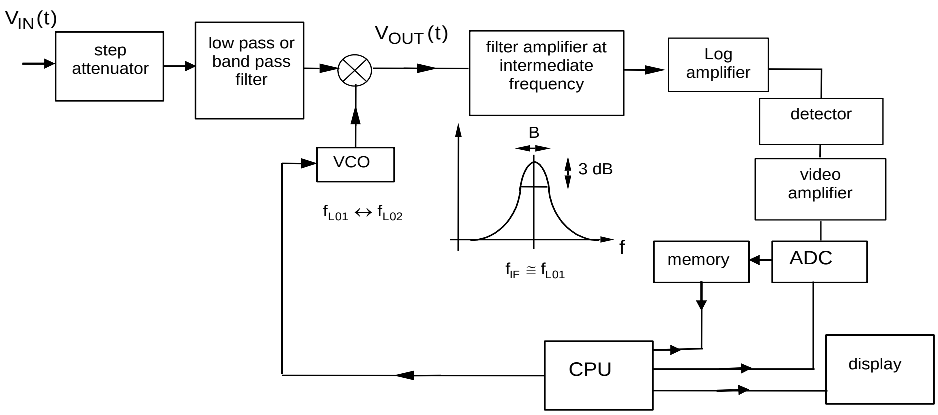
Spectrum Analyzers

Spectrum Analyzer

- The spectrum analyzer is an instrument that provides a representation of the signal in the frequency domain, unlike an oscilloscope that provides a representation of the signal in the time domain.
- Both instruments require a periodic input signal to be able to present a stable signal on the screen.
- The main advantage of the spectrum analyzer is that it reach **sensitivities of the order of μV**, therefore higher than those of the **oscilloscope (mV).**
- This is due to the fact that the spectrum analyzer, despite is able to cover a frequency range, depending on the models, between 10 kHz and 100 GHz, must be considered a narrow band instrument and therefore with low noise. In contrast, the oscilloscope, being a broadband device, finds its main limitation in the noise.

Spectrum Analyzer Structure



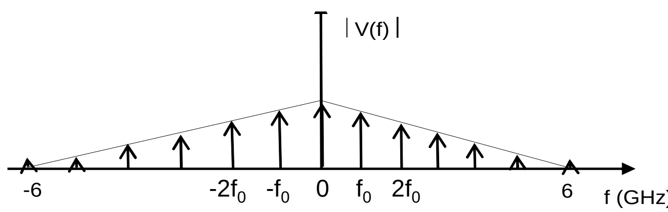
- In these systems, local oscillators based on sweep YIG resonators or indirect synthesis are used. In this case, to avoid losing information, we choose a frequency step (quartz) lower than the resolution bandwidth (eg 0.1 B)

- The step attenuator is used to prevent the mixer from working out of its dynamic range

- After the IF filter the signal is amplified and compressed on a logarithmic scale to be adapted to the dynamics of the detector

Periodic Input Signal

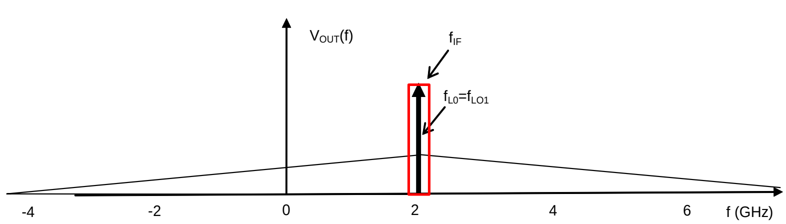
$$V_{IN}(f) = \sum_{i=-\infty}^{\infty} V_i \delta(f - i \cdot f_0) = \sum_{i=-\infty}^{\infty} V_i \delta(f - f_i)$$



spectrum magnitude for a signal with a 6 GHz bandwidth

Output Signal
(up-converter mixer)

$$V_{OUT}(f) = \sum_{i=-\infty}^{\infty} V_i \delta(f - f_i - f_{L0})$$

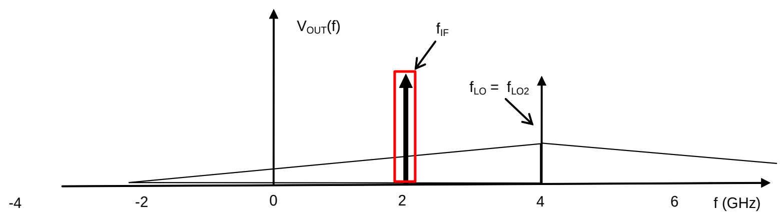


magnitude of the output spectrum when $f_{LO} = f_{LO1} = 2$ GHz

The output of the IF filter is the signal spectrum at $f_{IN} = 0$

Output Signal (up-converter mixer)

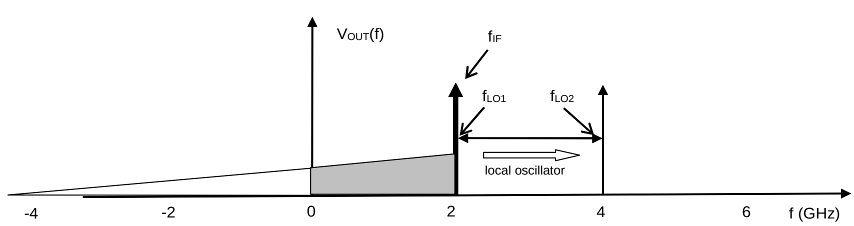
$$V_{OUT}(f) = \sum_{i=-\infty}^{\infty} V_i \delta(f - f_i - f_{L0})$$



magnitude of the output signal when f_{LO} = f_{LO2} = 4 GHz

The output of the IF filter is the signal spectrum at f_{IN} = 2 GHz

Output Signal (up-converter mixer)



Only the component of the input signal at the frequency f_i that differs of f_{IF} from the frequency generated by the local oscillator (f_{LO}) passes through the amplifier IF and therefore we have:

$$f_{LO} - f_i = f_{IF}$$

that is

$$\boxed{f_i = f_{LO} - f_{IF}}$$

Supposing, for example, that f_{IF} = 2 GHz and that the local oscillator can be tuned between f_{L01} = 2 GHz and f_{L02} = 4 GHz, the signals included in the following band will be output to the receiver:

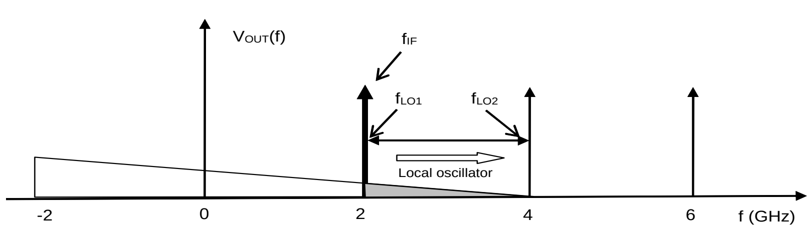
$$f_{iMIN} = f_{LO1} - f_{IF} = 2\text{ GHz} - 2\text{ GHz} = 0$$

$$f_{iMAX} = f_{LO2} - f_{IF} = 4\text{ GHz} - 2\text{ GHz} = 2\text{ GHz}$$

Output Signal (down-converter mixer)

The VCO generates also a negative frequency
(time product = frequency convolution)

$$V_{OUT}(f) = \sum_{i=-\infty}^{\infty} V_i \delta(f - f_i + f_{L0})$$



At the receiver output, therefore, there will be also the signals for which:

$$f_i - f_{LO} = f_{IF}$$

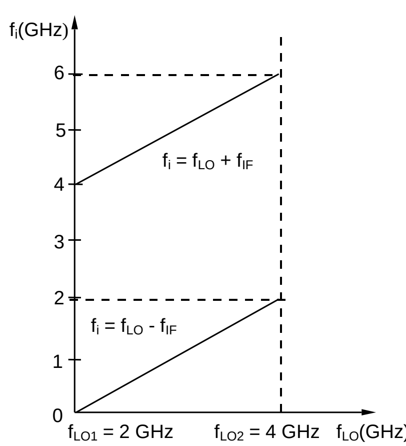
or

$$\boxed{f_i = f_{LO} + f_{IF}}$$

With reference to the data of the example, the signals included in the band will be revealed:

$$f_{iMIN} = f_{L01} + f_{IF} = 2\text{ GHz} + 2\text{ GHz} = 4\text{ GHz}$$
$$f_{iMAX} = f_{LO2} + f_{IF} = 4\text{ GHz} + 2\text{ GHz} = 6\text{ GHz}$$

Tuning Card



Overlay

- The tuning card in the figure shows that more input signals can produce the same output (Ex. 1 and 5 GHz in the figure).
- To overcome this drawback, a low-pass filter can be inserted, with a cut-off frequency of 3 GHz, at the analyzer input.
- In this way the components of the signal between 4 and 6 GHz are attenuated by the filter and do not give output contributions.

- However the analysis carried out does not take into account the fact that the mixer is not ideal and in particular does not present an infinite isolation between the RF and IF ports.
- Therefore, when a signal with a frequency $f_i = f_{IF}$ is present at the mixer input, a fraction of this signal passes through the mixer and is detected causing an undesired output.
- In conclusion, wanting to avoid that the signal at frequency f_{IF} creates disturbances, a low pass filter with a cutoff frequency of $0.8f_{IF}$ is placed at the input so that the filter presents high attenuation at f_{IF}.
  - In this way the mixer is able to process signals up to

$$\boxed{f_{iMAX} < 0.8\ f_{IF}}$$

Passing Local Oscillator

- It should be noted that having set $f_{LO1} = f_{IF}$, when the local oscillator generates the signal f_{LO1} this can pass directly to the output of the mixer and then inside the IF filter and is detected by generating at the left end of the screen a row called "zero frequency indicator" or "passing local oscillator".

- This line is not related to a DC term in the input signal. In fact, DC contribution is generally eliminated by a filter at the analyzer input.

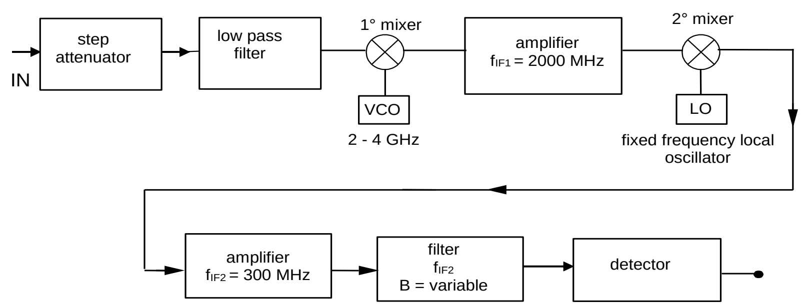
Multiple Conversions

- It is also important to note that for a given f_{IF} it is no possible to make filters with any fractional band.

- The fractional band of a filter ($\Delta f / f_0$) depends on the filter technology. Values of 10% are obtained with lumped elements, 1% with planar structures, 0.1% with dielectric resonators, 0.01% with waveguides.

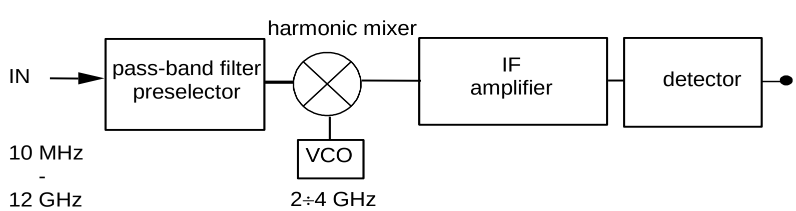
- As will be described in the following, from the amplifier band depends the frequency resolution of the spectrum analyzer.
- in particular, to have good resolutions, it is necessary to have an amplifier with a band as narrow as possible. <u>To improve the frequency resolution, the multiple conversions technique can be used.</u>

Multiple Conversions



Armonic Mixer

As seen above, if you want to increase the frequency range that can be displayed with the analyzer, f_{IF} must be increased. The same result can be achieved using a harmonic mixer.



Harmonic Mixer

$$V_{OUT}(f) = \sum_{i=-\infty}^{\infty} V_i \delta(f - f_i - nf_{LO})$$ where n = 1, 2, ..N

$$V_{OUT}(f) = \sum_{i=-\infty}^{\infty} V_i \delta(f - f_i + nf_{LO})$$ where n = 1, 2, ..N

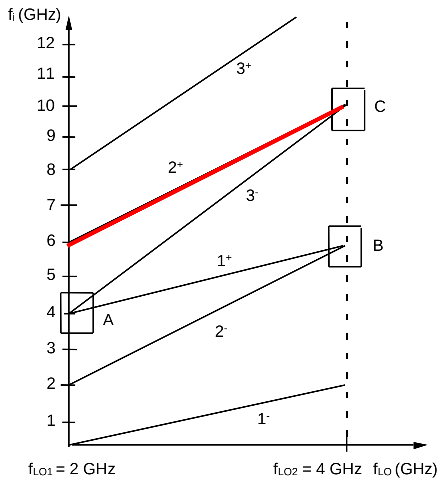
$$\boxed{f_i = nf_{LO} \pm f_{IF}}$$

Harmonic Mixer

As an example when f_{LO} change from f_{LO1} = 2 GHz and f_{LO2} = 4 GHz with f_{IF} = 2 GHz, the frequencies shown in the Table are achieved at thereceiver output for N = 3.

n	nf_{LO}	$nf_{LO} \pm f_{IF}$	
1	2 - 4	0 – 2 4 – 6	1^- 1^+
2	4 - 8	2 – 6 6 - 10	2^- 2^+
3	6 - 12	4 - 10 8 - 14	3^- 3^+

Tuning Card Harmonic Mixer



With the harmonic mixer the band of displayable frequencies is considerably extended but the problem of multiple harmonic responses (overlapping and splitting) is presented. To avoid this problem, an **input bandpass filter (preselector filter)** is inserted. It is a tunable filter whose central frequency is varied according to the chosen operating mode. For example, if you want to work on mode 2+, the center frequency of the input filter should vary between 6 and 10 GHz while the local oscillator varies between 2 and 4 GHz.

Signal Analyzer

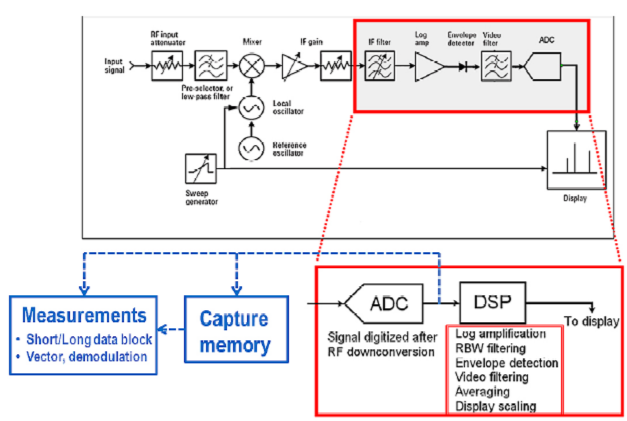
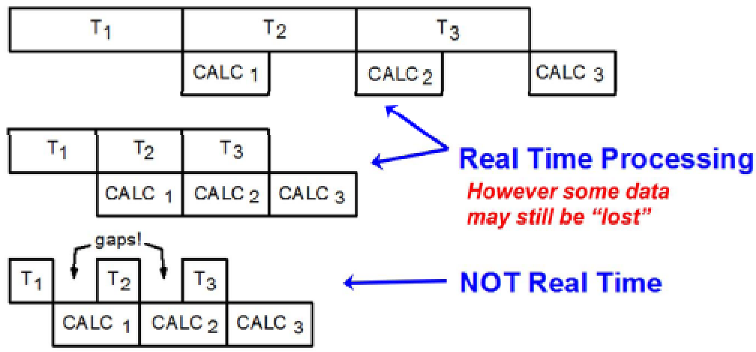


Figure 14. The signal-processing architecture of a vector signal analyzer is primarily a software extension of that used in a spectrum/signal analyzer with a digital IF. This architecture may be consistent with that of a real-time analyzer as well, as in the case of the Agilent PXA or MXA.

Real-Time Operation

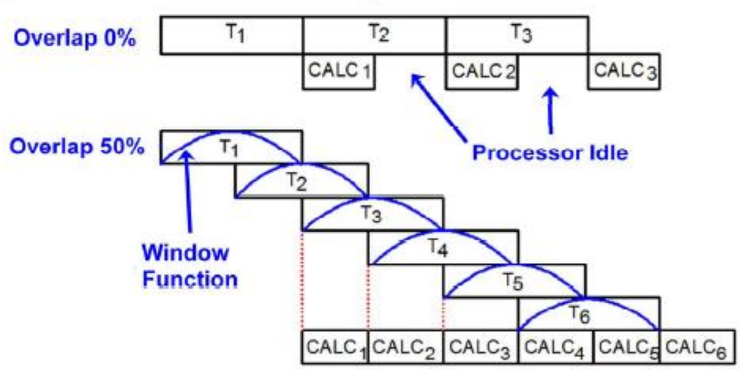
In Real-Time Operation the Analyzer's Processing **(CALC)** is Fast Enough to Keep Up with All Data Samples



CALC Time Includes FFT or Power Spectrum, Averaging, Display Updates, etc.

Overlap Processing

If Processing is Faster than Sampling, Perform Additional FFTs With Partially-New Time Records as Samples Come In



Avoid Loss of Data Due to Windowing

Accurate Amplitude Measurements of Short Duration Signals

Agile radar signal

The signal in question is one a receiving antenna would expect to see when a transmitter with a narrow beam performs a scan. The signal is a repeating sequence of radar pulses, each with a width of 6 µs and a pulse repetition interval (PRI) of 600 µs. Each pulse group consists of seven pulses that step in 10 MHz increments from –30 MHz to +30 MHz relative to the 3 GHz center frequency. The scanning is shown schematically in Figure 1.

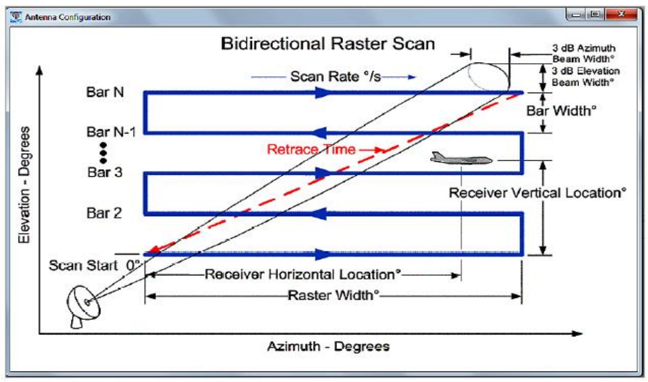


Figure 1. The scan pattern of an S-band acquisition radar.

Swept spectrum analyzer

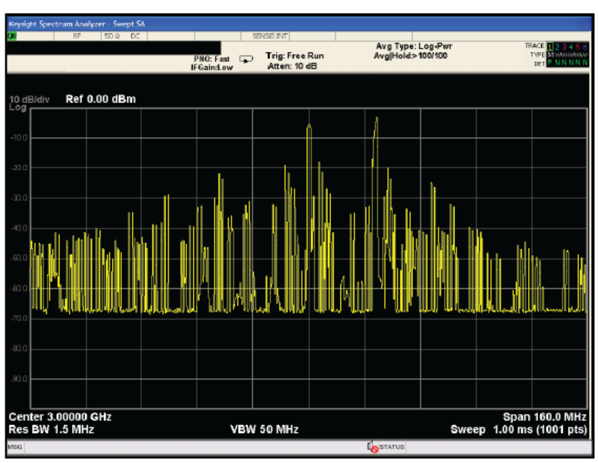


Figure 8-7 . Even when you use fast sweeps and max hold over a period of many seconds, the swept spectrum analyzer view of the radar signal is not very informative

Signal Analyzer

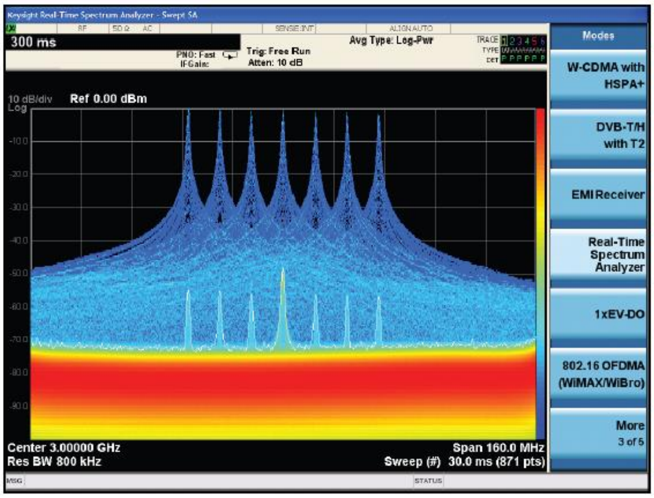


Figure 8-8. Real-time capture of S-band acquisition radar signal

The blue color of all but the noise floor indicates that the pulses, while prominent, have a very low frequency -of-occurrence

2.45 GHz ISM band

The 2.45 GHz ISM band is thus both dynamic and complex, and a good example of the challenges of agile signal analysis. Traditional swept spectrum analysis is not a very effective tool for understanding the activity in this band, as shown in Figure 9.

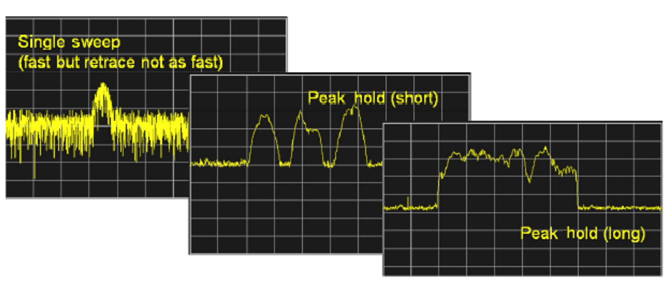


Figure 9. With multiple agile signals sharing a 100 MHz frequency band, it can be difficult to understand signal behavior using a swept spectrum analyzer. Using the peak-hold function over a period of time can catch some signal activity but subsequent activity can also obscure it.

Signal Analyzer

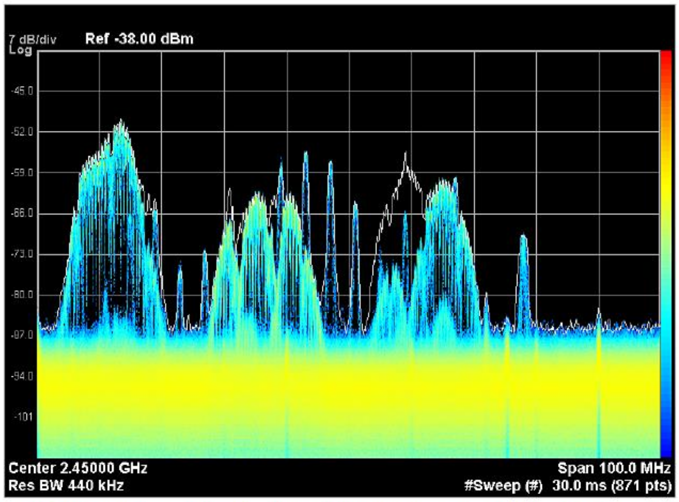


Figure 10. With a similar setup to the swept spectrum analysis approach (Figure 9) the real-time density display quickly reveals detail about the spectral occupancy of this band.

Real Time Spectrograms

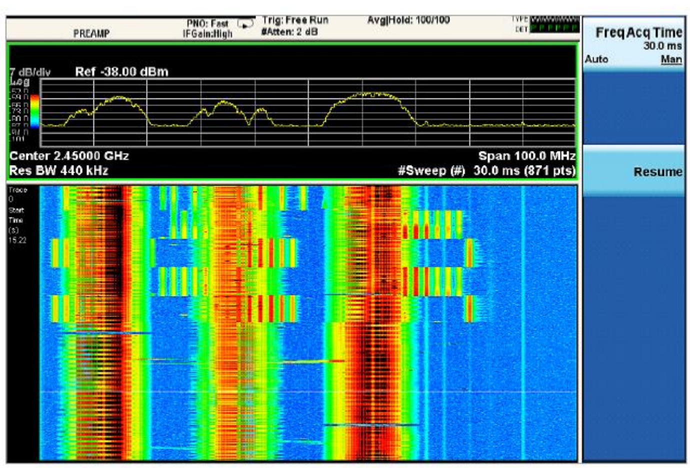


Figure 11. The spectrogram display of the ISM band summarizes signal behavior over a period of seconds, revealing mostly WLAN and Bluetooth signals.