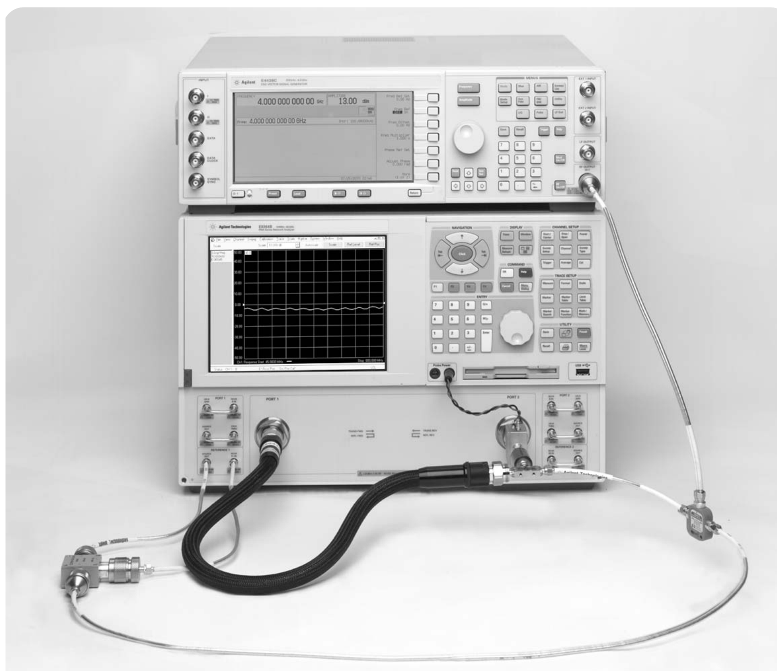
Agilent
PNA Microwave Network Analyzers

Application Note 1408-2

Mixer Conversion-Loss and Group-Delay Measurement Techniques and Comparisons



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Introduction

This application note compares techniques and instruments for measuring **Conversion Loss** and **Group Delay** on a single stage converter with an embedded low pass filter.

Conversion Loss using a:

- Spectrum analyzer
- Scalar network analyzer
- Vector network analyzer with frequency-offset mode
- Vector network analyzer with frequency-offset error correction

Group Delay using a:

- Vector network analyzer: golden-mixer technique
- Vector network analyzer: three-mixer technique
- Vector network analyzer with frequency-offset error correction

Mixer Terminology

The following terminology is used throughout this paper:

- Mixer ports are termed **in(put)**, **out(put)**, and **LO**.
- The frequencies are termed **input**, **outpu**t, **LO**. The traditional RF and IF terms are not used to avoid confusion when a mixer is used as both an upconverter and a down converter.

f^{Freq}_{Port} = The frequency (Freq) that appears at (Port)

For example:

f^{LO}_{in} = The LO frequency that appears at the input port.

f^{input}_{out} = The input frequency that appears at the out(put) port.

Measurement Setup

The following measurement setup is used in each conversion loss measurement technique:

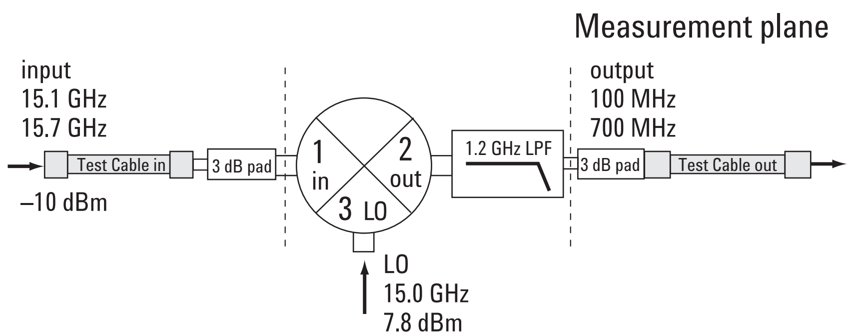

Figure 1. Example of a mixer-under-test configuration.

Each measurement technique is compared in the following areas:

- Test setup complexity
- Measurement accuracy
- Suggested implementation and costs

Test setup complexity
This includes physical setup, calibration techniques, time, and effort required.

Measurement accuracy
The measurement accuracy section examines the additional considerations that need to be addressed to get the most accurate results.

An airline experiment is performed to isolate the systematic errors present in the transmission path for measurement. The conversion loss or group delay measurement of the device-under-test (DUT) by itself is compared to the measurement of the DUT and airline. The airline is added to the measurement configuration as shown in Figure 2. It affects the phase relationship between the reflected error signals and the actual measurement signal. They will add together to produce a different result. In an ideal environment, the only change will be the loss of the airline. By comparing the measurement differences between the techniques, one can infer the level of uncertainly ripple caused by the systematic errors present in each method.

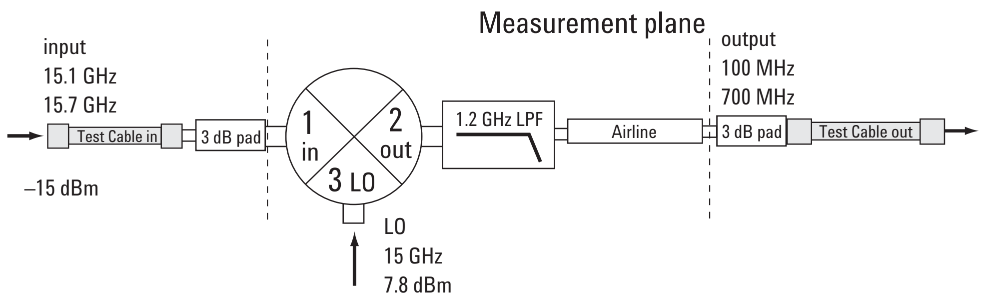

Figure 2. Example of a mixer-under-test with addition of airline.

Suggested implementation and costs
With a variety of instruments from different suppliers it is hard to generalize cost by simple categories. This final section aims to identify some relative price points in comparison to other alternatives and will identify other sources of cost including additional instruments required, operator training, test accessories, additional options, etc.

Conversion Loss

Conversion loss is a very important measurement that is used to quantify the transmission performance of frequency converting devices.

a) $$\text{Conversion loss}_{dB} = 10 \log \frac{|\boldsymbol{f}_{in}^{input}|_{mW}}{|\boldsymbol{f}_{out}^{output}|_{mW}}$$

b) $$\text{Conversion loss}_{dB} = |\boldsymbol{f}_{in}^{input}|_{dBm} - |\boldsymbol{f}_{out}^{output}|_{dBm}$$

Figure 3. Basic conversion loss formula in a) linear and b) logarithmic power. Conversion Loss is always expressed as a positive number.

Whether expressed in linear (mW) or logarithmic (dB) terms, conversion loss is the ratio of the input power, $\boldsymbol{f}_{in}$, to the output power $\boldsymbol{f}_{out}$. However, because the frequency at the input of the converter is different from the frequency at the output of the converter, this presents a considerable measurement challenge. Conversion loss is highly dependent on local oscillator (LO) power level.

Conversion Loss

Spectrum Analyzer

A popular technique for making a conversion loss measurement is to use a spectrum analyzer. A standard spectrum analyzer can be used to simultaneously measure absolute power at multiple frequencies. This is ideal when measuring signals with unknown frequency and power levels.

Test setup complexity

The setup and use of a spectrum analyzer is very straightforward. The output of the converter is connected to the input of the analyzer. All signals at the output of the mixer are immediately displayed. These signals include both the sum and difference mixing products, input signal, LO signal, and all of the spurious mixing products.

The measurement can be configured in about 15 minutes. It requires an external source for the input signal and another for the LO signal. Measurements can be made at a single input frequency or swept over a specific bandwidth.

The measurement can be made in at least two ways:

- The simplest way is to use the max hold feature, available on most spectrum analyzers, by increasing the dwell time of the input source to be greater than one spectrum analyzer sweep. Figure 4 shows the results of an absolute power measurement using the Agilent PSA Series spectrum analyzer. For this measurement, 50 milliseconds per point dwell time was used requiring approximately 23 seconds for one complete sweep.

- Another alternative is to control the sources and spectrum analyzer remotely (through a program you write). The program sets the CW frequency of the sources and spectrum analyzer, triggers the sources, and makes the power measurement at the correct frequency. The data is saved at that data point, the frequency incremented, and the processes repeated. The saved data can then be printed or plotted. Converters with internal LO's, with or without a lockable time base, can be tested with this method without any special considerations.

Figure 4. Output-power measurement of a mixer using the configuration illustrated in Figure 1.

Spectrum analyzers measure power; not conversion loss, therefore, conversion loss must be calculated externally. To use the equation in Figure 3, the input power to the converter must be measured as a reference. The best way is to connect the *test cable in* directly to the spectrum analyzer input, save the response, and remove it from the measured response.

A common mistake is to connect the *test cable in* and *test cable out* together using a thru connection, which would remove the response of both test cables. However, *test cable out* will see lower frequencies out of the converter during the measurement and therefore less loss than at the input frequencies of the normalization. To accurately remove the cable loss, a vector network analyzer (VNA) can be used to characterize the insertion loss of the *test cable out* over its intended frequency range. Figure 5 shows the addition of this correction factor in the general conversion loss equation. Note that the insertion loss of the cable is negative and should be added to the conversion loss.

$$\text{Conversion loss}_{\text{dB}} = \left[\left| \boldsymbol{f}_{\text{in}}^{\text{input}} \right|_{\text{dBm}} - \left| \boldsymbol{f}_{\text{out}}^{\text{output}} \right|_{\text{dBm}} \right] + S_{21\ \text{Cbl out}}^{\text{output}}$$

Figure 5. Spectrum analyzer conversion loss correction factor.

Using this corrected conversion loss formula, a spreadsheet can be used to calculate the response over frequency. Saving data, importing data, and applying the calculations to every measurement requires considerable time and resources.

Measurement accuracy

In addition to the response of the test cables, mismatches between the mixer and the test system hardware cause amplitude and phase ripple in the measurement. Using the airline technique describe earlier, the delta between two conversion loss measurements made on the same instrument can be seen. In Figure 6 the SA trace has over 1.5 dB of ripple due to these mismatch errors. In addition, the absolute amplitude accuracy of the SA is specified (for measurements < 3 GHz) as ±0.62 dB. Therefore, the total uncertainty is 1.5 + .62 = 2.12 dB.

Attenuators are used to reduce mismatch errors between the various test system components.

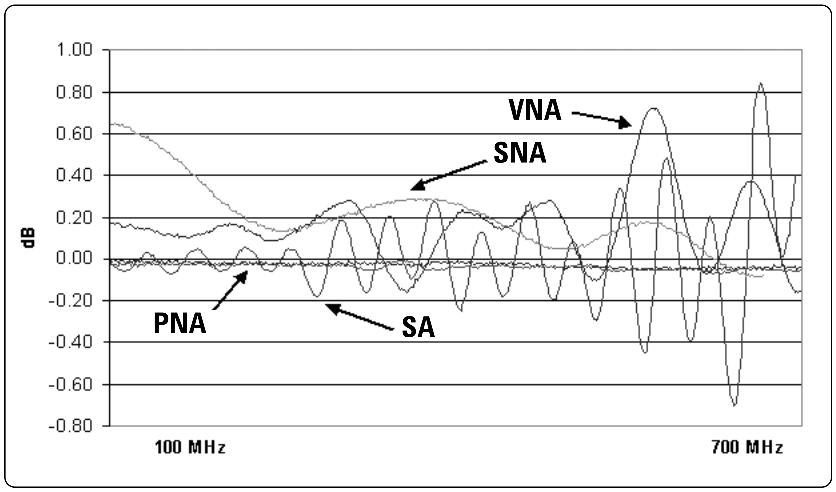

Figure 6. Conversion loss airline delta instrument comparison.

Suggested implementation and costs

In addition to a general-purpose spectrum analyzer, one or two external sources are required. Also, test accessories such as cables, attenuators, and filters are required. For more accurate results, access to a VNA for cable loss measurements and an external PC to save and calculate corrected data is required.

The real cost of using this solution may be hidden in programming and automation controls to collect data and apply correction factors. Setup is easy, but normalization can be time consuming and tedious requiring sufficient operator training.

Scalar Network Analyzer

Network analyzers apply a known stimulus over a range of frequencies to a device and measure the response. Network analyzers typically display the results as S-parameters, the ratio of the output (response) to the input (stimulus) in dB. However, S-parameters are not valid because with converters the input frequency is different from the output frequency. A new transmission parameter, denoted with a "C", is used to indicate that a frequency conversion has taken place between the stimulus and response ports. C-parameters use the same stimulus and response port notation as S-parameters.

Scalar network analyzers (SNA), such as the Agilent 8757D, consist of external broadband detectors and signal separation devices that measure the stimulus as a reference. Scalar analyzers cannot measure complex parameters, so only the magnitude of the signal is measured, which is sufficient for conversion loss measurements.

Test setup complexity

The initial SNA setup can be confusing. Setup requires external test set components and multiple signal sources. One source is used to sweep the stimulus over frequency. The sources and analyzer are connected using triggering lines and control the bus. The SNA triggers the stimulus to start sweeping, then detects and displays the measured results. Some modern SNAs have integrated the source and test set, which simplifies the setup.

One difficulty with older analyzers such as the 8757D is saving measurement data. It does not have an easy export function. GPIB commands must be used to extract data directly or the data can be printed to compatible printers.

The setup for the testing mixers generally includes attenuators at the input and output ports to reduce mismatch errors, and a filter at the mixer output to separate the two primary mixing produces. This filter complicates the normalization process but without it the broadband detector would measure the sum of all power at the output of the mixer. This includes $|\boldsymbol{f}^{output-}_{out}| + |\boldsymbol{f}^{output+}_{out}| + |\boldsymbol{f}^{input}_{out}| + |\boldsymbol{f}^{LO}_{out}|$ + other higher order mixing products.

Calibration consists of an internal power reference calibration for the detectors over the frequency range of interest. A normalization is performed at the RF input for the reference detector to remove the effects of the test cable in loss.

For this example with a bandwidth of 600 MHz, the calibration took four minutes for both the reference and measurement detectors.

$$C_{21} = \left[|\boldsymbol{f}^{output}_{out}|_{dBm} - |\boldsymbol{f}^{input}_{in}|_{dBm} \right] + S^{output}_{21\ Cbl\ out\ +\ IF\ filter}$$

Figure 7. Scalar network analyzer conversion-loss correction factor.

To overcome the previous normalization challenge, a “golden mixer” approach is often used. This is a quick and easy method used in manufacturing production test. A golden mixer is similar to the mixer-under-test and is known to have good performance. The mixer-under-test is measured and compared to the golden mixer. Because the response of the cables, filters, attenuators, receiver, and anything else in the path will be the same for both the golden mixer and the mixer-under-test, the only variable will be the mixer-under-test. Acceptable performance is judged to be within a predetermined tolerance. With this approach, no external calculations are required.

There are two limitations to this approach:

1. It is difficult to select a golden mixer response.
2. It is difficult to determine individual specifications of the test device independent to the golden mixer.

In a system design, many factors impact overall performance. Component level specifications that are derived independent of a golden mixer can make troubleshooting of integration problems easier.

Measurement accuracy

As was seen with the spectrum analyzer, the use of the airline experiment shown in Figures 1 and 2 is used to isolate systematic errors. Even with the addition of 3 dB attenuators, 0.6 dB of amplitude ripple is present in the measurement results on the SNA trace in Figure 6. The amplitude accuracy of the detectors used in DC mode add approximately 0.5 dB to the uncertainty of the measurement.

Suggested implementation and costs

Scalar network analyzers are often chosen because they are more economical then vector network analyzers. The complete cost of use will also include one or two external sources, detectors, bridges, and test accessories. User training time can be reduced with the use of automation techniques requiring an external PC. The golden mixer approach can reduce correction calculations.

The speed in which a SNA can make measurements is one thing that sets it apart from the other examples shown. The 600 MHz bandwidth measurement was made in 92 ms per sweep.

Because of its speed, the best application for the SNA is in manufacturing where a high level of accuracy is not required.

Vector Network Analyzer Using Frequency-Offset Mode

A more versatile solution for mixer test is a vector network analyzer (VNA). A VNA uses tuned-receivers, which allow measurements of both magnitude and phase. Normally, a VNA tunes its receivers to the same frequency as the stimulus and set its receiver IF bandpass filters narrow enough to reject noise in the measurement. With this approach a VNA can achieve a much higher dynamic range then is possible with a SNA.

Frequency-offset (an option that is available on many modern VNA's) enables the measurement receivers to be tuned independent of, and at a fixed offset from, the source stimulus. This allows the measurement of mixers, which have an output frequency at a fixed offset from the input frequency.

Test setup complexity

Because of the VNA's integrated test set, the mixer test setup is generally less complicated than the SNA. There are two basic configurations when using a VNA in frequency-offset mode:

1. The tuned receivers make absolute power measurements. Power versus frequency can be displayed, similar to a spectrum analyzer. The ratio of the reference signal at the input frequency to the output signal at the output frequency can also be displayed.

2. A second mixer, called a reference mixer, is placed in the reference signal path of the VNA. When available, this is done through external jumpers that give access to the internal reference signal path. This enables the reference signal to be synchronously converted, by sharing the same LO source as the mixer-under-test, to the same output frequency as the mixer-under-test. This is more complex and is most beneficial for relative phase measurements. It will be discussed further in the group delay section.

To minimize mismatch reflections, 3 dB attenuators are used; an IF filter should also be used at the output to separate the desired mixing products. Though the receivers are tuned to the desired frequency, other mixing products can be very large and could cause additional errors as their reflections reconvert in the mixer.

The VNA provides an internal stimulus source, but an external LO source is still required. It is important to lock the 10 MHz time bases of these two instruments together to prevent their oscillators from drifting.

Because absolute power measurements are being preformed, the source and receivers should be calibrated using a power meter. In most VNAs this is accomplished by first leveling the source power over the output frequency of the f^{output} mixer. This is done at the end of *test cable in*. *Test cable in* is connected to *test cable ou*t and the receivers are calibrated at f^{output}. Next the source power is leveled at the end of *test cable in* over the input frequency range. This moves the measurement planes to the end of the test cables and no separate cable characterizations or correction factors are required. This is a tremendous time-saver compared to previous methods.

Vector network analyzers that offer frequency-offset mode perform this process with varying degrees of ease. Some analyzers guide users though the process step-by-step. Others, require a specific documented procedure to be followed. This measurement took approximately 25 minutes to setup including 5 minutes to perform the calibration. The leveling itself required 45 seconds, for 401 points.

Setting up the measurement on a modern VNA usually involves a graphical user screen that illustrates the input, LO, and output frequency ranges and power levels to be tested. Often the VNA will provide control of an external source.

Measurement accuracy

The same airline method is used to compare error signals. The use of attenuators and filters help reduce the error effects, but as seen on the VNA trace in Figure 6, the remaining error level is still greater then 0.7 dB. It shows a slight improvement over the spectrum analyzer, but not a significant difference from the scalar network analyzer. The absolute accuracy of the power meter and sensor is transferred to the VNA after calibration. It has a specified accuracy of ±0.04 dB.

Suggested implementation and costs

Although the price of economy VNA's has decreased over time, the narrowband VNAs offering frequency-offset mode are still more of an investment over their scalar counterparts. These are directly due to the extra hardware requirements to create a phase coherent reference and offset the source and receivers. The required test accessories are similar to the SNA. The setup is easier than the SNA because the analyzer controls more of the measurement and no post measurement corrections need to be applied. Most interfaces are fairly intuitive. The main advantage of the VNA is its increased speed over a spectrum analyzer and increased dynamic range over a SNA. It also brings a higher level of accuracy to non-conversion loss measurements such as S-parameters and isolation with its vector-error correction.

Vector Network Analyzer with Frequency-Offset Error Correction

In general, the advantage of a VNA over an SNA is its ability to measure phase. From phase measurements, parameters such as group delay can be calculated. Measuring phase has the added benefit of enabling vector-error correction. Through the calibration process, the complex error signals are measured and mathematically removed from measurements. This is a significant advantage for accurate measurement of linear devices. However, it is not directly usable in frequency-offset measurements because the measured error signals will be at different frequencies at the input and output ports of the analyzer. Traditional VNA's cannot apply vector-error correction techniques at different frequencies. The microwave PNA Series network analyzer overcomes this traditional limitation by implementing a different error model created to describe frequency-offset measurements. This error model, described further in [1] Agilent Application Note 1408-1, enables the microwave PNA to apply vector-error correction techniques to frequency-offset devices measurements.

Test setup complexity

The test setup is generally similar to the standard frequency-offset VNA. Because of the vector-error correction, the need for attenuators used in previous configurations is eliminated. This increases the usable power available and overall dynamic range of the system. Filters are still recommended at the output of the mixer. The PNA has a frequency converter application that manages the frequency-offset measurement setup as well as the guided scalar-mixer calibration. This two-tiered calibration combines a matched corrected power calibration and a traditional 2-port calibration. The measurement setup is configured easily from a single graphical screen. An additional advantage is its ability to save mixer configurations or instrument states to be used later or on a different PNA. This reduces the time to setup repetitive measurements.

During calibration, the PNA guides the user through all the needed measurements to apply the frequency-offset error correction for C_{21} conversion loss measurements. Additionally, the calibration is valid for standard S_{11} and S_{22} reflection measurements. The complete calibration took only 3 minutes for the matched-power meter and the 2-port calibration using Agilent ECal. Including calibration, the measurement can be setup and performed in less the 15 minutes.

Frequency-offset error corrected conversion loss measurements are displayed directly without the need for external calculations. The 1.5 sec sweep time is the slowest of the three network analyzer solutions, but much faster then the spectrum analyzer. Similar to a 2-port calibrated measurement that requires a forward and reverse (source stimulus at port 2) sweep, a scalar-mixer calibration requires three sweeps. There are two forward sweeps at the input frequency and one reverse sweep at the output frequency.

Measurement accuracy

The scalar-mixer calibration is the most advanced calibration technique available for conversion-loss measurements. Looking back to Figure 6, the trace labeled PNA only shows the loss of the airline. Two measurements were made with the PNA: one using attenuators and one not using attenuators. There is no noticeable difference between the results. The amplitude ripple in all the other measurements is eliminated making it a significantly more accurate representation of the actual performance of the mixer-under-test. The absolute accuracy of the power meter and sensor is transferred to the PNA after calibration. It has a specified accuracy of ±0.04 dB.

Suggested implementation and costs

The initial instrument cost of the PNA solution is more then a standard frequency-offset VNA solution because of its advanced calibration, hardware, and application features. Cost savings can be realized in the reduced time needed for training, setup time, and required test accessories.

The best application of the PNA solution is for testing high performance mixers and converters, where tenths of dB ripple accuracy is desired. The scalar-mixer calibration makes an ideal choice for quickly moving between linear and conversion loss mixer measurements.

Conversion-loss summary

Comparing the four conversion-loss measurement techniques, the following general principles emerge:

- Spectrum analyzers have the easiest setup, but the time saved in setup is quickly consumed with tedious normalization techniques to remove the influence of cable loss.
- Network analyzers perform measurements faster and often can normalize out all cable losses and conversion loss can be displayed directly on the instrument.
- Spectrum analyzers have the advantage of measuring harmonics and unknown spurs.
- Vector network analyzers offer S-parameters measurements.
- Systematic mismatch errors are present in all solutions. These error signals add to the actual response to produce an amplitude ripple of up to 1.6 dB peak-to-peak in this example. Only the microwave PNA extends the accuracy of vector-error correction methodology to frequency-offset measurements; which in this example yielded at 0.05 dB level of accuracy.

Group Delay

Group delay is the measure of a signal's transition time through a device. It is classically defined as the negative derivative of phase versus frequency as shown in Figure 8. The result of a group-delay measurement depends upon many measurement factors including aperture, averaging, and IF bandwidth. The true negative derivative of phase versus frequency cannot be determined because any measurement made with a network analyzer is discrete, with one phase point per frequency point, so there is no continuous function from which to take a derivative. Instead, slope of the phase is calculated over a certain frequency range. The values of two frequency points on either side of the frequency of interest are selected and the corresponding phase slope is calculated. The number of frequency points over which the slope is calculated is the aperture. The default aperture is the smallest difference between any two frequency points. The aperture can be adjusted using the "smoothing aperture" feature available on Agilent network analyzers. The smoothing aperture should always be specified for a group delay measurement.

$$\text{Group delay}_{(t)} = \frac{-d\phi}{d\omega} = \frac{-1}{360} \times \frac{d\phi}{df}$$

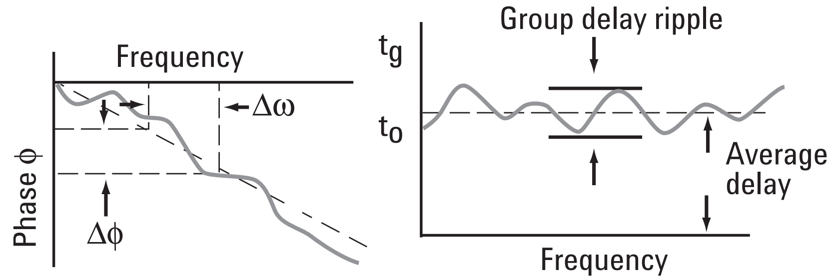

Figure 8. Group delay

Phase is a relative measurement. In order for any phase measurement to be made there must be a reference phase signal. Unlike conversion loss, where the power ratio can be done at different frequencies, a phase measurement on a frequency-translating device requires a reference at the same frequency.

To create a phase reference, a theoretical, instantaneous zero length (delay), zero loss phase shift must take place. Since this theoretical ideal cannot be achieved, a real mixer must be used to approximate it and its effects on the system must be de-embedded so the response of the mixer-under-test can be isolated.

The "golden mixer" method is one way to de-embed a reference mixer without knowing its delay and loss. The system, including the reference mixer, is normalized to the response of the golden mixer. In this case, phase deviation is measurement relative to the golden mixer and group delay is said to be relative.

Making absolute group-delay measurements requires a characterized reference mixer with a known delay and loss that can be mathematically de-embedded after the measurement.

A third option is to use a calibration mixer to calibrate the system thereby correcting for the response of the reference mixer with the reference channel.

The reference, golden, and calibration mixer should not be confused. They serve different functions and are used in different configurations. They are defined as:

Reference mixer (uncharacterized) – A mixer placed in the reference path of a network analyzer to create a frequency-translated reference signal. This mixer becomes part of the reference path response and should be normalized out of the measurement. Its response does not need to be known.

Characterized reference mixer – A mixer placed in series with the mixer-under-test that has been characterized for its conversion loss and delay response, and is used to re-convert the output of the mixer-under-test to the same frequency as its input. Once the output is re-converted a linear ratio can be preformed.

Golden mixer – A mixer that is similar to the mixer-under-test and is known to have good performance. It is used in conjunction with a reference mixer to normalize the test system to make *relative* measurements against the golden mixer's response.

Calibration mixer – A mixer that has been characterized for its conversion loss, delay, input match, output match, and is used as a characterized thru standard to calibrate the test system.

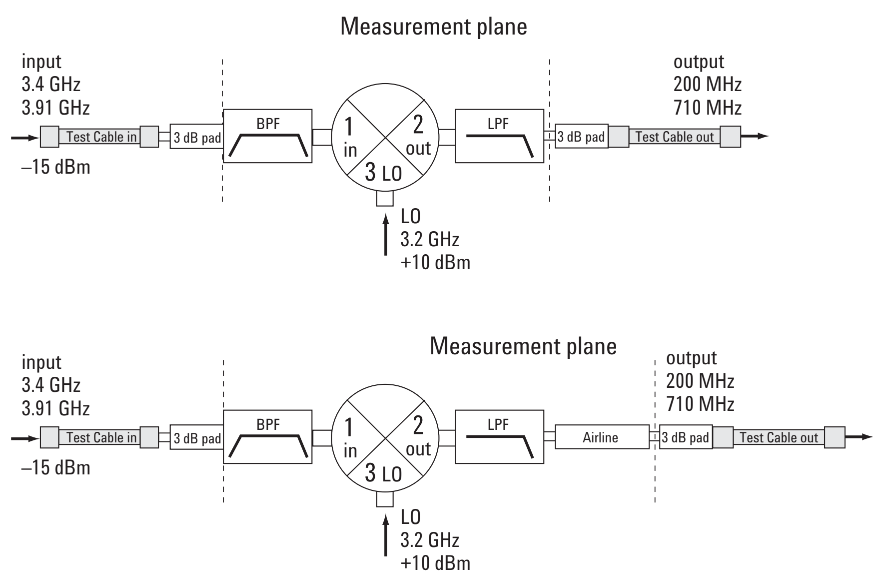

Figure 9. Converter configuration for airline delta comparison.

Vector Network Analyzer – Golden-Mixer Technique

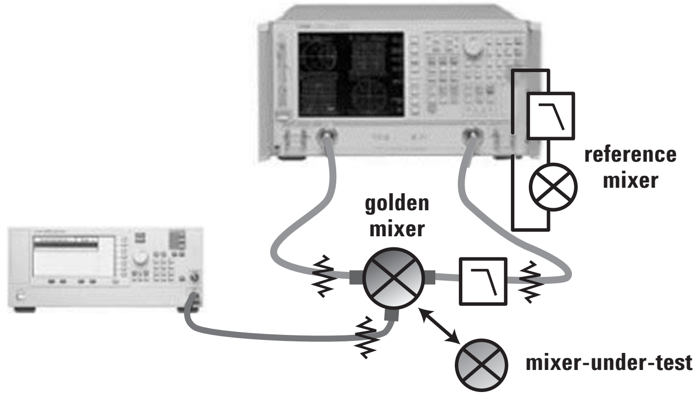

Figure 10. 8720ES group delay configuration using golden and reference mixers.

Figure 10 is the basic configuration of a VNA setup with a reference mixer using a golden mixer for normalization for relative measurements. Receiver power calibration is not required because of the normalization that will be performed. Phase shift is measured on the mixer-under-test versus the golden mixer. Group delay is calculated relative to the group delay from the golden mixer.

Test setup complexity

A reference mixer is selected and configured in the reference path. As illustrated in Figure 10, an IF filter is also required in the reference path to select the correct mixing product. The reference mixer is selected that has the same frequency range and conversion capabilities as the mixer-under-test, but does not need to match in performance. Selecting a reference mixer and filter can be the most time consuming part of the setup.

Setting up the measurement requires the frequency-offset feature. On a modern VNA, this usually involves a graphical user screen that illustrates the input, LO, output frequency ranges, and power levels to be tested. Often the VNA will provide control of an external source. After the interface is learned, measurements can be setup within a few minutes.

After the measurement is setup, the normalization can be performed with the golden mixer. The golden mixer is placed in the test system as shown in Figure 10. The response of the golden mixer is saved into trace memory and trace math is applied to divide data by memory. This normalizes the response of the reference mixer as well as the cable, filter, and attenuators. The mixer-under-test is measured and the VNA displays the group delay relative to the golden mixer.

Measurement accuracy

Phase measurements are more susceptible to system noise. Therefore, use the smallest IF bandwidth possible. This configuration will also be influenced by the systematic errors seen in the conversion loss example.

Suggested implementation and cost

The incremental costs for phase measurements include the reference mixer and an additional filter. In addition, the external jumpers that provide access to the reference signal path may require a hardware option on some VNA's.

Group delay and phase measurements are generally reserved for design applications and are generally not performed in manufacturing unless matching or tuning is required.

Vector Network Analyzer – Three-Mixer Technique

The three-mixer technique can also be used to characterize a characterized reference mixer's conversion loss and delay performance. This technique combines three up/down converter measurements to isolate the performance of each of the mixers. The up/down converter method requires that each mixer used is reciprocal and that the mixers both match.

- A mixer that is reciprocal has the same up-conversion response as its down-conversion response. Reciprocity is explained further in [1] Agilent Application Note 1408-1.
- Mixers that are matched to each other have identical conversion loss responses.

This is a significant requirement of this method because the mixers cannot be measured independently. The response is a function of both mixers because they are measured in series.

One advantage of this technique is that it does not require a frequency-offset VNA. Figure 11 shows that the input of the first mixer down converts to an intermediate frequency. The sum mixing product is filtered out by the IF filter. Because the two mixers share a common LO, the input to the second mixer is up converted back to the original input frequency of the first mixer. Then a standard S_{21} ratio is performed for the total conversion loss or delay. Half the response is attributed to each mixer, after the filter effects are removed. By adding a third mixer to the setup, three combinations of measurements can be made (A-B, A-C, B-C). This removes the matched requirement and only one mixer needs to be reciprocal (B in this example, because it will be used as an up converter in one measurement and a down converter in a second measurement). With three measurements, a simultaneous equation can be solved for the response of each mixer. These calculations must be performed manually or with the use of a software package running on an external PC. In addition, the same normalization and calibration techniques must be used to remove the cable losses. Once this characterized reference mixer has been characterized, it can be used to measure other non-matching, non-reciprocal mixers with the standard up/down converter method.

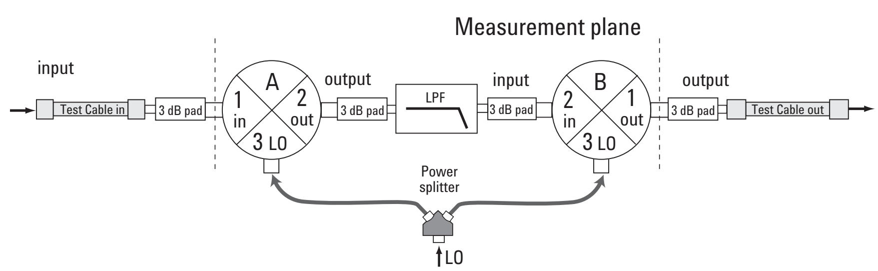

Figure 11. Up/down conversion method measures two mixers in series.

Test setup complexity

As seen from the brief overview of the three-mixer technique, there are multiple measurements and calculations that are required before the mixer-under-test can be placed in the system to be measured. Using a software-guided program, the characterization of the mixers requires approximately 30 minutes. After the characterization process, the mixer-under-test simply needs to be placed in the measurement path and the response of the characterized reference mixer removed. Measuring the characterized reference mixer for each new measurement is a significant time investment.

Measurement accuracy

Reducing the systematic errors for group-delay measurements is even more important then for conversion loss. One advantage of the up/down method is that because the source and receivers of the analyzer are at the same frequency, traditional vector-error correction can be used (however, other sources of errors are still present). In this technique, additional errors result from mismatches between the mixer-under-test, the IF filter, and the characterized reference mixer. Therefore, attenuators were used in these examples. Since these error signals are caused by the test configuration and not the instrument test set, they will not be removed with vector-error correction. In fact these error signals are present during the characterization of the reference mixer step and will corrupt the integrity of its characterization. This adds further error to the exact performance of the reference mixer that should be mathematical removed from the total response. It is very hard to quantify how these errors will interact in given measurements. Again, the best technique is the airline delta measurements to determine the error contribution for this example measurement. The three-mixer technique trace in Figure 12 shows the delta group delay ripple.

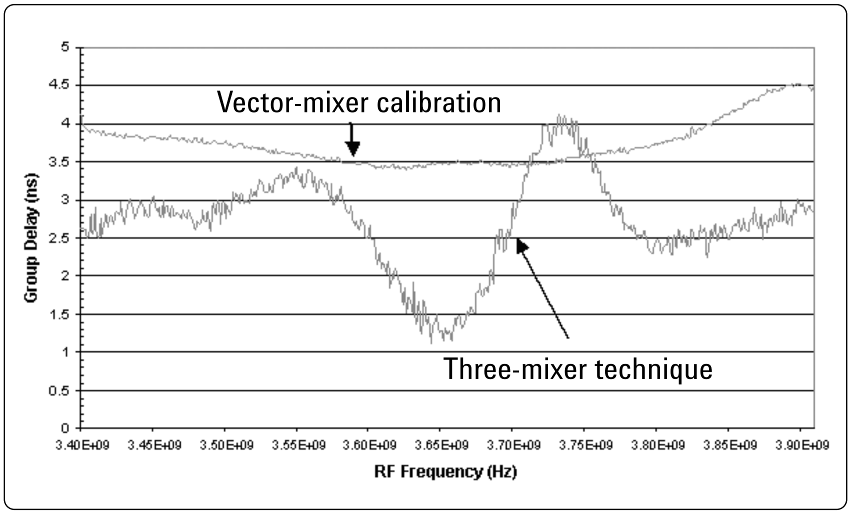

Figure 12. Measurement comparison of group delay techniques.

Suggested implementation and costs

The main of advantage of the three-mixer technique or the up/down converter method is that it does not require a frequency-offset VNA. When a characterized reference mixer is used, absolute measurements of phase deviation and group can be made, eliminating the need for golden mixer techniques.

Vector Network Analyzer with Frequency-Offset Error Correction

The PNA vector-mixer calibration uses a parallel method to create a phase reference instead of the series method employed by the up/down converter method. The guided vector mixer calibration begins by characterizing a mixer. However, it is not simply a characterized reference mixer. It is a calibration mixer that will be used in the network analyzer calibration process. The process is easier to setup and perform than the three-mixer technique because it only requires a single mixer. One set of reflection measurements are made to completely characterize the mixer's input impedance, output impedance, conversion loss, and delay. This information allows the mixer to be used as a calibration standard.

Test setup complexity

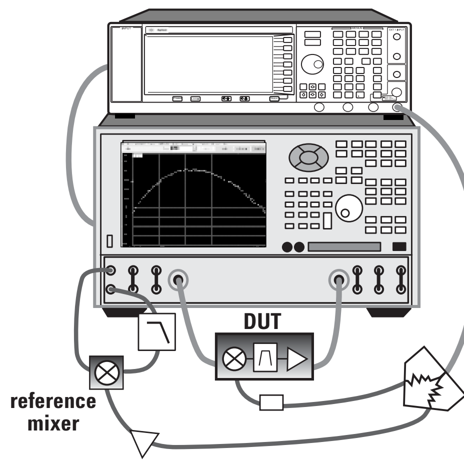

Figure 13. PNA group delay configuration using the vector-mixer calibration.

The measurement setup for a vector-mixer calibration looks very similar to the relative phase measurements setup in Figure 10. Both use the parallel method of creating a reference signal by placing a reference mixer in the reference path of the network analyzer. The difference will be seen in setting up the analyzer and the calibration techniques.

A single screen is used to set the mixer's test parameters. The vector-mixer calibration is implemented as a guided calibration wizard on the microwave PNA Series network analyzers. The vector-mixer calibration is a three-step process.

1. A standard 2-port calibration is performed over the input and output frequency ranges of the mixer-under-test.

2. A calibration mixer is characterized and later used as a thru standard. This innovative characterization technique removes most of the limitations of the three-mixer technique. It requires a single mixer and IF filter and one set of reflection measurements. Because reflection measurements are used, the calibration mixer serves to reconvert its own reference signal. This technique requires the calibration mixer to be reciprocal. Through this series of reflection measurements and calculations, the complex input match, output match, conversion loss and delay are determined. This technique is further explained in [1] Agilent Application Note 1408-1, *Mixer Transmission Measurements Using The Frequency Converter Application*, Appendix C. For information on selecting a calibration mixer see [2] Agilent Application Note 1408-3.

3. The calibration mixer is measured as a characterized thru line. The response, corrected for the mismatch between the mixer and the test system, is compared with its characterized response from the previous step. Any difference between these two measurements is an error due to the frequency response added by the reference path and reference mixer and cabling. Because the response of the calibration mixer is accurately known, the response of the reference mixer is mathematically removed by the PNA application. This establishes a measurement reference plan independent of the reference mixer.

The whole process, including the characterization step, can be performed in less then 15 minutes. In addition, unlimited calibration mixer characterization files can be saved and recalled later; eliminating the need to perform step 2 each time. Because this calibration measures and mathematically removes the errors in the transmission path, attenuators are not required in the test setup.

Measurement accuracy

Comparing the three-mixer and the vector-mixer calibration traces in Figure12, a significant difference in group-delay ripple can be seen. This is because the vector-mixer calibration is not exposed to the additional error signals created from mismatches between the two mixers in the up/down converter configuration.

The following techniques are available for special cases that will further reduce uncertainties when using the vector-mixer calibration.

- When measuring frequencies less then 250 MHz, the signal-to-noise ratio decreases due to the roll-off of the port 2 coupler, which reduces dynamic range. To increase this signal-to-noise ratio, reverse the port 2 jumpers and bypass the coupler as shown in Figure 14. This will also reduce the dynamic range by an equal amount in the reverse direction, but since only forward measurements are made, this is not a problem.

Figure 14. PNA Series front panel: port 2 and jumpers.

Note
When measuring output frequencies between 10 MHz and 250 MHz, a large signal-to-noise-ratio improvement can be made by reversing the port two coupler.

- It is important to separate the LO path of the mixer-under-test and the reference mixer. If the mixer-under-test has poor LO to output isolation ($\boldsymbol{f}^{LO}_{out}$), the mismatch of the reference LO port can be reflected though the power splitter to the LO port of the mixer-under-test. This creates additional errors that were not present during the calibration and will not be corrected. To eliminate this problem, an isolator or buffer amplifier can be placed in the LO path of the reference mixer.

Neither of these two optional techniques were used to obtain the results seen in Figure 12. Further insights for increased accuracy can be found in [2] Agilent Application Note 1408-3.

Suggested implementation and costs

The microwave PNA series network analyzers, and the optional frequency converter application is ideal for measuring phase linearity and group delay on high performance mixers and converters with accessible LO's.

One of its major advantages is its guided user interface, which gives even the occasional user confidence in setup and calibration that only those experienced in mixer measurements had previously.

The cost of a PNA frequency converter application instrument is more expensive then a standard network analyzer because of its advanced functionality. However, it will reduce test time and the incremental expenses of additional test accessories such as multiple characterized reference mixers and attenuators while showing the true performance of the mixer-under-test.

Group delay summary

Group delay, which is calculated from phase information, is a challenging measurement that is best preformed using a vector network analyzer. Relative and absolute measurements are both possible using the techniques shown in this section.

Absolute measurements have many advantages because they separate the measurement results from a golden mixer. This makes measurements results portable and easier to compare with similar measurements.

Absolute group-delay measurements can only be made with certainty when an accurate characterization of a reference or calibration mixer is available. The accuracy to which this is known directly affects the over-all measurement accuracy of the group delay. Unfortunately, how the reference is removed from the response is not the only issue governing the accuracy of the measurement. Systematic errors greatly effect results if not removed or minimized. Vector-error correction is the most effective way of removing these effects and achieving accurate mixer performance results.

References

This document is available under the library information on the Agilent MW PNA Series website: **www.agilent.com/find/pna**

[1] *Mixer Transmission Measurements Using the Frequency Converter Application*, Agilent application note 1408-1, literature number 5988-8642E.

[2] *Improving Measurement and Calibration Accuracy Using the Frequency Converter Application*, Agilent application note 1408-3, literature number 5988-9642E.

Additional References

Mixer Measurements Using Network and Spectrum Analysis; L. Dunleavy, T. Weller, E. Grimes, J. Culver; 48th ARFTG Conference; Clearwater, Florida, USA; December 5-6, 1996.

Web Resources

For additional literature and product information about the Agilent PNA Series visit:
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