TRANSMISSION RESPONSE MEASUREMENTS OF FREQUENCY TRANSLATING DEVICES

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ABSTRACT

This paper presents two methods for accurately determining the transmission response of frequency translating devices: an inferred response technique using a vector network analyzer, and a direct response technique utilizing a microwave transition analyzer. Tradeoffs between these two approaches are presented along with results for a 20 GHz downconverter. The emphasis here is on single-sideband converters, but the application to double-sideband converters is also described briefly.

1. INTRODUCTION

The capability to measure the transmission response of the devices in a communications channel is essential for accurate systems modeling. Both the amplitude and phase response are needed to assess the extent of signal distortion. The most common tool for characterizing non-frequency translating components is the *vector network analyzer* (VNA). Its design and error correction capabilities make it very fast and accurate. *Frequency translating devices* (FTDs), such as mixers, are more difficult to characterize due to the frequency offset between input and output, and cannot be measured by a VNA alone. The most common FTD measurement technique uses a reference test mixer to obtain the amplitude and phase match between FTDs [1]. This technique is limited in that it only provides the absolute difference between FTDs over a specified frequency range.

This paper discusses two methods for accurately obtaining the transmission response of FTDs. The first technique uses the VNA and provides an inferred response based on several measurements involving the swapping of test mixers. The second technique uses the *microwave transition analyzer* (MTA) to provide a direct response of the *device-under-test* (DUT). In this approach, a modulated carrier is passed through the DUT and demodulated at the translated frequency. A comparison is made between the demodulated and original modulating signal to determine the transmission response. Both of these techniques provide accurate characterization of FTDs, which can range from a simple mixer to a complete communications channel with offset frequencies. This paper will discuss accuracy and measurement complexity tradeoffs, as well as typical results for a 20 GHz downconverter.

Both methods apply to mixers operating as *single-sideband* (SSB) converters, which is how they would typically be used in a communications channel. However, mixers are also often used as *double-sideband* (DSB) converters in modulators and demodulators. For example, in a bi-phase shift keying modulator, a mixer can be used to upconvert a baseband digital signal. We will describe how the VNA inferred technique can be applied to DSB mixers.

2. VNA INFERRED TECHNIQUE

Figure 1 shows the test set up for the *VNA Inferred Technique* (VNAIT). For our work, we used a standard HP 8510C Network Analyzer which is capable of measurements from 0.05 to 50 GHz. In addition to the DUT and the VNA, three *bandpass filters* (BPFs), four attenuators, and a minimum of two test mixers, are used. The phase shifter on one *local oscillator* (LO) arm is only required for DSB converter testing. The test mixers are required to translate the first device's output back to the original input frequency. The

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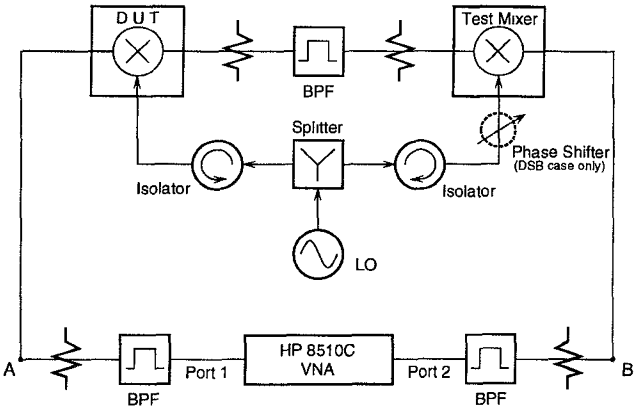

Figure 1: *VNAIT Test Set Up.*

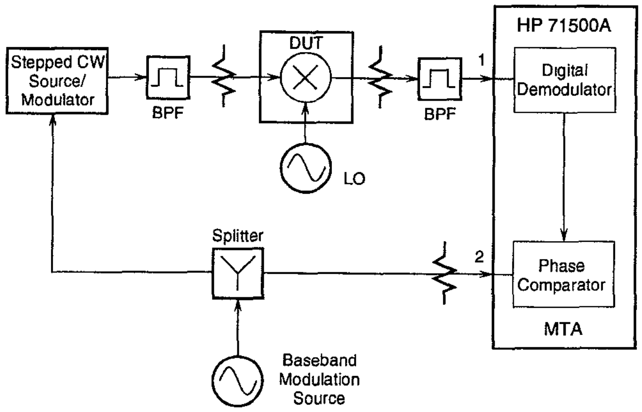

Figure 2: *MTADT Test Set Up.*

filters and attenuators are used to minimize measurement error. The reference plane for the two-port measurement is located at points A and B. A full two-port calibration allows for very accurate measurements due to the VNA's automatic 12 term error correction capability. Note that the VNAIT requires that the DUT either has an external LO input or provides its internal LO as an output. This is necessary for the VNA to perform a phase coherent measurement.

The transmission response of the DUT is inferred from the overall response of the DUT with a combination of test mixers. A minimum of two test mixers must be used, and additional test mixers can be used to improve accuracy. A full two-port VNA measurement provides two transmission responses ($s21$ and $s12$) for each mixer combination test case. When two test mixers are used, three test cases provide the following six results:

H_A : DUT + Test Mixer 1 ($s21$)
$H_{A'}$: Test Mixer 1 + DUT ($s12$)
H_B : DUT + Test Mixer 2 ($s21$)
$H_{B'}$: Test Mixer 2 + DUT ($s12$)
H_C : Test Mixer 1 + Test Mixer 2 ($s21$)
$H_{C'}$: Test Mixer 2 + Test Mixer 1 ($s12$)

where $H_X = H_X(f)$ represents the measured transfer function. Assuming DUT and test mixer reciprocity, eight possible responses of the DUT can be inferred using the following expression:

$$R_n^{DUT}\Big|_{n=1}^{8} = \frac{\{R_A,R_{A'}\} + \{R_B,R_{B'}\} - \{R_C,R_{C'}\}}{2}, \quad (1)$$

where $R = R(f)$ represents the amplitude (dB) or phase (degrees) portion of the corresponding total response H; R^{DUT} is the inferred response of the DUT; and $\{R_X, R_{X'}\}$ means choose one of the responses $R_X(f)$ or $R_{X'}(f)$, $X = A, B, C$. Equation (1) applies for the case in which the downconversion uses low-side LO injection and the upconversion uses high-side injection. For the case in which the downconversion uses high-side injection and the upconversion also uses high-side injection, then $R^{DUT}(f)$ must be replaced by $R^{DUT}(-f)$ for the amplitude and $-R_{DUT}(-f)$ for the phase. The application of this technique requires that at least one of the test mixers or the DUT be reciprocal. For each non-reciprocal mixer or DUT used, there is a subsequent reduction in the number of valid responses that can be calculated from Eq. (1). The calculated DUT amplitude and phase responses can be averaged to obtain a more accurate final result.

3. MTA DIRECT TECHNIQUE

Figure 2 shows the test set up for the *MTA Direct Technique* (MTADT) [2]. For our work, we used the HP 71500A Microwave Transition Analyzer which is capable of measurements from dc to 40 GHz. It requires less test equipment and measurement time than the VNAIT since there is no requirement for test mixers. In this technique, a modulated carrier is passed through the DUT, and then applied to port 1 of the MTA. Internal to the MTA, the signal is demodulated and compared to the original baseband modulating signal applied at port 2. The CW source is stepped

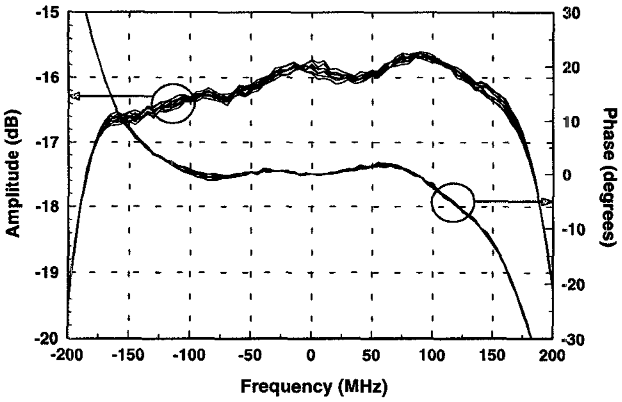

Figure 3: *Transmission Response from VNAIT.*

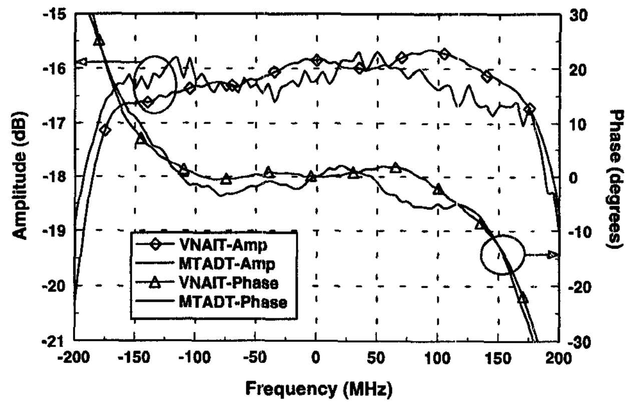

Figure 4: *Comparison of VNAIT and MTADT Results.*

across the RF band of interest for the complete transmission response measurement.

The calibration procedure requires only a through path for normalization. The accuracy is therefore limited in comparison to the network analyzer approach where full vector error correction is used. Measurement time is determined by the speed of the stepped CW source and the extent of noise reduction required for high accuracy. The MTADT does not require phase coherency between the LO and the test equipment. This is beneficial when it is necessary to measure a device without access to an internal LO. The measurement procedure has been automated in an IBASIC program available from Hewlett-Packard [2].

4. 20 GHZ DOWNCONVERTER MEASUREMENTS

To compare the accuracy of the two measurement techniques, a 20 GHz to 8 GHz frequency converter was characterized. The measurement bandwidth was 500 MHz, using 101 frequency points. For consistency, both techniques used an averaging factor of eight with no data smoothing applied. For the VNAIT, the eight calculated responses for both the amplitude and phase are shown over a 400 MHz bandwidth in Figure 3. The tight grouping between response curves indicates that the DUT and both test mixers are reciprocal.

Measurements from the MTADT were compared with the average of the eight calculations from the VNAIT as shown in Figure 4. In the MTADT measurement, 2.5 MHz frequency modulation was used. Additional trace averaging could have been used to enhance noise reduction at the expense of increased measurement time. The average deviation between the technique measurement curves was found to be 0.37 dB and 1.80° for the amplitude and phase, respectively, over the 400 MHz band. This difference is primarily due to port mismatch error inherent to the MTADT.

5. DSB CONVERTER CHARACTERIZATION

The VNAIT can be applied to DSB mixers with some modification. For example, if we have three mixers that perform DSB conversion from baseband up to an RF band centered at the LO frequency, we can characterize them using the setup shown in Figure 1. The VNA should sweep across the baseband frequency range (0 to f_c), with the VNA signal going into the *intermediate frequency* (IF) port of the mixer and the BPFs at the VNA ports replaced by *low-pass filters* (LPFs). The back-to-back mixer responses must be measured at two settings of the phase shifter that are 90° apart at the LO frequency in order to completely characterize the mixers.

For the DSB characterization, the baseband VNA output signal mixes with the LO signal in the DUT to produce upper and lower sidebands. Both sidebands are downconverted in the test mixer back to the baseband IF frequency. The sidebands recombine at any relative phase, based on the setting of the phase shifter.

For example, if one setting of the phase shifter gives a maximum IF signal at a given IF frequency, then a setting 90° away will give a minimum IF signal. At the maximum IF signal, the two sidebands are in-phase, so the IF response is the sum of the two sideband responses. At the minimum IF signal, the sidebands are out-of-phase, so the IF response equals the difference of the two sideband responses. By taking the sum and difference of the IF responses at the two phase settings with an appropriate phase shift, one can calculate the two sideband responses separately. This is only an example, in practice it is unnecessary to find the maximum IF response; any two phase settings 90° apart will do. The *low-pass equivalent* (LPE) (see [3]) DSB response can be calculated from

$$H_X(f) = \begin{cases} \frac{[H_X^I(-f)]^* + \jmath [H_X^{II}(-f)]^*}{2}, & -f_c < f < 0, \\ \frac{H_X^I(f) + \jmath H_X^{II}(f)}{2}, & 0 < f < f_c, \end{cases} \quad (2)$$

where $[\,]^*$ is the complex conjugate operation, $\jmath$ is the square root of -1, and $H_X^I(f)$ is the complex $s21$ response of the back-to-back mixers at phase shifter setting I and $H_X^{II}(f)$ is the complex $s21$ response of the back-to-back mixers at phase shifter setting II (setting II − setting I = +90°), with $X = A, B, C$. The overall LPE DSB response of the DUT is calculated by applying the VNAIT to $H_A(f), H_B(f)$, and $H_C(f)$.

6. MEASUREMENT PRECAUTIONS

Taking basic precautions in an FTD test setup can minimize the extent of measurement errors. The first consideration is the port termination sensitivities of the specific FTD under test. Stand-alone mixers will often require special care in contrast to frequency converter units where isolation is often provided by filters, isolators or amplifiers. If any of a mixer's ports are terminated reactively at unwanted mixing product frequencies, both the transmission response and intermodulation performance can vary significantly [4]. Broadband attenuators can be used to minimize the effects of reactive port terminations. The attenuation value required is based on the specific characteristics of the mixer and termination and is typically 6 to 10 dB. In cases where excessive loss cannot be tolerated, broadband isolators, diplexers or constant impedance filters may be used.

The second measurement consideration is filtering. In the VNAIT, the filter between the mixers is required to remove the unwanted mixing products. These spurious responses would otherwise interact in the test mixer resulting in measurement error. The filter bandwidth should be larger than the desired response bandwidth. The response of the filter and accompanying attenuators are included in the measurement and can be removed mathematically. The filters used directly on the VNA and MTA ports prevent mixer-generated spurious products from causing equipment measurement error. The response of these filters and accompanying attenuators is removed by the calibration process.

7. CONCLUSION

Two methods of obtaining the transmission response of FTDs have been presented. The VNAIT can provide the most accurate results due to the 12 term error correction procedure automatically applied at the measurement ports. The MTADT provides a simpler, more cost effective solution with less accuracy. In addition, the MTADT can be applied to DUTs having inaccessible internal LOs whereas the VNAIT may not.

8. REFERENCES

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