Basic RF Technic and Laboratory Manual - Mixer.

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CONTENTS

1. PRELAB EXERCISE

1. Define the following terms related to mixers: Conversion Loss, One dB Compression Point, Two Tone Third Order Intecept Point and Isolation.

2. BACKGROUND THEORY

2.1 Mixing Action

The mixing action of a mixer arises from two distinct processes acting in tandem. The input signal (designated as RF) is multiplied with a locally generated signal (the Local Oscillator, LO), thus generating two output signals at the sum and difference frequencies. The difference frequencies are referred to as the 'Intermediate Frequency' (IF). In a receiver, the sum frequency is normally rejected by a bandpass IF filter leaving only the difference. Multiplication, however, is effected using non-linear elements (diodes) and these non-linearities are responsible for the generation of many additional frequencies other than the pure sum and difference frequencies.

2.2 Spurious Products

While we would wish for all of the input signal power to be converted without loss to the IF frequency, mathematics tells us that the generation of both sum and difference frequencies is inevitable. Thus, even with an ideal mixer we will necessarily lose half the input signal power (or 3 dB) in the mixing process. Other undesired or spurious products generated, as result of diode non-linearities will further increase the amount of signal power lost. In mixers design, every effort is made to ensure that the generation of such spurious products is kept to a minimum.

2.3 Sum and Image Frequencies

As indicated above, an input RF signal and a local oscillator, LO, signal are multiplied to generate the sum and difference IF frequencies. If another input frequency is found that, when mixed with the LO, the correct IF frequency will be generated, then signal or noise power at this frequency will be passed to the mixer IF terminals.

A frequency of 2 x LO - RF is such an input frequency. This particular frequency is called the image frequency (See Figure 1).

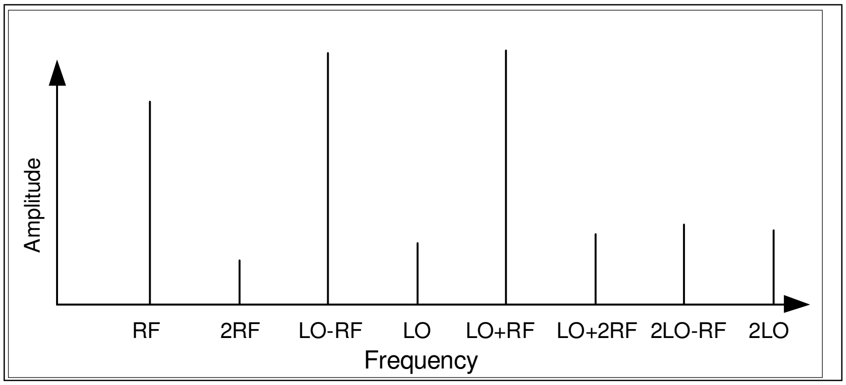

Figure 1 - Typical mixer output, without filtering.

2.4 Conversion Loss

As indicated above, half of the converted power is inevitably lost in the mixing process. Hence this loss (the Single Sideband Conversion Loss) between the RF input power and the IF output power will have a minimum value of 3 dB. In practice, there are extra losses due to the generation of spurious products. Resistive losses in the diodes, mismatches at the mixer ports, etc., will combine to increase this figure. Careful selection of the local oscillator power to bias the diodes at their optimum operating points will minimize mixer conversion loss. All mixers have been designed, with optimum diode/LO drive power combinations. Accordingly, our devices always should be operated with the LO drive power specified in its data sheet.

2.5 Two-Tone Third Order Intercept Point

Mixers have made possible frequency conversion through the use of nonlinear devices, such as a diode. We have seen, however, that this nonlinearity also gives a rise to a number of undesired harmonics and mixer products. These spurious signals increase the conversion loss of a mixer, and can also lead to signal distortion. In general, any system using a nonlinear device has a voltage transfer function that can be written as the Taylor series:

$$v_{out} = a_0 + a_1 v_{in} + a_2 v_{in}^2 + .. + a_n v_{in}^n \tag{2.1}$$

In our case, a mixer, the a_0 term corresponds to the DC bias voltage, while the mixed output is part of the v_{in}^2 term. If the input of the system consists of a single frequency, e.g. $v_{in} = \cos\omega t$, the output voltage given by equation (2.1) will consist all harmonics of the form mω, of the input signal.

These harmonics are classified by their order, which is equal to m. More serious problems arise when the input to the system consists of multiple relatively closely spaced frequencies, for example the two-tone input signal, $v_{in} = \cos\omega_1 t + \cos\omega_2 t$. Then the output spectrum will consist all harmonics of the form mω_1+ nω_2, where m and n are positive or negative integers. The order of a given product is then defined as $|m|+|n|$. The v_{in}^2 term of (2.1) will produce harmonics at the frequencies $2\omega_1$, $2\omega_2$, $\omega_1 - \omega_2$, and in $\omega_1 + \omega_2$, which are all second-order products (see Figure 2) . These frequencies are generally far away from the fundamentals ω_1 and ω_2, thus can easily be filtered. The $\omega_1 - \omega_2$ product is usually the desired result for a mixer. The v_{in}^3 term will lead to third-order products, such as $3\omega_1$, $3\omega_2$, $2\omega_1 + \omega_2$, $2\omega_2 + \omega_1$ (see Figure 2), which can be easily filtered, while the products $2\omega_1 - \omega_2$ and $2\omega_2 - \omega_1$ cannot be simply filtered, even in a narrow-band system, since they are closed to the desired product. Such signals are called the 'intermodulation distortion'.

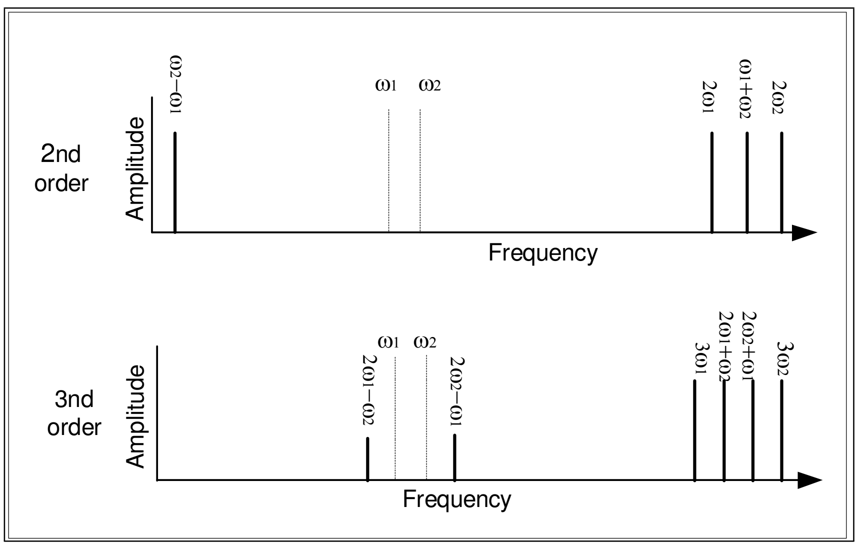

Figure 2 - Clasification of intermodulation products.

The third-order two-tone intermodulation products $2\omega_2 - \omega_1$ and $2\omega_1 - \omega_2$ are especially important because they can set the dynamic range of the mixer. Third order intermodulation products have an amplitude proportional to the cube of the input signal, whereas second order components have an amplitude proportional to the square of the input signal. Thus if two input signals, equal in magnitude, each rise by 1 dB, then the third order intermodulation products rise by 3 dB, and the 2nd order components by 2 dB. Higher order terms behave accordingly. However, although 3rd order intermodulation products grow at higher rates, their levels are initially very small compare to lower order components which generally dominate. This RF level dependency leads to a simple test to establish the mechanism responsible for various distortion products, i.e. 2nd order or 3rd order effects. Intermodulation products from either side of the signal tones may not behave symmetrically. The difference in their level indicates the presence of a more complex mechanism, or in the case of widely spaced tones, it may indicate the effects of frequency response. If the levels of fundamental 3rd order components are plotted against the input level, theoretically, there would be points where the third order levels intercept with the fundamental component. These points are known as a T0I, 'Third Order Intercept point', (otherwise known as IP3). In reality, the mixer reaches compression first. The T0I are found by extrapolation. Figure 3 shows an example of TOI (IP3). The third order intercept point is used as mean of rating different amplifiers and mixers, allowing a comparison of the devices independent of their input level. In the absence of any specified value for IP3, it may be estimated from the specified 1 dB compression point. As a rule of thumb, the third-order intercept point is approximately 10-15 dB higher than the 1 dB compression point.

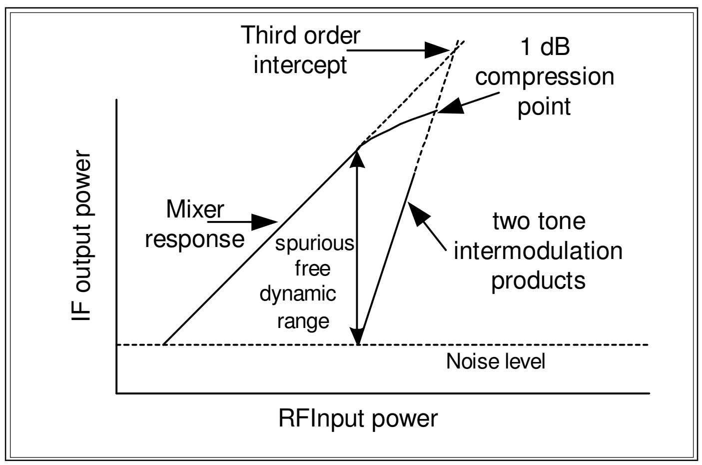

Figure 3 - Two tone intermodulation products diagram.

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2.6 Dynamic Range

Another major mixer parameter to be considered is the RF dynamic range of the device. This is limited at low levels by the noise floor of the mixer and system, while the high limit is generally taken to be the 1 dB Compression Point, defined below. This can be best understood with an input-output characteristic, as shown in Figure 3.

2.7 1 dB Compression Point

The dynamic range of a mixer is the range of the input RF power levels (in dBm) for which the mixer produces useful IF output power. Dynamic range is limited at the low end by the noise performance of the mixer device. When the input power produce a discernible IF output signal, which result in a constant power ratio (equal to the conversion loss) established between input RF power and output IF power, the conversion loss begins to increase. When conversion loss has increased by 1 dB, the upper limit of the mixer's dynamic range has been reached (see Figure 3). The "1 dB Compression Point" generally defines the upper level of input power for which the mixer should be used. The 1 dB compression point is tied in closely with the third order intercept point; as a rule of thumb, two tone third order intercept point is 10 - 15 dB above the 1 dB compression point. The 1 dB compression point is primarily a function of the specified LO power and will increase with higher LO power level mixers. Generally, mixers using Schottky diodes will have a 1 dB compression point between 5 and 10 dB below the LO drive.

2.8 Standing Wave Ratio (SWR)

Efficient operation of a mixer requires that a maximum signal power transfer will be effected at each of the three ports. The degree at which this ideal is met is indicated by the Standing Wave Ratio (SWR), which quantifies the amount of mismatch at each port. A perfect match of a 50Ω system implies a SWR of 1:1, while a port with a SWR of 2:1 means that approximately 10% of the incident power would be reflected from that port. The importance which minimize the mixer SWR to ensure efficient driving of the diodes and power transfer of RE/IF energies is, therefore, apparent.

2.9 Isolation

All references to the mixer so far have assumed that RF/LO/IF signal powers are present at their respective ports and at no other. In practice, a small portion of the power applied to any port will leak through to the other two ports. This is particularly undesirable in the case of the relatively high level LO signal. The degree at which the LO power is masked from the other two ports is specified by the $L - R$ and $L - I$ isolations (in dB). These are in insertion losses between the respective ports.

2.10 Noise Figure

Noise Figure (NF) is the signal to noise ratio (SNR) at the input of the mixer divided by the signal to noise ratio at the output, expressed in dB.

$$NF = \frac{SNRin}{SNRout} \quad (dB)$$

This formula is only valid when the input termination is at standard noise temperature, T0.

The noise introduced by the mixer consists of the conversion loss (SSB), thermal noise in the series resistance of the diodes and other components. Noise figure parameter is generally between 0.5 and 1 dB of the conversion loss performance.

2.11 Mixer as a Phase Detector

If the signals applied to the RF and to the LO ports of a mixer have the same frequency and arbitrary phase (see Figure 4), then it can be shown that the resultant IF voltage will be:

$$V_o = \cos\omega t \cos(\omega t + \alpha)$$

Using the trigonometric identity:

$$\cos A \cos B = \frac{1}{2}\cos(A+B) + \frac{1}{2}\cos(A-B)$$

One gets:

$$V_o = \frac{1}{2}\cos\alpha + \frac{1}{2}\cos(2\omega t + \alpha)$$

Using LPF to remove the $2\omega t$ term, the output voltage will become:

$$V_o = \frac{1}{2}\cos\alpha \tag{2.2}$$

V_o is a DC voltage and will vary as the cosine of the phase difference between the input signals. Accordingly, a double balanced mixer may be used as a phase detector. Theoretically, when α is equal to $\pi/2$ the DC voltage at the IF port should be zero. In practice, diode imbalance and transformer asymmetry may cause a DC offset. This offset can be counteracted by applying a DC bias to the IF port.

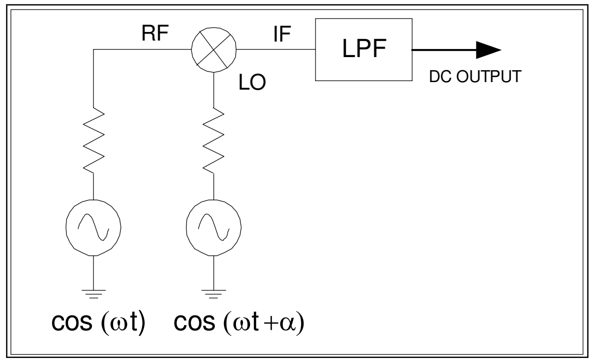

Figure 4 - Applying two sinusoidal signal to a mixer.

2.12 Glossary of Terms

2.12.1 Conversion Loss (SSB)

The ratio of the RF input power to the IF output power of one sideband (either F_{LO}- F_{RF} or $F_{LO} + F_{RF}$).

2.12.2 Noise Figure (SSB)

The ratio of the SNR at the mixer input divided by the SNR at the mixer output of one mixer sideband.

2.12.3 Isolation

The amount an input signal is attenuated, when measured at another mixer port.

2.12.4 1 dB Compression Point

The RF input power that causes a 1 dB increase above a mixer's small signal conversion loss.

2.12.5 Harmonic Intermodulation Products

Mixer output signals other than the desired $F_{LO} \pm F_{RF}$, which are harmonically related to either or both of the input signals (also termed as N_{LO}, $M_{RF,}$ N x M or "Spurs").

2.12.6 **Two-tone Intermodulation Products**

Undesired mixer output products caused by the simultaneous presence of two RF input signals (3rd order IM consists of $[(2F_{RF1} \pm F_{RF2}) \pm (F_{LO})]$ and $[(F_{RF1} \pm 2F_{RF2}) \pm (F_{LO})]$).

2.12.7 DC Polarity

The mixer IF voltage polarity, either positive or negative when in phase LO and RF signals are applied.

2.12.8 DC OFFSET

The IF output voltage measured with only the LO operating and the RF terminated in 50 ohm.

3. EXPERIMENT PROCEDURE

3.1 Required Equipment

1. Spectrum Analyzer-HP-8590E or HP-8590L.
2. Signal Generator $HP - 8647A$.
3. Two Arbitrary Waveform Generators $(AWG)HP - 33120A$.
5. Double Balanced Mixer Mini-Circuit $ZAD - 6$.
6. Termination - 50Ω.
7. Band pass filter Mini-Circuit BBP-21.4 .
8. Power splitter/combiner Mini-Circuit ZSC-2-2.

3.2 Mixing Action

In this part of the experiment you will realize the non-ideal operation of the mixer. You will use the basic component Double Balanced Mixer as a frequency converter or a frequency multiplier, and identify the major component at the IF.

1. Connect the double balanced mixer according to Figure 5.

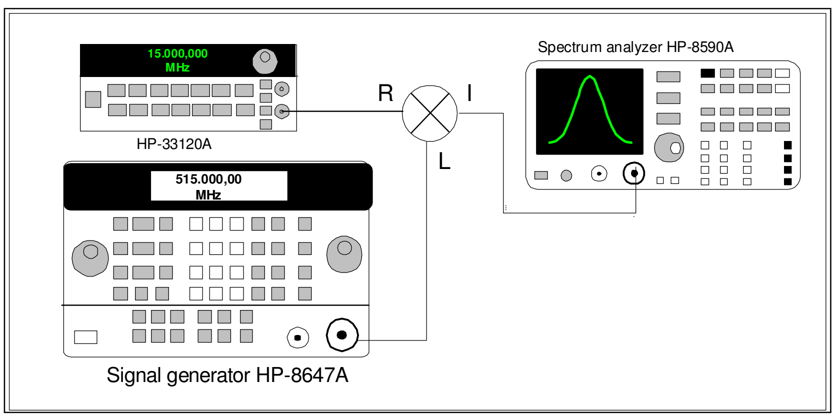

Figure 5 - Mixing action and spurious products.

2. Adjust the $T\&M$ equipment as follow:
$LO-$ Signal Generator - Frequency 60 MHz and amplitude 0dbm.
RF - AWG - Frequency 15 MHz and amplitude -10dbm.

3. Set the spectrum analyzer to center frequency 80 MHz and span 140 MHz. **Sava the Data on magnetic media.**

4. Measure the frequency and amplitude of the main signals and fill Table-1:

Signal	Frequency	Amplitude
RF		
LO-RF		
LO		
LO+RF		
LO+3RF		
2LO		
2LO+RF		

Table-1

3.3 Mixer as Phase Detector

In this part of the experiment you will use the mixer as a phase detector between two signal with equal frequency.

1. Connect the double balanced mixer according to Figure 6.

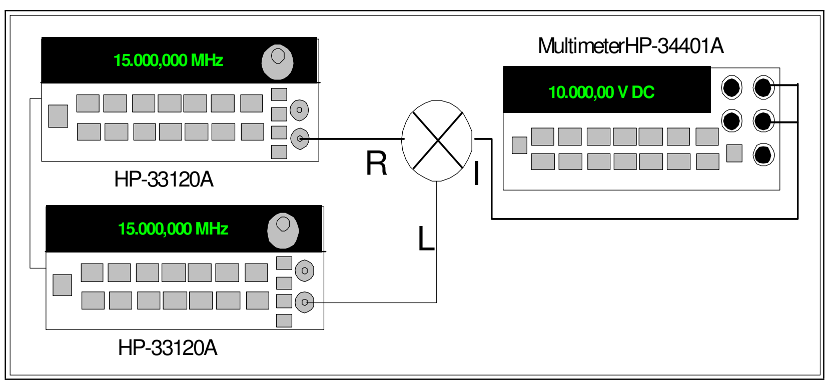

Figure 6 - Mixer as a phase detector.

2. Adjust the $T\&M$ equipment as follow:

$LO-AWG$ - Frequency 10 MHz and amplitude 0dbm.

RF - AWG - Frequency 10 MHz and amplitude -10dbm.

3. Lock the two $AWG\prime s$ and set the phase between them to zero, according to Appendix-1.

4. Change the phase between the AWG's according to Table-2 and fill it:

Phase(deg.)	Voltage (mv)	Phase(deg.)	Voltage (mv)
0		210	
30		240	
60		270	
90		300	
120		330	
150		360	
180			

Table-2

3.4 1 dB compression point

In this part of the experiment you will find the 1 dB compression point by changing the RF power, in one dB steps, while watching the compression process, using the spectrum analyzer.

1.Connect the system as indicated in Figure 5.

2. Adjust the $T\&M$ equipment as follow:

$RF-$ Signal Generator - Frequency 10 MHz and amplitude according to Table-3.

$LO - AWG$ - Frequency 55 MHz and amplitude +5dbm.

3. Set the spectrum analyzer to center frequency of LO - RF (45MHz) and span of 0.5 MHz. Only the LO - RF signal will be displayed.

4. Fill in Table-3:

RF Amp(dBm)	LO-RF Amp(dBm)	RF Amp(dBm)	LO-RF Amp(dBm)
-5		0	
-4		1	
-3		2	
-2		3	
-1		4	

Table -3

3.5 Two Tone, Third Order Intermodulation Distortion

In this part of the experiment you will measure the two tone intermodulation products and define the third order intercept point.

1. Connect the double balanced mixer according to Figure 7.

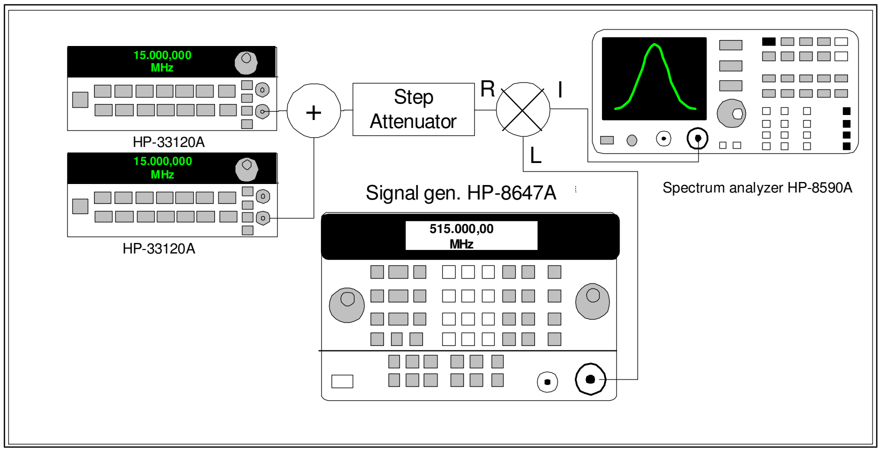

Figure 7 - Two tone inremodulation measument.

2. Adjust the $T\&M$ equipment as follow:

$LO-$ Signal Generator - Frequency 55 MHz and amplitude 7dbm.

$RF1$ - AWG – Frequency 10 MHz and amplitude -15dbm.

$RF2$ - AWG – Frequency 10.1 MHz and amplitude -15dbm.

3. Set the spectrum analyzer to frequency LO - RF of 45MHz and span 1 MHz. The LO-RF1 signal, LO-RF2 signal and the two intermodulation products will be displayed.

4. Measure the amplitude of the signal and fill in Table-4:

Amp. (dBm) RFl&RF2	Amp. (dBm) LO-RF1	Amp. (dBm) LO-(2RF1-RF2)
-90		Noise level
-80		Noise level
-70		Noise level
-60		Noise level
-50		Noise level
-40		Noise level
-30		Noise level
-25		
-20		
-15		
-10		

Table-4

3.6 SWR of the Mixer

1. Connect the mixer to the network analyzer according to Figure 8.

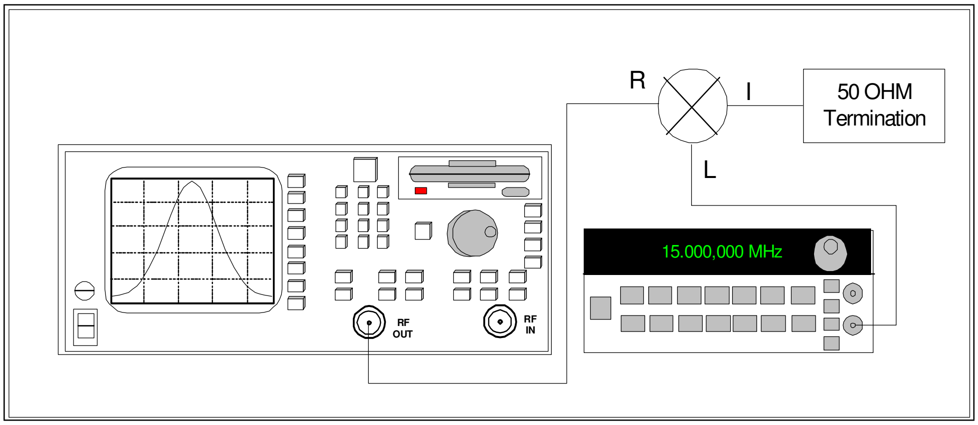

Figure 8 - SWR measurement of a mixer.

2. Adjust the $T\&M$ equipment as follow:

$LO-$ AWG – Frequency 10 MHz and amplitude 7dbm.

RF - Network analyzer setting to reflection measurement, frequency range 0.3-100 MHz.

3. Measure the SWR at the RF port as a function of frequency. **Sava the Data on magnetic media.**

4. Exchange between the network analyzer and the 50Ω termination (network analyzer is connected to IF and the 50Ω termination is connected to the RF port).

5. Measure the SWR as a function of frequency. **Sava the Data on magnetic media.**

3.6.1 Isolation

In this part of the experiment you will measure the isolation between the LO to the RF port and the LO to the IF.

1. Connect the mixer to network analyzer, as indicated in Figure 9.

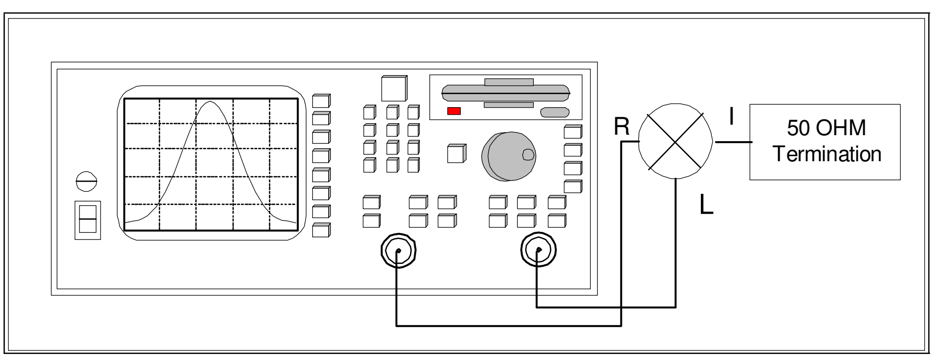

Figure 9 - Setup for isolation measurement.

2. Adjust the $T\&M$ equipment as follow:

$RF-$ Connected to Transmission port of the network analyzer.

$IF-$ Terminated by 50 Ω load.

LO - Connected to Reflection port of the network analyzer .

3. Set the network analyzer to transmission measurement, frequency range 0.3-100 MHz.

4. Measure the isolation between the LO and RF ports as a function of frequency. **Sava the Data on magnetic media.**

5. Connect the LO port of the mixer to the reflection port of the network analyzer and the IF port of the mixer to the $t$ransmission port of the network analyzer. Use a 50Ω termination to the RF port. Measure LO to IF isolation. **Sava the Data on magnetic media.**

3.7 Final Report

1. Using your stored data of 'Mixing Action' part, draw a graph of the mixing product as a function of frequency, fill Table-6 by dividing the signals into two categories (and explain why) - Mixing products and Leakage products.

Category	Signal	Frequency	Amplitude	Order
	RF			
	2RF			
	LO-RF			
	LO			
	LO+RF			
	2LO			

Table-6

2. Using matlab or other mathematics software, draw a graph of voltage as a function of phase difference, according to Table-2.

a. Find the linear (or other) equation of the curve between 0-180°.

b. According to the equation, calculate the phase for -100 mV DC at the output of the mixer.

c. If you use the mixer as a phase detector, what is the phase range that can operate correctly? explain.

3. Refer to Table-3, draw a graph of the $LO-RF$ power as a function of the RF power and denote on the graph the 1 dB compression point.

4. Refer to Table-4, draw a graph of the $LO-RF1$ power as a function of the input power. On the same graph, draw a second graph, of the power of the intermodulation product (LO-(2RF1-RF2)) as a function of the input power. Using mathematic software, find the equation of each line and calculate the two-tone third order intercept point. Denote on the graph the noise level and the dynamic range of the mixer.

5. Draw a graph of the SWR of the RF port of the mixer and find the point (level and frequency) for which maximum power of the RF port is reflect to the source.

6. Draw a graph of the LO to RF isolation as a function of frequency. Compare your results to specification of the mixer (see Appendix-2).

3.8 Appendix-1

3.8.1 Phase locking two function generators

1. Connect the rear - panel *Ref Out* 10MHz output terminal of the master Arbitrary Waveform Generator HP-33120A to the *Ref in* on the rear panel of the slave HP-33120A, as shown in top of Figure 10.

2. Connect the two AWG's to the oscillocope, as shown in bottom of Figure 10.

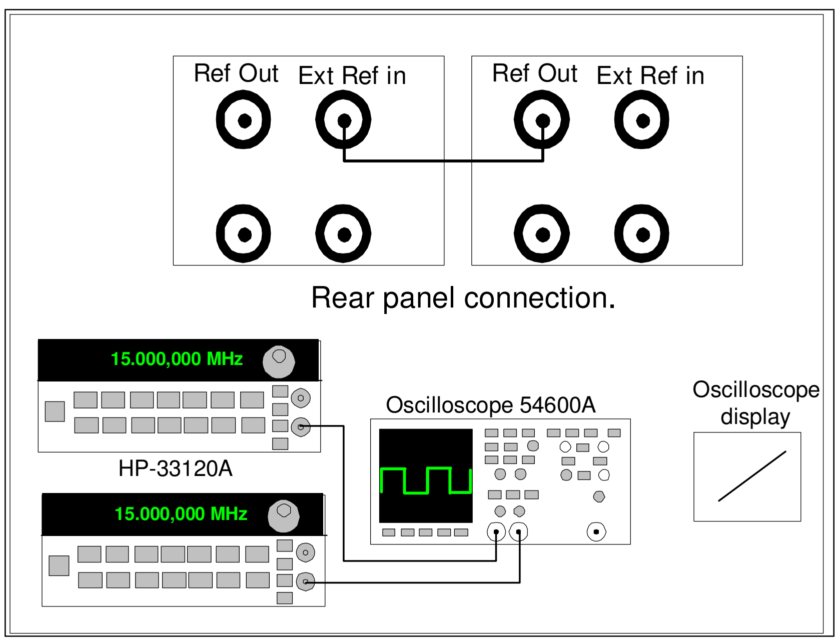

Figure 10 - Setting zero phase using Lissajous method.

3. Set the oscilloscope to XY function, in order to measure the phase difference.

4. Turn on the menu of the AWG by pressing $\boxed{\text{shift}}$ $\boxed{\text{Menu On/Off}}$, the display will look like $\boxed{\text{A: MOD MENU}}$.

5. Move across to $\boxed{\text{G: PHASE MENU}}$, by pressing the $\boxed{\lhd}$ button.

6. Move down a level to the ADJUST command, by pressing $\boxed{\nabla}$. The display will look like $\boxed{\text{1: ADJUST}}$.

5. Press $\boxed{\nabla}$ a level and set the phase offset, change the phase continuously between the two AWG until you get a straight line, incline of 45° to the X axis, which indicate zero phase (see bottom-right of Figure 10). You will see a display like $\boxed{\wedge 120.000\text{DEG}}$.

6. Turn off the menu by pressing $\boxed{\text{ENTER}}$.

3.8.2 Setting a zero phase reference at the end of the cable.

1. Turn on the menu by pressing $\boxed{\text{shift}}$ $\boxed{\text{Menu On/Off}}$. The display will look like $\boxed{\text{A: MOD MENU}}$.

2. Move across to PHASE MENU choice on this level, by pressing $\boxed{\lhd}$. The display will look like $\boxed{\text{G: PHASE MENU}}$.

3. Move down a level and then across to get to SET ZERO, by pressing $\boxed{\nabla}$ and $\boxed{\rhd}$ buttons. The display will look like $\boxed{\text{2: SET ZERO}}$.

4. Move down a level to set the zero phase reference. Press $\boxed{\nabla}$ button. The display will look like $\boxed{\text{PHASE} = 0}$.

5. Press $\boxed{\text{Enter}}$, save the phase reference and turn off the menu.

Important:

1. At this point, the function generator HP-33120A is phase locked to another HP-33120A or external clock signal with the specified phase relationship. The two signals will remain lock unless you change the output frequency.

3.9 Appendix-2

3.9.1 Specification of Frequency Mixer Mini-Circuits $ZAD-6$

LO port - maximum input level +1dBm.

RF port - maximum input level +7dBm

LO frequency range $f_L - f_U$ 0.003-100 MHz.

RF frequency range $f_L - f_U$ 0.003-100 MHz.

IF frequency range $f_L - f_U$ DC-100 MHz.

Conversion Loss (dB) - Mid-Band m, $\bar{x} = 4.65$, $\sigma = 0.08$, $Max. - 7.5$.

Conversion Loss (dB) - Total range $Max. - 8.5$.

$LO - RF$ isolation $(dB) - L_{Typ}-$ 60, $L_{Min.}$- 50, M_{Typ}- 45, $M_{Min.}$-30.U_{Typ} - 35, $U_{Min.}$-25.

$LO - IF$ isolation $(dB)-$ $L_{Typ}-$ 60, $L_{Min.}$- 45, M_{Typ}- 40, $M_{Min.}$-25. U_{Typ} -30, $U_{Min.}$-20.

Notes:

$L-$ low range (f_L to $10f_L$).

M - mid range ($10f_L$ $to\frac{1}{2}$ f_U).

U - upper range ($\frac{1}{2}f_U$ to f_U).

m - mid band ($2f_L$ to $\frac{1}{2}$ f_U).

$\bar{x}$ - Average of conversion loss at center of mid-band frequency (f_L to $\frac{1}{4}f_U$).

σ - Standard deviation.