EE 257 – Signals & Systems

Swept – Tuned Spectrum Analyzer

Objective of this text is to give an understanding about the basic architecture of the superheterodyne spectrum analyzer, its operation and the basic configurations. This text could be used for the discussion segment of the EE 257 lab experiment about the spectrum analyzer and also as a referance material for answering the discussion questions of the experiment.

When discussing the front panel practical configurations and controls, the **Tektronix 2712** spectrum analyzer is taken as the primary example. It should be noted that all these configuration changes that are discussed using the Tektronix 2712 spectrum analyzer can be easily performed in all the other types of spectrum analyzers as well, even though the configuration process may slightly differ.

1. Basic Architecture

A simplified block diagram of a superheterodyne spectrum analyzer is illustrated in Fig. 01.

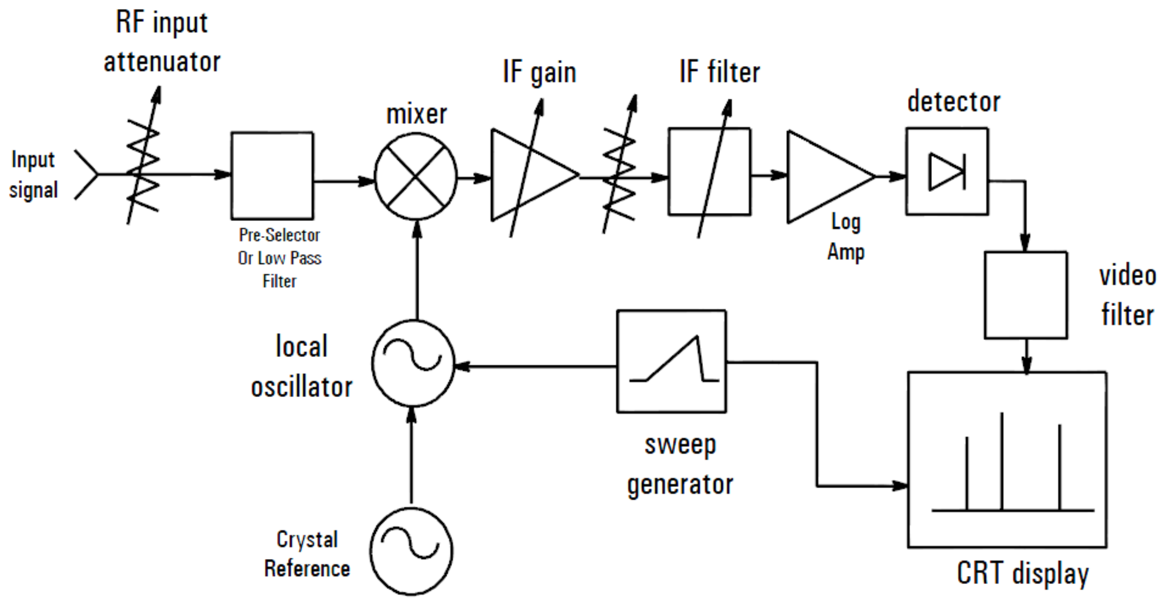

Figure 1: Block Diagram of a Spectrum Analyzer

The most commonly used type of spectrum analyzer is swept tuned spectrum analyzer and it is the most widely accepted general purpose tool for frequency domain measurements. Superheterodyne is the most widely used technique in these spectrum analyzers. Here, heterodyne means the mixing or translation of frequencies and super refers to the frequencies well above the audio range. Basic idea behind the operation of these spectrum analyzers is that they "sweep" across the frequency range of interest and display the frequency components that are present.

The major components of a superheterodyne spectrum analyzer are the RF input attenuator, IF (Intermediate Frequency) gain, IF filter, detector, video filter, local oscillator, sweep generator and LCD display. In the next sections of this text, a detailed account of each of these components and their operation will be provided.

2. Operation

2.1. RF Input Attanuator

The purpose of this input attanuator is to control the signal level applied to the instrument. If the signal is too large, the components will saturate and hence the output will be distorted. If the signal is too small, it will be masked by noise present in the analyzer. Therefore the input attanuator can be used to prevent this problem and apply the desired signal level to the analyzer.

The low pass filter is used to block the high frequency signals from reaching the mixer.The purpose of this is to prevent out-of-band signals from mixing with the local oscillator and creating unwanted responses at the IF filter. Microwave spectrum anlyzers replace the low – pass filter with a preselector which can be tuned to a desired band as illustrated in Fig. 02.

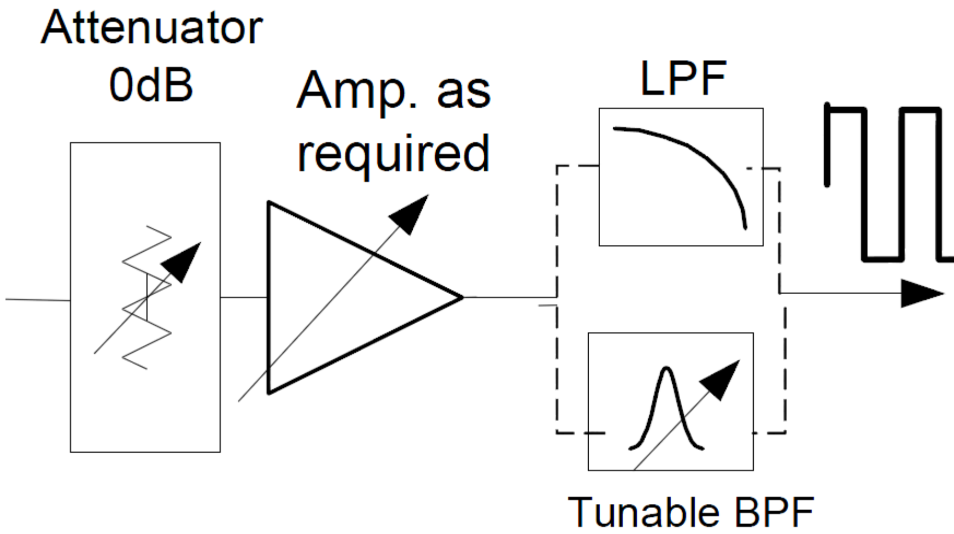

Figure 02 – Input Attanuator with a preselector

2.2. Mixer

Mixer is a frequency translation device(or a frequency converter) which converts a signal from one frequency to another. It shoule be noted that the mixer is a non – linear device which will produce frequencies that were not present in it's inputs. The operation of the mixer used in the superheterodyne spectrum analyzer is illustrated in Fig. 03.

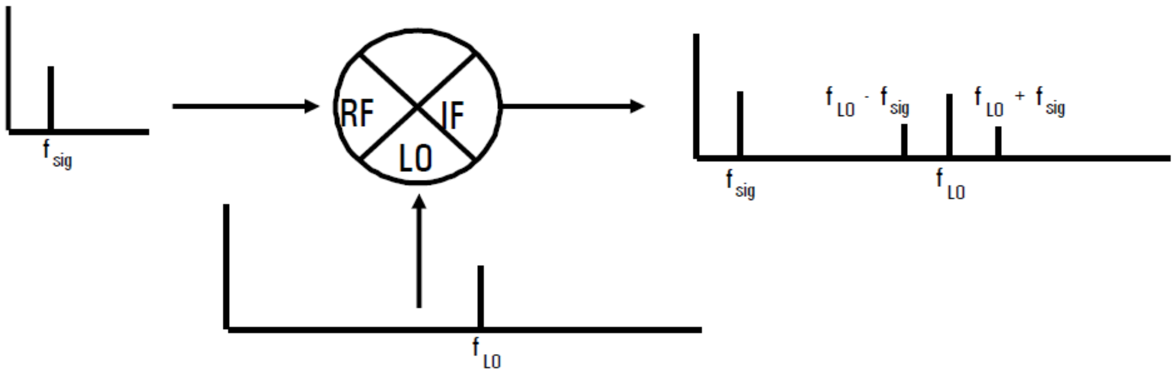

Figure 03 – The frequecy translation process by the mixer

As seen from Fig. 03, the local oscillator signal(f_{lo}) is applied to one input port of the signal and the signal to be converted(f_{sig}) is applied to the other input port. The output of the mixer would then contain the two original signal frequencies(f_{lo} and f_{sig}), as well as the sum(f_{lo} + f_{sig}) and the difference(f_{lo} - f_{sig}) frequencies of these two original signals.

As will be explained in the next chapters of this text, it is actually the difference frequency that is of interest in the operation of the spectrum analyzer. This frequency is called the Intermediate Frequency(IF). It can be seen that the mixer has converted the RF input signal to an IF signal that the analyzer can be filter, amplify and detect.

2.3. IF filter

The IF filter is a bandpass filter which is used as the window for detecting signals. This is one of the most important components of the spectrum analyzer and the performance of the spectrum analyzer largely depends on the correct configuration of the paramenters associated with the IF filter.

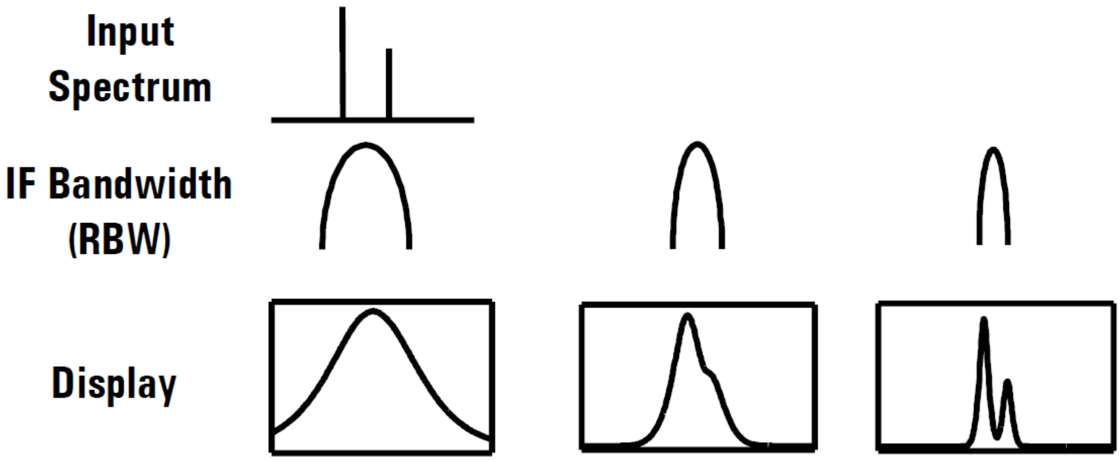

Figure 04 – IF bandwidth and resolution

The bandwidth of the IF filter is called the Resolution Bandwidth(RBW) and can be configured via the front panel of the spectrum analyzer. In the Tektronix 2712 spectrum analyzer the **RES BW** block can be used for this configuration.
A wide range of variable relolution bandwidths let you optimize the spectrum analyzer for sweep and signal conditions, letting you trade – off frequency resolvability, Signal to Noise Ratio(SNR) and the measurement speed.

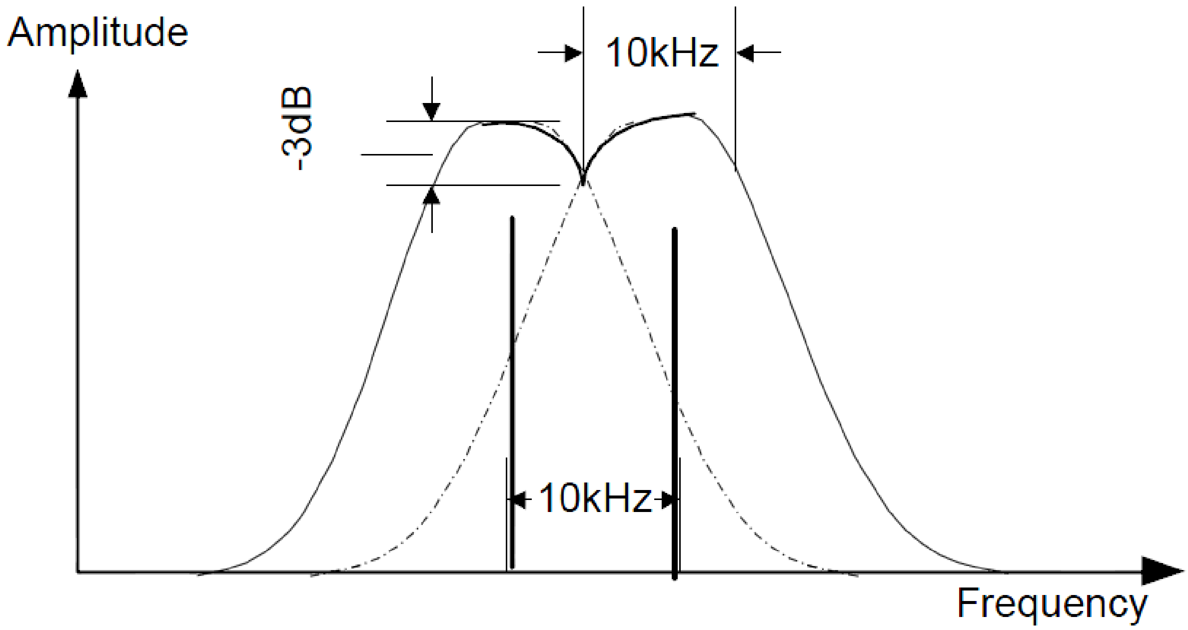

Figure 05 – Resloving two signals with equal amplitude

It can be seen from Fig. 04 that a narrower resolution bandwidth inproves the resolvability of the signals and the SNR as well. However, a narrower resolution bandwidth would degrade the trace update rate. The important point that should be noted here is that the optimum resolution bandwidth settings always depend heavilly on the caharacteristics of the signals in interest. For example, in order to resolve two signals with equal amplitudes and smaller frequency differences a narrower bandwidth would be required. With wider bandwidths, the two signals may appear as one in the spectrum analyzer.This scenario is illustrated in Fig. 05.
It should be noted that, not only the bandwidth but also the shape of the IF filter bears a great importance in the resolving signals with a sufficient accuracy. In this text, the configuration of the shape of the IF filter is not discussed excessively. Students can use the provided referances to gain an understanding about this.

It is highly recommended that the students read the sections 5 -10, 5- 13 of the Tektronix 2712 user manual that is available in the laboratory in order to gain a good understanding about how these configurations can be used effectively.

Another important point that should be discussed with the IF filter of a spectrum analyzer is the SNR level and how it is affected by different configurations.

In practice all receivers, including spectrum analyzers , add some amount of internally generated noise. The internally generated noise of a spectrum analyzer is thermal in nature and therefore can be characterized by,

$$N = kTB \tag{1}$$

Where N is the noise power, k is Boltzmann's constant, T = temperature in Kelvin degree, and B is the bandwidth of the system in Hz.

Since the thermal noise is random and is flat over a large range of frequencies, the resolution bandwidth decides the injected noise level. In other words, when the resolution bandwidth is increased, more noise hits the detector and the displayed average noise level would be increased(this scenario would be even more clearer when proceeding to the next chapters.) Therefore the spectrum analyzers lowest noise level is achieved with its narrowest IF bandwidth. This scenario is illustrated in Fig. 06.

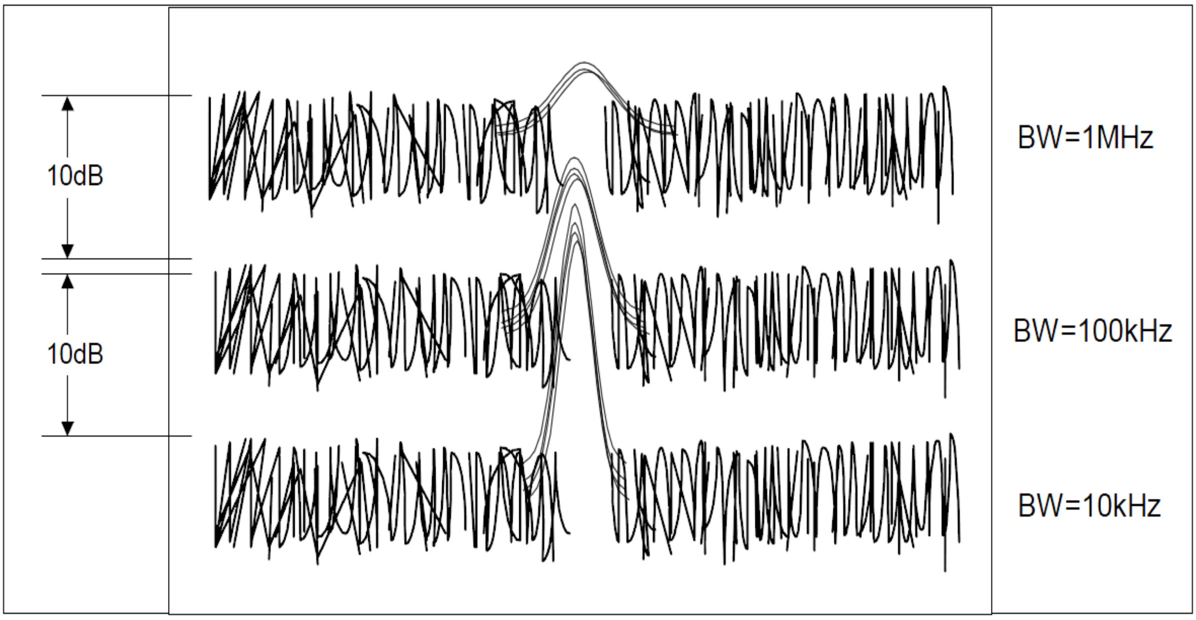

Figure 06 – Variation of SNR with IF filter bandwidth

The sweep speed and trace update rate, however, will degrade with narrower resolution bandwidths. In other words, route and trace update rate will be higher with larger resolution bandwidths.

Therefore it can be seen that the required resolution bandwidth settings highly depend on the signal characteristics (i.e. the required signal resolvability, SNR levels and trace update rate depends on the signal in concern).

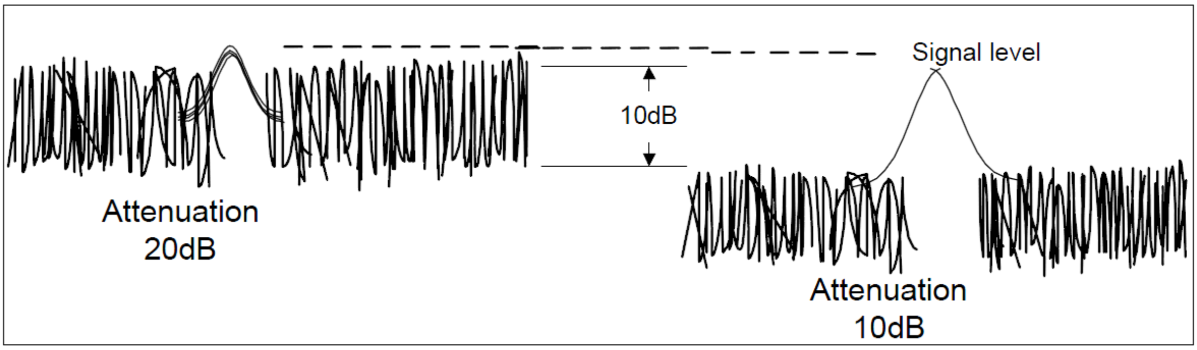

Figure 07 – Variation of SNR Input attanuation

Another important thing that should be noted in this section is the effect of input attenuation of the SNR level. The internal noise is generated after the mixer. Therefore the RF input attenuator has no effect on the actual noise level. However the input attenuator does affect the signal level ay the input. Therefore when the attenuation increase the SNR will decrease. This scenario is illustrated in Fig. 07.

2.4. Detector

The next step is the detection of the output of the IF filter. Envelope detection **(instructor should give a basic idea about envelope detection since the students of EE 257 have not come across this term yet)** is used for this purpose. The output of the envelope detector is then digitized using an Analog to Digital Converter(ADC).

Several detector modes are used for this purpose and some of them are illustrated in Fig. 08. Each of these modes have their own advantages and disadvantages which are not discussed in this text.

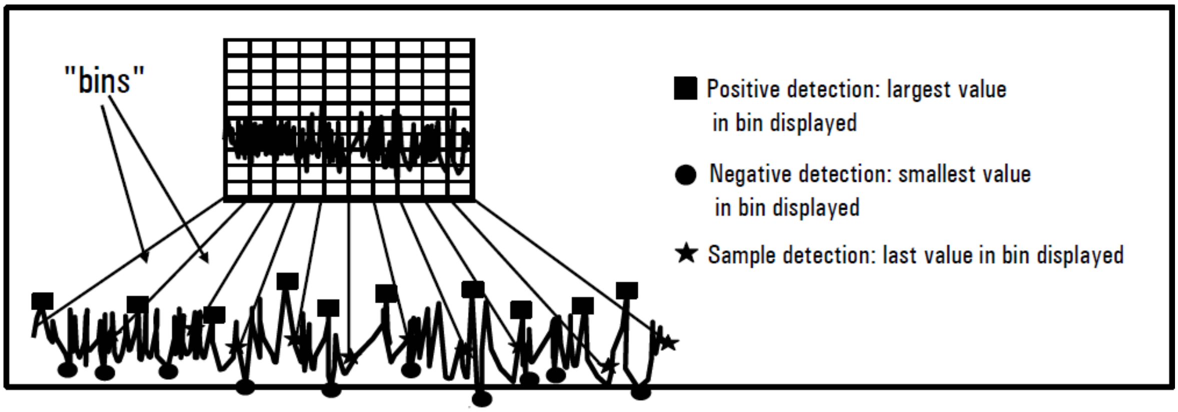

Figure 08 – Various detector modes

The digitized output of the ADC is then represented as the signal's amplitude on Y axis of the display.

2.5. Video Filter

Video filter is a low pass filter which determines the bandwidth of the video amplifier. This is used mainly to average or smooth the trace on the spectrum analyzer screen. The spectrum analyzer displays both signal and the associated noise. Therefore when a signal is closer to the noise level it makes the signal difficult to read. Careful tuning of the video bandwidth settings may however help to decrease the peak-to-peak variations of noise, thus halping to find signals that may otherwise be masked by noise.

It should also be noted that the video bandwidth does not effect the frequency resolution of the analyzer and thefore changing the video bandwidth does not improve the sensitivity. However, it does certainly help to improve the low SNR measurements.

In the Tektronix 2712 spectum analyzer, the video bandwith configurations can be adjusted using the **VID FLTR** control located in the front panel.

2.6. Other Components

So far in this text, many of the most important components, their functions and possible configuration changes were discussed. Few of the components which were not discussed previously will be explained here.

2.6.1. Local Oscillator & Sweep Generator

This is a voltage controlled oscillator which is used to tune analyzer. In other words this moves the fixed bandwidth IF filter through the desired range of frequencies. The sweep generator associated with this would tune oscillator so that its frequency changes in proportion to the ramp voltage.The sampling of the video signal by the ADC is also synchronized with the sweep generator to create the frequency axis on the x-axis. Therefore the horizontal axis of the display can be calibrated in terms of the input signal's frequency.

2.6.2. IF Gain

If Gain(Fig. 01) is used to adjust the vertical position of signals in the display without affecting signal level at the input mixer. The value of the referance level can be changed by varying the IF Gain. In the Tektronix 2712 spectrum analyzer this can be done using the **REF LEVEL** control located on the front panel.

It shoule be noted that the referance level shoule not change with the variation of the input attanuations. To achive this, the two components are internally connected. Such that the IF gain will automatically be changed to compensate for input attanuator changes.

3. Overall Operation

In this section, the overall operation will be discussed using an example and the students will be able to interconnect their knowledge about different components of the spectrum analyzer and hence visualize its operation.

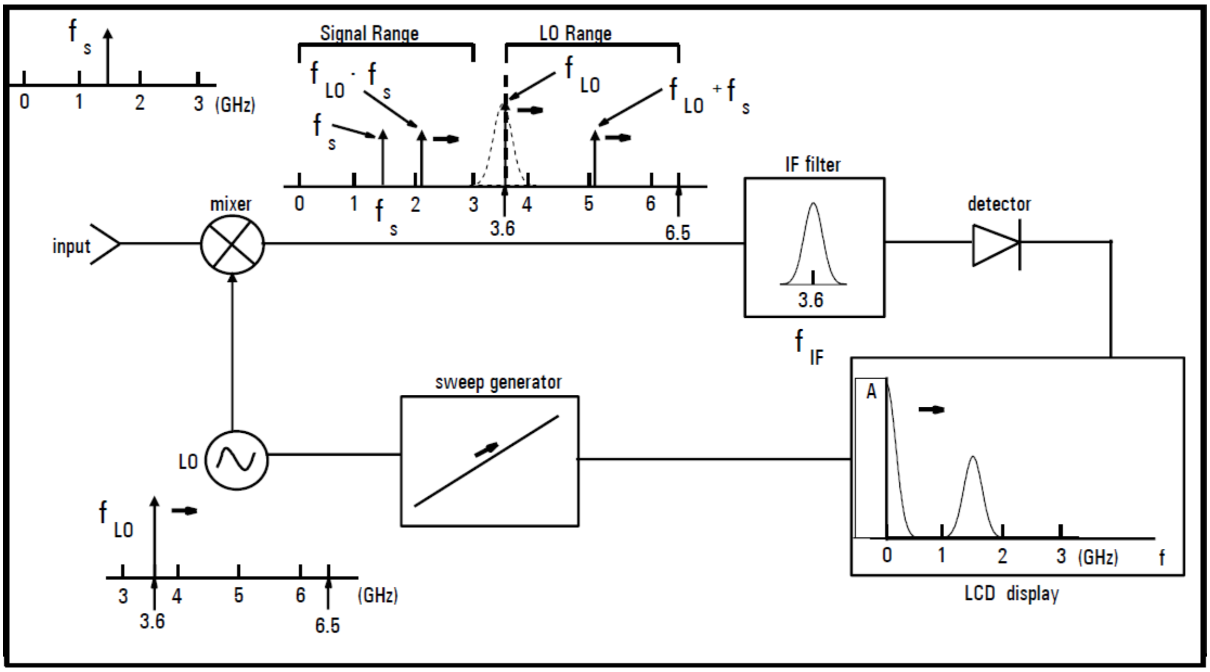

Figure 09 – Operation of the Spectrum Analyzer: an example

Let's go through the steps that follow after a signal is given to the spectrum analyzer as the input (Fig. 09).

1. Signal to be analyzed (f_s = 1.5 MHz) is connected to the input of the spectrum analyzer.

2. Signal is then combined with the LO at the mixer and then it is translated to an intermediate frequency (IF). This would generate four signal components with frequencies f_{LO}, f_s, $f_{LO} - f_s$ and $f_{LO} + f_s$. Here, IF = $f_{LO} - f_s$ = 3.6 – 1.5 = 2.1 MHz.

3. Then these signals are sent through the IF filter which is also located at the f_{LO}.

4. Then the f_{LO} would keep increasing from 3.6 MHz according to the sweep generated by the sweep generator. As LO sweeps, so too will the three of the outputs (f_s would be stationary as it is the signal frequency). Since the IF filter is also located at 3.6 Mhz at the beginning we would see a signal at the 0 Hz position of the display (Fig. 09). This is called as the "LO feedthrough".

5. When the "LO feedthrough" moves out of the IF filter bandwidth, it is tapered off of the display.

6. Next, when the difference signal comes in to the skirts of the IF filter, it begins to appear in the display. When it is at the center (3.6 MHz in this case) the full amplitude of the signal will be visible at (f_{LO} – (f_{LO} - f_s)) = 1.5 Mhz.

7. As the difference signal moves further to the right, it leaves the filter skirt and no signal will appear in the analyzer display.

This is how a normal, spectrum analyzer operates in analyzing spectrums of given input signals.

References

1. *Spectrum Analyzer Basics (Hewlett Packard)*
2. *Spectrum Analyzer Basics (Agilant Technologies)*
3. *Spectrum Analyzer and Spectrum Analysis by Shimshon Levy (October 2012)*
4. *Superheterodyne Spectrum Analyzer and Spectrum Analysis by Shimshon Levy and Harel Mualem (August 2006)*
5. *Tektronix 2712 Spectrum Analyzer User Manual (A hard copy is available in the Communication Laboratory)*