Frequency Conversion — Mixer Measurements

By: Larry Dunleavy
Wireless and Microwave Instruments
University of South Florida

Objectives

1) To develop an understanding of frequency conversion principles and the performance of non-ideal mixers.
2) To learn how to measure some basic characteristics of a microwave mixer.

Introduction

TA's: Before beginning the TA's should:

1) Perform a frequency and amplitude calibration on the Spectrum Analyzer (SA), by connecting a short cable between the 300MHz cal. output and the SA input and pushing CAL → Cal. Freq. & Amplitude.
2) Setup the local oscillator arrangement on each bench as illustrated in the setup figure. Turn the bias supplies on and adjust such that the LO signal is set to 1000MHz.
3) Provide sufficient cables to perform the procedure.

Basic Equipment set-up - The general measurement configuration to be used is shown in the figure. Note that on most commercial mixers the notation "R", "L" , and "I" are used to label the RF, LO and IF ports respectively.

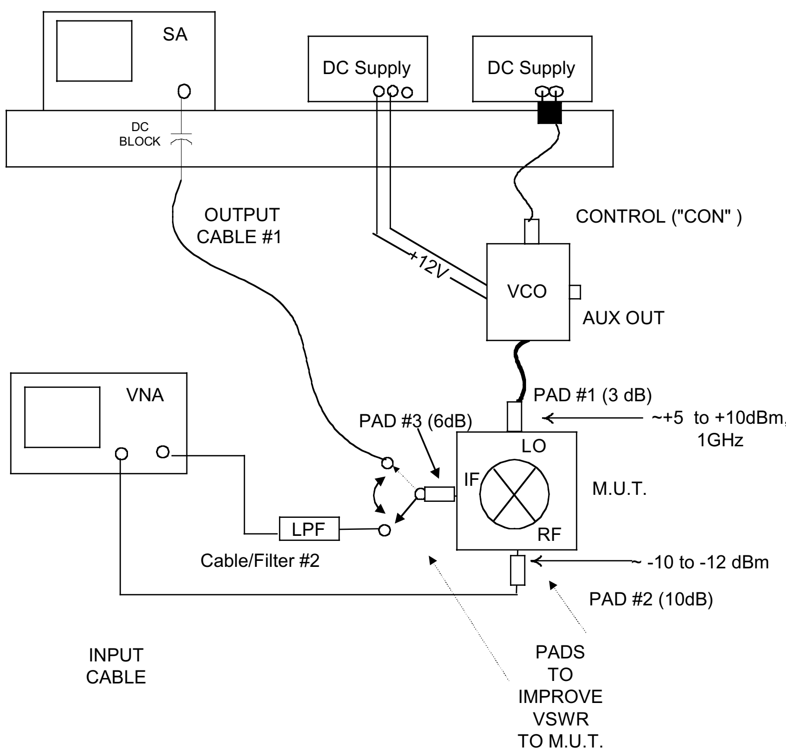

Figure 1. Basic measurement set-up to be used in this laboratory. ***Note: For this experiment <u>it is important that the dc block be in place when measuring the mixer</u>. If the RF and LO are at the same frequency a dc output is produced at the IF port. This can damage the spectrum analyzer.***

Lab Summary

This lab concentrates on various measurements of a commercial coaxial mixer. In this lab you will:

I) Use the VNA to test the frequency dependent loss of cable, pad and filter assemblies that are critical to the accurate measurement of power levels at various frequencies.

II) Establish the LO power level to be input to the mixer "L" port.

III) Establish the RF signal power level. The power level of the VNA will be set to a specified value in CW frequency mode and the SA will be used to measure the power at the R port of the mixer, at a number of discrete RF frequencies.

IV) Use the SA to test the mixer product power levels and allow for conversion loss and isolation calculations to be made. The VNA will be used in CW mode to provide the signal to the RF mixer port.

V) Use the VNA to measure mixer conversion loss and compare to SA Conversion Loss Measurement.

Assignment / Procedures

Before beginning this laboratory it is recommended that you look over the specifications for the mixer (see Appendix and associated lecture material). We will be measuring the characteristics for a fixed LO frequency of 1000MHz, and an RF frequency range of 700 to 900MHz. This latter range corresponds to an IF frequency range of 100MHz to 300MHz.

PART I: Measuring Insertion Loss of Cable Assemblies

Use the VNA to test the frequency dependent loss of test cables, attenuators (pads), and cable assemblies critical to the accurate measurement of power levels at various frequencies. Figure 2 shows the test arrangement.

1. Perform a transmission calibration over the default frequency range of 0.3 to 3000MHz with the input cable (no pads) connected directly to the type N to SMA adapter connected to the receive port of the VNA. Insertion Loss is usually defined such that positive loss numbers are attained for passive components, or since the S21 magnitude will be negative for a passive element the following should clarify the relationship, where S_{21} represents a linear magnitude (not in dB):

$$\mathrm{I.L.(dB)} = -20\mathrm{Log}(|S_{21}|) = -\mathrm{Gain(dB)}$$

2. Use the VNA to test the components shown in Figure 1, and record the insertion loss at the various frequencies indicated in the Table below. Cable assy. #1 consists of a long coaxial cable connected to a 6dB pad. Cable assy. #2 can be configured by simply adding the low pass filter to end of cable assy. #1. Note that we need not test the 3dB attenuator it is used only to set the LO power level. The 10dB pad helps to set the input power while minimizing reflections and can be considered to be part of the input cable. The components to be tested include:

   a) Output CableAssembly #1 (cable plus the 6dB pad connected on one end).
   b) Output Cable/Filter Assembly #2 (filter, cable plus 6dB pad).

3. What is the measured 3dB cutoff frequency of your filter (measure as frequency at which magnitude is 3dB below minimum value in measurement window)?

f_c = _______ MHz.

4. At your option you can store these measurements to disk using disk save operations described in previous laboratories. A useful approach here may be to save formatted log-mag displays using graphics (PCX) files with markers set to (a subset of) the frequencies of interest.

Table 1. Loss Data for Cables, Filter and Pads (Note: express loss values as positive numbers)

Freq (MHz)	Cable #1 + 6dB Pad	Cable/ Filter #2 + 6dB Pad
100		
200		
300		
700		
800		
900		
1000 (LO Freq.)		

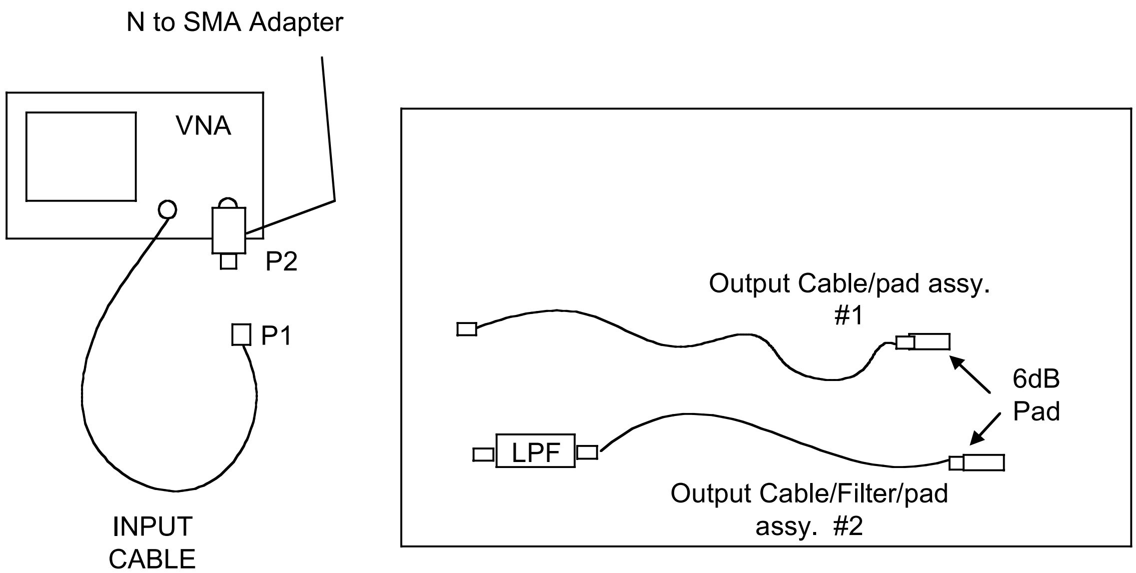

Figure 2. Set-up for characterizing loss of critical components of test system.

PART II: Establishing the LO input level

This part uses the configuration of the following figure.

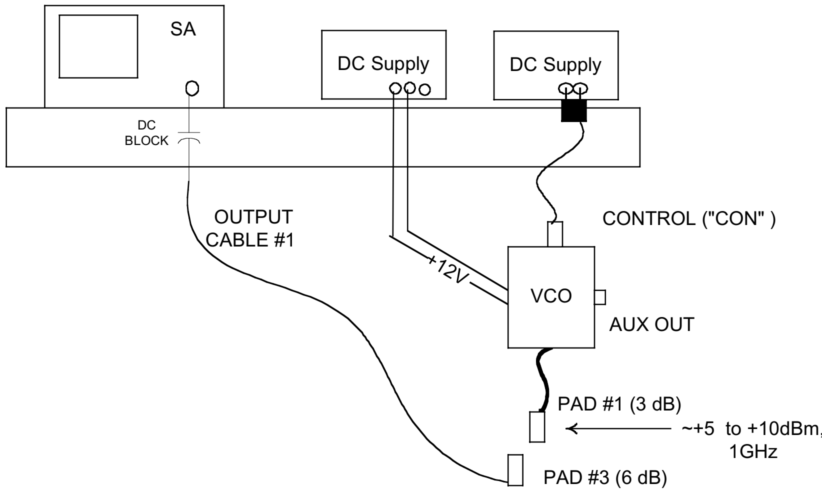

Figure 3. Local Oscillator Signal Set-up and Power Level Determination

1) Set the internal attenuator on the SA to a setting of 30dB by pressing “AMPLITUDE” => “ATTEN” and using the arrow keys or keypad to set the attenuator to 30dB. Set the REF LVL to 10dBm, also under the “AMPLITUDE” menu. Make the connections to the VCO output as indicated in Figure 3. **Note the short 4” section of semi-rigid cable and 3dB pad connected to the output of the VCO. Leave it connected this way throughout the laboratory**.
2) Check the LO oscillation frequency and adjust the control voltage if necessary so that the highest peak (other than the SA’s dc signal) is at 1000MHz (do not hesitate to ask TA for help).
3) Correct the observed SA power level for the loss of output cable #1 and 6dB pad, using the 1000MHz cable loss results from Table 1.

   Corrected Power = Power at SA(dBm) + |Cable + pad Loss (dB)|

   Note that we want the power at the output of the 3dB pad so DO NOT CORRECT FOR THE 3DB PAD LOSS.

4) Summarize LO power measurements in the following table.

Table 2. Measured Power Level To Be Input to LO port of mixer.

	Meas. Power at 1000MHz	
	On SA Display (dBm)	**Corrected For Cable#1 /6dB pad loss (dBm)**
Power Level at LO port input (VCO output + semi-rigid cable + 3dB pad) (dBm) => $P^{L}_{f_{LO}}$		

<u>Comment:</u> The corrected power here establishes the LO power level which will later be used in calculating the LO to RF isolation. This power will be denoted by the notation $P^{L}_{f_{LO}}$, where the superscript corresponds to the mixer port at which the power is incident or exiting, and the subscript indicates the frequency component measured.

PART III: RF Input Set-up and Power Measurements

The power level of the VNA will be set to a specified value in CW frequency mode and the SA will be used to measure the power that will be incident on the R port of the mixer.

1. Set-up the VNA power and frequency in CW mode at a frequency of 900MHz. Set the frequency to the desired RF test frequency in CW mode. Recall, to do this press FREQUENCY - CW Frequency, enter the frequency then press MENU - TRIGGER - HOLD. Attach the 10dB pad to the Input Cable.
2. Now connect Output Cable #1 (with 6dB pad attached) between the Spectrum analyzer and the RF input cable, with the 10dB pad attached to the end of the input cable. Adjust the SA frequency and span to view the output signal and measure the displayed power level. (e.g. center freq. of 900MHz, and span of 1MHz should produce a good view.).
3. To simplify life we will use the default power level setting on the VNA, which is 0dBm. **Verify that the power level setting is set to 0dBm** (or if different than 0dBm change the setting) by pushing "POWER" => "Level". This setting represents the approximate RF signal level at the VNA RF OUT test port. This signal will be reduced by the loss of the input cable and the 10dB pad before entering the mixer R-port (Fig. 1).

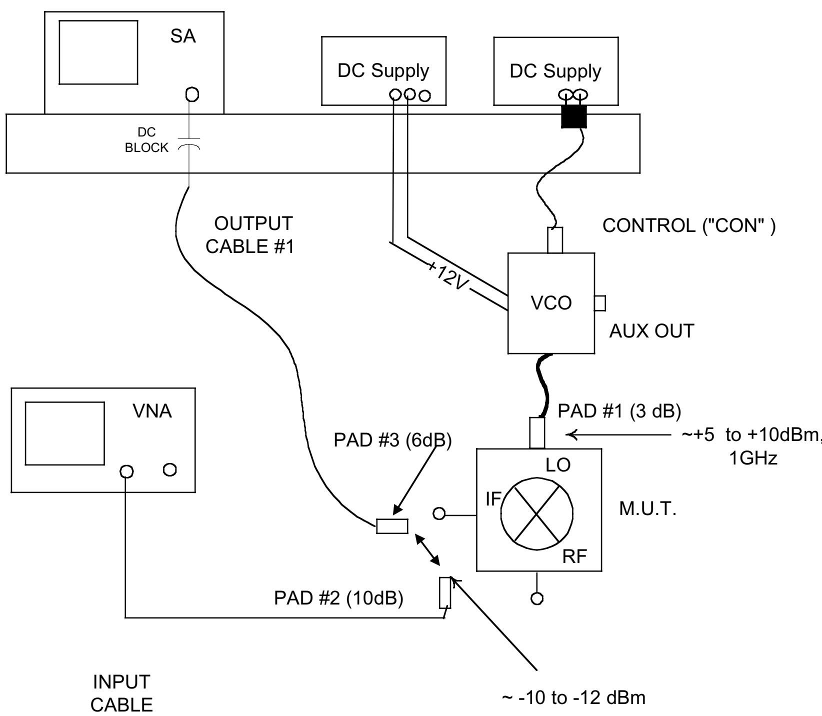

Figure 4. RF Input Power Level Measurement Set-up.

4. Leaving the VNA power level setting at the 0dBm value verified in step 3, change the CW frequency and SA settings to measure the power levels presented to the R port at 700, 800, and 900MHz.
5. **Use the data of Table 1 for Output Cable #1 + 6dB pad loss to correct the power at <u>each corresponding frequency</u>**. Remember the corrected power should be higher than the power observed remotely on the SA. The resulting power level corresponds to a notation of $P^{R}_{f_{RF}}$. That is, the power level at the RF frequency measured (one at a time) at the RF mixer port.

Table 3. SA Measurements of RF Input Power Level

	700MHz	800MHz	900MHz
Mixer RF Input Level Observed at SA (dBm)			
RF Input Level Corrected for Cable + 6dB pad loss (dBm) => $P^R_{f_{RF}}$			

PART IV: Spectrum analyzer measurements of the mixer

1. Connect the mixer into the measurement system as shown below

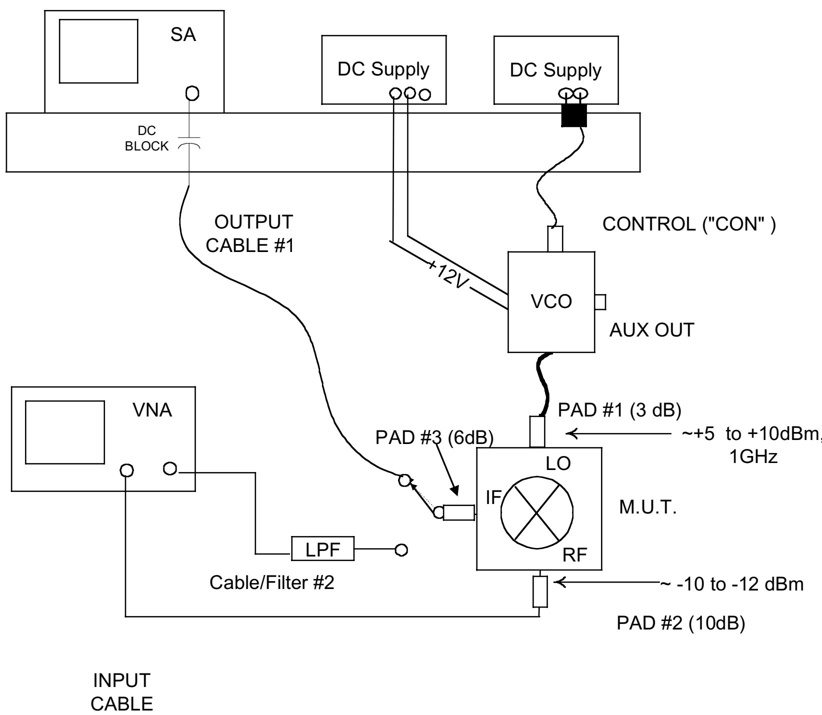

Figure 5. Set-up for Mixer Test Using Spectrum Analyzer

2. With the VNA in CW mode at 900 MHz (LO at +5 to +10dBm, 1000MHz) set the frequency span on the SA for maximum by hitting “Pre-Set” (DC to 2.9GHz) and view the mixer products on the SA.

3. <u>Record the frequencies of observed mixer products using the peak search function (recall better frequency accuracy is obtained by reducing the span once you have identified a mixer product.)</u> To the extent possible, associate the observed mixer products with the expected frequencies (refer to lecture and/or pre-lab assignment). Turn the RF on and off on the VNA (Power Menu) and observe the difference in the mixer products displayed. Ignore the internally generated peak near zero frequency.

4. Use the loss data of Table 1 to correct the observed amplitude at each corresponding frequency to represent the power of the signal at that frequency referenced to the mixer I port (leave corrected power blank if you did not measure a loss at the observed frequency).

Table 4. Broadband Mixer Output Peaks Observed on SA (RF at 900MHz, LO at 1000MHz).

Freq (GHz)					
Observed Amplitude at SA (dBm)					
Amplitude Corrected for loss of Cable #1 + 6dB pad (dBm)					
Comment (e.g. f_{LO}, f_{RF}, f_{RF}-f_{LO}, etc.)					

Additional Comments:

5. Replace Output Cable #1 with the Cable/Filter/pad Assembly #2. Note the effect this has on the frequency products that can be observed on the SA. Record the observable responses in Table 5 below.

Table 5. Broadband Mixer Output Peaks Observed on SA w/ Filter (RF at 900MHz, LO at 1000MHz).

Freq (GHz)					
Observed Amplitude at SA (dBm)					
Amplitude Corrected for loss of Cable/filter Assy. #2 + 6dB pad (dBm)					
Comment (e.g. f_{LO}, f_{RF}, f_{LO}-f_{RF}, etc.)					

6. Remove the Output Cable/Filter/pad Assy. #2, and replace with Output Cable/pad assy. #1. Adjust the CW RF frequency on the VNA and SA frequency settings appropriately (e.g. set each center frequency with a 1MHz span) in order to take the data indicated in the table below.

Table 6. Spectrum Analyzer Mixer RF/IF Pair Measurements (LO at 1000MHz)

RF Freq. MHZ	IF Freq. MHZ	Observed amplitude on SA at IF freq. (dBm)	Observed amplitude on SA at 1GHz LO freq.(dBm)	Observed amplitude on SA at RF freq. (dBm)
700	300			
800	200		ONLY NEED	
900	100		TO MEASURE	
			ONCE	

7. Using the results of the above steps, we will perform first a calculation of the LO-to-IF isolation.

   a) Recall the value of the LO power from Table 2: $P^{L}_{f_{LO}}$ = _______ dBm

   b) Correct the LO power level at the IF port as recorded in Table 6 for the loss of Output Cable #1 + 6dB pad from Table 1 at the LO frequency:

      $P^{I}_{f_{LO}}$ = _______ dBm .

   c) Calculate the LO-to-IF isolation in dB as $P^{L}_{f_{LO}}$ (dBm) - $P^{I}_{f_{LO}}$ (dBm). (Note the superscripts indicated the mixer port where power is observed, the subscripts indicate the frequency.)

LO-to-IF isolation = ______ dB

8. Proceed by correcting the power level measurements made at the IF and RF frequencies to represent best estimates of the power levels corrected to the mixer IF port. First record the incident RF power level from. Use the loss results of Table 1, for Output Cable #1 + 6dB pad, to correct the power levels of Table 6 at each corresponding frequency to the mixer I port. **Important: be careful to use the correct loss values corresponding to the frequency component measured in each case.** Record the corrected power levels in the table below. Note the power levels exiting the I port at the IF freq. and RF freq. are denoted, respectively, as: $P^{I}_{f_{IF}}$, and $P^{I}_{f_{RF}}$.

9. Calculating isolation and conversion loss. Use the definitions given in lecture and the information contained in to calculate the SA measured results for the RF-to-IF isolation and the conversion loss of the mixer. Recall, the following relations apply and result in positive numbers for the diode based mixers measured used in this lab:

$$\text{RF - to - IF Isolation} = P^{R}_{f_{RF}}(dBm) - P^{I}_{f_{RF}}(dBm)$$

$$\text{Conversion Loss (dB)} = P^{R}_{f_{RF}}(dBm) - P^{I}_{f_{IF}}(dBm)$$

Where the power levels are all referenced or corrected directly to the mixer ports. Record the calculated results in the same table as the corrected amplitudes.

Note that if your conversion loss is not on the order of the conversion loss given by the manufacturer's specifications you have done something incorrectly and need to ask for assistance before proceeding.

Table 7. Spectrum Analyzer Mixer RF/IF Pair Measurements Corrected to The Mixer IF Port and RF-to-IF Conversion Loss and Isolation Results

RF Freq. MHz	IF Freq. MHz	Incident RF Port Power $P^{R}_{f_{RF}}$ (dBm)	Corrected Amplitude at IF freq. $P^{I}_{f_{IF}}$ (dBm)	Corrected Amplitude at RF freq. $P^{I}_{f_{RF}}$ (dBm)	Conversion Loss dB	RF-to-IF Isolation dB
700	300					
800	200					
900	100					

PART V: VNA Measurement of Mixer Conversion Loss

Use the VNA to measure mixer conversion loss and compare to the SA Conversion Loss Measurement.

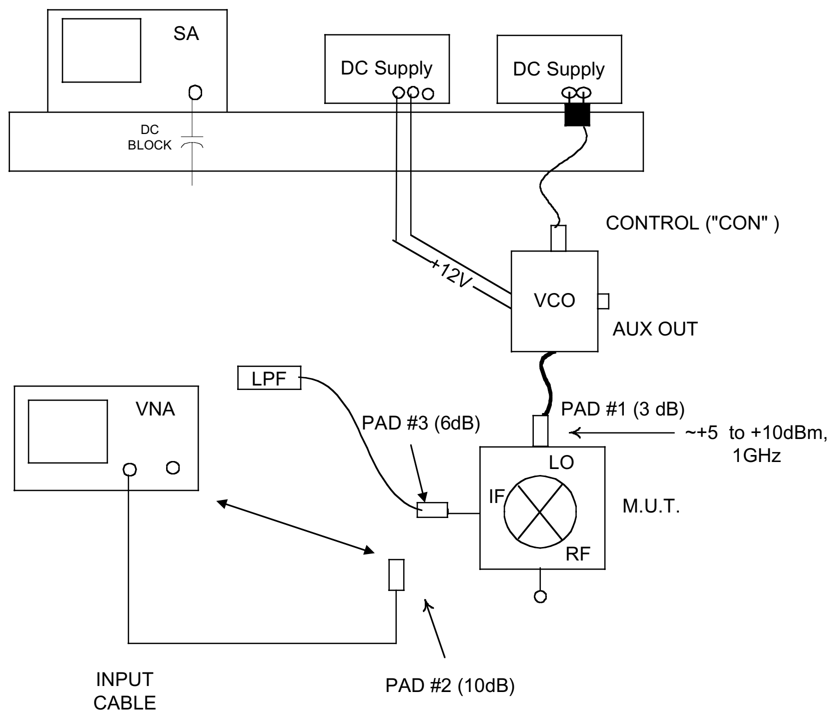

Figure 6. Set-up for calibrating VNA for Mixer conversion loss measurement. Note that the VNA is placed in a broadband detector mode and a normalization calibration is performed to reference a ratio measurement to the RF power incident on the mixer R port.

1. Set-up and calibration. Figure 6 shows the configuration to use for calibration.
   a) Connect the RF input cable, with the 10dB pad attached, directly to the N to SMA adapter on the VNA receive port.
   b) Hit "PRESET", and verify the VNA power level is still set to 0dBm.
   c) Push CHAN 1 (or MEAS 1), then the "Begin Measure" key. Select Mixer Conversion Loss as the measurement. This will put the VNA in a broadband detector mode, such that the receiver (port 2 of the VNA) will respond to RF energy at any frequency in the 10MHz to 3000MHz range. In this mode the VNA is essentially a broadband power meter. It is for this reason we will use a filter when actually measuring the filter conversion loss as we only want to measure the IF frequency product. If we do not use the filter, more than one frequency component will be incident on the broadband detector and the detected response will not properly represent the IF signal power.
   d) Now push Cal => Normalize. What you have just done is to calibrate the instrument to the RF power level incident on the mixer R port, $P^{R}_{f_{RF}}$.

2. Measuring conversion loss. Now that you are calibrated, connect the input cable + 10dB pad to the mixer R-port once again. Connect the Output Cable/Filter/pad Assembly #2, characterized in Part I, between the mixer I port and the VNA receive port connector as shown below in Figure 7.

3. Interpreting the display. As we have the instrumentation set-up and calibrated, the x-axis of the VNA represents the RF frequency incident on the RF port, though what is actually received at the VNA receive test port (the one labeled "TRANSMISSION RF IN") is at the corresponding IF frequency. The y-axis represents the difference between the received IF power in dBm minus the incident RF power in dBm used in the normalization calibration. Note for conversion loss we want the algebraic negative of this result. Also, the displayed result includes the loss of Cable/Filter Assy #2 + 6dB pad.

4. Using Markers, record the measured conversion loss at the frequencies indicated in the table below along with the relevant loss data for the Cable/Filter Assembly #2 and the 6dB pad, from Table 1. Note that the loss of these components at each corresponding IF frequency is what we need to correct for.

5. Observation of broadband conversion loss: Display the "raw" or uncorrected conversion loss measurement using a scale of 2.5dB/div or 5dB/div. You should notice a band centered around the LO frequency that has the lowest conversion loss, and a distinct roll off on either side at some separation in frequency from the LO frequency.
   a) See if you can correlate anything about this roll-off behavior and your filter cut-off frequency. (comment below)
   b) Using procedures described in previous laboratories plot the display to a PCX disk file for later printout.

Comments:

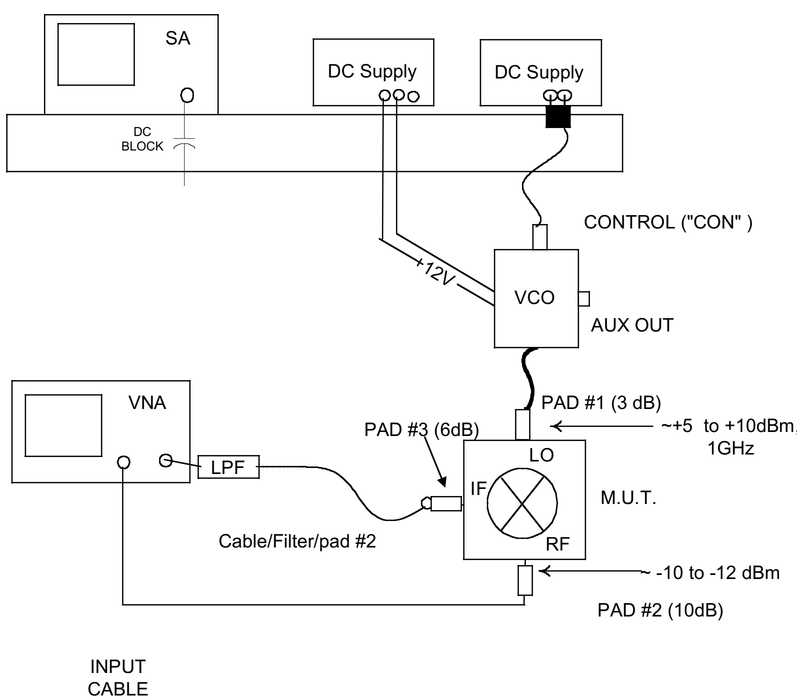

Figure 7. Measurement of mixer conversion loss. Note that the frequency dependent loss of the cables, filter, and pad attached between the I port and the VNA must be corrected for.

Table 8. VNA Measurement of Mixer Conversion Loss (Conversion loss should be a positive number according to our conventions)

A	B	C	D	E	F	G
RF Freq. MHZ	IF Freq. MHZ	Observed VNA "raw" C.L. Measurement read at RF Freq. (dB)	Cable/Filter Assy #2 + 6dB pad. Loss at IF Freq. (dB)	Corrected VNA Conversion Loss (dB)	SA Measured Conversio n Loss (dB)	Difference (SA - VNA) (dB)
700	300					
800	200					
900	100					

6. Correcting the conversion loss measurements.

The VNA conversion loss measurements may be corrected with the following relation:

|Corrected C.L.| = |Uncorr. C.L| - |Correction Factor|

where in our case:

|Correction Factor| = |Cable/Filter #2 +6dB Pad loss|.

Record your corrected measurements in the table above and also list, for comparison, the SA measured conversion loss measurements from Part IV.

Wrapping Up

In addition to handing in this write-up with the indicated observations filled in, a short well written lab summary report is to be prepared. Your summary report should include the following information:

1. A one paragraph description of the laboratory assignment.
2. The following plots to be prepared using Excel and/or VNA generated graphics files:
   a) "Raw" or uncorrected VNA conversion loss measurement over 10 to 3000MHz.
   b) Corrected VNA conversion loss compared to SA conversion loss over 700 to 900MHz.
3. A one or two paragraph discussion summarizing the results of the laboratory and referring to the plots prepared according to Step 2. Include reference to the mixer specifications where possible, and discuss other relevant results (e.g. LO-to-IF isolation) not included in the plots.
4. A one paragraph discussion of recommendations for improving the laboratory, and/or recommendations for mixer measurement practice you have formulated as a result of your experience with this week's lab.

-APPENDIX TO LAB 10 (Revised 11/2/98)-

SPECIFICATIONS FOR MINI-CIRCUITS ZEM4300 DOUBLE-BALANCED MIXER

Table A.1. Conv. Loss and Isolation From Typical Unit Data (+7dBm LO Power)

LO Freq. (MHz)	RF Freq. (MHz)	Typ. Unit Conv. Loss (dB)	LO-to-RF Isolation (dB) Typical Unit	LO-to-IF Isolation (dB) Typical Unit
1000	900	5.45	37.81	30.37
2028.571	2128.571	7.43	33.7	17.76