

3 SPECTRUM ANALYZER

1. Introduction

A spectrum analyzer is one of the most important instruments in microwave electronics and radio communications. It essentially provides measurement results in the frequency domain, in particular the spectral content of signals. Therefore, it is an indispensable instrument to quantify distortions (harmonics and third-order intermodulation) and out-of-band and spurious emissions that may be caused by these distortions. Related to this, spectrum monitoring is an important frequency-domain measurement activity where various radio services are regularly checked if they operate at the assigned frequencies and within the allocated channels. Similarly, it is typically required to check and regulate unwanted emissions of various electrical (not necessarily communication) devices which might impair operation of other electrical devices or systems – this area is generally called electromagnetic compatibility (EMC) and spectrum analysis is essential for these tests.

In this laboratory session we will perform some basic measurements with spectrum analyzer in order to study the main capabilities of this instrument.

2. Theoretical background

At the most basic level, a spectrum analyzer can be described as a frequency-selective, peak-responding voltmeter calibrated to display the root-mean-square (rms) value of a sine wave [1]. The horizontal axis of its display is linearly calibrated in frequency, while the vertical axis is calibrated in amplitude.

The spectrum analyzer is rather complex device and here we only consider its basics. More on this topic can be found in [1] and [2]. In microwave electronics and radio communications, a super-heterodyne spectrum analyzer, whose block diagram is shown in Fig. 6.1, is typically used. In the remainder of this section, we briefly describe its main components.

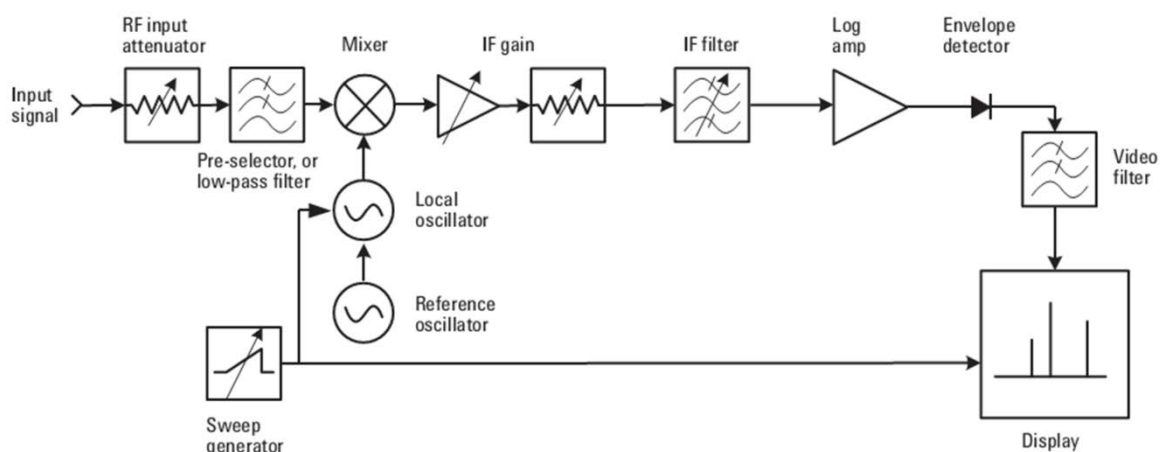


Fig. 6.1 Block diagram of a classic super-heterodyne spectrum analyzer [1].

The purpose of the RF input attenuator is to ensure the signal enters the mixer at the optimum level to prevent overload, gain compression and distortion. The low-pass filter (or band-pass filter, i.e. pre-

selector) blocks unwanted signals (image frequency) that would be translated to the intermediate frequency (IF) in the mixer and cause unwanted responses on the display.

The mixer is by definition a non-linear device (frequencies are present at the output that were not present at the inputs). Therefore, apart from the f_{LO} (local oscillator signal) and f_s (input signal to be measured), harmonics and sum and difference signals are present at the output. In fact, in the super-heterodyne spectrum analyzer the difference frequency $f_{LO} - f_s$ is the frequency of interest. After the mixer (and the IF gain amplifier that will be addressed later), we find the IF filter (also known as the resolution bandwidth (RBW) filter). This is a fixed pass-band filter operating at the IF frequency f_{IF} . The local oscillator is, in the simplest approach, swept from the f_{IF} to the $f_{IF} + f_{sH}$ (where f_{sH} is the highest signal frequency supported). Therefore, in the beginning of the sweep cycle (when $f_{LO} = f_{IF}$) the IF frequency is directly present on the mixer output, passed through the IF filter and further processed. It is even possible to see a response on the display because of that (called a LO feed-through) even though this is not a real signal from the outside world. At any other moment of the local oscillator sweep cycle, the signal frequency f_s that is lower than the local oscillator frequency f_{LO} by one IF frequency f_{IF} will be passed through the IF filter (as the mixer output component $f_{LO} - f_s$ will be equal to f_{IF}) and shown on the display. This process is illustrated in Fig. 6.2. [2]. Notice also that, even though input and local oscillator signals are idealised, we do not observe ideal spectral lines on the display. In fact, what we see is the IF filter band-pass characteristic. Naturally, the width of this filter will define the minimum distance in frequency between two signals that can still be resolved on the display (hence the name RBW filter).

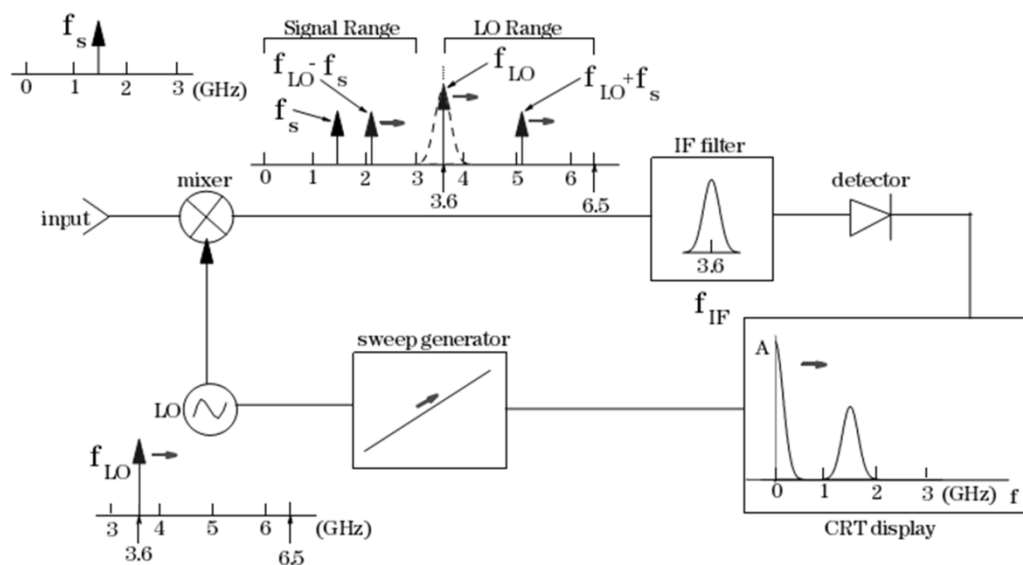


Fig. 6.2 How the result on the spectrum analyzer display is obtained [2]. Here, $f_{IF} = 3.6$ GHz; signal frequency range is 0...3 GHz and the signal is present at $f_s = 1.5$ GHz; local oscillator range is $f_{LO} = 3.6$...6.6 GHz. Local oscillator starts at $f_{LO} = 3.6 = f_{IF}$ (we see the LO feedthrough on the left of the display). When the local oscillator reaches the frequency of 5.1 GHz ($= f_s + f_{IF}$), the difference signal $f_{LO} - f_s$ on the mixer output is equal to IF. Hence, we see the response on the display corresponding to $f_s = 1.5$ GHz (we do not see just a spectrum line, but the IF filter shape).

The IF gain amplifier is used to adjust the vertical position of signals on the display without affecting the signal level at the input mixer. This amplifier is internally coupled with the RF input attenuator so

any change in input attenuation is compensated by the change of the IF gain. Thus, the signal on the display is kept at a constant position and attenuation does not have to be accounted for when measuring the amplitude.

After the IF section, the signal is amplified by the logarithmic amplifier (as the display scale is typically exponentially calibrated) and detected (essentially rectified) by the envelope detector. The detected (baseband or video) signal is filtered by another low-pass filter (the video filter), which generally results in a smoother trace. The horizontal movement on the display is controlled from the same sweep generator that also controls the local oscillator frequency.

Finally, it should be noticed that modern spectrum analyzers profit a lot from the digital technology. Nowadays the processing is typically digital from (and including) the IF section. Digital technology brings many improvements such as smaller RBW (hence better resolution), faster sweep, even the phase information of spectral components. However, the basic operating principle, as described above, remains the same.

3. Experiments

3.1. Utilised equipment

- Spectrum analyzer 30 Hz to 6.5 GHz *HP8561E*
- Signal generator *HP8648C* (x2)
- Signal generator *R&S SMR20*
- Dual directional coupler 20 dB *HP778D*
- Coaxial termination (matched load)
- SMA attenuators 10 dB and 20 dB
- 30 dB amplifier *Mini Circuits ZHL-42W*
- DC-power supply *HP E3610A*
- Rod antenna

3.2. Basic measurements

Connect the devices according to Fig. 6.3. Turn on only the spectrum analyzer. Take some time to get familiar with the main controls such as frequency, span and amplitude control. Observe the instrument display and notifications. Finally, explore other commands such as the resolution bandwidth control and markers.

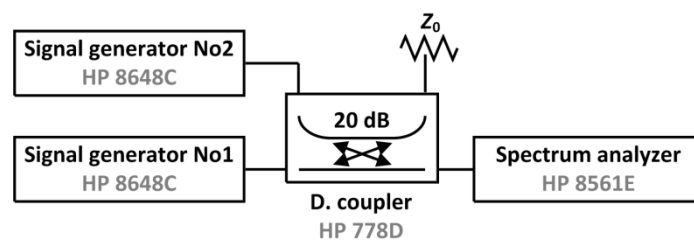


Fig. 6.3 Basic experiment setup.

3.2.1. Frequency and amplitude measurement

Turn on the signal generator No1. Set $P_1 = -40$ dBm, $f_1 = 200$ MHz, no modulation. Turn the RF power on and observe the spectrum analyzer display. Measure the signal frequency and amplitude.

Note: Utilise the normal marker for this measurement. Frequency accuracy generally improves with decreasing the frequency span, therefore reduce it to at least 1 MHz. For most accurate frequency measurement, an internal frequency counter can be utilised. Finally, note that the amplitude accuracy is improved when the peak level is close to the top of the display grid.

Decrease the power of the generator No1 to $P_1 = -90$ dBm (leave other settings intact) and measure the signal again.

Note: The spectrum analyzer sensitivity can be improved by the following actions:

- (a) Reducing the resolution bandwidth (noise is directly reduced; $N = kTB$);*
- (b) Reducing the input attenuation (noise is reduced because the IF gain is reduced);*
- (c) Averaging and video filtering (smoothing the noise trace).*

Decrease the power level of the generator No1 further, to $P_1 = -130$ dBm (leave other settings intact) and measure the signal again.

Resume what has to be done in order to lower the noise floor and measure low amplitude signals. What is the most obvious trade-off when reducing the resolution bandwidth? What is the correct approach to alleviate it?

3.2.2. Resolution of two closely separated signals

Preset the spectrum analyzer. Turn on the second generator, turn off the RF power of both generators and apply the following settings: $P_1 = -40$ dBm, $f_1 = 199.95$ MHz; $P_2 = -20$ dBm, $f_2 = 200.05$ MHz; no modulation. Turn the RF power on. This results in two signals having practically the same amplitudes and whose frequency difference is $\Delta f = 100$ kHz. Adjust the spectrum analyzer to be able to resolve them.

Note: Two equal-amplitude signals can be clearly resolved if their separation is greater or equal to the 3 dB bandwidth of the RBW filter.

Set the RBW to 30 kHz and note that the signals are easily distinguishable one from another. Now decrease the power of the generator No1 to $P_1 = -80$ dBm. Adjust the spectrum analyzer to be able to resolve the signals again.

Resume what has to be done in order to distinguish two closely separated signals having equal amplitudes. Why do additional steps need to be taken in order to resolve closely separated signals with considerably different amplitudes? Which spectrum analyzer specification provides information regarding the distinction of two signals being close in frequency and different in amplitude?

3.2.3. Measurement of AM index

Preset the spectrum analyzer, turn off the generator No2 and turn off the RF power of the generator No1. Set the generator No1 to $P_1 = -40$ dBm, $f_1 = 200$ MHz, amplitude modulation (AM) ($m_a = 30\%$, $f_m = 1$ kHz) and turn the RF power on. Adjust the spectrum analyzer in order to clearly see the spectrum lines. Measure the sideband level and the index of amplitude modulation. Confirm that this measured value is close to the predefined value.

Note: Use the delta marker for this measurement. In general, it is the most convenient type of marker for relative measurements. The (linear) power ratio of the sideband and the carrier signal is equal to $m_a^2/4$.

Feel free to explore the spectrum of a frequency modulated (FM) signal.

3.3. Distortion measurements

Connect the devices according to Fig. 6.4. Harmonic levels of the amplifier will be measured at the input power of **-10 dBm (do not exceed this level)**. The 20 dB attenuator protects the spectrum analyzer from the excessive input power.

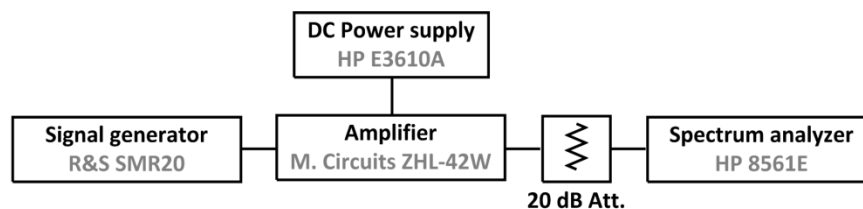


Fig. 6.4 Distortion experiment setup.

Note: Always follow the amplifier connect and disconnect procedure:

To connect: (a) Connect output load; (b) Apply DC voltage 15 V; (c) Apply RF input;

To disconnect: (a) Remove RF input; (b) Remove DC voltage; (c) Remove output load.

Preset the spectrum analyzer. Turn the RF power off and set the generator to $P = -10$ dBm, $f = 200$ MHz, no modulation. Before turning the RF power on, count the losses and the gain in the signal path from the generator to the spectrum analyzer in order to be sure that the input power into the amplifier and particularly into the spectrum analyzer is below the prescribed limit (0 dBm for the amplifier; +30 dBm for the spectrum analyzer). Turn the RF power on and observe the fundamental and the harmonics on the spectrum analyzer display. Set the start and stop frequency in order to see the fundamental and first three overtones.

Note: Before any distortion measurement, the 'attenuator test' should be performed in order to be sure that the spectrum analyzer itself is not contributing significantly to the harmonic levels. Do the following: Vary the input attenuation (increase it by 10 dB from the automatically predefined value) and observe if the harmonic levels remain essentially the same. If this is the case, then the distortion is solely caused by the device under test (DUT) and the attenuation can be left at the starting level. If not, increase the attenuation further until the harmonic levels are stabilised.

Put the fundamental peak to the reference level for the best accuracy. Measure the levels of the fundamental and its first three overtones. Decrease the input power by 1 dB, therefore to $P = -11$ dBm and measure again the levels.

Why it is important to control the harmonic levels? If the input power into an amplifier is decreased by 1 dB, what is the expected decrease of the output signal at the fundamental frequency and the frequency of the 1st and 2nd harmonic?

Table 6.1. Distortion measurement results.

Input power	Fundamental	2 nd harmonic	3 rd harmonic	4 th harmonic
-10 dBm				
-11 dBm				

3.4. Spectrum monitoring

Connect the rod antenna to the spectrum analyzer as shown in Fig. 6.5. Preset the instrument.

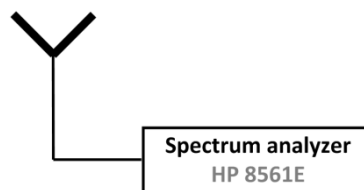


Fig. 6.5 Experiment setup for spectrum monitoring.

Adjust the antenna to the small length. Set the spectrum analyzer in order to see the GSM 900 signal. For instance, set the start and stop frequencies to 850 MHz and 1000 MHz, respectively.

Note: In order to visualise the spectrum occupation, use the spectrum analyzer function max hold. In this way the maximum values on the display are kept after each frequency sweep and the spectrum envelope is noticeable after a few sweeps.

Feel free to explore other interesting frequency bands (ISM band, UMTS band...).

Adjust the antenna to the large length. Set the spectrum analyzer in order to see the FM radio signals (88 MHz to 108 MHz). Tune to some station: set the marker to the peak of the desired signal, choose zero span and external trigger. Finally, activate the internal FM demodulator.

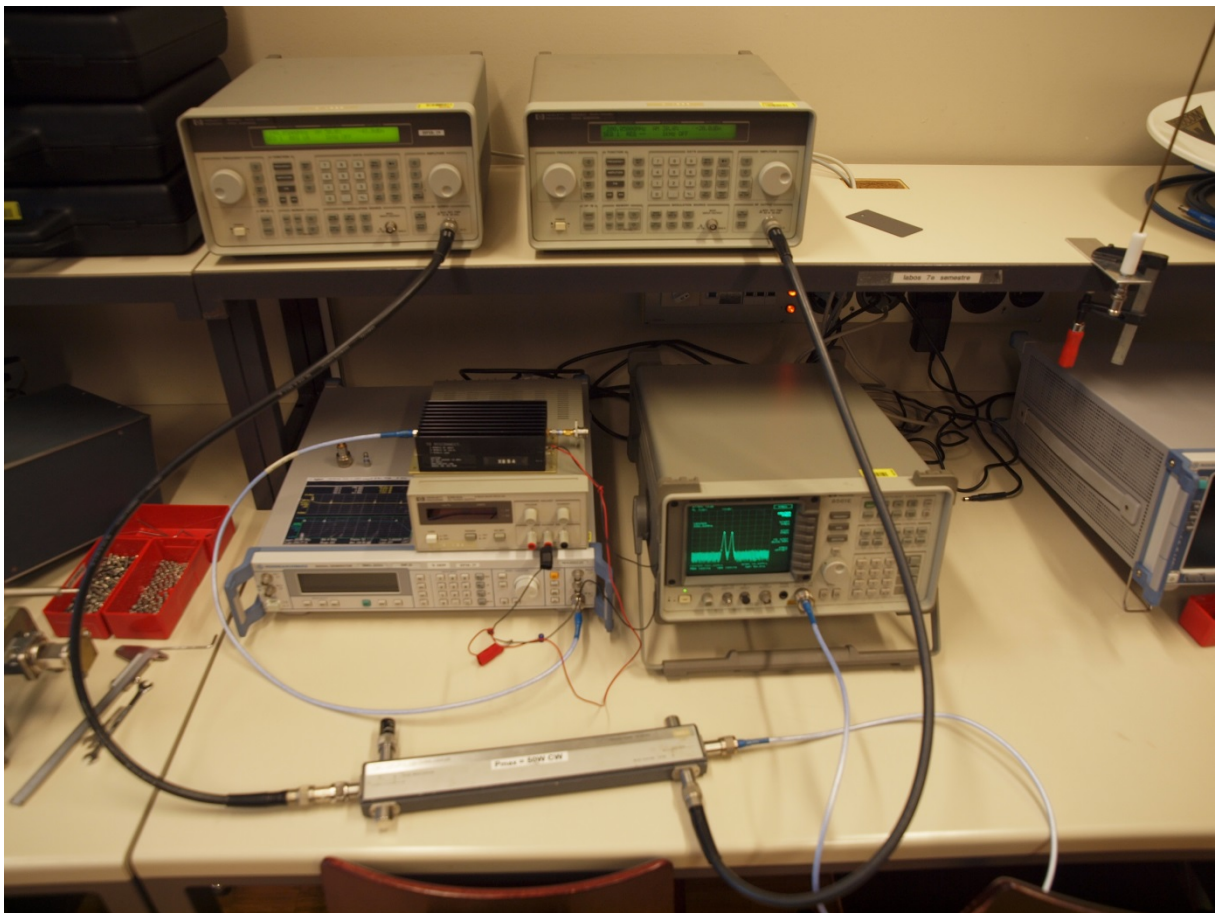
4. References

[1] Agilent Application Note AN150: Spectrum Analyzer Basics

https://www.home.agilent.com/agilent/gated.jsp?lb=1&gatedId=1000000159:epsg:apn&cc=US&lc=eng&parentContId=worldwide_home&parentContType=sr&fileType=VIEWABLE&searchType=GR

[2] Spectrum Analyzer Basics: From 1998 Back to Basics Seminar

<http://www.home.agilent.com/agilent/redirector.jsp?action=doc&lc=eng&cc=CA&id=1000001598-1%3Aepsg%3Aatcn<ype=External%20File>



Photography of the experiment setup for Laboratory session 6.