Superheterodyne Spectrum Analyzer and Spectrum Analysis

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Part I

Superheterodyne Spectrum Analyzer and Spectrum Analysis

Chapter 1
INTRODUCTION

This experiment deals with spectrum analyzer basic operation. The student will learn the basic concept of frequency domain measurements also called spectral analysis. During the experiment the student examine it using different kind of signals.

1.1 Objectives

Upon completion of the experiment the student will:

· Get acquainted with the front panel of Spectrum Analyzer.
· Understand the function of each block of the spectrum analyzer .
· Making basic measurements with a Spectrum Analyzer.
· Know- how to operate the spectrum analyzer.
· Possess the necessary tools to evaluate signals in frequency domain.

1.2 Necessary Background:

The student needs to have an understanding of Fourier transform.

1.3 Prelab Exercise

1. Using Matlab, draw a graph of squarewave, frequency 1MHz, amplitude $1V_p$,in time domain and frequency domain (magnitude only), compare your graph to theoretical plot.

2.Using Matlab, draw a graph of repetitive exponent fall signal (one period $y = e^{-t/T}$) in time domain, and frequency domain (magnitude only)
frequency 100kHz, amplitude $1V_p$,assume T=$1.84\mu s$.

3. Draw block diagram of a spectrum analyzer and explain each of the following blocks (Attenuator, amplifier,LPF, IF filter,
envelope detector, video filter, display, LO, Ramp generator).

4. Draw a graph in frequency domain of sine wave, square wave, triangle wave Frequency 150kHz, amplitude 10 volt,
consists of first five harmonics.

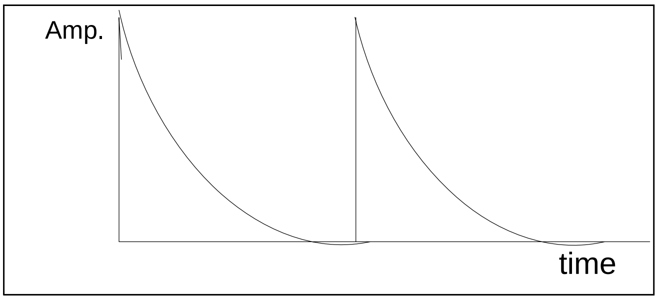

Figure 1 Repetitive one side exponent fall signal

1.4 References

1. ROBERT A. WITTE "Spectrum and Network Measurements" . New Jersy , Prentice Hall,1991

2. CYDE F. COOMBS, Jr. "Electronic Instrument Handbook". McGraw-Hill, second edition 1995.

3. C. Rauscher: "Fundamental of Spectrum analysis" Rhode&Schwarz 2001.

4. Agilent Company: "Spectrum Analysis Basics". Application Note 150, January 2005.

Chapter 2
BACKGROUND THEORY

2.1 Frequency and Time Domain

Traditionally, when you want to look at a periodic or non-periodic signal, you use an oscilloscope with or without memory capability to see how the signal varies with time. This is very important information; however, it doesn't give you the full picture. To fully characterized the performance of your device or system, you are required to analyze the components of the signal(s) in the frequency-domain. This is a graphical representation of the signal's amplitude as a function of frequency. The Spectrum Analyzer () is a dedicated tool for analyzing and measuring in the frequency domain, such as the oscilloscope is to the time domain. Figure-1 shows three sinewave signals in both the time and frequency domains. In the time domain, all frequency components of the signal are summed together and displayed as one signal. In the frequency domain, complex signals (that is, signals composed of more than One frequency) are separated into their frequency components, and the level at each frequency is displayed.

Frequency domain measurements have several distinct advantages. For example, let's say you're looking at a signal on an oscilloscope that appears to be a pure sine wave. A pure sine wave has no harmonic distortion. If you look at the signal on a spectrum analyzer, you may find that your signal is actually made up of several frequencies. What was not discernible on the oscilloscope becomes very apparent on the spectrum analyzer. From this view of the spectrum, measurements of frequency, power, harmonic content, modulation, spurs, and noise can easily be made. Given the capability to measure these quantities, we can determine total harmonic distortion, occupied bandwidth, Signal stability, output power, intermodulation distortion, power bandwidth, carrier-to-noise ratio, and other measurements, using just a spectrum analyzer.

2.2 Spectrum Analyzer Block Diagram and Theory of Operation

The main components of Spectrum Analyzer are an RF input attenuator, input amplifier, mixer, IF amplifier, IF filter, envelope detector, video filter, CRT display, LO, ramp generator(see Fig - 2). Lets describe each component individually

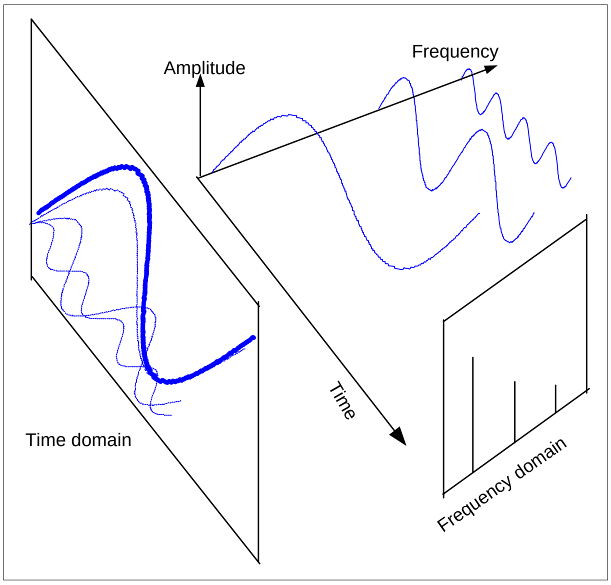

Figure 1 Time and Frequency Domain

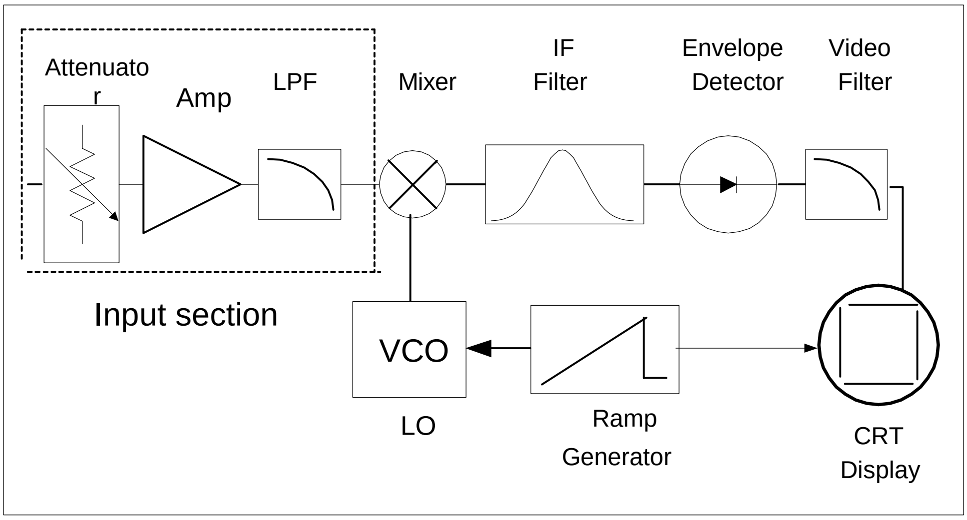

Figure 2 simplified block diagram of Heterodyne spectrum analyzer

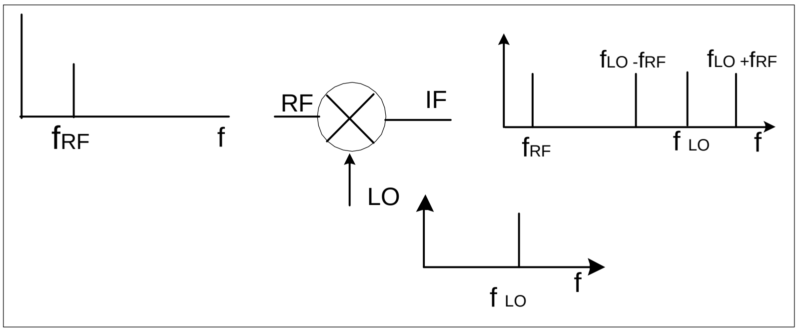

Figure 3 Mixer stage

2.3 Input Section

The input to the spectrum analyzer block diagram has a step attenuator, followed by an amplifier. The purpose of this input section is to control the signal level applied to the rest of the instrument. If the signal level is too large, the analyzer circuits will saturate the mixer and distort the signal, causing distortion products to appear along with the desired signal. If the signal level is too small, the signal may be masked by noise present in the analyzer. Either problem tends to reduce the dynamic range of the measurement. The new instruments provide an autorange feature, which automatically selects an appropriate input attenuation. The input circuitry of a typical analyzer is very sensitive and will not withstand much abuse. Careful attention should be paid to the allowable signal level at the input, particularly for microwave analyzers. Some instruments tolerate DC voltages at their inputs, but others require that no DC be applied, or be restricted to small values. The front end of Spectrum Analyzer is made with wide open on the basis that we have no idea how many signals are involved in our measurement, in order to control somehow on the measured spectrum it is necessary to add LPF for image rejection

2.4 Mixer

A mixer (Fig-3) is a device that converts a signal from one frequency to another. It is therefore sometimes called a frequencyconverter

device

The output of a mixer consists of the two original signals f{LO} and f{RF} as well as the sum f{LO}+f{RF} and difference f{LO}-f{RF} frequencies of these two signals.

2.5 IF Filter and Selectivity

The IF filter is a Band Pass Filter (BPF) which is used as the "window" for detecting signals. Its bandwidth is also called the Resolution Bandwidth (RB, RBW) of the

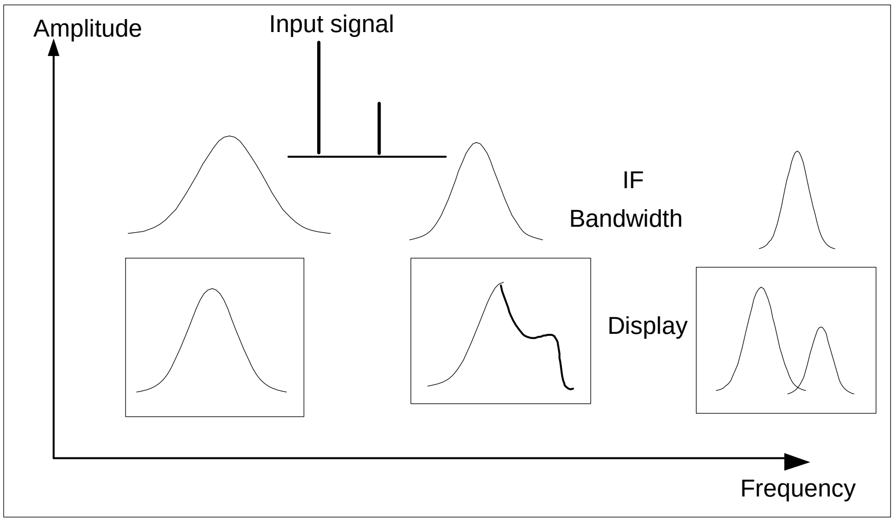

Figure 4 IF filter width and resolution

analyzer and can be changed via the front panel of the analyzer. By giving you a broad range of variable resolution bandwidth settings, the instrument can be optimized for the sweep and signal conditions, letting you trade-off frequency selectivity (the ability to resolve signals), signal-to-noise ratio (SNR), and measurement speed.

One of the first things to note is that a signal cannot be displayed as an infinitely narrow line such as mathematics (δ) delta function. It has some width associated with it. This shape is the analyzer's tracing of its own IF filter shape as it tunes past a signal. Thus, if we change the filter bandwidth, we change the width of the displayed response. This concept enforces the idea that the IF filter bandwidth and shape determines the resolvability between signals.

When measuring two signals of equal-amplitude, (Fig-5) the value of the selected BW tells us how close together they can be and still be distinguishable from one another (by a 3 dB 'dip'). However, with wider BWs, the two signals may appear as one. In general then, 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.

2.6 Signals of Unequal Amplitude

2.7 Sensitivity

One of the primary uses of a spectrum analyzer is to search out and measure low-level signals. The sensitivity of any receiver is an indication of how well it can detects small signals. A perfect receiver would add no additional noise to the natural amount of thermal noise present in all electronic systems, represented by

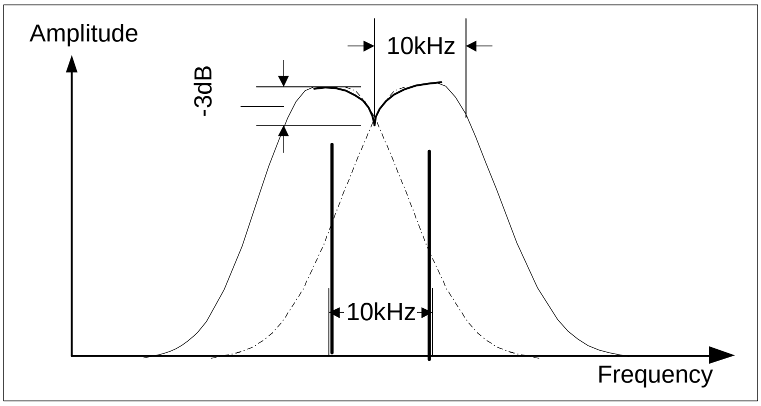

Figure 5 Resolving two signal with equal amplitude

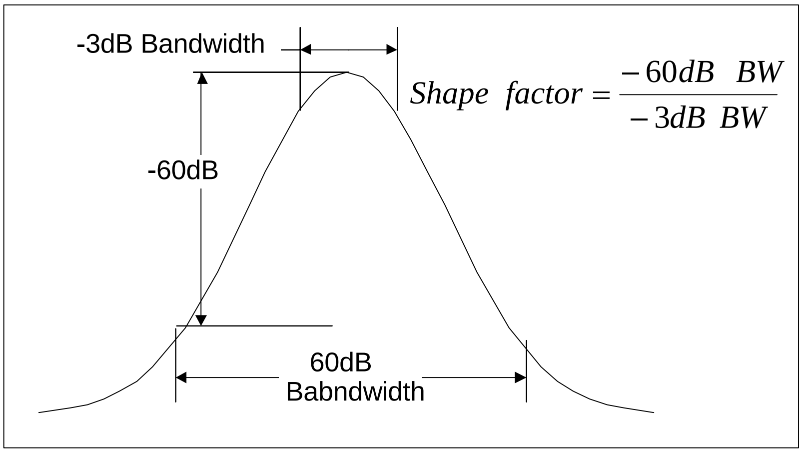

Figure 6 If filter shape and selectivity

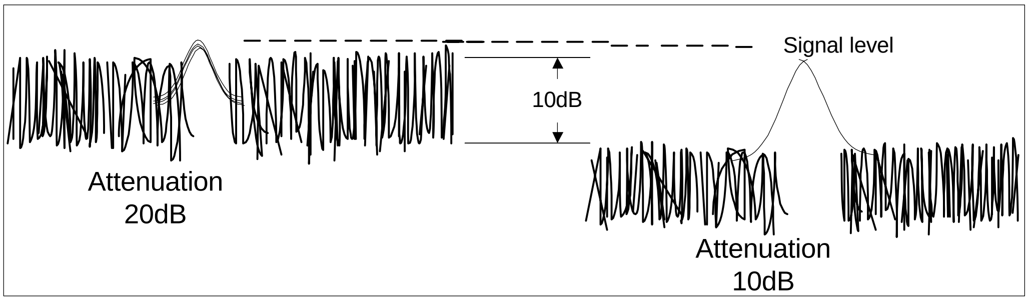

Figure 7 SNR decrease as input attenuation increase.

$$N = kTB$$

where N is the noise power, k is Boltzman's constant, T = temperature in Kelvin degree, and B is the bandwidth of the system in Hz. In practice, all receivers, including spectrum analyzers, add some amount of internally generated noise.

Spectrum analyzers usually characterize this by specifying the displayed average noise level in dBm, with the smallest RBW setting. An input signal below this noise level cannot be detected. Generally, sensitivity is on the order of -90 dBm to -145 dBm depending on quality of spectrum analyzer. It is important to know the sensitivity capability of your analyzer in order to determine if it will measure your low-level signals. One aspect of the analyzer's internal noise that is often overlooked is its effective level as a function of the RF input attenuator setting (Fig-7). Since the internal noise is generated after the mixer (primarily in the first active IF stage), the RF input attenuator has no effect on the actual noise level. (Refer to the block diagram Fig.-2). 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.

This internally generated noise in a spectrum analyzer is thermal in nature; that is, it is random and has no discrete spectral components. Also, its level is flat over a frequency range that is wide in comparison to the ranges of the RBWs. This means that the total noise reaching the detector (and displayed) is related to the Resolution bandwidth (Fig-8) selected. Since the noise is random, it is added on a power basis, so the relationship between displayed noise level and Resolution bandwidth is a ten log basis. In other words, if the Resolution bandwidth is increased (or decreased) by a factor of ten, times more (or less) noise energy hits the detector and the displayed average noise level increases (or decreases) by 10 dB. Spectrum analyzer noise is specified in a specific Resolution bandwidth. The spectrum analyzer's lowest noise level (thus slowest sweep time) is achieved with its narrowest Resolution bandwidth.

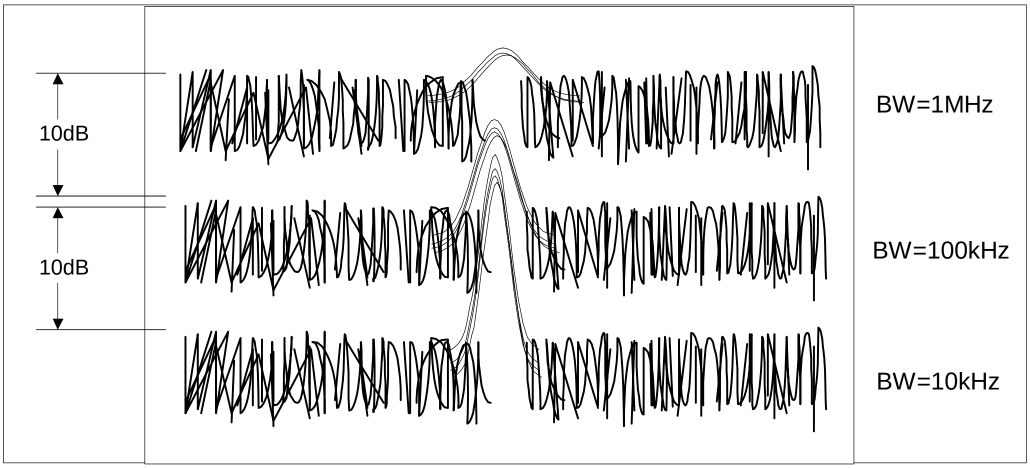

Figure 8 SNR increase as IF Banwidth decrease

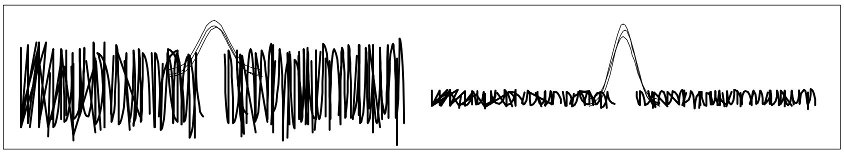

Figure 9 Effect of video filter on displayed noise

2.8 Detector

Many modern spectrum analyzers have digital displays, which first digitize the video signal with an analog-todigital converter (ADC). This allows for several different detector modes that dramatically effect how the signal is displayed. Ordinary spectrum analyzer use peak-detection technic. Video Filter

The video filter is a low-pass filter that is located after the envelope detector and before the ADC. This filter determines the bandwidth of the video amplifier, and is used to average or smooth the trace seen on the screen. The spectrum analyzer displays signal-plus-noise so that the closer a signal is to the noise level, the more the noise makes the signal more difficult to read. By changing the video bandwidth setting, we can decrease the peak-to-peak variations of noise. This type of display smoothing can be used to help find signals that otherwise might be obscured in the noise

The VBW, however, does not effect the frequency resolution of the analyzer (as does the resolution bandwidth filter), and therefore changing the video filter does not improve sensitivity. It does, however, improve discernibly and repeatability of low signal-to-noise ratio measurements.

Chapter 3
EXPERIMENT PROCEDURE

3.1 Required Equipment

· Two Arbitrary Waveform Generator (AWG) HP-33120A.
· Spectrum analyzer Agilent ESA series
· Signal generator Agilent-8647.

3.2 Reading Amplitude and Frequency

This experiment demonstrate basic spectrum analyzer measurement, each measurement focused on different functions of the spectrum analyzer . We begin with the measuring of the CAL OUT signal (calibration sinusoidal signal, frequency 50 MHz amplitude -20dBm).

1. Connect the spectrum analyzer AMPTD REF OUT to the INPUT 50Ω with an appropriate cable (see Fig-1).

2. Turn on the spectrum analyzer by pressing **ON** button, Wait for the power-up process to complete.

3. Press the green **PRESET** key.

4.Activate the reference signal by pressing I**NPUT/OUTPUT**, **AMPTDREF OUT**on.

3.2.1 Set the Frequency.

Press the **FREQUENCY** key. **CENTER FREQ** appears on the right side of the screen, indicating that the center-frequency function is active. The **CENTER FREQ** softkey label appears in inverse video to indicate that center frequency is the active function. Their values can be changed with the knob, step keys, or number/ units' keypad. Set the center frequency to 50 **MHz** with the **DATA** keys by pressing **50 MHz**.

3.2.2 Set the Span.

Press SPAN. Span is now displayed in the active function block, and the SPAN softkey label appears in inverse video. Reduce the span to 20 MHz by using the knob, pressing the down key (↓), or pressing 20 MHz.

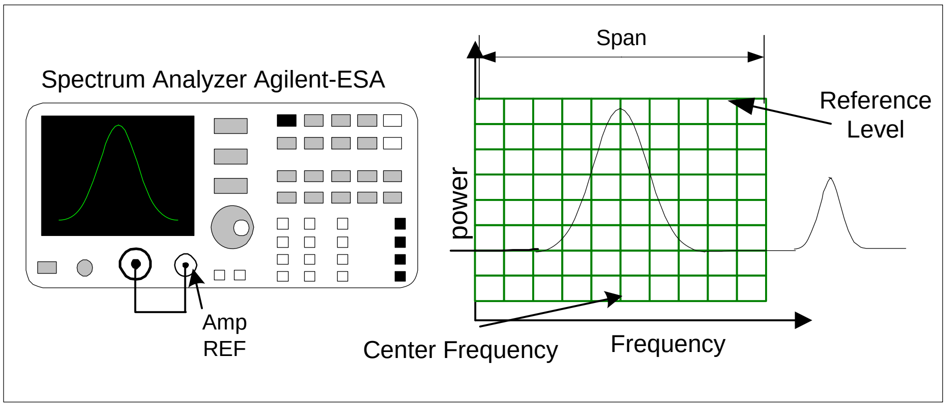

Figure 1 Frequency and amplitude setting

3.2.3 Set the Amplitude.

When the peak of a signal does not appear on the screen, it may be necessary to adjust the amplitude level on the screen Press AMPLITUDE. The REF LVL softkey label appears in inverse video to indicate that reference level is the active function. The reference level is the top graticule line on the display and is set to 0.0 dBm. Changing the value of the reference level changes the amplitude level of the top graticule line. Figure 1 demonstrates the relationship between center frequency and reference level. The box in the figure represents the spectrum analyzer screen. Changing the center frequency changes the horizontal placement of the signal on the screen. Changing the reference level changes the vertical placement of the signal on the screen. Increasing the span increases the frequency range that appears horizontally on the screen.

3.2.4 Set the Marker

You can place a diamond-shaped marker on the signal peak to find the signal's frequency and amplitude. To activate a marker presses the MKR key. The MARKER NORMAL label appears in inverse video to show that the marker is the active function. Turn the knob to place the marker at the signal peak. You can also use the PEAK SEARCH key, which automatically places a marker at the highest point on the trace. Readouts of marker amplitude and frequency appear in the active function block and in the upper-right corner of the display. Look at the marker readout to determine the amplitude of the signal.

3.3 Resolving Two Signals of Equal amplitude

1.To obtain two signals with a 0.1 MHz separation, connect the system as shown in Fig.-2

2. Set the first AWG to frequency 11 MHz amplitude -20dBm. Set the second AWG to 11.1 MHz and amplitude -20dBm.

3. On the spectrum analyzer, press PRESET. Set the center frequency to 11

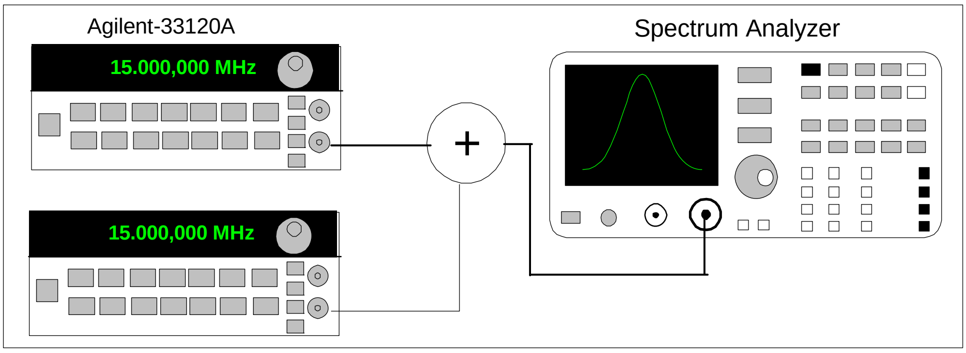

Figure 2 Setup for resolving two equal amplitude signals

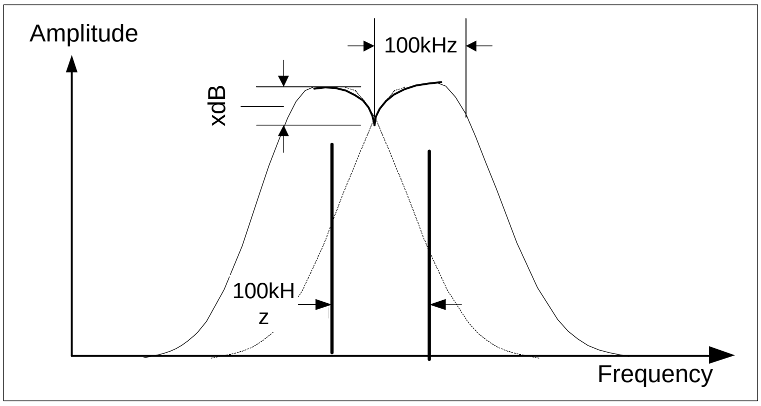

Figure 3 Measuring the depth of the dip

MHz, the span to 3 MHz, and the resolution
bandwidth to 300 kHz by pressing FREQUENCY 11 MHz, SPAN 3 MHz, Then BW to 300 kHz. A single peak is
visible.

4. Since the resolution bandwidth must be less than or equal to the frequency separation of the two signals, a resolution bandwidth of 100 kHz must be used. Change the resolution bandwidth to 100 kHz by pressing BW 100 kHz. Two signals are now visible as indicated Figure 3. Use the knob or step keys to further reduce the resolution bandwidth and span to better resolve the signals **Save the data on magnetic media.**

3.3.1 Notice!

As the resolution bandwidth is decreased, resolution of the individual signals is improved and the sweep time is increased.

5. Set the SPAN 1 MHz Then BW to 100 kHz.
6. Change the vertical scale to 3dB/division by pressing AMPLITUDE, SCALE/DIV

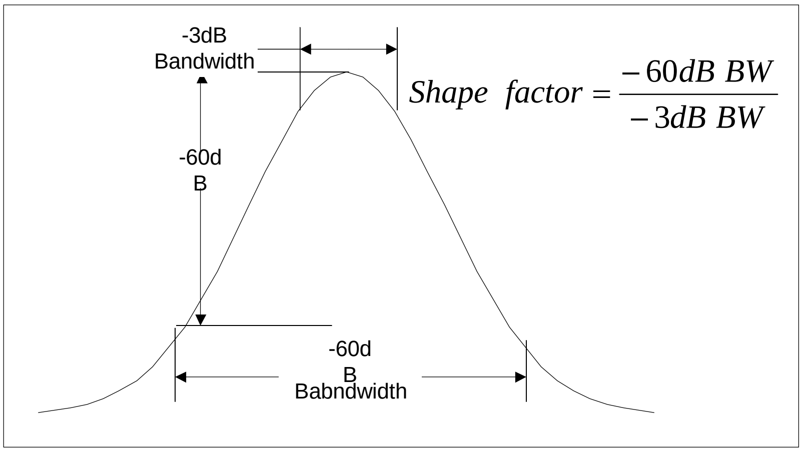

Figure 4 Measuring shape factor of IF filter

3 dB, set the trace near the top of the graticule by pressing AMPLITUDE, REF LVL , -20 dBm

7. Verify that the two signal have the same amplitude (change amplitude if necessary) Measure the depth of the 'dip' between the two signals, by using PEAK SEARCH and MARKER,**Save the data on magnetic media**

3.4 Shape Factor

In this part of the experiment you measure the shape factor of the 100 kHz IF filter of the spectrum analyzer (see Fig-4).

1. Disconnect one of the AWG's -33120A from the spectrum analyzer; set the other AWG -33120Asignal generator to frequency 10 MHz, amplitude

2. Set the spectrum analyzer frequency 10 MHz, span 10 MHz, BW 100 kHz, using the MARKER Δ functions to find and record the 3 dB bandwidth of IF filter.

3. Use the MARKER Δ function to measure the 60 dB bandwidth of the IF filter, using the data calculate the shape factor (-60dB/-3dB bandwidth) of the 1 MHz BW filter. **Save the data on magnetic media.**

3.5 Measuring Signals using Logarithmic and Linear mode, Absolute and Relative Quantities.

In this part of the experiment you measure the amplitude and frequency of the harmonics of 1 MHz Squarewave. The measurement will be in Absolute and Relative mode.

1. Connect the equipment as shown in Fig-5

2. Set the AWG-33120 to **Squarewave** Frequency 1 MHz Amp 1 Vpp.

3. Set the Spectrum Analyzer to center frequency **1 MHz** and **Span** to **10 MHz** . By pressing **FREQUENCY 1 MHz**, then **SPAN 10MHz.**

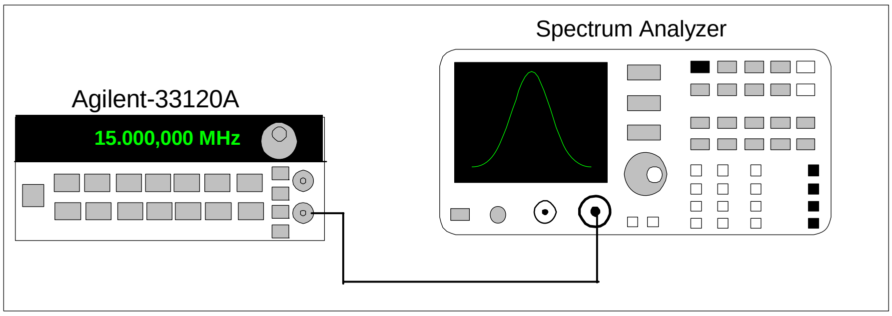

Figure 5 Setup for measuring signals, logarithmic and linear mode, and Minimum and Maximum hold measurement

4. Use the Marker function to identify the frequency and amplitude of the first five harmonics, by pressing **PEAK SEARCH**,
(choose the +1 MHz harmonics) and fill the first two columns of the following table. **Save the data on magnetic media**.

Absolute Measurement			
Harmonics	Frequency(MHz)	Amplitude(dBm)	Amplitude(mv)
First			
Second			
Third			
Fourth			
Fifth			

Table -1

5. Set the Spectrum Analyzer to Linear mode, by pressing **AMPLITUDE** and **SCALE TYPE LOG LIN**, measure the linear value of the harmonics and fill the last column of table-1.**Save the data on magnetic media**.

6. Measure the relative Amplitude and Frequency difference between the odd harmonics, by pressing **MARKER**,**DELTA** and choosing the appropriate harmonics. Fill the relevant columns of table -2, and compare the result to your prelab simulation. **Save the data on magnetic media**

Relative Measurement				
Harmonics (No)	Frequency difference (MHz)	Amplitude difference(dB)	Amplitude difference(%)	Matlab Simulation Result
First-Third				
Third-Fifth				

Table -2

7. Set the Spectrum Analyzer to Linear mode, by pressing **AMPLITUDE** and twice on **SCALE LOG LIN,** measure the linear difference value of the harmonics and fill the last column of table-2.**Save the data on magnetic media**

3.6 Time and Frequency Domain of Exponent Fall Signal

1. Connect the equipment as shown in Fig-5.

2. Set the function generator to arbitrary exponent fall signal, frequency 100kHz, amplitude 0 dBm.

3. Set the spectrum analyzer to center frequenc 500kHz, span 1 MHz, amplitude linear mode

4. Measure the amplitude of each 5 first harmonics, and compare the measured value to the values of prelab-2.

3.7 Using the Maximum -hold Function to View the Frequency Response of LPF

The maximum hold function is useful for characterize of passive elements such as LPF.

1. Connect the equipment as shown in Fig-5.

3.7.1 Setting the AWG

2. Set the function generator to swept source by setting, sweep mode, frequency 100Hz to 10MHz.Enable sweep mode by pressing **Shift Sweep**.Enter frequency range by using the default start frequency 100 Hz, and pressing **Shift MENU,**and **>,**the display will be B: SWP MENU, press ∨ button and twice on > to display 2: STOP F, then press ∨ **10MHz.**

3.7.2 Setting the spectrum analyzer

In order to measure the frequency response of the LPF, we will use the maximum hold function, while the source is swept. C for minimum hold signal. The peak deviation frequency measured between maximum and minimum traces.

3. Press **PRESET, FREQ CENTER FREQUENCY 5 MHz, SPAN 10 MHz,**

4. Press **VIEW/TRACE** then **MAX HOLD** . now you see the maximum of the measured signal (see Fig.-6).

5. The negative frequency is a false display of the spectrum analyzer(due to the spectrum structure), refer only to the positive frequency.

3.8 Measuring Low-Level Signals Using Attenuation, Video Bandwidth, and Video Averaging.

Spectrum analyzer sensitivity is the ability to measure low-level signals. It is limited by the noise generated inside the spectrum analyzer. The spectrum analyzer input attenuator, and bandwidth settings affect the sensitivity, by changing the signal-to-noise ratio. The attenuator affects the level of a signal passing through the instrument, whereas the bandwidth affects the level of internal noise without affecting the signal. If, after adjusting the attenuation and resolution bandwidth, a signal is still near the

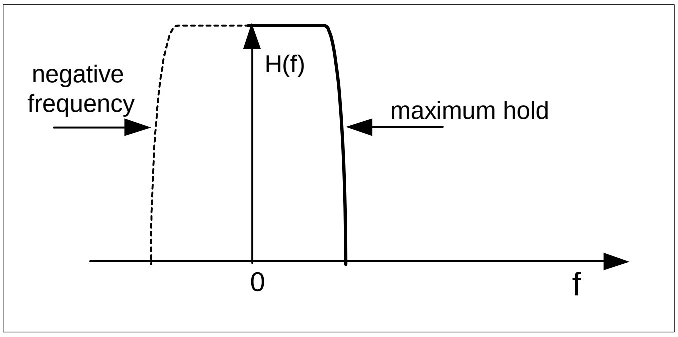

Figure 6

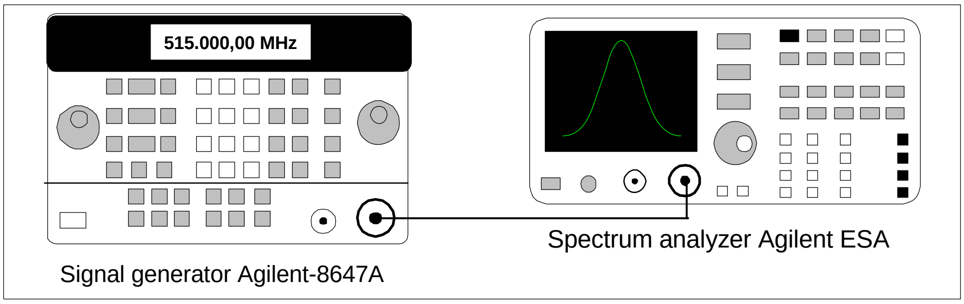

Figure 7 Setup for low level signal measurement

noise, visibility can be improved by using the video-bandwidth and video-averaging functions.

1.Connect the equipment as shown in Fig-7.

2. Set the Signal Generator to frequency 80 MHz, amplitude -60dBm.

3. Set the Spectrum analyzer to 80 MHz , by pressing **FREQUENCY, CENTER FREQUENCY 80 MHz ,SPAN 10 MHz,**
AMPLITUDE REF LVL -30 dBm.

4. Place a marker on the low-level signal (80 MHz). Press **MKR** and use the knob to position the marker at the signal's peak.

5. Place the signal at reference level by pressing .$\underrightarrow{MKR}$, then MARKER-$\rightarrow$ **REF LVl.**

6. Reduce the span to 5 MHz, and bandwidth to 100 kHz, by pressing **SPAN,** and then use the step-down key (↓), press **BW 100 kHz.**

7. Press **BW** , and **Average On** , to activate the video average. Measure the level of the noise, and the signal to noise ratio (SNR). **Save the data on magnetic media**

8. Change the attenuation to 20 dB by Pressing on **AMPLITUDE, ATTENUATION 20 dB** keys. Measure the level of the Noise and the Signal, to Noise Ratio (SNR) Describe what happens to the noise floor and to SNR? **Save the data**

on magnetic media.

9. Set again the attenuation to 10 dB, reduce the bandwidth to 10 kHz, by pressing **BW/Avg 10kHz**, describe again, what happens to the noise level? **Save the data on magnetic media**.

3.9 Measuring a Signal Very Close to the Noise Floor

The video-filter control is useful for noise measurements and observation of low-level signals close to the noise floor. The video filter is a post-detection low-pass filters that smooths the displayed trace. When signal responses near the noise level of the spectrum analyzer are visually masked by the noise, the video filter can be narrowed to smooth this noise and improve the visibility of the signal. (Reducing video bandwidths requires slower sweep times to keep the spectrum analyzer calibrated). Now after you recognized all the main user function of the Spectrum Analyzer, try to find by yourself low level signal (about15dB above noise floor).

1. Connect the equipment as shown in Fig-7.
2. Set the Signal Generator to frequency 80 MHz, amplitude -100dBm.
3. Try to achieve maximum signal to noise ratio, place a marker on the low-level signal. and **Save the data on magnetic media**.

3.10 Final Report

1. Using the data of the "Resolving signals of equal amplitude" draw a graph of the two signals, and find the depth of the 'dip' between the two signals, compare it to your measurement.

2. Draw a graph of the 1 MHz IF filter, use the record data of the filter, find the Shape factor of the IF filter. compare the calculated and measured Shape factor.

3. Use the data of 'Measuring Signals using Logarithmic and Linear mode, Absolute and Relative Quantities' Draw two Graphs of 1 MHz squarewave signal in frequency domain, one with Logarithmic scale, and second Linear scale, find the amplitude of each harmonics, and describe what happen to the even harmonics, in linear mode.

4. Use the data of the Measuring Low-Level Signals Using ....paragraph, draw three graphs, first for 10 dB attenuation and BW 100kHz, second for 20 dB attenuation and BW 100kHz, and third for 10 dB attenuation and 10 kHz band width, denote on each graph the level of the noise, and signal to noise ratio. Describe what happen to the Noise when you change the Attenuation and the Bandwidth.

5. Uses the data of Measuring a Signal Very Close to the Noise Floor paragraph draw a graph of the low-level signal, using the data find SNR.