Errata

Document Title: Microwave Component Measurements Mixer Measurements Using the Scalar Network Analyzer (AN 345-2)

Part Number: 5954-8369

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HP References in this Application Note

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Application Note 345-2

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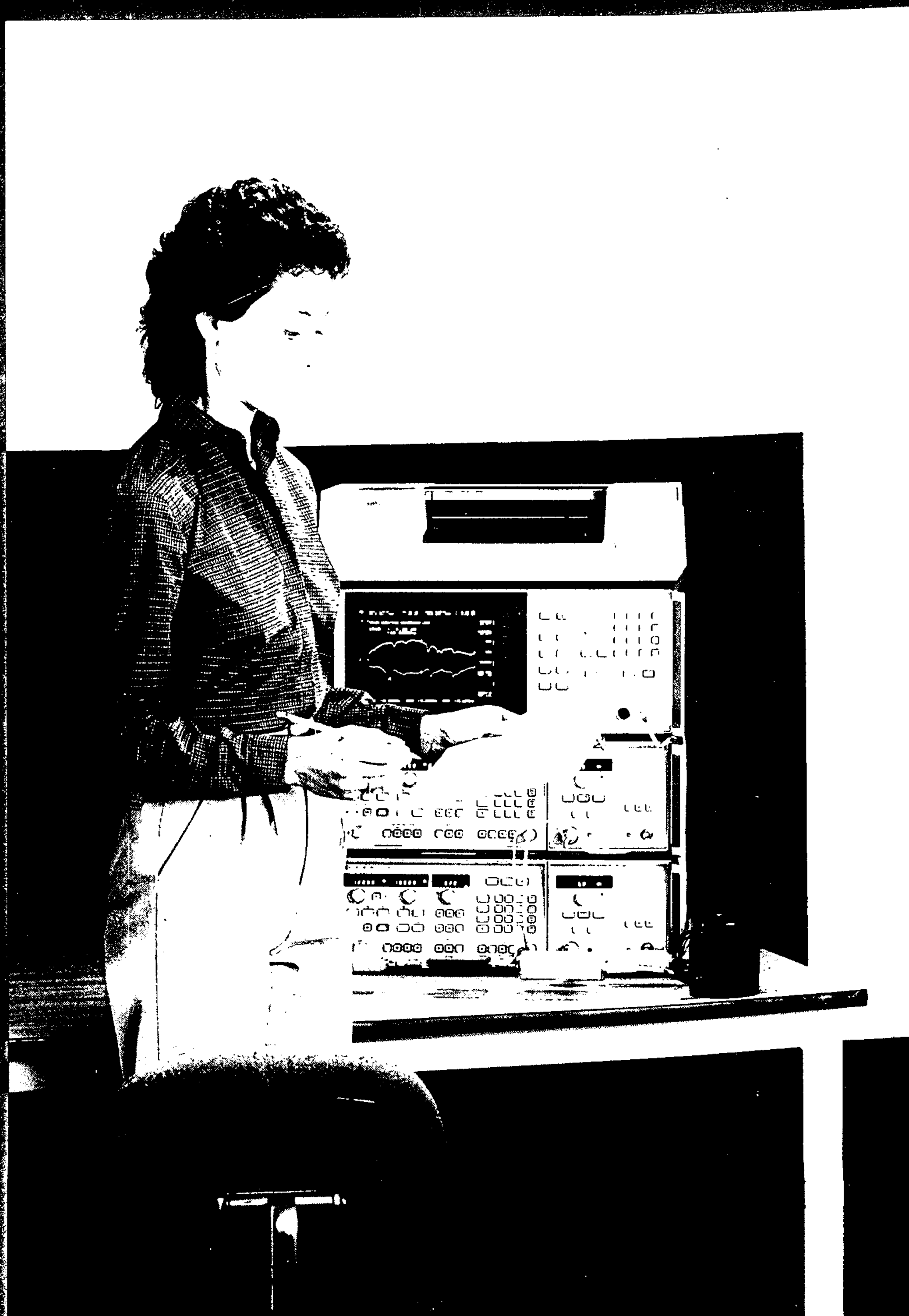
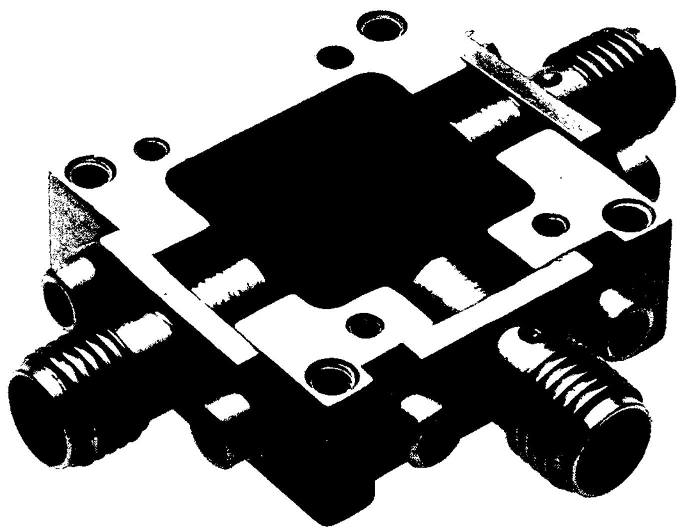
Microwave Component Measurements
Mixer measurements using the scalar network analyzer



Measuring a mixer's performance is a difficult task considering the specifications for comprehensive testing of mixers and the measurement setup required. While the use of a vector network analyzer may assure that the design engineer has the pertinent and accurate facts, this very thorough approach may be too expensive or complicated for production testing and preliminary design efforts.

The scalar network analyzer can be a powerful tool to assist in the design, production and final testing of microwave components such as mixers. The scalar network analyzer measures the magnitude of signals that are transmitted and reflected by the device under test (hence the term "scalar"). Measurements of group delay, phase shift, and electrical length require the use of a vector network analyzer, which can measure the magnitude and phase of the microwave signals transmitted and reflected by the device under test, and also measure device performance in the time domain.

Besides presenting and analyzing the measurement procedures, this note will focus on the hardware required for making mixer measurements using the scalar network analyzer. The scalar analyzer, sources, and accessories needed to make the typical mixer tests in the 50-ohm broadband environment will be described.



Mixer Term Definitions

Conversion Loss

Conversion loss is the measure of efficiency of the mixer. This measure is usually expressed in dB as the ratio of sideband IF power to RF signal power (Figure 1a). The mixer converts the incoming signal, RF, to a replica, IF, displaced in frequency by the local oscillator, LO. This frequency translation exacts a penalty that is characterized by a loss in signal amplitude and the generation of additional sidebands. For a given translation, two equal output signals are usually of interest, a lower sideband and an upper sideband (Figure 1b). Typically, the lower sideband is filtered and measured.

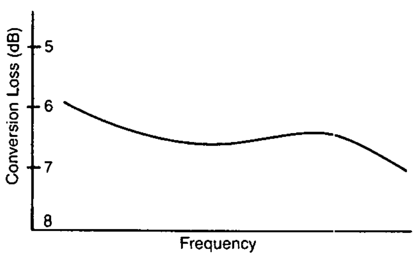


Figure 1a. *Plot of mixer conversion loss, i.e. IF power relative to RF input power as a function of frequency.*

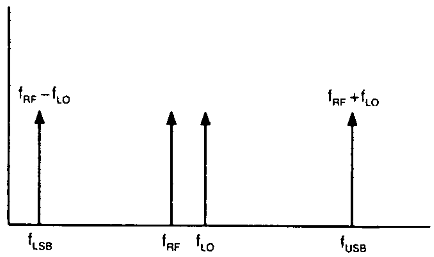


Figure 1b. *Spectrum of RF, LO and IF signals present in mixer measurements.*

Conversion Compression

Conversion compression is a measure of the maximum RF input signal level for which the mixer will provide linear operation. The conversion loss is the ratio of the IF output level to the RF input level and this value remains constant over a specified input level range (Figure 1c). When the input level exceeds a certain maximum, usually when the RF signal level is within 10 dB of the LO drive level, the constant ratio between IF and RF will begin to change. The point at which the constant ratio has changed 1 dB is described as the 1-dB compression point. This provides information about the mixer's two-tone performance and its linear operating range (Figure 1d).

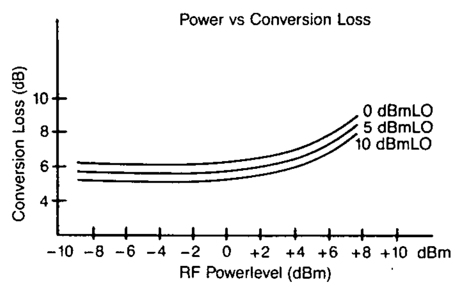


Figure 1c. *Plot of a typical mixer's conversion loss as a function of RF input power level. The different traces show that conversion loss decreases when the LO signal power level is increased.*

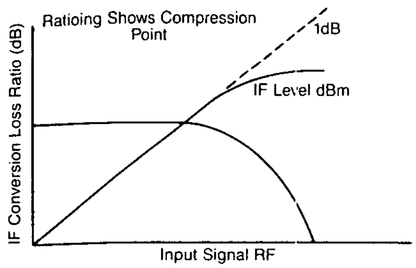


Figure 1d. Plot of conversion loss and IF output power as a function of RF input power level as normally shown on the scalar analyzer. Note that the IF output power increases linearly with the increasing RF signal, until mixer compression begins and the mixer saturates.

Isolation

Isolation is a measure of the circuit balance in the mixer. High isolation means that the amount of leakage or feedthrough between the mixer's ports is very small. The LO to RF isolation and the LO to IF isolation are typically measured with the third port terminated in 50 ohms. Measurement of the RF or LO leakage to any other port may be required when all signals are being applied to the mixer and can be measured with the appropriate filtering to separate the IF from the input signals (Figure 1e).

Return Loss/SWR

Return Loss/SWR measurements are more complicated to make since the device is a three-port. The operating conditions the mixer will encounter during use should be the test levels at which the SWR measurements are made. This means that to make RF port SWR measurements, the LO must be connected and at the desired operating level, and the IF port must be terminated with 50 ohms. The LO feedthrough could affect the accuracy of the measurement at the RF port unless some precautions are taken. Broadband mixers may show greater errors. At increasingly higher frequencies, the LO to RF and LO to IF isolation tends to drop.

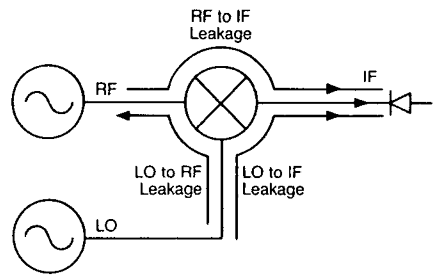


Figure 1e. Diagram showing the signal flow in a mixer. Note that RF and LO feedthrough signals may appear at the mixer IF output, together with the desired IF signal.

Distortion Tests

Many of the two-tone and distortion tests are best done with a spectrum analyzer and will not be discussed in this note except for compression measurements. However, a thorough treatment of these tests can be found in HP Application Note 150-11 in the Spectrum Analyzer Series.

Equipment Considerations

The measurements to be described are essentially generic in that the principles will apply with almost any scalar network analyzer and associated equipment. However, to permit the descriptions to be as explicit as possible, specific equipment will be used to illustrate the procedures. The basic equipment configuration for the measurements in this note is shown in Figure 2.

The setup consists of:

- 1 each HP 8757A Option 001 scalar network analyzer[1]
- 2 each HP 8350B sweep oscillators
- 2 each HP 83592B sweep oscillator RF plug-ins
- 1 each HP 8349B microwave amplifier (optional)
- 1 each HP 85027B directional bridge
- 3 each HP 11664E detectors[2]
- 2 each HP 11667B power splitters[2]
- 1 each HP 85023B verification kit
- 1 each HP 85022A system cable kit
- 1 each HP 10501A BNC(m) cable
- 1 each RF cable (for LO drive signal)
- 1 each HP Part Number 08350-60050 sweep control cable[3]
- 1 each HP 7440A ColorPro plotter (optional)
- 1 each HP 2225A ThinkJet printer (optional)

The process by which the equipment configuration of Figure 2 was derived included the considerations of cost, maximum performance for the investment, and the ability to accurately measure typical mixer specifications. The frequency range of the RF and LO and the output power of the sources were chosen for proper characterization and to provide the widest bandwidth solution. Any of the HP 8350B RF plug-ins can be used in specific frequency applications. The HP 8620C RF plug-ins and the HP 11869A adapter in the HP 8350B mainframe can also be used except for the RF power sweep portions.

The HP 8757A is a powerful, easy-to-use scalar analyzer. It provides three detector inputs (a fourth input is optional), and four independent display channels. With the HP 11664E detectors, the HP 8757A offers −60 dBm sensitivity at sweep speeds as fast as 50 ms. The HP 8757A offers a choice of detection modes. In AC mode, the detectors detect the envelope of signals modulated by a 27.778 kHz square wave. This modulation is provided internally by the HP 8350B sweep oscillator.

[1] *Option 001 adds a fourth detector input (input C), which is useful for measurements referenced to the LO signal power level.*

[2] *If measurements relative to the LO are not required, a standard HP 8757A is sufficient, and two detectors and one power splitter will suffice.*

[3] *This part can be purchased or constructed (see HP Application Note 312-1, "Configuration of a Two-tone Sweeping Generator," HP literature no. 5952-9316).*

Spurious unmodulated signals and broadband noise can occur in mixer measurements and may or may not affect the detected AC signal, depending on levels. In the broadband mixer measurements described, the best performance and accuracy is obtained when the level of the IF is kept at −20 dBm or less. This keeps the diode in square law region for best rejection of harmonically related and spurious signals.

DC detection requires no modulation and the detector responds to all signals in its frequency range. With mixer testing, there is usually a high level LO that may feed through to the IF. Unless the IF is adequately filtered, the accuracy of the measurement is affected. AC detection mode is chosen throughout this note to give a more accurate representation of mixer performance with a minimum of external precautions to prevent the problems inherent in DC detection for this kind of testing. High levels of non-desired signals can cause problems in the AC detection mode if some care is not taken. Appendix 2 discusses this further. Two types of conversion loss measurements, two power sweep tests for mixer compression, and return loss measurements can be configured with the hardware described.

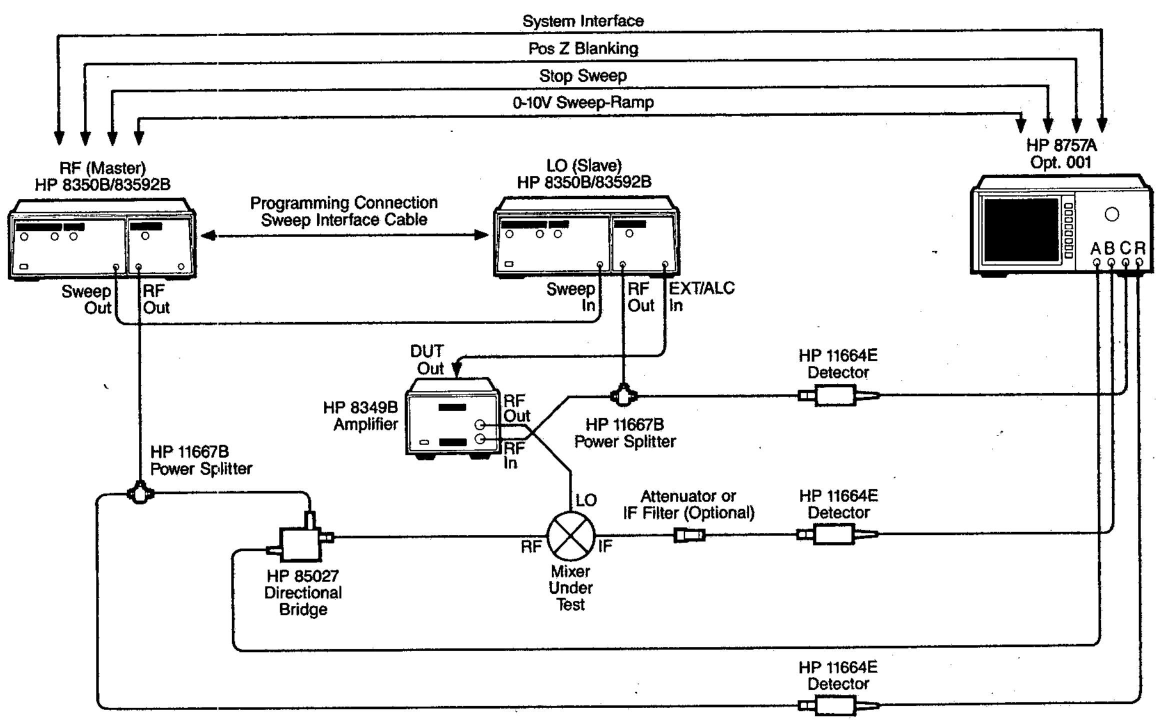


Figure 2. Setup diagram for measurements of mixer conversion loss, conversion compression, and RF input return loss. The amplifier is optional, and can be used to provide LO drive levels of up to +20 dBm.

Swept Frequency Measurements

Fixed IF Measurements

In the case where the mixer produces a fixed IF, the RF and LO are swept across a specified frequency range with a specific frequency difference. Two HP 8350B sweep oscillators can be configured as a master-slave pair as described in Application Note 312-1 to produce two tracking signals. The IF can be selected and the start and stop frequencies set to measure a mixer's conversion loss and compression level. The HP 83592B RF plug-in has a leveled power out of +13 dBm to 18.6 GHz. These two sources will provide the required power for the LO and RF for most mixers. In cases requiring more RF or LO power, the HP 8349B microwave amplifier can be used to get typically +20 dBm to 20 GHz. Figure 2 shows the equipment and connections to make these tests.

The two sweep oscillators track each other by connecting a BNC cable to the sweep in/out connectors and then putting the "slave" sweep oscillator in the external sweep mode. Pressing **[SHIFT]** **[VERNIER]** on the slave sweep oscillator, followed by a frequency, enters the frequency offset.

Measurement Sequence

Fixed IF Conversion Loss and RF Input Return Loss

Described below is the keystroke sequence required to measure mixer conversion loss at a fixed IF and the RF input return loss. The keystrokes assume the instruments are configured as shown in Figure 2. If return loss measurements are not required, the directional bridge is not needed in the setup. The third detector (to analyzer input C) is optional and is required only if the optimum LO drive level for the mixer is also to be measured.

To obtain the fixed IF frequency, the two sources will be set to track each other, with a constant difference in frequency.

1. Connect the instruments as shown in Figure 2. Press **[PRESET]*** on the HP 8757A, and on the LO (slave) sweep oscillator. This brings the analyzer and sweepers to a known state. Ignore the E003 message indicated on the start frequency display of the LO sweeper. Set the slave source to external sweep mode so the master's sweep voltage controls the slave's sweep by pressing the [EXT] key on the slave source.

   The source control cable must be connected between the programming connectors on the back panels of the two sources. A BNC cable connects the SWEEP IN/OUT connector of the master source to the SWEEP IN/OUT connector of the slave source.

2. Set the desired start and stop frequencies of the RF (master) sweep oscillator using the **[START]** and **[STOP]** keys, followed by the appropriate frequencies. Terminate the entries with the **[GHz]** or **[MHz]** keys. Set the desired power level using **[POWER LEVEL]**, followed by the appropriate number. Terminate the entry with the **[dBm]** key.

3. Set the start and stop frequencies and the power level of the slave sweep oscillator to the same frequencies as those of the master using the procedure described in step 2.

   If the HP 8349B amplifier is being used as an external amplifier, be sure a BNC cable is connected between the EXT ALC input and the DET OUT connector on the back of the amplifier. Set the slave sweep oscillator's ALC mode to external leveling by pressing [EXT].

4. On the slave sweep oscillator, press **[SHIFT]** **[VERNIER]** and enter the desired frequency offset. The slave sweep oscillator will now track the master with the offset in frequency just entered. Save this state in Register 1 by pressing **[SAVEn]** **[1]**.

If measurements of the return loss of the mixer's RF input are required, perform step 5, otherwise, press **[CHANNEL 1]** [CHAN 1 OFF] and proceed directly to step 6.

5. To measure the mixer's RF input return loss, press **[CHANNEL 1]** **[MEAS]** and select [A/R]. Then select **[CAL]** [SHORT/OPEN]. This initiates the short/open calibration procedure. As prompted, connect a short to the test port of the bridge and press [STORE SHORT]. Then connect an open and press [STORE OPEN].

   Now the average of the short and open circuit responses has been stored into the memory of the analyzer. Press **[DISPLAY]** [MEAS - MEM] to place the analyzer in normalized mode.

* *In this note, the HP 8757A front panel keys such as* **[PRESET]** *appear in bold type, as opposed to the "soft keys" labeled on the CRT, which appear in regular type (e.g. [CHAN 1 OFF]).*

This value can range from zero to the bandwidth limit of the plug-in. The only constraint is the tuning non-linearity of the plug-in, which for the HP 83592B is ±10 MHz full band (see HP 8350B or the RF plug-in operating and service manual for specific band specifications). Sweep activity is coordinated with a control cable connected to the HP 8350B rear panel AUX programming connector. The offset accuracy of the system is determined by the combined frequency accuracy and sweep linearity of the two sweep oscillators. This offset accuracy can be improved by following the procedure outlined in HP Product Note 8350A-2, "Improved Frequency Accuracy by Calibrating HP 83590 Series RF Plug-ins to HP 8350A Sweep Oscillator Mainframe", HP literature no. 5952-9330.

There are some considerations required when making this test to lower the potential for errors. The first problem when making frequency translation measurements is calibration. Since the RF and LO frequencies compared to the IF are usually quite far apart in mixer measurements, the calibration process is not straightforward. The normalization capabilities of a scalar analyzer are limited to the given sweep band and attempts to correct for an offset frequency response

6. To measure the fixed IF conversion loss, press **[CHANNEL 2] [MEAS]** and select [B/R]. The annotation on the HP 8757A display is the RF frequency range for this measurement. Store the instrument state in Register 1 by pressing **[SAVE]** [1].

7. Connect the B detector and an attenuator directly to the test port of the directional bridge (or the power splitter output arm if the bridge is not being used). The attenuator is recommended to keep signals incident on the detector below −20 dBm to minimize the effect of IF signal harmonics.

   Press **[CAL]** and select [THRU]. Be sure the THRU connection is made and press [STORE THRU] to place the calibration into the analyzer's memory, so that the RF to IF conversion loss measurement is made relative to the RF signal which will be incident on the mixer. Now press **[DISPLAY]** [MEAS-MEM] to view the normalized trace (B/R − M). The result should be a flat trace.

8. Connect the mixer's RF input port to the test port and the mixer's LO input port to the LO (slave sweep oscillator) output. Connect the B detector and the attenuator to the mixer's IF output port.

   Press **[SCALE]** [AUTOSCALE] to center the trace on the analyzer screen. The resulting trace is now the conversion loss of the mixer with a fixed IF and the RF and LO sweeping in frequency. The HP 8757A trace cursor can be used to measure the mixer's conversion loss at frequencies of interest. The frequency annotation indicates the RF start and stop frequencies, not the IF frequency.

9. If step 5 was performed to calibrate for the return loss measurement, the return loss of the mixer RF input can be viewed at this time by pressing **[CHANNEL 1]**, **[SCALE]** [AUTOSCALE].

10. The setups can be recalled quickly now if there are any problems by simply recalling register 1 on the HP 8757A by pressing **[RECALL]** [1] and recalling register 1 of the slave sweep oscillator by pressing **[RECALLn]** [1]. The HP 8757A communicates with the master sweep oscillator over the HP 8757A System Interface and can recall the configuration of the master sweep oscillator automatically.

Two common connection errors are: 1) not remembering to put the slave into EXT SWEEP mode and 2) forgetting to install the source control cable. By using the save/recall registers, and checking the connections, these problems will be minimized.

The power level at the detector should be −20 dBm or less. The typical mixer conversion loss is approximately 5 to 7 dB and the loss of the power splitter and a 10 dB attenuator are approximately 17 dB. This setup depends on the B detector's flatness across the IF to RF frequency band to provide an accurate representation of the mixer conversion loss. Normalization of the frequency response alone does not account for all the errors, since the effect of harmonics and LO feedthrough cannot be compensated for.

For the most accurate measurements, an estimate of the LO feedthrough signal's amplitude at the input to the B detector and the amplitude of IF harmonics should be made using a spectrum analyzer. Appendix 2 discusses the effect of harmonics in detail.

to the current sweep are difficult. An attempt to handle the calibration would require a computer to store the RF, LO, and IF frequency responses, sum these responses with the current trace data algebraically, and then display the corrected response. The general solution is to use detectors with the flattest frequency response across the RF, LO and IF frequency ranges. Detectors usually have an offset that can be removed with the scalar analyzer by using the detector offset feature in the CALIBRATION menu. The HP 11644E has the best flatness, ±0.5 dB to 18.6 GHz, and this approach represents a good compromise. The effects of detector flatness on mixer measurements are discussed further in Appendix 1.

The other possible error is a function of the mixer test. The detectors are peak detectors and will respond to any signals in the detection bandwidth. The desired signal, IF, is modulated by 27.778 kHz. Although the LO is at a high level and attenuated by the mixer (the LO to IF isolation), it will also be detected. The effect of this LO leakage term is dependent on its level relative to the IF. If the level is −20 dBc or more, its effect is to add a nominal uncertainty of ±0.1 dB. At levels greater than −20 dBc and IF test levels greater than −20 dBm at the detector, the measurement uncertainty becomes larger. These effects are discussed further in Appendix 2.

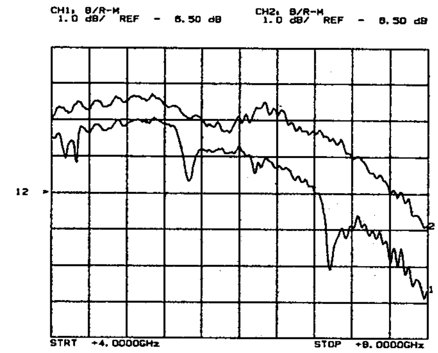


Figure 3. Plot of mixer conversion loss (fixed IF) measured with and without a filter at the mixer's IF output (traces 1 and 2, respectively). Note that filter insertion loss increases the apparent mixer conversion loss.

An attenuator inserted between the IF output of the mixer under test in the detector input is the best way to keep the incident signals at levels below −20 dBm. This technique also improves the effective match of the IF detector. A low pass filter can also be used to remove the LO leakage signal and may be required in some cases, but the filter complicates the detector flatness issue and either introduces offset errors or requires a computerized calibration process and limits the test set bandwidth. Shown in Figure 3 is a measurement of mixer conversion loss, made with and without a low-pass filter between the IF output and detector. Note that the filter's insertion loss increases the apparent conversion loss of the mixer under test. The HP 8757A Detector Offset function can be used to compensate for the insertion loss of the filter.

The typical offset frequency accuracy of the system in Figure 2 is ±12 MHz. Within a given frequency band of the sweeper, the offset frequency accuracy improves typically to ±5 MHz. The larger IF frequency offset error occurs at the sweeper band switch points when one sweeper is on one band and the second sweeper is on the next band up or down. The larger the IF frequency offset selected, the more time it takes for the two sweep oscillators to get back onto the same band. The offset frequency error is present through each band transition occurring between the start and stop frequencies chosen (Figure 4).

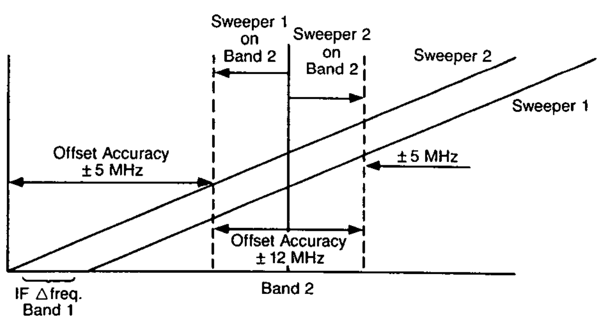


Figure 4. Representation of the frequency errors induced when the two sweep oscillators are on the same frequency band (±5 MHz), and when the sweep oscillators are on different bands (±12 MHz).

Swept IF Measurements

A second mixer measurement is a swept IF test. The two sweep oscillators are set up as shown in Figure 2. The difference from the fixed IF test is that the slave (LO) sweep oscillator is set to a fixed LO frequency and the master (RF) sweep oscillator is swept across the specified RF bandwidth. The resulting IF sweep provides conversion loss, the IF bandwidth, passband ripple of any filters in the IF signal path, and amplifier performance. Figure 5 shows a block diagram of the type of device this test may characterize. Figure 6 shows an example measurement of swept IF conversion loss. Remember that the offset frequency accuracy and residual FM of the sweep oscillator may limit use to broader IF bandwidths.

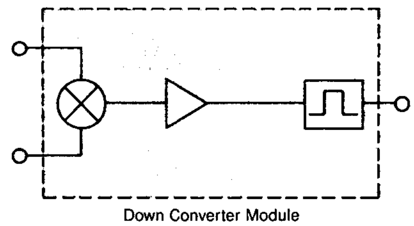


Figure 5. Block diagram of a typical downconverter module which can be characterized using the techniques described in this note.

To minimize errors and maximize the speed of changing configurations from swept IF to fixed IF, power sweeps, or detector selections, use the save and recall registers of the sweep oscillators and the scalar network analyzer. The HP 8757A can store a total of nine instrument setups and of these nine, four will retain calibration data and limit line information.

Measurement Sequence

Swept IF Conversion Loss

The setup of Figure 2 can be used to measure the IF conversion loss as a function of IF frequency by sweeping the RF source in frequency, and keeping the LO source's frequency constant. The following keystroke sequence describes how to perform a swept IF conversion loss measurement, assuming steps 1 through 9 in the fixed IF section above have been performed.

1. On the LO (slave) sweep oscillator, set the desired LO frequency using [SHIFT] [CW], followed by the desired frequency. On the RF (master) sweep oscillator, set the same frequency using [CF], followed by the frequency used on the LO sweep oscillator. Now enter the frequency span required to obtain the swept IF using the [ΔF] key followed by the frequency range. On the slave sweep oscillator, set the frequency offset to 0 MHz by pressing **[SHIFT] [VERNIER] [0] [MHz]**.

   For example, to measure swept IF conversion loss from an IF of −200 to +200 MHz at an RF frequency of 6 GHz, one would set a frequency of 6 GHz on the slave sweep oscillator using [SHIFT] [CW] [6] [GHz], and on the master sweep oscillator using [CF] [6] [GHz]. Set the span of the master sweep oscillator with [ΔF] [4] [0] [0] [MHz].

2. Perform the thru calibration as in step 7 above so that the swept IF conversion loss is measured relative to the RF input signal level. The analyzer should be in the normalized mode (B/R − M).

3. Insert the mixer under test, and on the HP 8757A press [SCALE] [AUTOSCALE] to view the swept IF trace (Figure 6). The frequency annotation indicates the RF start and stop frequency.

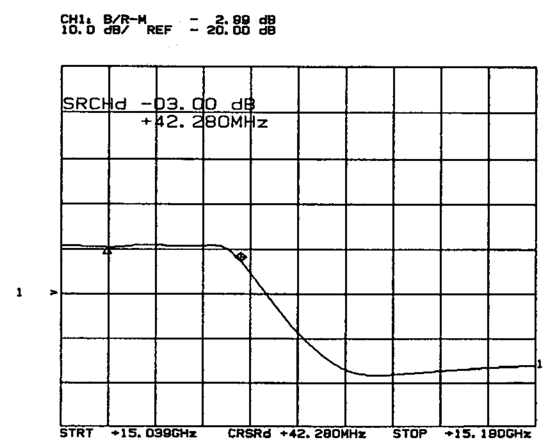


Figure 6. Plot of mixer conversion loss as a function of IF frequency (swept IF conversion loss). With this technique, IF mixer bandwidth and flatness can be characterized.

Swept Power Measurements

Conversion Compression Measurements

The power sweep feature of the HP 8350B sweep oscillator and HP 83500 series RF plug-in simplifies compression tests on the mixer. The 1-dB compression point is where the conversion loss increases by 1 dB, and generally occurs 5 to 10 dB below the LO input level. The 1-dB compression point and the noise floor describe the useful operating range of the mixer. To measure the 1-dB compression point, the master and slave sweep oscillators are set to the CW (constant frequency) mode. The master sweep oscillator is then set to the power sweep mode by pressing [POWER SWEEP] and entering the desired power sweep range in dB. The slave sweep oscillator is set to the desired LO power level. The power sweep range of the master sweep oscillator is then adjusted until the conversion loss shows a 1-dB drop on the scalar analyzer. Ratioing is the best way to obtain this value since the reference signal and IF level should track until the mixer begins to compress. Figure 7 shows a measurement of the 1-dB conversion compression point of a mixer.

If the equipment configuration of Figure 2 is used, an additional power sweep test can be performed. In this test, the LO power is swept with the resulting displayed IF conversion loss. The test can be configured as a ratio against the RF power which then shows the optimum LO drive level for minimum conversion loss (Figure 8). The test can also be run as a non-ratioed power measurement showing the conversion loss sensitivity to LO power. The test must be performed at single frequencies since the system is in power sweep mode.

AC detection is the best way to make this test since the modulation provides some isolation from the effects of harmonics generated in the mixer as it is driven into compression by the higher drive levels. It is recommended that if DC detection is being used to measure conversion compression, suitable filtering be utilized so that the IF signal alone is being measured. High LO feedthrough may affect this measurement and these effects are discussed in Appendix 2. The splitter/detector combination can be moved to the LO port to obtain the ratio relative to the LO power rather than the RF if desired.

Measurement Sequence

Conversion Compression

Swept RF power measurements

To measure mixer conversion compression, the power sweep capability of the HP 8350B sweep oscillator can be used. This is a swept power measurement, performed at fixed RF and LO frequencies, with the slave sweep oscillator operating at a desired offset from the master sweep oscillator to generate a fixed IF.

1. Connect the instruments as shown in the Figure 2. Press [PRESET] on the HP 8757A and on the slave sweep oscillator. This brings the analyzer and sweeper to a known state.

2. On the analyzer, press [CHANNEL 1] and select [MEAS] [B/R].

3. On the master sweep oscillator, press [SHIFT] [CW] followed by the desired CW frequency. Terminate the entry with the [GHz] key.

4. On the slave sweep oscillator, press [SHIFT] [CW] followed by the same frequency. Terminate the entry with the [GHz] key. Place the slave sweep oscillator in the external sweep mode by pressing [EXT].

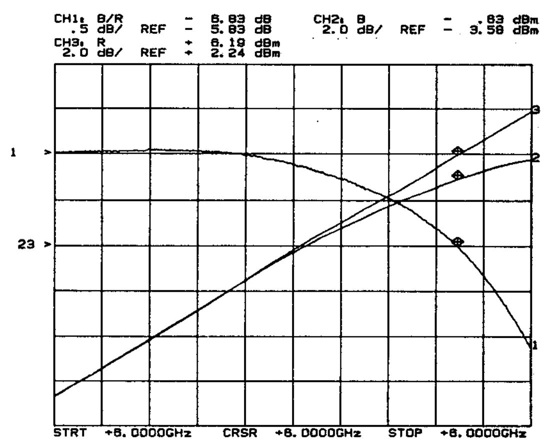


Figure 7. Plot of a 1-dB conversion compression measurement. This test is performed at fixed frequency, with the RF sweep oscillator in power sweep mode. Trace 1 shows the conversion loss (IF relative to RF), trace 2 the IF output power, and trace 3 shows the RF input power.

If the HP 8349B amplifier is being used, be sure the BNC cable between the EXT ALC input on the slave sweep oscillator and DET OUT connector on the rear panel of the amplifier is connected, and set the ALC MODE to [EXT]. Enter the desired frequency offset using [SHIFT] [VERNIER], followed by the desired offset.

5. Now activate the power sweep mode on the master sweep oscillator by pressing [POWER SWEEP] and entering the desired power sweep range in dB. For example, to set up a power sweep from 0 to +12 dBm, press [POWER LEVEL] [0] [dBm], followed by [POWER SWEEP] [1] [2] [dB].

   If the unleveled light blinks when the power sweep range has been set, the RF power will be unleveled. Reduce the master sweep oscillator's start power level by pressing [POWER LEVEL] and turning the knob or pressing the step down arrow key until the unleveled light remains off.

6. On the analyzer, press [SCALE] [AUTOSCALE] to bring the compression trace onto the screen. The HP 8757A should now show the mixer's conversion loss as a function of RF input power level (Figure 7). If the conversion loss does not increase by the desired amount (usually 1 dB), then increase the power sweep range further, or increase the starting power level of the master sweep oscillator.

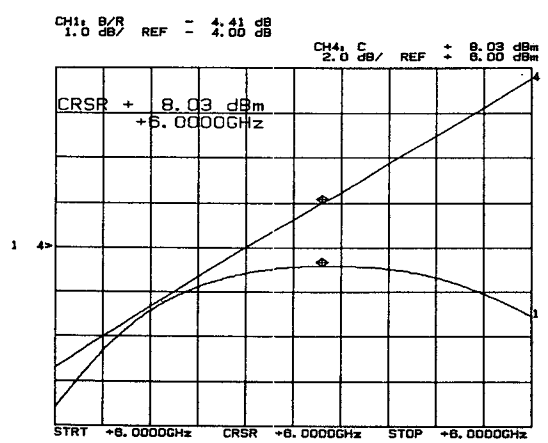


Figure 8. Plot of mixer conversion loss as function of LO input power level. Note that the conversion loss decreases until the optimum LO drive level is reached, and then increases as the mixer compresses at high LO drive levels.

7. To view the output IF power, press [CHANNEL 2] on the HP 8757A, and select [SCALE] [AUTOSCALE].

   Shown on the screen of the analyzer is the output power of the mixer under test as a function of RF input power. Note that this power increases linearly until compression of the mixer begins.

8. To find the power out at 1-dB compression, use the cursor search function on channel 1 of the analyzer. The power output can then be read directly from the output power trace on channel 2.

   Press [CHANNEL 1] [CURSOR], and select [MAX]. Activate the cursor delta function by selecting [CURSOR△ ON]. Press [SEARCH], then select [SEARCH VALUE] and enter the desired search value, in this case −1.0 dB using the keys on the analyzer. Select [SEARCH RIGHT] and the cursor symbol will move to the 1-dB compression point. De-activate the cursor search trace hold by pressing [CURSOR]. Press [CHANNEL 2] to activate the channel 2 trace. The channel 2 cursor should now read the mixer IF output power at the 1-dB compression point.

   If the message "Cursor value not found" appears on the analyzer, then the mixer is not reaching its 1-dB compression point in the specified sweep, or you may have not turned on the Cursor Delta mode. Increase the power sweep range or the start power level to force 1-dB compression, or repeat step 8.

   The HP 8757A's detector offset function can be used to compensate for the insertion loss of an attenuator or filter placed between the IF output of the mixer and the B detector. To enter an offset, press [CAL] [MORE] [DET OFFSET]. Select [DET B] and enter the desired offset in dB. Terminate the entry with the [dB] key.

9. To view the RF input power to the mixer, press [CHANNEL 1] [CHAN 3] [MEAS] [R]. Press [SCALE] [AUTOSCALE] to bring the RF input power trace onto the screen of the analyzer. The detector offset function can be used to compensate for the insertion loss of the directional bridge if it is being used in the RF signal path.

10. To make a measurement of mixer conversion compression at another frequency, change the frequency on both sweep oscillators using [SHIFT] [CW], followed by the desired new frequency. The frequency offset required for a desired new IF frequency can also be changed at this time by pressing [SHIFT] [VERNIER], and entering the new IF frequency on the slave sweep oscillator.

    It is not normally necessary to adjust the power sweep parameters once they are set up. The sweepers must, however, stay in the swept CW mode.

Measurement Sequence (Cont'd)

Swept LO power measurements

The setup of Figure 2 can also be used to determine the optimum LO drive level for a mixer with the third detector connected to detector input C on the HP 8757A Option 001. (Option 001 adds the fourth detector input as shown in the figure). The procedure to perform such a measurement is very similar to that for conversion compression measurements just described.

1. To find the optimum LO drive level at a specific RF input power level to the mixer (in order to maximize the efficiency of the mixer), simply activate the power sweep mode on the slave sweep oscillator instead of on the master sweep oscillator, using the same keystrokes as given earlier, after setting the appropriate CW frequencies, offset frequency, and source power levels. If channels 2 and 3 are on, turn them off by pressing **[CHANNEL 1]**, [CHAN 3 OFF], [CHAN 4 OFF].

2. Configure channel 1 to measure the ratio [B/R] by following the procedure outlined in step 2 above, and press **[SCALE]** [AUTOSCALE] to view the trace. Find the minimum value of conversion loss (maximum value of the displayed trace) by pressing **[CURSOR]** [CURSOR MAX]. Press **[DISPLAY]** [HOLD ON] to freeze this trace.

3. Configure channel 4 of the analyzer to measure input C by pressing **[CHANNEL 1]**, [CHAN 4] and selecting **[MEAS]** [C]. Turn on modulation on the slave sweep oscillator by pressing **[MOD]***. Press **[SCALE]** [AUTOSCALE]. Press **[CURSOR]** to activate the cursor on channel 4. Assuming the cursor position has not been changed from step 2, the optimum LO input power level is now shown by the cursor readout (Figure 8). To return the system to AC mode, press **[SYSTEM]** [AC].

To compensate for the insertion loss of the power splitter, use the Detector Offset function, so that the indicated power is representative of the LO source power level. To enter a detector offset, press **[CAL]** [MORE] [DET OFFSET], select [DET C] and enter the desired offset. Terminate the entry with the **[dB]** key.

Note that AC mode is used to make this measurement, so the LO signal must be modulated. When this measurement is completed, turn the slave sweep oscillator modulation off again by pressing* **[MOD].

Isolation Measurements

To measure mixer IF to RF isolation, the setup of Figure 2 can be used. The measurement technique is very similar to measurements of fixed IF conversion loss, except that the LO input of the mixer under test is terminated with a 50 ohm load (instead of being connected to the RF output of the LO sweep oscillator). To measure IF to RF isolation, the mixer is reversed within the measurement setup, so that the RF signal is incident on the IF output port of the mixer. Similar techniques can be used to measure LO to IF and LO to RF isolation measurements.

To accurately measure RF and LO feedthrough to the IF output port requires the use of narrowband filters so that only the desired signal is measured at the IF port. Since the mixer is operating with both the LO and RF turned on, an IF output signal will be present as well. The scalar analyzer detectors are broadband detectors, and will respond to all of the signals. To measure RF feedthrough, a narrowband filter should be placed between the IF output and detector to prevent the LO and IF signals from reaching the detector. The same applies for measurements of LO feedthrough. Note that for LO feedthrough measurements, if AC detection is being used (as with the HP 11664E detector), then the modulation of the LO sweep oscillator must be turned on.

Hardcopy Output of Measurement Results

Plotting the measurement traces from the HP 8757A is very easy with the HP 7440A Colorpro plotter or the HP 2225A ThinkJet printer. The softkeys under the SYSTEM key provide the operator with the flexibility to output any or all of the current display, limit lines, and custom outputs. This provides an easy way to document the mixer's performance. Figure 9 shows a plot of a simultaneous measurement of a mixer's fixed IF conversion loss and RF input return loss.

Return Loss Measurements

Mixer reflection measurements are easy to do with the equipment configured as Figure 2. The HP 85027B directional bridge can be used on any of the three ports. Typically, the main interest is in the RF and IF ports. Figure 9 shows a measurement of RF input return loss, and IF conversion loss.

A tempting configuration would be to use a directional bridge at the IF port for conversion loss measurements and IF return loss. This configuration is not recommended for the general case. It is practical, but some extra precautions are needed. (Remember that IF conversion loss measurements are made relative to the incident RF signal level). The dynamic accuracy of the bridge will contribute measurement uncertainty because of the difference in incident power between the RF and the IF signal levels. Also, the bridge's frequency response will contribute a significant error (because of the difference in frequencies between the RF and IF signals). The flatness of the directional bridge is

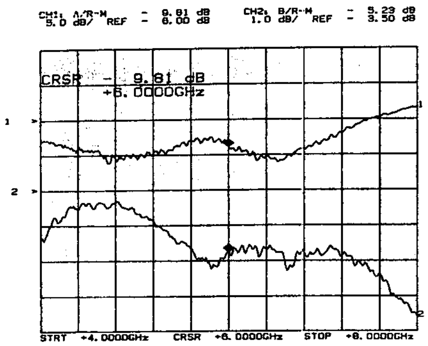


Figure 9. Plot showing simultaneous measurement of mixer conversion loss and RF input return loss made using the instrument setup shown in Figure 2. RF input return loss is shown on trace 1 and conversion loss is shown on trace 2.

typically +3, −1 dB with leveled RF compared to the detector flatness specification of ±0.5 dB from 10 MHz to 18 GHz. A computerized system could improve the measurement accuracy by managing the calibration process. The flatness of the directional bridge is not a problem in standard reflection measurements, since this response variation is normalized out of the measurement with the open/short calibration technique.

One further consideration in using the directional bridge and a power splitter is the loss of signal power at the mixer port. The total loss through the two devices is approximately 16 dB at 20 GHz. Making the power sweep tests with the directional devices in the test setup will require the HP 8349B microwave amplifier to get the power needed to operate and to compress some types of mixers. The amplifier should be inserted between the power divider and the directional bridge. The maximum power into the directional bridge is +23 dBm.

The HP 8757A scalar analyzer provides the necessary memories to store the two reflection calibrations for the mixer's IF and RF ports in channels 1 and 2, and to store the thru calibration in channel 3 for the RF to IF conversion loss calibration. The HP 8757A Option 001 provides the fourth channel detector input (Input C) for measurements made relative to the LO source's signal.

Measurement Sequences

Using Limit Lines and SAVE/RECALL

Using the limit line feature of the HP 8757A, specification limits can be entered on the screen for comparison to the measured data. Up to 12 limit entries can be entered as point limits, sloped lines, or flat lines. The maximum conversion loss specification can be entered as a lower limit. If the conversion loss falls below this lower limit, a FAIL condition exists. Upper and lower limits could also be entered for testing of conversion loss flatness and displayed as the pass/fail criterion.

The following procedure describes how to enter a series of flat limit line entries for testing the maximum conversion loss on channel 2, assuming a calibrated trace of conversion loss is being displayed.

1. Press [**CHANNEL 2**] to activate channel 2. Press [**SPCL**], then press the [ENTER LMT LNS] softkey. Erase any limits that may have already been entered by selecting [DELETE ALL LNS].

2. Select [FLAT LIMIT], and the label "FLAT FREQ #1?" appears on the display. Enter the frequency of the start of the limit line, and terminate the entry using the appropriate softkey.

3. The analyzer will prompt you for the upper and lower limit values. In this case, we only use a lower limit, since we are testing against a maximum conversion loss specification. Just press the [**ENT**] key when prompted for the upper limits. When prompted for the lower limit, enter the maximum conversion loss specification and terminate the entry with the [**dBm/dB**] key.

4. Repeat steps 1 through 3 above as necessary until all limits are entered.

5. Turn limit lines on by selecting [DONE], then [LIM LNS ON]. Figure 10 shows an example limit entry with 3 segments.

SEG	FREQUENCY	UPPER	LOWER	FREQUENCY	UPPER	LOWER
1	+4.0000GHz		- 8.25	+5.8000GHz		
2	+5.8000GHz		- 7.00	+6.0000GHz		
3	+6.0000GHz		- 7.00	+8.0000GHz		- 8.00

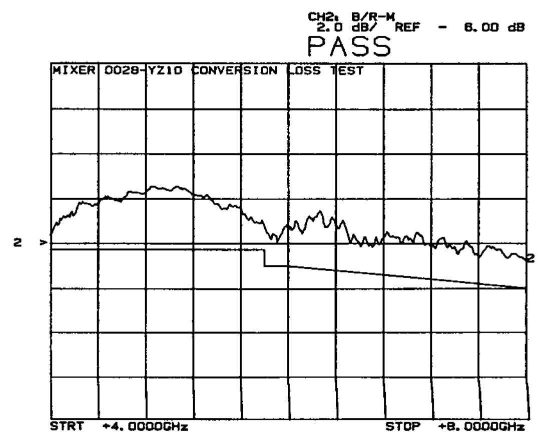


Figure 10. (a) Example limit entries for the maximum conversion loss conversion specification and (b) plot showing the limit lines, conversion loss trace, and PASS/FAIL status.

APPENDIX 1
Detector Flatness Effects

The HP 11664E detectors were chosen for this application because the detector exhibits the best overall performance. The primary concerns in a mixer measurement are bandwidth, power flatness (or efficiency), and return loss. A trade-off in detector performance is between flatness and return loss. The HP 11664E detector is the optimum choice; its flatness is specified as ±0.5 dB from 10 MHz to 18 GHz and is typically less than ±0.3 dB. This flatness specification translates into an equivalent efficiency. In the ideal case, the detector's flatness would be perfect across the measurement frequencies and represent a constant efficiency.

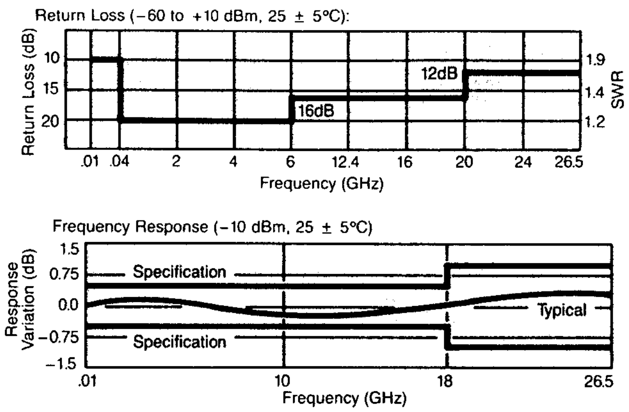


Figure A. (1) Graph of specified return loss and (2) specified and typical frequency response (flatness) for the HP 11664E detector.

The reason why detector flatness (also called frequency response) is of such importance in mixer testing is that the detector's response variation cannot be calibrated out of the measurement. Since the thru calibration is performed at the RF frequency, and the measurement is performed at the IF frequency, any variation in the detector's response between the RF and IF frequencies will appear as part of the mixer's own conversion loss. For example, if the detector response is perfectly flat except for a hump in the middle of the swept RF frequency range of +0.5 dB, then that response peak will show itself as a −0.5 dB dip in the mixer's conversion loss in the middle of the conversion loss trace on the analyzer screen. Therefore, the flatness specification is added directly to the mixer conversion loss measurement uncertainty.

A typical detector data sheet shows the detector flatness versus frequency and the return loss (Figure A). The detector's offset at the IF frequency can be determined by performing a measurement of a constant-power signal at the IF frequency with a power meter (which can be calibrated to eliminate its flatness) and then with the scalar analyzer detector. The difference between the two measurements can be calculated and then removed at the analyzer during the measurement sequence using the Detector Offset function. For example, if the power meter measures a 100 MHz IF signal as being at 0 dBm, and the scalar analyzer detector measures 0.5 dBm, enter a detector offset of −0.5 dB for that detector.

APPENDIX 2
AC versus DC Detection

The HP 11664E detector recommended in the *Equipment Considerations* section operates only in the AC detection mode. AC detection mode is the best broadband, least prone to error, measurement technique for mixer testing when compared to DC detection. High-level LO feedthrough affects the measurement significantly more when the DC detection mode is used than when AC detection mode is used. If the DC detection mode must be used, filtering the IF to eliminate the LO and RF feedthrough will improve the measurement.

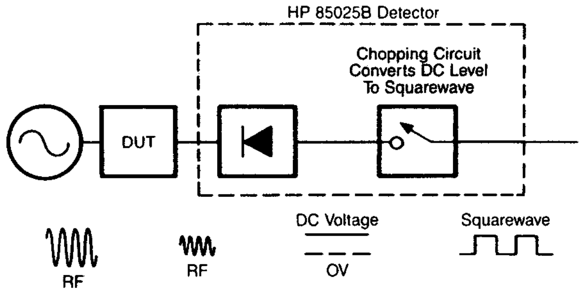


Figure C. *DC detection detects unmodulated RF, then chops the detected signal. The receiver thus measures the desired signal, plus any other signals present at the detector.*

Let's inspect the exact impact of spurious signals on the detector and how they affect mixer measurements of mixer conversion loss and conversion compression.

The AC detection mode uses a 27.778 kHz square-wave modulated source. The square wave is demodulated by the detector and only the modulation envelope is passed to the scalar analyzer (Figure B). At the analyzer, the demodulated signal is AC coupled into the log amplifiers and then digitized. It can be seen that two parameters of the modulation affect the results. Square-wave symmetry is very important and care is taken to achieve 50±5% duty cycle. The second parameter that we have less control over is modulation depth. It is desired that the on/off ratio exceed 30 dB. It can be shown that as this ratio degrades, the absolute accuracy of the detector changes. The amount of LO feedthrough influences the modulation depth, the detector's diode bias, and the diode's operating point. The advantage of the AC detection mode results from AC coupling into the logging amplifiers of the scalar network analyzer which strips off the DC offset caused by the LO feedthrough since the LO is not modulated. The AC detection mode cannot correct for the change in the diode's operating point however.

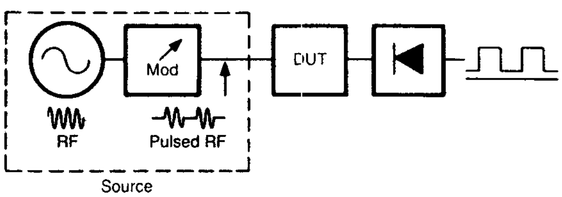


Figure B. *AC detection uses RF modulation. The modulation envelope is then passed to the scalar analyzer. Sensitivity to non-modulated signals present at the detector is minimized when this technique is used.*

In DC detection mode, the detector diode responds to the signals the same way it responds in AC mode, but the receiver circuitry now measures the sum of the power from the signals incident on the diode (assuming low level inputs). In mixer testing, the possibility for high level signals is likely and unless special precautions are employed, significant errors may occur. The HP 85025B detector operates in either AC or DC detection mode. The difference between the AC and DC modes is a chopper interface (Figure C). It is used to produce the 27.778 kHz signal for the receiver.

The receiver is identical in both modes. In DC detection mode, however, the chopper circuit maintains a DC reference which is circuit ground. The chopper amplifier switches from DC ground to the peak DC output of the detector. The LO feedthrough signal produces a DC voltage and this DC offset is passed directly through to the analyzer, superimposed on the diode's output voltage due to the desired IF signal. The only way to effectively remove this offset voltage due to the LO feedthrough is to insert a filter between the mixer's IF output and the detector. This filtering effectively band limits the detector to the filter's bandwidth, and so prevents the LO feedthrough signal from being detected (Figure D), but adds the uncertainty of the filter's response to the mixer data.

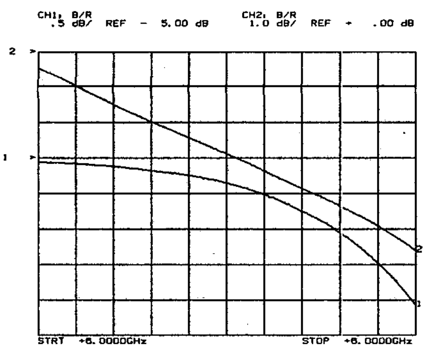


Figure D. Plot of mixer conversion compression measured using the HP 85025B detectors in DC mode. Trace 1 shows the characteristic compression of the mixer because a low-pass filter is used at the IF port to eliminate LO feedthrough. Without filtering of the IF, the measurement is invalid, because in DC detection mode, the sum of the IF and LO feedthrough signals is measured by the analyzer (trace 2).

Using AC detection mode minimizes the impact of LO feedthrough, but will not reduce the effect of harmonics of the IF or the RF feedthrough signal, since they are modulated and thus detected along with the desired IF signal (Figure E). For measurements of conversion loss when the mixer is operated in its linear range, the magnitude of these

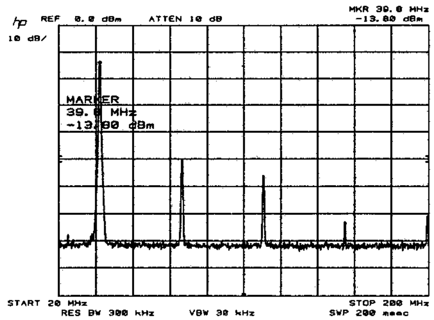


Figure E. Spectrum of the IF signal and its harmonics when the mixer is operating in the small-signal level range.

harmonics is typically low enough that their effect is negligible. When the mixer is driven into compression, these harmonics (and the RF feedthrough) grow in amplitude (Figure F) and begin to affect the accuracy of the scalar analyzer.

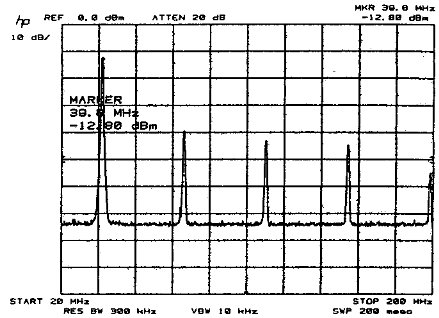


Figure F. Spectrum showing the increase in harmonic levels when the mixer is driven into compression with higher RF input power, as in the case of conversion compression tests.

Figure G shows the worst case uncertainty of a scalar power measurement in the presence of second harmonics as a function of funda-

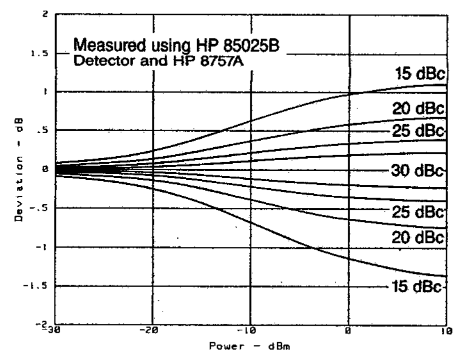


Figure G. Worst case power measurement uncertainty in the presence of second harmonics of different levels, as a function of fundamental power level at the detector. For example, for an IF signal at −10 dBm, and a second IF harmonic at −20 dBc (−30 dBm), the error is ±0.4 dB. Note that for power levels below −20 dBm, the error is minimized.

mental (IF) signal power level. It can be seen that for power levels of the fundamental (IF) signal below −20 dBm, the errors are very small, because the detector measures total rms power (square law region). At higher power levels, the detector operates in the transition region, and errors become significant. For this reason, it is recommended to either insert an attenuator between the mixer IF output and detector to keep incident power levels below −20 dBm, or insert a low pass filter to reduce/eliminate the harmonics and feedthrough signals themselves (Figures H and I). Figure J shows a measurement of conversion compression made in AC detection mode, with and without filtering at the IF output.

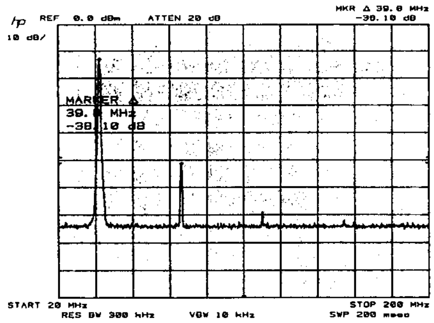


Figure I. With the filter in place between the mixer's IF output and detector input, the IF harmonics are reduced/eliminated during compression testing.

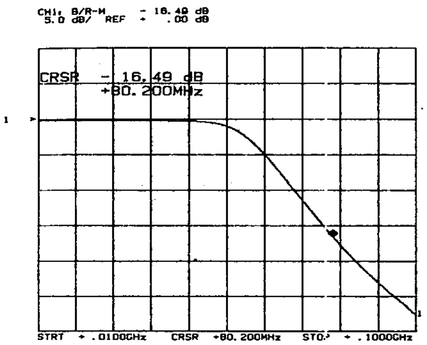


Figure H. Insertion loss of a low-pass filter used to remove the IF harmonics, as well as the RF and LO feedthrough signals.

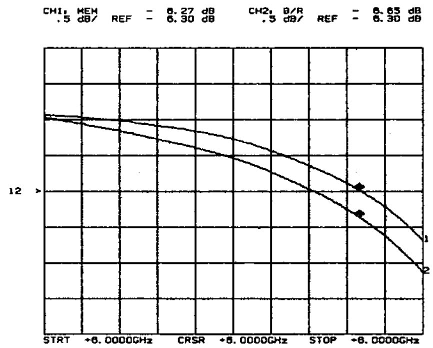


Figure J. Plot of a measurement of mixer conversion compression made using AC detection mode without and with the low-pass filter of Figure H (traces 1 and 2, respectively). No attenuation was used, in order to maximize the effect of the IF harmonics and feedthrough signals.

List of References

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HP Application Note 326, "Principles of Microwave Connector Care," HP literature no. 5954-1566.

HP Product Note 8350A-2, "Improved Frequency Accuracy by Calibrating HP 83590 Series RF Plug-ins to the HP 8350A Sweep Oscillator Mainframe," HP literature no. 5952-9330.

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"Barretter and Diode Comparison For Insertion-Loss Measurements in the Presence of Harmonics," by Fritz K. Weinert, Dr. Bruno O. Weinschel, and Donald D. Woodruff, Microwave Journal, March, 1975, pp. 39-43.

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