VECTOR METHOD OF CHARACTERIZING NONLINEARITY IN MICROWAVE POWER DEVICES

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ABSTRACT

A new vector method for simultaneously measuring the nonlinear amplitude and phase distortion is described. This simple method, particularly suited for repetitive measurements, is used to characterize high-power amplifiers for 64-QAM digital microwave systems. Graphic display on a "T-chart" clearly identifies gain, compression, expansion, and the order of distortion in devices.

INTRODUCTION

Spectrum conservation has created the need for such modulation methods as quadrature amplitude modulation (QAM) in digital signals, and single sideband (SSB) in analog signals. These methods, when used in long distance transmission, require a high degree of linearity in the transmitting amplifiers. The linearity of these amplifiers is commonly specified by the output power at 1-dB compression and the third-order intercept point, based on 2-tone measurements. Alternately, nonlinearity can be thought of as the vector sum of AM-to-AM and AM-to-PM distortions, the two being in quadrature.

Methods currently used to measure 1-dB compression point and third-order intercept[1] require multipoint measurement with an elaborate test set, requiring two stable sources and a spectrum analyzer. A graphical extrapolation of data, under the assumption of pure third-order (3:1 slope), is necessary to extract the information. In GaAs FET microwave power amplifiers, higher-order distortion contributions [2], beginning at 3 to 5 dB below the 1-dB compression point, distort the slope significantly. Furthermore, AM to PM is either considered small or disregarded in the measurements. The vector method of distortion measurement provides a simple way to determine amplitude and phase distortion from a single measurement. This method, although devised for microwave power amplifiers, can be easily adapted to other devices.

THEORY AND MEASUREMENT SYSTEM

The measurement method uses the HP8410 Network Analyzer and its capability to do transmission measurement of relative amplitude and phase. An HP8414B Polar Display is used for simultaneously observing attenuation or gain and the associated phase angle. Microwave signals, sampled using 20-dB couplers at the input and output of the device under test, are fed to the HP8411 Harmonic Converter. A precision step attenuator and a line stretcher or phase shifter (0 to 360°) is added in the output line. A completed test set is shown in figure 1. A TWT amplifier and a precision attenuator is used to set and adjust input drive level. For linearity reasons, a 40-watt TWT backed off to 1- to 2-watt level was used. A power meter is used to measure output power of the device.

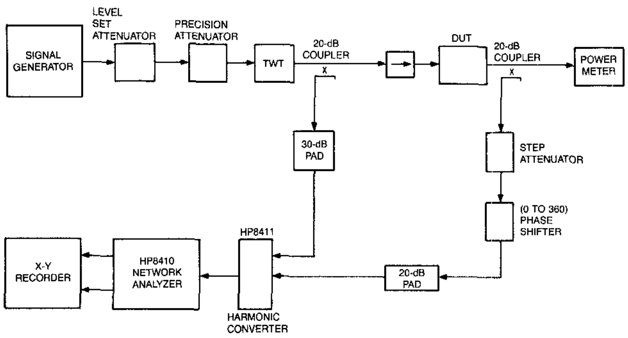

Fig. 1 Vector Distortion Measurement Set.

The two sampled voltages, V_{in} and V_{out}, are vectors with magnitude and phase. The ratio of these vectors at a single frequency is displayed on the polar plot as a function of varying level.

$$\frac{V_{out}}{V_{in}} = \frac{|V_{out}|}{|V_{in}|} \quad \angle \phi_{out} - \phi_{in} \tag{1}$$

The magnitude response in decibels is the gain or attenuation of the service

$$\text{Gain or attenuation} = 20 \log_{10} \frac{|V_{out}|}{|V_{IN}|} \text{ dB} \tag{2}$$

For varying input drive, the polar display shows the variations in the gain (attenuation) and phase of the output of the device under test. An X-Y recorder is used to graphically display this information on a special "T-chart", [3] shown in figure 2. T-chart is a new, enlarged segment of a polar plot showing linear gain and regions of compression and expansion. Lines of constant third-order distortion and constant compression and expansion are also plotted on the chart. Figure 2, furthermore, shows the vectors for actual gain and total distortion voltages.

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Total distortion at a power level can be computed from the length of distortion vector, L, and the length of the linear gain vector, R as

$$\text{Total distortion} = 20 \log_{10} \left(\frac{L}{R}\right) \text{dBc} \quad (3)$$

The AM/AM and AM/PM can be calculated from the curve by using two points, 1 dB apart. The phase of the total distortion vector is significant in systems where predistortion is used to compensate the third-order distortion. The 1-dB compression point can be read directly off the plots as the intersection between constant 1-dB compression contour and the distortion plot.

It is also possible to identify the order of the distortion from the shape and change in length of total distortion curve. The distortion mechanism can be modeled as the sum of a linear and two nonlinear signals, one of which is delayed by 90°. For the same order of distortion, the relative amplitude of distortion remains constant. Hence pure third- or pure fifth-order type distortion curves are straight lines emanating from the reference point, with no change in direction as the input signal level is changed. A change in the direction is an indication of the presence of higher order distortions. Furthermore, for a pure third-order distortion, the length of the vector would double for every 3-dB change in input power.

MEASUREMENT PROCEDURE AND RESULTS

The set is calibrated to a zero reference point, at small signal levels, using the attenuator and the line stretcher. HP8410 has about 17 dB of dynamic range that is used to cover the measurement range from linear to deep compression (3 to 5 dB beyond 1 dB compression point). The two inputs to HP8411 are adjusted to be nearly equal at the maximum calibrated level for HP8410. The input signal to DUT is then reduced by 17 dB to begin the measurements.

The method consists of varying the input drive level to the device under test, using the precision attenuator and noting the power output from the power meter. Several vector distortion curves of GaAs power FETs, high-power amplifiers and TWT were measured. These are shown as figure 3. Measurements are conducted at a single frequency, but can be easily repeated for different frequencies.

CONCLUSIONS

A vector method of distortion characterization, requiring much less equipment, has been presented here. This method is easy, fast, and can be automated using electronically controlled attenuators. It provides much more information than the earlier methods in a hurry. The effect of impedance matching on nonlinearity can also be studied by adding tuners around the devices. This method measures odd-order nonlinearities in the moderate to large distortion regions, at a single frequency. It is particularly suited for nonlinearity characterizations in a production environment.

REFERENCES

[1] G.L. Heiter, "Characterization of Nonlinearities in Microwave Devices and Systems," IEEE Trans. MTT, 21 No. 12, Dec. 1973.

[2] J.A. Higgins, "Intermodulation Distortion in GaAs FETs," IEEE MTT-Symposium, Ottawa, June 27-29, 1978.

[3] Thompson & Agarwal, "T-Chart, a New Tool for Displaying Nonlinearities in Devices," to be published.

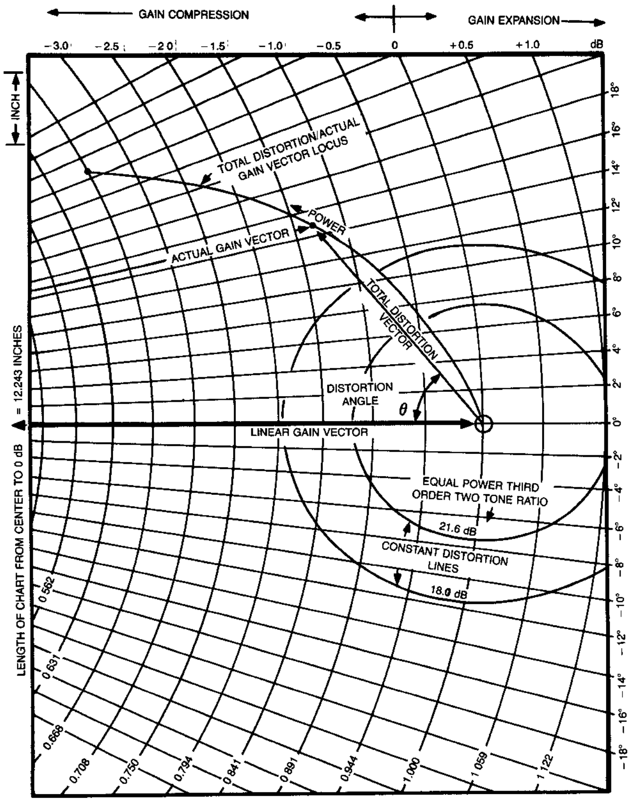

Fig. 2 T-Chart for Vector Distortion Measurement.

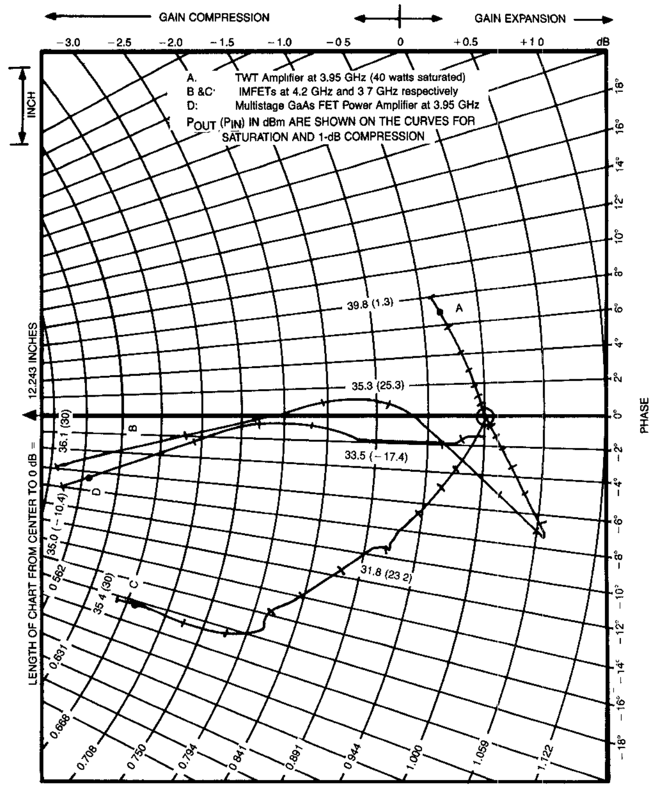

Fig. 3 Distortion Curve Measured for Various Devices.