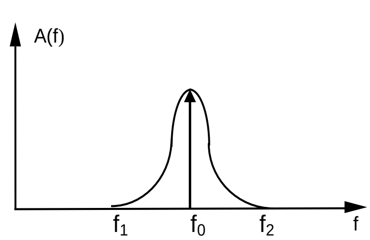
Spectrum Analyzer Parameters

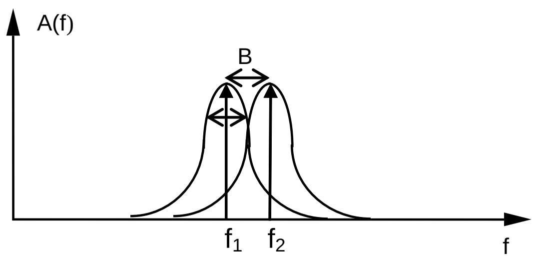
Frequency Resolution

- **The frequency resolution represents the ability of the spectrum analyzer to present on the screen two sinusoids close in frequency and equal in amplitude.**
- **It should be noted that if a single sine wave at frequency f_0 is present at the input, the spectrum analyzer screen shows not a single line but the frequency response of the last amplifier.**
- In fact, if the input signal f_0 is translated to the center of the IF filter for a given f_{LO} value of the local oscillator, a fraction of this signal arrives on the detector even when the local oscillator generates a signal comprised between $f_{LO}-(f_0-f_1)$ e $f_{LO}+(f_2-f_0)$ f_2.



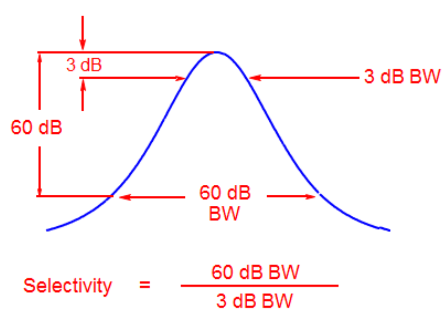
Resolution

- In order for two sinusoidal signals of the same amplitude to be distinct they must be spaced in frequency at least by the 3 dB bandwidth B of the IF filter.
- For this reason, the resolution depends on the bandwidth B of the IF amplifier and, in the case of multiple conversions, the bandwidth B of the last stage.
- **Spectrum analyzers have the possibility of varying the bandwidth of the IF filter and therefore the resolution by a panel command usually indicated as RBW (Resolution Band-Width)**

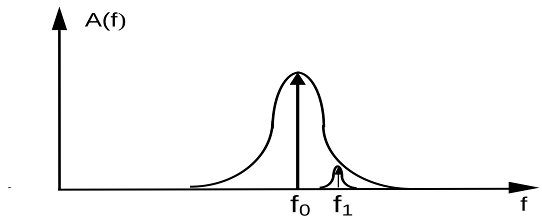


Selectivity

Another parameter that affects the frequency resolution of the spectrum analyzer is the selectivity of the IF filter.
The selectivity (Q) of a filter is defined as the ratio between the B_{60dB} band of the filter at an attenuation of 60 dB and the B_{3dB} band of the filter at 3 dB.

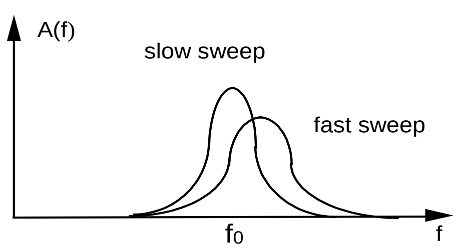


Selectivity



- As can be seen from the figure, a signal at frequency f_1 at a distance from f_0 greater than the 3dB band at the filter is not displayed due to the non-infinite selectivity of the filter itself.
- **The selectivity values of analog filters vary between 11 and 15, while with digital filters it can reach 5. This is one of the reasons that pushes towards the use of digital converters (signal analyzers).**

Sweep Time



In a spectrum analyzer it is also possible to set the sweep time. If the scan is too fast, the output of the filter may not reach its maximum value causing distortion in the output signal. This behavior is shown in the figure for a sinusoid.

Sweep Time

The filter response time is given by:

t_R= k/RBW

while the permanence (stay) time of the spectral line within RBW is given by:

$\Delta F : t_{SWEEP} = RBW : t_{stay}$

t_{stay}= RBW * $t_{sweep}/\Delta F$

where:
ΔF is the frequency range displayed
t_{SWEEP} is the interval scan time

Sweep Time

Obviously it must be:

$t_{PERM} > t_R$

$RBW * t_{sweep}/\Delta F \;>\; k/RBW$

From which it results:

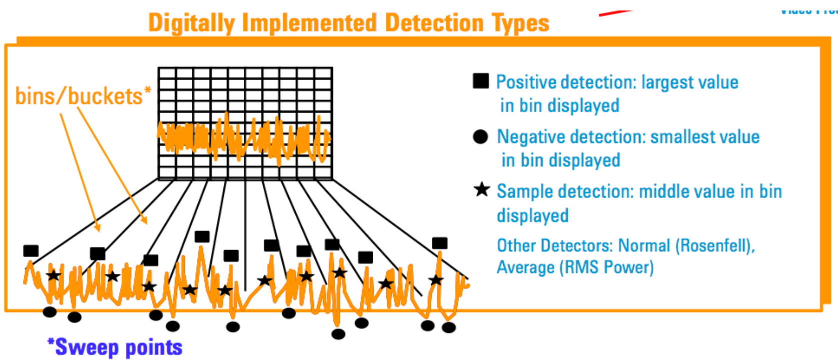
$$t_{SWEEP} \geq \frac{K\,\Delta F}{RBW^2}$$

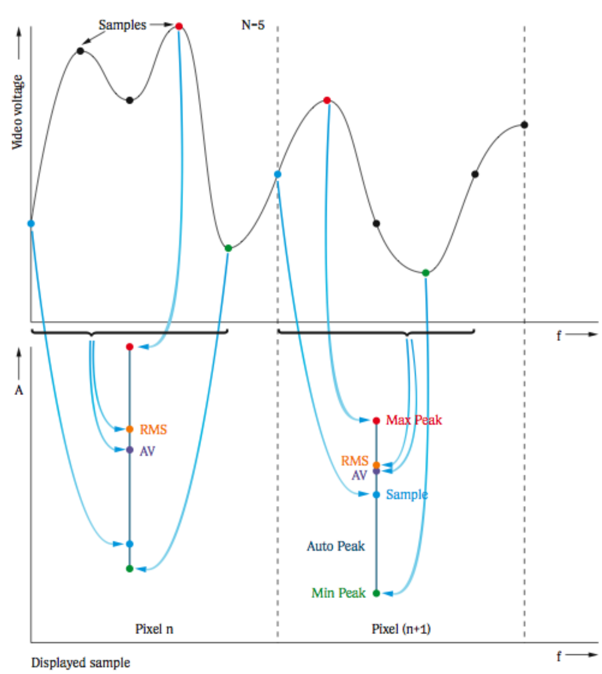
This time is chosen automatically by the spectrum analyzer but can also be changed by the operator (large time = slow speed)

Detector Types

Each pixel of the spectrum analyzer display contains the spectral information of a certain range of frequencies.

The value shown will be:





RMS

$$V_{RMS} = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} v_i^2}$$

$$P = \frac{V_{RMS}^2}{R}$$

AVERAGE

$$V_{AV} = \frac{1}{N} \cdot \sum_{i=1}^{N} v_i$$

Detector Choice

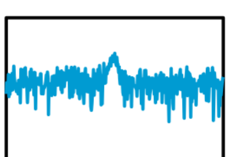
Positive detection: it is typically used to analyze sinusoids while it is not suitable for displaying noise as it does not show real noise fluctuations.

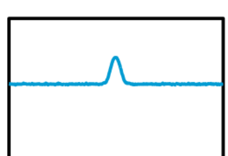
Sample detection: it is used to display noise.

normal mode, or rosenfell mode: it is used for signals in the presence of noise. In this mode, if the signal rises and falls in the bin it is assumed to be noise and pos & neg det are used alternately. Conversely, if the signal grows in the bin it is assumed to be a signal and the **pos det** is used.

Video Bandwidth

- The video amplifier placed after the detector filters the signal and eliminates the random noise superimposed to the signal to be displayed.
- It is possible to vary the band of this amplifier with a **VBW (Video Band-Width)** command





RBW and VBW

The VBW must be set according to the RBW and the particular application

For measurements of sinusoidal signals with high SNR a VBW approximately equal to RBW must be selected (RBW / VBW = 0.3 ÷ 1)

To obtain stable results in noise measurements one must select a low VBW (RBW / VBW = 10)

Sensitivity

Sensitivity is a measure of the analyzer's ability to detect low amplitude signals.

The sensitivity is limited by the noise of the instrument. The noise can be quantified by means of the noise factor F :

$$F = \frac{S_i / N_i}{S_o / N_o}$$

The sensitivity of an analyzer is evaluated in the condition in which the available power of the output signal equals that of the noise ie:

$$S_o / N_o = 1$$

Sensitivity

It can therefore be said that the sensitivity represents the power of the input signal which gives rise to an output signal with the same power available as the noise:

$$S = FN_i$$

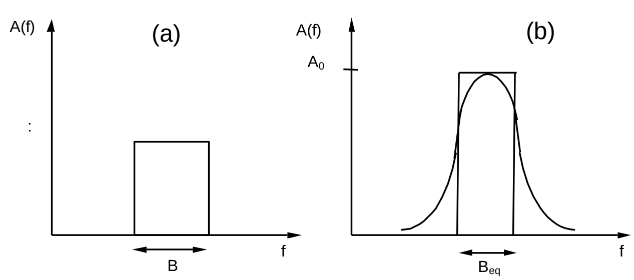
$$N = \frac{\langle V_{ni}^2 \rangle}{4R}$$

$$S = FKTB$$

$$\langle V_{ni}^2 \rangle = 4kTRB$$

Sensitivity

The above result is valid in the case where the band B of the amplifier is of the type of Figure a, in practical cases the situation is instead of the type of Figure b.



The amplification gradually decreases when we move towards the ends of the band.

Sensitivity

In practical applications we introduce an equivalent noise band (B_{eq}) defined as the bandwidth of the ideal (rectangular) response curve of amplitude A or equal to the maximum of the real curve and such that:

$$A_0^2 B_{eq} = \int_0^\infty A(f)^2 df \qquad B_{eq} = \int_0^\infty \frac{A(f)^2}{A_0^2} df$$

In practical cases it is approximately $B_{eq} = 1.2$ B where B is the 3 dB band at of the amplifier.

With this position the sensitivity becomes :

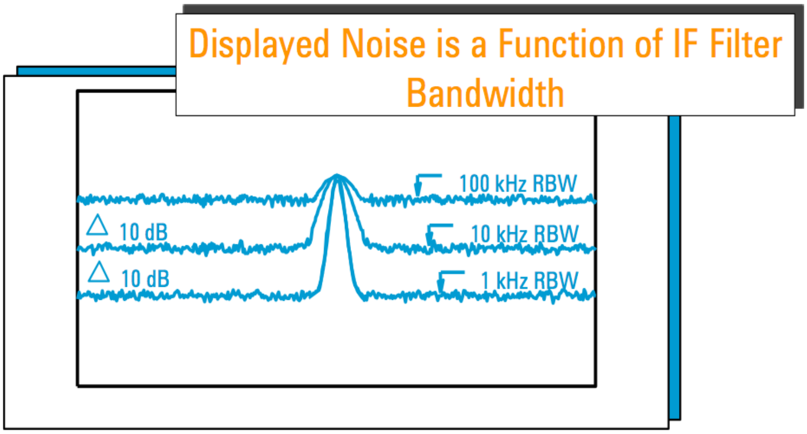
$$S = F\,k\,T\,B_{eq}$$

$$S\,(dBm) = NF(dB) - 174\,(dBm/Hz) + 10\log(B_{eq})$$

Displayed Average Noise Level (DANL)

- One way to characterize the sensitivity of a spectrum analyzer is to provide the displayed average noise level (DANL) which is a function of the RBW.

Displayed Noise is a Function of IF Filter Bandwidth

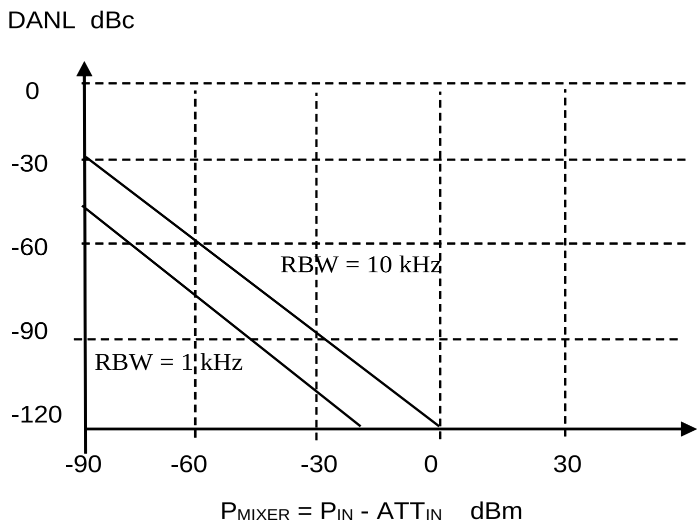


Decreased BW = Decreased Noise

Displayed Average Noise Level (DANL)

- Graphs can be traced which report the DANL with respect to the carrier (DANL dB_C)) as a function of the input power to the mixer given by the difference between the power of the input signal and the attenuation level introduced by the step attenuator. A graph of this type is shown in Figure

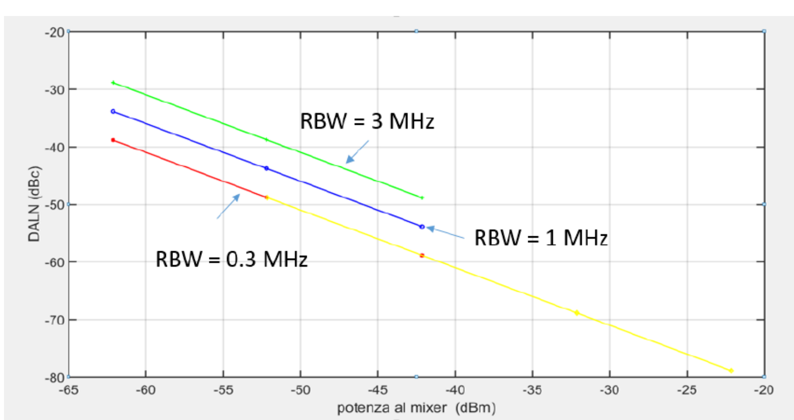
DANL



A signal at f = 1 GHz is set on the R&S generator.

The R&S spectrum Analyzer is set at a central frequency of 1 GHz and a Span of 100 MHz.

We use the Average detector for all measurements.
We measure the signal strength at the peak and the noise 30 MHz far from the carrier.



Monitor

- The spectrum analyzer CPU that manages the sampling process also manages the data display.
- In particular, the CPU manages the video memory consisting of a matrix of MxN positions corresponding to the screen pixels.
- The display of the spectrum on the screen is carried out with repeated readings of the memory.
- With this technique (raster) it is also possible to report on the screen the scales and information on the configuration of the instrument.

Uncertainty

- **With the spectrum analyzer it is possible to carry out both frequency and amplitude measurements**.
- **The uncertainty of frequency measurements** depends on the uncertainty on the frequency reference (VCO). This uncertainty has an initial contribution plus a contribution that depends on the time elapsed since the last calibration of the instrument. Other causes of uncertainty are associated with frequency SPAN, RBW, and other residual factors. Ultimately the maximum difference is given by:
- $\delta f = \pm$ (reading $\times$ a + s% $\times$ frequency SPAN + b% $\times$ RBW + r Hz).
- Therefore, if for example: $a = 1.3\times10^{-7}$, s = 1, b=15 , r = 10, if you measure a 2 GHz signal with a 400 kHz SPAN and RBW = 3 kHz results:
- $\delta f = \pm [(2\times10^{9}) \times(1.3\times10^{-7})$ + 1% $\times$ 400 kHz + 15% di 3 kHz + 10 Hz]
  = $\pm$ (260 + 4000 + 450 + 10) = $\pm$ 4720 Hz
- The measurement is written : f = (2.000.000,0 $\pm$ 4,8) kHz.

Uncertainty

- As far as **amplitude measurements** are concerned, these are divided into **absolute measurements and relative measurements**.
- For example, if a harmonic distortion of an oscillator is to be measured, the value of the second or third harmonic must be evaluated relative to the fundamental.

Uncertainty

- **Absolute amplitude measurements** are performed with respect to the calibration signal that is present inside all the spectrum analyzers.
- This source provides a reference signal with assigned frequency and amplitude (for example 300 MHz, 20 dBm).
- So there will be an **uncertainty related to the accuracy of the calibration source.** Furthermore, as one moves away from this frequency value or the amplitude varies, **frequency and amplitude uncertainty contributions** must be taken into account.

Uncertainty

- Another important cause of error is the **mismatch** between the source and the analyzer input. This mismatch produces an error given by

$$E(dB) = -20 \log [1 \pm |\Gamma_S| |\Gamma_{ANA}|].$$

- Where Γ_S and Γ_{ANA} are the reflection coefficients seen at the input of the source and the spectrum analyzer.

Uncertainty

- **For example if a signal is measured at a frequency of 1 GHz with a power of -30 dBm,**
- based on the analyzer parameters (attenuation, RBW, SPAN, scales), for example, a calibration uncertainty equal to 0.54 dB, frequency response 0.10 dB and amplitude response ± 0.36 dB .
- In this way we obtain a worst case uncertainty given by ± 1 dB = 20-25% in power (the mismatch uncertainty was neglected).
- So the measurement is written: P = (1.00 ± 0.25) μW

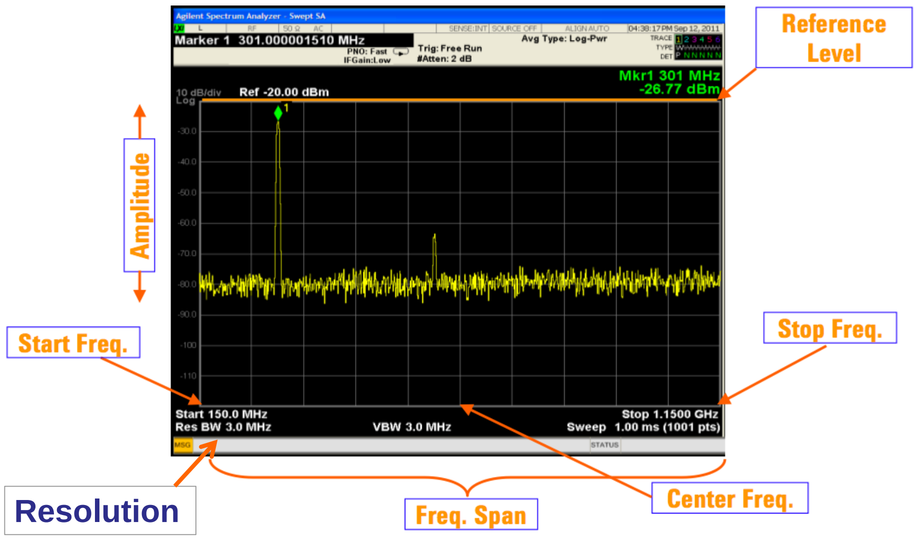
Standard Uncertainty Evaluation

Error Calculation for Rohde & Schwarz Spectrum Analyzers

Inherent errors	unit	s = stand. uncertainty w = worst case	specified error	variance σ_i^2	contribute y = yes , n = no
Absolute error 120 MHz	dB	❶ w	❷ 0.3	0.03 ❸	❹ y
Frequency response	dB	w	0.2	0.01	y
Input attenuator	dB	w	0.2	0.01	y
If gain	dB	w	0.2	0.01	y
Log linearity	dB	w	0.2	0.01	y
Bandwidth switching error	dB	w	0.2	0.01	y
Bandwidth error	%		10.00	0.07	y
Combined variance		$\sigma_{tot}^2 = \sigma_1^2 + \sigma_2^2 + ... + \sigma_n^2$		0.17	
Combined standard uncertainty		$\sigma_{tot} = \sqrt{\sigma_{tot}^2}$		0.41	
Total error **(95% confidence level)**	dB			0.80 ❺	
(99% confidence level)	dB			1.05	
Error due to source mismatch		a = return loss / dB v = VSWR	specified values		
VSWR of SA		❻ v	❼ 3.1		
VSWR of DUT		v	1.57	0.55	
Combined variance		$\sigma_{tot}^2 = \sigma_1^2 + \sigma_2^2 + ... + \sigma_n^2$		0.71	
Combined standard uncertainty		$\sigma_{tot} = \sqrt{\sigma_{tot}^2}$		0.85	
Error including source mismatch **(95%)**	dB			1.66 ❽	
(99%)	dB			2.18	

Spectrum Analyzers Functions

Parameter Setting



Horizontal axis

- The instrument's horizontal axis shows the frequencies that can be assigned by identifying the start and stop frequency of the scan or assigning to the central frequency (f_0) and a symmetrical band around this frequency (frequency span Δf).
- Then there is the **zero span mode** in which the VCO is set to a single frequency so that the signal envelope is represented in the time domain. For example, in the presence of a amplitude modulated carrier, if you select an RBW that includes the sidebands, you can view the modulation. Similarly, in the presence of a frequency-modulated carrier (FM) by positioning f_{LO} on the rising edge of the IF filter it is possible to display the modulating signal. With some spectrum analyzers it is also possible to carry out the Fourier transform (FFT) of the modulated signal.

x Axis (Frequency)

- **Frequency (grid with 10 divisions)**
  - START (Value , Measurement Unit)
  - STOP (Value , Measurement Unit)
  - CENTER (Value , Measurement Unit)
  - SPAN (Value , Measurement Unit)

- **Full Span**
  - View all available bandwidth

- **Zero Span**
  - demodulator

X Axis

- **Sweep time**
  - Continuous, Single

- **Resolution Bandwidth (RES BW, RBW)**

  1 – 3 – 10 – 30 - 100 etc. (between 30 Hz e 3 MHz)

  auto/man

- **Video Bandwidth (VID BW, VBW)**

  1 – 3 – 10 – 30 - 100 etc.

  auto/man

- **VBW/RBW RATIO**

Vertical Axis

- The vertical scale can be set in volts per division (V/div) or in dB per division (dB / div).
- In the latter case, the 0 dBm level is usually positioned on the high end of the screen
- The vertical scale can be adjusted for discrete values or continuously by acting on the variable attenuator, located at the analyzer input, or on the gain of the intermediate frequency amplifiers.

Y Axis (Amplitudes)

- **Scale (grid with 8 divisions)**
  - Log, Lin (dB/div can be varied)
- **Ref. Level**
  - upper grid value
- **Attenuation (Auto/Manual)**
  - Adds an incoming attenuation which it automatically takes into account
- **Unità di misura**
  - dBm, dBmV, dbμV, Volt, Watt

Marker

- **Marker**
  - Normal: Marker 1, Marker 2, etc.
  - Delta
- **Marker function**
  - Marker center, start stop , etc.
    - change the x scale to bring the marker where selected
- **Peak Search**
  - Max, Min, Next Peak, Bandwidth, etc..

- **Video Avg**
  - Average of traces
- **Trace**
  - Max hold
- **Measurement**
  - % AM
  - TOI