HEWLETT hp PACKARD

Spectrum Analyzer Series
Application Note 150-14

SPECTRUM ANALYSIS . . . Using External Waveguide Mixers Above 40 GHz

INTRODUCTION

The internal mixers of the HP 8555A and 8565A Spectrum Analyzers are able to directly measure signals up to 18 and 22 GHz respectively. To measure higher frequency signals, an external mixer is used in place of the analyzer's first mixer to convert the input frequency down to the analyzer's first intermediate frequency (IF). This application note will describe how to use other external mixers to extend the frequency range of HP spectrum analyzers above 40 GHz. Application Note 150-12 discusses how to use the HP 11517A External Mixer up to 40 GHz.

HARMONIC MIXING

Referring to the set-up shown in Figure 1, when the spectrum analyzer is switched into one of its external mixer bands and an input signal (RF) is applied to the external mixer, three signals are present at the analyzer's EXT MIXER port: the analyzer's first local oscillator (LO), the mixing products, and the external mixer bias (I_{BIAS}).

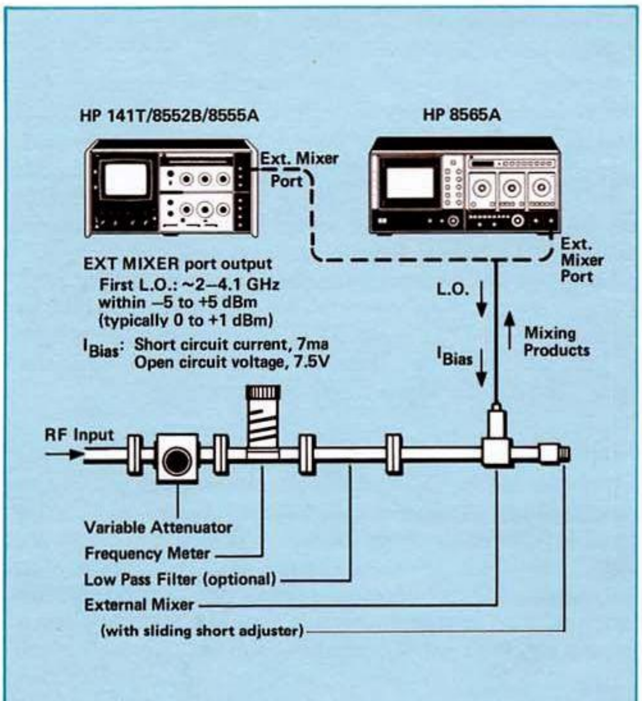


Figure 1. Harmonic Mixing Set-Up.

The analyzer's first local oscillator sweeps from approximately 2 to 4 GHz and generates harmonics in the external mixer. These harmonics mix with the RF input signal to generate mixing products. Because the harmonics of the LO mix with the RF signal, this process is called harmonic mixing and is described by the equation:

$$f_{RF} = nf_{LO} \pm f_{IF} \qquad (1)$$

where:

f_{RF} = input signal frequency
n = harmonic mixing number 1, 2, 3, . . .
f_{LO} = local oscillator frequency, 2 to 4.1 GHz
f_{IF} = 2.05 GHz

The mixing products travel back to the analyzer and pass through a 2.05 GHz bandpass filter network. Then the IF signal is processed by further filtering and amplification, detected, and finally displayed on the CRT as a signal response. Equation 1 shows that each RF input signal can cause a response in the first IF (f_{IF}) for more than one harmonic of the LO frequency. This produces a series of signal responses similar to those in a Full Band Scan, as shown in Figure 2.

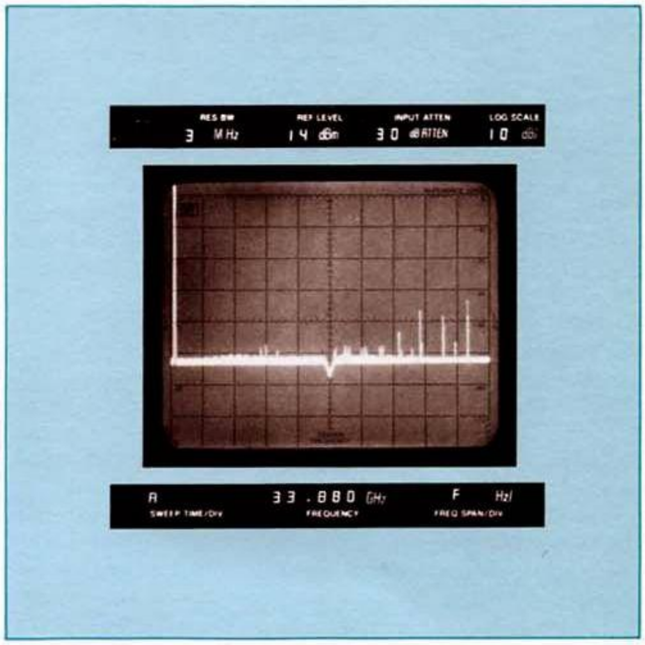


Figure 2.

Signal analysis depends on a calibrated display of the components of a signal. Harmonic mixing can yield several responses to a signal which will effect the interpretation of the display. The following sections describe how to measure the true frequency and amplitude of a signal's components.

FREQUENCY MEASUREMENT

In the setup shown in Figure 1, the frequency meter is used to measure the RF input signal's frequency. When the meter is tuned to the RF input frequency, the input signal's amplitude will be reduced at least 1 dB, and all responses associated with that input signal will be reduced by the same amount. If more than one input signal is present at the external mixer input, the signal responses not associated with the frequency meter's tune frequency will remain unchanged. Thus, responses due to different RF input signals are easily identified with the frequency meter. Different input signals can be removed with waveguide filters such as the optional lowpass filter shown in Figure 1.

For more detailed signal analysis, a narrower, Per Division span may be selected. Sensitivity will be maximized by tuning the marker notch to the signal displayed furthest right on the CRT in the Full Span mode. Typically, this response will be generated by the lowest harmonic number (n) and will give the best sensitivity.

Frequency Calibration

The analyzer's frequency span must be calibrated according to the harmonic mode being used. To do this, the values of f_{LO}, f_{IF}, and n of equation 1 for the signal response must be determined.

The f_{LO} may be determined after centering the signal response with the TUNE control on the CRT in a Per Division span mode. This may be read directly from the "L.O." scale on the 8555A. On the 8565A, f_{LO} can be calculated by solving equation 1 for f_{LO}.

$$f_{LO} = (f_{RF} - f_{IF})/n \qquad (2)$$

where n is the harmonic number for the selected band. Calculation is simplified if we choose n = 10 by selecting the 8565A's 22.9 to 40 GHz external mixer band.

Equation 2 becomes:

$$f_{LO} = (\text{Center Freq. readout} - 2.05 \text{ GHz})/10 \qquad (3)$$

where the Center Frequency readout is taken from the analyzer's displayed center frequency, not the frequency meter's.[1] For example, if the center frequency readout was 42.05 GHz for a signal centered on the display, then,

$$f_{LO} = (42.05 - 2.05)/10 = 4.00 \text{ GHz}$$

Next, use the signal identifier to determine the sign of the harmonic mixing mode. Zoom-in on the signal response to a frequency span of 1 MHz/DIV and activate the signal identifier. With the analyzer set to the 10^+ (8565A = 22.9-40 GHz) external mixer band, signals which identify with the smaller response to the left are on a positive (+) mixing mode. Signals which identify with the smaller response to the right are on a negative (−) mixing mode. See Figure 3.

Since the true harmonic mixing number is typically greater than 10 for signals above 40 GHz, the distance between responses produced by the signal identifier will be less than two divisions. To determine the sign of the tuning equation, all that is important is the direction the smaller response is shifted from the larger one.

In harmonic mixing, the optimum conduction angle varies with LO frequency and harmonic number. To optimize the mixer bias, adjust the BIAS control to peak the signal of interest. Since more than one peak normally occurs, it is important to adjust the BIAS to the maximum peak. The BIAS control should be adjusted for each amplitude measurement. However, if the bias is adjusted at 1 GHz intervals, the frequency response will typically be degraded by less than 1 dB.

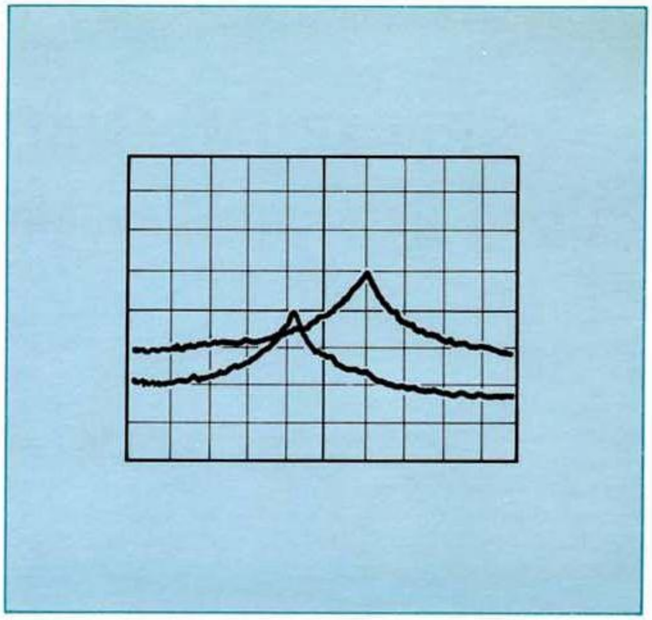


Figure 3. Signal Identification. Smaller response to the left indicates positive mixing mode for 10^+ band.

Sliding Short Adjustment

Some waveguide mixers are internally terminated with a tapered load for optimum broadband performance. But if the external mixer is equipped with a sliding short, it may be adjusted to achieve better sensitivity and flatness. To adjust the sliding short, tune it to peak the signal response. It is not necessary to search for a maximum peak as it is with the BIAS control. The sliding short should be adjusted over 1 GHz input frequency segments. However, for best sensitivity and flatness, it should be adjusted for every different RF input frequency measured.

Amplitude Calibration

Both the HP 8555A and 8565A can be used to measure the amplitude of signals with external mixers provided a signal of known power is used to calibrate the Reference Level.

Using the LO frequency and the harmonic mixing mode sign, the true harmonic mixing number may be found. Solving equation 1 for n yields:

$$n_{TRUE} = (f_{RF} - f_{IF})/f_{LO} \qquad (4)$$

where f_{RF} is the RF input frequency measured with the frequency meter, and f_{IF} is +2.05 GHz for positive mixing modes and −2.05 GHz for negative mixing modes.

If, in the preceding example, f_{RF} was 82.1 GHz and the signal identified as shown in Figure 3, then

$$n_{TRUE} = (82.1 - 2.05) \text{ GHz}/4.00 = 20$$

[1] Or a frequency counter such as the HP 5342A may be connected to the first LO output to measure it directly for better accuracy.

The true frequency span may be calibrated using the following equation:

$$SPAN_{TRUE} = SPAN_A \times (n_{TRUE}/n_A) \quad (5)$$

where $SPAN_A$ is the analyzer's frequency span readout, n_{TRUE} is determined from equation 4, and n_A is the analyzer's external mixer band setting (e.g., 10). Completing the previous example, if a signal was viewed in a nominal 1 MHz/div span, the true span/div would be

$$SPAN_{TRUE} = 1\ \text{MHz/div} \times (20/10) = 2\ \text{MHz/div}.$$

AMPLITUDE MEASUREMENT

One or two adjustments are necessary to achieve the best sensitivity and flatness. The adjustments are mixer bias and the mixer's sliding short if it has one.

Bias Adjustment

To operate, the mixer diode must be properly biased. Both the HP 8565A and 8555A provide a means of adjusting a dc bias current, I_{BIAS}, to the external mixer's diode. Thus, a current value may be set which will bias the mixer diode for minimum conversion loss by changing the diode conduction angle.

With the known signal applied to the mixer:

1. Tune to it in a span of approximately 10 MHz/div and adjust mixer bias and sliding short to maximize the signal deflection.
2. Select a resolution bandwidth wide enough to include the signal's significant sidebands so the signal's maximum deflection represents the total signal power.
3. Using the IF step gain control, bring the signal peak to within 5 dB of the reference level.
4. Set the Input Attenuation and Reference Level Fine control to give a reference level indication equal to to the signal's actual amplitude.
5. Position the displayed signal on the reference level graticule line using the Reference Level Cal adjustment (AMPL CAL on the 8555A).

Amplitude calibration is now complete. The IF or Reference Level controls may be used to make measurements, but the input attenuator must not be changed (although it is bypassed by the ext mixer input, its setting affects the displayed reference level value). Since the preselector in the 8565A is also bypassed, the PRESELECTOR PEAK control will not affect the display. Other analyzer controls function as usual.

If calibration and measurement are performed on two different harmonic mixing numbers (n_{TRUE}) or if the same signal is measured using different harmonic numbers without recalibration, an amplitude error will occur. This amplitude error (ΔP_{dB}) is approximated by the equation:

$$\Delta P_{dB} = 20 \log (n_1/n_2) \quad (6)$$

where n_1 and n_2 are the true harmonic mixing numbers. The mixing mode sign (i.e. positive or negative) does not affect the amplitude error. For example, if a 60 GHz signal was measured with $n_1 = 15+$ and again with $n_2 = 17-$ (adjusting the BIAS control for both measurements), the amplitude error is approximately 1 dB. As a general rule of thumb, measurements can be made plus or minus two harmonic numbers without seriously affecting amplitude uncertainty.

MEASUREMENT PROCEDURE

The following procedure will serve as a guide when making measurements with the HP 8565A or 8555A Spectrum Analyzers above 40 GHz.

A. INITIALIZE ANALYZER CONTROLS: Use the setup shown in Figure 1. Set the analyzer's frequency band to 10^+ (8565A = 22.9–40 GHz), the frequency span to FULL, and the resolution bandwidth to $\geq$300 kHz.

B. CONNECT SIGNAL: Set the variable waveguide attenuation to insure that the mixer's input power limitations (gain compression as well as damage level) are not exceeded.

C. MEASURE SIGNAL FREQUENCY: Tune the frequency meter to the frequency of interest. All CRT signal responses which simultaneously "dip" are due to an RF input frequency at the frequency shown on the frequency meter.

D. TUNE ANALYZER TO SIGNAL: Tune the analyzer to the rightmost signal response, identified in step C, with the TUNE control. While keeping the response centered, reduce the frequency span to 1 MHz/DIV. Determine the analyzer's LO frequency (equation 3).

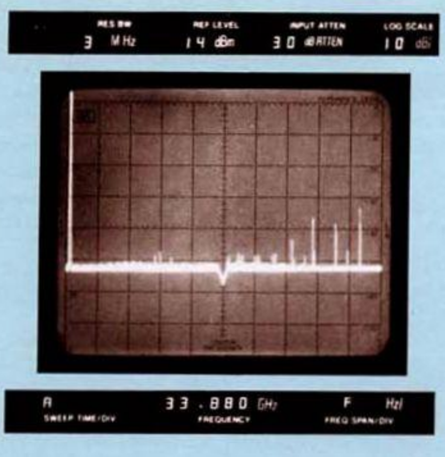
E. IDENTIFY MIXING MODE: Turn on the signal identifier and determine if the mixing mode is positive (left shift) or negative (right shift). Calculate the true harmonic mixing number using equation 4.

F. CALIBRATE FREQUENCY SPAN: Calculate the true frequency span using equation 5.

G. OPTIMIZE MIXER: Adjust the analyzer's mixer BIAS control and the mixer's sliding short control until the signal response reaches its maximum peak.

H. MEASURE SIGNAL: Use the analyzer's reference level controls to position the signal on the reference level (top CRT graticule line). Record the RF input signal's frequency using the frequency meter and its amplitude from the reference level readout.

NOTE: Unless the analyzer's amplitude readout was calibrated with the external mixer and an external calibration source, the amplitude readout will not have absolute amplitude calibration. However, relative amplitude measurements can be made between responses to the same mixing mode, e.g., 22^+.



Step 1

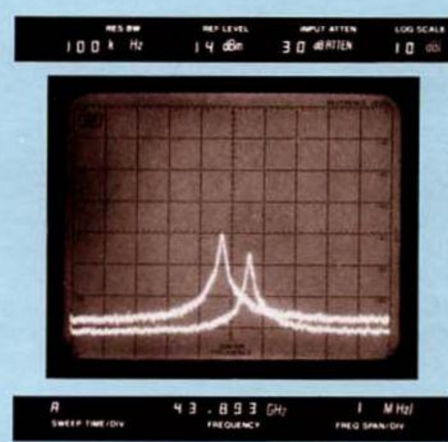
The analyzer is set to the 10⁺ (22.9 to 40 GHz) external mixer band and its frequency span is set to FULL. The input signal's frequency is measured with the frequency meter. $f_{RF} = 94.4$ GHz.

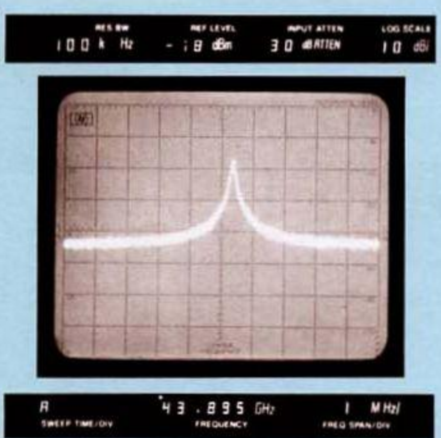
Step 2

Zoom-in on the furthest right signal response to a nominal frequency span of 1 MHz/Div. The signal identifier shows the sign of the mixing mode as negative. From equation 2, the LO frequency is $f_{LO} = (43.89 - 2.05)/10 = 4.18$ GHz.

From equation 5, the true harmonic number is:

$n_{TRUE} = (94.4 + 2.5)/4.18 = 23$





Step 3

From equation 4, the true frequency span is found to be:

$$SPAN_{TRUE} = 1 \text{ MHz/div} \times (23/10) = 2.3 \text{ MHz/div}$$

Figure 4. Measurement Example.

MEASUREMENT EXAMPLES

As an example, the text and photos in Figure 4, record the measurement of a 94 GHz IMPATT oscillator using a Hughes model 47346H-1200 (75-110 GHz) millimeter wave mixer and the HP 8565A.

A second Hughes mixer, model 47343H-1200 (40-60 GHz) was also evaluated with the following results:

1 dB gain compression: −10 dBm.

Sensitivity:

noise level in a 100 kHz bandwidth

−52 dBm at 40 GHz.

−48 dBm at 60 GHz.

Frequency Response from 40 to 60 GHz:

Adjusting mixer bias and sliding short at 1 GHz intervals, ±2 dB.

Adjusting mixer bias at 1 GHz intervals, sliding short adjusted only at 50 GHz, ±4 dB.

The 8555A Spectrum Analyzer will produce similar frequency response and sensitivity results.

Other waveguide mixers are available from Hughes[2] and TRG[3]. The following table lists some of the Hughes mixers and their expected sensitivities (based on manufacturer's specifications) when used with the HP 8555A or 8565A Spectrum Analyzers in a 100 kHz resolution bandwidth. If ordering a mixer other than those listed in this table, be certain to order a mixer with a grounded cathode N-type diode.

Hughes Mixer	Frequency Band (GHz)	Expected Sensitivity (100 kHz BW)
47432H-1200	33-50 (Q-band)	−51 dBm
47343H-1200	40-60 (U-band)	−50 dBm
47344H-1200	50-75 (V-band)	−49 dBm
47345H-1200	60-90 (E-band)	−47 dBm
47346H-1200	75-110 (W-band)	−45 dBm

2 Hughes, Electron Dynamics Division, 3100 W. Lominta Blvd., Torrance, CA 90505.
3 Alpha Industries Inc., TRG Division, 20 Sylvan Road, Woburn, MA 01801.