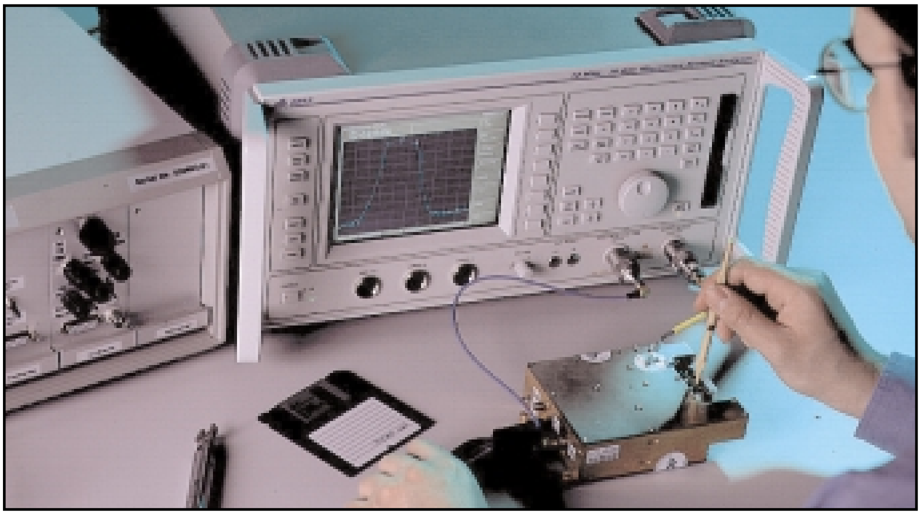
application note

Microwave Mixer Measurements using 6840 Series Microwave System Analyzer

by M Edwards, Microwave Components Group



Measurement of Mixer performance using the 6840 series Microwave System Analyzer (MSA), including Conversion and Return Loss, Distortion and AM Noise Suppression

Introduction

There are three classes of mixer; fundamental, harmonic and sampling, the most common being the fundamental mode mixer, which uses the fundamental frequency of the local oscillator for the mixing process.

The provision of a microwave source for the LO can often be technically demanding or expensive. Employing the harmonic mode of conversion as an alternative to using the fundamental mode of conversion means that local oscillators operating at lower frequencies can be used.

Sampling mixers extend the concept of harmonic mixing by using very large harmonic numbers with a relatively constant conversion efficiency for each harmonic response. They are used when the frequency of the signal to be converted is several tens of octaves or more above the available local oscillator frequency.

Conventions

The following conventions are used to indicate keypresses on the MSA:

[**BOLD**]- Hardkey press, i.e. a dedicated front panel function key
[normal] - data entry via numeric keypad
[*Italic*]- Softkey press i.e. software menu key
[●] - toggle function enabled
[◉] - toggle function disabled

Numeric entries are made using either the keypad or the rotary control. Keypad entries must be followed by a terminator key. To delete a partial entry use the back space key.

From the [**PRESET**] condition the 6840 MSA is operating with channel 1 configured as a spectrum analyzer and channel 2 a scalar analyzer. The signal source output is switched to the OFF state.

MIXER TESTING

The testing of frequency translation devices with a scalar network analyzer can present a number of measurement problems. Firstly, for many measurements two microwave sources are required, one to provide the local oscillator signal and the second to provide the RF signal. The second problem arises from the need to differentiate the many signals that the mixer generates. The prime signal, commonly known as the IF signal, can be accompanied by unwanted mixing products and leakage of the local oscillator and its harmonics.

By integrating a spectrum analyzer with a scalar network analyzer and a microwave source in the 6840 MSA, IFR Ltd have created an instrument that greatly simplifies the testing of mixers. The combination of these three instruments with a single processor and additional synchronising circuitry delivers more capability than three individual measuring instruments.

The microwave source can be used to provide either the RF or LO signal. To assist in the measurement of mixers the microwave source of the 6840 MSA can be set up as an offset tracking generator which can track the spectrum analyzer with any offset within the frequency range of the source. The source can be swept up or down in frequency as the spectrum analyzer sweeps from low to high frequencies. This feature allows both upper and lower sideband measurements to be made. A further enhancement has been added to the synchronization capability of the 6840's spectrum analyzer and source, in that a multiplication factor can be applied before or after the addition of the offset allowing harmonic mixers to be measured. The spectrum analyzer is capable of accurately measuring wanted signals generated by the mixer whilst rejecting unwanted conversion and leakage products.

With the general setup either the LO or RF source can be provided by the MSA synthesiser. The RF or LO source would be a standalone synthesizer source as the IFR 2023/25, 2040 series or the GT9000 or GT12000 range of synthesizers.

With very complex measurements it is necessary to add a PC to the suite of instruments. Whilst PC based measurements are not as fast as the synchronized sweep measurements, instruments with double source synchronization are not needed. The PC based setup not only enables more complex measurements to be carried out, but the extra power of the PC allows sophisticated data collection and presentation. Unattended tests can be carried out when environmental test schedules demand multiple tests at various temperatures and component conditions.

Please refer to the Remote Operating Manual for a comprehensive description of the GPIB command set for the MSA. For a description of the generic GPIB system, please refer to the appropriate documentation supplied with the GPIB card.

1. CONVERSION LOSS MEASUREMENTS

Conversion loss is defined as the ratio of the power delivered to the IF load to the power available from the RF source. The available power from the source can be fixed by selecting a specific source power using the front panel data entry, or for greater accuracy, the power can be checked using a sensor or levelled using a detector. For the measurement of the IF power two measurement configurations are possible; firstly by using a detector of the scalar network analyzer system or secondly by using the narrow band detection capability of the spectrum analyzer known as the tuned input mode. The detection only setup permits a simple detector ratio measurement to be conducted albeit at two different frequency bands.

1.1 Conversion Loss Measurement Using the Scalar System

In this example we are testing an upconverting mixer which converts signals between 1 GHz and 5 GHz with an RF power of -10 dBm. The first task is to check the magnitude of the unwanted conversion products and LO leakage and see if they are likely to give rise to significant measurement error. The spectrum analyzer will be used to examine the spectrum at the IF port of the mixer. The required LO frequency is 6 GHz for a lower sideband conversion. First place the MSA into its predefined state. Connect the IF port of the mixer to the spectrum analyzer and the RF port of the mixer to the signal source output on the front panel of the MSA (Fig. 1).

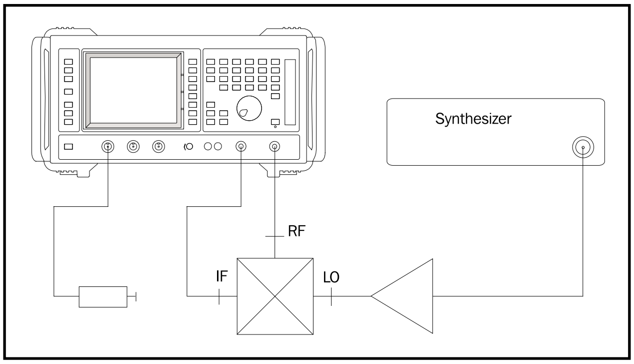


Fig. 1 Upconverter Test

Connect the local oscillator signal generator to the LO port of the mixer. Set the power level and frequency necessary for mixing. Amplification may be required. Then configure the MSA source. After the key presses with both LO and RF signals present at the appropriate power levels examine the spectra at the IF port. The marker facility is used to measure the relative magnitudes of the various signals.

[**PRESET**] [*Full*] to place the MSA into a known state.
[**SOURCE**] [*CW*] [*Set Frequency*] [1] [**G n**] [*Set Output Power*] [-10] [**ENTER**] to configure the RF source.
Configure the LO source.
[**MARKER**] [*Peak Search*] [*Delta Mkr*] [*Delta Mkr*] to check mixer signals.

From Fig. 2 it can be seen that the wanted conversion product is at least 23 dB above any unwanted product which suggests that a scalar measurement is perfectly adequate.

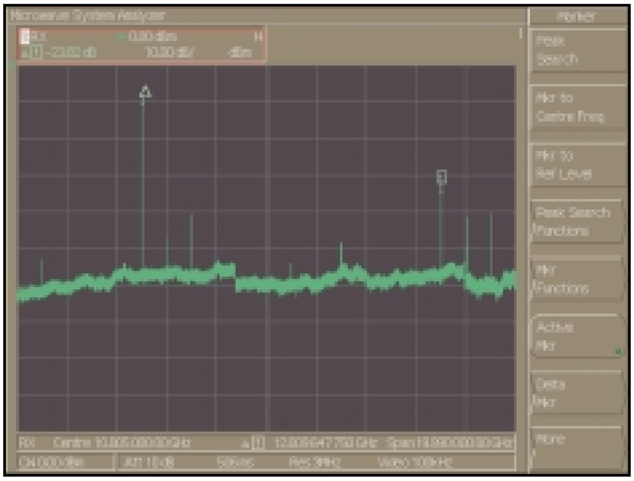


Fig. 2 Spectrum of IF signals

Now connect detector A to the IF port of the mixer (Fig. 1) in place of the connection to the spectrum analyzer. Switch to channel 2 which by default is a scalar test system and access the mixer measurement routine. Open the mixer test data entry form, define the mixer type as an up-converter using the lower sideband for conversion.

[**SWITCH CHANNEL**] [**SCALAR**] [*Conversion Measurements*] [*Mixer Meas Set-up*] [*Cntr/Span*]

Define the RF frequency, span and power level, the LO frequency. Use the up arrow and down arrow soft keys to navigate around the entries in the mixer setup table (Fig. 3). Not all parameters need to be defined, once the minimum set have been entered the missing parameters are automatically calculated.

Exit from the mixer setup:
[*Return to Conv Meas*] [*Return to Scalar*]

The next task is to calibrate the system. Having entered the mixer test mode the MSA is now aware that two possible frequency bands are available for calibration, either the RF or IF frequencies. With this measurement example as the detector is to be connected directly to the IF port of the mixer, no excess loss will need to be accounted for and a simple Source Frequency Range Through calibration is all that is necessary.

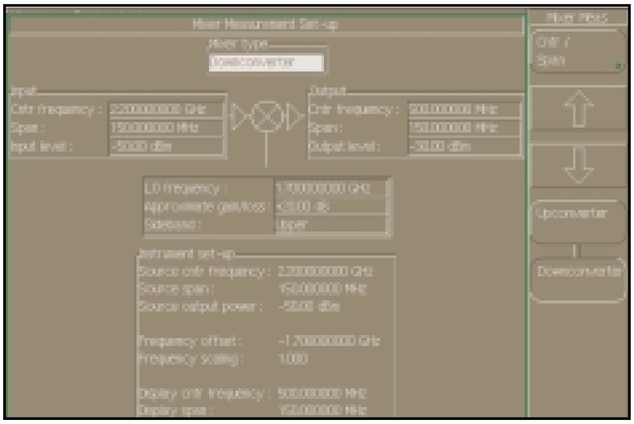


Fig. 3 Mixer Measurement Setup form.

To calibrate the system, attach the detector to the end of the cable used to connect the source to the RF port of the mixer.

[**CAL**] [*Through Cal*] [*Source Freq Range*] [*Continue*]

When the calibration process has finished connect up the system which is now ready to make the measurement.

In this mixer measurement example, we can see that the IF filter is slightly asymmetric in passband shape. Use the marker facilities to display details of the IF passband shape (Fig. 4).

[**MARKER**] [*Active Mkr to Maximum*] [*Mkr Functions*] [*Bandwidth*] [*Set n dB Value*] [3] [**ENTER**] [*Bandwidth Search*].

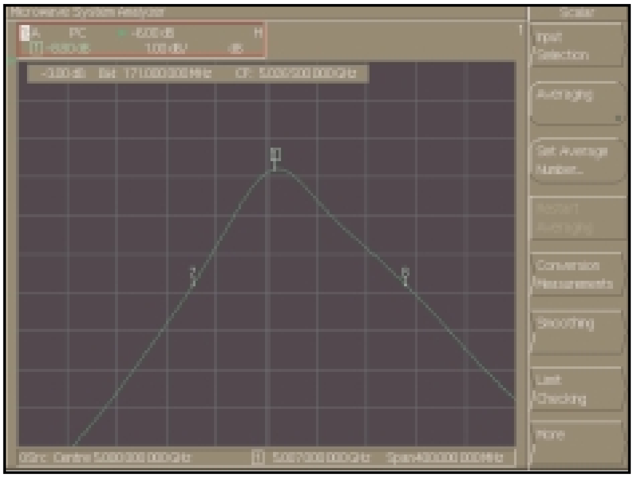


Fig. 4 Conversion Loss Measurement

To turn on the marker display to read the frequencies of markers 7 and 8 if these are required:

[**MARKER**] [*More*] [*Mkr Table*]

1.2 Conversion Loss Measurement Using the Spectrum Analyzer.

In the next measurement example, the mixer under test has no rejection of LO leakage and unwanted products. Again, an initial test to establish the ratio of wanted to unwanted signals is carried out. In this example we have an upconverting mixer with a RF frequency of 450 MHz at a power of -10 dBm. The LO frequency in this example is 6 GHz. Fig. 5 shows the IF spectrum of this example mixer test operating under these conditions.

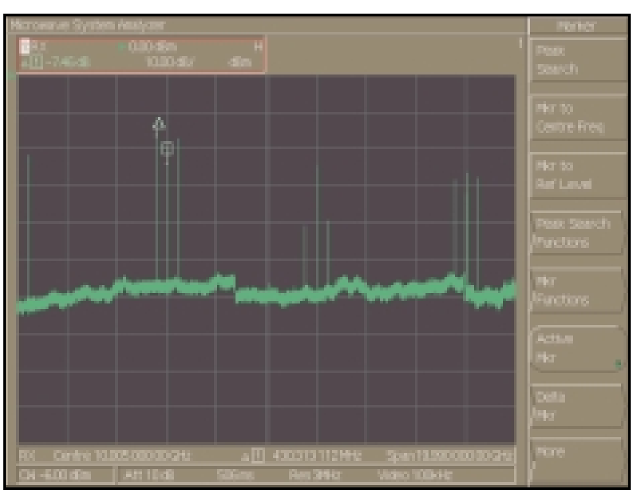


Fig. 5 IF Spectrum of mixer with no IF filtering.

It is clear that there are many unwanted signals which will give rise to scalar detector errors. Having used channel 1 as the spectrum analyzer for the initial test, channel 2 can be used as a scalar analyzer with a tuned detector. Again the mixer test data entry form will be used to define the mixer type as an up-converter using the lower sideband for conversion. The IF system will be selected for calibration. This selection is made because with this measurement the greatest error comes from the spectrum analyzer and the IF cable.

[**SWITCH CHANNEL**] [*Input Selection*] [*Tuned Input*] [*Tuned Input*] [*Return to Input Sel*] [*Return to Scalar*] [*Conversion measurements*] [*Mixer meas Set-up*] [*Cntr/Span*]

Using the up and down soft keys set the following parameters.

Mixer type: up-converter; Sideband: lower; Cntr Frequency: 1 GHz; Span: 50 MHz; LO Frequency: 6 GHz.

[*Return to Conv Meas*] [*Return to Scalar*] to exit the mixer test data entry.

The display will show the uncorrected conversion loss measurement. To calibrate the system

[**CAL**] [*Through Cal*] [*Display Freq Range*].
Connect the IF cable to the MSA signal output
[*Continue*] to start the calibration process.

Reconnect the mixer and the screen should now display a corrected tuned conversion loss measurement as shown in Fig. 6. Being wideband with no filtering at either the IF port or the RF port the mixer exhibits a very flat conversion loss over the bandwidth of the measurement.

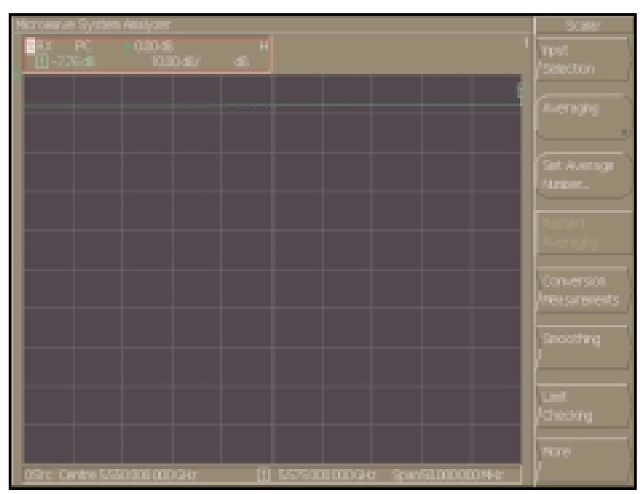


Fig. 6 Conversion Loss measurement using the tuned input scalar mode.

The MSA informs the user as to the type of scalar measurement carried out. The letters RX that appear in the top left corner of the screen indicate a tuned input measurement is being made. Plots stored to disk retain this indicator.

2. RF/IF Port Return Loss

For fundamental and harmonic mixers based on semiconductor diode technology the small signal RF and IF port return loss measurements need to be made with the appropriate LO drive present. With sampling mixers the diodes are only switched on for relatively short periods in relationship to the period of the RF or IF signals. This property of sampling mixers allows the tests to be carried out without LO drive. Active mixers often possess a degree of isolation between the mixing function and the port impedances. The design of each mixer needs to be considered carefully before embarking upon return loss measurements at the RF and IF ports.

Scalar return loss measurements can be made on diode mixers when low values of unwanted conversion components and LO power leakage are present. Two common devices used to measure return loss are return loss bridges and directional couplers. Return loss bridges that include an integrated detector are called autotesters.

2.1 RF Port Return Loss Measurement Using the Scalar System.

In this measurement example using an autotester we will be measuring the RF port return loss of a wideband mixer over a frequency range of 10 MHz to 5 GHz. First an assessment is made of the unwanted conversion products and LO leakage to see if they are likely to give rise to measurement error. The LO frequency and power are set to 6 GHz and 17 dBm respectively. The MSA key presses are not repeated here, as they are identical to the spectra tests demonstrated when conducting conversion loss measurements. Calibration of the autotester in this example is performed by using a short circuit calibration piece only. This type of calibration process provides a normalization correction only and attention to source match and directivity errors has to be made to maintain measurement accuracy.

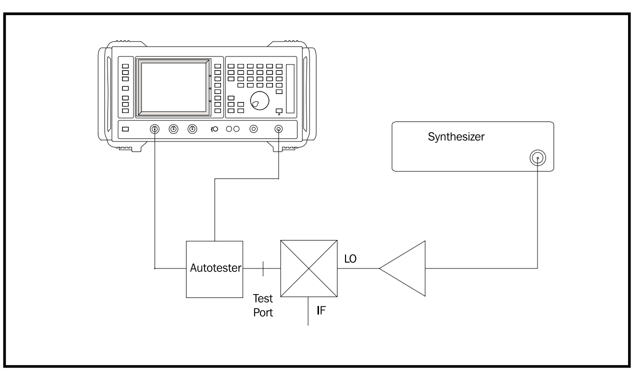


Fig. 7 Return Loss Measurements Using an Autotester.

Connect the autotester to the MSA using input A. To establish the dependence of mixer RF port return loss with varying LO power, two measurements will be made and the results displayed together.

The measurement procedure is as follows: set the instrument into a known state with channel 1 configured as a scalar with both measurements enabled. Then set both measurements of channel 1 to use the detector connected to input A and set up the measurement frequency definition. Lastly, define the scale of the two measurements and then calibrate the system by connecting a reference short or open circuit termination to the test port of the autotester.

[**PRESET**] [*Full*] [**SCALAR**] [*Yes*] [**DISPLAY**] [*Channel 1 Meas 2* ●] to place the MSA into a known state and enable both measurements.
[**SCALAR**] [*Input Selection*] [A] [**SELECT MEAS**] [A] to assign detector to input A.
[**SOURCE**] [*Set Start Frequency*] [10] [**M m**] [**ENTER**] [*Set Stop Frequency*] [5] [**G n**] [**ENTER**] to define the frequency range.
[**SCALE/FORMAT**] [*Set Scale..*] [2] [**ENTER**] [**SELECT MEAS**] [*Set Scale..*] [2] [**ENTER**] defines scales.

With an open or short circuit connected

[**CAL**] [*Short OR Open Cal*] [*Continue*] [**SELECT MEAS**] [*Short OR Open Cal*] [*Continue*].

With both measurements calibrated connect the mixer under test to the autotester and apply the local oscillator power. Set the LO power to the desired maximum, in this example it is 17 dBm. Make the first return loss measurement.

[**DISPLAY**] [*Hold* ●] [**SELECT MEAS**] to hold the measurement and switch the active display to the other measurement. Now vary the LO power to the minimum value. Fig. 8 shows the results of this measurement.

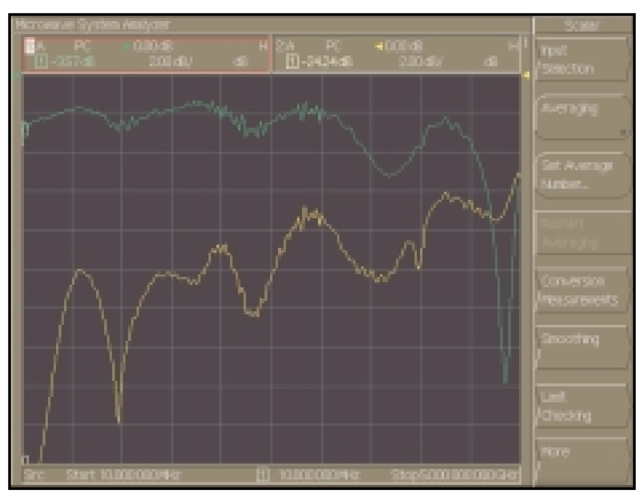


Fig. 8 Return Loss Measurements at 2 LO Powers

3. LO Port Return Loss

Unlike the RF and IF port return loss measurements the LO port needs to be measured at the operating power of the LO. The signal loss in the autotester and bridges can be as high as 7 dB, which is unacceptable when a high level mixer is being tested. Because of this restriction directional couplers are used in place of the autotester or bridge. For medium and high power tests it is likely that the LO drive power requirement exceeds the capabilities of the 6840 and therefore some amplification may be necessary. The inclusion of the amplification can worsen the source match which in turn will affect the accuracy of the measurement. Some accuracy can be recovered by using two directional couplers, one to monitor the incident power and one to monitor the reflected power. Another possible measurement problem may arise from the harmonic energy generated by the mixer causing detector error. If this is the case, then the tuned receiver mode can be employed for the detection of the reflected signal and the detector used with the C input to measure the incident signal. In each case the ratio of reflected to incident power (proportional to the return loss) can be displayed, and the test power can be varied allowing power-independent testing to be carried out.

3.1 LO Port return loss measurement using the scalar system.

In this example, it is assumed that tests have been carried out to assess the degree of harmonic content of the reflected signal. It has been found to be low enough for a detector measurement to be made. The MSA is driving a microwave power amplifier with 12 dB of gain to drive the mixer LO port at 17 dBm. Connect the test system as shown in Fig. 9 but without the mixer.

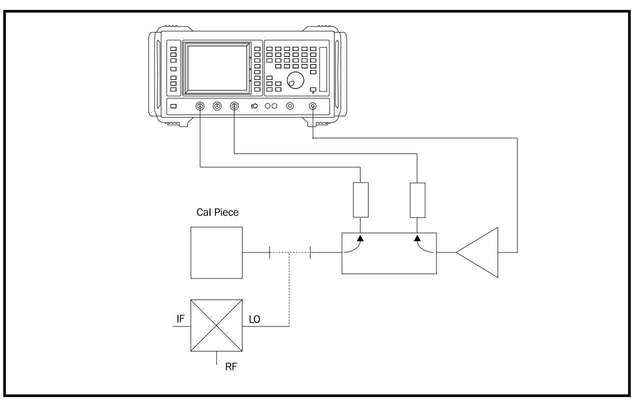


Fig. 9 LO Port Return Loss

Configure the MSA as a scalar network analyzer with two measurements enabled. Next, set up the source frequency and power range and then set up the detection system with both measurements on channel 1 as the ratio of the detectors at inputs A and C. As we are going to make return loss measurements at two power levels using the same display it is necessary to set up the same reference levels and scales. The system is then calibrated for both measurements.

[**PRESET**] [*Full*] [**SCALAR**] [*Yes*] [**DISPLAY**] [*Channel 1 Meas 2* ●] to place the MSA into a known state and enable both measurements.
[**SOURCE**] [*Set Start Frequency*] [8.2] [**G n**] [*Set Stop Frequency*] [9.2] [**G n**] [*Set Output Power*] [5] [**ENTER**] to define frequency and power conditions.
[**SCALAR**] [*Input Selection*] [*A/C*].
[**SCALE/FORMAT**] [*Set Scale..*] [2] [**ENTER**] [**SELECT MEAS**] [*Set Scale..*] [2] [**ENTER**].
Connect a short circuit or open circuit calibration piece.
[**CAL**] [*Short Or Open Cal*] [*Continue*] Wait for calibration to complete then
[**SELECT MEAS**] [*Short Or Open Cal*] [*Continue*] Both measurements now share the same scale and calibration.

Disconnect the calibration piece and the connect the mixer under test.

[**SOURCE**] [*Set Output Power*] and set to the minimum required mixer drive power (remember the level shift due to the amplifier gain). To hold this measurement in memory: [**DISPLAY**] [*Hold* ●].

To make the other measurement active:
[**SELECT MEAS**] then vary the LO power as before. To hold this measurement in memory [**DISPLAY**] [*Hold* ●]. The results of these measurements are shown in Fig. 10.

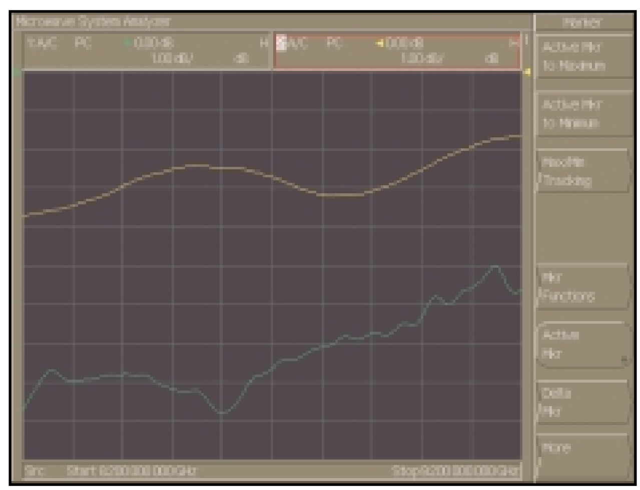


Fig. 10 LO Port Return Loss Measured at Two Power Levels.

4. Two Tone Distortion

The two tone third order intercept point (two tone IP3) of a non-linear device is used as a figure of merit to define the degree of third order distortion when only two tones are present at its input. To measure the two tone IP3 of a mixer three signal sources are needed, one for the LO port and the other two for the RF port. The two RF signals can be provided either by combining the outputs from two microwave sources or by using a multi-source instrument. If the two tone measurements are to be made below 2.4 GHz then the IFR Ltd 2026 Multi Source Generator which includes three signal sources makes an able companion to the MSA.

In this measurement example an up-converting mixer is being tested. The mixer converts signals from 1 GHz to 5 GHz with a 6 GHz LO frequency. The first task is to ensure that the residual test system distortion is well below that of the mixer under test.

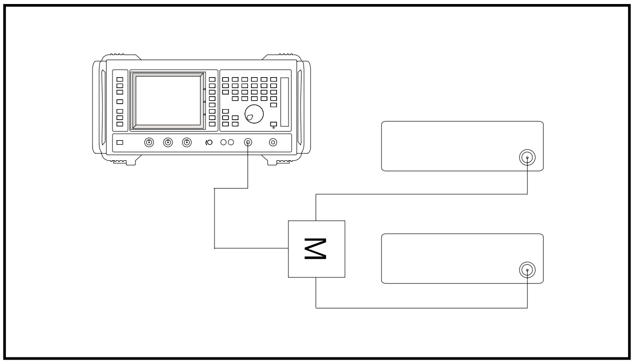


Fig. 11 Measurement of system two tone distortion

Set the MSA into the spectrum analyzer mode. Connect the signal sources along with attenuation or isolation components if needed as shown in Fig. 11. Set the frequency and power level of the sources. Set the centre frequency and span of the spectrum analyzer and adjust the resolution bandwidth to 10 kHz.

[**PRESET**] [*Full*] [*Cntr/Span* ●] [*Set Cntr Frequency*] [1] [**G n**] [*Set Span..*] [2] [**M u**] to set up the spectrum analyzer.
[*More*] [*Set Res BW..*] and use the down arrow to set the resolution BW to 10 kHz.
[**MARKER**] [*Peak Search Functions*] [*Identify Peaks*] which will display up to 8 peaks.
To remove the unwanted markers:
[*Return to Marker*] [*More*] [*Set-up Mkrs*] and use the up and down arrows with [*Marker On*] to toggle the markers from On to Off.

We can see from Fig. 12 that the system at the RF frequency provides an adequate residual carrier to distortion difference of 62.3 dBc at a power level of -6.6 dBm. This corresponds to a system two tone IP3 of 24.5 dBm. This has been calculated as follows:

IP3 = dBc/2 + Pin.

$$24.5\ \text{dBm} = \frac{(68.9 - 6.6)\ \text{dBc}}{2} - 6.6$$

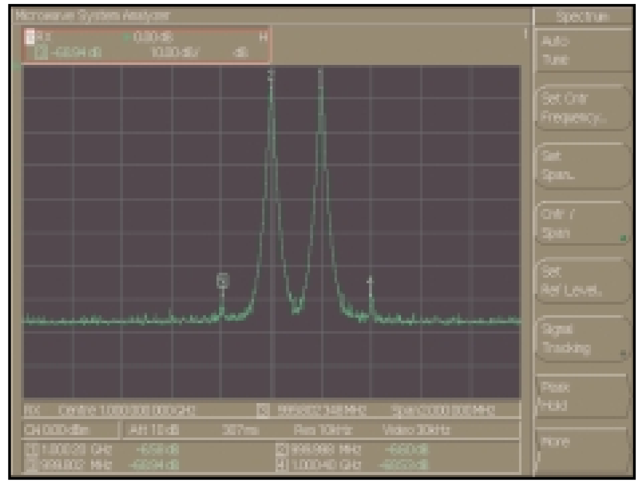


Fig. 12 Residual third order distortion of the test system.

Having checked the test system we are now ready to connect the mixer under test (Fig. 13).

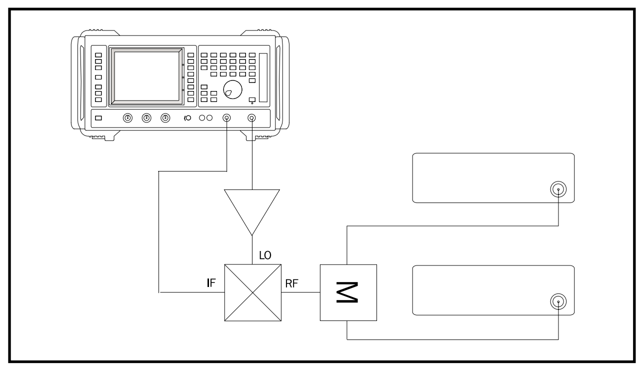


Fig. 13 Two Tone Measurement of Mixer.

The source of the MSA is used to provide the LO drive via a microwave amplifier.

[**SOURCE**] [*Set Output Power*] [10] [**ENTER**] [*Set Frequency*] [6] [**G n**] [**SOURCE ON/OFF**] to set frequency and power and turn on the source.

In this example the LO port amplifier has a gain of 12 dB.
Now set the centre frequency of the spectrum analyzer to 5 GHz but leave all other setting in their current state.

[**SPECTRUM**] [*Set Cntr Frequency*] [5] [**G n**].

With the mixer in place we now see that the side band levels have increased by 8.6 dB (Fig. 14). The IP3 referred to the input of the mixer under test is

(69.1 -15.5) / 2 + (-6.6) = 20.2 dBm

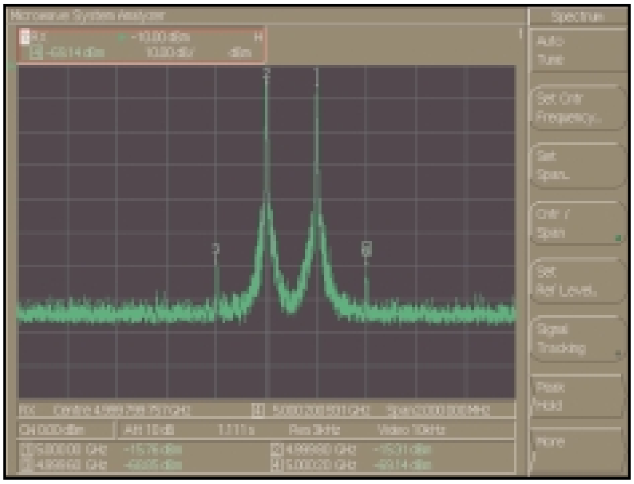


Fig. 14 Measurement of the Mixer

5. LO AM Noise Suppression

For some systems the ability of the mixer to suppress LO AM noise can be critical. If noise-like signals originating from digital and analog sources modulate the LO directly or through the DC rails of any LO power amplification, it is possible for AM noise to be generated. With the AM suppression test, the mixer LO port is driven with a known level of AM. The AM depth is measured at the LO port and at the IF port, the difference being the degree of suppression, commonly known as the AM suppression ratio.

In this measurement example the MSA is used to provide the clean unmodulated RF signal and to measure the IF spectrum. The LO drive is provided by a signal generator with an external amplifier and amplitude modulator. The spectrum analyzer's FM demodulation capability is used to ensure that no angle modulation is present on the test signal. Care has to be taken to ensure that no angle modulation is also present as this will cause measurement errors. For example, if the power amplifier suffers from AM to PM conversion then the AM spectrum will be corrupted.

First place the MSA into its predefined state and set the centre reference level, centre frequency and span. Connect the modulated LO source to the spectrum analyzer and set up the AM modulation. Having checked that no residual PM/FM is present connect the mixer into the system to make the measurement of AM at the IF port.

[**PRESET**] [*Full*] [*Set Cntr Frequency*] [5] [**G n**] [*Set Span..*] [10] [**M u**] [**SCALE/FORMAT**] [*Set Ref Level*] [20] [**ENTER**] to set up the spectrum analyzer.

Connect the amplifier and modulator to the spectrum analyzer input. Set the frequency of the LO source to 5.400 GHz and the power 5 dBm. In this example we have an amplifier with 12 dB gain and the mixer port for optimum performance requires a drive level of 17 dBm. Turn on the LO source and adjust the depth of amplitude modulation to 30 dBc (Fig 15).

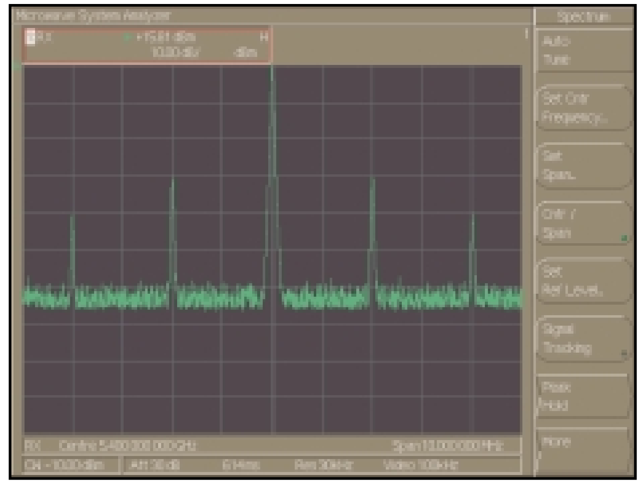


Fig. 15 Reference AM on Local Oscillator

To finely tune the spectrum analyzer for the FM demodulation check:

[**SPECTRUM**] [*Auto Tune*] [**MARKER**] [*Peak Search*] [*Mkr to Centre Freq*] to place the marker at the centre of the LO signal ready for a PM/FM check.
[**SPECTRUM**] [*More*] [*Demodulation*] [*View Waveform*] to display the residual PM (Fig. 16).

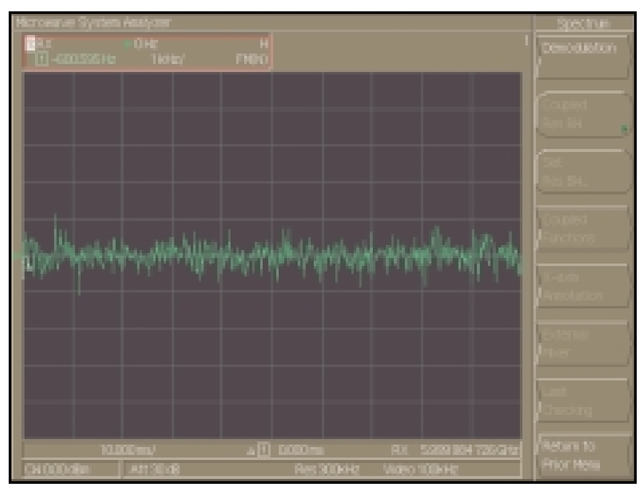


Fig. 16 Residual PM on AM test signal

With this test signal some PM noise is present but no coherent signals related to the amplitude modulation process can be seen.

[*View Waveform*] to return to the spectrum analyzer display. Connect up the test system with the mixer (Fig. 17), connecting the IF port of the mixer to the spectrum analyzer.

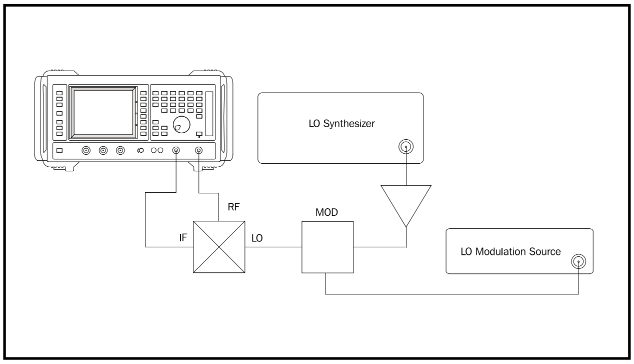


Fig. 17 Measurement of LO AM suppression

With the mixer connected and properly driven retune the spectrum analyzer to the IF, in this example 400 MHz. Set up the source to provide the reference RF signal.

[**SPECTRUM**] [*Set Cntr Frequency..*] [400] [**M u**].
[**SOURCE**] [*Set Output Power..*] [10] [**ENTER**] [*Set Frequency..*] [6] [**G n**]
[**SOURCE ON/OFF**].

Use the marker function to measure the relative magnitudes of the fundamental signal and the reduced AM sidebands.

In this example (Fig. 18) the AM sidebands have been reduced from -30 dBC to -49 dBC, therefore the AM suppression is 19 dB.

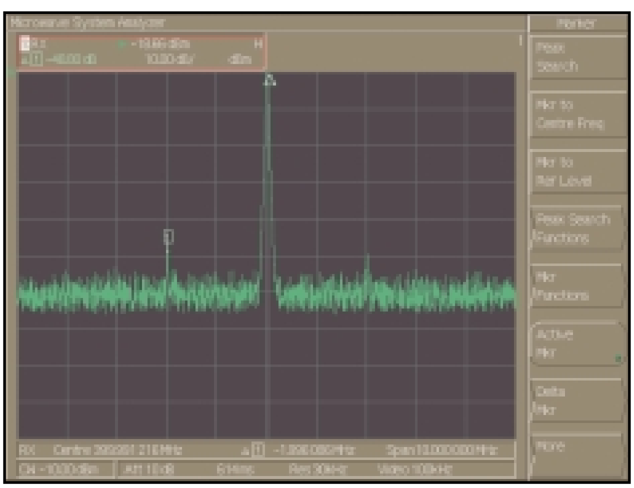


Fig. 18 Measurement of LO AM suppression.

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