Comparison of Mixer Characterization using New Vector Characterization Techniques

White Paper

Agilent Technologies

Abstract

This paper presents a novel method for characterizing RF mixers, yielding magnitude, phase, and group delay response of the conversion loss, as well as the input match and output match. This technique works for mixers which have reciprocal conversion loss and for which the image response can be filtered out. This technique is compared with a new vector corrected power technique, and with traditional power meter measurements. An error analysis on the new technique is presented for the first time.

This paper was originally presented at the European Microwave Conference, September 24, 2002 [1].

Introduction

Many wireless and RF systems require frequency converters or mixers with specified and well-controlled amplitude and group delay response. The amplitude response measurements of these devices have always had large uncertainties. Further, there have been few techniques that can characterize the phase or group delay response of mixers.

A previous method described making group delay measurements by making three measurements on three pairs of mixers [2]. From these measurements, one can calculate the amplitude and phase response by solving the three linear equations for the overall response. This method makes use of up/down conversion but requires an IF filter between the pairs of mixers to avoid re-converting the unwanted side band. A second key aspect of the technique is that it assumes at least one of the mixers is reciprocal in its response, that is, it has the same conversion loss and group delay in the up-conversion mode as in the down-conversion mode. For some mixers, this holds approximately true.

A difficulty with the previous method is that it requires three sets of measurements, with reconnections between the mixer pairs and the filter. With each connection, there is room for random error (connector repeatability) and systematic error, for example, mis-match effects between the filter and mixer pairs, and between the mixers and test equipment. Mixers typically have poor return loss, so these mis-matches can be quite severe. It has been suggested that adding padding (attenuation) between the mixers and filters can reduce this effect, but it introduces further sources of mismatch between attenuators and the filter, and it reduces the levels of signal measured creating a noisy measurement.

Overview of the new method

One of the novel methods presented here can characterize the amplitude, phase, and delay response of a mixer, without the need to employ any other mixers. The input and output matches of the mixer are also determined. A second method can characterize the amplitude response of a mixer, correcting for input and output match through proper calibration steps of a vector network analyzer. These new methods are compared with traditional measurements using power meters.

The first method, which was described for the first time at the 2002 Microwave Theory and Techniques Symposium [3], does not require the LO signal of the test mixer to be accessible. The only requirement is a filter that can separate the response of the desired IF output signal from the unwanted side band. This method assumes a reciprocal mixer response, as do the previous methods, and any errors in this assumption will be errors in the final result. This method provides additional information on the input and output match of the mixer, which can be used in a later calibration step to remove instrumentation mismatch errors at the input and output of the test equipment [4]. Because this does not require multiple mixer connections, connector repeatability does not add into errors of the measurement.

A second method, using a power meter to calibrate a vector network analyzer, is novel in that it corrects for all the mismatches in the system, including the mis-match between the source and the power meter, the source and the receiver, and the mixer-under-test and the source and receiver of the network analyzer. The authors believe this provides the state-of-the-art in amplitude measurements of frequency converting devices. Further, this method is less sensitive to LO leakage and does not require filters to remove the image signals.

Characterization method details

Reciprocal Cal Method

The first new method requires a vector network analyzer (VNA). The analyzer is first calibrated for return loss measurement (S11) over the RF frequency range. This provides a “perfect” network analyzer (with only small residual errors). The mixer to be characterized is connected to this port, followed by the IF filter, as shown in Figure 1. Measurements of a metrology grade open/short/load are made (though any other one-port calibration method will do) and these are saved. Note that the signals measured at the test port are a composite of the reflection from the mixer input port, and a pair of converted signals, one undesired which is reflected of the IF filter, and re-converted to the input signal, and another which is the desired IF signal that passes through the IF filter, and is reflected off the various standards used for a one-port calibration.

The three measurements, Γ_O, Γ_S, Γ_L, are sufficient to calculate the “one-port” error model of the mixer/filter combination. That is, the values of Γ_O, Γ_S, Γ_L can be used as inputs to the formulations for calculating the error terms of a one-port calibration.

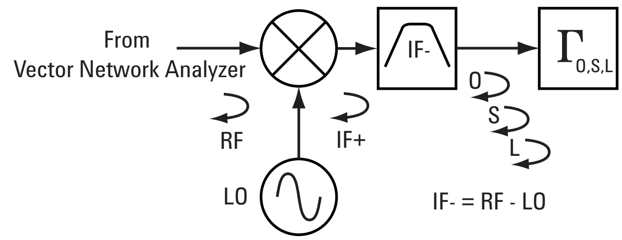

Figure 1: Mixer characterization diagram. Three measurements are made: open, short, and load response.

The one-port error model generates three terms: Directivity, Source Match and Reflection Tracking. The Reflection Tracking term represents the two-way transmission (magnitude and phase) through the mixer, T1*T2. If the mixer is reciprocal in nature, taking the square root of this term gives the one-way insertion loss of the mixer, that is, T1=T2. The one-port error model already extracts the effects of the source match, and the calibrated VNA with which the data was taken, and includes effects of the input match. Thus, this term can be used as the actual two-way conversion loss of the mixer. Since this data is taken with a calibrated network analyzer, the effective mismatch, tracking, and directivity of the VNA are eliminated.

In practice, the one-port calibration function of the VNA can be used to extract the one-port error model of the mixer by downloading the previously measured Γ_O, Γ_S, Γ_L responses into the VNA as the calibration standards of a one-port cal. However, remember that the standard data was taken over the RF range of the mixer, and while the standards are applied at the IF range, so it is necessary to reset the analyzer frequency before the download to ensure that the proper frequencies are used for the models of the calibration standard. Further, for cases where the RF is less than the LO frequency, it is necessary to reverse the data before downloading, so the response matches the “backward” sweep of the IF. However, the terms of the mixer can be found without using the VNA functions. Formulations for determining the extraction of Directivity, Source Match, and Tracking can be found in many references [5].

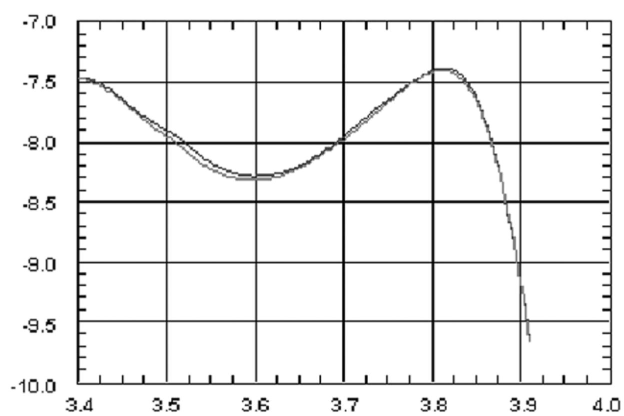

Figure 2: Conversion loss using the first new method, up and down conversion.

Figure 2 shows the result of performing this characterization on an RF mixer. A filter-mixer-filter combination was created, and characterized two times, once as an up-converter, and once as a down-converter. This mixer can also be used as a calibration mixer in a test system as described by Dunsmore in [3].

Power Meter Calibrated VNA

An alternate method for characterizing the amplitude response of mixers consists of using a power meter to characterize the vector network analyzer, then using the vector network analyzer to characterize the mixer. Using a power meter is not new [6], but previous methods have been sensitive to mismatch, and to power level fluctuations. The new method uses a one-port error correction to characterize the source match of the VNA, and to measure the return loss of the power meter. The source power is measured by the power meter and corrected for source match interactions. This calibration is transferred to the reference channel of the VNA to allow continuous measurement of the source output and correct for source level fluctuations.

Next, a one-port calibration is performed at the output frequency of the mixer under test, and port 1 of the VNA is connected to port 2. The load match of the VNA port 2 is measured, as well as the receiver response. This response is also referenced to the reference channel. An additional step of performing a one-port calibration on port 2 can be done if it is desired to correct for mixer output match. Finally, a mixer is connected between ports 1 and 2. Figure 3 shows the measurements using a vector corrected power-meter calibrated VNA. In this measurement method, which can only measure the amplitude response, it is apparent that there is some non-reciprocal nature over a portion of the mixer's frequency response. However, the average of the up and down conversion is nearly identical to the response in Figure 2, thus validating that the first method does indeed characterize the "round-trip" conversion loss of the mixer.

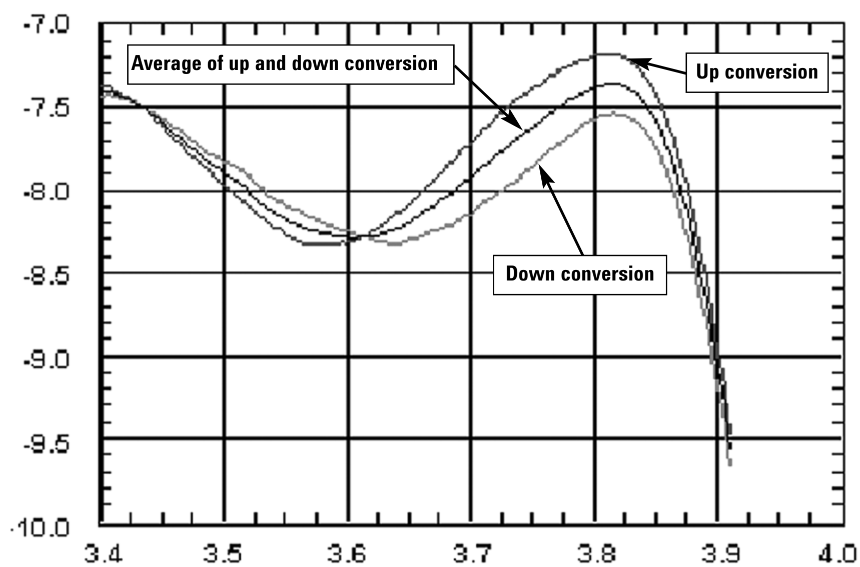

Figure 3: Conversion loss using a power corrected VNA with match correction.

Evaluating the test method errors

The test method errors can be evaluated to understand their interactions. The errors come from a variety of sources, including power meter linearity, image signals, calibration kit residuals, and dynamic accuracy limitations in the VNA. Analysis of the error of the first method gives the error in the "round-trip" conversion loss as

$$\Delta(T1^{*}T1) = \frac{r1 \bullet r2}{(1-m1 \bullet D)^2 \bullet (1-d2 \bullet M)^2}$$

where r1, m1 are the residual tracking and source match of the cal kit used to correct port 1; r2, d2 the residual tracking and directivity of the cal kit at the output of the filter; and D and M the input and output match of the mixer, and T1, T2 the forward and reverse conversion gain. There is also the source of error in the first characterization method associated with the non-reciprocal aspect of the mixer under test. The reciprocity can be confirmed using the second method, but only for the amplitude response. Figure 4 shows an idea for estimating the phase non-reciprocity from the amplitude non-reciprocity, assume the non-reciprocal behavior is due to an independent signal adding and subtracting as a vector. Analysis shows that errors of this type contribute 6.6 degrees of phase for each dB of amplitude error. Thus, the result of Figure 3, with about +-0.2 dB of non-reciprocal behavior would predict 1.3 degrees of phase error. It is important to note that this is only an estimate of the error based on an assumed relation between the main signal and error signal.

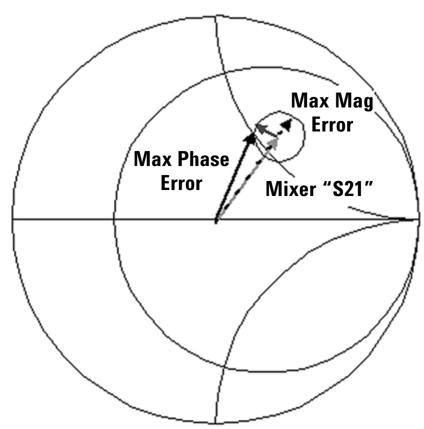

Figure 4: Amplitude error expressed as phase error.

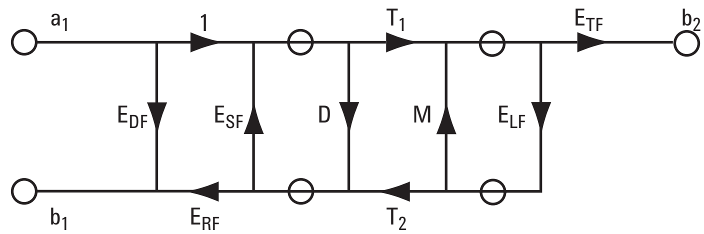

Figure 5: Error model for a mixer measurement, where D is the mixer input match, M is the mixer output match, T1 is the forward conversion gain and T2 is the reverse conversion gain. EDF, ESF, ERF are the port 1 directivity, source match and reflection tracking errors; ELF is the port 2 load match, and ETF is the b2 receiver tracking error.

Figure 5 shows the error model for a mixer measurement using the power meter calibrated VNA to measure the output power (b2). The input power can be corrected and can be measured on the reference channel, represented by a2. During the calibration procedure, the system source match will interact with the power meter match to create a small error. Also, when the source is connected to the analyzer port 2 to calibrate the b2 receiver, there can be a small port mismatch effect. These errors are typically small, and they contribute to the final system error as a product of the mismatches. Finally, there can be a large mismatch effect from the input match (D) and the output match (M) of the mixer, as mixers typically have poor match. The importance of vector correction of mixer measurements can be demonstrated through examples where the test system match will be artificially corrupted. Figure 6 shows a measurement made with a power meter (traditional way) verses a match corrected VNA measurement. One reason the power meter may show lower conversion loss (higher trace) is that it is measuring other spurious signal out of the mixer, even though there was some filtering on the mixer.

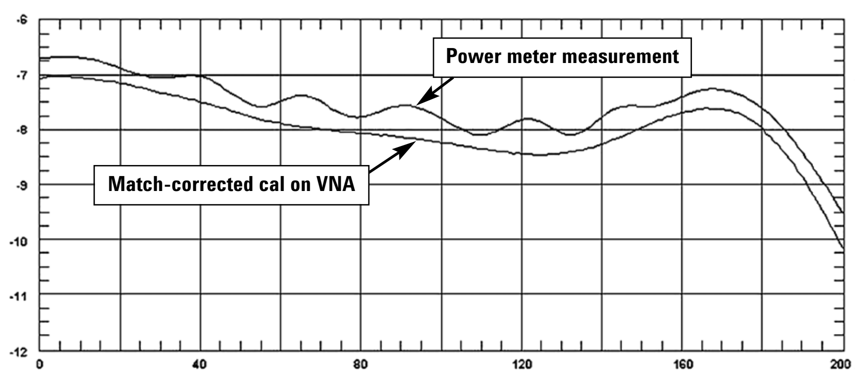

Figure 6: Power calibrated VNA with correction (lower trace) versus the mixer measured with a power meter.

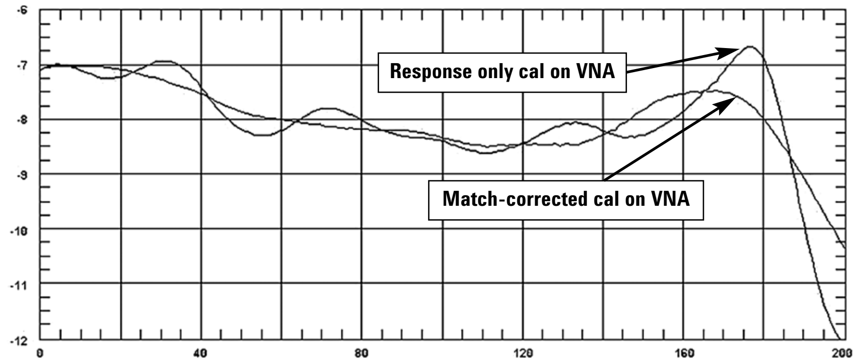

Figure 7: Power meter corrected VNA amplitude measurements for a test system with bad (-5dB) match, without match correction (trace with ripple) and with match correction (smooth trace).

Figure 7 shows the measurement of the mixer on a test system with bad (-5 dB) match (trace with ripple), using a response cal as described in [5]. The plot also shows the same mixer with the same test system, but this time with match correction. The bad match system with error correction shows nearly identical results (within 0.07 dB) as a good match system presenting confirmation that this technique works.

Other errors remain, including re-mixing of signals and residuals in the calibration kit used for match correction. The effects of these other errors for this test mixer are quite small. The mixer here included input and output frequency filtering. Further work continues to evaluate the effects in the absence of such filtering.

Conclusion

The careful characterization of mixers using state-of-the art techniques is presented. A new characterization technique making use of reflection measurements, and assuming a reciprocal mixer is compared to a new VNA measurement method that use vector corrected power measurements. The characterization of the calibration mixer is approximately the sum of the reflection tracking error of the calibration standards used for the VNA calibration, and the mixer characterization.

References

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[4] United States Patent 6,448,786 *Stimulus/response System and Method of Vector Characterization of Frequency Translation Devices*, September 10, 2002.
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[6] Agilent 8753E Network Analyzer User's Guide, manual number 08753-90367, Chapter 6.

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