Basic RF Technic and Laboratory Manual - Vector Network Analyzer Measurement.

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August, 2008.

CONTENTS

1. INTRODUCTION

1.1 Objectives

Upon completion of the study, the student will become familiar with the following topics:

1. Get acquainted with the major function of the network analyzer.

2. Using the network analyzer to measure reflection , Standing Wave Ratio (SWR), reflection coefficient and impedance.

3.Using the network analyzer to measure transmission, attenuation, gain and insertion phase.

4. Display the device under test parameters (SWR, return loss, reflection coefficient, impedance) in various formats: linear, log, polar, amplitude-phase, real-imaginary and Smith - chart.

5. Basic knowledge on network analysis measurement and concepts.

6. Verification of the calibration of the network analyzer.

1.2 Prelab Students Preparation and Report

1. Refer to Figure 3 and describe the signal flow when measuring the SWR and the attenuation of the attenuator.

2. Define the following parameters: Reflection Coefficient, S-parameters, Return Loss (RL) and SWR.

3. Which measurement the network analyze perform under Reflection and which under Transmission?

2. BACKGROUND THEORY

2.1 Transmission Line Basic

Electronic circuits which operate at high frequencies present some unique challenges for a proper characterization. At high frequencies the wavelengths of operation become similar in dimension to the physical properties of circuit elements. This results in circuit performance that is distributed in nature rather than describing the voltage and current at a specific circuit node. It is more appropriate to describe how waves in a transmission medium respond to a component in their path. Network analyzers are a class of instruments that have been developed to characterize Radio Frequency (RF) components accurately and efficiently as a function of frequency. Network analysis is the process of creating a data model of the transfer and/or impedance characteristics of a linear network through stimulus-response testing over the frequency range of interest. At frequencies above 1 MHz, lumped elements actually become circuit consisting of the basic elements plus parasitic elements like stray capacitance, lead inductance and unknown absorptive losses. Since parasitic depend on the individual device and its construction, they are almost hard to predict. Above 1 GHz, component geometries are comparable to a signal wavelength, intensifying the variance in circuit behavior due to device construction. Network analysis is generally limited to the definition of linear networks. Since linearity constrains networks stimulated by a sine wave to produce a sine-wave output, sine-wave testing is an ideal method for characterizing magnitude and phase response as a function of frequency. This chapter discusses the key parameters used to characterize RF components, the types of network analyzer techniques used to make measurements and the considerations to be made in obtaining the most accurate results.

2.2 Component Characteristics

RF (frequencies less than 3 GHz) or microwave (frequencies in the 3 to 30 GHz range) energy can be likened to a light wave. Incident energy on a Device Under Test (DUT) (for example, a lens) is either reflected from or transmitted through the device (see Figure 1). By measuring the amplitude ratios and phase differences between the two waves it is possible to characterize the reflection (impedance) and transmission (gain) characteristics of the device.

2.3 Reflection and Transmission

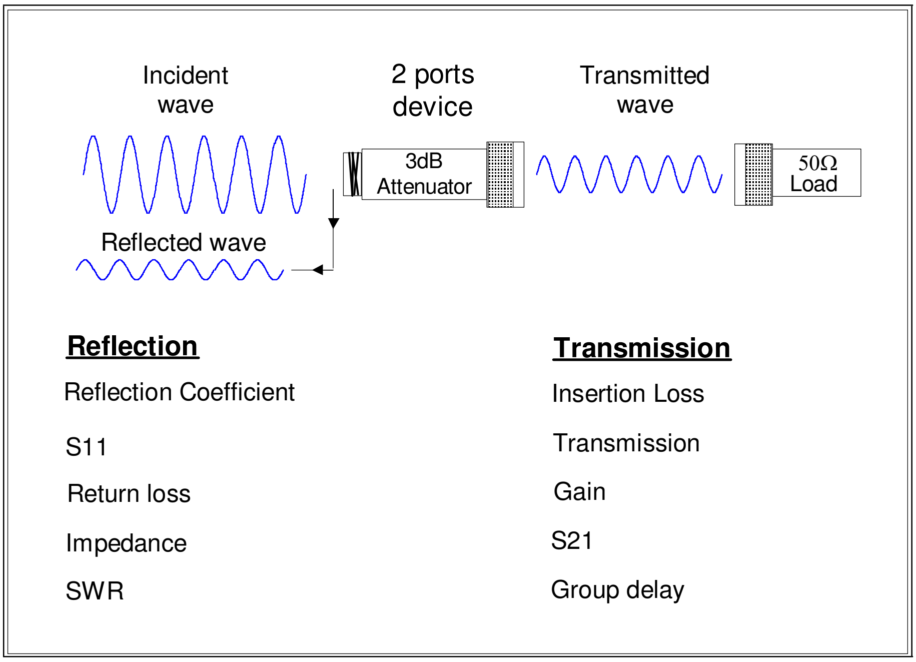


Figure 1 - Reflection and Transmission measurement

There are many terms used to describe these characteristics. Some use only magnitude information (scalar) and others include both magnitude and phase information (vector). If an incident wave on a device is described as V_{INCID}, the ratio of V_{INCID} and I_{INCID} is called the transmission system characteristic impedance Z_0, and a device terminating a transmission system has an input impedance called a load impedance Z_L, then the device characteristics can be defined by:

Reflection terms:

$$\begin{aligned} \Gamma &= \frac{V_{REFLECT}}{V_{INCID}} = \frac{Z_L - Z_0}{Z_L + Z_0} \\ -1 &< \Gamma < 1 \end{aligned}$$

where Γ = As the device reflection coefficient (complex).
V_{INCID} = As the incident wave on a DUT.
V_{REFLEC} = reflected wave from a DUT.
Z_0 =Transmission medium characteristic impedance.
Z_L = Load impedance of DUT.

$$\begin{aligned} \rho &= |\Gamma| \\ 0 &< \rho < 1 \end{aligned}$$

where ρ = magnitude of reflection coefficient.

$$\mathrm{Re}\,turn\ Loss\ (dB) = -20\log\rho$$

$$\begin{aligned} S &\equiv SWR = \frac{1+\rho}{1-\rho} \\ 1 &< S < \infty \end{aligned}$$

where SWR = Standing-Wave Ratio of current or voltages on a transmission medium. The load impedance is connected to the reflection coefficient by the relation

$$Z_L = \frac{1+\Gamma}{1-\Gamma} Z_0$$

Transmission terms:

$$Transmission\ coefficient = \frac{V_{TRANS}}{V_{INCID}}$$

$$Insertion\ loss\ (dB) = 20\log(\frac{\mid V_{TRANS} \mid}{\mid V_{INCID} \mid})$$

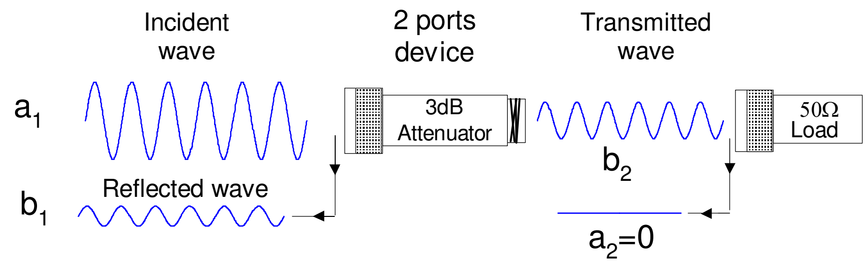
$$Gain(dB) = 20log(\frac{\mid V_{TRANS} \mid}{\mid V_{INCID} \mid})$$

$$Insertion\ phase = \angle V_{TRANS} - \angle V_{INCID}$$

Where $< V_{INCID}$ = vector relative phase angle of incident wave on a DUT.
$< V_{TRANS}$ = vector relative phase angle of transmitted wave through a DUT.

2.3.1 Scattering (S) Parameters

Many component measurements are two-port networks, such as amplifiers, filters, cables and antennas. These component characteristics are typically used to determine how a particular device would contribute as a part of a more complex system. To provide a method that models and analyzes a full two ports device in the RF environment, scattering parameters (S parameters) were defined (see Figure 2).



$$S_{11} = \frac{Reflected}{Incident} = \frac{b_1}{a_1} \quad a_2 = 0$$

$$S_{21} = \frac{Transmitted}{Incident} = \frac{b_2}{a_1} \quad a_1 = 0$$

Figure 2 - S-parameter measurement of two port element.

This is a characterization technique similar to a lower-frequency Z or Y modeling, except that it uses incident, transmitted and reflected waves to characterize the input and output ports of a device as opposed to using voltage and current terms which are impossible to measure at high frequencies. The S parameter terms are related to other parameters with certain conditions. For instance, S_{11} is equivalent to a device input reflection coefficient Γ_{IN} under the condition the device has a perfect Z_0 match on its output. S parameter characterization of devices plays a key role in the ability of measuring, modeling and designing complex systems with multiple components. By definition, S parameters can be measured with a network analyzer.

Network Analyzer System Elements

A network analyzer measurement system can be set of four major parts: a signal source providing the incident signal, signal separation devices to separat the incident, reflected and transmitted signals, a receiver to convert the microwave signals to a lower Intermediate Frequency (IF) signals, a signal processor and a display section to process the IF signals and display detected information, as shown in Figure 3.

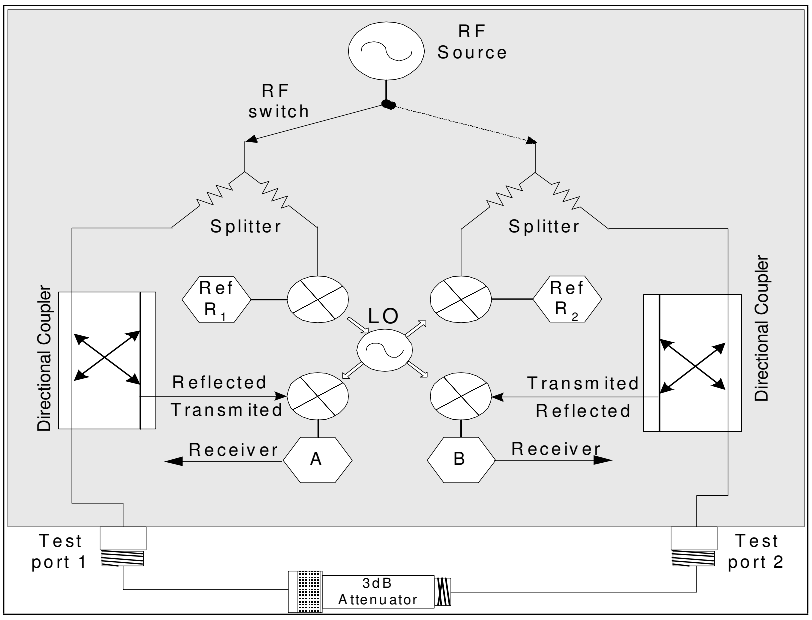


Figure 3 - The major elements of a Network Analyzer.

The receiver perform the full S parameters which defined as:

$$
\begin{aligned}
S_{11} &= \frac{reflected\ wave}{Incident\ wave} = \frac{A}{R_1} \\
S_{22} &= \frac{reflected\ backward\ wave}{Incident\ backward\ wave} = \frac{B}{R_2} \\
S_{21} &= \frac{Transmitted\ wave}{Incident\ wave} = \frac{B}{R_1} \\
S_{12} &= \frac{Transmitted\ backward\ wave}{Incident\ backward\ wave} = \frac{A}{R_2}
\end{aligned}
$$

Signal Source

The signal source (RF or microwave) produces the incident signal used to stimulate the Device Under Test (DUT). The DUT responds by reflecting part of the incident energy and transmitting the remaining part. By sweeping the frequency of the source the frequency response of the device can be determined. Frequency range, frequency stability, signal purity, output power level and level control are factors which may affect the accuracy of a measurement. The source used for the network analyzer measurements, is a synthesizer, which characterized by stable amplitude frequency and a high frequency resolution (less than 100 Hz at microwave range).

Signal Separation

The next step in the measurement process is to separate the incident, reflected and transmitted signals. Once separated, their individual magnitude and/or phase differences can be measured. This can be accomplished through the use of wideband directional couplers, bridges or power splitters.

A directional coupler is a device that consists of two coupled transmission lines that are configured to couple energy to an auxiliary port if it goes through the main port in one direction and not in the opposite direction. Directional couplers usually have relatively low loss in the mainline path and thus present little loss to the incident power. In a directional coupler structure (see Figure 3) the coupled arm samples a signal traveling in one direction only. The coupled signal is at a reduced level and the relative amount of reduced level is called the coupling factor. For instance a -20dB directional coupler means that the coupled port power level is 20 dB below the input, which is equivalent to 1% of the incident power. The remaining 99% travel through the main arm. The other key characteristic of a directional coupler is directivity. Directivity is defined as the difference between a signal detected in the forward direction and a signal detected in the reverse direction (isolation between the forward and reverse signals). A typical directional coupler will work over several octaves with 30 dB directivity.

The two-resistor power splitter (see Figure 3) is used to sample either the incident signal or the transmitted signal. The input signal is split equally between the two arms, with the output signal (power) from each arm being 6dB below the input (power). A primary application of the power splitter is for producing a measurement with a very good source match. If one side of the splitter output is taken to a reference detector and the other side goes through a DUT to a transmission detector, a ratio display of transmitted to incident has the effect of making the resistor in the power splitter determine the equivalent source match of the measurement. Power splitters are very broadband, have excellent frequency response and present a good match at the DUT input. Separation of the incident and reflected signals can be accomplished using either a dual directional coupler or a splitter.

Receiver

The receiver provides the means of converting and detecting the RF or microwave signals to a lower IF or DC signals.There are basically two receiver techniques used in network analysis (see Figure 4).

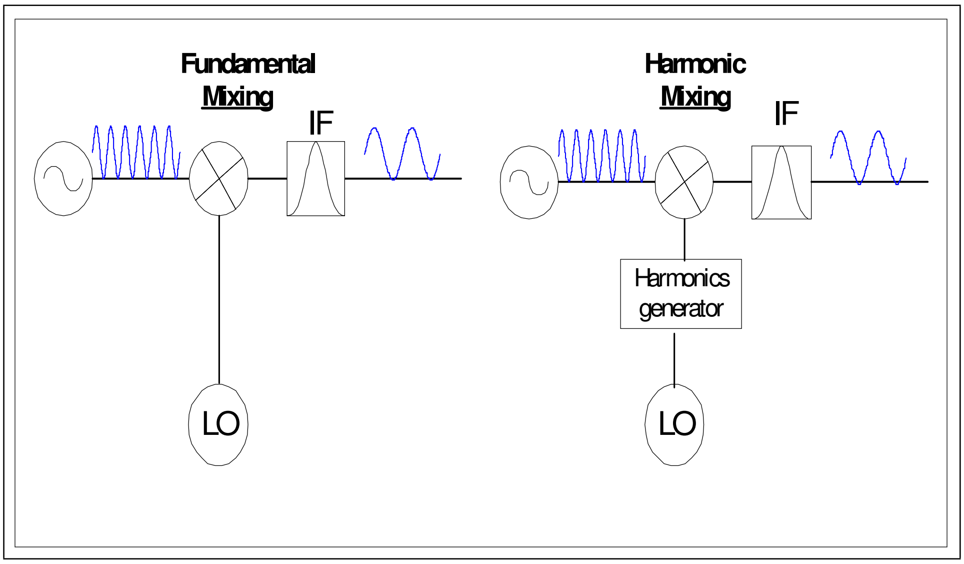


Figure 4 - Fundamental and harmonics mixing receiver

The receivers are broadband tuned receivers that use either a fundamental mixing or harmonic mixing input structure to convert an RF signal to a lower-frequency IF signal. The tuned receivers provide a narrowband-pass Intermediate-Frequency (IF) filter to reject spurious signals and minimized the noise floor of the receiver. The vector measurement systems (tuned receivers) have the highest dynamic ranges, are less suspect from harmonic and spurious responses, they can measure phase relationships of input signals and provide the ability to make complex calibrations that lead to more accurate measurements.

Analyzing and Display

Once the RF signals have been detected, the network analyzer must process the detected signals and display the measured values. Network analyzers are multichannel receivers utilizing a reference channel and at least one test channel. Absolute signal levels in the channels, relative signal levels (ratios) between the channels, or relative phase difference between channels can be measured by the network analyzer. Relative ratio measurements are usually made in dB, which is the log ratio of an unknown signal (test channel) with a chosen reference signal (reference channel). For example, 0 dB implies that the two signal levels have a ratio of unity, while +/–20 dB implies a 10: 1 voltage ratio between two signals. All network analyzer phase measurements are relative measurements, with the reference channel signal considered to have zero phase. The analyzer then measures the phase difference of the test channel with respect to the reference channel.

2.4 Operator Calibration

2.4.1 General

All real measurement systems are affected by three types of measurement errors:

* Systematic errors.

* Random errors.

* Drift errors.

Calibration is a set of operations which improve measurement accuracy. The calibration procedure compensation for systematic measurement errors (repeatable measurement variation), such as:

Systematic Errors

In our case, systematic errors are caused by non-perfect devices. We assume that these errors do not vary over time, therefore they can be characterized and mathematically removed during the calibration process. Systematic errors are related to (see Figure 5):

* Frequency response errors during transmission or reflection measurements.

* Signal leakage within or between components of the system, directivity and crosstalk errors.

* Impedance mismatch due to unequal input and output impedance of the DUT and the network analyzer.

Manufacturers assume that the operator takes care of random errors that are caused by connectors repeatability and by the cables.

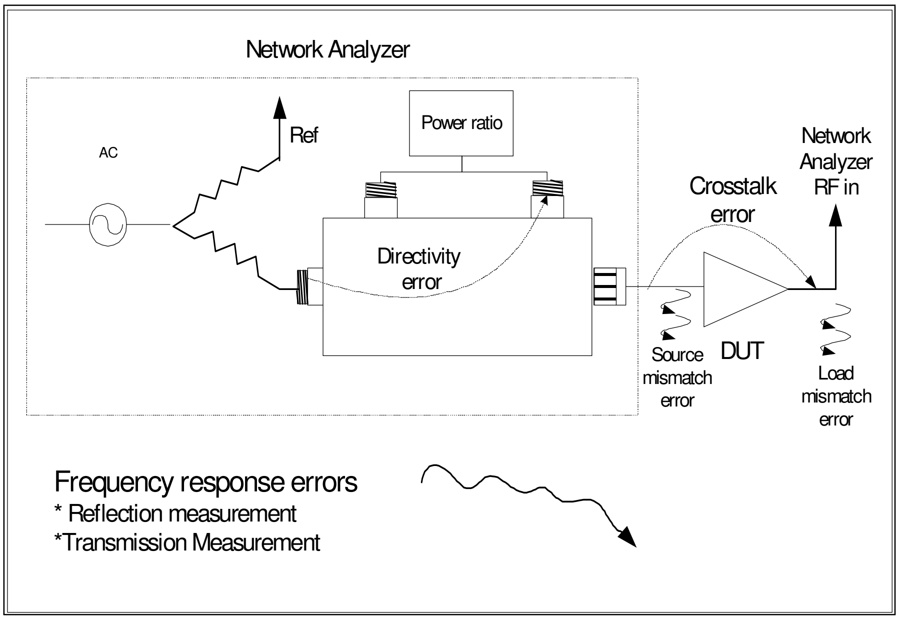


Figure 5 - Error correction due to calibration

Random Errors

Random errors vary randomly as a function of time (amplitude and phase). Since there is no way to predict them, they can not be removed. Sources of random errors are:

* Internal noise of the instrument.
* Connector and adapters.
* Cables.

As it mention above it is impossible to remove these errors, but it is possible to minimize their effects by:

Internal noise * Increasing source power.
* Narrowing IF filter.
* Using trace averaging.

Connectors and adapter care Connector repeatability is a source of random measurement errors. For all connectors and adapters, you have to frequently do the following :

* Inspect all the connectors for damage or visual defect.
* Clean the connectors.

Use high quality, well known and preserved connectors and adapters.

Cables Care Coaxial cables connecting the DUT to the analyzer. Cables

can cause random errors, you have to frequently do the fallowing :

* Inspect for unusual lossy cables.

* Inspect for damage cable connectors.

* Inspect for cables which change response when flexing (this may indicate for damage near the connectors).

It is strongly recommended to use known high quality and well preserved cables, if high accuracy measurement is needed.

Drift Errors

Drift errors occur when the test results of measurements change, after calibration has been performed. They are primary caused by temperature variation. This errors can be minimized by frequently calibration or use the equipment in a controlled temperature range, such as 25±5°C.

2.4.2 Calibration Reference Plane

Reference plane is where you actually connect your DUT. In most cases, you will not connect your DUT directly to the Analyzer's port. More often you will connect your DUT to the analyzer's port via some adapters and cables (see Figure 6).

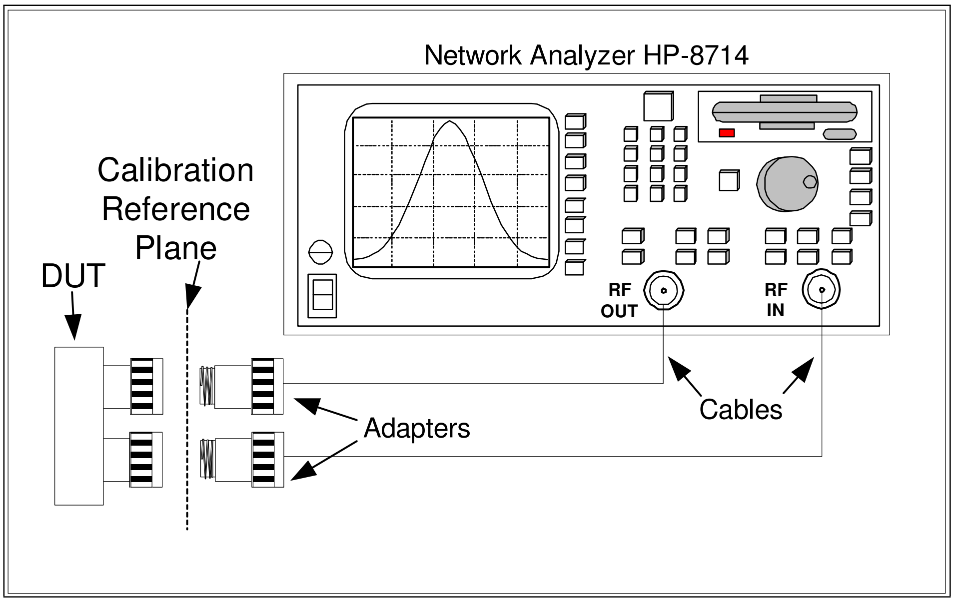


Figure 6 - Calibration reference plane

It is important to remove the effects of the cables and adapters, by performing the calibration process at the calibration reference plane.

2.4.3 When a Calibration Is Necessary

. You need the best accuracy possible.
· You are adapting to a different connector type or other impedance.
· You are connecting cables between the DUT and the analyzer test ports.
· You are measuring a narrow band or electrically long device.
. You are connecting any attenuator or other device on the input or output of the DUT.

2.4.4 When a Calibration Is Not Necessary

If your test setup meets these conditions, you do not need to perform any additional calibrations, however without a user-calibration, the analyzer is not guaranteed to meet its published measurement port specifications.
· Your test doesn't require the best accuracy possible.
· Your DUT is connected directly to the reflection part. with no adapters or intervening cables.
· Your DUT impedance matches the impedance of the analyzer.

2.5 Purpose and Use of Different Calibrations

2.5.1 Normalization or Response

Normalization is the simplest type of calibration. The analyzer stores data in its memory and divides subsequent measurements by the stored data to remove frequency response errors. Standard devices are used, Thorough (High quality coaxial cable) for transmission, an Open or a Short for reflection.

2.5.2 Response and Isolation

This method of calibration is only necessary when trying to achieve maximum dynamic range (>100 dB) when performing crosstalk measurement or high insertion loss devices (such as a band pass filter). A response and isolation calibration uses loads to both ports and Thorough cable to connect them. These measurements are used to remove systematic errors caused by crosstalk in transmission.

2.5.3 Transmission

Transmission calibration removes systematic errors, caused by source mismatch, frequency response. This calibration requires an Open, a Short and a Thorough standard devices (Enhance mode).

2.5.4 Reflection

This type of calibration removes systematic errors, frequency response, directivity and source mismatch. This calibration requires three standard devices: an Open, a Short and a Load.

Note

All the above calibrations may be slightly different, depend on a specific model or manufacturer.

3. EXPERIMENT PROCEDURE

3.1 Required Equipment

1. RF Network Analyzer HP-8714C or HP-8714B.
2. Type N calibration kit HP-85032E.
3. High Quality coax cable.
4. Band Pass Filter Mini-Circuit BBP-10.7 MHz.
5. Termination 50Ω.
6. Agilent ADS simulation software.

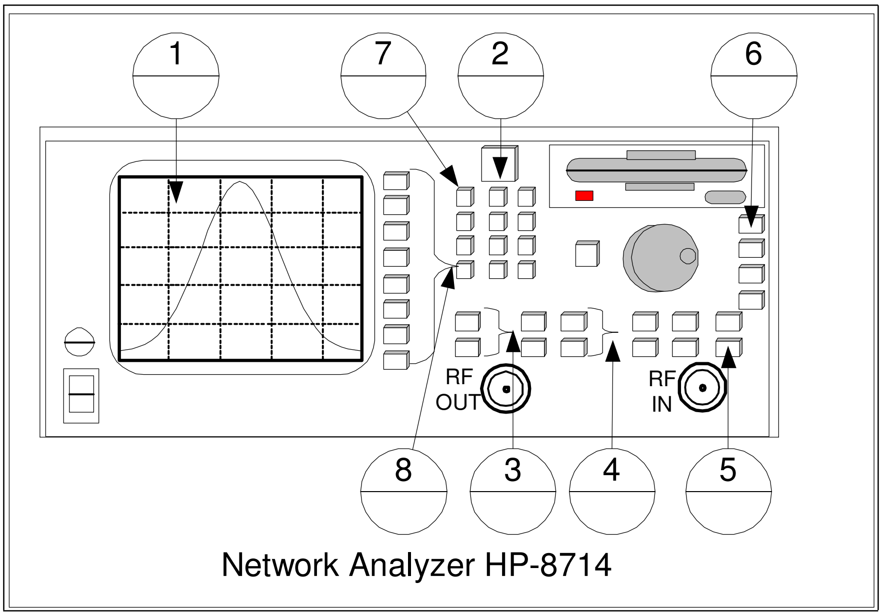


Figure 1 - Network analyzer - A front panel tour.

3.2 Front Panel Tour

Refer to Figure 1.

1. CRT Display -The analyzer's large CRT display
2. **BEGIN-** The **BEGIN** key simplifies measurement setups. The **BEGIN** key allows quick and easy selection of basic measurement parameters for a user-specified class of devices (e.g. filters ,amplifiers,or mixers). For example, when

making a transmission measurement, selecting **Filter** as your device type puts the analyzer into narrowband detection mode, maximizing measurement dynamic range. In comparison, selecting **Mixer** as your device type puts the analyzer into broadband detection mode, enabling frequency translation measurements.

3. **MEAS** The measure key select the measurements for each channel. The analyzer's measurement capabilities include transmission, reflection, power, conversion loss.

4. **SOURCE**- The source keys select the desired source output signal to the device under test, for example, selecting source frequency or output power. The source keys also control sweep time, number of points, and sweep triggering.

5. **CONFIGURE**- The configure keys control receiver and display parameters. These parameters include receiver bandwidth and averaging, display scaling and format, marker functions, and instrument calibration.

6. **SYSTEM**- The system keys control system level functions. These include instrument preset, save/recall, and hardcopy output.

7. Numeric Keypad- Use the number keys to enter a specific numeric value for a chosen parameter. Use the **ENTER** key or the softkeys to terminate the numeric entry with the appropriate units. You can also use the front panel knob for making continuous adjustments to parameter values, while the ⇑ and ⇓ keys allow you to change values in steps.

8. **Softkeys**- Soft keys are keys whose labels are determined by the analyzer's firmware. The labels are displayed on the screen next to the 8 blank keys next to the display screen on the analyzer. In text, these keys will be represented by the keyname with shading behind it, such as 'Sweep Time'.

3.3 Entering Frequency Range

1. Connect a BPF to the Network Analyzer, as shown in Figure 2.

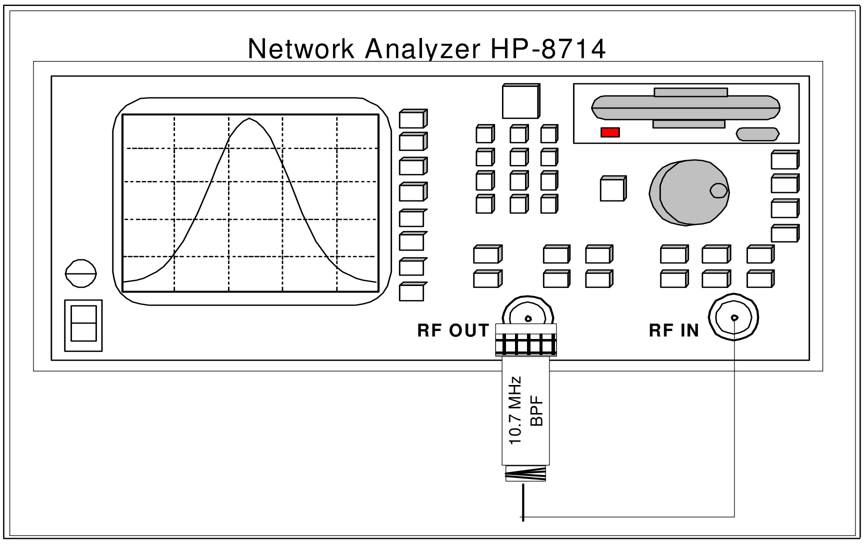


Figure 2 - Connecting a Band Pass Filter to a network analyzer.

2. Press the **PRESET** key.

When the analyzer is preset with the **PRESET** key, it reverts to a known operating condition.

3. Press the **FREQ** key to access the frequency softkey menu.

4. Press **Start** 5 MHz and **Stop** 20 MHz.

5. you can also set the frequency range by using the **Center** and **Span** softkeys. For instance, if you set the center frequency to 12.5 MHz and the span to 15 MHz, the resulting frequency range would be 5 to 20 MHz.

3.4 Entering Source Power Level

1. Press the **POWER** key to access the power level softkey menu.

2. To change the power level to 3 dBm, press **Level, 3**, **dBm** and **ENTER**.

3.5 Scaling the Measurement Trace

1. Press the **SCALE** key to access the scale menu.

2. To view the complete measurement trace on the display, press **Autoscale**.

3. To change the scale per division to 10 dB/division press **Scale/Div, 10** and **Enter**.

4. To change the reference level to 0 dB, press **Reference Level, 0** and **Enter**.

5. To move the reference position (indicated by the ▶ symbol on the left side of the display) to the first division down from the top of the display, press **Reference Position, 9** and **Enter** .

3.6 Entering Active Measurement channel.

The **MEAS 1** and **MEAS 2** keys allow you to choose which measurement channel is active, and choose the measurement parameters for that channel. When a particular measurement channel is active, its display is brighter than the inactive channel, and any changes made to measurement parameters will affect only the active measurement channel (Some measurement parameters cannot be independently set on each measurement channel. For these parameters, both channels will be affected regardless to the active channel status).

1. To measure Transmission on measurement channel 1 and reflection on measurement channel 2, press the following keys: **MEAS 1, Transmission, MEAS 2 Reflection, FREQ Start** 5 MHz, **Stop** 20 MHz

2. Both channel's measurements are now visible on the analyzers display screen. Note that the active measurement channel's (channel 2) measurement trace is brighter than the other measurement channel's trace.

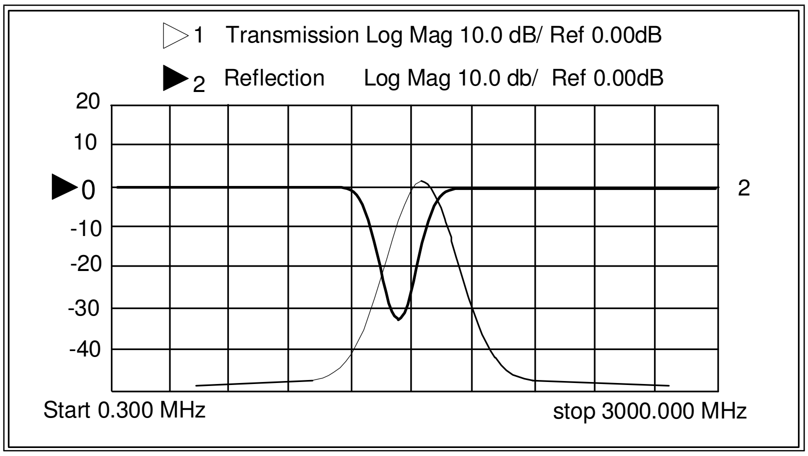


Figure 3 - Two channel active

3.7 Viewing Measurement Channels

1. To view only the measurement of channel 2 (reflection measurement), press **MEAS 1, Meas OFF .**

2. To view both measurement channels again, press **MEAS1**.

3. To view both measurement channel separately on a split screen, press **DISPLAY, More Display**, **Split Disp FULL split** .You have now learned how to enter common measurement parameters and how to manipulate the display for optimum viewing of your measurement.

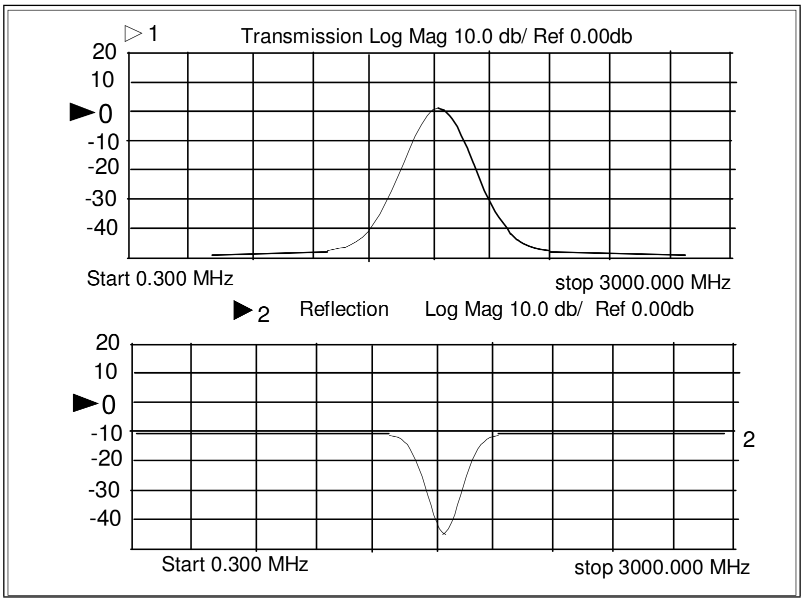


Figure 4 - Viewing a split display measurement.

3.8 Calibration for Reflection Measurements

When you are required for the best accuracy or you are adapting to a different connector type or you are connecting a coaxial cable between the DUT and the analyzer test port, it is strongly recommended to perform a proper calibration.

1. Connect the system as indicated in the Figure 5.

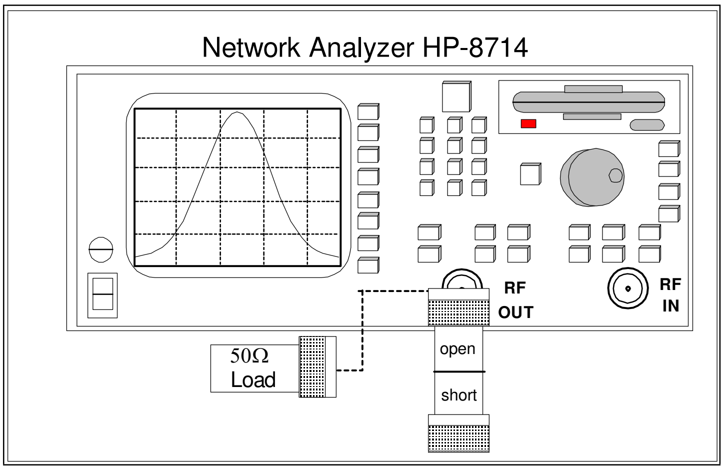


Figure 5 - Calibration for Reflection measurement

2. Press **Preset**, **Begin**, **broadband passive**, **reflection**, **cal** and **one port.**
4. Connect an open to the reflection port and press **measure standard**
5. Connect a short to the reflection port and press **measure standard**
6. Connect a load to the reflection port and press **measure standard**
7. Disconnect the load (50Ω termination) and return the standards devices carefully to their box.

3.9 Make a Reflection Simulation and Measurement

In this part of the experiment you will simulate and measurent the reflection coefficient magnitude $|\Gamma|$ measured in dB of the return loss of a coaxial cable and the return loss of a 50Ω termination.

3.9.1 Simulation

1. Draw a network analyzer, using the ADS software and a bank of components (see Figure 3 of theory part and Figure 6 of experiment part).
2. Assume that the data measurement is done at RF (you don't need a mixer and a LO).
3. Assume that the network analyzer operate in the range 300kHz to 1 GHz and the coupling of the coupler is 10 dB.
4.Connect a cocaxial cable to your simulation of a network analyzer, terminated with a 50Ω load, as indicated in Figure 6.

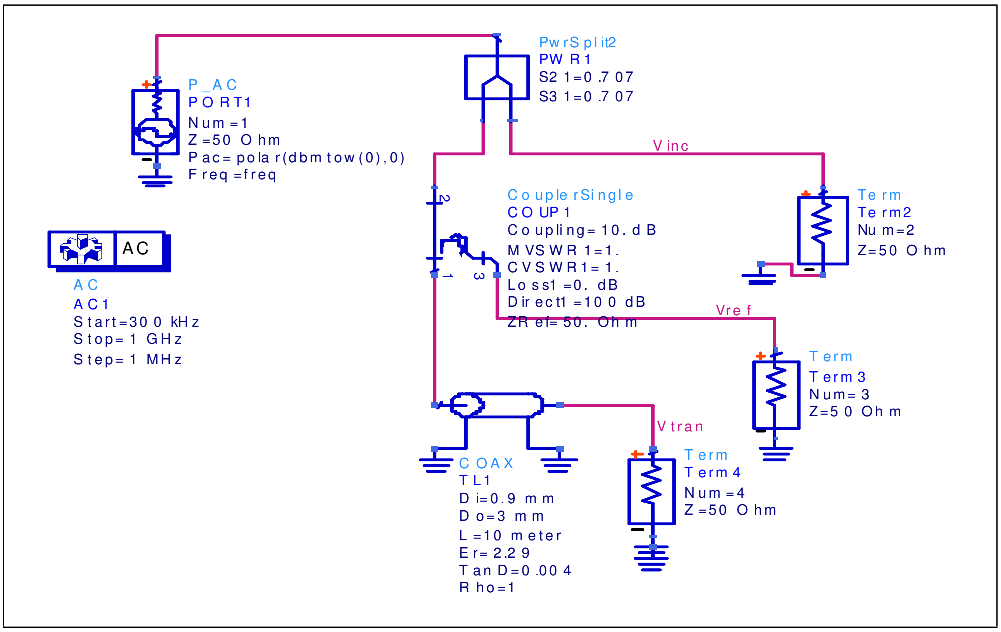


Figure 6 - Simulation of a coaxial cable connected to a network analyzer.

5. Simulate $S_{11}(A/R)$ freq 300kHz to 1 GHz. Verify that the data trace falls completely below -16dB. **Save the data.**

3.9.2 Measurement

6. Connect a cocaxial cable to the real network analyzer, terminated with 50Ω load, as indicated in Figure 7.

7. Press **MEAS 1, Reflection, SCALE, 10dB ,Enter, Feq, Start 0.3 MHz Stop 1 GHz.** The Return Loss of the coaxial cable is displayed.

8. Verify that the data trace falls completely below -16dB. **Save the data.**

9. Disconnect the cable with load, and connect only the 50Ω termination directly to the RF OUT port.

10 Measure S_{11}, verify that the data trace falls completely below -30dB. **Save the data on magnetic media.**

11. Measure the smith chart of the 50Ω load. **Save the data on magnetic media.**

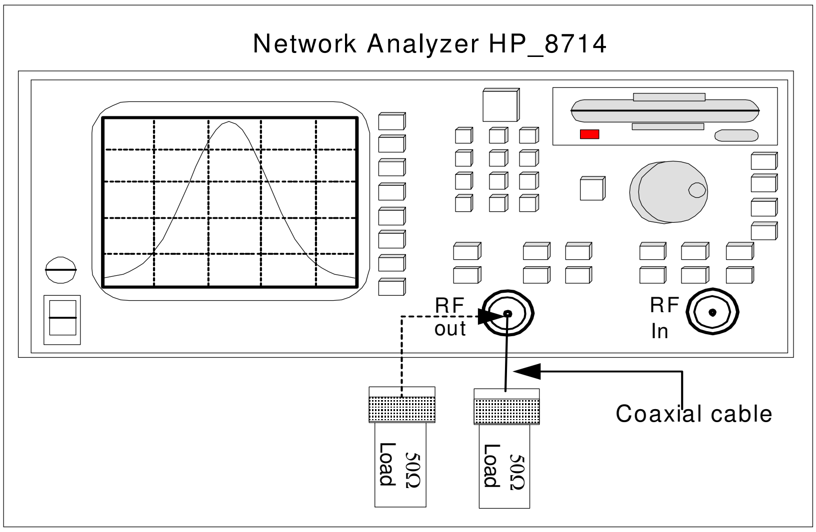


Figure 7 - Reflection measurement of a coaxial cable with a 50 Ohm termination.

3.10 Calibration for Transmission Measurement

1. Connect a coaxial cable to the network analyzer.
2. Set the frequencies range to 300kHz - 1GHz.
3. Press **CAL, Response, Measure Standard**.

3.11 Make a Transmission Measurement

In this part of the experiment you will measure and simulate the insertion loss (attenuation, S_{21}) of a good coaxial cable as a function of frequency using Transmission measurement.

3.11.1 Simulation

1. Simulate $S_{21}(B/R)$, frequency range 300kHz to 1 GHz. **Save the data on magnetic media.**

3.11.2 Measurement

2. Connect a coaxial cable to the real network analyzer, as shown in Figure 8.
3. Press **PRESET**, **MEAS 1, TRANSMISSION, SCALE, AUTOSCALE**.

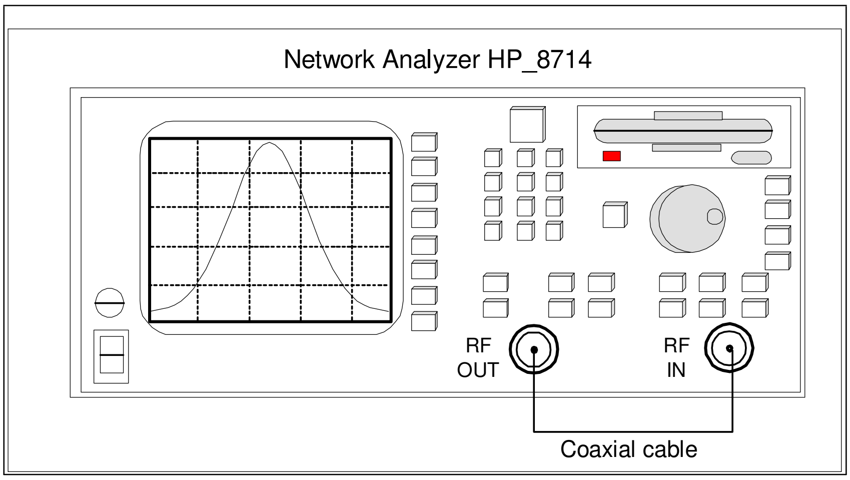


Figure 8 - Transmission measurement using a coaxial cable.

3. Verify that the measurement trace falls within 0±1.5 dB. See Figure 9 for a typical result. **Save the data on magnetic media.**

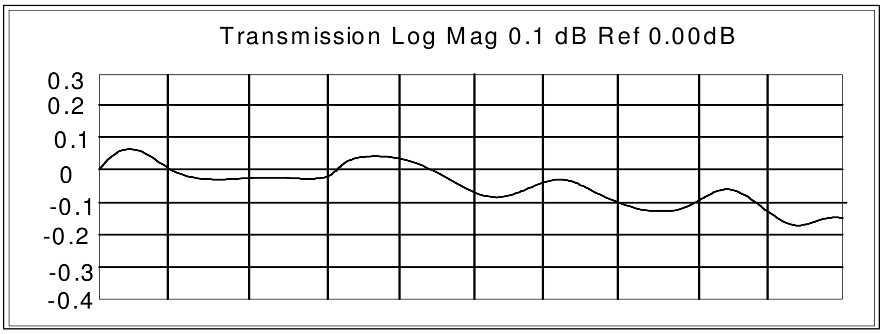


Figure 9 - A typical Transmission measurement of a coaxial cable.

3.12 Measurement of Basic Filter Parameters.

In this part of the experiment you will measure and simulate the electrical characteristic of elliptic, 3 section 10.7 MHz Band Pass Filter using Reflection and Transmission function of the network analyzer. Before you measure Low losses, such as insertion loss (less than 1dB) you have to perform Normalization, which compensate the network analyzer for error due to the coaxial cable (insertion loss of the coaxial cable).

3.13 Transmission Simulation and Measurement.

3.13.1 Simulation

1. Connect an elliptic BPF to the simulated network analyzer, as indicated in Figure 10.
   2. Set the BPF to:

- Center frequency 10.7 MHz
- Bandwidth of the passband 3.6 MHz.
- Ripple 0.1 dB.
- BWstop = 10MHz.
- Astop = 20dB.

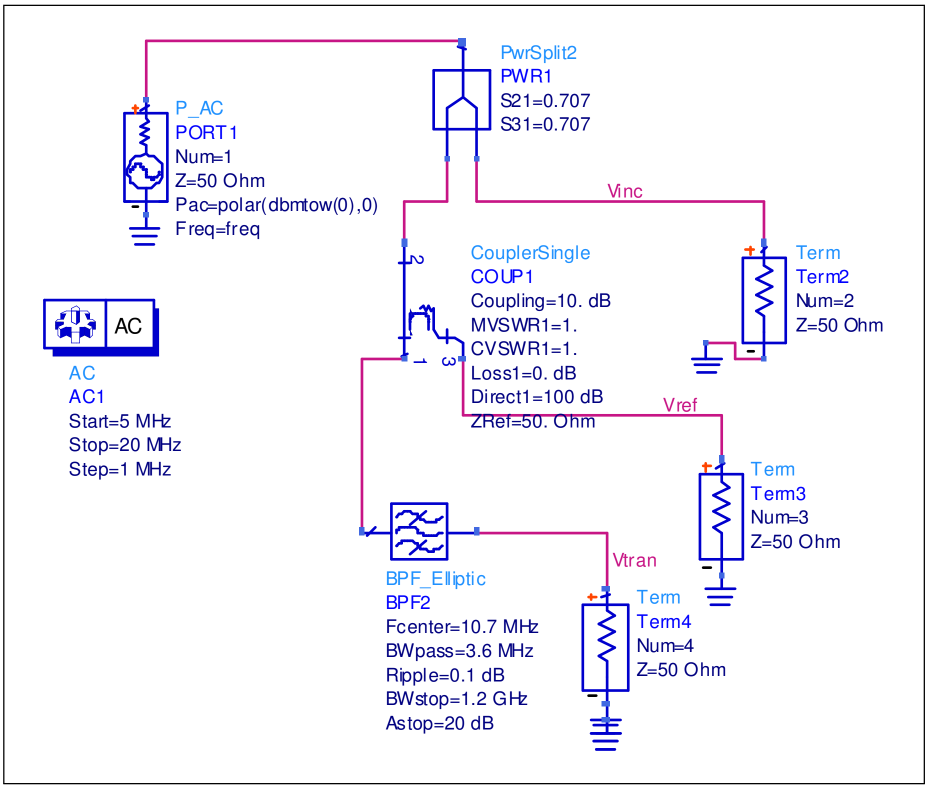


Figure 10 - BPF Simulation.

3. Simulate $S_{21}(B/R)$ 5 to 20MHz. **Save the data on magnetic media.**

3.13.2 Measurement

4. Connect a coaxial cable to the real network analyzer, as indicated in Figure 8.

4. Press **Display** and **Normalize,** the Network Analyzer 'removes' frequency errors.

3. Reconnect the BPF to the reflection port of the network analyzer, as indicated in Figure 2.

4. Press **Preset**, **Begin**, **Filter** and **Transmission**.

5. Press **Freq**, **Start** 5 MHz, **Stop** 20 MHz, **Scale, Autoscale.**

Save the data on magnetic media.

3.13.3 Pass Band Insertion Loss Measurement

The Insertion Loss of the BPF in the pass band (9.5-11.5 MHz) is less than 1.5 dB, you have to verify that the BPF meets its specification.

1. Press **Scale, 1 dB**.

2. Press **Marker**, **Marker Search**, **Max Search** verify that the center frequency of the filter is about 10.7 MHz and fill Table-1.

3. Set the marker to 9.5 MHz and 11.5 MHz , by pressing **Marker** 9.5 **MHz** , and then 11.5 **MHz**, verify that the insertion loss is less than 1.5 dB.

Center Frequency	I.L@9.5 MHz	I.L@11.5 MHz
	Freq.@-1.5dB	Freq.@-1.5dB
Table-1		

3.13.4 -3 dB Band Width

The maximum -3 dB bandwidth of the BPF is 2.8 MHz (8.9-12.7 MHz), you have to verify that the BPF meets its specification.

1. Press **Marker**, **Marker Search** and **Max Search** to find the center frequency.

2. Press **Marker**, **Marker Search, Target Value, -3dB, Search Left, Search Right** and fill Table-2.

Center Frequency	Freq.@-3dB	Freq.@-3dB
Table-2		

3.13.5 -20 dB and -35 dB Band Width

Use similar procedure as above and fill Table-3.

IL@7.5 MHz	IL@15 MHz	IL@0.6 MHz	IL@50-1000 MHz
Freq.@-20dB	Freq.@-20dB	Freq.@-35dB	Freq.@-35dB
Table-3			

3.14 Reflection Measurement

Under Reflection measurement you will measure Reflection Coefficient magnitude and phase, Return Loss, SWR, and impedance magnitude and phase.

3.14.1 Reflection Coefficient

1. Press **Begin**, **Filter** and **Reflection.** The return loss of the filter is displayed. What is the meaning of 0 dB Return Loss near the 25 MHz?

2. Press **Freq**, **Start** 1 MHz, **Stop** 25 MHz, **Scale, Autoscale**. The reflection coefficient $|\Gamma|$ in dB as a function of frequency is displayed**. Save the data on magnetic media.**

3. Press **Format, Lin Mag,** to get the absolute value of reflection coefficient $(|\Gamma|)$. $|\Gamma|$ as a function of frequency is displayed**. Save the data on magnetic media.**

4. Press **Polar** to get the absolute amplitude value and phase of reflection coefficient $(|\Gamma| \angle \theta)$ as a function of frequency is displayed. **Save the data on magnetic media.**

3.14.2 Standing Wave Ratio and Impedance

1. Press **Format** and **SWR**. The SWR as a function of frequency is displayed. **Save the data on magnetic media.**

2. Press **Format, More format, Impedance Magnitude** to get $|Z_0|$ as a function of frequency. **Save the data on magnetic media.**

3. Press **Format** and **Smith Chart** to get a display of the real and imaginary values of the impedance as function of frequency. Set the start frequency to 9 MHz and stop frequency to 13 MHz, verify that the impedance of the filter is about 50Ω in the pass Band. **Save the data on magnetic media.**

3.15 Final Report

1. Draw a graph with two traces of the insertion loss (S_{21}) of a coaxial cable RG-58 as a function of frequency. One trace is of the real measurement and the second is of the simulation. Find the maximum of Insertion Loss of the cable.

2. Draw a graph with two traces of the return loss (S_{11} in dB) of a coaxial cable RG-58 as a function of frequency. One trace is of the real measurement and the second is of the simulation. Calculate the worst SWR of the cable.

3. Draw a graph with two traces of the return loss (S_{11} in dB) of a 50Ω termination as a function of frequency. One trace is of the real measurement and the second is of the simulation.

a. Use the model of high frequency resistor (see attenuator experiment real resistor), find the value of the capacitor and inductor at frequencies 10,30,100,300 and 1000 MHz, based on the smith chart data (real and imaginary part).

b. Find the two equations that describe the value of the capacitor and the inductor as a function of frequency.

c. Simulate S_{11}in dB of the termination using ADS software (use frequency as the independed element)

d. Compare the graphs of simulation and measurement of the S_{11} in dB.

1. Refer to the specification of a Band Pass Filter at table-5 and the measured data. Draw a graph of the insertion loss of the filter, as a function of frequency and answer the following questions:

Model N_0	Center Freq (MHz)	Passband IL<1.5dB (MHz)	3dB Band. Typical (MHz)	Stop Band	
				IL>20dB at MHz	IL>35dB at MHz
BBP-10.7	110.7	9.5-11.5	8.9-12.7	7.5&15	0.6&50-1000
SWR	At Passband<1.7:1				
SWR	At Stopband>16:1				

Table-5

a. What is the maximum insertion loss of the filter in the passband?

b. What is the measured 3dB bandwidth?

c. What is the measured frequencies of 20dB and 35dB insertion Loss of the filter.

d. Compare the result of pharagraphes a,b,c to the specification in table-5.

5. Using the stored data of the Band Pass Filter, draw the following graphs:

   a. Return loss as a function of frequency.

   b. Reflection Coefficient as a function of frequency.

   c. Polar plot Absolute amplitude and phase of Reflection Coefficient as a function of frequency.

   d. SWR as a function of frequency.