Application Note

OPTIMIZING MIXER GROUP DELAY MEASUREMENTS

Characterizing Mixers and other Frequency-conversion Devices

Products:

- R&S®ZNA26 Vector Network Analyzer, 4 Ports, 26.5 GHz
- R&S®ZNA43 Vector Network Analyzer, 4 Ports, 43.5 GHz
- R&S®ZNA-B5 Second Internal LO Source
- R&S®ZNAxx-B16 Direct Source and Receiver Access
- R&S®ZNAxx-B213 Internal Combiner
- R&S®ZNA-K4 Scalar mixer and Arbitrary Frequency-converting Measurements
- R&S®ZNA-K9 Group Delay Measurements on Frequency Converters without LO Access
- R&S®ZNAxx-Z9 Cable Set for R&S®ZNA-K9

Rohde & Schwarz | | Version 01 | 10.2020

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Contents

1 Overview

In every mixer-based system, constant group-delay is essential to achieving the highest levels of performance. However, as new designs become more tightly integrated, the use of an embedded local oscillator (LO) makes testing more difficult. The solution is a vector network analyzer that can stimulate the device under test (DUT) using a two-tone signal. The analyzer measures the phase differences between the two signals at the DUT's input and output, and it then calculates group delay. This white paper offers ten tips that will improve group delay measurements made with this technique. As shown in a series of actual measurements, the result improvement in peak-to-peak variation in group delay ranged from 5x (satellite block converter) to 39x (calibration mixer).

2 Measuring Group Delay in Mixers

Mixers are a fundamental component of any receiver or transmitter, and every such system depends on well-controlled amplitude, phase and group-delay characteristics. In particular, phase-linearity and constant (or flat) group-delay are essential to achieving low bit-error rates in data transmissions or high resolution in phased-array radar systems.

Traditionally, relative phase and group delay have been measured using the “reference” or “golden mixer” technique, and this requires direct access to the local oscillator (LO). However, with increasing integration and miniaturization, neither the LO nor a common reference signal are accessible. To make the necessary measurements, a vector network analyzer (VNA) must stimulate the device under test (DUT) with a two-tone signal. After measuring the phase differences between these two signals at both the input and the output of the DUT, the VNA then calculates the phase transfer function or the group delay through the DUT.[1]

There are many ways to improve group delay measurements on mixers and other frequency-converting devices that have an embedded LO. Several of these are well-documented in a Rohde & Schwarz Application Note titled *Group Delay Measurements on Frequency Converting Devices*. [2]

This white paper is an adjunct, offering ten tips for better group delay measurements. All of the example measurements shown here were performed on a satellite block downconverter or a calibration mixer using an R&S®ZNA vector network analyzer. The analyzer was designed specifically for this type of measurement. The enabling option is R&S®ZNA-K9, group delay measurements on frequency converters without LO access (i.e., two-tone measurements). The analyzer must also be configured with R&S®ZNA-K4, scalar mixer and arbitrary frequency-converting measurements. Two additional options are used with certain of the combining techniques shown here: R&S®ZNA-B16, direct source and receiver access; and R&S®ZNA-Z9, cable set.

2.1 Preview: Before and After Results

As noted above, measurements were made on two DUTs: the satellite block converter and an external calibration mixer. As a preview of the techniques shown in this paper, before and after measurements highlight the resulting improvements for each DUT. The key metric is peak-to-peak variation in group delay, and the gradual improvement is documented through measurement traces shown at the end of tips 2, 3, 5, 6, 8 and 10 (tips 4, 7 and 9 provide other benefits).

Figure 1 shows before and after measurements on the block downconverter. The upper trace was made using a preset state modified with a few necessary changes to the measurement configuration: frequency sweep from 19 GHz to 21 GHz, LO frequency of 18.75 GHz, and LO1 power of 10 dBm. As shown, the measurement is noisy and erratic, and the summary table at the upper left of the trace (green text) shows a peak-to-peak variation of 827 ps. The lower trace shows a fully optimized result produced via the application of the tips. Here, the summary trace (blue text) shows a peak-to-peak variation of just 159 ps. That is a 5x improvement in the measurement of the satellite block converter.

Figure 2 shows before and after measurements of the calibration mixer. In the upper trace, the peak-to-peak variation in group delay is 1.279 ns; in stark contrast, the lower trace is comparatively steady, with peak-to-

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[1] Measurement accuracy does not depend on the frequency stability of the embedded LO as long its deviation is within the measurement bandwidth of the analyzer’s receivers.
[2] You can download Rohde & Schwarz Application Note 1EZ-81 from our website.

peak variation of roughly 32 ps (lower-left table, blue text). This result demonstrates an improvement of roughly 39x in peak-to-peak variation in group delay.

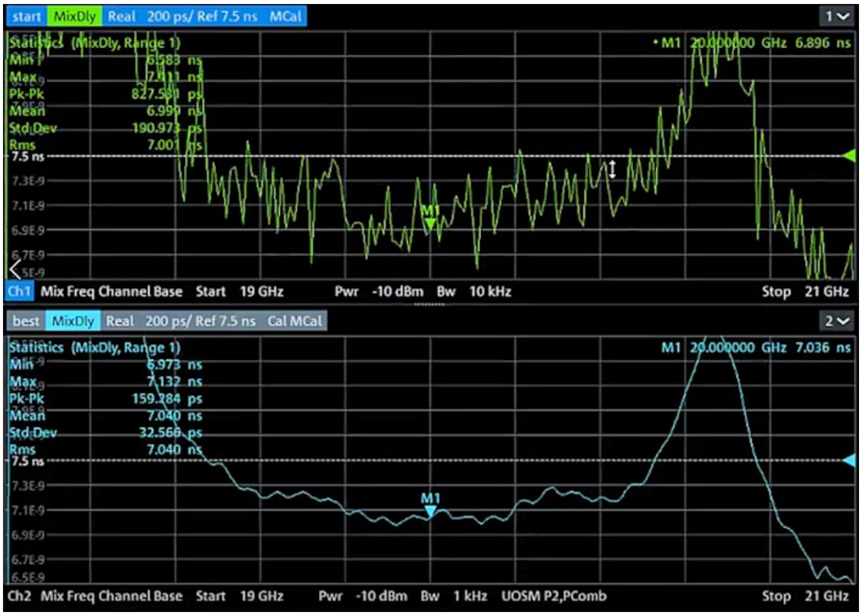


Figure 1. Application of a few useful tips transformed a quick measurement based on a preset state (top trace) into a stable result with significantly improved peak-to-peak variation (blue table) when testing the satellite block converter.

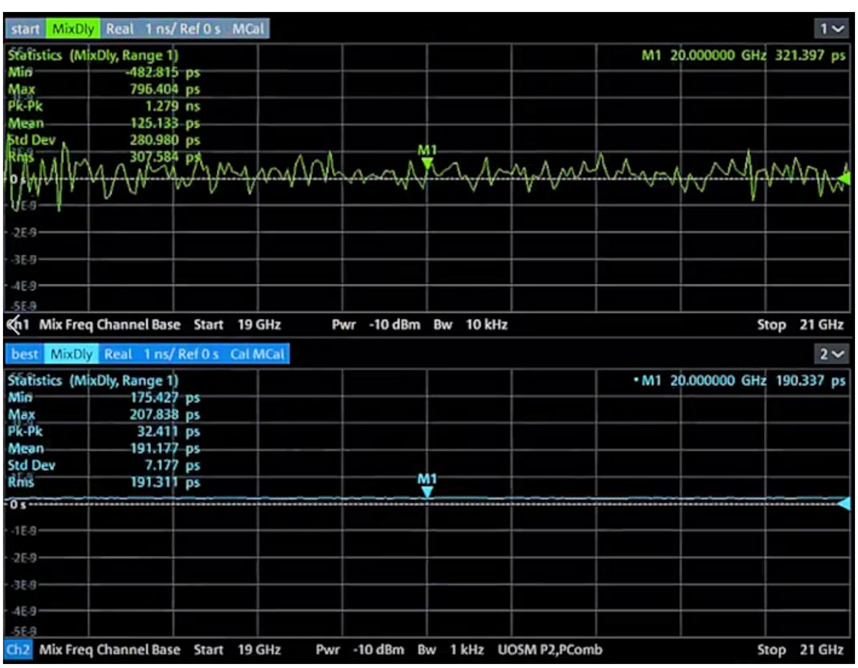


Figure 2. Similarly, application of the tips provided major improvements in measurements of the calibration mixer.

2.2 Ten Tips for Better Group Delay Measurements

As you scan through the main body of this note, you'll notice Tip 2 is longer and more detailed than the others. The reason: the second tip provides an essential foundation for the ensuing narrative. Specifically, Tip 1 provides a bit of general guidance that occasional users will find to be especially useful. Tips 3 through 10 focus on the essential ideas that help enhance your measurement results.

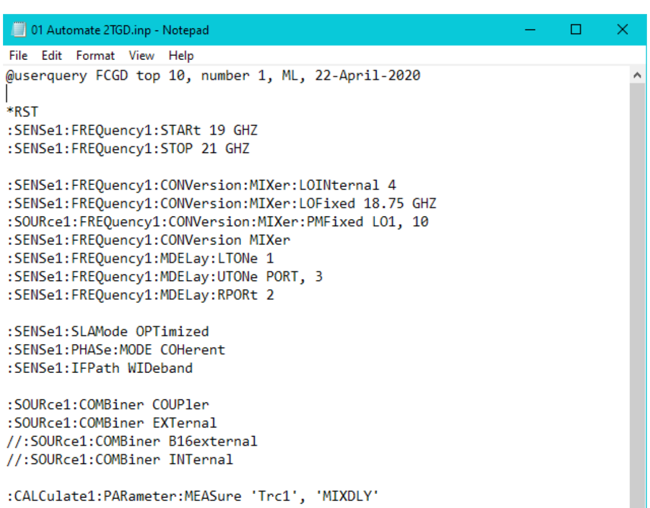
If you are generally familiar with either group delay measurements or operation of the R&S®ZNA, focusing on the first few paragraphs of Tip 2 will provide the essential information. On the other hand, if you would like a detailed walk-through of any or all of these tips, please visit the Rohde & Schwarz channel on YouTube. Under PLAYLISTS, look for "10 Techniques to Improve Group Delay Measurements…" The full series includes 11 videos that cover the ten tips plus one that provides a final recap.

2.2.1 Tip 1: Automate Your Measurements

Automating your measurements with the built-in scripting capability may be especially useful if you rarely or infrequently make group delay measurements but don't want to relearn the step-by-step process every time. There are three more reasons to automate your measurements:

- **Reason 1:** Automating ensures that you capture and execute all of the necessary settings and actions in the measurement process. You can save the process as a SCPI file (*.inp) then recall it and run it through the Windows interface of the R&S®ZNA.
- **Reason 2:** This approach is self-documenting, which can be helpful if you make such measurements only occasionally. Rather than relearning the process each time, you can review the steps as captured in the SCPI file.[3]
- **Reason 3:** No matter how often you make such measurements, automating saves time compared to the manual process of configuring the analyzer and applying any of the other tips described here.

This technique was used throughout the video series that documents these tips. Figure 3 shows a few lines of SCPI code from a file named "01 Automate 2TGD.inp" that sets up the initial group delay measurement.


01 Automate 2TGD.inp - Notepad

File Edit Format View Help

```
@userquery FCGD top 10, number 1, ML, 22-April-2020

*RST
:SENSe1:FREQuency1:STARt 19 GHZ
:SENSe1:FREQuency1:STOP 21 GHZ

:SENSe1:FREQuency1:CONVersion:MIXer:LOINternal 4
:SENSe1:FREQuency1:CONVersion:MIXer:LOFixed 18.75 GHZ
:SOURce1:FREQuency1:CONVersion:MIXer:PMFixed LO1, 10
:SENSe1:FREQuency1:CONVersion MIXer
:SENSe1:FREQuency1:MDELay:LTONe 1
:SENSe1:FREQuency1:MDELay:UTONe PORT, 3
:SENSe1:FREQuency1:MDELay:RPORt 2

:SENSe1:SLAMode OPTimized
:SENSe1:PHASe:MODE COHerent
:SENSe1:IFPath WIDeband

:SOURce1:COMBiner COUPler
:SOURce1:COMBiner EXTernal
//:SOURce1:COMBiner B16external
//:SOURce1:COMBiner INTernal

:CALCulate1:PARameter:MEASure 'Trc1', 'MIXDLY'
```

Figure 3. This snippet of SCPI code sets the start and stop frequencies of the measurement and configures the LO and mixer before moving on to the details of the group delay measurement.

[3] Note: You can also save the setup script with the data, further documenting the test setup that was used to make the measurement.

To establish a baseline for comparison, Figure 4 highlights the table of statistical values from the measurement shown in Figure 1.

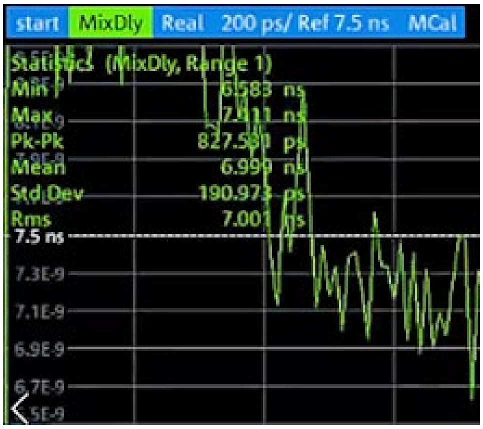


Figure 4. As shown in the table, the initial measurement of group delay through the satellite block converter had peak-to-peak variation of about 830 ps ("Pk-Pk" entry).

2.2.2 Tip 2: Select the Optimal Combining Method

As noted in the introduction, neither the LO nor a common reference signal are accessible in highly integrated designs. In this scenario, the network analyzer stimulates the DUT with a two-tone signal and measures the phase differences between the two signals at both the input and the output. The network analyzer then calculates the phase transfer function or the group delay of the DUT.

2.2.2.1 Four possible methods

The R&S®ZNA offers four ways to combine the two signals:

- **Use an external combiner after the main port connector**: this requires two signals of identical output power, and it can be done with a standard R&S®ZNA (Figure 5). A good choice, but the next three alternatives produce better results.
- **Use an external combiner before the main port coupler**: this also requires two signals of identical output power; the required connections have no effect on coupler directivity. This method requires the addition of R&S®ZNA-B16, an option that provides direct access to the analyzer's source and receiver (Figure 6).
- **Use a coupler as the combiner**: routes the source to analyzer Port 1 to create the two-tone signal; uses the coupler within Port 3 as the combining element; and the reference receiver monitors the combined two-tone signal (Figure 7). This method also requires option R&S®ZNA-B16.
- **Use an internal combiner**: using an internal combiner before the main port coupler requires option R&S®ZNA-B213 (Figure 8). This approach is useful if you need to frequently switch back and forth between two-tone and single-ended measurements.

The fourth method, use an internal combiner, is the preferred alternative. The combiner can be electronically activated or deactivated through front-panel controls and therefore through a SCPI file or under programmatic control via LAN, USB or GPIB.

Even so, the measurements performed in the video series and included here were made using the third alternative, use a coupler as the combiner. This is the simplest approach, and lowest-cost option, because the necessary connections use two short, semi-rigid cables.

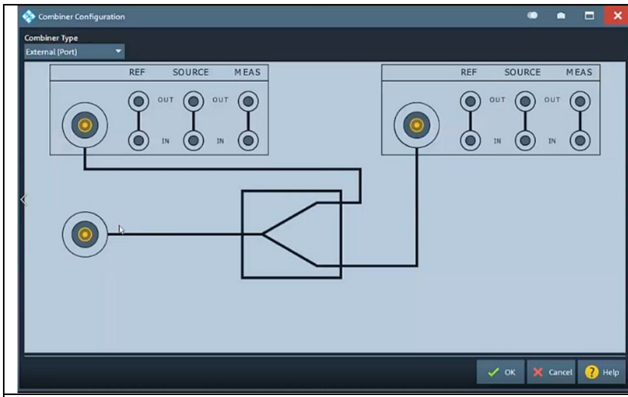


Figure 5. The on-screen guide uses an illustration of the analyzer front panel to show the placement and connection of the external combiner in method 1.

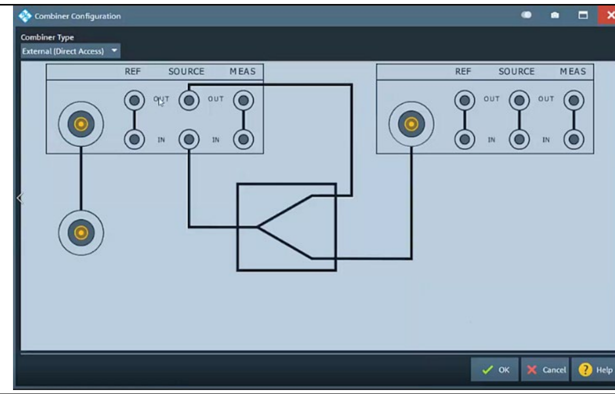


Figure 6. Method 2 requires option R&S®ZNA-B16 and slightly different connections of the external combiner.

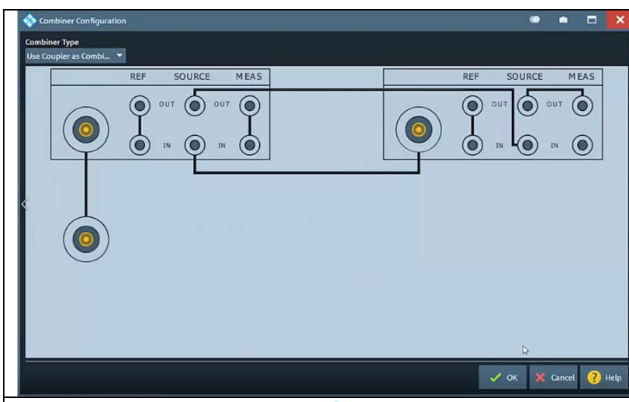


Figure 7. Method 3 requires only front-panel connections to create the necessary two-tone signal (also requires option R&S®ZNA-B16).

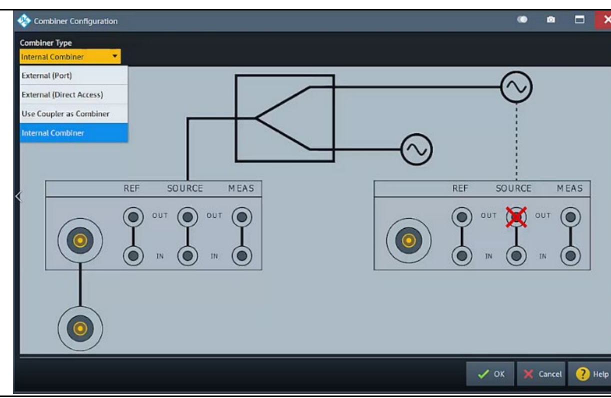


Figure 8. With option R&S®ZNA-B213, internal combiner, method 4 simplifies the process of switching back and forth between two-tone and single-ended measurements.

2.2.2.2 Three things to consider

When considering which method to use, three factors will help you decide:

Loss: The key question is, "How much, and where?" Using an external combiner adds loss after the coupler, and this makes it harder to measure group delay accurately. Because methods 1 and 2 use an external combiner, the other two methods are superior with regard to the potential for loss.

Phase: The next question is, "How is it measuring relative phase of the two tones?" When using an external combiner, measurements are made with two independent, coherent receivers in the network analyzer. However, using two separate sets of hardware (i.e., individual receivers) can affect the measurement results. It is better to combine the signals and measure their relative phase using a single reflectometer and reference receiver because it results in less hardware-induced phase variation. Again, because methods 1 and 2 use an external combiner, methods 3 and 4 are superior in terms of phase measurements.

Dominant setup: The practical question is, "How often will you make two-tone measurements versus other necessary tests?" If you are focused on measuring group delay with the two-tone technique, then it makes sense to create a dedicated test setup. If you will be making such measurements only occasionally, then it is more efficient to go with the internal option that lets the R&S®ZNA switch the combiner in or out as needed. In either case, the fourth method (internal combiner) provides the most flexibility.

2.2.2.3 Measurement results

As noted above, method 3, *coupler as combiner*, was used throughout the video series. Figure 9 shows measurements made with that method (green trace) and the *external combiner after main port* method (blue trace). Initial measurements starting from the two-tone group delay preset condition produced peak-to-peak variations of about 1.4 ns (green "Statistics" table) and 972 ns (blue table). The 1.4 ns variation is worse than that seen in the initial measurement. The good news: we will correct this using Tip 3.

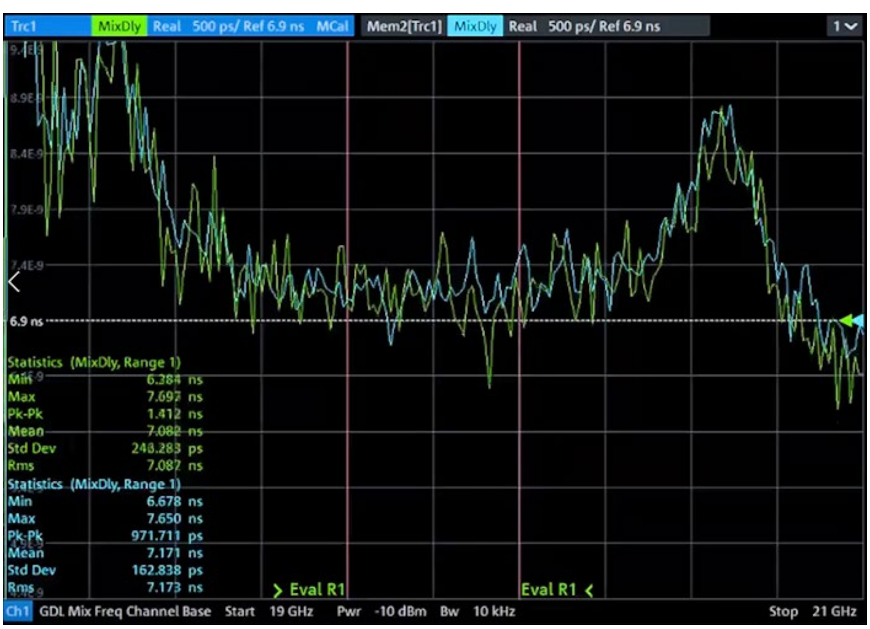


Figure 9. Subsequent tips will overcome the much larger peak-to-peak variation produced by an abundance of default settings in the "coupler as combiner" configuration.

2.2.3 Tip 3: Optimize Power Levels and Attenuation

In Tip 2, the *coupler as combiner* method produced suboptimal results due to the differences in loss experienced by the two tones as they passed through the respective arms of the coupler. The easiest solution is to increase the power level of the tone that passes through the coupled arm (versus the one that passes through the main arm). Both signals should have the same level at the input to the DUT.

The "best" power levels ensure that the DUT is operating in its linear region while also staying above the noise floor. Fully optimized signal levels are set such that the stimuli are neither starving nor overdriving the DUT.

This idea also applies to the analyzer's source and receiver ports. Here, the alternatives are to either increase the power levels or adjust the attenuation settings.[4]

In this case, the best combination of power levels and input attenuation was as follows: upper tone, –10 dBm at the DUT input; lower tone, –10 dBm at the DUT input; Channel 1 receiver IF gain 0 dB; and Channel 2 receiver IF gain 10 dB. With these optimized settings, the results from the *coupler as combiner* method show a marked improvement: when measured with the calibration mixer in place, the 1.4 ns peak-to-peak variation in tip 2 dropped into the range of 240 ps (blue table, Figure 10) from an initial value of 1.279 ns (Figure 2).

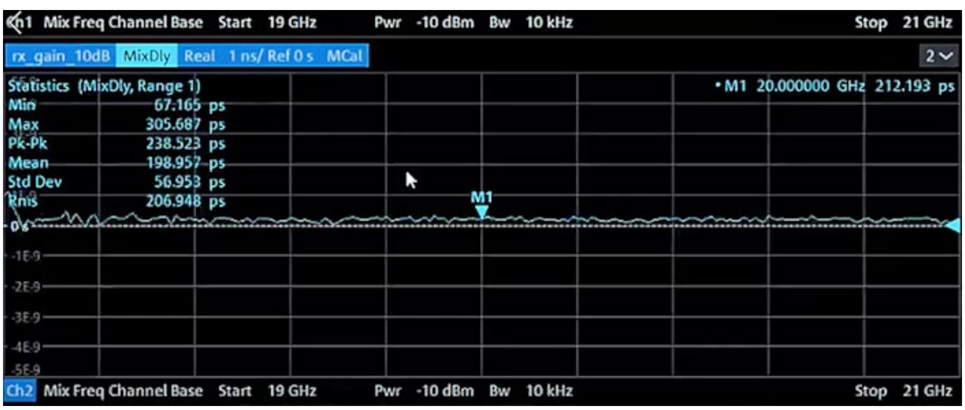


Figure 10. With the satellite block converter (and calibration mixer in place), optimizing two-tone power output and receiver IF gain leads to a substantial improvement in the group delay measurement.

2.2.4 Tip 4: Optimize Tone Spacing

Choosing the right frequency spacing between the two stimulus tones requires a balancing act between noise and the difference in phase (i.e., "delta phase"). The signals must be spaced far enough apart such that delta phase helps negate any noise effects. However, spacing the signals too far apart will create phase wrap, which is delta phase greater than 360 degrees. Here, the rule of thumb is to go as wide as possible without causing phase wrap.

An essential related factor is the user-selected aperture setting for the group delay measurement. The aperture must be narrow enough to reveal the details in any variation in group delay through the DUT. This is typically a process of making several measurements at different aperture values, starting wide and gradually shifting to narrower settings. Successive measurements will exhibit a relatively consistent shape as the

[4] It may go without saying, but any increases in power levels or decreases in attenuation should be kept within a safe range that will not cause damage to the DUT or the analyzer.

measurements progress from "wide and quiet" to "narrow and noisy." The consistent shape will begin to break down when the aperture setting is too narrow for the characteristics of the DUT.

Figure 11 shows a series of measurements on the satellite block converter while following the rule of thumb of "go as narrow as possible before the trace begins to deteriorate." With a 5 MHz aperture (upper trace) the result was excessively noisy due to narrow tone spacing. The lower-right plot (50 MHz) showed rounding of the rightmost peak, and this was due to wide tone spacing. The lower-left trace (20 MHz aperture) provided a usable tradeoff between noise and rounding of the peak.

Figure 11. When measuring the satellite block converter, the consistent shape of the group delay measurement gradually deteriorated as aperture was decreased from 50 MHz (lower right) to 20 MHz (lower left) to 5 MHz (top).

Even though the 50 MHz aperture provided an improvement in peak-to-peak variation over the 20 MHz (roughly 190 ps versus 360 ps), choosing greater resolution will be more beneficial. As was the case with Tips 2 and 3, the benefits of Tip 5 will more than make up for the temporary step backwards in variation seen here.

2.2.5 Tip 5: Optimize IF Bandwidth

In a VNA, measurement quality and repeatability depend on interrelated tradeoffs between IF bandwidth, sweep speed and trace noise. From a quality perspective, narrow filter settings reduce trace noise. However, narrower filters have longer settling times and therefore longer measurement times. This remains true whether the filters are implemented with analog or digital technology.

Up to this point, all measurements of the satellite block converter have been made with a 10 kHz IF bandwidth. Figure 12 shows a series of measurements made on the calibration mixer with successively narrower IF bandwidth values: 50 kHz, 10 kHz, 3 kHz and 1 kHz.

Figure 12. This series of measurements on the calibration mixer shows the reduction in noise at successively narrower IF bandwidths, proceeding clockwise from 50 kHz (upper left) to 10 kHz to 3 kHz to 1 kHz (lower left).

The conclusion: a 1 kHz IF bandwidth provided the best tradeoff between measurement time and peak-to-peak variation in group delay. At the halfway point of this exercise, the combined effect of Tips 2 through 5 is a peak-to-peak variation of roughly 80 ps when measuring the calibration mixer (orange table, lower-left trace). This is a 16x improvement over the baseline measurement of the calibration mixer.

2.2.6 Tip 6: Apply Averaging During Calibration

To maximize accuracy, it is necessary to calibrate the analyzer channel before each measurement. For the measurements shown here, the calibration measurement was performed using a known mixer in place of the DUT. This shifts the measurement plane from the analyzer ports to the inputs and outputs of the DUT. The resulting calibration factors are applied to subsequent measurements of the device.

Rather than a single measurement, averaging can be used during calibration. If noise is present in the system, it will be a constant presence in every measurement *unless averaging is used during the calibration process*. This reduces the noise level in the error model, and this makes subsequent measurement more tolerant of noise.

Here, calibration measurements were made using zero, 3, 10 and 32 averages. It's worth noting that the cal process takes much longer to complete with 32 averages. A comparison of the results led to a potentially surprising conclusion: using just three averages in the cal process provided an optimal tradeoff between measurement speed and noise reduction. As shown in the upper-right trace in Figure 13 (blue stats table), the peak-to-peak variation is down to roughly 60 ps (versus 80 ps after optimizing IF bandwidth in Tip 5).

Figure 13. After considering the tradeoff between noise reduction and measurement time, using just three averages during calibration (upper-right trace) provides a meaningful improvement in peak-to-peak variation in group delay when measuring the calibration mixer.

At this point, it is worth pausing to highlight an important distinction that spans Tips 3 through 6. Optimizing power levels, attenuation and tone spacing should be done while measuring the DUT (Tips 3 and 4). In contrast, optimization of resolution bandwidth and averaging can be done during measurements of the calibration mixer (Tips 5 and 6).

2.2.7 Tip 7: Use LO Tracking for Troubleshooting

In a real-world DUT, the actual LO frequency may be slightly off from the expected or specified value. An especially noisy group delay measurement is a telltale sign of this condition.

In the R&S®ZNA, an automated function called LO tracking compensates for this type of frequency deviation. It performs the correction by measuring the frequency offset and then changing the VNA settings accordingly to ensure a stable trace. This enables the use of narrower IF bandwidths, thereby improving the signal-to-noise ratio (SNR) of the measurement (Figure 14).

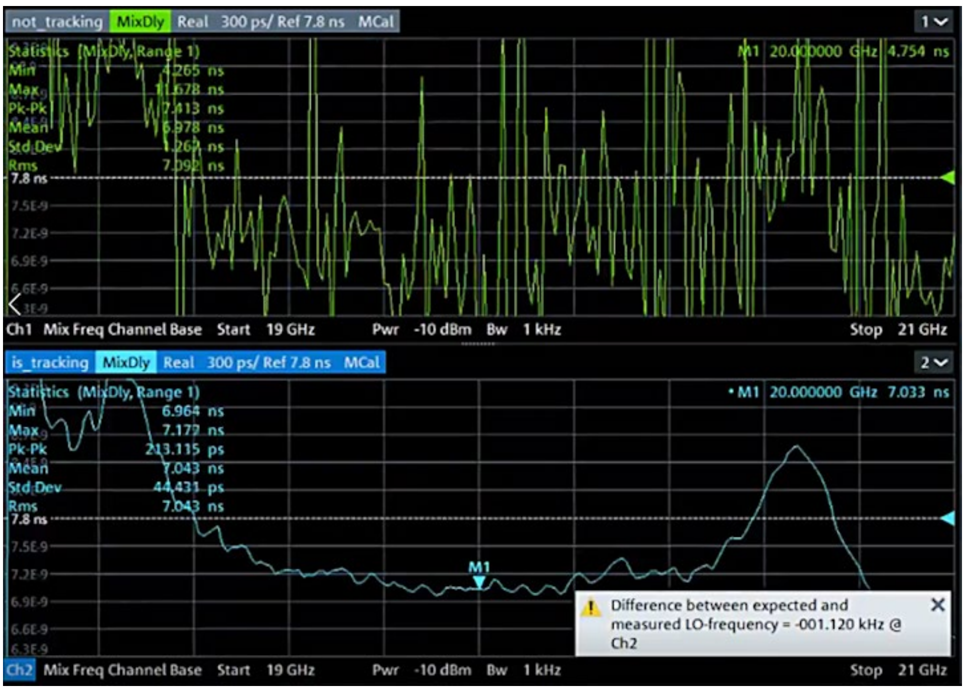


Figure 14. During a measurement of the satellite block downconverter, applying LO tracking (lower trace) provided a dramatic reduction in the noise and instability of the upper trace. The popup window (lower right) reported the measured difference between the actual and expected LO frequencies.

Please note that we recommend using this capability as a troubleshooting tool, not as a regular part of your measurement process. If it is relatively easy to adjust the LO frequency inside the DUT, that is the recommended first step. If this isn't possible, the use of LO tracking in the R&S®ZNA should correct for the error. *One caveat*: it is usually best to use this technique *before* applying Tips 2 through 6.

2.2.8 Tip 8: Utilize Both Internal Receiver LOs

One more option adds capabilities that can also improve group delay measurements: R&S®ZNA-B5, which is a second internal LO source for a four-port R&S®ZNA.

In this configuration (Figure 15), port 1 can monitor the RF signal connected to the DUT input. Port 2 can be dedicated to looking at the IF signal coming from the DUT (i.e., at a different frequency). This has two advantages: measurements are twice as fast because the receiver doesn't have to switch between the two ports to make each measurement; and results are more accurate because there is no chance of phase drift between the respective measurements of the two channels.

As shown in Figure 16, using two LOs provides a significant improvement in trace noise, resulting in peak-to-peak variation in group delay of about 54 ps. And, as expected, the measurements are twice as fast.

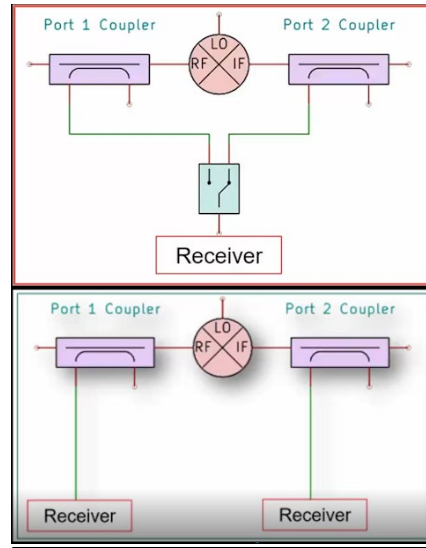


Figure 15. With a second internal LO, measurement time is halved because the single receiver is no longer switching back and forth between ports.

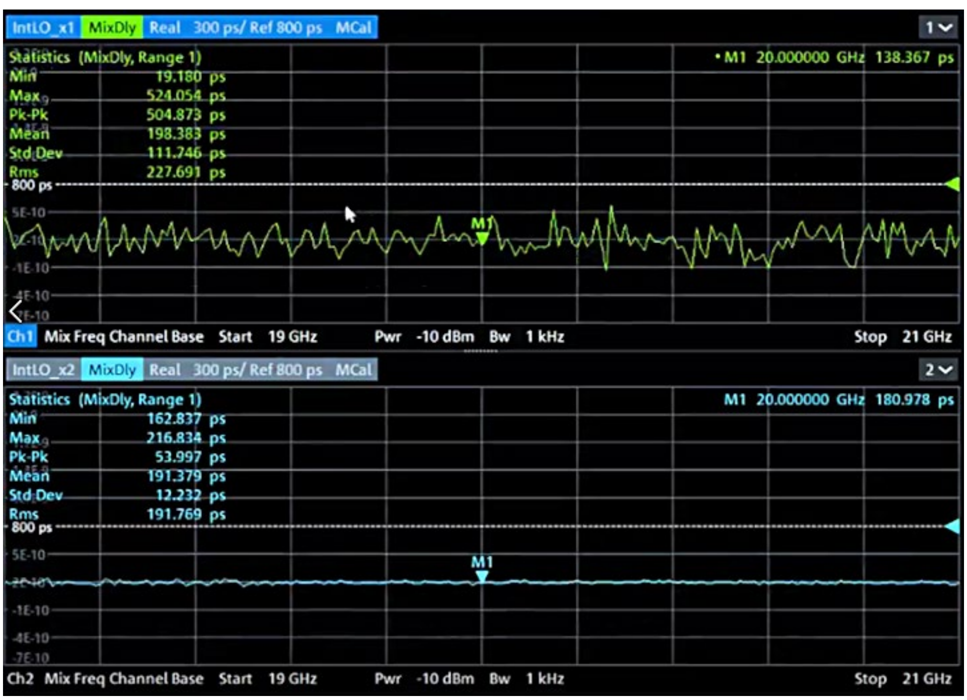


Figure 16. With two LOs (lower trace), overall noise is visibly improved and the peak-to-peak variation is roughly 9x better (54 ps versus 505 ps) when measuring the calibration mixer.

2.2.9 Tip 9: Use Small Attenuators to Mitigate Mismatch

In a group delay measurement, the calibration process adds a term to the normalization table. That term takes into account the mismatch (or return loss) from the output of the calibration mixer at the input of the VNA receiver (i.e., at the calibration plane).

Comparing the calibration setup to the DUT measurement, the analyzer sees different mismatches (or return losses) in the outputs of the calibration mixer or the DUT. The DUT has a different mismatch, and it may be better or worse than that of the calibration mixer. In a VNA, any difference in mismatch is enough to affect measured results.

Attenuators can help minimize the effects of those differences. Attaching small, external attenuators to the ends of the respective cables can mitigate mismatch. The reason: the attenuators reduce reflection and thereby “settle down” the mismatch. This technique is so effective that it is commonly used between the functional blocks inside test instruments and between the stages of real-world devices.

Of course, it may be necessary to increase source power levels to compensate for any added attenuation. This is especially true if the DUT is sensitive to input level (i.e., exhibits nonlinear behavior).

2.2.10 Tip 10: Apply Vector Error Correction

Measuring S-parameters is perhaps the most common application of a vector network analyzer. In this context, group delay measurements are more accurate when S-parameter error correction is included in the two-tone measurement process. Beyond the measurement of group delay on devices that have an embedded LO, applying S-parameters also provides vector-corrected return loss that can be used to compensate for the mismatch that occurs between the DUT and the VNA.

In Figure 17, the upper trace has the benefit of mixer-delay correction and the use of external attenuators (Tip 9). Looking at the lower trace, the "Cal MCal" label in the gray bar (upper left of trace) indicates the application of S-parameter correction and mixer-delay correction (external attenuators were also used). As shown in the introduction, the peak-to-peak variation in group delay is now in the range of 38 ps for the calibration mixer.

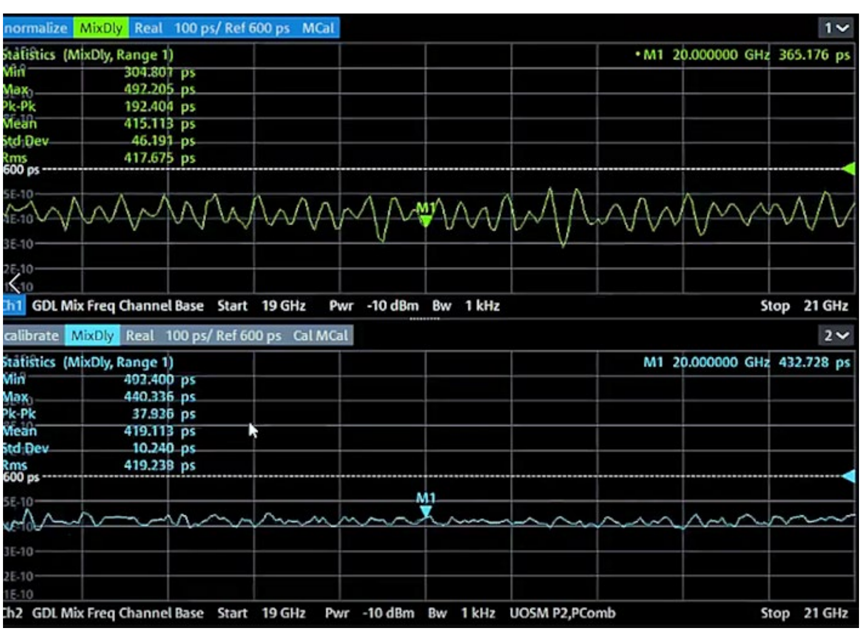


Figure 17. With the cumulative benefits of the tips presented here, the peak-to-peak variation in group delay through the calibration mixer is more than 39x lower than at the beginning, decreasing to 38 ps from an initial reading of about 1.28 ns.

2.3 Summary

Throughout this application note, our goal has been to make progress towards the best-possible measurements of group delay. While this can be especially difficult in DUTs that do not provide access to the LO, the two-tone technique provides a path to stable, repeatable, and accurate results (Figure 18).

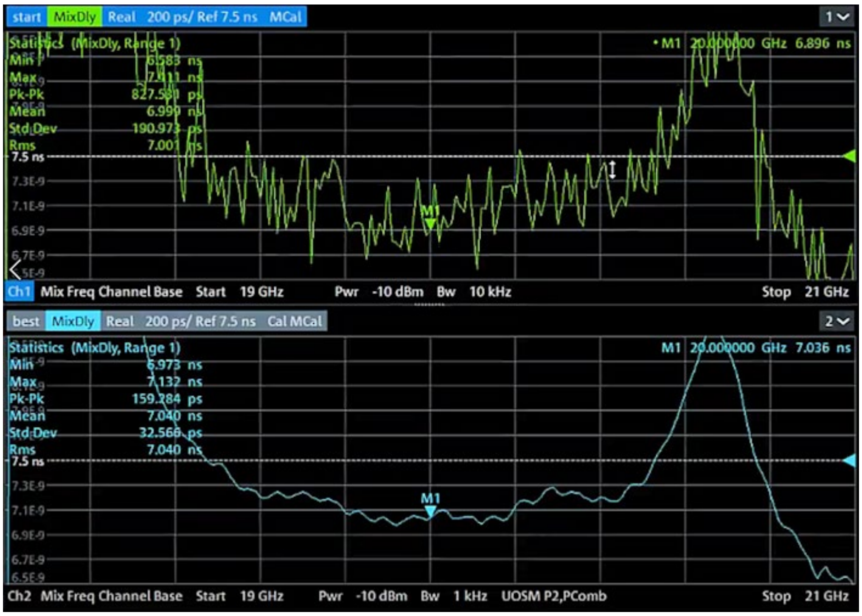


Figure 18. In the measurement of a satellite block converter, the tips presented here transformed a quick preset measurement (top trace) into a stable result with significantly improved peak-to-peak variation (blue table).

As shown in the before and after traces, a few practical tips can produce noteworthy reductions in the peak-to-peak variation of group delay measurements on a satellite block converter and a calibration mixer:

- ► Tip 1 is especially useful if you invest a lot time learning how to make these measurements but will use that skill only occasionally
- ► Tips 2 through 6 and 8 through 10 address measurement settings that help reduce variation
- ► Tip 7 is a troubleshooting tip that addresses the all too common problem of an LO that drifts away from its expected frequency

The two-tone method and the 10 tips presented here should provide similar improvements when characterizing group delay in any type of frequency-conversion device.

3 Literature

- **Video series**: Rohde & Schwarz channel on YouTube, playlist titled “10 Techniques to Improve Group Delay Measurements on Frequency-Converting Devices with Embedded LO”
- **Application Note 1EZ-81:** *Group Delay Measurements on Frequency Converting Devices*
- **Application card**: *Use the GPIB (SCPI Command) Explorer on the R&S®ZNA*
- **Application card**: *Automated Testing: Measure Frequency-Converting Group Delay on the R&S®ZNA*
- **Application card**: *Test Set Options in the R&S®ZNA*
- **Video**: Jamie Lunn, product manager, Option K9, Group Delay Measurements on Mixers without LO Access

4 Ordering Information

Designation	Type	Order No.
Vector network analyzer, 4 ports, 26.5 GHz, 3.5 mm connectors	R&S®ZNA26	1332.4500.24
Direct source and receiver access	R&S®ZNA26-B16	1332.4581.24
Vector network analyzer, 4 ports, 43.5 GHz, 2.92 mm connectors	R&S®ZNA43	1332.4500.44
Direct source and receiver access	R&S®ZNA43-B16	1332.4581.44
2nd internal LO source for R&S®ZNA (4 ports)	R&S®ZNA-B5	1332.4675.02
Internal combiner, port 1 and port 3	R&S®ZNA26-B213	1332.4846.13
Internal combiner, port 1 and port 3	R&S®ZNA43-B213	1332.4869.13
Scalar mixer and arbitrary frequency-converting measurements	R&S®ZNA-K4	1332.5342.02
Group delay measurements on frequency converters without LO access	R&S®ZNA-K9	1332.5394.02
Cable set for R&S®ZNA-K9 (3.5 mm for R&S®ZNA26)	R&S®ZNA26-Z9	1332.4730.26
Cable set for R&S®ZNA-K9 (2.92 mm for R&S®ZNA43)	R&S®ZNA43-Z9	1332.4730.44

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Application Note | Optimizing mixer Group Delay Measurements
Data without tolerance limits is not binding | Subject to change