Corso di Laboratorio di misure ad alta frequenza

Introduzione all'analizzatore di spettro: principio di funzionamento e principali applicazioni

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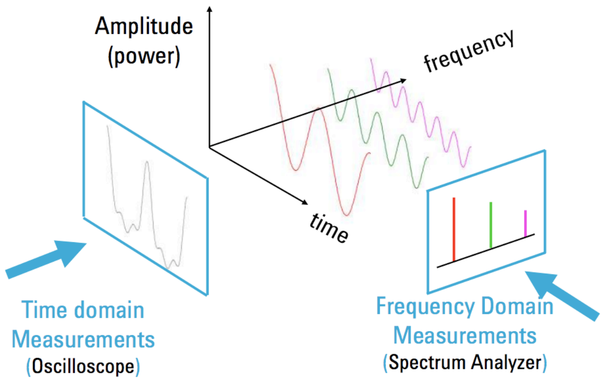
Definizione

Spectrum Analyzer

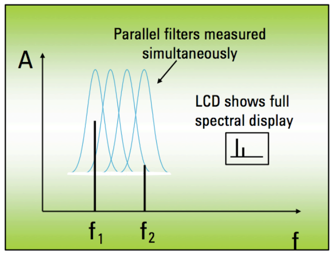
– "A spectrum analyzer measures the magnitude of an input signal versus frequency within the full frequency range of the instrument. The primary use is to measure the power of the spectrum of known and unknown signals."

Analisi nel dominio della frequenza

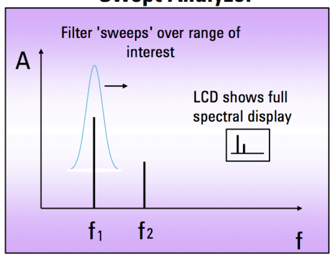


Tipi di analizzatori

FFT Analyzer



Swept Analyzer



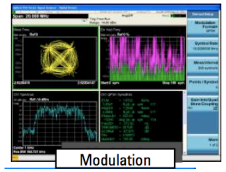
The Fourier analyzer basically takes a time-domain signal, digitizes it using digital sampling, and then performs the mathematics required to convert it to the frequency domain. It is as if the analyzer is looking at the entire frequency range at the same time using parallel filters measuring simultaneously.

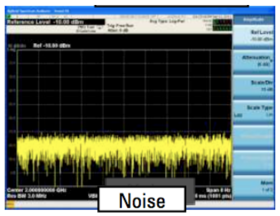
The most common type of spectrum analyzer is the swept-tuned receiver. The technique most widely used is superheterodyne. Heterodyne means to translate frequency -and super refers to super-audio frequencies. Very basically, these analyzers "sweep" across the frequency range of interest, displaying all

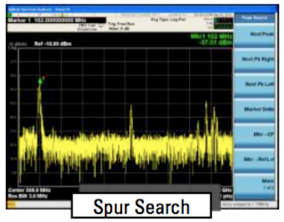
Applicazioni

Frequency, power, modulation, distortion & noise

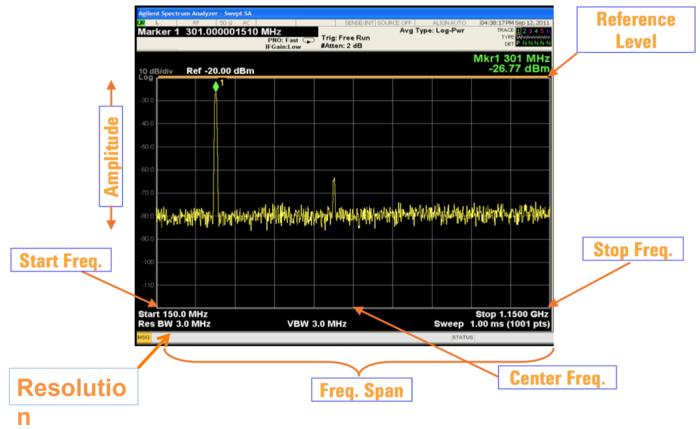
- Spectrum monitoring
- Spurious emissions
- Scalar network analysis
- Noise figure & phase noise
- Harmonic & intermodulation distortion
- Analog, digital, burst & pulsed RF Modulation
- Wide bandwidth vector analysis
- Electromagnetic interference



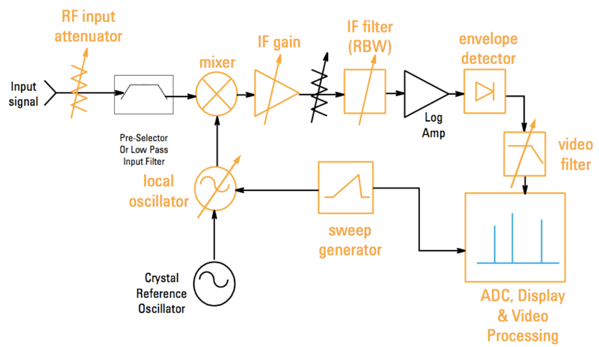




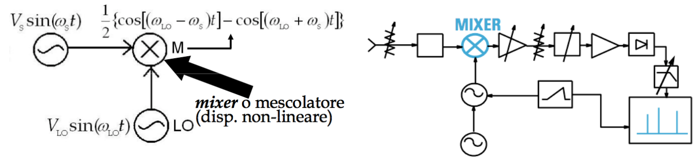
Settaggio dei parametri

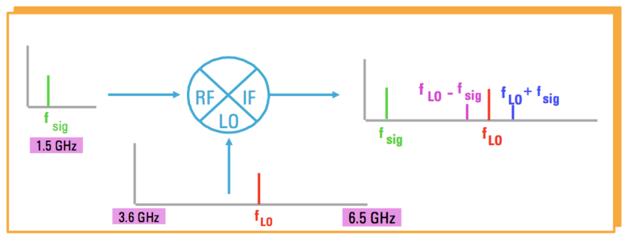


Funzionamento analizzatore di spettro supereterodina: schema a blocchi

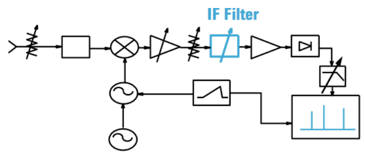


Mixer





Filtro IF



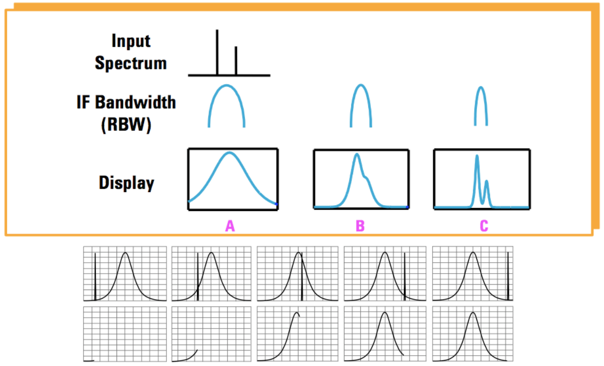
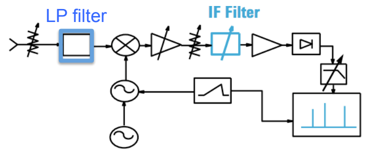


Figure 2-6. As a mixing product sweeps past the IF filter, the filter shape is traced on the display

Il problema della frequenza immagine

$$|f_{LO} \pm f_{in}| = f_{IF}$$



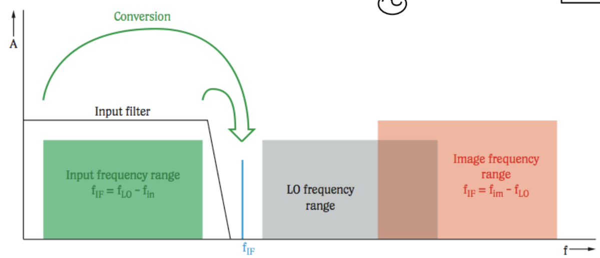
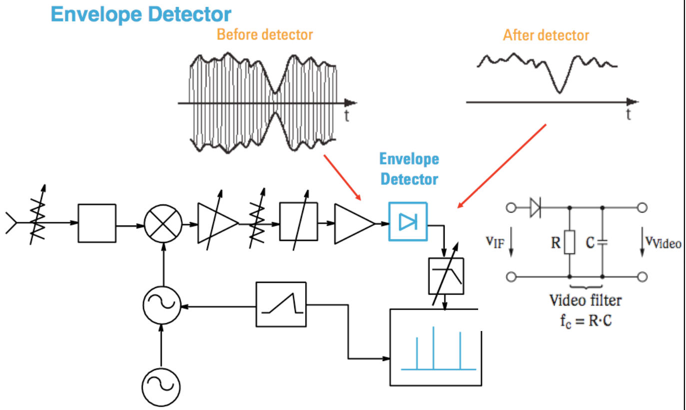


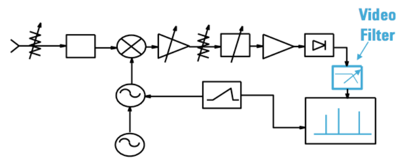
Fig. 4-4 Principle of high intermediate frequency

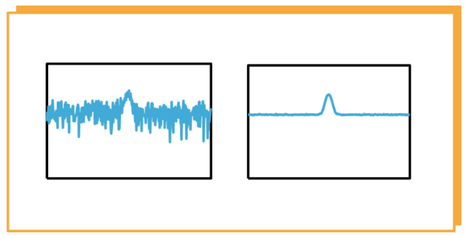
Envelope detector



Video filter

The video filter is a a first order low-pass filter after the envelope detector and before the ADC. This filter is used to average or smooth the trace seen on the screen. By changing the video bandwidth (VBW) setting, we can decrease the peak-to- peak variations of noise.

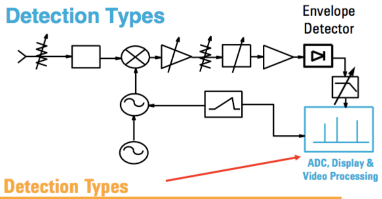


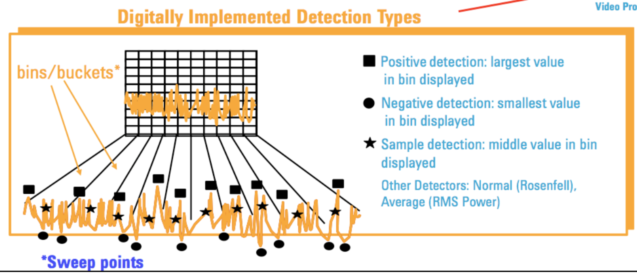


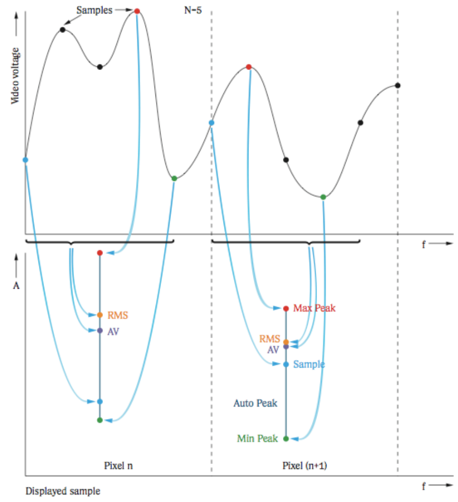
Visualizzazione dei campioni

Envelope Detector and Detection Types

Particularly when large spans are displayed, one pixel contains the spectral information of a relatively large subrange.







RMS

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

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

AVERAGE

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

Scelta del detector

Positive detection mode is typically used when analyzing sinusoids, but is not good for displaying noise, since it will not show the true randomness of the noise.

In **sample detection**, a random value for each bin is produced. This is best for looking at noise or noise-like signals. For burst or narrowband signals, it is not a good mode to use, as the analyzer might miss the signals of interest.

When displaying both signals and noise, the best mode is the **normal mode**, or the rosenfell mode. This is a "smart" mode, which will dynamically change depending upon the input signal. For example, if the signal both rose and fell within a sampling bin, it assumes it is noise and will use pos & neg det alternately. If it continues to rise, it assumes

RBW e VBW

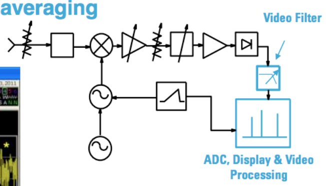
The VBW has to be set as a function of the resolution bandwidth and the specific measurement application.

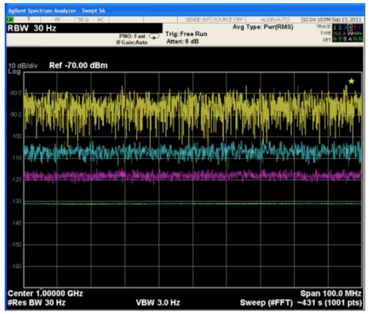
- For measurements on sinusoidal signals with high SNR a VBW equal to the RBW is usually selected.
- With a low SNR, the display can be stabilized by reducing the VBW.
- To obtain stable and reproducible results of noise measurements, a narrow video bandwidth should be selected.
- Averaging should be avoided when making measurements on pulsed signals. Pulses have a high peak and a low average value. In order to avoid too low display levels, the VBW should be selected much greater than the RBW.

• Sine	RBW/VBW = 0.3 to 1
• Pulse	RBW/VBW = 0.1
• Noise	RBW/VBW = 10

Video filter vs. trace averaging

Video Filter vs. Trace/Video averaging

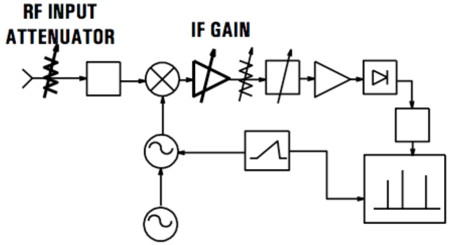




Trace averaging for 1, 5, 20, and 100 sweeps, top to bottom (trace position offset for each set of sweeps)

- Video Filter operates as the sweep progresses, sweep time may be required to slow down by the transient response of the VBW filter.
- Trace/Video Average takes multiple sweeps, sweep time for each sweep is not affected
- Many signals give the same results with either video filtering or trace averaging

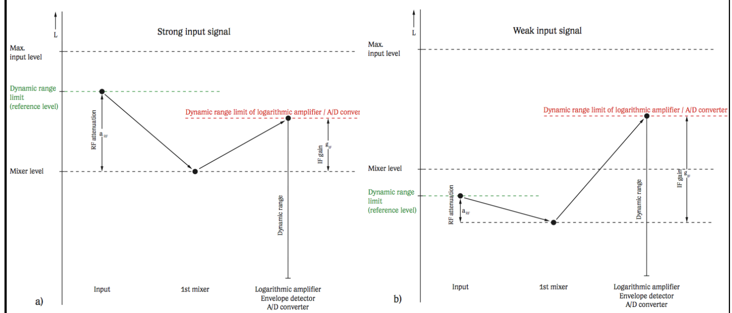
RF input attenuator-IF gain



The RF input attenuator is used to adjust the level of the signal incident upon the first mixer. This is important in order to prevent mixer gain compression and distortion due to high-level and/or broadband signals.
The IF gain is used to adjust the vertical position of signals on the display without affecting the signal level at the input mixer. When changed, the value of the reference level is changed accordingly. Since we do not want the reference level to change (i.e. the vertical position of displayed signals) when we change the input attenuator, these two components are tied together. The IF gain will automatically be changed to compensate for input attenuator changes, so signals remain stationary on the LCD display, and the reference level is not changed.

RF input attenuator-IF gain

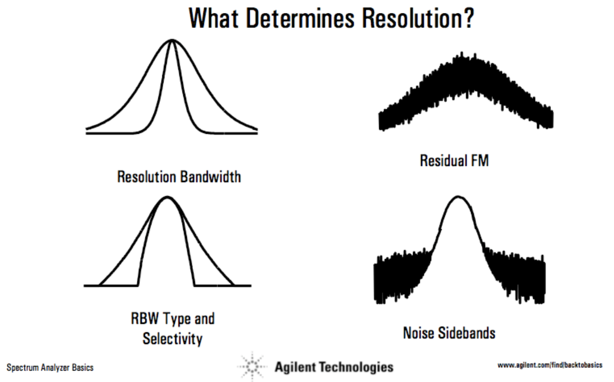
The user selects the reference level (maximum signal level to be displayed). The RF attenuation and the IF gain are automatically adjusted as a function of the reference level



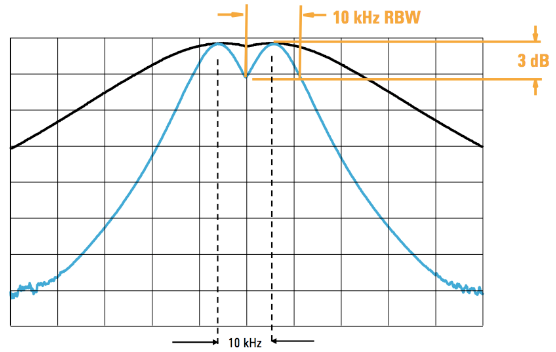
Specifiche

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

Risoluzione



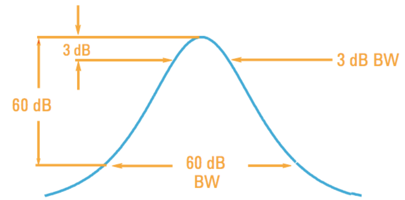
Resolution bandwidth



Determines resolvability of equal amplitude signals

Two equal-amplitude signals can be resolved if their separation is greater than or equal to the 3 dB bandwidth of the selected resolution bandwidth filter.

Fattore di forma

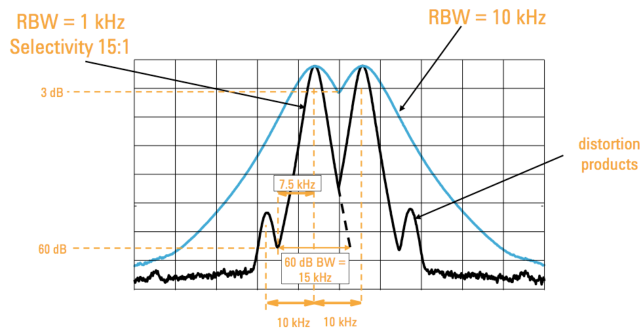


$$\text{Selectivity} = \frac{60\ \text{dB BW}}{3\ \text{dB BW}} \qquad SF_{60/3} = \frac{B_{60dB}}{B_{3dB}}$$

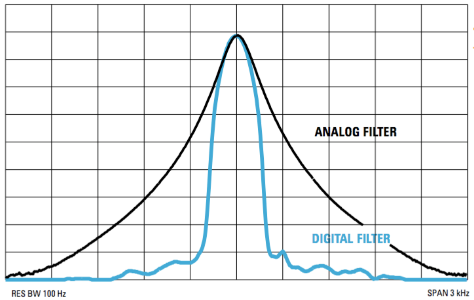
Determines resolvability of unequal amplitude signals

Fattore di forma

Two-tone test where the signals are separated by 10 kHz. With a 10 kHz RBW, resolution of the equal amplitude tones is not a problem. But the distortion products, which can be 50 dB down and 10 kHz away, could be buried. Two signals unequal in amplitude by 60 dB must be separated by at least one half the 60 dB bandwidth to resolve the smaller signal.



Filtri analogici e digitali



Typical Selectivity

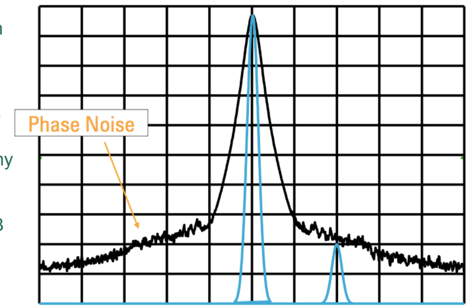
Analog 15:1

Digital ≤5:1

Rumore di fase

Resolution: Noise Sidebands

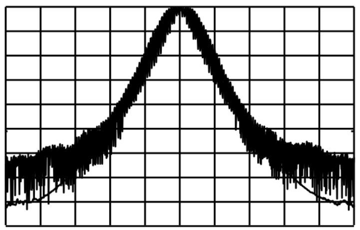
No oscillator is perfectly stable. All are frequency or phase modulated by random noise. Instability in the LO is transferred to any mixing products resulting from the LO and input signals. So the LO phase-noise modulation sidebands appear around any spectral component on the display. Phase noise is specified in terms of dBc (dB relative to a carrier) and normalized to a 1 Hz noise power bandwidth. It is specified at specific frequency offsets or a curve is given to show the phase noise over a range of offsets.



Noise Sidebands can prevent resolution of unequal signals

Modulazione FM residua

In early spectrum analyzer designs, oscillators had residual FM of 1 kHz or more. This instability was transferred to any mixing products and it was not possible to determine whether the input signal or the LO was the source of this instability. The minimum resolution bandwidth is determined, at least in part, by the stability of the first LO. However, modern analyzers have dramatically improved residual FM. This allows bandwidths as low as 1 Hz. So any instability we see on a spectrum analyzer today is due to the incoming signal.

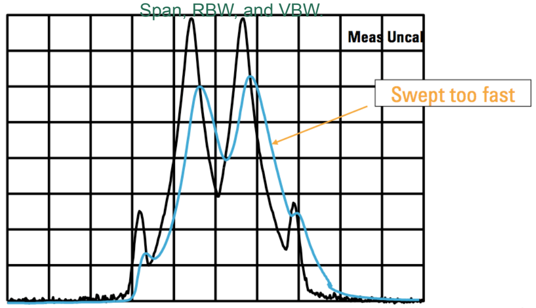


Residual FM "Smears" the Signal

Spectrum Analyzer Basics Agilent Technologies www.agilent.com/find/backtobasics

Sweep time

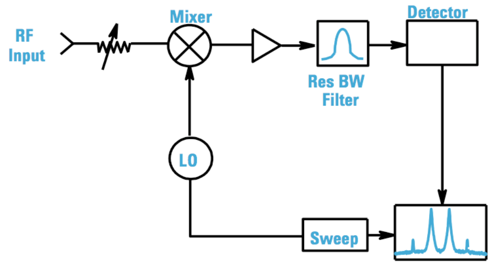
If sweep time is too short, the RBW filters cannot fully respond, and the displayed response becomes uncalibrated both in amplitude and frequency - the amplitude is too low and the frequency is too high. Spectrum analyzers have auto-coupled sweep time which automatically chooses the fastest allowable sweep time based upon selected Span, RBW, and VBW.



Penalty For Sweeping Too Fast Is An Uncalibrated Display

$$T_{Sweep} = k \cdot \frac{\Delta f}{B_{IF}^2}$$

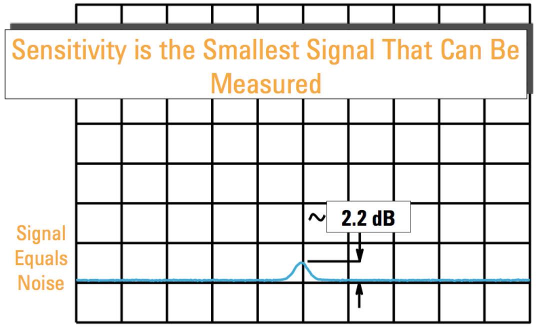
Sensibilità



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

Sensibilità

Sensitivity is the Smallest Signal That Can Be Measured

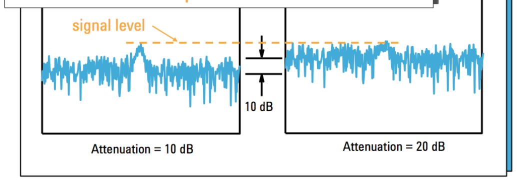


Displayed average noise level (DANL)

DANL in dBm, with the smallest RBW setting

An input signal below this noise level cannot bedetected

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

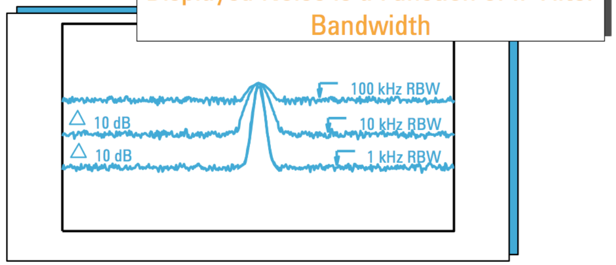


Signal To Noise Ratio Decreases as RF Input Attenuation is Increased

Since the internal noise is generated after the mixer, the RF input attenuator has no effect on the actual noise level. However, the RF input attenuator does affect the signal level at the input and therefore decreases the signal-to-noise ratio (SNR) of the analyzer. The best SNR is with the lowest possible RF input attenuation

Sensibilità e RBW

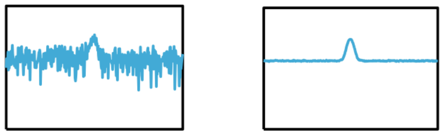
Displayed Noise is a Function of IF Filter Bandwidth



Decreased BW = Decreased Noise

Sensibilità e VBW

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



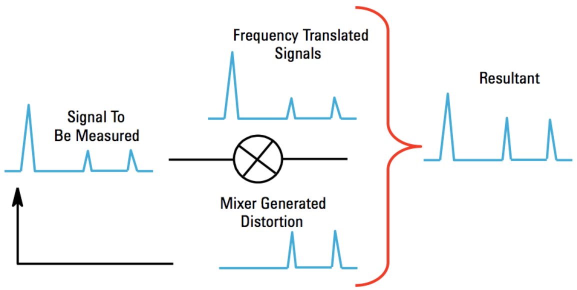
Migliore sensibilità

For Best Sensitivity Use:

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

Distorsione

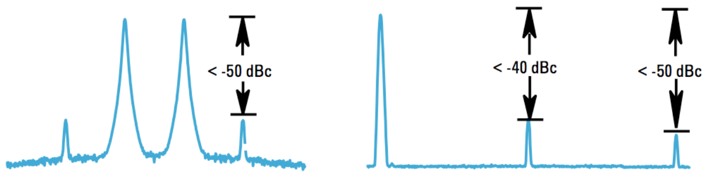
Mixers Generate Distortion



Although distortion measurements, such as third order intermodulation and harmonic distortion, are common measurements for characterizing devices, the spectrum analyzer itself will also produce distortion products, and potentially disturb your measurement.

Distorsione

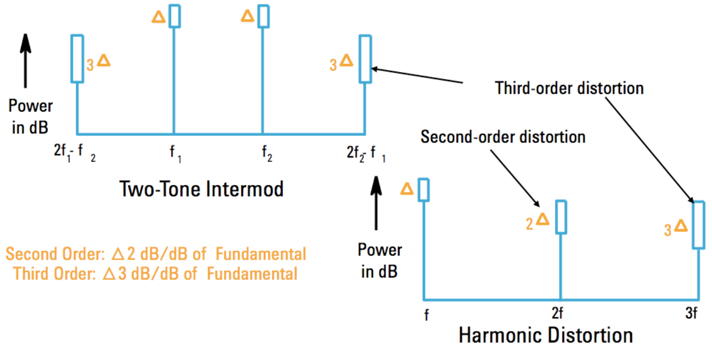
Most Influential Distortion is the Second and Third Order



Two-Tone Intermod

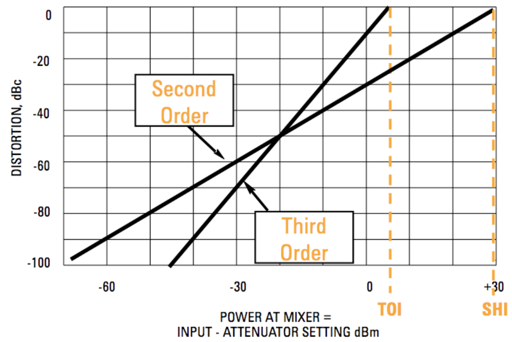
Harmonic Distortion

Distorsione



Distorsione

Distortion is a Function of
Mixer Level



Third order

Distortion test

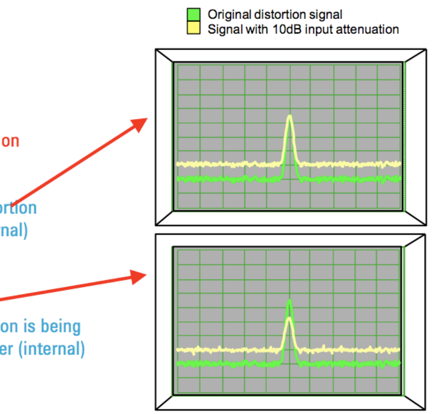
Distortion – Internal or External?

Attenuator Test:
Change power to the mixer

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

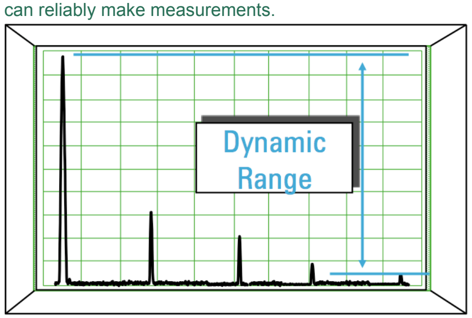
No change in amplitude: distortion is part of input signal (external)

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



Dinamica

The dynamic range of the instrument determines the amplitude range over which we can reliably make measurements.

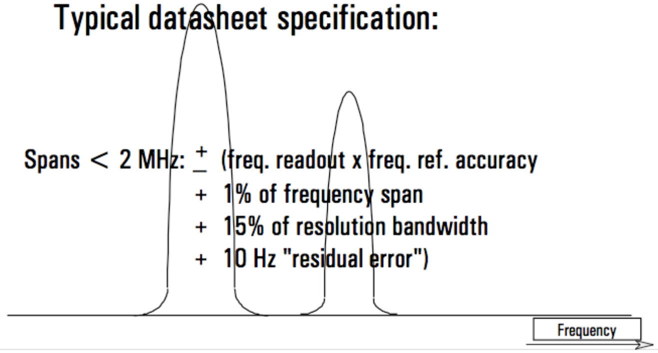


The ratio, expressed in dB, of the largest to the smallest signals simultaneously present at the input of the spectrum analyzer that allows measurement of the smaller signal to a given degree of uncertainty.

- **What settings provide the best sensitivity?**
  - **Narrowest resolution bandwidth**
  - **Minimal input attenuation**
  - **Sufficient averaging**
- **How do you test for analyzer distortion?**
  - **Increase the input attenuation and look for signal amplitude changes**
  - **Then set the attenuator at the lowest setting without amplitude change**
- **What determines dynamic range?**
  - **Analyzer distortion, noise level, and sideband/phase noise**

Incertezza lettura in frequenza

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")

Esempio

Single Marker Example:

2 GHz
400 kHz span
3 kHz RBW

Calculation:	$(2\times10^{9}$Hz) x $(1.3\times10^{-7}$/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

Incertezza lettura livello

- ABSOLUTE ERROR (CALIBRATOR)
  è definito per fissati valori di riferimento
- FREQUENCY RESPONSE
  se la frequenza è diversa dalla sorgente interna
- LINEARITY (DISPLAY FIDELITY)
  dovuta principalmente al log-amplif. Dipende dal livello rispetto al livello riferimento
- ATTENUATOR
- IF GAIN ERROR (ERROR OF REFERENCE LEVEL)
- BANDWIDTH SWITCHING
- BANDWIDTH ERRORS
- MISMATCH ERROR

Misura assoluta

- ABSOLUTE ERROR
- FREQUENCY RESPONSE (se la frequenza è diversa da quella di calibrazione)
- ATTENUATOR (se l'attenuazione è diversa da quella specificata nell'abs. err.)
- IF GAIN (se il ref. level è diverso da quello specificato nell'abs. err.)
- LINEARITY (dipende da quanto il segnale è lontano dal ref. lev.)
- BANDWIDTH SWITCHING (se la RBW è diversa da quella specificata nell'abs. err.)

Misura relativa

- FREQUENCY RESPONSE (se la frequenza varia molto nelle due misure)
- ATTENUATOR (si ignora se l'attenuazione non varia nelle due misure)
- IF GAIN (si ignora se il ref. lev. non varia nelle due misure)
- LINEARITY
- BANDWIDTH SWITCHING (si ignora se la RBW non varia nelle due misure)

Errori in misure tipiche

Error contribution \ Measurement	Absolute level of CW signal	Harmonic distortion	3rd order intermodulation products (close to carrier)	3rd order intercept	Channel power	Adjacent-channel power ratio	Power versus time (e.g. for TDMA signals), relative	Phase noise, far off carrier, with variation of RF attenuation and reference level	Phase noise, close to carrier
Absolute error	•			•	•				
Frequency response	•	•		•	•				
Attenuator error	•			•	•			•	
IF gain error	•			•	•			•	
Linearity error	•	•	•	•	•	•	•	•	•
Bandwidth switching error	•			•	•				
Bandwidth error					•	•		•	•
Error due to limited number of samples					•	•			
Mismatch error	•	•		•	•				

Table 5-2 Error contributions in typical measurements using a spectrum analyzer

Calcolo incertezza standard

Error Calculation for Rohde & Schwarz Spectrum Analyzers

Inherent errors	unit	s = stand. uncertainty w = worst case (1)	specified error (2)	variance σ_i^2 (3)	contribute y = yes, n = no (4)
Absolute error 120 MHz	dB	w	0.3	0.03	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 (5)	
(99% confidence level)	dB			1.05	
Error due to source mismatch		a = return loss / dB v = VSWR	specified values		
VSWR of SA		(6) v	(7) 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 (8)	
(99%)	dB			2.18	