Agilent
Measuring Absolute Group Delay of Multistage Converters Using PNA Microwave Network Analyzers

White Paper

Agilent Technologies

Abstract

This paper describes new calibration and measurement techniques for measuring absolute group delay of frequency converters with multiple mixing stages. The calibration methodology used is Agilent's Vector Mixer Calibration (VMC), where reflection measurements are used to characterize a calibration mixer, which is then used as a characterized through adapter to calibrate a frequency-translating test system for absolute magnitude and phase. The measurement methodology includes the use of a "meta-LO", which is a local oscillator derived from the LOs used for the converter under test. The meta-LO drives a reference mixer and the calibration mixer. For converters employing embedded LOs for which there is no access, but where access to a common time base is provided, an alternative measurement methodology is described.

1.0 Introduction

For frequency converters used in modern electronic systems, such as those employed in communications, satellite, and radar systems, group delay ripple (deviation from uniform group delay) is a very important performance aspect. This parameter is most often measured with a vector network analyzer (VNA). Previous techniques often use a so-called "golden mixer", where the device under test (DUT) is measured relative to an accepted ("golden") standard. As long as the performance of the DUT is similar to the golden device, the DUT is assumed to be acceptable for use in a given system. This approach does not yield the absolute performance of the device, since ripple that is common to both the golden mixer and the DUT is cancelled out. Knowledge of absolute group delay is essential for accurate system simulations and for accurate performance-budget analysis. For example, system designers often need to know the absolute group delay ripple of every component in a system to ensure that group-delay equalizers have sufficient range to handle the sum of the group delay variations.

One common calibration technique used when measuring absolute group delay is the three-mixer technique. This technique utilizes three sets of measurements of mixer pairs to produce a calibrated reference mixer. With three equations and three unknowns (the mixers), the complex transmission characteristics of the mixers can be calculated. This technique has two limitations. One, it is susceptible to mismatch errors introduced by interaction between the various mixers and the IF filter used to select the desired mixing product. Secondly, it does not scale well to converters with multiple conversion stages, since the characterized reference mixer is driven from a single local oscillator (LO), while the converter under test requires multiple LOs.

2.0 New Measurement Methodology Employing a "meta-LO"

The optimum way to measure converters with multiple conversion stages is to use a single reference mixer which is driven by an LO that is phase synchronous with the LOs used for the mixers inside the DUT. This phase synchronous LO will be called a "meta-LO", because it is a derived LO that is only used during calibration and measurement, and not during the actual operation of the DUT. The meta-LO is derived by mixing the LOs used in the converter to produce an LO that, when driving a single mixer, will produce the same output frequency in response to a given input frequency as would the multistage converter. Figure 1 shows an example of deriving a meta-LO for a triple-stage down converter. By selecting the right mixing product(s) [sum or difference] of the mixer(s) used to derive the meta-LO, one can accommodate converters using any combination of high- and low-side LO mixing.

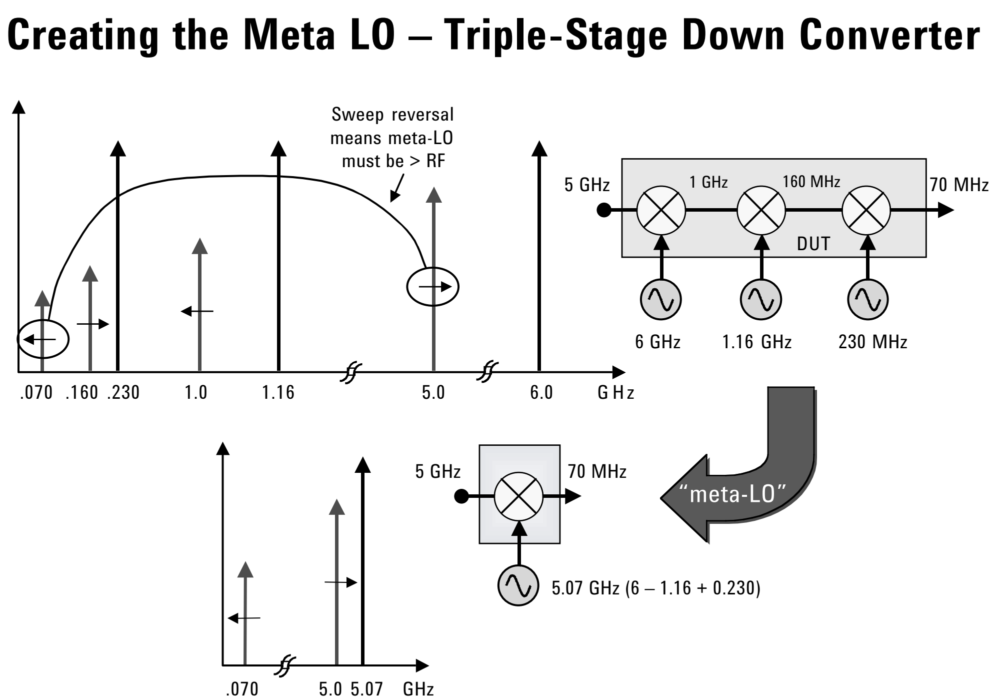

Figure 1. An example of calculating the meta-LO frequency for a triple-stage down-converter.

Once the meta-LO is derived, it is used to drive both the reference mixer and the calibration mixer. Amplification of the meta-LO signal is generally necessary to boost the signal to a level sufficient to drive the LO ports of the reference and calibration mixers. Figure 2 shows the calibration setup for a triple-stage down converter. For the measurement, the meta-LO continues to drive the reference mixer, but the DUT requires the multiple LOs used for each mixing stage (see Figure 3).

VMC Calibration Setup – Triple Conversion

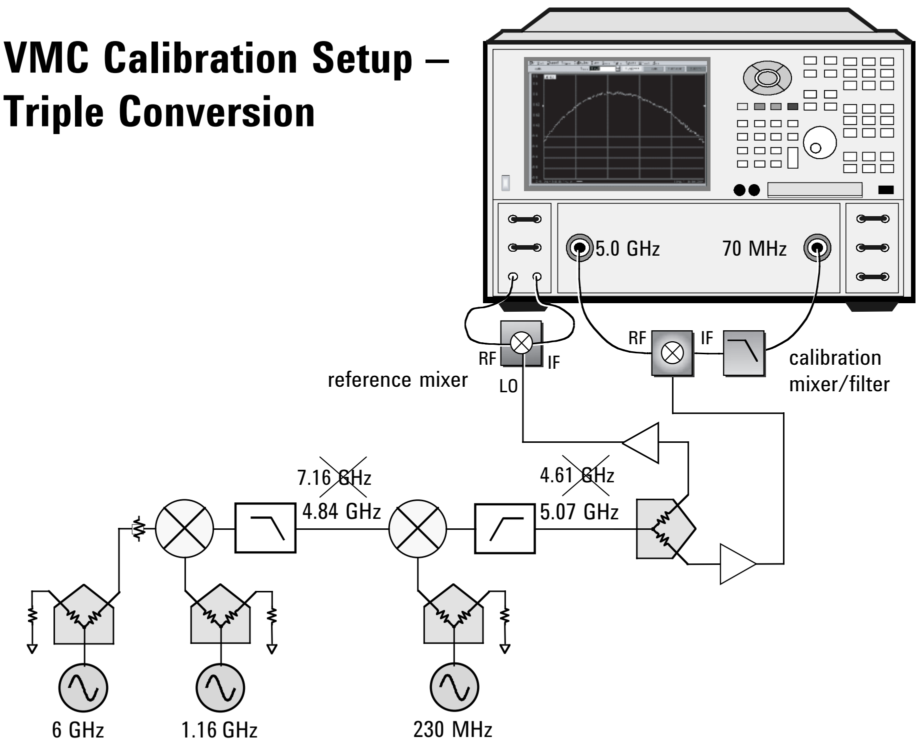

Figure 2. Use of the meta-LO for calibrating the test system for measurements of a triple-stage down-converter. The use of VMC eliminates the effects of the reference mixer and the rest of the test system from subsequent DUT measurements.

Note that the LOs used to derive the meta-LO can come from external signal sources (for converters without embedded LOs or converters that can utilize LO substitution), or from access to embedded LOs within the DUT itself. In practice, the best results are usually obtained when good quality external sources are used since the resulting LO signals have low phase noise and low spurious content. If internal LOs are used to derive the meta-LO, spurious mixing products and sidebands that appear at the LO outputs of the DUT should be minimized as much as possible. Spurious mixing products are often easily removed by external filtering. Sidebands are more problematic since they often cannot be eliminated with practical RF or microwave filters. For this reason, the converter may require extra isolation between its internal LOs and mixers than what would be needed strictly for operational use.

VMC Measurement Setup – Triple Conversion

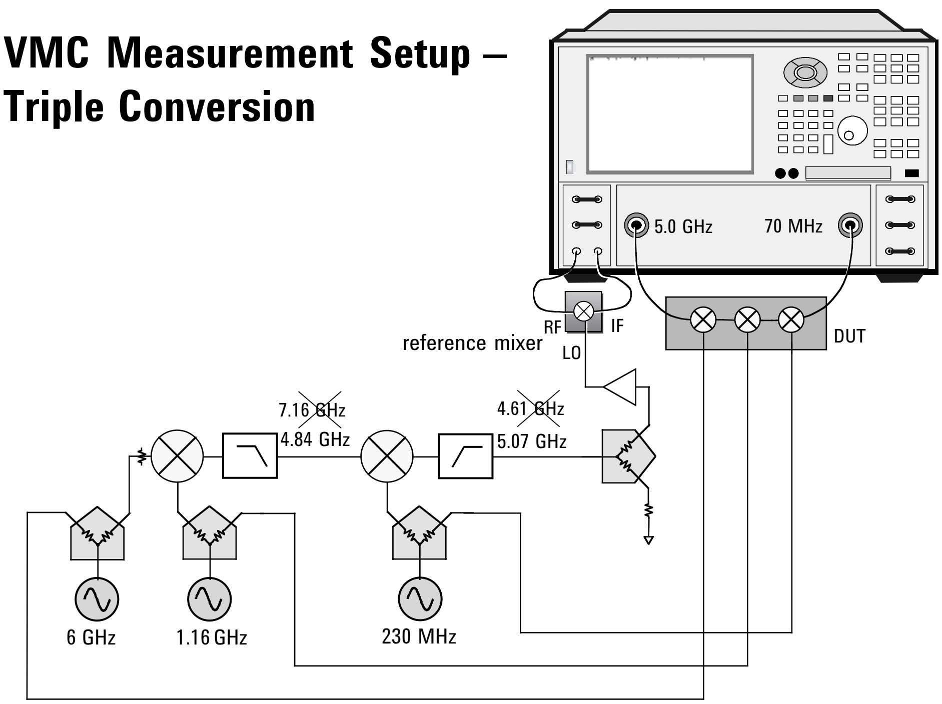

Figure 3. Test setup for measuring a triple-stage down-converter. The meta-LO is used to drive the reference mixer.

Whenever possible, the time bases of the VNA and the LOs should be tied together, to ensure that the VNA receivers are tuned exactly to the desired output frequency. If embedded LOs are used without a common time base that can be shared with the VNA, then the VNA must be manually tuned to ensure that the signals being measured fall very near the center of the VNA's IF bandwidth filters. In this case, the embedded LOs must be very stable so that frequency drift does not cause unacceptable measurement errors. When access to embedded LOs is not possible, but a common time base is available, then group delay measurements can still be made using an alternative measurement technique described in Section 4.0.

3.0 Review of Vector Mixer Calibration Technique

In order to accurately measure the absolute group delay performance of a DUT, the test system must be calibrated for both magnitude and phase. Previous papers [1], [2] describe a technique called Vector Mixer Calibration (VMC) that uses a characterized mixer to calibrate a VNA-based test system. The characterized mixer is called a calibration mixer, and it used as a characterized through adapter to derive the complex forward transmission-tracking error term of the test system. The key to VMC is that the calibration mixer is characterized by making three reflection measurements (using open, short, and load standards). Reflection measurements do not require the VNA to offset its source and receiver frequencies, as is required for transmission measurements of frequency-converting devices. The only constraints on the calibration mixer are that it must be reciprocal, and a filter must be present at the mixer's output to select the desired mixing product (sum or difference). A reciprocal mixer is one where the magnitude and phase response versus frequency of the mixer is the same when it is characterized as a down-converter in one direction, or an up-converter in the opposite direction.

VMC characterizes the calibration mixer/filter pair for transmission magnitude and phase, as well as input and output match. This means that a very accurate, match-corrected measurement of the transmission-tracking error term can be obtained. During transmission measurements of the mixer or converter under test, vector error correction is applied at the input and output of the DUT (at the corresponding input and output frequencies) to achieve high accuracy, match-corrected measurements of conversion loss/gain, phase, and group delay.

4.0 Optimizing Calibration for Converters with High Gain

When measuring converters with high gain, improved results can be obtained by carefully optimizing the power levels during calibration. For measurements of a high-gain converter, the input power must be lowered enough so that the converter and the VNA's receivers are not operating in compression. Typically, this requires increased attenuation in the source path, and the attenuation must be included in the transmission tracking term. However, during the portion of the calibration where the calibration mixer is characterized with reflection measurements, a low power level is not necessary since there is no gain in the calibration mixer. To achieve a calibration with the least amount of noise, the calibration procedure should be split into two parts. During the first part, the calibration mixer is characterized at a higher power level than that used during measurements of the converter, and the resulting calibration-mixer data file is saved. Care must be taken to not compress the calibration mixer, as the VMC technique requires that the mixer operate in a linear region. For the second part of the calibration, the VNA's power is set to the highest level possible using the source attenuation that is required for subsequent measurements of the DUT, and instead of characterizing the calibration mixer at the lower power level, the data for the calibration mixer obtained in the first portion of the calibration is recalled. When actually measuring the DUT, the input power can be further lowered if necessary to avoid compression, as long as the source attenuation remains the same as it was during the second part of the calibration. Due to the high degree of linearity of most VNA receivers, the amount of error introduced by lowering the source power after a calibration has been performed is negligible, and is certainly less than the improvement obtained by maximizing the signal-to-noise ratio during calculation of the transmission-tracking error term.

5.0 Alternative Measurement Methodology for Converters with Embedded LOs with Access to a Common Time Base

For converters with embedded LOs for which there is no access to the LOs, derivation of a meta-LO is impossible. However, it is still possible to measure absolute group delay, if there is access to a common time base used in the DUT to phase-lock the embedded LOs. For this technique, a separate external signal source is used as an LO for the reference and calibration mixers. The frequency of this LO is the same frequency as that of a meta-LO, were it possible for a meta-LO to be derived. However, in this case, the external LO will not share phase synchronicity with the LOs in the DUT. The result of this arrangement is that the phase noise present on the DUT LOs will not ratio out as would occur when the reference mixer and DUT share phase-synchronous LOs. Practically, using non-phase-synchronous LOs means the group delay measurements will be considerably noisier than those resulting from use of a meta-LO. More averaging and trace smoothing must be employed to get acceptable results. Figure 4 shows the calibration and measurement setup for this technique. Although non-phase-synchronous LOs are used during measurement of the DUT, the calibration is performed using a phase-synchronous LO. During VMC, the external LO is split so that the same LO is supplied to both the reference and calibration mixers, yielding accurate measurements of the system's error terms.

Measuring Multistage Converters with Embedded LOs and an External Ref-Mixer Source

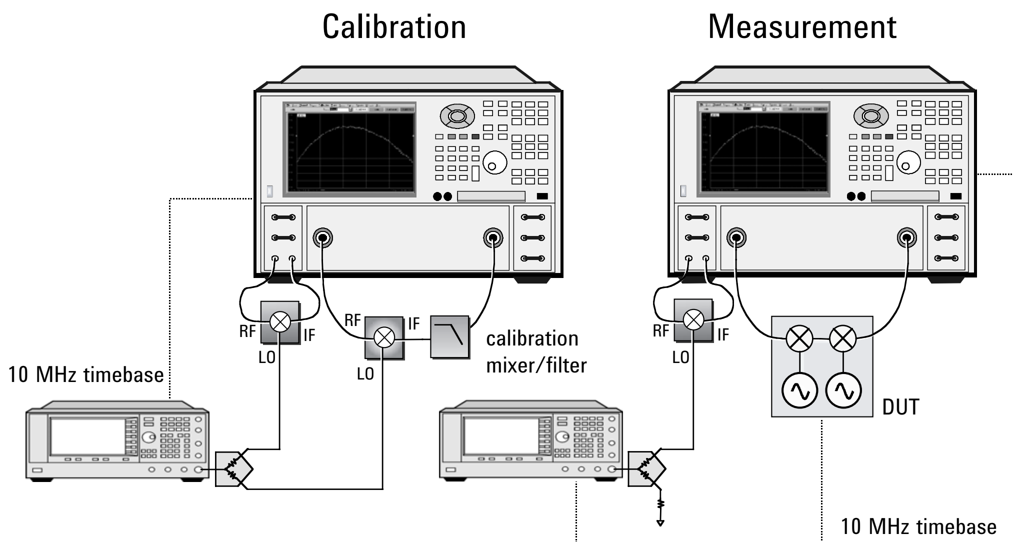

Figure 4. Alternative test setup for measuring a double-stage down-converter when there is no access to the embedded LOs, but access to a common time base is available.

In this alternative methodology, the time bases of the LOs, the VNA, and the external signal source used to drive the LO port of the reference and calibration mixers must be tied together. Agilent test equipment uses 10 MHz as the time base reference, as does most test equipment. If the DUT's time base is something other than 10 MHz, then a second signal source can be locked to the common 10 MHz time base, and the RF output of the second source can be set to the correct frequency required for use as the DUT's time base (see Figure 5).

Measuring Multistage Converters with an Arbitrary Timebase

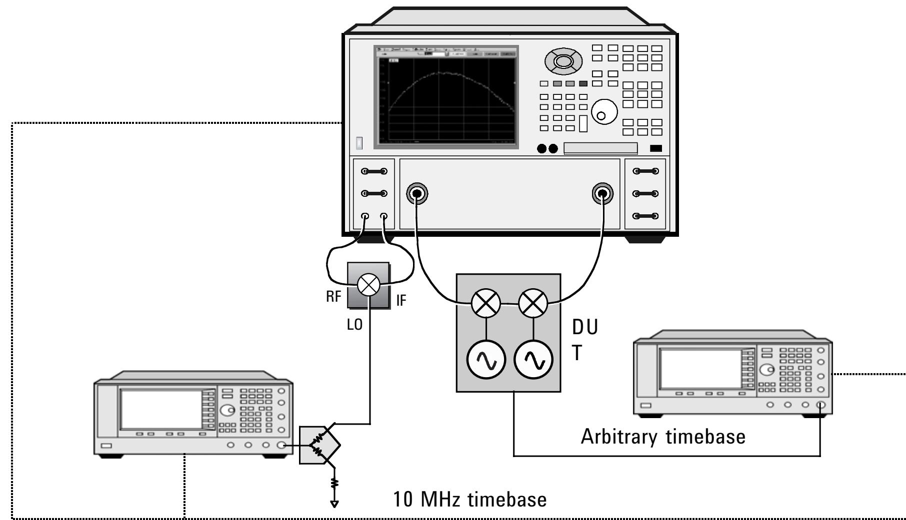

Figure 5. When the DUT's time base is something other than 10 MHz, a second signal source can be locked to the system's 10 MHz time base and used to generate an arbitrary time base for the DUT.

6.0 Measurement Results

Figure 6 shows the conversion loss and group delay of a dual-stage converter with an input of 10.24 GHz and an output of 177 MHz. The first LO was at 12.263 GHz, and the second LO was at 2.2 GHz. The measurements were done using an E8364B PNA Series vector network analyzer, with 101 points and a 300 Hz IF bandwidth. Figure 7 shows a zoomed-in measurement of group delay only. The smooth traces in both Figures 6 and 7 were obtained using the meta-LO technique. The noisier traces were obtained by using a separate external source for the reference mixer (and calibration mixer during VMC). With sufficient trace smoothing and averaging, the non-phase-synchronous external-source technique gives results that approximate the results obtained when using a meta-LO.

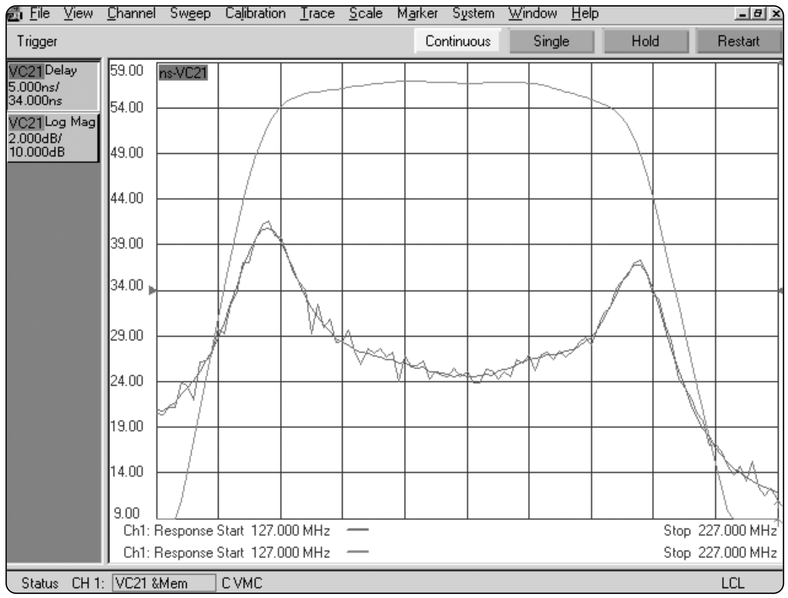

Figure 6. Conversion loss (top) and group delay (bottom) of a dual-stage down converter, with a 100 MHz span. The smooth group delay trace is the result of the meta-LO technique, and the noisier trace is the result of using a non-phase-synchronous signal source for the reference mixer.

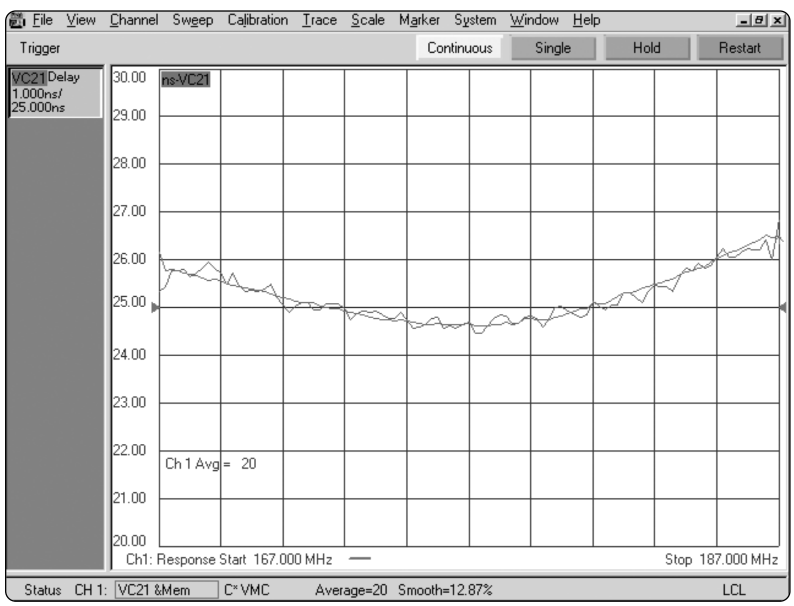

Figure 7. Group delay of a dual-stage down converter with a 20 MHz span. The smooth group delay trace is the result of the meta-LO technique, and the noisier trace is the result of using a non-phase-synchronous signal source for the reference mixer. For the latter case, a combination of smoothing and averaging is necessary to reduce trace noise. Note that the scale has been reduced by a factor of five compared to Figure 6.

7.0 Conclusion

It has been shown that accurate group delay measurements of multistage converters can be made by combining Vector Mixer Calibration and phase-synchronous local oscillators. To derive a phase-synchronous LO for use with the reference and calibration mixers needed for VMC, a meta-LO is created by mixing the various LOs that are required by the converter under test. For converters without access to embedded LOs, but with access to the LO's time base, an alternate technique can be used that does not use phase-synchronous LOs. This technique produces noisier results.

References

[1] Joel Dunsmore, "Novel Method for Vector Mixer Characterization and Mixer Test System Vector Error Correction", 2002 IEEE MTT-S International Microwave Symposium Digest, vol. 3, pp. 1833-1836.

[2] Joel Dunsmore, et al, "Comparison of Mixer Characterization Using New Vector Characterization Techniques", 32nd European Microwave Conference Proceedings (2002), vol.1, pp. 163-166.

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