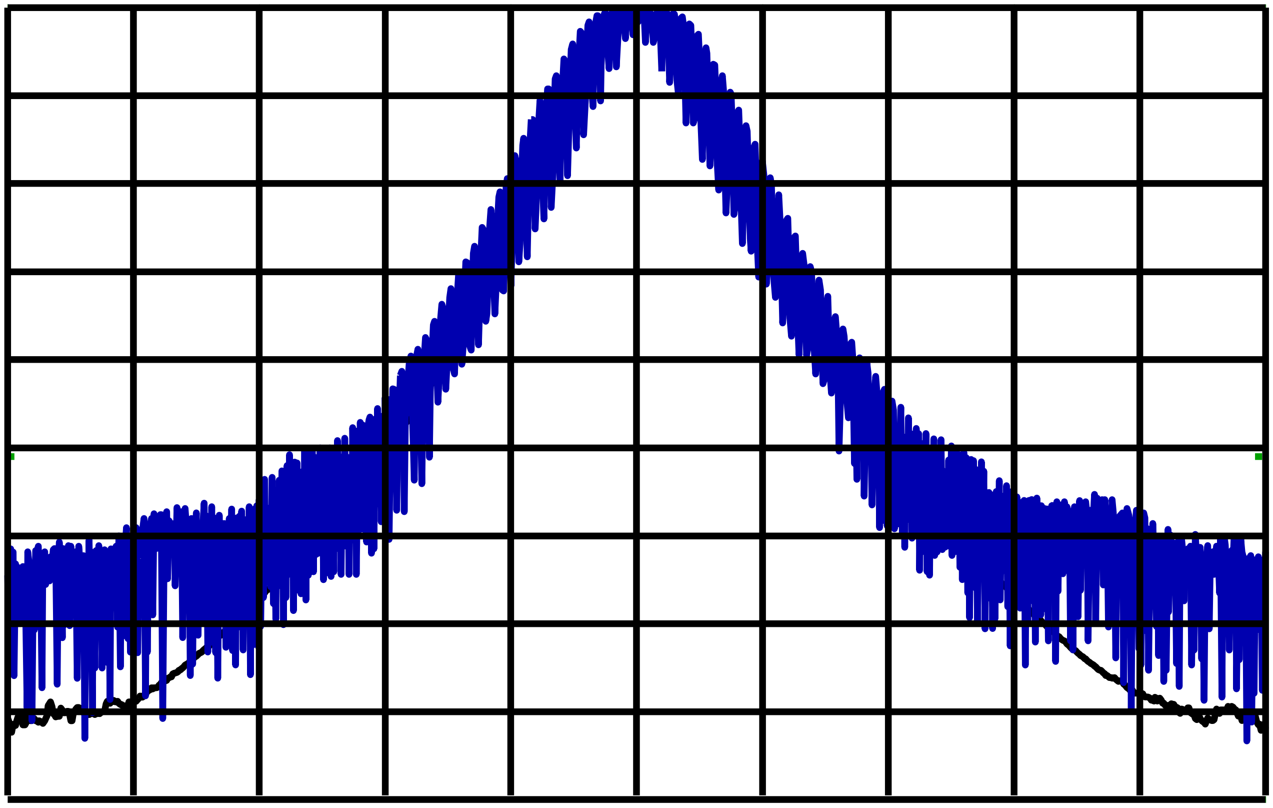


RBW Type and Selectivity

Noise Sidebands

Specifications

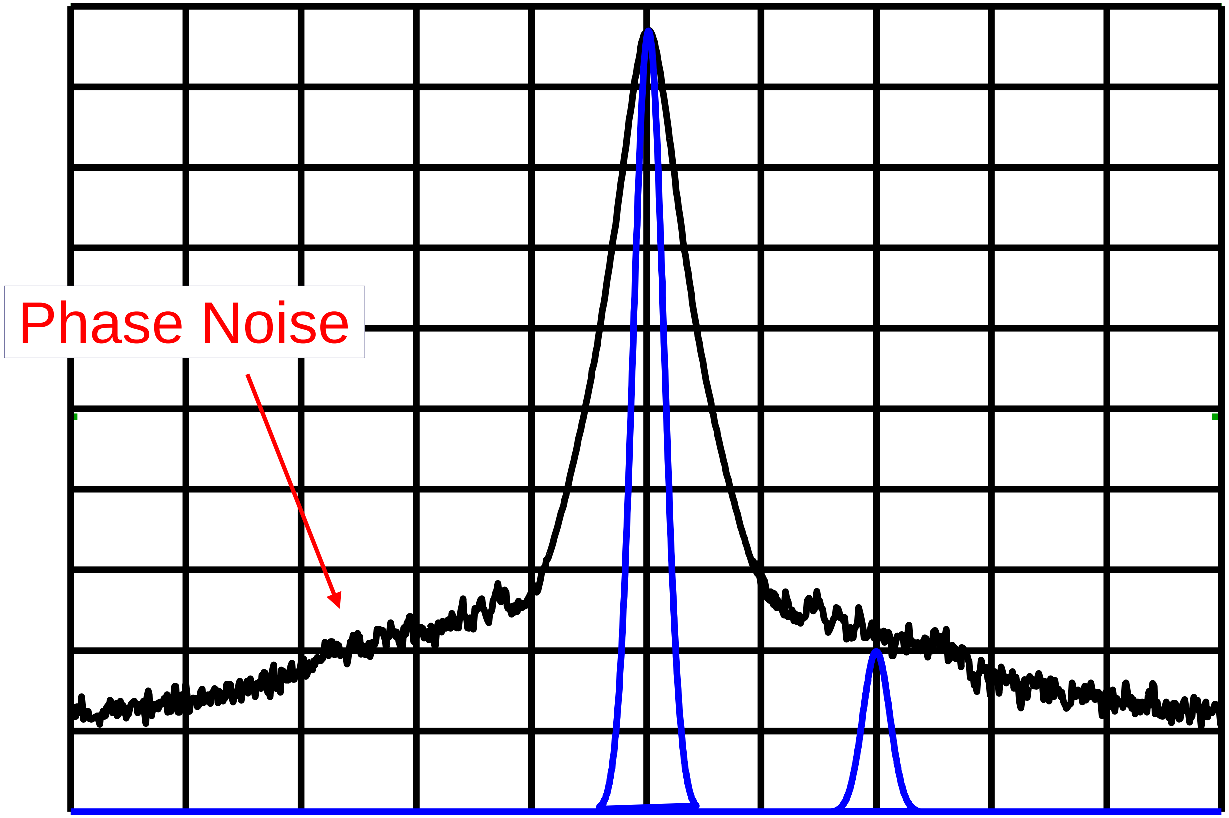
Resolution: Residual FM



Residual FM
"Smears" the Signal

Specifications

Resolution: Noise Sidebands

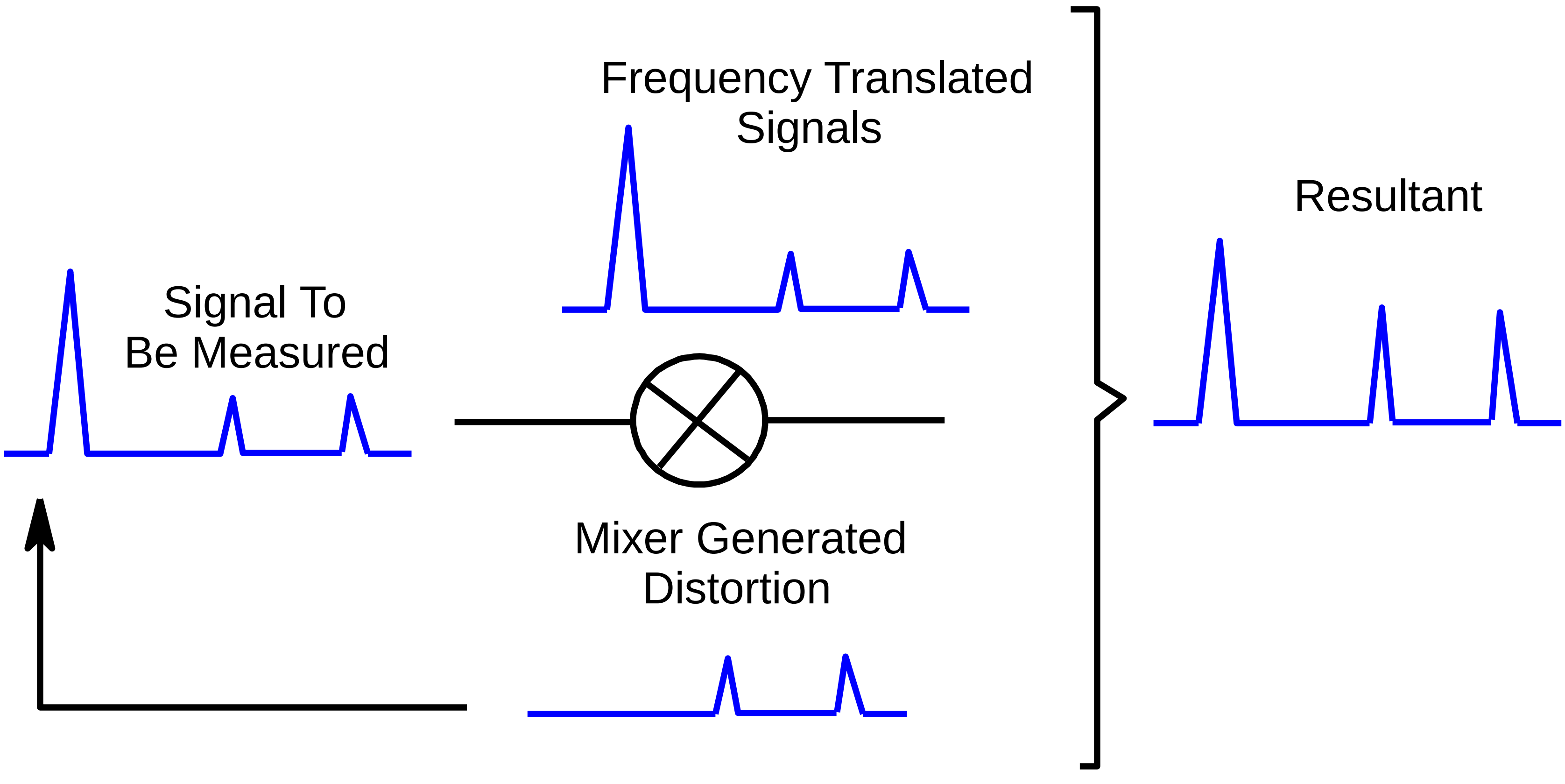


Noise Sidebands can prevent resolution of unequal signals

Specifications

Distortion

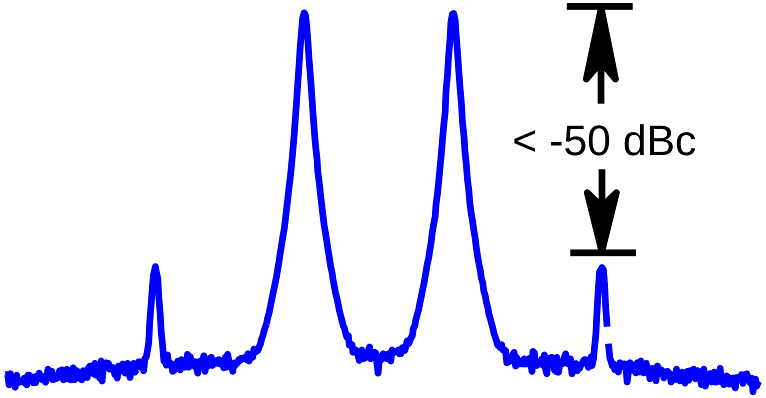
Mixers Generate Distortion



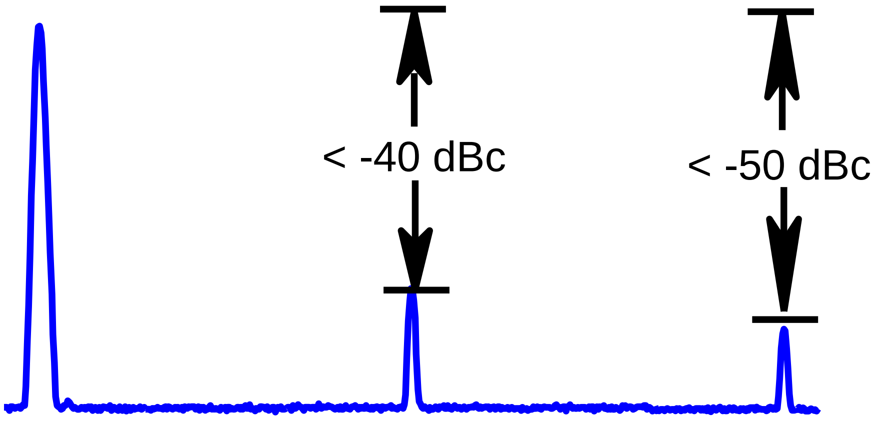
Specifications

Distortion

Most Influential Distortion is the Second and Third Order



Two-Tone Intermod

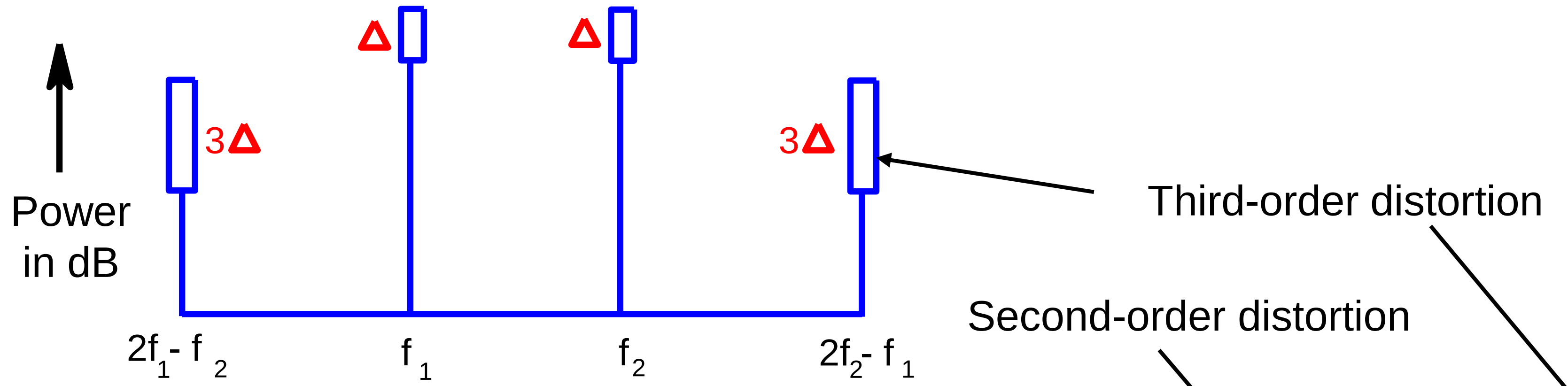


Harmonic Distortion

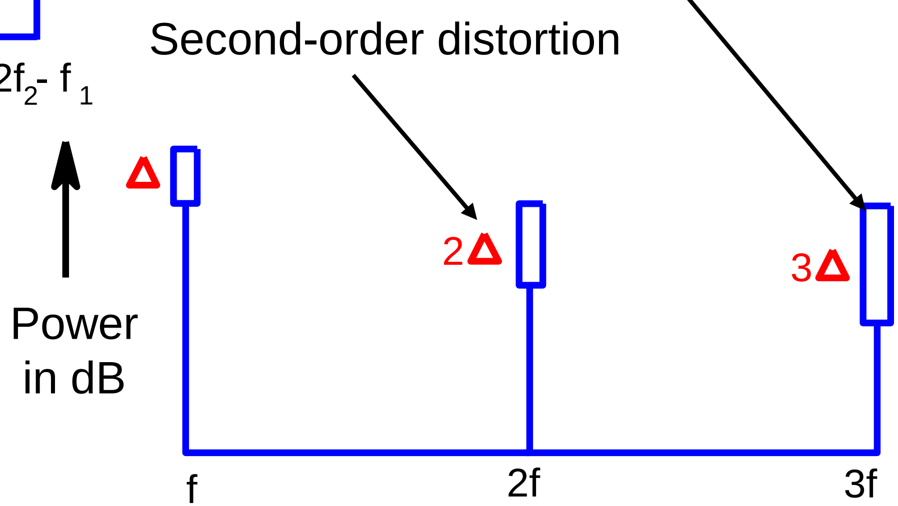
Specifications

Distortion

Distortion Products Increase as a Function of Fundamental's Power



Two-Tone Intermod



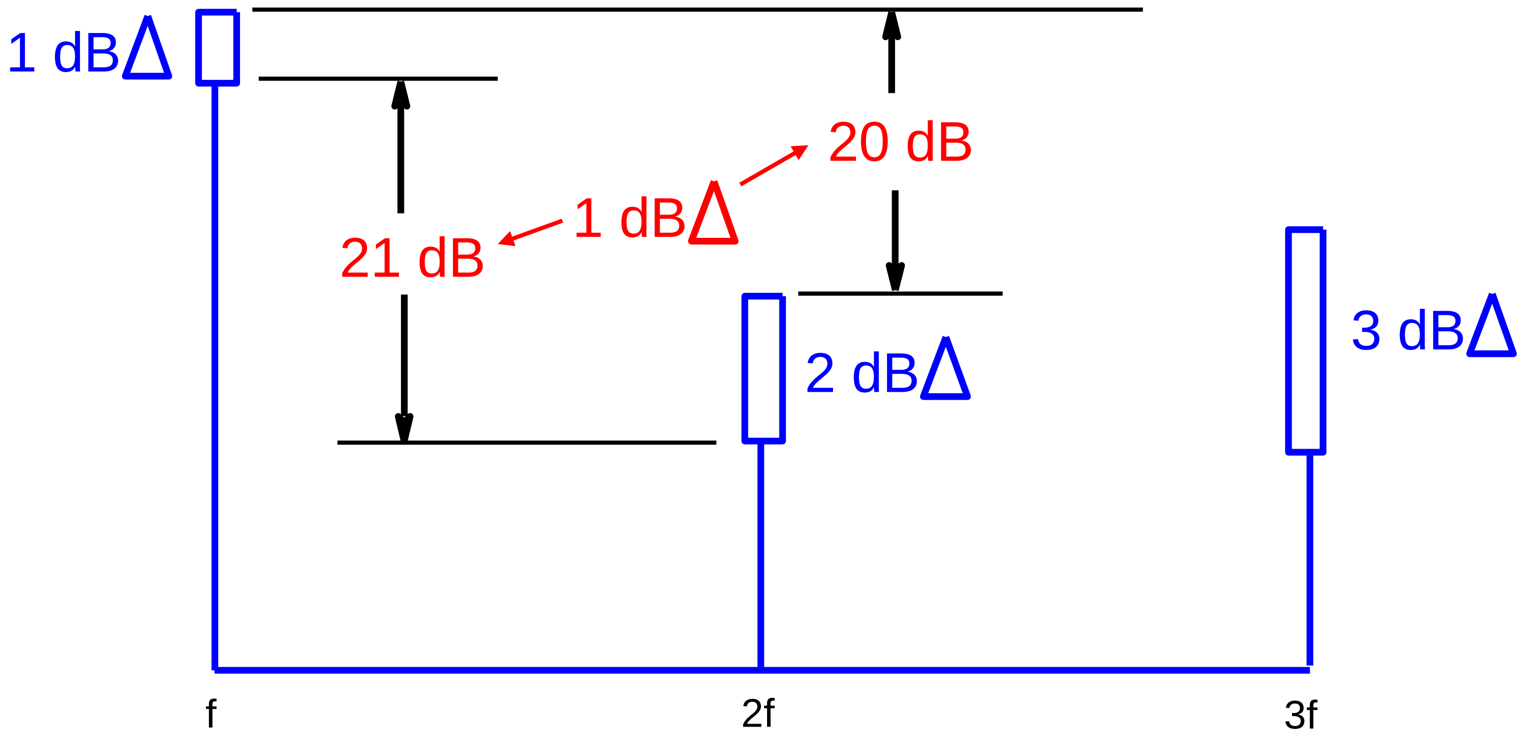
Harmonic Distortion

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

Specifications

Distortion

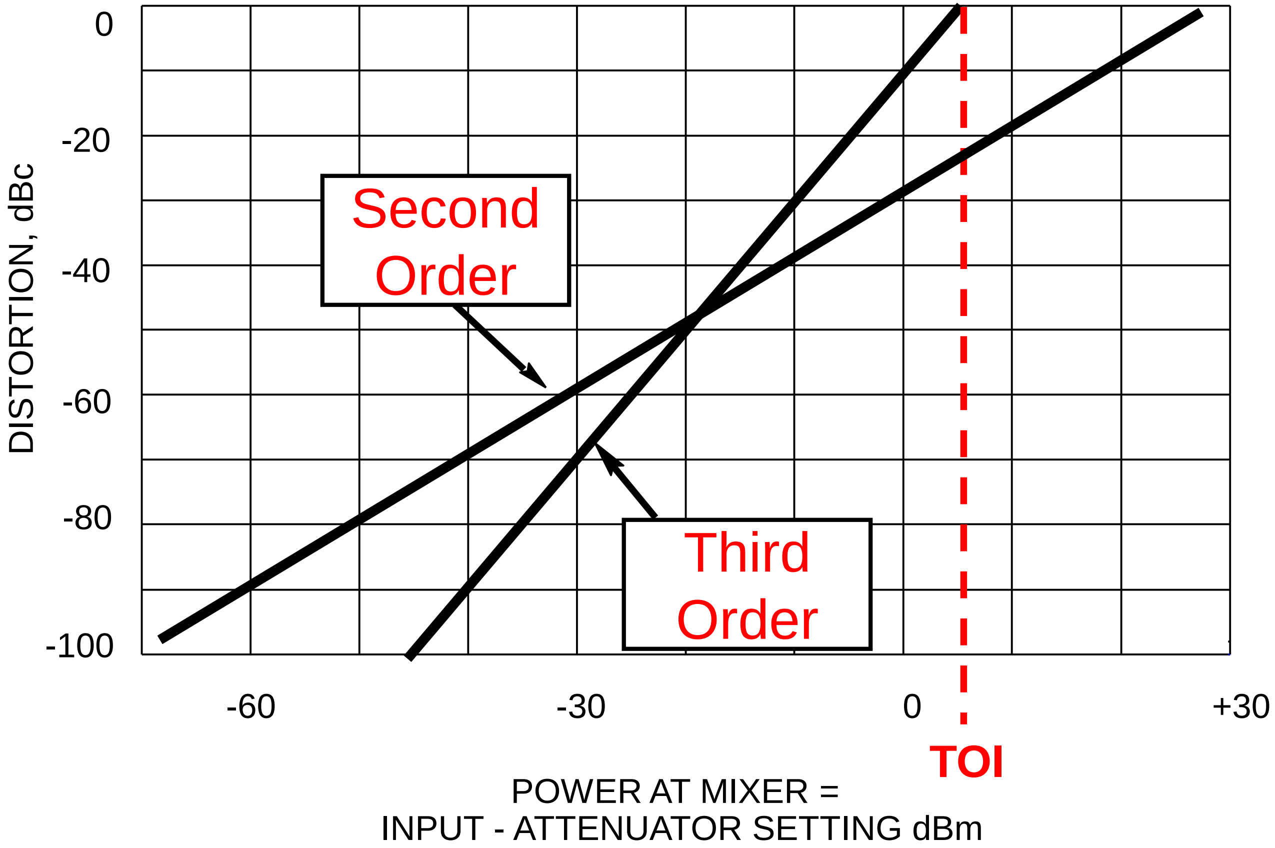
Relative Amplitude Distortion Changes with Input Power Level



Specifications

Distortion

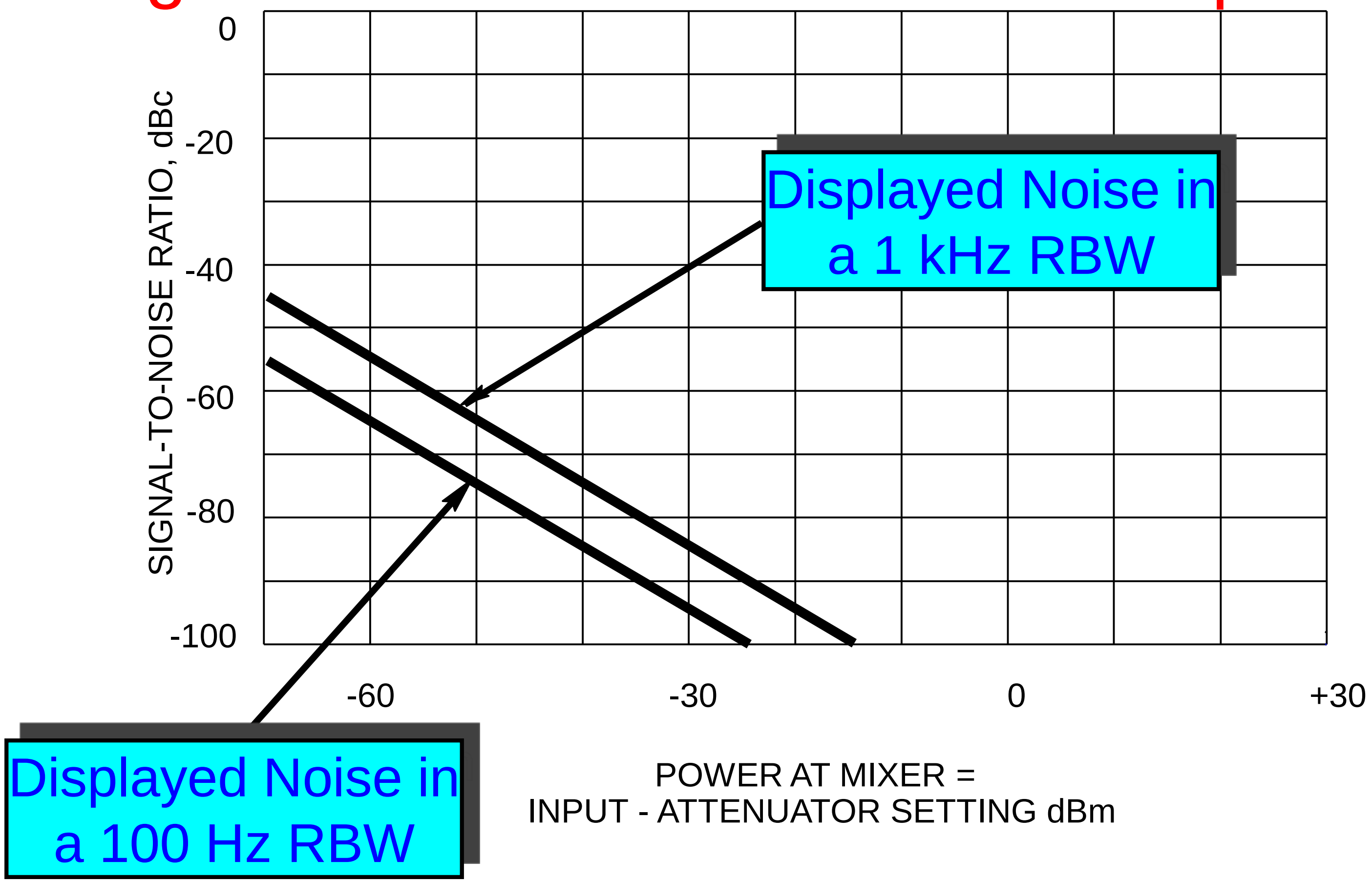
Distortion is a Function of Mixer Level



Specifications

Dynamic Range

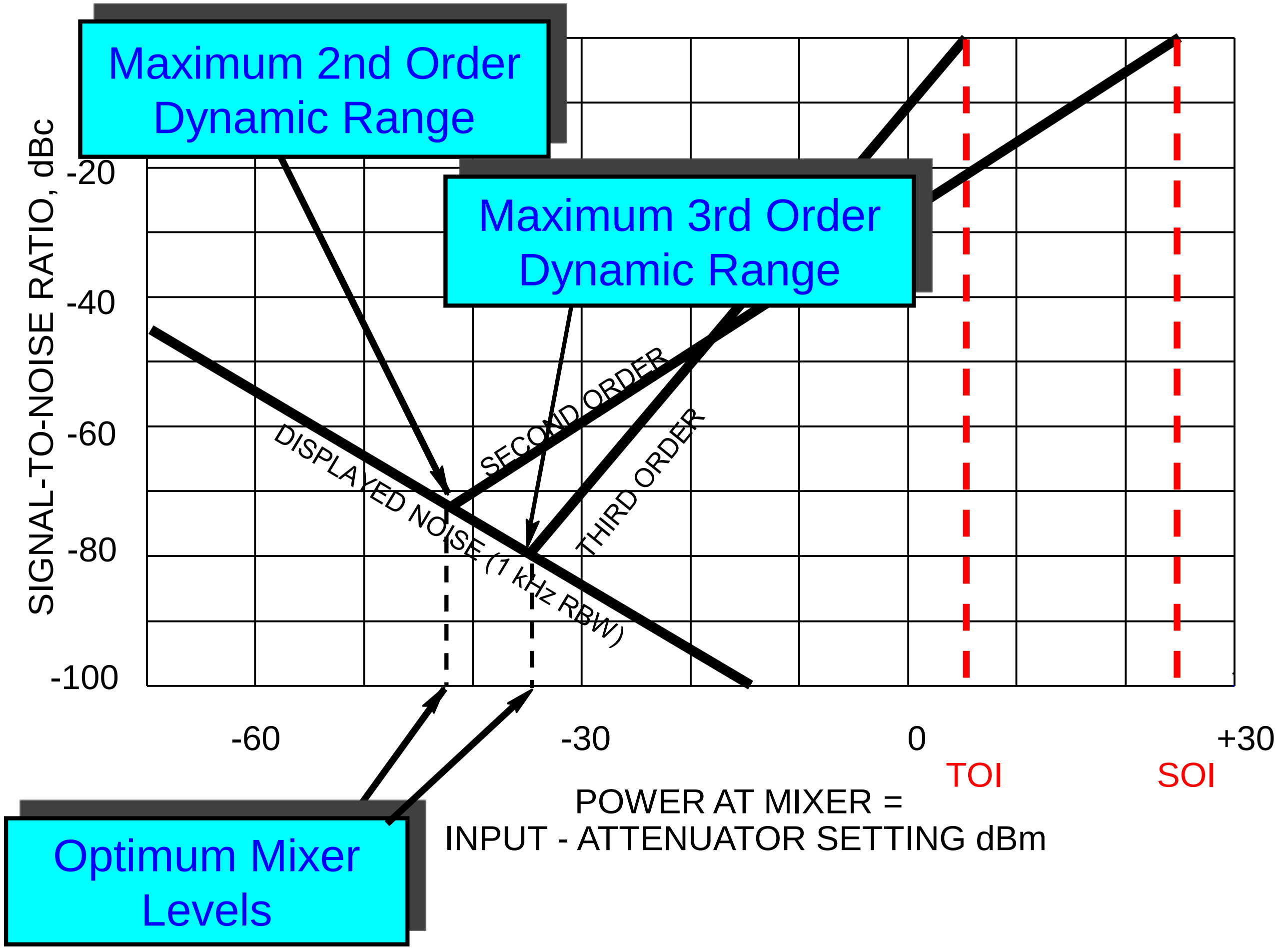
Signal-to-Noise Ratio Can Be Graphed



Specifications

Dynamic Range

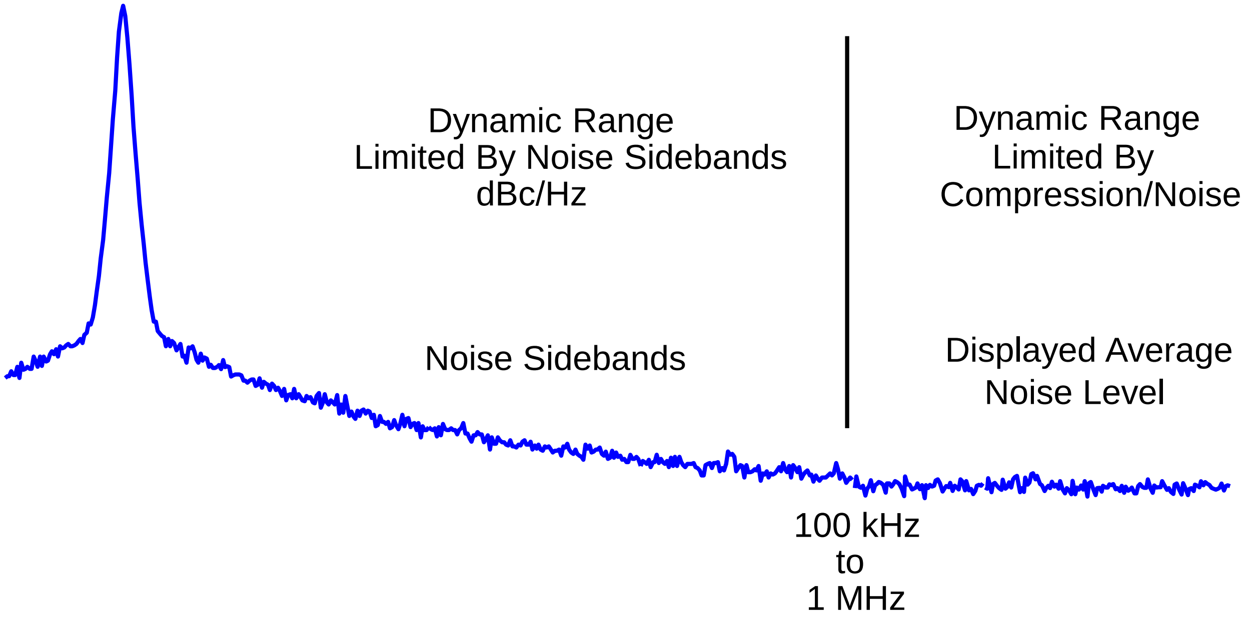
Dynamic Range Can Be Presented Graphically



Specifications

Dynamic Range

Dynamic Range for Spur Search Depends on Closeness to Carrier



Specifications

Dynamic Range

Actual Dynamic Range is the Minimum of:

Maximum dynamic range calculation

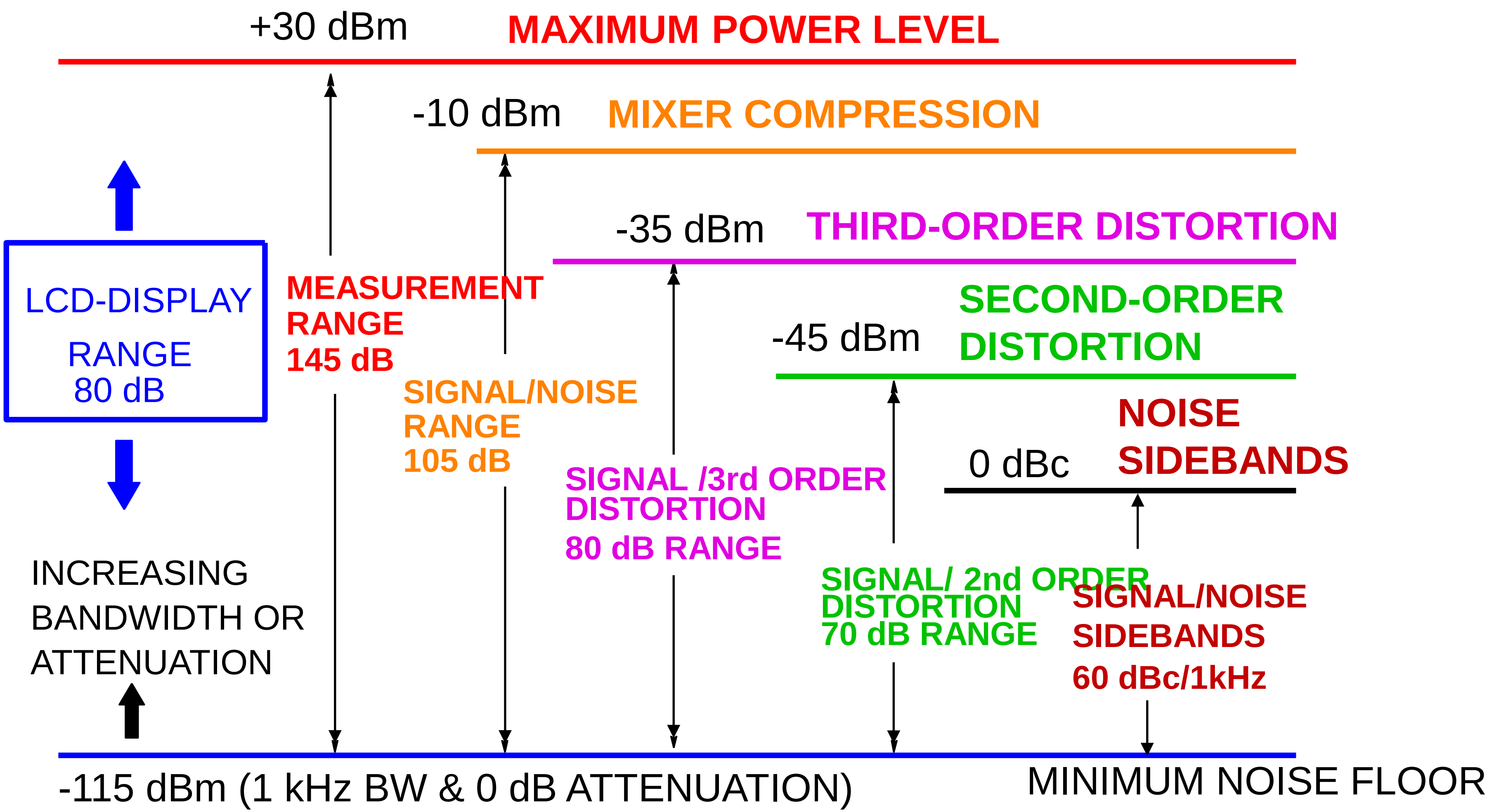
Calculated from:

- distortion
- sensitivity

Noise sidebands at the offset frequency

Specifications

Dynamic Range

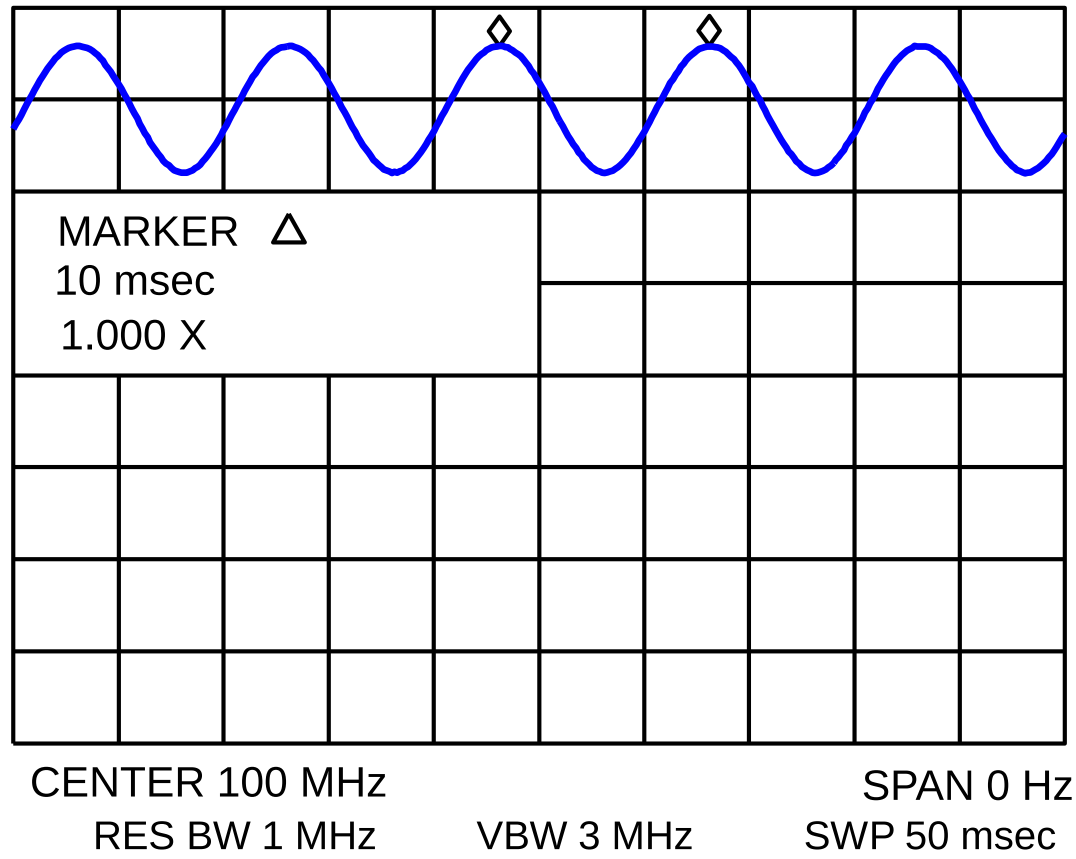


SPAN ZERO

Modulation Measurements: Time Domain

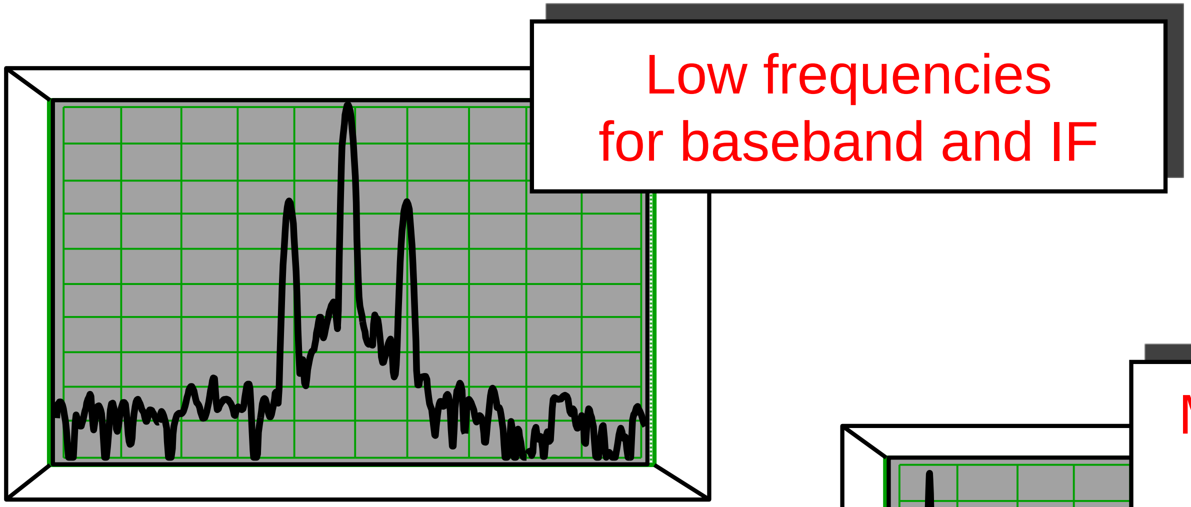
It was mentioned briefly that although a spectrum analyzer is primarily used to view signals in the frequency domain, it is also possible to use the spectrum analyzer to look at the time domain. This is done with a feature called zero-span. This is useful for determining modulation type or for demodulation.

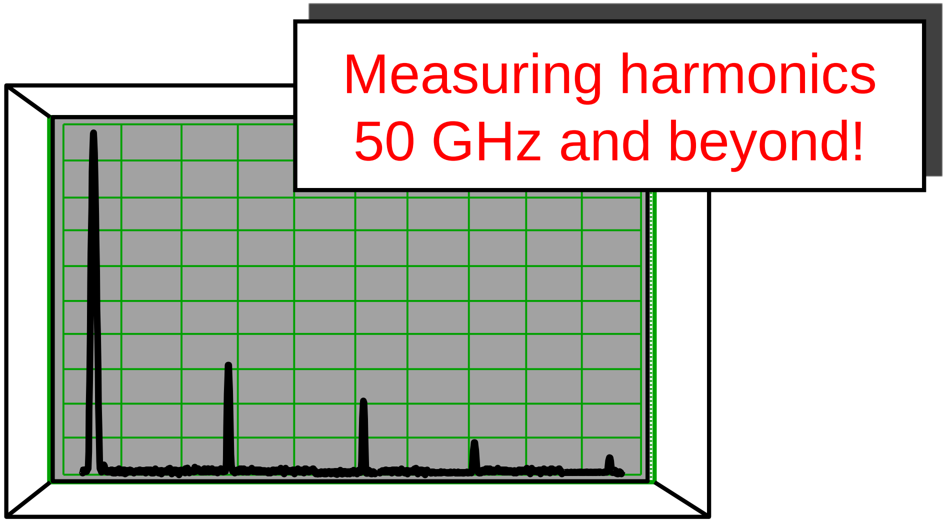
The spectrum analyzer is set for a frequency span of zero (hence the term zero-span) with some nonzero sweep time. The center frequency is set to the carrier frequency and the resolution bandwidth must be set large enough to allow the modulation sidebands to be included in the measurement . The analyzer will plot the amplitude of the signal versus time, within the limitations of its detector and video and RBWs.



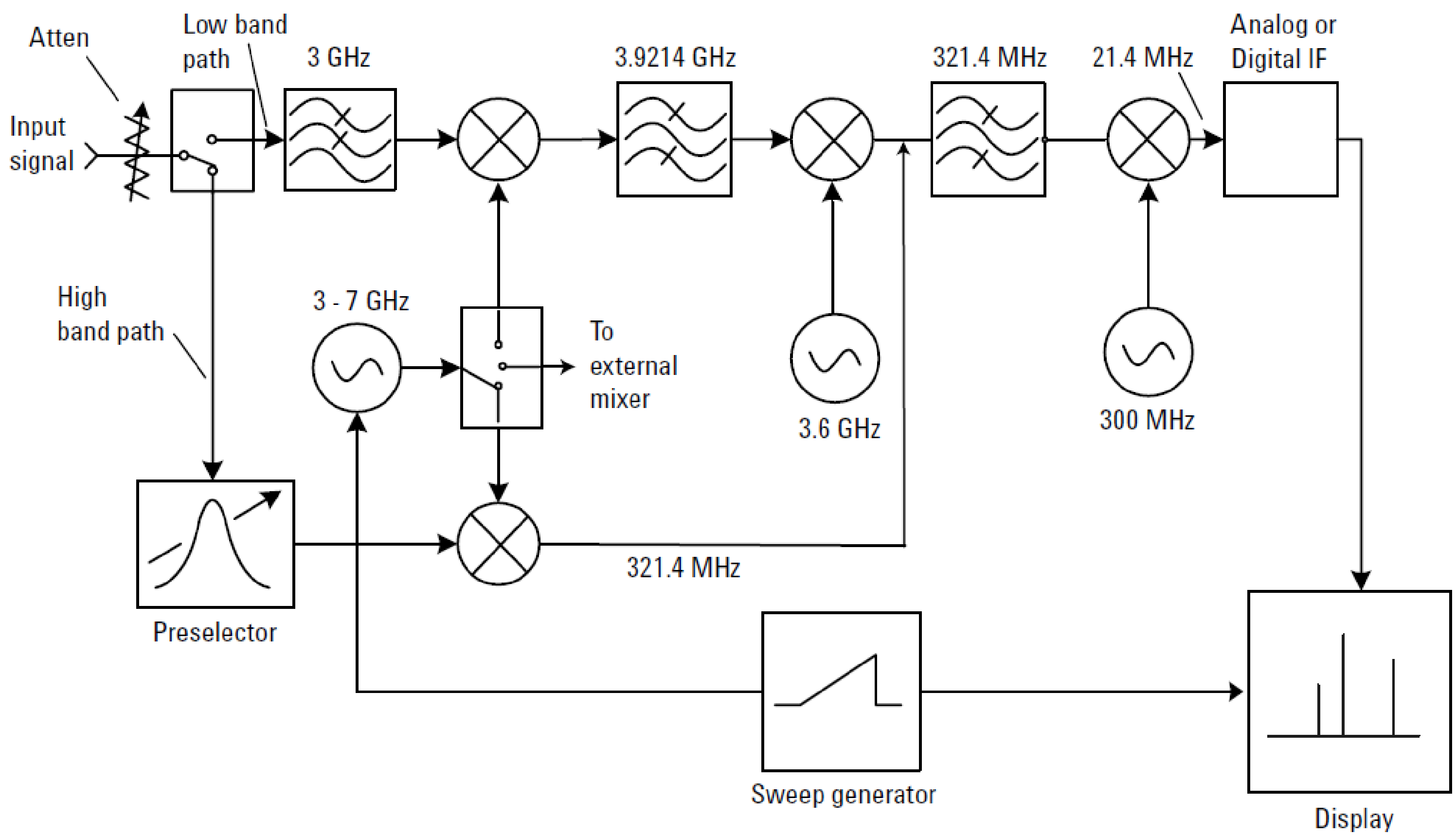
Specifications

Frequency Range

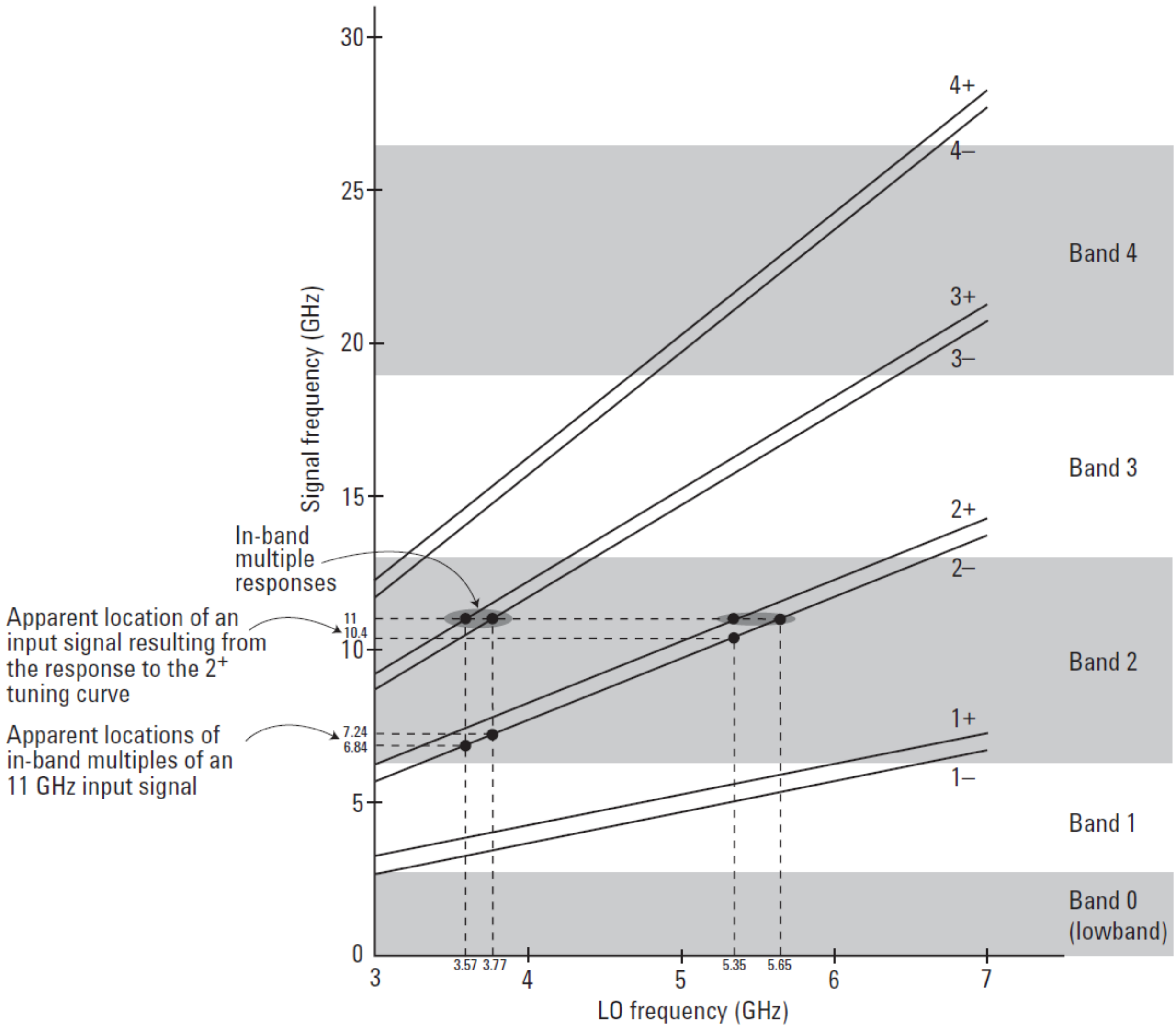




Higher Bands



LO Harmonics



Noise level for higher bands

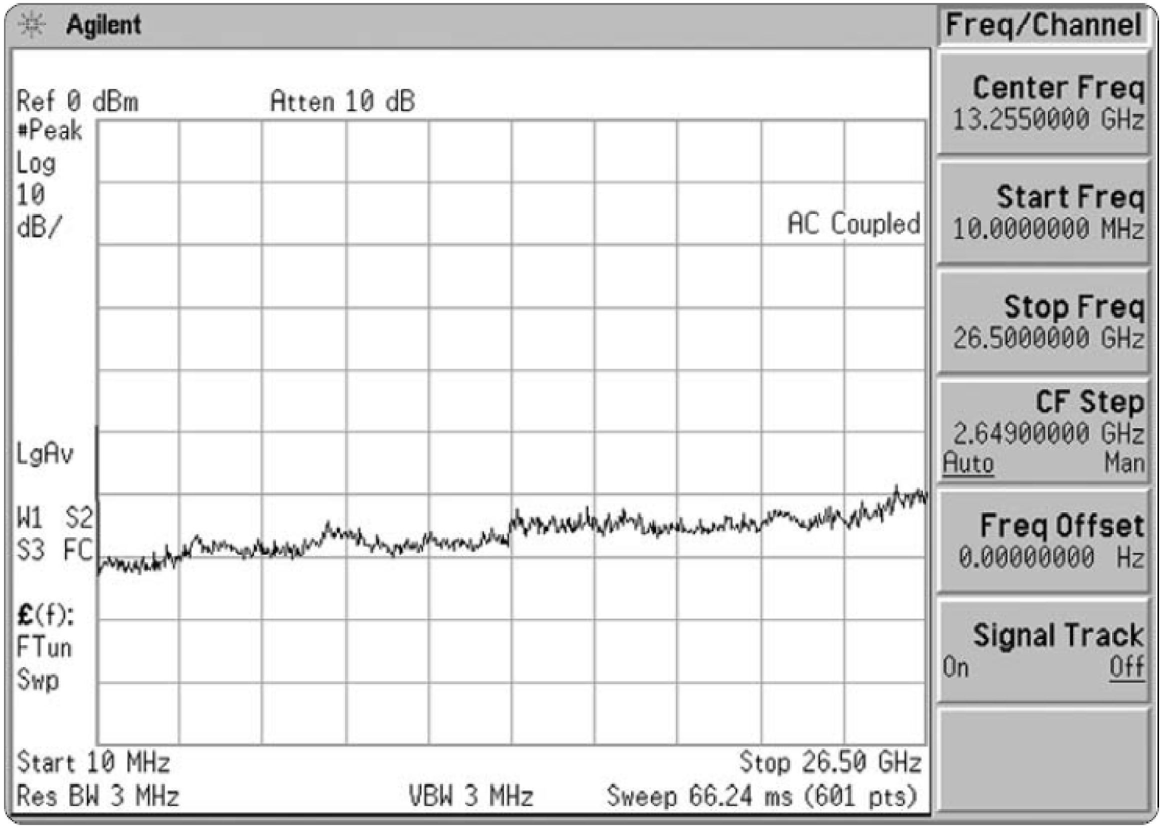
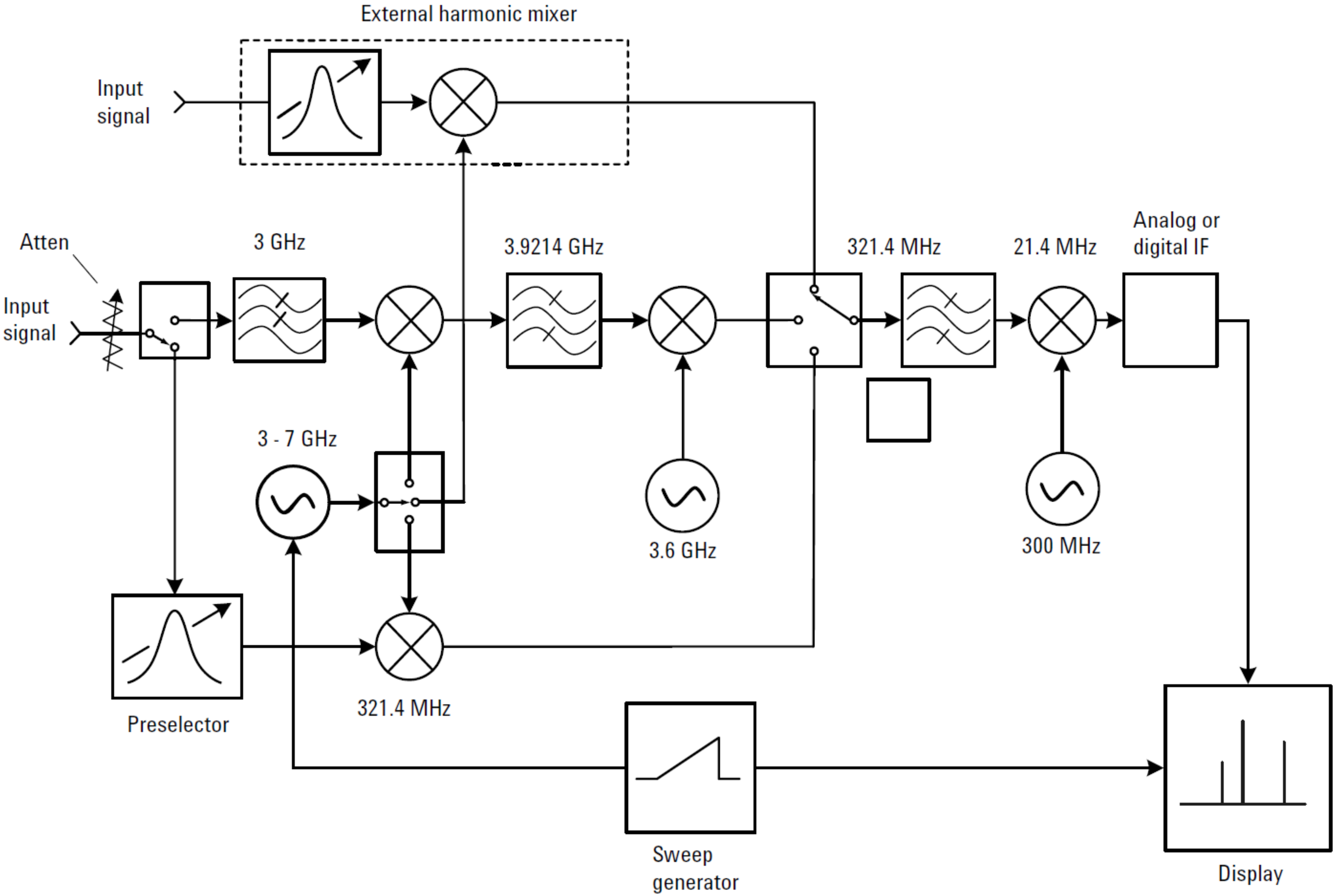


Figure 7-9. Rise in noise floor indicates changes in sensitivity with changes in LO harmonic used

External Mixer

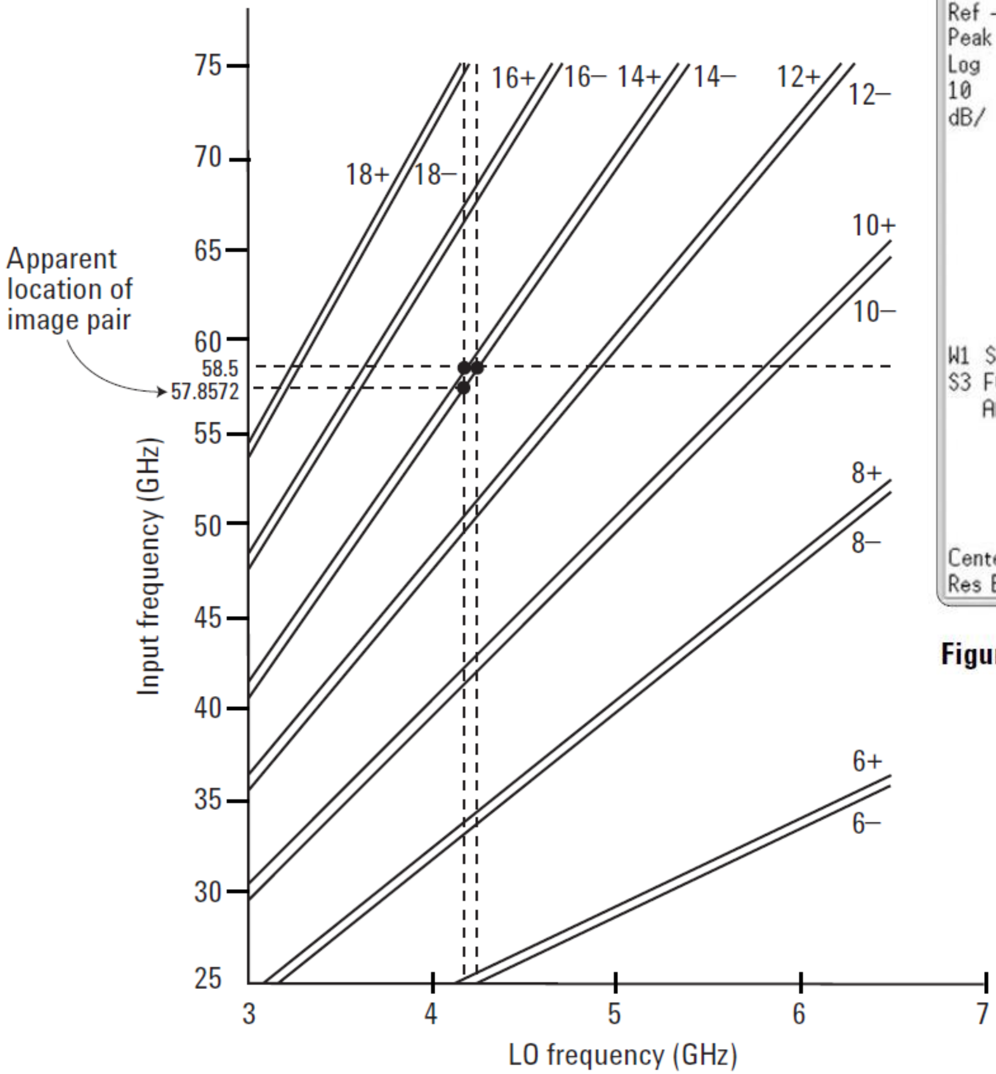


External Mixer

Table 7-1. Harmonic mixing modes used by ESA-E and PSA Series with external mixers

Band	Harmonic mixing mode (N[a])	
	Preselected	Unpreselected
K (18.0 to 26.5 GHz)	n/a	6^{-}
A (26.5 to 40.0 GHz)	8^{+}	8^{-}
Q (33.0 to 50.0 GHz)	10^{+}	10^{-}
U (40.0 to 60.0 GHz)	10^{+}	10^{-}
V (50.0 to 75.0 GHz)	14^{+}	14^{-}
E (60.0 to 90.0 GHz)	n/a	16^{-}
W (75.0 to 110.0 GHz)	n/a	18^{-}
F (90.0 to 140.0 GHz)	n/a	20^{-}
D (110.0 to 170.0 GHz)	n/a	24^{-}
G (140.0 to 220.0 GHz)	n/a	32^{-}
Y (170.0 to 260.0 GHz)	n/a	38^{-}
J (220.0 to 325.0 GHz)	n/a	46^{-}

Image shift



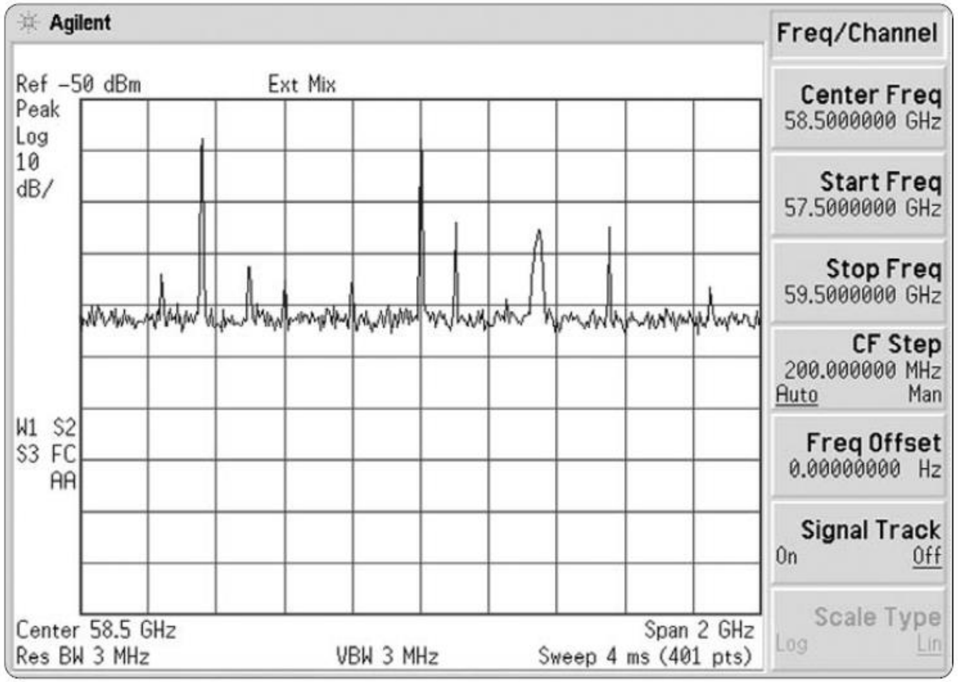
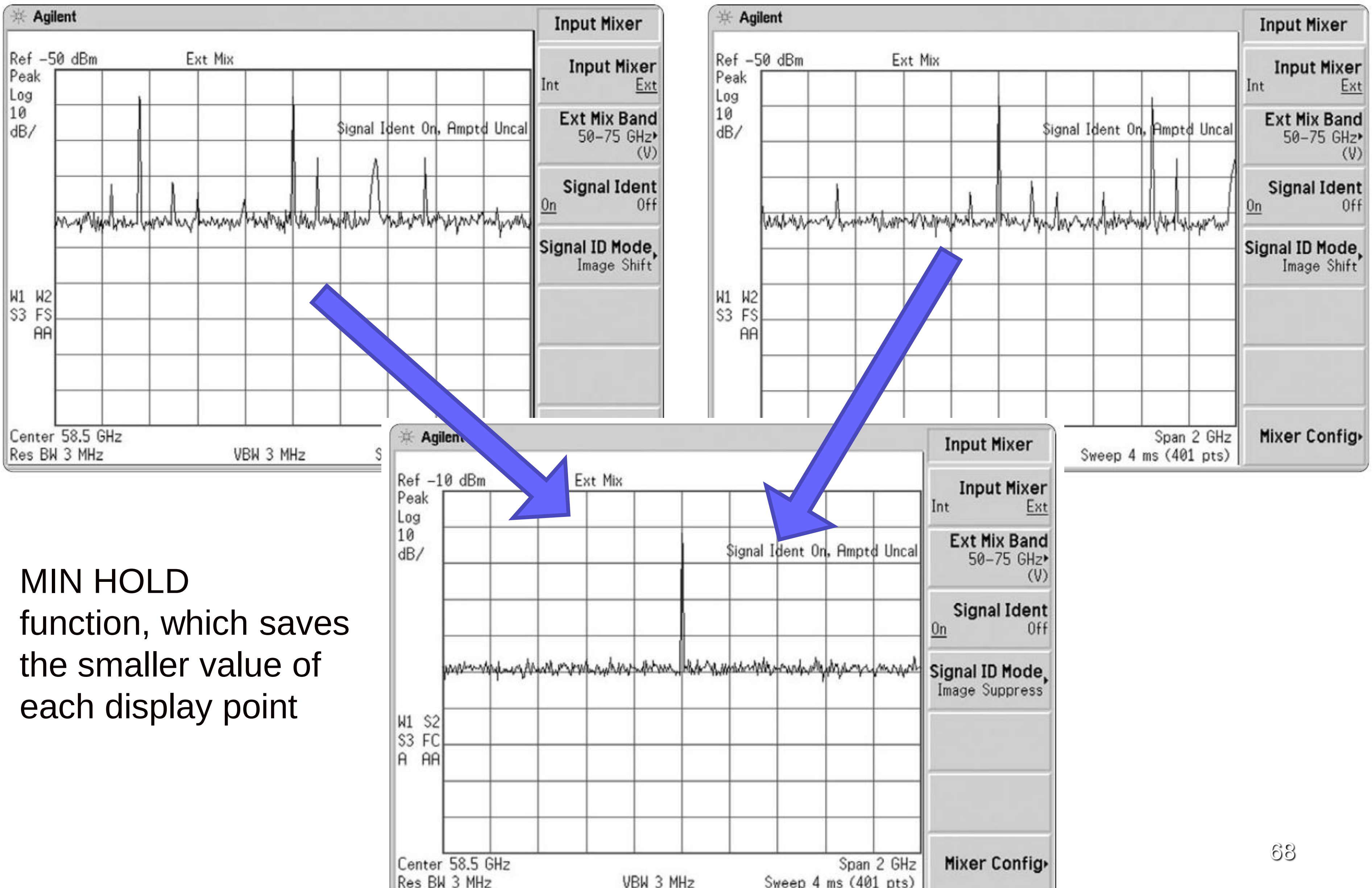


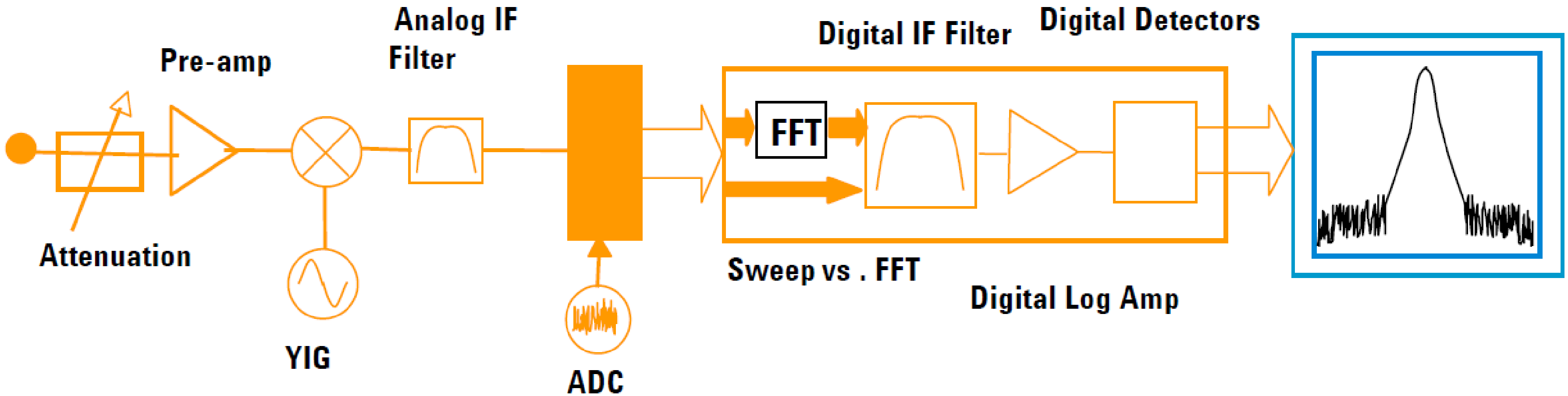
Figure 7-15. Which ones are the real signals?

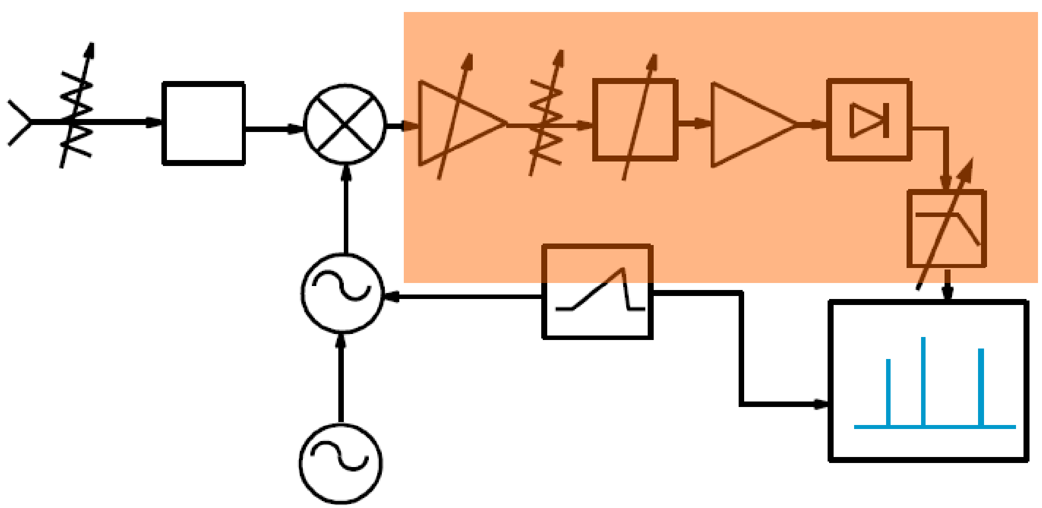
Image suppress



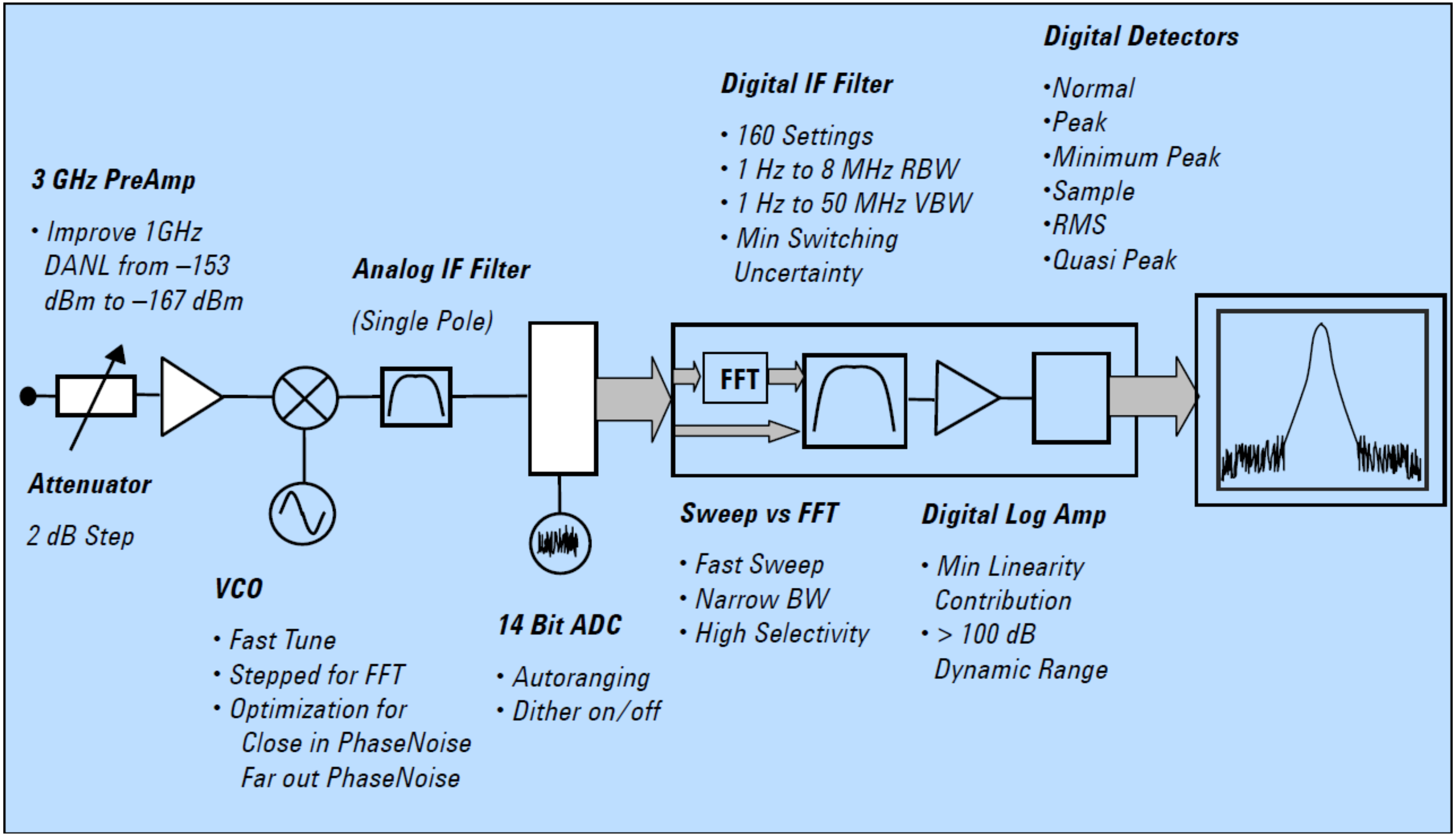
MIN HOLD function, which saves the smaller value of each display point

Modern Spectrum Analyzer: Digital Receiver

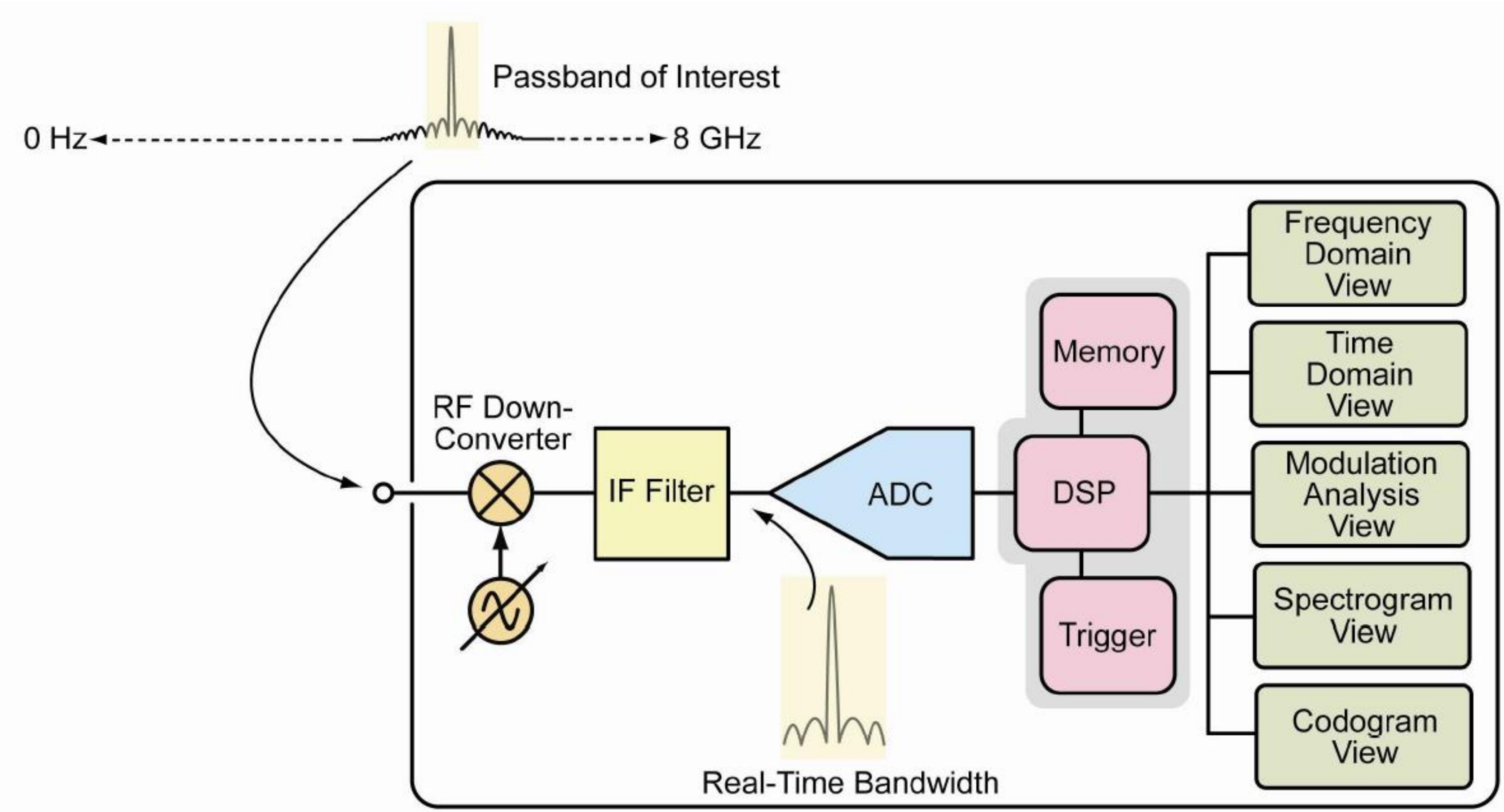




Modern SA block diagram

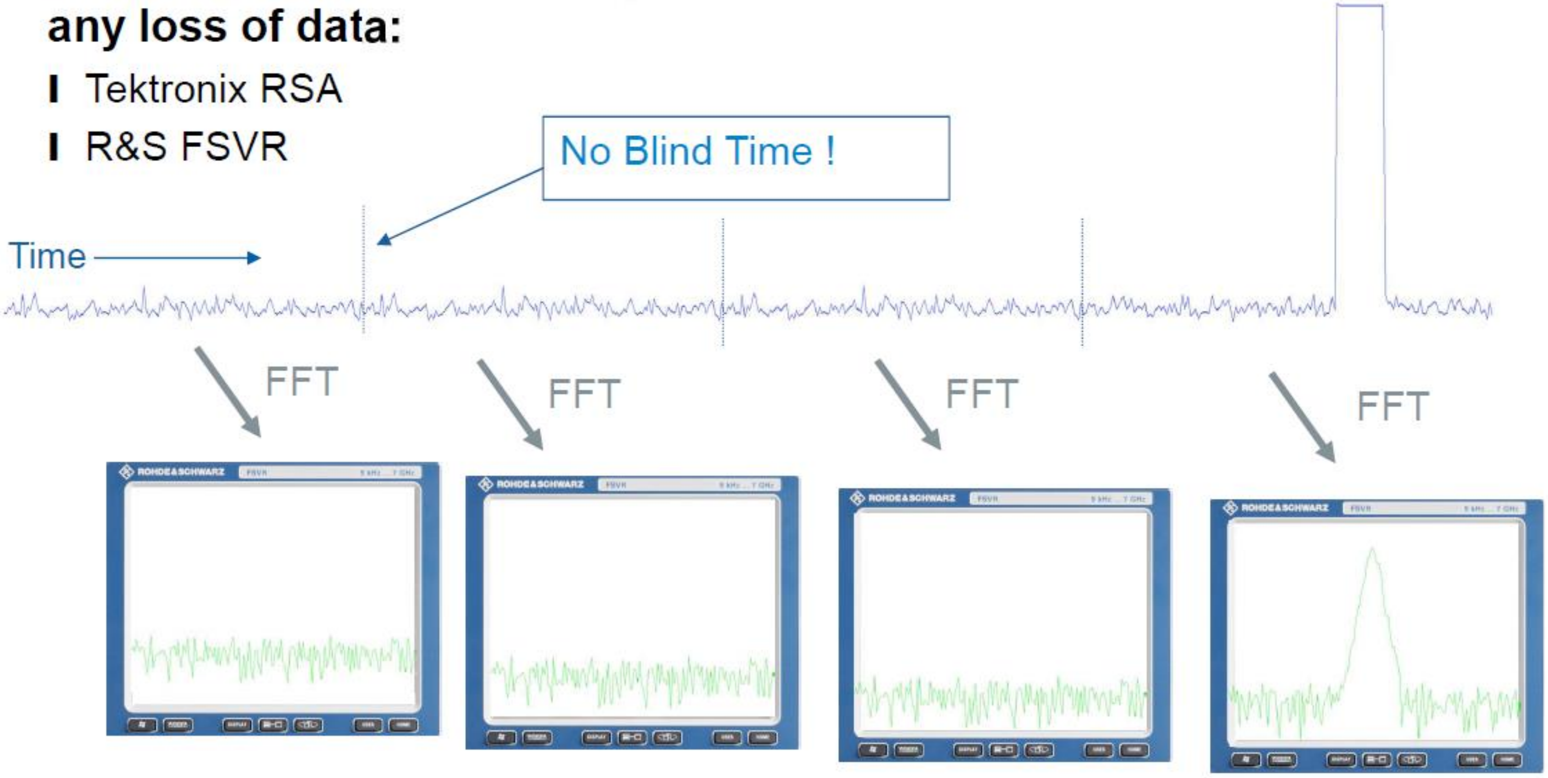


Real-time Architecture



Real-Time

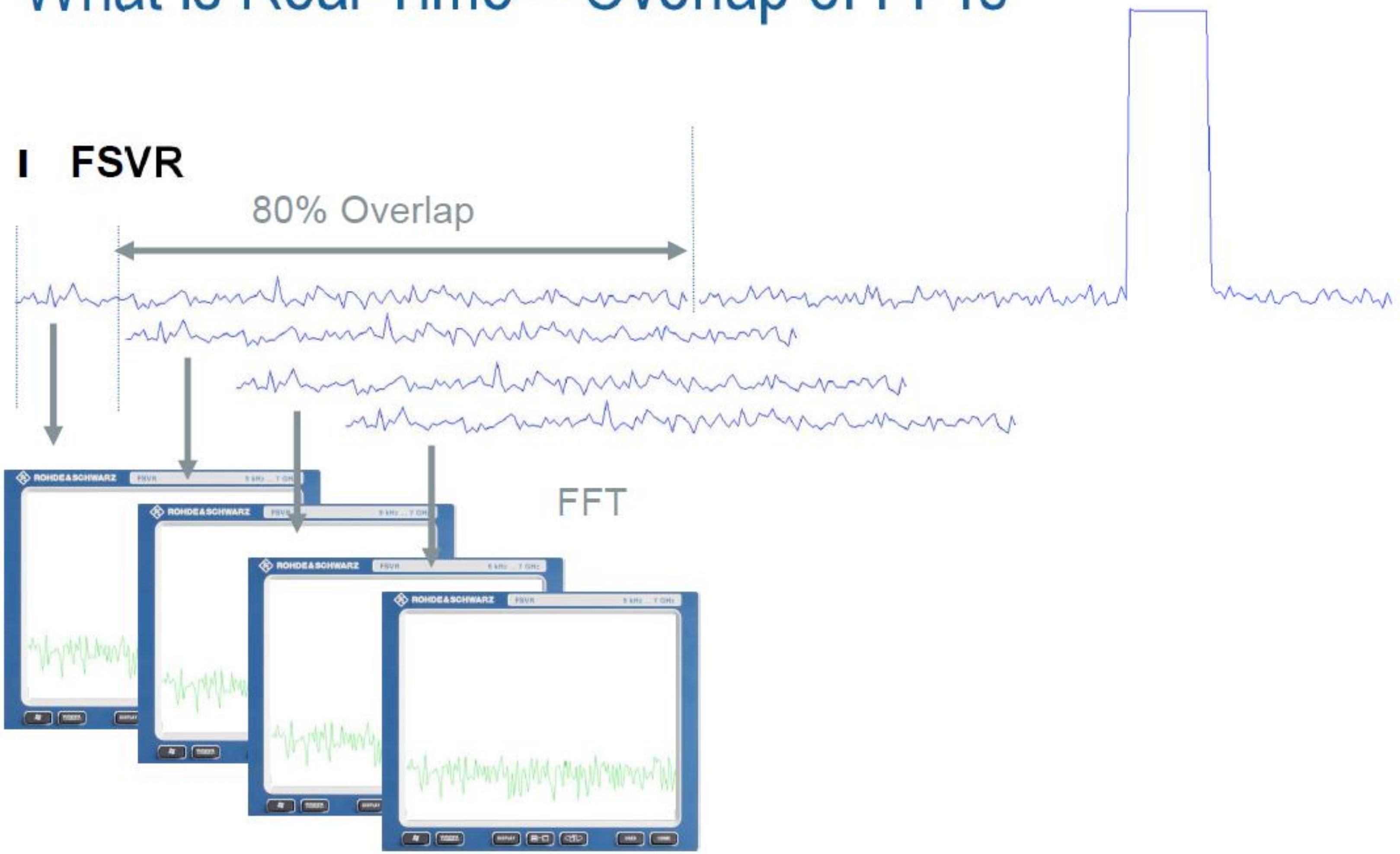
- **A Real-Time spectrum analyzer shows the spectrum without any loss of data:**
  - Tektronix RSA
  - R&S FSVR



Real-Time

What is Real-Time – Overlap of FFTs

- **FSVR**



Measurement Time

The system is no-more swept: the local oscillator is at a fixed frequency and the frequency measurement is made by an FFT technique.

If *SPAN* < *RTB* (real time bandwidth), the measurement time is limited by the frequency resolution:

Acquisition time = *T* = *1 /RBW*

We have to consider also the time needed for the FFT elaboration, but it is often negligible (and some FFTs are made in parallel)

If *SPAN* > *RTB*, the local oscillator is moved for discrete steps, and the screen spectrum is a collage of some FFT results (no more phase coherence in the whole spectrum)

Screen time = *SPAN* / *RTB* × (*1 /RBW)*

For low RBW values it is much faster than swept analyzer (ST ≅ 3SPAN / RTB^2)

New measurement possibilities

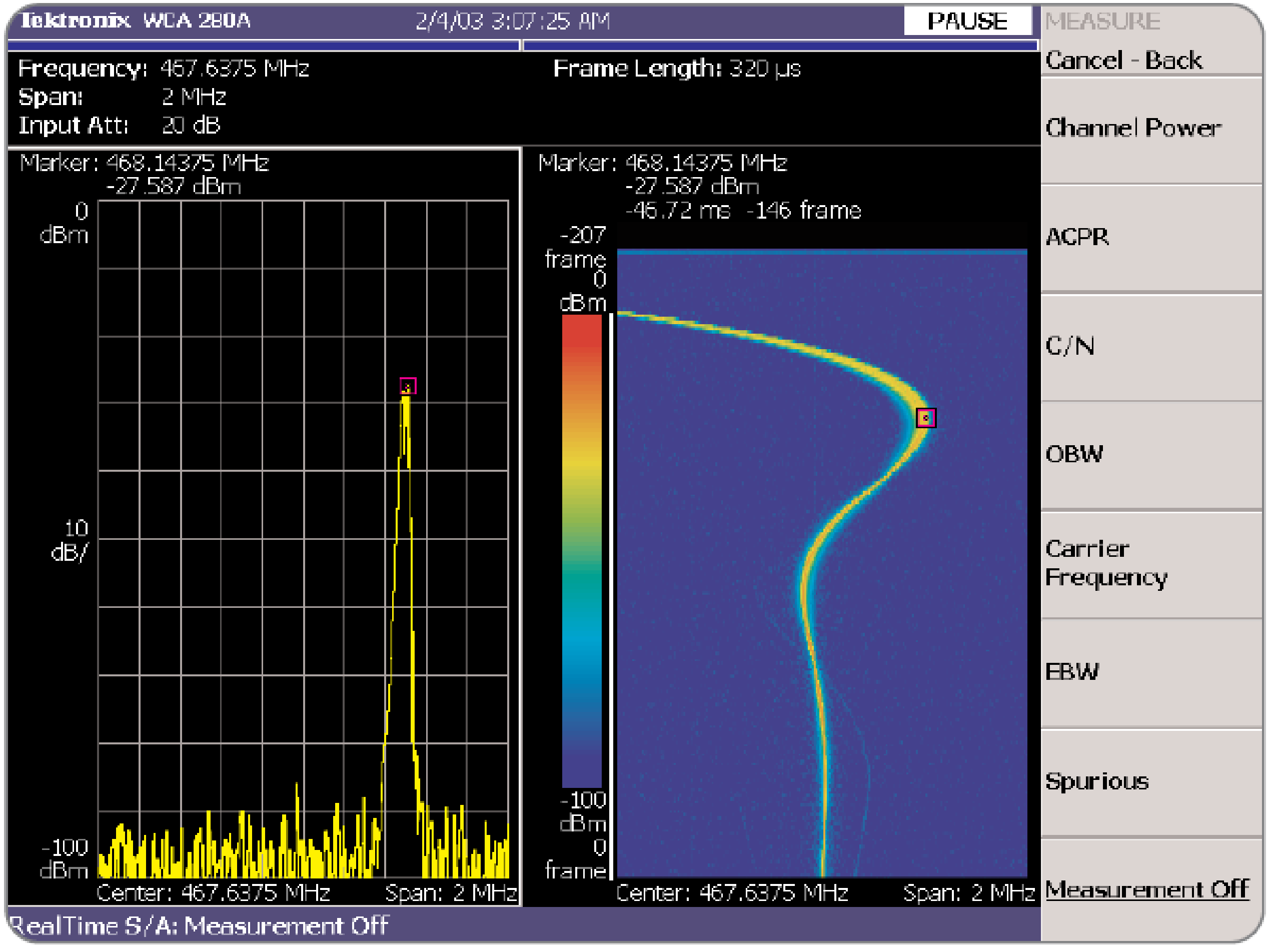


Figure 8. *Analysis of phase-locked loop. Spectrogram (right display) captures PLL response as it settles over time (top to bottom). Vertical axis is Time, horizontal axis is Frequency, and Power Density is represented by color.*

Typical Applications
Find Hidden Signals