A DYNAMIC AM/AM AND AM/PM MEASUREMENT TECHNIQUE

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ABSTRACT

The AM/AM and AM/PM characteristics of a power amplifier are typically measured in a static manner using a CW signal. For communications signals, the amplitude envelope is varying so the distortion is actually occurring dynamically. This paper presents a technique to measure dynamic AM/AM and AM/PM. Results are presented for two examples of power amplification: a traveling-wave tube amplifier and a solid-state amplifier.

1. INTRODUCTION

Microwave transmitters generally rely on a nonlinear power amplifier as the final amplification stage. Operating the power amplifier at or near saturation improves power efficiency compared to linear operation, but signal distortion is generally increased. The two major nonlinear distortions can be described in terms of AM/AM and AM/PM conversion. These conversion characteristics are often used in communication systems modeling [1]. These models are important for predicting end-to-end link performance as well as simulating spectral regrowth.

An amplifier's AM/AM and AM/PM characteristics are often obtained with a *vector network analyzer* (VNA) by measuring the gain and phase as a function of input power. Typically this measurement is a CW or static measurement, so it does not give the dynamic response. For communications signals, the amplitude envelope can vary at a frequency corresponding to the information rate, so the AM/AM and AM/PM distortion is actually occurring dynamically. A simple technique is presented to measure the dynamic AM/AM and AM/PM at a modulation rate that is consistent with actual applications. The results may be used in communication systems models in place of VNA-derived static measurements.

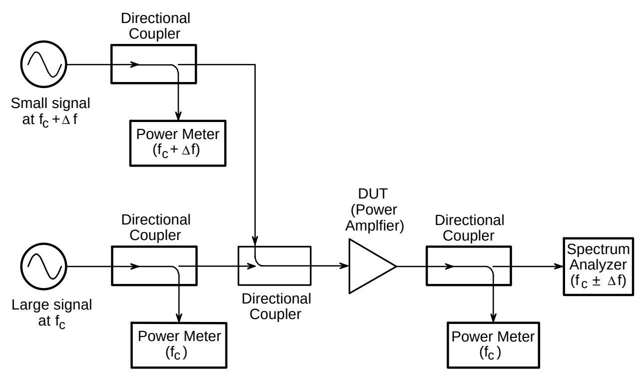

Figure 1: *Dynamic AM/AM, AM/PM test configuration.*

2. TEST SYSTEM CONFIGURATION

The technique described here derives AM/AM and AM/PM from measurements of intermodulation product amplitudes [2]. Since no phase measurements are required, the test equipment requirements are simpler and less costly than those used in the VNA-based static approach. A block diagram of the measurement setup is shown in Figure 1. The input signal to the power amplifier *device-under-test* (DUT) consists of two CW tones, one at $f_c + \Delta f$ being 20 to 30 dB smaller than the other tone at f_c. The output signal would consist of tones only at the two input frequencies if the DUT were linear. In a nonlinear DUT, AM/AM and AM/PM conversion generates an intermodulation product at $f_c - \Delta f$. Amplitude measurements of the two input tones and of the three output

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tones yield all the information required to calculate the AM/AM and AM/PM conversion.

To derive the AM/AM and AM/PM, a reference measurement is first made where the input tones are reduced in power to the point that the DUT is in linear operation. Four reference measurements are made: the input voltage V_{ic}^r at f_c, the input voltage V_{i+}^r at $f_c + \Delta f$, the output voltage V_{oc}^r at f_c, and the output voltage V_{o+}^r at $f_c + \Delta f$. The input tones are then increased in power to the desired operating point. Five additional measurements are made: the input voltage V_{ic} at f_c, the input voltage V_{i+} at $f_c + \Delta f$, the output voltage V_{oc} at f_c, the output voltage V_{o+} at $f_c + \Delta f$, and the output voltage V_{o-} at $f_c - \Delta f$. From these measurements, the normalized output amplitudes of the sidebands, denoted by S_+ and S_- at the frequency $f_c + \Delta f$ and $f_c - \Delta f$, respectively, can be defined [2]:

$$S_+ = S_+(V_{ic}) := \left(\frac{V_{i+}^r}{V_{o+}^r}\right)\left(\frac{V_{oc}^r}{V_{ic}^r}\right)\left(\frac{V_{o+}}{V_{i+}}\right)\left(\frac{V_{ic}}{V_{oc}}\right) \tag{1}$$

$$S_- = S_-(V_{ic}) := \left(\frac{V_{i+}^r}{V_{o+}^r}\right)\left(\frac{V_{oc}^r}{V_{ic}^r}\right)\left(\frac{V_{o-}}{V_{i+}}\right)\left(\frac{V_{ic}}{V_{oc}}\right) \tag{2}$$

Note that the normalization removes the dependence on the sideband input voltage, so that these normalized sideband amplitudes should be a function only of the operating point, which is set by the input voltage V_{ic} at f_c. The AM/AM (dB/dB) and AM/PM (deg/dB) are then calculated from

$$\frac{dV_{oc}}{dV_{ic}} = S_+^2 - S_-^2 \tag{3}$$

and

$$\frac{d\theta_{oc}}{dV_{ic}} \approx \frac{18 \ln 10}{\pi}\left[S_+^2 - \left(\frac{1 + S_+^2 - S_-^2}{2}\right)^2\right]^{\frac{1}{2}}, \tag{4}$$

respectively, where the AM/AM expression is exact, and the AM/PM expression is within a 0.5% error when the difference between the two input tone levels is 20 dB or more.

This technique derives the distortion characteristics directly at a modulation frequency of Δf. Thus it will not be in error due to fading from temperature variations or bias circuitry as may occur in static measurements.

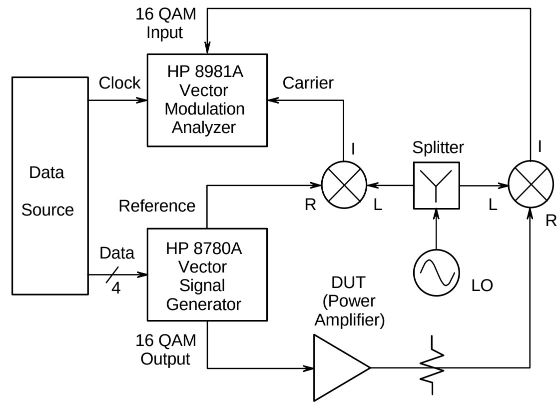

Figure 2: *16-QAM dynamic AM/AM, AM/PM test configuration.*

3. TRAVELING-WAVE TUBE AMPLIFIER (TWTA) MEASUREMENT RESULTS

This section presents the measurement of AM/AM and AM/PM for a TWTA (Hughes Model 1277H) operating at 1.65 GHz. To contrast the differences between static and dynamic measurement, AM/AM and AM/PM curves were measured using three different methods: (1) the standard static VNA technique, (2) the two-tone dynamic technique with an offset frequency of 0.5 MHz, and (3) another dynamic technique using a 16-QAM input signal.

The 16-QAM dynamic method used a signal at a symbol rate of 1 MHz, conveniently generated by a Hewlett Packard 8780A Vector Signal Generator, and demodulated by a Hewlett Packard 8981A Vector Modulation Analyzer. This setup is shown in Figure 2, where the mixers are needed because of the modulation analyzer's 200 MHz carrier limit.

The 16-QAM signal was sent through the TWTA. A reference measurement was first made with the TWTA in linear operation, then the signal level was increased to the desired operating point. The phase rotation and amplitude compression of the outer 12 constellation points was compared to the inner four points to derive the AM/PM and the AM/AM, with the reference measurement being used to correct for the non-ideality of the modem. The HP 8981A has A/D converters that digitize the constellation points, simplifying the calculations. Since this QAM measurement is also a dynamic technique, the results are expected to agree more closely with the two-tone dy-

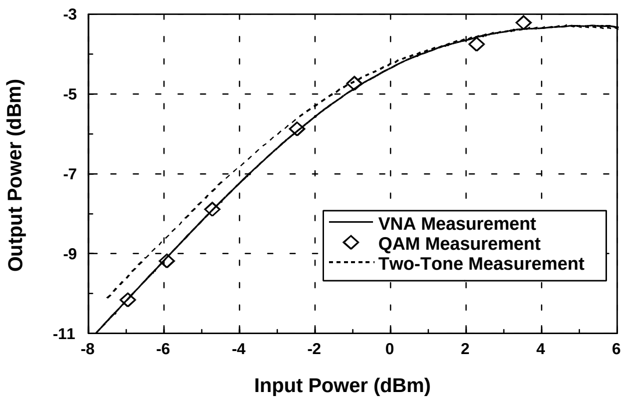

Figure 3: *Comparison of TWTA AM/AM measurement results.*

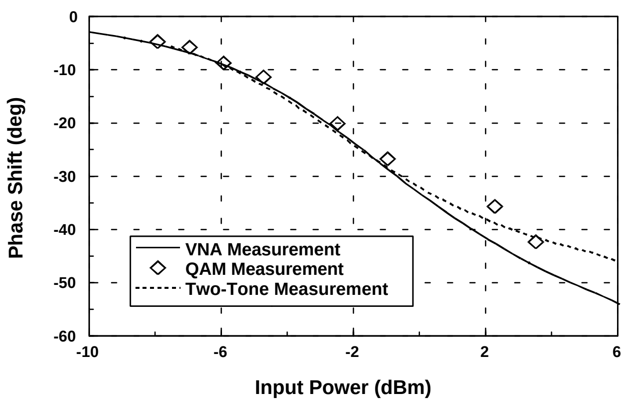

Figure 4: *Comparison of TWTA AM/PM measurement results.*

namic technique than the VNA static technique.

The results shown in Figures 3 and 4 demonstrate that the 16-QAM and two-tone techniques do indeed exhibit better agreement than either one does to the VNA measurement, particularly for the phase shift versus input power. The dynamic AM/PM of this TWTA maybe lower than its static value due to the dynamics of the power supply as it is driven into saturation. Driving this TWTA with a stepped input signal, a settling time of several milliseconds was observed.

4. SOLID-STATE AMPLIFIER (SSA) MEASUREMENT RESULTS

This section presents the dynamic AM/AM and AM/PM for an SSA (DBS Model 028N315). In this

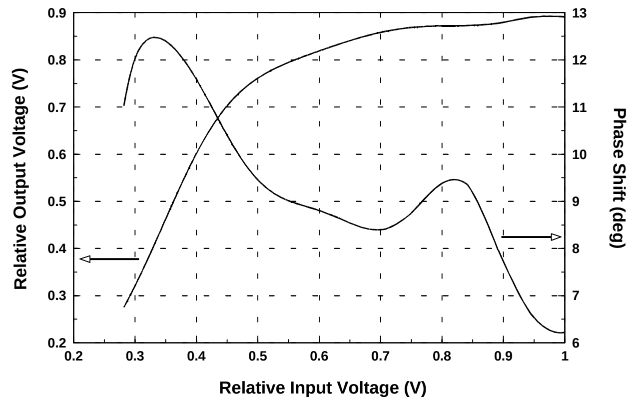

Figure 5: *Measured SSA dynamic AM/AM and AM/PM.*

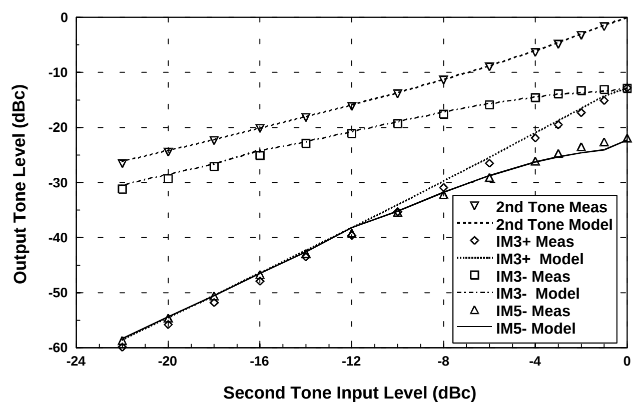

Figure 6: *Modeled vs. measured SSA distortion characteristics.*

example the large tone at f_c was at 2.8 GHz and the offset tone was at 2.81 GHz, 25 dB smaller than the large tone. Figure 5 shows the dynamic measurement results for AM/AM and AM/PM.

To check the validity of these results, a nonlinear model of the amplifier was constructed. A comparison of the output distortion was then made between the model's prediction and the measured results. This was performed for a two-tone input signal over a 20 dB power range. The tones were separated by 10 MHz and the first tone input power was at 6 dB input backoff from saturation. The second tone input power was swept from 26 to 6 dB backoff from saturation. Figure 6 shows how well the model predicts the output level of the tones and the third- and fifth-order intermodulation products. Thus even though the model was generated from third-order intermodulation measurements of a two-tone input with a 25 dB difference in power level, it accurately predicts not only the output for two-tones of equal magnitude, but also the magnitude of the fifth-order intermodulation products.

5. MEASUREMENT PRECAUTIONS

The two-tone dynamic technique does not require that the microwave components (e.g. couplers) or the microwave instruments (e.g. power sensors, spectrum analyzer, signal generators) have a flat frequency response. Equation (1) involves amplitude ratios of signals at the same frequency. Equation (2) as it stands, does involve a ratio of amplitudes at the upper and lower sideband, requiring an identical frequency response at the two sidebands. This requirement can be eliminated if another measurement is made, where the small-signal input is at the lower sideband instead of the upper sideband. If one assumes that the normalized amplitude S_- should not depend on whether the input signal is at the upper or lower sideband, combining the two measurements yields an equation where only ratios at the same frequency are used.

Since Eqs. (1) and (2) involve only amplitude ratios, absolute power measurements are not required. However, it is essential that the power sensors and the spectrum analyzer have excellent linearity with power. Fortunately, power sensors, when operated somewhat below their maximum power input, have negligible deviation from linearity. The spectrum analyzer is not as linear, but can be made acceptable by following certain precautions. First, spectrum analyzer settings other than the center frequency must not be changed in the course of the measurement sequence. Changing the resolution bandwidth, for instance, can change the power reading by a few tenths of a dB, which is unacceptable. Second, the spectrum analyzer power readings should be linearized by means of a lookup table. The table can be generated by a comparison between spectrum analyzer measurements and power meter measurements. Third, the video bandwidth and other settings should be such that spectrum analyzer readings are consistent from sweep to sweep. Automation of the lookup table generation, as well as the main measurement sequence, was implemented in the LabVIEW® application.

Note that Eq. (4), which is used to derive AM/PM, is sensitive to small errors for low AM/PM values. For instance, if the AM/PM is only 0.9 deg/dB, then an error in the measurement of S_+ and S_- of 0.09 dB can yield 100% error in this value. In contrast, if the AM/PM is 4 deg/dB, then an error in S_+ and S_- of 0.1 dB yields less than 5% error in the AM/PM value. Note that in devices with low AM/PM, nearly all the signal distortion is caused by the AM/AM curve, so the two-tone technique can still be used as a means to generate a dynamic AM/AM curve, even though the AM/PM results will be subject to large error.

Finally, this technique may not be applicable for all types of power amplifiers. Erroneous results may be obtained for devices which contain more than one nonlinearity (e.g. a multistage amplifier with more than one saturating stage or an amplifier containing saturated devices in parallel).

6. CONCLUSION

This paper has presented a simple technique to measure the dynamic AM/AM and AM/PM curves of a nonlinear device for systems modeling. The curves can be generated at modulation rates consistent with real-world applications rather than relying on statically generated curves which could be in error due to thermal or power supply effects. A measurement of a TWTA was presented where the dynamic curves did indeed differ from the static curves. The dynamic measurement was validated by comparison to a measurement of the distortion in a 16-QAM constellation.

Measurements were also given for an SSA. These measurements were validated by demonstrating the ability to predict intermodulation products out to fifth order over a wide range of input levels.

7. REFERENCES

[1] M. C. Jeruchim, P. Balaban, and K. S. Shanmugan, *Simulation of Communication Systems*. New York: Plenum Press, 1992.

[2] J. P. Laico, H. L. McDowell, and C. R. Moster, "A Medium Power Traveling-Wave Tube for 6000-Mc Radio Relay," *Bell System Technical Journal*, **35**(6), pp. 1285-1346, Nov. 1956.

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