A NEW TIME-DOMAIN MEASUREMENT TECHNIQUE FOR MICROWAVE DEVICES

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ABSTRACT

A new time-domain measurement technique for repetitive microwave signals is described. The microwave signal is converted to baseband before measurement, improving the accuracy compared to measurements at the carrier frequency. Applications include nonlinear device and modulator measurements, for the purpose of model generation and verification.

1. INTRODUCTION

We present here a new method to measure microwave signals in the time domain. In this method, the microwave signal is mixed down to baseband, where it is a *lowpass-equivalent* (LPE) waveform [1], having both in-phase and quadrature components, which are recorded by means of a *Microwave Transition Analyzer* (MTA). The downconverting mixer frequency response is then removed from the recorded waveforms by application of the baseband-double-sideband mixer characterization method [2], providing an accurate LPE representation of the original microwave signal.

The above outlined technique alleviates the accuracy and noise limitations of measurements performed at the carrier frequency. A time-domain measurement of a microwave signal provides a complete characterization of that signal, including both phase and amplitude information. Thus, time-domain measurements at the input and output of a microwave device can be used to provide a complete characterization of the device. In particular, the behavior of nonlinear microwave devices can be fully characterized for the purposes of model generation and verification. A companion paper [3] describes an example of generating a nonlinear amplifier model using time-domain measurements.

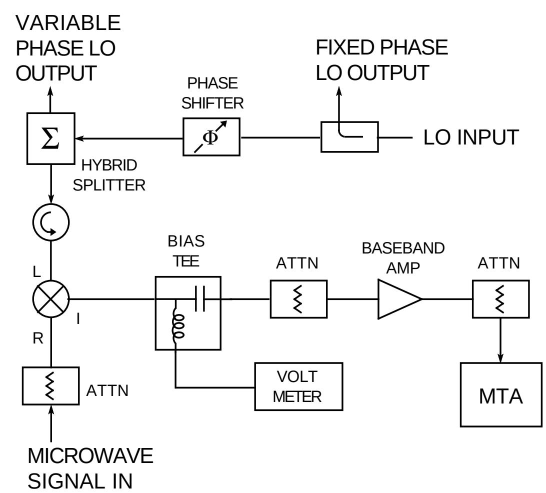

Figure 1: *Simplified receiver block diagram.*

2. TEST SYSTEM CONFIGURATION

The basic measurement system consists of a downconverting receiver followed by an MTA as shown in Figure 1. The DC level, which corresponds to the Fourier component at the carrier frequency, is measured separately by means of a bias tee and a volt meter at the output of the downconverting mixer. This is required since the baseband amplifier blocks the DC component. Note that a *digital storage oscilloscope* (DSO) could be used in place of the MTA with reduced accuracy, because most DSOs do not have the calibrated accuracy of the MTA.

The microwave signal to be measured can have any arbitrary repetitive phase or amplitude modulation imposed upon it, but it must be accompanied by an unmodulated carrier to feed the receiver's LO input. The receiver has two coherent LO outputs, a fixed phase and a variable phase LO. These outputs can be used with the transmitter (see Figure 2), and are needed for the transmitter and a test mixer in the calibration procedure outlined below.

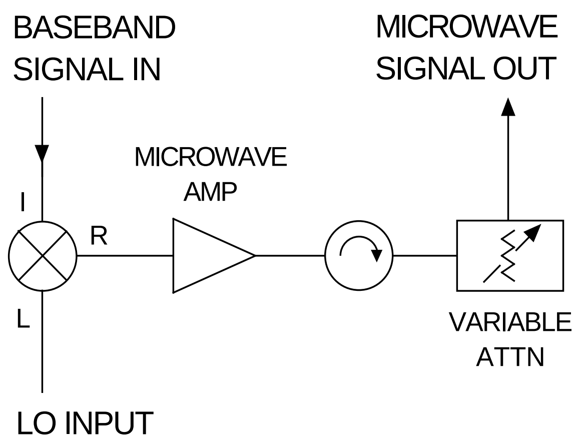

Figure 2: *Simplified transmitter block diagram.*

The stability requirements on the carrier need not be high, because its phase noise is canceled by the downconversion. The baseband modulation signal, however, must be stable, preferably with a 10 MHz reference output to be used by the MTA as an external reference. The modulating source can be used to trigger the MTA if a separate trigger output is not available.

With the equipment configured as shown in Figure 1, the downconverted signal is recorded at an arbitrary relative carrier phase between the microwave signal source and the receiver to record the uncorrected in-phase component of the LPE signal. The phase shifter is then adjusted by 90° and the downconverted signal is again recorded to form the uncorrected quadrature component of the LPE signal. In practice, four phase settings 90° apart are used to cancel DC mixer offsets. The 0° and the inverse of the 180° measurements are combined to form the in-phase component, and the 90° and the inverse of the 270° measurements are combined to form the quadrature component. Note that the LPE signals thus obtained include the frequency response of the receiver and are therefore uncorrected. To obtain corrected LPE signals, the frequency response of the receiver must be removed. The correction procedure required to remove this frequency response is described below.

Among the signals that can be recorded are input and output waveforms of a nonlinear *device under test* (DUT). The signal source and the receiver are connected together to record the input LPE signal, and the DUT is inserted between the source and the receiver to record the output LPE signal. Another application of this technique is to record the output waveforms of microwave-frequency modulators. These time-domain measurements can then be used to optimize and validate simulation models of these components and systems.

To enhance the usefulness of the time-domain measurement system, an upconverting transmitter is also included that can be used with a coherent LO source and a baseband waveform synthesizer to provide modulated microwave signals defined by the user. The transmitter is illustrated in Figure 2. The microwave amplifier and variable attenuator are provided to allow the input power to the DUT to be adjusted over its operating range.

Once the uncorrected signals are obtained, the receiver frequency response must be analytically removed. The receiver's frequency response is measured by means of the baseband-double-sideband-mixer characterization method [2]. The setup for this characterization method consists of connecting an upconverting “transmitter” followed by a downconverting “receiver” that both use the same LO, with a phase shifter used in the receiver LO path as shown in Figure 1. A *vector network analyzer* (VNA) is used to measure this combination at two relative LO phase settings 90° apart. The two measurements only provide the frequency response of the pairwise combination of the transmitter and receiver. They are not sufficient to extract the frequency response of the receiver alone.

To calculate the response of the receiver, two additional similar configurations using a third frequency converter (a test mixer) are required. The second configuration consists of the test mixer used as an upconverting transmitter followed by the receiver, and the third configuration consists of the transmitter followed by the test mixer used as a downconverter. The method requires that the test mixer have the same frequency response whether it is used as an upconverter or a downconverter. In practice, commonly available double-balanced mixers exhibit this reciprocal response if a low VSWR is provided on all ports by use of fixed attenuators. By mathematically combining the six measurements provided by the three setups, the LPE frequency response of the receiver may be obtained. This response is then removed analytically from the uncorrected LPE signal measurements, leaving an accurate LPE representation of the microwave signal. Note that the frequency response of the MTA has not been removed from the measurements.

3. RESULTS

Although any modulated signal may be used, as a simple demonstration of our technique, we used a 0.35 ns wide, 0.5 V amplitude baseband pulse as the modulation input to the transmitter. The LO frequency was 19.6 GHz. The transmitted pulse was measured using our baseband time-domain measurement technique and the receiver correction was applied. As a validation of our baseband technique,

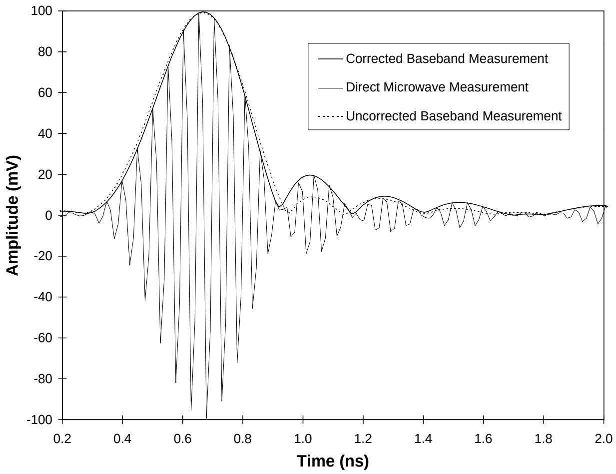

Figure 3: *Comparison of time-domain measurement techniques applied to a microwave pulse.*

(a)

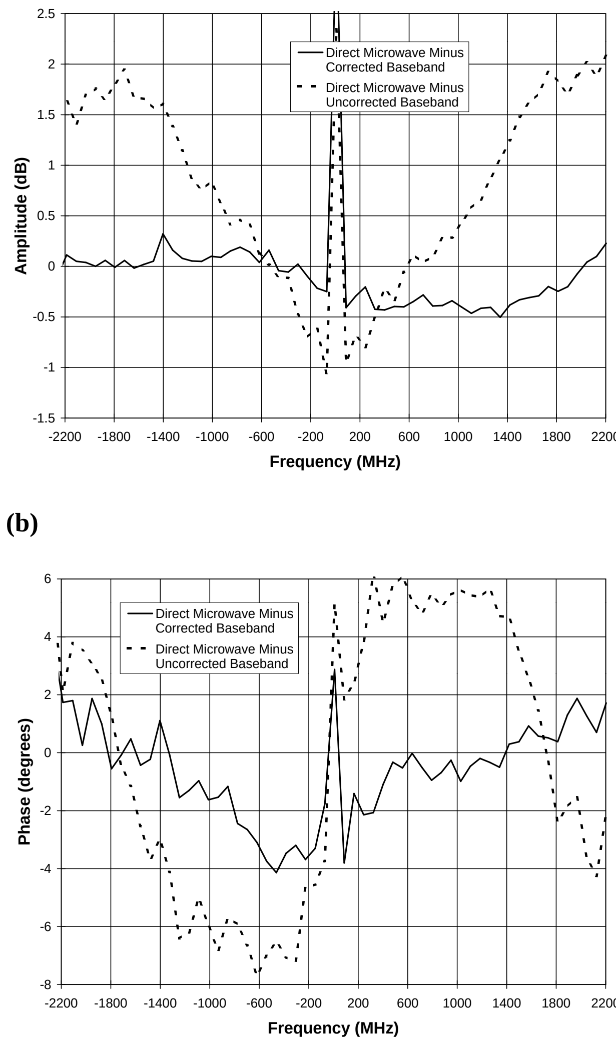

Figure 4: *Comparison of time-domain measurement techniques applied to a microwave pulse transformed to the frequency domain. The direct microwave measurement has been downconverted to baseband in software.* (a) *Comparison of measurement amplitudes.* (b) *Comparison of measurement phases.*

the same signal was measured directly at 19.6 GHz using the MTA. Figure 3 shows the signal envelope of the both the corrected and uncorrected baseband measurement and the directly measured microwave pulse at 19.6 GHz. The excellent agreement between the corrected baseband and the direct microwave measurement indicates the validity of the baseband measurement technique. The disagreement of the uncorrected baseband measurement with the other two measurements indicates the validity of the corrections applied to remove the response of the receiver. Figure 4 compares the same three measurements after transformation to the frequency domain. The maximum deviation between the corrected baseband and the microwave measurements is $\pm 3^{\circ}$ and ± 0.4 dB across a 4 GHz bandwidth (except at the DC frequency where the power spectral density is low, so the error is larger). This comparison illustrates the consistency of the baseband technique with the direct measurement. The value of the baseband technique lies not in this simple case, but rather in situations where the direct microwave measurement is inadequate, for example where the carrier frequency is beyond the range of the MTA, or the phase noise is too high, or the repetition period of the signal is too long to allow Nyquist sampling of the signal at the carrier frequency given the limited number of samples available (1024 samples for the MTA).

4. COMPARISON WITH OTHER MEASUREMENT TECHNIQUES

Measuring signals at baseband has several advantages compared to measuring them directly at the carrier frequency. One is that the sample rate can be reduced by the ratio of half the signal bandwidth to the carrier frequency, thereby allowing for a longer time record or higher time resolution of the signal for the same number of samples. Another advantage is that the timebase accuracy and stability requirements for the DSO or MTA are reduced by the same ratio of half the signal bandwidth to the carrier frequency. Another advantage is that the phase noise of the carrier is eliminated since the same LO is used for both the upconversion and the downconversion. Finally, the MTA or DSO has a flatter frequency response at baseband than

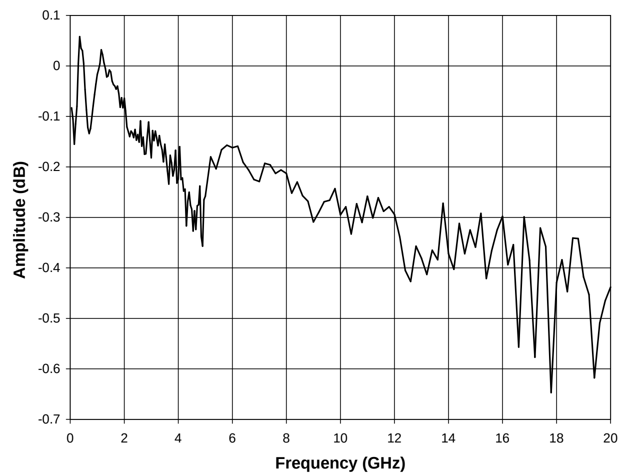

Figure 5: *MTA amplitude response calibration using an HP8485D Power Sensor as a "gold" standard.*

at high carrier frequencies (see Figure 5). For example, signals with a 4 GHz bandwidth require only 2 GHz at baseband, over which the MTA has a gain variation of only ± 0.1 dB. The phase deviation from linearity can be as high as 40° for a typical digitizing oscilloscope at 20 GHz, but it is negligible below 5 GHz [4].

The Hewlett-Packard Co. has developed a *Nonlinear Vector Network Analyzer* (NVNA) that performs calibrated time-domain measurements of signals up to 50 GHz. The NVNA includes calibration standards and software that calibrates the sampling oscilloscope for A/D nonlinearity and gain/phase response versus frequency. This calibration eliminates any inaccuracy associated with the gain/phase response of the MTA, however, it still has limitations imposed by a limited number of samples and phase noise errors.

5. CONCLUSION

A new method to measure microwave signals in the time domain has been presented. This new technique does not suffer the accuracy and noise limitations of measurements performed directly at the carrier frequency. Accurate *lowpass-equivalent* (LPE) waveforms are obtained after correcting for the receiver response by means of the baseband-double-sideband frequency-translating-device measurement technique. These LPE waveforms provide a complete characterization of the microwave signal, including both phase and amplitude information. LPE waveforms recorded at the input and output of a microwave device provide the information required to completely characterize its behavior. The new method is particularly useful in the characterization of nonlinear devices for the purposes of model generation and verification.

6. REFERENCES

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