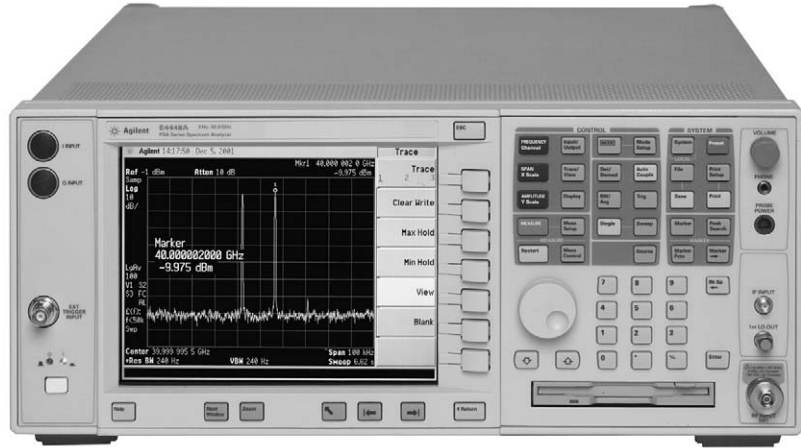


# External Waveguide Mixing and Millimeter Wave Measurements with Agilent PSA Spectrum Analyzers

Application Note 1485



Using the PSA models E4440/46/48A spectrum analyzers with external mixing Option AYZ

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# Overview

External mixing is a useful and economical technique for extending the frequency coverage of a spectrum analyzer. By performing the first frequency mixing (downconversion) operation external to the analyzer itself, frequencies to 325 GHz – far beyond the ordinary range of the analyzer – can be effectively and accurately measured. Indeed, some very high frequencies (typically over 50 GHz) can only be measured in this way.

## Combining external and harmonic mixing

The techniques and technology of external waveguide mixing are closely associated with harmonic mixing. In harmonic mixing, the input signal is downconverted by mixing it with a harmonic of the analyzer's local oscillator (LO), rather than the fundamental. For microwave spectrum analyzers, higher frequencies are usually measured using harmonic mixing, and the very highest frequencies are measured by combining the techniques of harmonic and external mixing.

As you might expect, measurements made using external mixers are not as direct and straightforward as those made entirely within the spectrum analyzer. Equipment setups are somewhat more complex, and the measurement results may require more interpretation. The additional complexities are quite manageable, however, and the benefits are considerable. This note will describe measurements using external mixing and the associated harmonic mixing processes as they apply to the Agilent PSA Series spectrum analyzers. Principles and practice will be demonstrated through a measurement example.

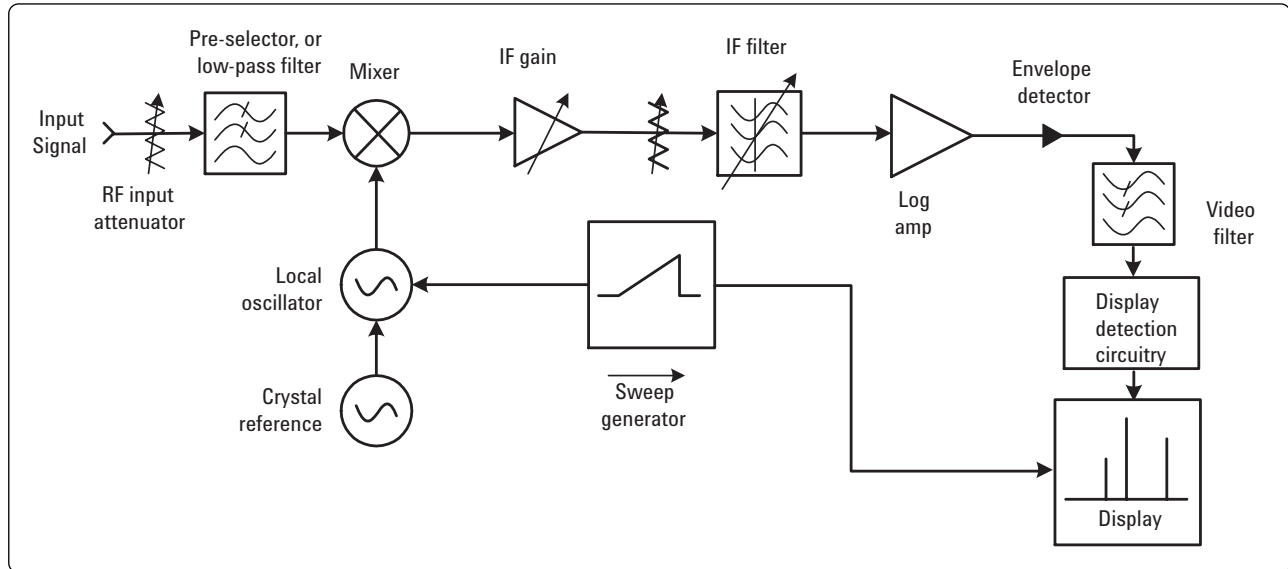
## Features of the PSA Series for external mixing

The PSA Series Option AYZ provides an excellent solution for applications requiring external mixers. This option includes the required hardware and software to make and display the measurements, and a number of features to improve ease-of-use and measurement quality.

- Front panel analyzer connections for external waveguide mixers (LO output and IF input)
- Signal identification through the use of image suppression or image shift
- Compatibility with Agilent preselected, unpreselected, and third-party external waveguide mixers
- Broad frequency coverage from 18 to 325 GHz, in standard waveguide bands
- Automatic or manual harmonic number selection
- Analyzer-supplied external mixer bias, adjustable from the front panel or by program control
- Analyzer-controlled mixer tuning for preselected mixers
- Accurate amplitude measurements through the use of amplitude corrections for mixer conversion loss as a function of frequency. Correction factors can be downloaded from disks provided with the mixers, or input manually.
- Accurate amplitude measurements are supplied, even with signal identification methods (image shift and image suppression) in use
- Excellent amplitude accuracy, as good as  $\pm 0.48$  dB plus the uncertainty of the external mixer
- Excellent frequency accuracy from a fully-synthesized local oscillator and precision internal frequency reference

# Harmonic Mixing and External Mixing in High Frequency Measurements

Making spectrum measurements at millimeter-wave frequencies gets progressively more difficult as the frequencies get higher. This is true both for the analyzer itself and the spectrum analyzer user.



**Figure 1. Block diagram of a common architecture for spectrum analysis**

The most common architecture for spectrum analysis measurements uses fundamental mixing (using only the fundamental frequency of the analyzer's local oscillator in the first mixer stage) and a local oscillator operating in a frequency range above that of the range of frequencies to be analyzed. Such an architecture is shown in Figure 1.

This approach offers many benefits including high sensitivity and freedom from extraneous signals in the measurement results. However, this technique is less desirable for measurements at higher microwave frequencies due to the need for a high performance local oscillator with a very high and very wide frequency range – even higher than the frequencies of interest.

Instead, using a harmonic of the local oscillator in the first mixer stage provides several benefits, and these benefits apply whether the first mixer is located inside (internal mixing) or outside (external mixing) of the analyzer. The main benefit of harmonic mixing is the ability to analyze higher frequencies by using the same local oscillator and most of the same IF structures that are also employed to analyze lower frequencies. With harmonic mixing, the local oscillator need not have a frequency range higher than the frequencies to be measured. The LO need only have a harmonic (with sufficient energy to drive a mixer stage) at a frequency similar to the frequency range to be measured.

More specifically, the analyzer's LO provides a high-level drive signal to the external mixer for efficient mixing and since the mixer is a highly nonlinear device, it generates high-level harmonics of the LO signal. Incoming signals mix against (add and subtract from) the LO harmonics, just as they do with the LO fundamental, and any mixing product that equals the IF frequency will produce a response in the measurement display. The tuning (mixing equation) can be described as follows:

$$F_{\text{signal}} = n \cdot F_{\text{LO}} \pm F_{\text{IF}}$$

where  $n$  is the LO harmonic number

and  $F_{\text{IF}}$  is the analyzer's IF frequency, 321.4 MHz in the PSA

This expression shows that for a given LO frequency (changing as the analyzer is sweeping during a measurement) the two frequencies to which the analyzer is tuned (and therefore where a response will be produced in the display) will be separated by twice the IF frequency. For external mixing with unpreselected mixers in the PSA series, the lower-frequency (signified by the minus sign in the tuning equation) is used for measurements.

While there are significant benefits to the harmonic mixing approach, there are also some drawbacks and performance limitations, and these apply whether the mixing is internal or external:

- **Reduced amplitude sensitivity** and thus a higher displayed average noise level (DANL) or noise figure are drawbacks of harmonic mixing. Microwave harmonic mixers exhibit reduced conversion efficiency as frequency increases, due to the reduced LO drive level of each succeeding LO harmonic. This is manifest by higher conversion loss, increased noise figure, and lower sensitivity for each higher-order harmonic that is employed in the mixing process.
- **Reduced frequency accuracy and stability**, or increased phase noise. The use of LO harmonics is an effectively way to multiply up the LO frequency. However frequency instabilities are also multiplied up along with the harmonic number, and even very high quality oscillators will show some instability after this multiplication.
- **Undesired and unidentified mixer products** appearing in measurement results. Mixers themselves are inherently broadband devices, and all harmonics of the LO will mix with all frequencies present at the input. This will often produce many signals in a measurement display which are not part of the desired results. This situation can be improved by using preselected mixers, which have filters to remove these extraneous signals. For unpreselected mixers, Agilent spectrum analyzers such as the PSA Series also have features that provide signal identification or suppress undesired mixer products.
- **Increased cost, and reduced sensitivity** are drawbacks specifically for preselected external mixers due to the insertion loss of the preselector filter. Preselector impedance mismatches and the associated matching networks may contribute frequency response errors and/or additional effective insertion loss.
- **Measurement setup complexity**, including needed amplitude and frequency calibration or corrections. Using external mixing is inherently more complicated than the unambiguous setups and unique responses of spectrum analyzers using internal and fundamental mixing or internal harmonic mixing with preselection. For the user there is the need to choose and connect external mixers along with (for preselected mixers) power supplies and preselector tuning signals. For some high frequency external mixers it is necessary to supply and set the value of a bias current. Finally, the user must account for frequency and amplitude conversion factors, and ensure signal integrity
- **Reduced amplitude accuracy**. External cables, connectors and adapters combine with the variable conversion loss of the external mixer to add uncertainty to the measurement. Since some critical signal paths are now external to the analyzer and outside its calibration routines, repeatability and stability may be compromised unless good measurement practices are consistently used.

## Preselected and unpreselected mixers

The PSA Series spectrum analyzers are compatible with both preselected and unpreselected external mixers. Preselectors are tunable bandpass filters placed in front of the first (external, in this case) mixer stage. These filters are controlled by a voltage output from the PSA, and automatically track the desired mixing mode. For preselected external mixers, Agilent uses barium-ferrite technology in the filters that are part of the external mixers. Since these filters prevent unwanted signals from reaching the mixer, no mixing occurs, and the signals appearing in the measurement display can be assumed to be from the input signal and not from other mixing modes (image responses and undesired LO harmonic responses).

The unambiguous results from these filter-equipped or preselected mixers are most beneficial for applications where the characteristics of the input signal are unknown, and where the user wants to avoid the task of separating real responses from undesired and unintended ones. Preselectors can also improve the dynamic range of some measurements when input signals are significantly separated in frequency. Since the preselectors can prevent both large and small signals from being present at the mixer at the same time, preselectors can, for example, prevent the attached mixer from contributing to the measured harmonic distortion of an input signal.

Unfortunately, as mentioned previously, preselected mixers have several drawbacks. Their upper frequency range is limited to 75 GHz in present versions. In addition, the preselected mixer is a larger, more complex, and more expensive device than a mixer by itself, and connections to the spectrum analyzer (measurement setup) are slightly more complex. Finally, preselectors add their insertion loss to the measurement, and reduce dynamic range and sensitivity by approximately the amount of this insertion loss, typically 6-10 dB.

Unpreselected mixers offer a number of benefits for external mixer measurements. They are available to cover a broad range of frequencies, from 18 to 325 GHz, and are a relatively inexpensive solution. The lack of a preselector filter preserves conversion efficiency, providing maximum sensitivity and lowest noise level.

For some applications, the input signals are well enough known that the undesired responses from the unpreselected mixer can be ignored. For many other applications, the PSA's built-in signal identification and signal suppression features provide a fast and easy way to interpret measurement results without preselection. These signal identification and suppression features are described below in the section "Using the signal identification features in the PSA."

## Connecting external mixers to the PSA

In the PSA, the LO for the external mixer is provided by the analyzer's "1st LO Out" port on the front panel. The fundamental of this oscillator covers 2.85 to 6.9214 GHz at a power output level of  $16.5 \pm 2$  dBm. Signal inputs to the RF port of external mixers are downconverted to the analyzer's 321.4 MHz main IF stage using harmonics of the LO. The IF output of these external mixers is connected to the "IF Input" port on the front panel of the PSA. This is described graphically in the block diagram in Figure 2 below.

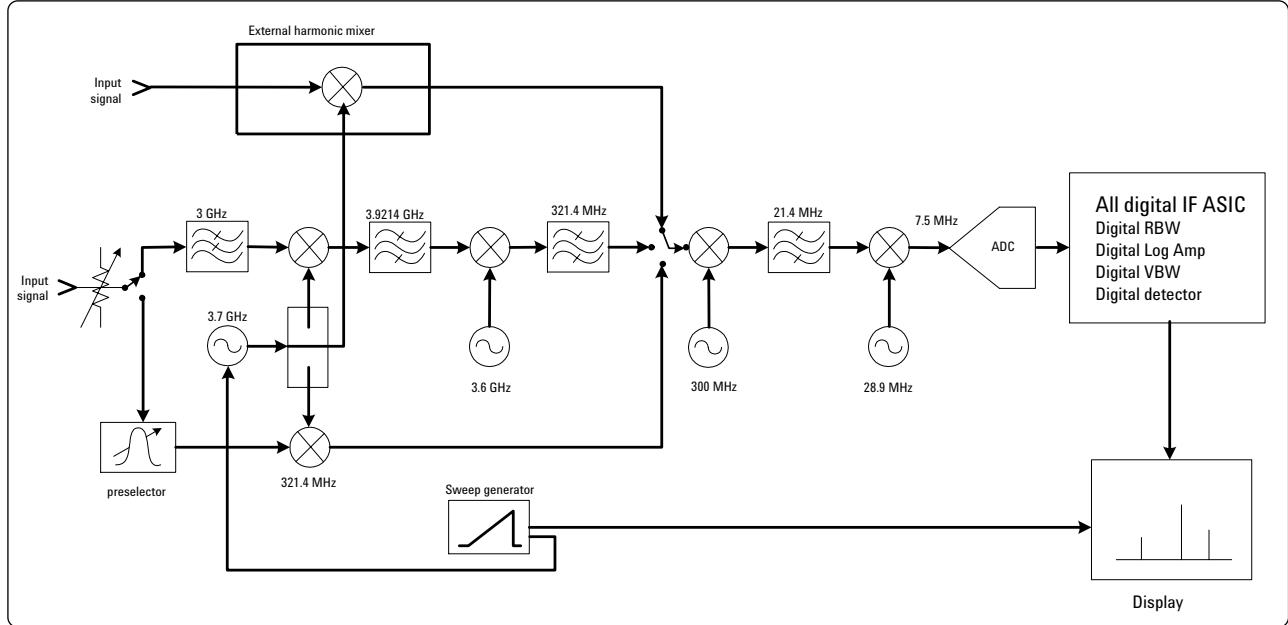


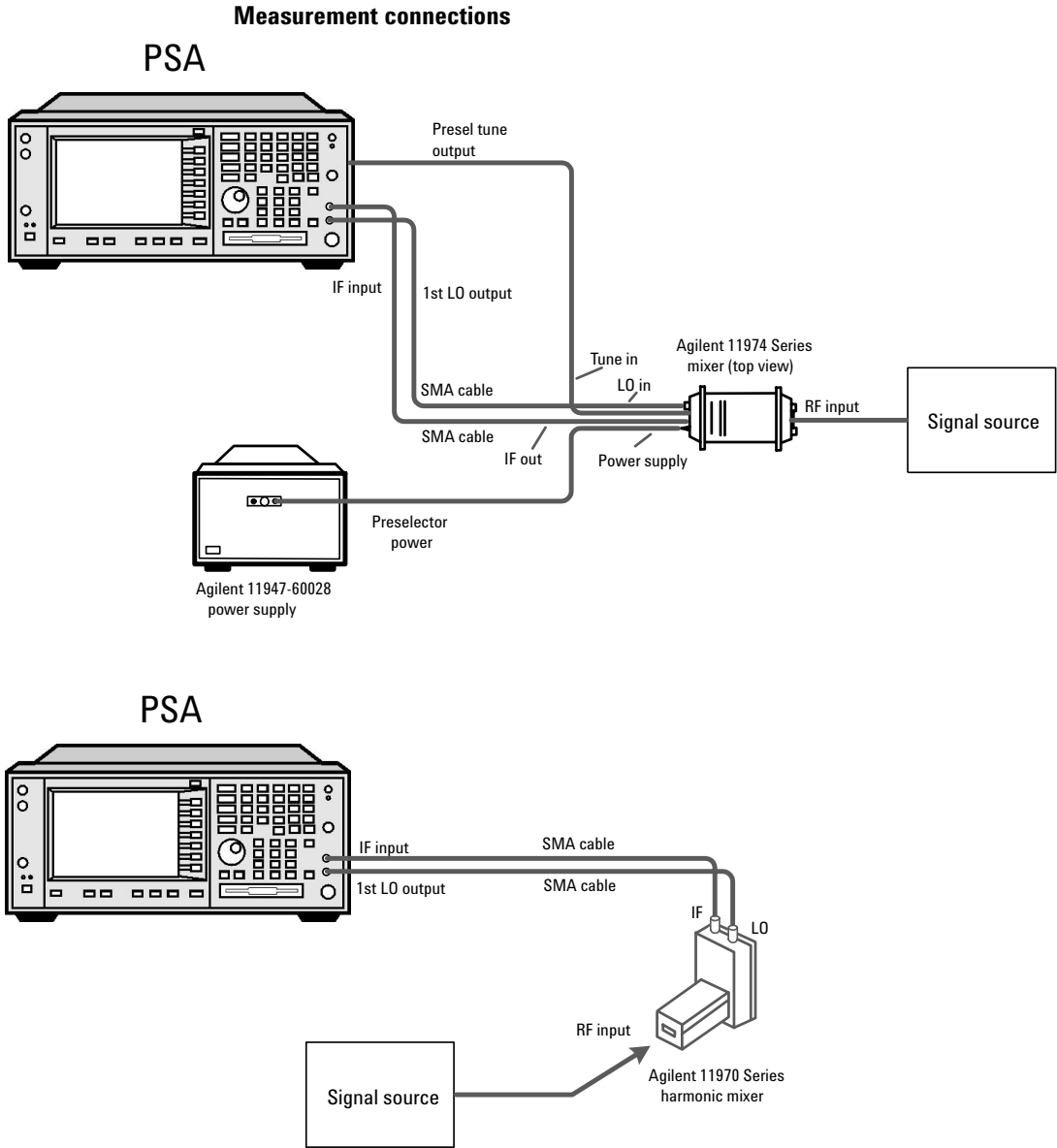
Figure 2: Block diagram of Agilent PSA series spectrum analyzers with external mixing Option AYZ

# Measurement Example – An External Mixing Measurement Using the PSA

This example will demonstrate measurement of a 35 GHz CW signal at a power level of  $-20$  dBm using an Agilent PSA series E4440A with Option AYZ.

### Step one: Connecting the external mixer

For this measurement example, an Agilent 11970A Series unpreselected mixer covering frequencies from 26.5 to 40 GHz is used since it will help demonstrate the production of unwanted signals in the measurement display and signal identification methods that help select and accurately measure the desired signals.



**Figure 3: Connection diagrams for preselected and unpreselected mixers and the Agilent PSA spectrum analyzer**

## Step two: Setting up the measurement

Setting up the signal source

Select a CW frequency of 35 GHz

Select an output power Level of -20 dBm

Setting up the PSA spectrum analyzer

Select the external mixer mode on the PSA

Hardkey: **Input/Output**

Softkeys: **Input Mixer, Input Mixer Ext.**

Next, select the mixer type, unselected in this example. (For preselected mixers, selecting the "Presel" mixer type activates a tuning signal that is routed to the Presel Tune Output connector on the rear panel of the analyzer.)

Hardkey: **Input/Output**

Softkeys: **Input Mixer, Mixer Config, Mixer Type Unpre**  
(the analyzer default setting)

Then select the external mixer band. (For more detailed information on band selection, see the band table in the "Practical Measurement Considerations" section later in this note.)

Hardkey: **Input/Output**

Softkeys: **Input Mixer, External Mixer, Ext Mix Band, 26.5 - 40 GHz (A)**

Store the amplitude (mixer conversion loss) corrections and enable the PSA's amplitude correction function. Begin by inserting the disk with the conversion loss corrections (if available) into the analyzer's floppy disk drive. If conversion loss corrections are not available on disk, they can be read from the data provided with the mixer (or printed on the mixer itself) and entered manually. Please see the operating instructions for Option AYZ.

Load the correction factors from disk and store them in the analyzer.

Hardkey: **File**

Softkeys: **Load, Type, More, Corrections**

Highlight the corrections file and press **Load Now**

Enable amplitude correction

Hardkey: **Amplitude**

Softkeys: **More, Corrections**

Select the type of correction file that was just loaded

Selecting the mixer harmonic

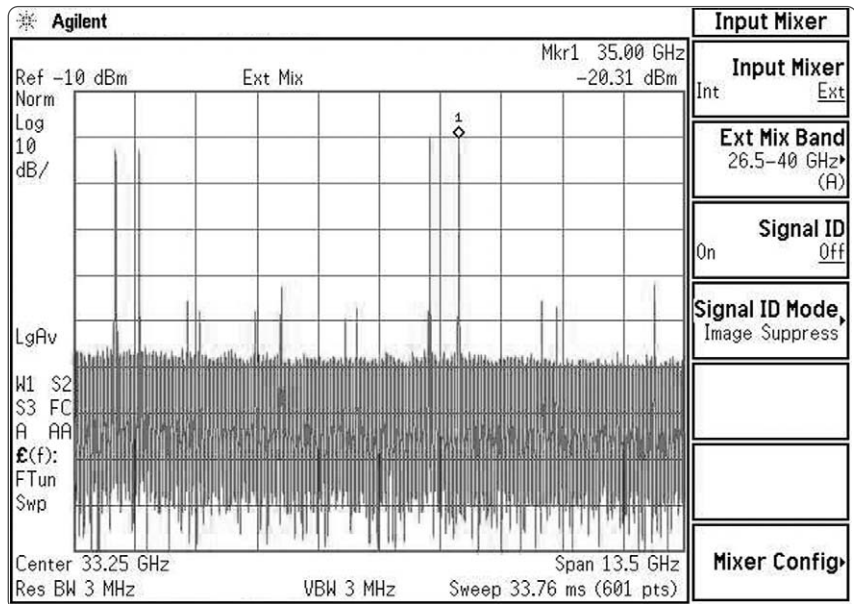
The harmonic mixing number, its associated sign and the availability of mixer bias can be automatically controlled by setting the harmonic mode to Auto, as used in this example. The harmonic number may be selected manually by pressing the **Input/Output** hardkey, followed by the **Input Mixer, Mixer Config,** and **Harmonic** keys to select **Man**. More information on manual harmonic selection is available in the operating instructions for Option AYZ.

At this point the desired center frequency and span would normally be selected.

For this measurement, we will begin with the default full frequency range for this band, which is a start frequency of 26.5 GHz and a stop frequency of 40 GHz (center frequency = 33.25 GHz, span = 13.5 GHz).



**Measurement result:**



**Figure 4: Example measurement of 35 GHz signal with an unselected external mixer. Note the large number of unwanted signals, created from undesired mixing modes.**

**Step three: Interpreting the measurement and identifying signals**

The input signal in this example is known to be a single, 35 GHz CW signal source. It is apparent that the external mixing process and the many mixing modes involved have produced many signals in the measurement in addition to the desired one. If the frequency of the input signal is accurately known, one can proceed to step four below, to set the center frequency and span for final analysis.

In many cases, however, it is important to identify undesired signals in the measurement display, and it may be useful to understand how these signals are created. Two sections that follow, "Understanding the Origin of the Signals in the Display" and "Using the Signal Identification Features in the PSA" will describe these important aspects of external mixing operations.

**Step four: Setting final center frequency and span**

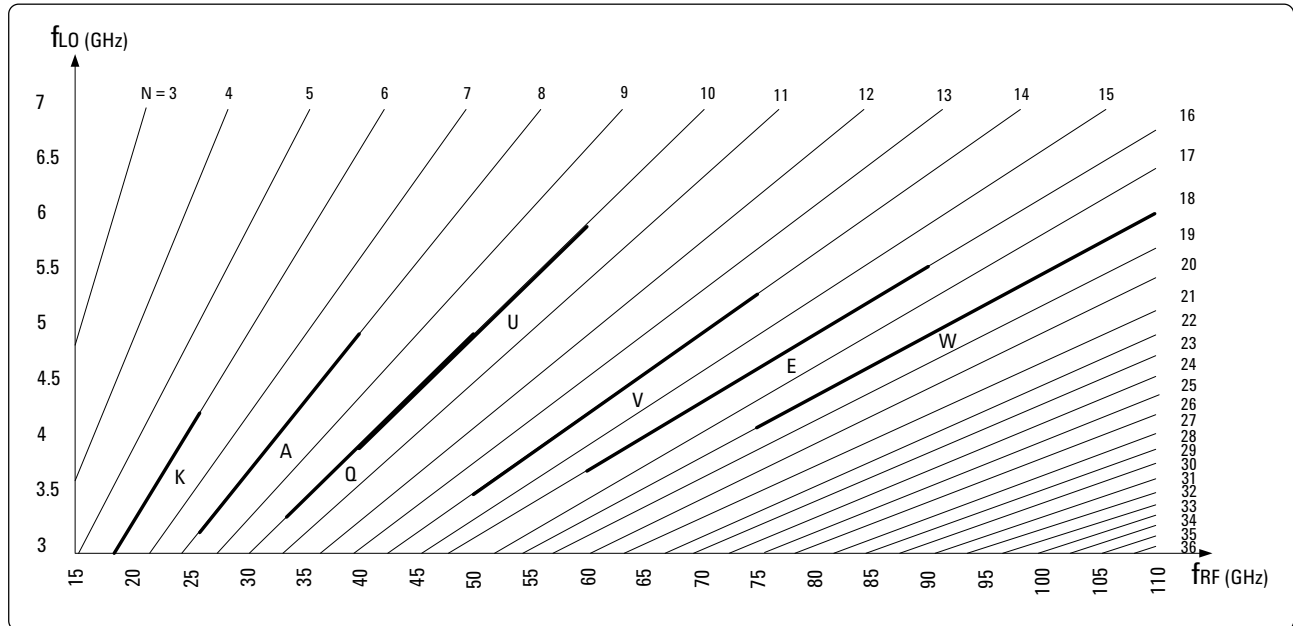
Initial analysis and signal identification is often done on a relatively wide frequency span, to find signals whose precise center frequency is not known, and to identify potential interfering signals or unwanted conversion products. After this analysis and verification, the frequency span is centered around the signal(s) of interest and the span is reduced to show the desired signals more clearly. This is also a good time to set reference level and scaling to show important features of the signal, such as sidebands or modulation.

## Understanding the origin of the signals in the display

As described above, the intended LO drive for the external mixer is a harmonic of the first LO from the spectrum analyzer. For the external mixing "A" band, which covers frequencies from 26.5 to 40 GHz, the 8th LO harmonic has been used. However, the external mixer generates all of the LO harmonic frequencies in addition to the 8th one. Thus, the incoming RF signal mixes with all of the LO harmonics and any mixing products produced at the 321.4 MHz IF frequency (as the LO sweeps through the selected span) will result in a response in the display.

One other factor affects the signals seen in the measurement display – the harmonics of the input signal. In this example, the 35 GHz signal source has considerable second harmonic energy at 70 GHz. This 70 GHz signal will mix with all of the LO harmonics resulting in additional signals in the measurement display.

Much of this mixing can be represented graphically starting with a general spur chart, which shows the external mixing bands. That spur chart listing responses from  $N = 3$  to  $N = 36$  is shown in Figure 5 below.



**Figure 5: Multiple response or spur chart. The dark lines mark the external mixing bands K, A, Q, U, V, E, and W. Bands F, D, E, Y, and J can be used by the PSA, but are not shown here.**

The analysis below is based on this spur chart. For simplicity, only the true signal has been used and its image ignored. Remember, however, that in external mixing applications, all true signals come with an image to form a pair.

**For PSA A-band external mixing:**

|                     |               |
|---------------------|---------------|
| Display frequency:  | 26.5 – 40 GHz |
| Display N:          | 8             |
| Input RF frequency: | f1 = 35 GHz   |
|                     | f2 = 70 GHz   |
| IF frequency:       | 321.4 MHz     |

Figure 6 below shows all of the possible mixing products projected into the A-band display screen at the RF input frequencies of 35 GHz (fundamental) and 70 GHz (second harmonic).

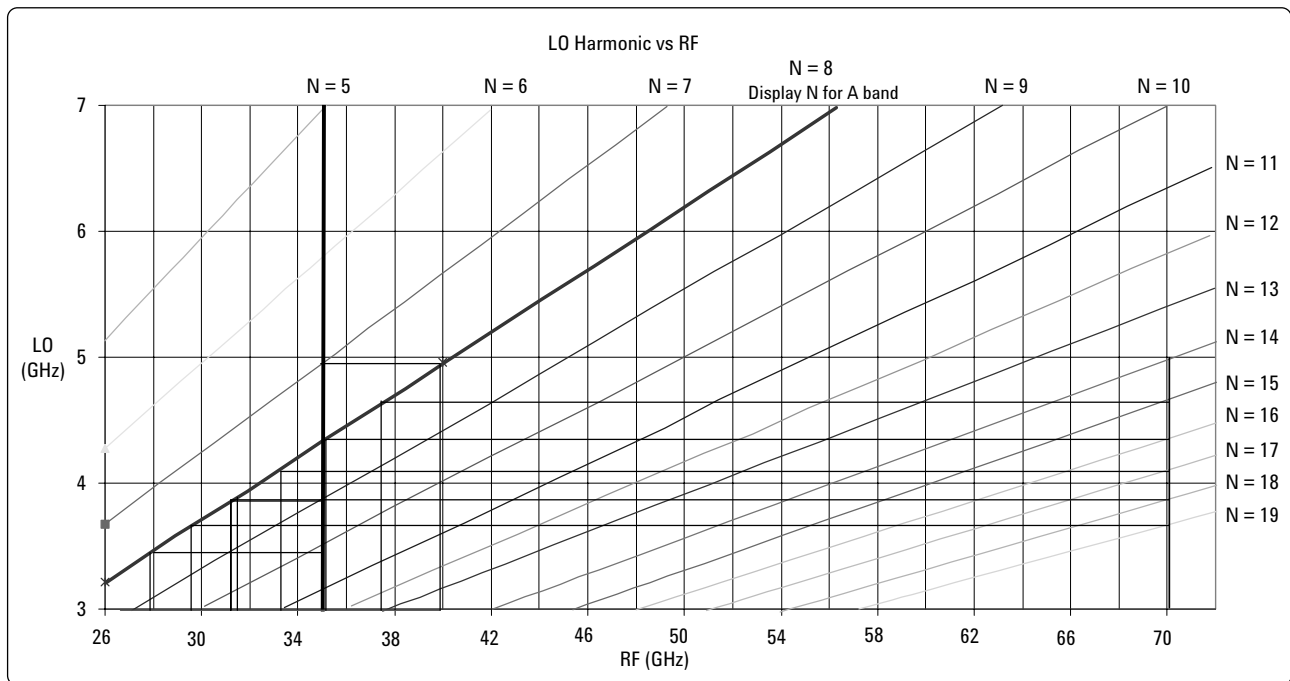


Figure 6: Possible mixing products in the A-band display, resulting from 35 and 70 GHz inputs.

To match our display results with the possible mixing products, it is useful to increase the scale of the display, and show the input frequency and LO harmonic number, as shown in Figure 7.

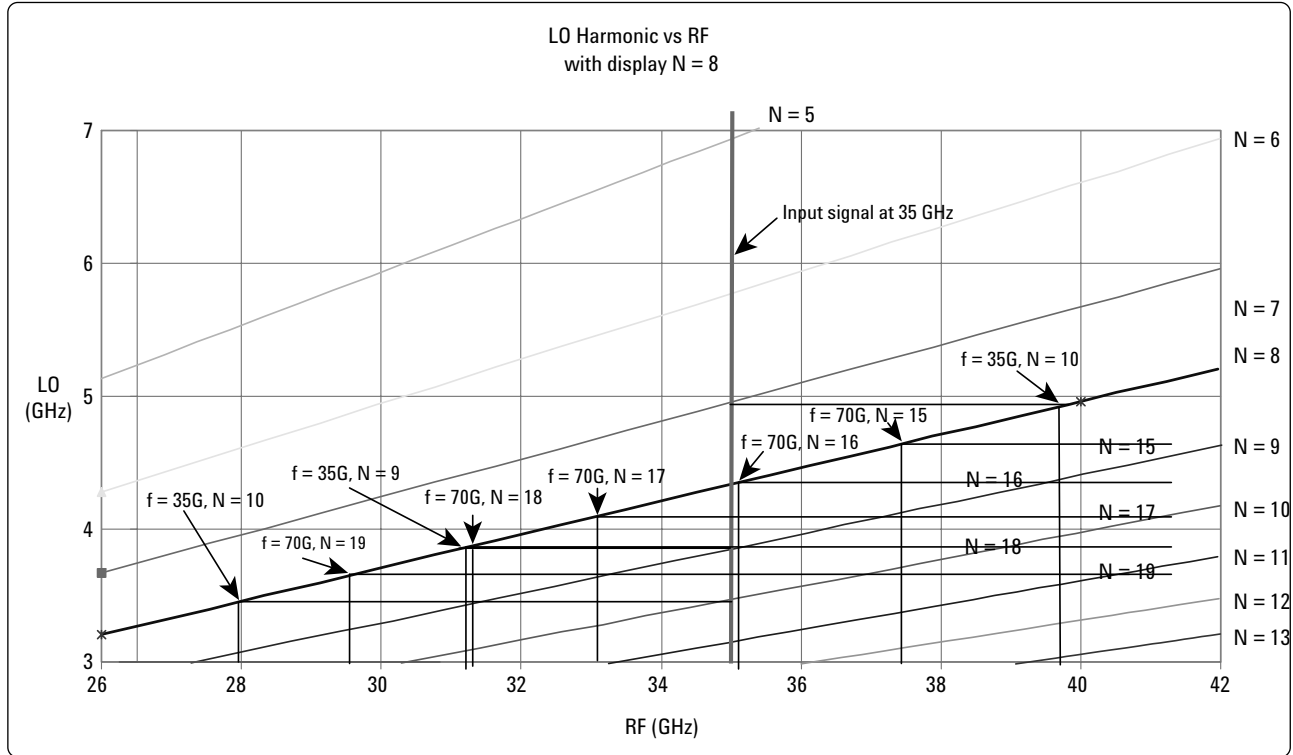


Figure 7: Mixing products, which appear in the example measurement result. The RF input frequency (35 or 70 GHz) is shown along with the LO harmonic number.

## Using the signal identification features in the PSA

Before we select a signal to analyze more closely we may wish to know which signals have been generated by an unintended LO harmonic or mixing mode, and therefore which are displayed at incorrect amplitudes and frequencies. This task may be performed in one of several ways with the PSA, and is called signal identification. While it may be instructive to manually analyze signal origin as described above, it is not necessary in most situations. Instead, we will use the signal identification and undesirable signal suppression features provided with the PSA Option AYZ.

The PSA Series spectrum analyzer offer two different signal identification methods: *Image Shift* and *Image Suppress*.

### The image shift function

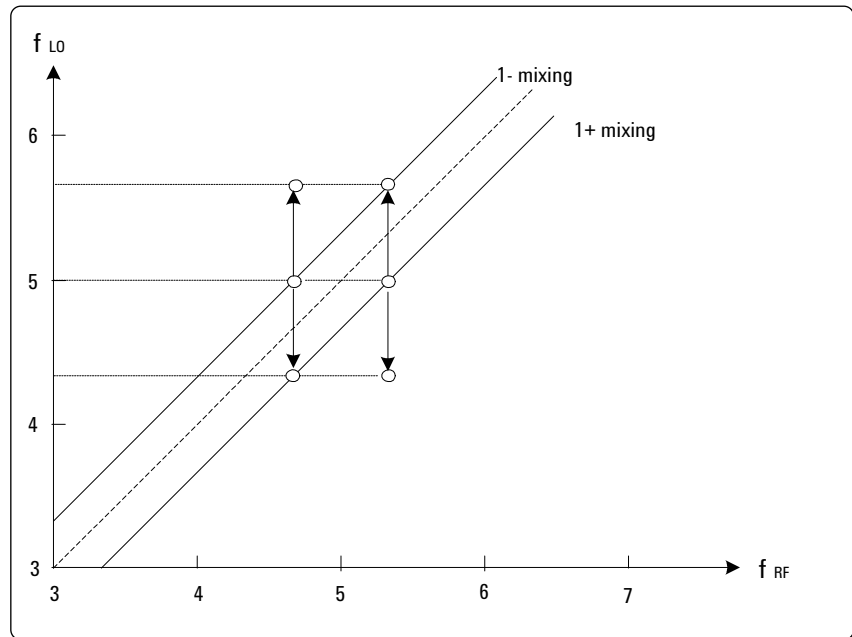
The image shift method does not remove undesired signals from the measurement display, but it causes them to shift position (or disappear in some cases) on alternate sweeps. The desired signals are unaffected, and can be identified in that way. This method is implemented by shifting the analyzer's LO by a frequency equal to twice the IF frequency divided by the harmonic number currently in use. In other words

$$F_{\text{shift}} = 2 * F_{\text{IF}} / N$$

or

$$F_{\text{shift}} = 642.8 \text{ MHz} / N$$

This division by N ensures that the desired LO harmonic used for external mixing is shifted by twice the IF frequency. This is shown graphically in Figure 8 below.



**Figure 8: Graphic description of the image shift method, showing both + mixing and - mixing.**

To explain this method by example, we have made these assumptions:

- we have tuned the spectrum analyzer to a frequency of 5.3214 GHz (the analyzer LO frequency will be 5 GHz) and we see a response in the center of the display, and
- the actual input signal is at either 5.3214 GHz or at 4.6786 GHz, though we do not know which one.

When the image shift function is activated, the spectrum analyzer changes its LO output by twice the IF frequency, first in one direction and then in the other, as shown in Figure 8 above.

Figure 8 shows that if our signal is indeed at 5.3 GHz and the analyzer shifts the LO frequency up, there will still be a response in the center of the display due to the "1+" mixing mode. On the other hand, when the LO is shifted downward there will be no response in the display.

Conversely, if the analyzer is tuned to 5.3214 GHz and the input signal is actually at 4.6786 GHz, the response would still appear in the middle of the display. In this case, using the image shift method there is no response when the LO is shifted up, but there is a response when the LO is shifted down. This result reveals that when the analyzer is tuned to 5.3214 GHz it is actually observing the image of 5.3214 GHz. Therefore, the analyzer must be tuned down in frequency by an amount equal to twice the IF frequency, to 4.6786 GHz to observe the response on the "1+" mixing mode for which the analyzer is calibrated.

The effect of the image shift function on this example measurement is shown in Figure 9 below.

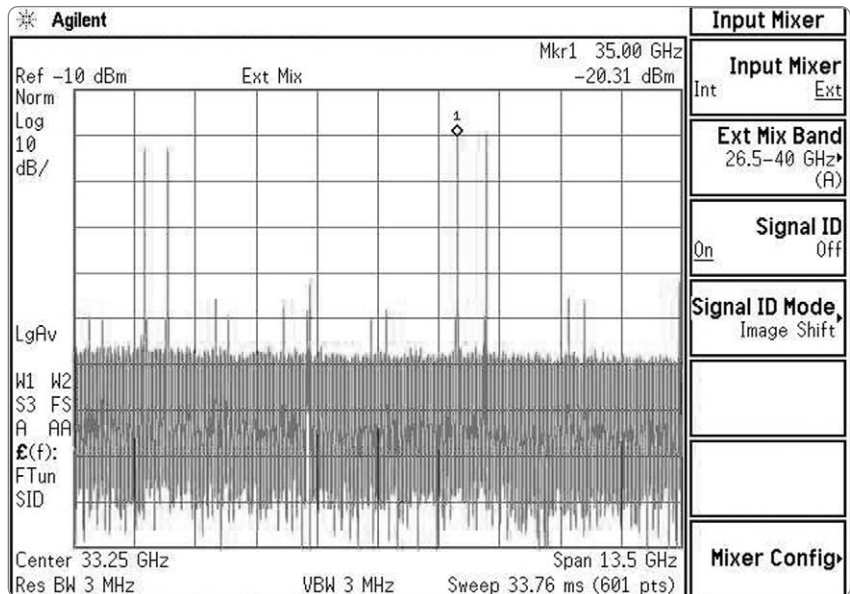
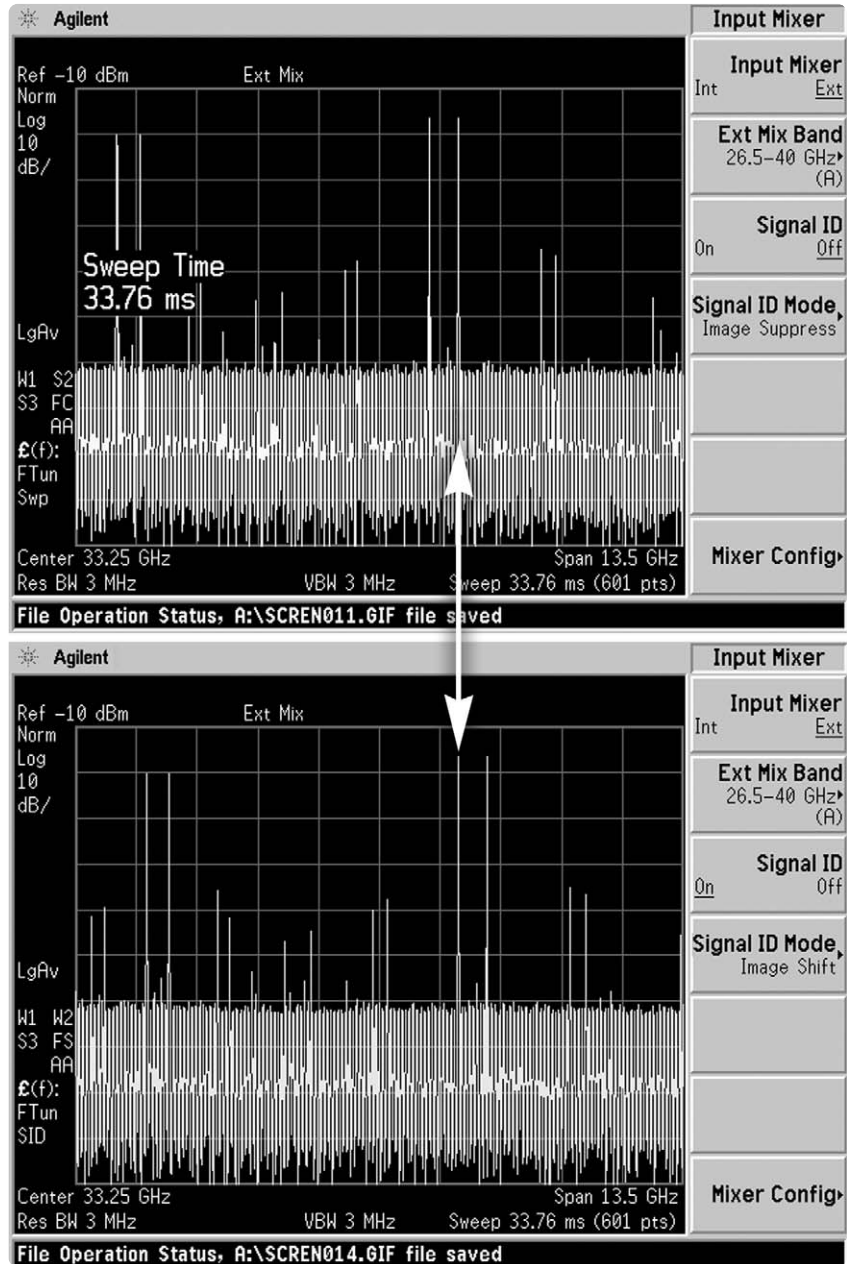


Figure 9: Example measurement of 35 GHz signal with the image shift function enabled.

The visual effect of the image shift function is perhaps easier to see if comparable displays are stacked and aligned as shown in Figure 10 below.



**Figure 10: Measurement results before (above) and after (below) the use of the image shift function on a 35 GHz signal. The actual signal location is marked by the vertical line between the measurement results.**

*The image suppress function*

The image suppress function builds on the image shift function, and offers the benefit of actually removing undesired signals from the measurement display.

In the image suppress mode, each displayed measurement is actually composed of the results of two sweeps, with the Min Hold function applied to the data, and where one sweep is performed with the LO in the image shift mode. The display function causes only the smaller amplitude value from the two sweeps to be displayed for each point.

Since all display responses that are shifted are present in only one of the two measurements, only the unshifted or valid response remains above the displayed noise level. This effectively removes undesired responses from the measurement display. The effect of the image suppress function is shown in Figure 11 below.

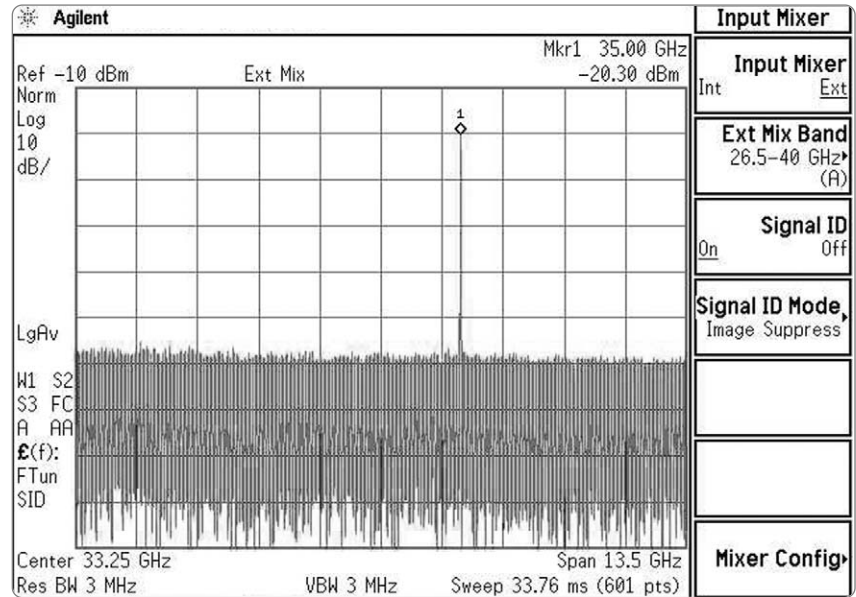


Figure 11: Example measurement of 35 GHz signal with the image suppress function enabled.



# Practical measurement considerations

## Choosing an external mixer

Agilent offers two external mixer families, the 11970 Series unpreselected mixers and 11974 Series preselected mixers, both of which are calibrated for amplitude over their full operating frequency ranges.

### Agilent 11970 Series harmonic mixers, 18 to 110 GHz

|        |                |
|--------|----------------|
| 11970K | 18 to 26.5 GHz |
| 11970A | 26.5 to 40 GHz |
| 11970Q | 33 to 50 GHz   |
| 11970U | 40 to 60 GHz   |
| 11970V | 50 to 75 GHz   |
| 11970W | 75 to 110 GHz  |

These unpreselected mixers offer flat frequency response and use a dual-diode design to provide low conversion loss and eliminate the need for mixer bias and tuning adjustments. For these mixers, the PSA uses its "-" mixing mode.

### Agilent 11974 Series preselected harmonic mixers, 26.5 to 75 GHz

|        |                |
|--------|----------------|
| 11974A | 26.5 to 40 GHz |
| 11974Q | 33 to 50 GHz   |
| 11974U | 40 to 60 GHz   |
| 11974V | 50 to 75 GHz   |

The 11974 Series preselected harmonic mixers eliminate the time-consuming signal identification process required with unpreselected harmonic mixers, in which the images and harmonics created by the mixing process must be removed from the display to identify the signal of interest. Preselection also reduces mixer overload from broadband signals and reduced radiation of LO harmonics back to the device under test. These mixers come with a standalone power supply.

The preselector filters have a bandwidth of approximately 100 MHz, sufficient to remove almost all undesired harmonic and image frequencies.

The preselected mixers require a tuning voltage for their internal filters. The PSA Series spectrum analyzers provide this voltage from a rear panel connector:

$$V_{\text{Prese Tune}} = 1.5 * F_{\text{LO}} \text{ Volts}$$

Where  $F_{\text{LO}}$  in GHz

Maximum  $V_{\text{Prese Tune}}$  is 10 Volts

### Other external mixers

External mixers are available from other manufacturers to cover frequencies to 325 GHz. Some mixers are of a single-diode design and require DC bias. The PSA can provide this bias from its IFinput connector. The bias current is adjustable from the analyzer front panel or remotely, through program control, to a maximum of 10 mA

#### Choosing a PSA external mixing band

More detailed information on the PSA's external mixing bands, mixing modes, and harmonic numbers is provided below in Table 1.

| Band name/<br>frequency range | 11970/other<br>unpreselected*<br>mix mode | 11974<br>preselected*<br>mix mode | LO<br>harmonic<br>number | Unpreselected display<br>minimum frequency<br>in GHz | Frequency range<br>maximum frequency<br>in GHz |
|-------------------------------|---|-----------------------------------|--------------------------|--|--|
| K band<br>18.0 to 26.5 GHz    | –   |                                   | 6                        | 17.7286  | 41.0786  |
| A band<br>26.5 to 40.0 GHz    | –   | +                                 | 8                        | 23.5286  | 54.8786  |
| Q band<br>33.0 to 50.0 GHz    | –   | +                                 | 10                       | 29.3286  | 68.6786  |
| U band<br>40.0 to 60.0 GHz    | –   | +                                 | 10                       | 29.3286  | 68.6786  |
| V band<br>50.0 to 75.0 GHz    | –   | +                                 | 14                       | 40.9286  | 96.2786  |
| E band<br>60 to 90 GHz        | –   |                                   | 16                       | 46.7286  | 110.0786                                       |
| W band<br>75 to 110 GHz       | –   |                                   | 18                       | 52.5286  | 123.8786                                       |
| F band<br>90 to 140 GHz       | –   |                                   | 22                       | 64.1286  | 151.4786                                       |
| D band<br>110 to 170 GHz      | –   |                                   | 26                       | 75.79286   | 179.0786                                       |
| G band<br>140 to 220 GHz      | –   |                                   | 32                       | 93.1286  | 220.4786                                       |
| Y band<br>170 to 260 GHz      | –   |                                   | 38                       | 110.5286   | 261.8786                                       |
| J band<br>220 to 325 GHz      | –   |                                   | 48                       | 139.5286   | 330.8786                                       |
| <b>User defined</b>           |   |                                   | N                        | See note   | See Note                                       |

\*Note:

For N = “+” mixing mode

Minimum frequency = (N x 2.9 GHz) + 321.4 MHz

Maximum frequency = (N x 6.9 GHz) + 321.4 MHz – 650 MHz

For N = “–” mixing mode

Minimum frequency = (N x 2.9 GHz) - 321.4 MHz + 650 MHz

Maximum frequency = (N x 6.9 GHz) - 321.4 MHz

**Table 1: PSA external mixing band summary**

## Amplitude calibration and amplitude accuracy

The amplitude measurements made by the PSA Series spectrum analyzers can be calibrated with Agilent preselected mixers, and any other external mixers that are characterized for conversion loss (either by the manufacturer or the user).

The PSA selects an IF gain of 20 dB when in the external mixing mode to approximately compensate for the external mixer's conversion loss. Thus, a signal with an amplitude of 20 dBm at the input of the IF port of the PSA will appear at 0 dBm at the display. Since actual conversion loss varies from mixer to mixer, and also with frequency, it is not typically equal to exactly 20 dB. The PSA uses a video shift to offset the amplitude difference of the analyzer's IF gain setting and external mixer's conversion loss.

Measured conversion loss is usually marked on the external mixer itself, and may be provided electronically on a floppy disk. As described in the example above, the conversion loss of an external mixer can be stored in the amplitude correction tables of the PSA under the amplitude key. Loss or gain from other elements such as cables, filters, and amplifiers can also be compensated for in this way.

Using an all-digital IF section and careful analog design, the Agilent PSA Series spectrum analyzers provide very accurate amplitude or power measurements. This accuracy, along with the amplitude corrections described above, ensures accurate measurements of externally-mixed signals as well.

Assuming the analyzer's display has been calibrated at the frequency of operation of the external mixer, table 2 lists the sources of amplitude measurement uncertainties that apply when measuring an absolute signal level. Note that the uncertainties shown here are from the analyzer, and are in addition to external uncertainties such as errors in the conversion loss measured for the mixer. These external uncertainties should be added to those contributed by the spectrum analyzer.

| <b>Source of uncertainty</b> | <b>Uncertainty (<math>\pm</math> dB)</b> |
|------------------------------|--|
| Absolute amplitude accuracy  | 0.27                                     |
| IF path frequency response   | 0.4                                      |
| Total uncertainty            | 0.67                                     |
| Total uncertainty in RSS     | 0.48                                     |

**Table 2: PSA Series amplitude accuracy in external mixing mode**

Unlike many other spectrum analyzers using external mixing, the PSA's display remains correctly calibrated for the desired signal when the analyzer's signal identification modes are in use. Recall from the discussion above that two sweeps are performed in the signal identification modes, where the LO frequency is offset by twice the IF frequency for the second sweep. Although the conversion loss of the mixer may change because of the different parameters in the second sweep, the amplitude information is derived solely from the first sweep. Therefore, amplitude measurements are accurate whether signal identification techniques are used or not, eliminating the need for the measurement step of disabling signal identification before final amplitude measurements.

## Frequency accuracy

The E4440 PSA Series has a synthesized first local oscillator for exceptional frequency accuracy and stability throughout its tuning range. The frequency accuracy is based on the analyzer's temperature-stabilized internal reference oscillator or on an external reference, if supplied.

The two terms for frequency accuracy in these measurements are frequency readout accuracy and span accuracy.

Frequency readout accuracy can be calculated as:

$$\pm (\text{marker freq.} * \text{freq.ref. accy.} + 0.25\% * \text{span} + 5\% * \text{RBW} + 2 \text{ Hz} + 0.5 * \text{horizontal resolution})$$

Where Freq. Ref. accy. =  $\pm 7 * 10^{-8}$  Hz for the internal reference,

and

$$\text{Horizontal resolution} = \text{span} / \text{number of trace points}$$

The default number of trace points for the PSA is 601, and can be set by the user to values from 101 to 8192 points.

If an external reference is used, its accuracy should be substituted for the internal reference accuracy term above. If desired, horizontal resolution can be adjusted by the user.

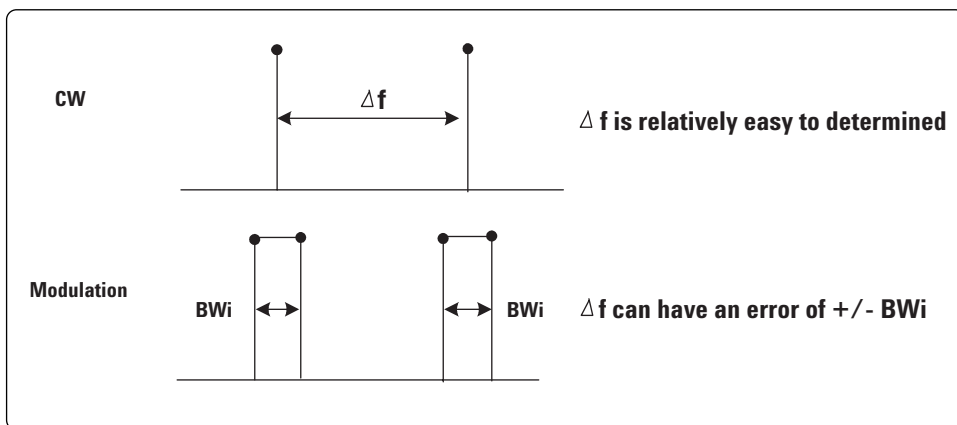
Span accuracy can be calculated as:

$$\pm (0.2\% * \text{span} + \text{horizontal resolution})$$

## Measuring modulated signals

There are two challenges when measuring modulated signals: the difficulty in measuring carrier frequencies or frequency differences, and measurement of modulation bandwidth that may be distorted if the LO harmonic used in the mixing is not the intended one.

Modulation on a signal, especially wide and/or flat modulation types such as high modulation index FM or CDMA, can cause errors in determining carrier frequency, as shown in Figure 12 below.

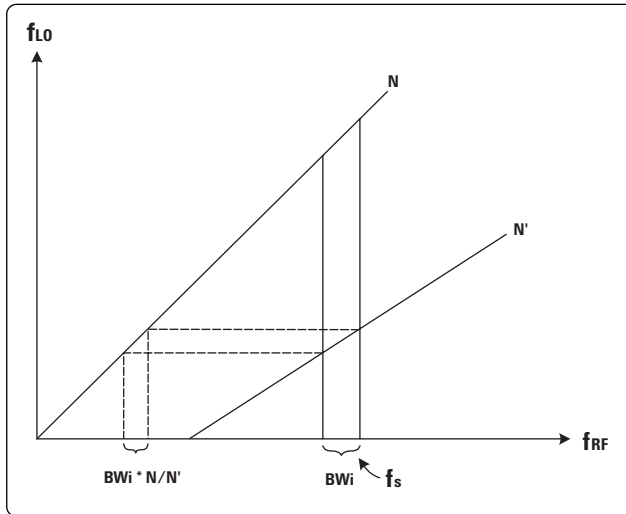


**Figure 12: Comparing measurement of CW and modulated signals. While  $\Delta f$  is relatively easy to determine in the CW case,  $\Delta f$  measurements may be in error by  $\pm BW_i$  in the case of modulated signals.**

For a modulated signal, its displayed bandwidth changes when its harmonic  $N'$  is different from the display calibrated  $N$ . Figure 13 below graphically shows that when  $N'$  is higher than the display calibrated  $N$ , the apparent modulation bandwidth is decreased.

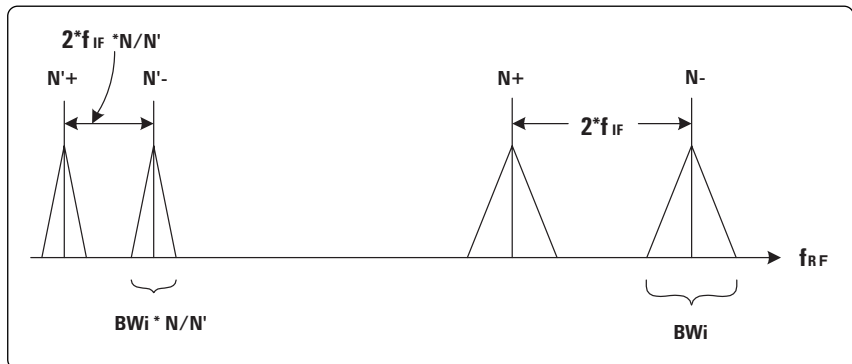
Assuming the display is calibrated for  $N$ ,  $f_s$  has modulation bandwidth equal to  $BW_i$ . Figure 13 shows that the modulated signal resulting from the  $N'$  harmonic that projects onto the  $N$  harmonic calibrated display, has a displayed  $BW = BW_i * N/N'$ .

For  $N' > N$ ,  $BW_i * N/N'$  is smaller than  $BW_i$ , as shown in Figure 13. For  $N' < N$ ,  $BW_i * N/N'$  is larger than  $BW_i$ .



**Figure 13: Graphic demonstration of distortion of apparent modulation bandwidth and frequency spacing by the use of the wrong LO harmonic.**

Figure 14 shows an example of these errors on a modulated signal for a display calibrated to the  $N$  harmonic, and where  $N' > N$ . In this case, not only is the apparent tone spacing reduced, but also the apparent bandwidth is reduced to  $BW_i * N/N'$ .



**Figure 14: Display appearance of errors in apparent bandwidth and frequency spacing due to use of incorrect LO harmonic.**

## Conclusion

External mixing is a practical and economical technique for extending the frequency coverage of a spectrum analyzer. By performing the first frequency mixing (downconversion) operation external to the analyzer itself frequencies far beyond the basic range of the analyzer can be effectively and accurately measured.

For microwave spectrum analyzers, higher frequencies are usually measured using harmonic mixing, and the very highest frequencies are measured by combining the techniques of harmonic and external mixing. This application note has demonstrated basic theoretical background and typical operations for applications requiring external mixers.

By performing the first frequency mixing (downconversion) operation external to the analyzer itself, frequencies to 325 GHz can be effectively and accurately measured. The PSA Series Option AYZ provides an excellent solution for applications requiring external mixers. This option includes the required hardware and software to make and display the measurements, and a number of features to improve ease-of-use and measurement quality.

## References and Resources

*8 Hints for Better Millimeter-Wave Measurements*  
Application Note 1391, Literature Number 5988-5680EN

Web:  
[www.agilent.com/find/externalmixers](http://www.agilent.com/find/externalmixers)





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Revised: May 7, 2007

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Printed in USA, October 25, 2007  
5988-9414EN



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