ELC 4383 RF/Microwave Circuits I
Laboratory 10: Mixer Measurements

Note: This lab procedure has been adapted from a procedure written by Dr. Larry Dunleavy at the University of South Florida for the WAMI Laboratory. It has been modified for use at Baylor University.

Printed Name:_____________________

Lab Partner: _____________________________

Please read the reminder on general policies and sign the statement below. Attach this page to your Post-Laboratory report.

General Policies for Completing Laboratory Assignments:

For each laboratory assignment you will also have to complete a Post-Laboratory report. For this report, you are strongly encouraged to collaborate with classmates and discuss the results, but the descriptions and conclusions must be completed individually. You will be graded primarily on the quality of the technical content, <u>not the quantity</u> or style of presentation. Your reports should be neat, accurate and concise (the Summary portion must be less than one page). <u>Laboratory reports are due the week following the laboratory experiment</u>, unless notified otherwise, and should be turned in at the start of the laboratory period. See the syllabus and/or in-class instructions for additional instructions regarding the report format.

This laboratory report represents my own work, completed according to the guidelines described above. I have not improperly used previous semester laboratory reports, or cheated in any other way.

Signed: _________________________________

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Laboratory 10: Mixer Measurements

Laboratory Assignment:

Overview

In this laboratory, you will perform frequency down-conversion measurements on a commercial Mini-Circuits ZFM-2 mixer. The datasheet is available for your use to compare with manufacturer specifications. The procedure will walk you through a detailed characterization process. Cable losses must be taken into account at appropriate frequencies. The process begins by measuring the losses of the input (RF) and output (IF) cables to the mixers. In addition, the LO input power is measured. Finally, you will connect the mixer and perform spectrum analyzer measurements at the IF port.

Note some vocabulary that will be used in the laboratory procedure:

"**Corrected**" means that the power has been changed to compensate for cable losses.
"**Uncorrected**" means that the power has not been changed to compensate for cable losses.

Reference planes should be kept in mind during the experiment.

Laboratory Procedure

A. Preliminary Calculations

For these calculations, assume the following mixer setup:

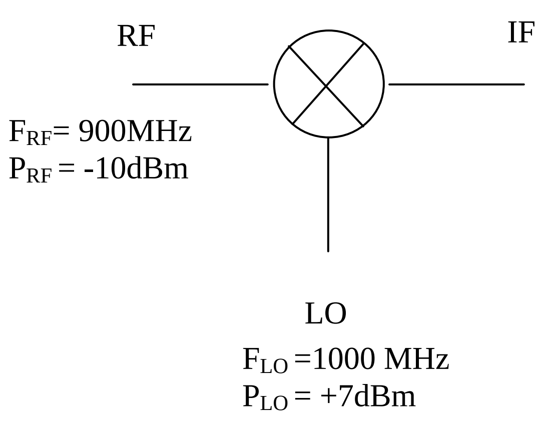

Figure 1: RF Mixer

1. If f_{LO} = 1000 MHz and f_{RF} = 900 Mhz, what are the primary mixer products we would expect to see by connecting a SA to the IF port of the mixer (we will assume the second-order Taylor Series approximation)

Table 1: Mixer Frequencies

DIFF. FREQ. (f_{IF})	FUND. LO	FUND. RF	2^{nd} HARM. LO	SUM FREQ.	2^{nd} HARM. RF

B. Insertion Loss Measurement of Cable Assemblies

In this section, you will use the VNA to measure cable losses of the input and output cables at necessary frequencies. <u>Note that the output cable must be tested at all RF and IF frequencies, while the input cable must be tested at all RF frequencies.</u>

1. Perform a transmission (response – thru) calibration over the frequency range of **10 MHz to 3 GHz** *with the input cable connected directly to the connector on the instrument of the VNA port 2*. Use 401 data points with an IF bandwidth of 100 Hz. Insertion loss is usually defined such that positive loss numbers are attained for passive components, so <u>insertion loss will be the negative (in dB) of the S21 measurement.</u>

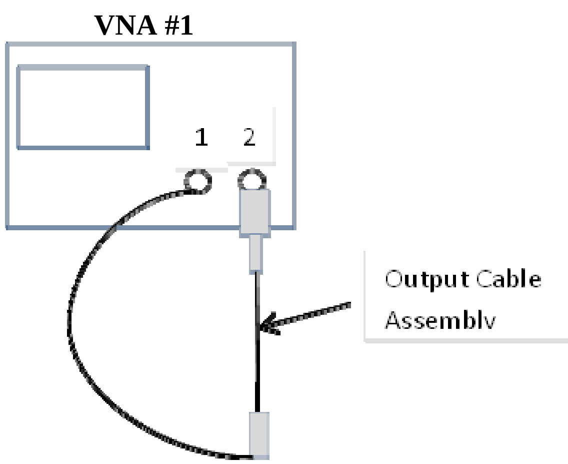

Figure 2: Insertion Loss Measurement Setup

2. Use the VNA to test the Output Cable Assembly, the setup is shown above in Figure 2. Your output cable assembly will consist of a cable and 6 dB pad, to remain together for the duration of the experiment. This assembly will be connected to the mixer output (IF port). Record the insertion loss at the frequencies shown in Table 1.

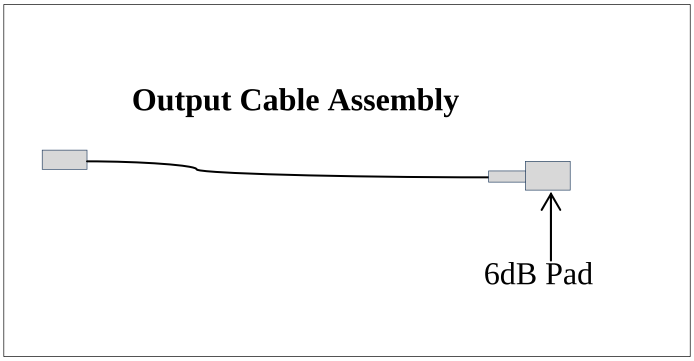

Figure 3: Output (IF) Cable Assembly

Table 2. Loss Data for Output Cable Assembly

Frequency (MHz)	Output Cable Assembly (dB)
100	
200	
300	
700	
800	
900	
1000 (LO Freq.)	

Helpful Hints:
This table indicates the Insertion Loss of the cable assembly from fig. 3.
Insertion Loss can be easily obtained from the VNA by taking the negative of the transmission coefficient @ each frequency. (i.e. -S21_dB).

C. Establishing the LO Input Level

1. Set the internal attenuator on the SA to 30 dB. Set the Reference Level to 10 dBm. Connect the second VNA as the local oscillator by connecting the port 1 cable of VNA #2 to the output cable. The setup is shown below in Figure 4.

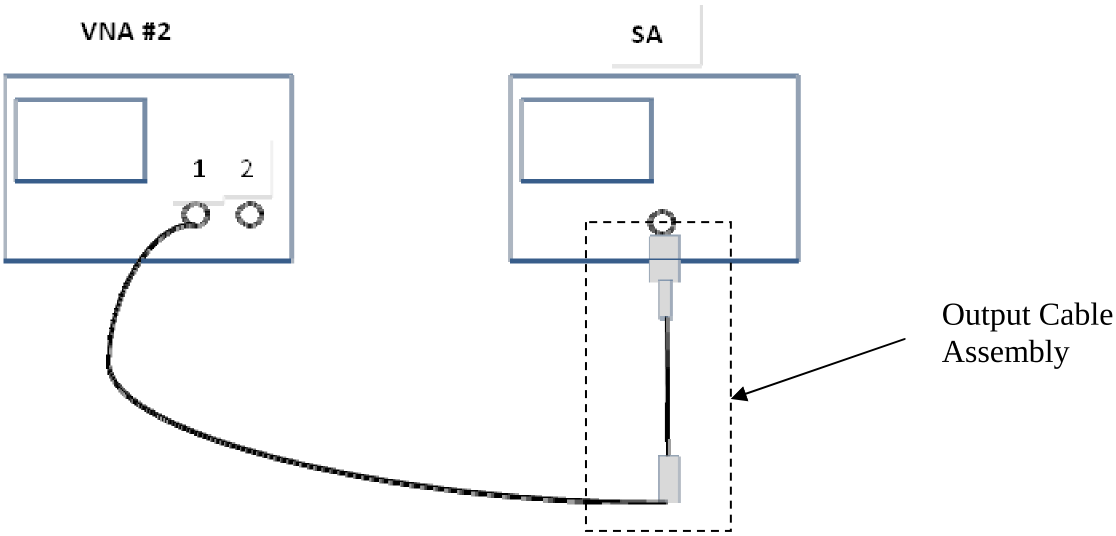

Figure 4: LO Power Measurement Setup

2. Set the internal power of the LO VNA to 10dBm and set it to operate at a CW frequency of 1000MHz.

3. Correct the observed SA power level for the loss of the output cable assembly (from Table 1). Be sure that you use the value at 1000MHz. Record the results in Table 2.

Corrected Power = Power at SA (dBm) + Cable assembly loss (dB)

Your LO output power (corrected) should be within +5 to +10 dBm. If it is not, adjust the LO VNA power until it is within this range.

Table 3. Measured Power Level to be Input to the LO Port of the Mixer

	Meas. Power at 1000MHz	
	SA Display (dBm)	**Corrected For Cable Assembly #1 loss (dBm)**
Power Level at LO port input (VCO output + semi-rigid cable + 6dB pad) (dBm) => $P^{L}_{f_{LO}}$		
Helpful Hint: *We obtain* P^{L}_{fLO} *:(the "corrected" power into the L port of the Mixer @ the LO frequency of 1GHz).*		

D. RF Input Setup and Power Measurements

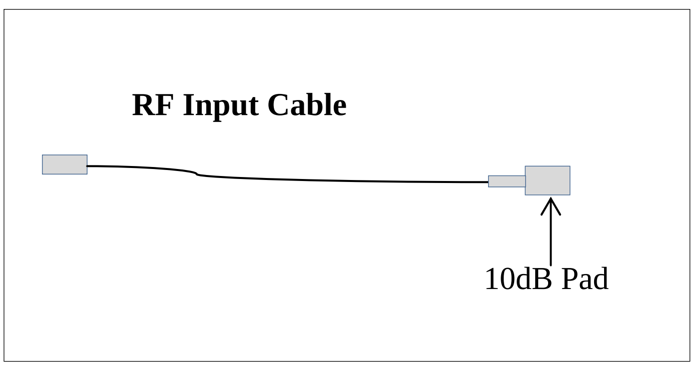

Figure 5: RF Input Cable Assembly

In this portion of the laboratory, the power level of the RF VNA will be set to a specified value in CW mode and the SA will be used to measure the power that will eventually be incident on the R port of the mixer.

1. Set up the RF VNA (the VNA previously used for the insertion loss measurements) in CW mode at a frequency of 900MHz. Attach a 10 dB pad to the input cable.

2. Connect the output cable assembly between the SA and the RF input cable assembly, the setup is shown below in Figure 6.

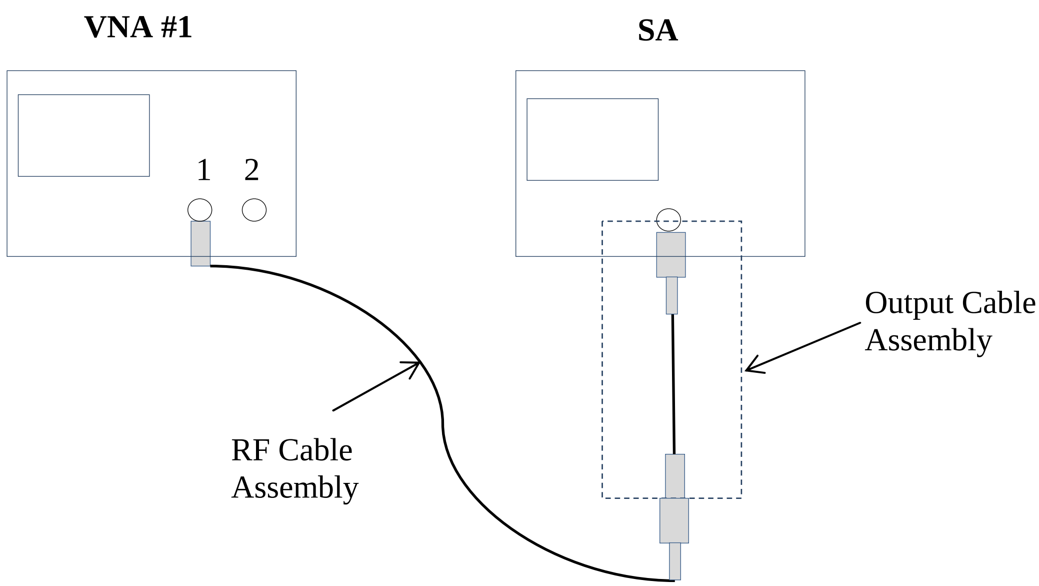

Figure 6: RF Input Power Measurement Setup

3. Set the power level on the VNA to 0dBm. This is the power at the test port, which will be reduced by the loss of the input cable assembly before entering the RF port of the mixer (R port from Figure 1).

4. Leaving the VNA power setting at 0dBm, change the CW frequency and SA settings to measure the power levels presented to the R port at 700, 800, and 900MHz. Record the results in Table 4.

5. Use the data of Table 1 for "Output Cable #1" to correct the power at each corresponding frequency. Remember that the corrected power should be higher than the power observed on the SA. The resulting power level corresponds to a notation of $P_{f_{RF}}^{R}$. That is, the power level at the RF frequency, measured at the RF mixer port.

Table 4. SA Measurements of RF Input Power Level

	700MHz	**800MHz**	**900MHz**
Mixer RF Input Level Observed at SA (dBm)			
RF Input Level Corrected for Output Cable Assembly loss (dBm) => $P^R_{f_{RF}}$			
Helpful Hint: *We obtain* P^R_{fRF} *as the "corrected" power in port R of the Mixer @ the RF frequencies of 700 MHz– 900MHz.*			

E. Spectrum Analyzer Measurements of the Mixer

In the first part of the laboratory exercise, you determined at what frequencies you might expect to see mixer products. In this part, you will use the SA to measure the frequency and amplitude of various mixer products. You will then take careful, loss-corrected readings of the observed output signal spikes for various RF frequency settings. This data will be used to calculate mixer conversion loss and signal leakage characteristics.

1. Connect the mixer into the system. The input cable from the RF VNA should attach to the R port of the mixer, the output cable assembly should be attached to the I port of the mixer and to the SA input, and the LO VNA should be attached to the L port of the mixer as shown below in Figure 7.

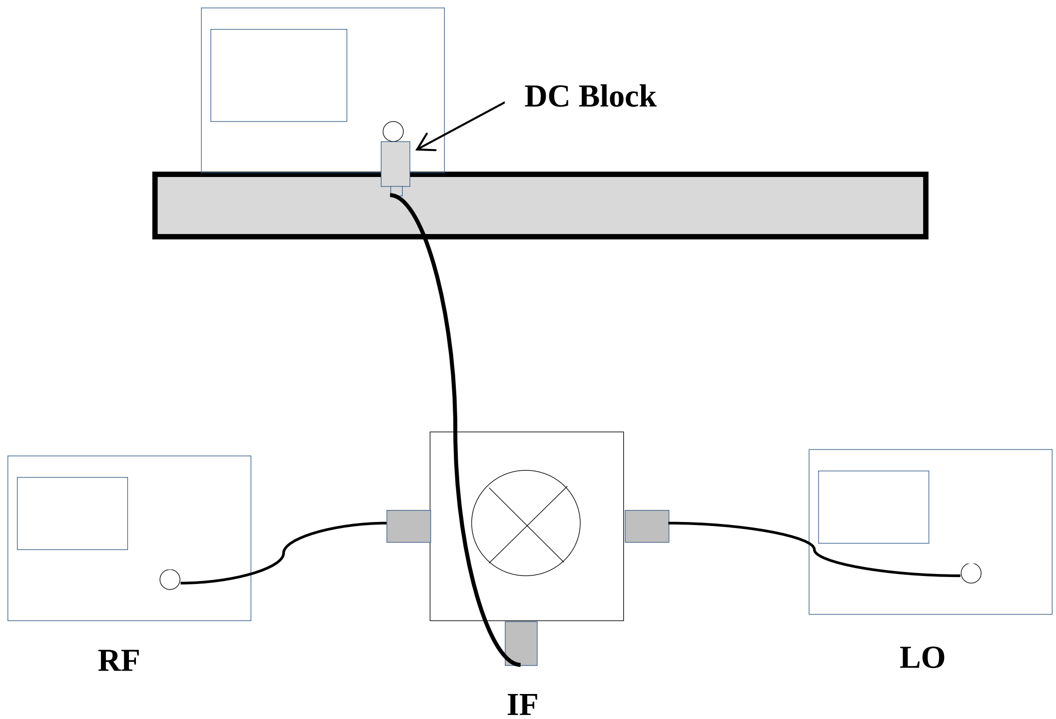

Figure 7: Measurement Setup

2. With the RF VNA in CW mode at 900 MHz, set the frequency span on the SA for maximum by hitting "Preset" and then changing the viewable range from 0 to 3.5 GHz. Observe the mixer products on the SA.

3. Record the frequencies of the largest mixer products using the peak search function, starting from the peak just to the right of DC. To the extent possible, associate the observed mixer products with the expected frequencies. Turn the RF on and off on the RF VNA and observe the difference in the mixer products displayed. Do not perform loss corrections, but keep in mind that your reference plane will be the input connector of the SA.

Table 5. Broadband Mixer (IF Port) Output Peaks Observed on SA (RF at 900 MHz, LO at 1000 MHz).

Frequency (GHz)	f_{LO}	f_{RF}	f_{RF}-f_{LO}	f_{RF}+f_{LO}	f_{LO} 2nd Harmonic	f_{RF} 2nd Harmonic
Observed Amplitude at SA (dBm)						

4. Adjust the CW RF frequency on the VNA and SA frequency settings appropriately (e.g. set each center frequency with a 1 MHz span) in order to take the data for Table 5.

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

RF Freq. (MHZ)	IF Freq. (MHZ)	Observed amplitude on SA at IF freq. $P^{I}_{f_{IF}}$ (dBm)	Observed amplitude on SA at 1GHz LO freq. $P^{I}_{f_{LO}}$ (dBm)	Observed amplitude on SA at RF freq. $P^{I}_{f_{RF}}$ (dBm)
700	300			
800	200		ONLY NEED	
900	100		TO MEASURE	
			ONCE	

Helpful Hints:
Column 3: *We obtain P^{I}_{fIF} :(the "uncorrected" power out of port I of the Mixer @ the IF frequencies of 100-300 MHz).*
Column4: *We obtain P^{I}_{fLO} :(the "uncorrected" power out of port I of the Mixer @ the LO frequency of 1GHz).*
Column 5: *We obtain P^{I}_{fRF} :(the "uncorrected" power out of port I of the Mixer @ the RF frequencies of 700-900 MHz).*

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

Uncorrected LO Input Power from Table 3: $P^{L}_{f_{LO}}$ = _____________________dBm

IF output power level at the LO frequency corrected for the output cable assembly loss:

$P^{I}_{f_{LO}}$ = ___________________________dBm

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

LO-to-IF Isolation = _____________ dB

6. Correct 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 Table 4. Use the loss results of Table 2, for the "Output Cable Assembly" to correct the power levels of Table 6 at each corresponding frequency to obtain the power at the mixer I port. Record the corrected power levels in Table 7.

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

1	2	3	4	5	6	7
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					
Helpful Hints		*Table 4*	*Table 6, Col. 3+ Cable Loss*	*Table 6, Col. 5+ Cable Loss*	*Column 3 – Column 4*	*Column 3 – Column 5*

Other Hints:

Column4: *Get values from Column 3 of Table 6. Then add the cable loss to each value obtained from Table 6 to get the corrected Power. (e.g. the 1st row & 3rd Column in Table 6 corresponds to the uncorrected P^{I}_{fIF} @ 300 Mhz. In order to find the "corrected" P^{I}_{fIF} we must factor in the cable loss @ 300 MHz. So we add the value in the 3rd row (300Mhz) & 2nd column (Cable #1) of Table 2.)*

Column 5: *Get values from Column 5 of Table 6. Then add the cable loss to each value obtained from Table 6 to get the corrected Power. (e.g. the 1st row & 5th Column in Table 6 corresponds to the uncorrected P^{I}_{fRF} @ 700 Mhz. In order to find the "corrected" P^{I}_{fRF} we must factor in the cable loss @ 700 MHz. So we add the value in the 4th row (700Mhz) & 2nd column (Cable #1) of Table 2.)*

7. Calculate RF-to-IF isolation and conversion loss for each RF frequency in Table 7 using the following formulas:

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

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

8. Set the RF frequency to 900 MHz. Add a 250 MHz low-pass filter between the IF port of the mixer and the output cable assembly. Note the effect that this has on the mixer products that can be observed on the SA. Record the observable responses in Table 8.

Table 8. Broadband Mixer Output Peaks Observed on the SA with the Lowpass Filter in Place (RF at 900 MHz, LO at 1000 MHz).

Frequency (GHz)	f_{LO}	f_{RF}	f_{RF}-f_{LO}	f_{RF}+f_{LO}
Observed Amplitude at SA (dBm)				

F. VNA Measurement of RF-to-IF Isolation

1. Set up the VNA for S21 measurement. Disconnect the pads from the RF and IF ports of the mixer and connect them together with a thru connection (i.e. connect the output cable assembly, including the pad, to Port 2 of the VNA and the input cable, including the 10 dB pad, to port 1 of the VNA with a thru in between for calibration).

2. Perform a transmission response calibration on the VNA.

3. Connect the mixer between the pads and measure the RF-to-IF isolation directly. Since no frequency conversion is performed, this measurement can be performed on the VNA. Note that the VNA is in frequency selective mode and will only measure the output frequency component that is at the same frequency as the input frequency, even though other mixer frequency components are present.

4. Using marker features on the VNA, record your results for the RF-to-IF isolation in the table below and also list the corresponding measurements obtained using the Spectrum Analyzer in the previous part of the experiment. Note that isolation is generally discussed as a positive number, which is in agreement with the way the RF-to-IF isolation has been defined in this laboratory procedure. Therefore, list the isolation measurement as the negative of the S21 (in dB) transmission measurement (isolation will be a positive number).

1	2	3	4
RF Freq. MHz	VNA RF to IF Isolation (dB)	SA (corrected) RF to IF Isolation (dB)	Difference (SA - VNA) (dB)
700			
800			
900			

Column 2: *Insertion Loss of port R of mixer to port I (i.e. -S21_dB, where S21_dB can be directly read off the VNA)*
Column3: *Get directly from column 7 of Table 7.*
Column 4: *Column 3 – Column 2*

<u>Report</u>

1. Provide the usual summary.

2. Prepare, using Microsoft Excel, a plot of conversion loss versus frequency obtained from the Spectrum Analyzer measurements.

3. Comment on the conversion loss plots of the previous step.

4. Using the datasheet for the ZFM-2 mixer, comment on the conversion loss you measured in comparison with the manufacturer specifications.

5. Prepare using Microsoft Excel, a plot that shows RF-to-IF isolation as measured by (a) the Spectrum Analyzer and (b) the VNA at 700, 800 and 900MHz.
6. Comment on the RF-to-IF isolation plot from Step 4.