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AM–AM and AM–PM Measurements Using the PM Null Technique

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***Abstract* —This paper describes a new method for measuring AM–AM and AM–PM nonlinearities in microwave radio components. This new method is called the PM null technique. This method is accurate and easy to implement. Both the carrier and modulation frequencies can be changed easily. Results of AM–AM and AM–PM measurements performed on a 8-GHz amplifier are given. This new method was compared with Moffatt's parabolic phase method and found to be in good agreement.**

I. Introduction

If the gain of a two-port network is dependent on the input amplitude, amplitude modulation to amplitude modulation (AM–AM) conversion will occur. If the phase shift through a two-port network is dependent on the input amplitude, amplitude modulation to phase modulation (AM–PM) conversion will occur. If an AM signal is injected into a two-port network, the AM–AM conversion will change the modulation index. If the network has an AM–PM conversion, the phase of the output signal will be modulated at the same rate as the input AM modulation.

There are several methods of measuring AM–AM and AM–PM conversion [1]–[3]. The method described here, the PM null technique, is the most direct, uses simple components, and is highly accurate.

The PM null technique works as follows: An AM signal with very little residual PM is input to the device under test (DUT). A calibrated AM receiver at the DUT output demodulates the AM component, ignoring the PM sidebands. This baseband output is a measure of the modulation index at the output of the DUT. By comparing the input and the output modulation indices, the AM–AM conversion can be found. Similarly, if the output signal is demodulated by a calibrated PM receiver, the AM sidebands will be ignored, and the baseband output will be proportional to the peak phase deviation. Since the input signal has no PM component, the PM measured must be caused by the DUT nonlinearities. Comparing the input AM modulation index and the output peak phase deviation yields the AM–PM conversion.

Manuscript received September 26, 1986, revised April 6, 1987.
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IEEE Log Number 8715418

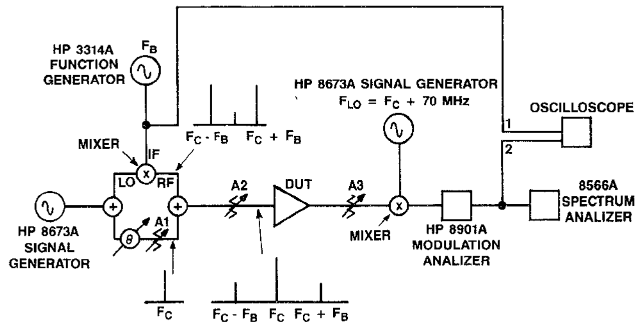

Fig. 1 AM/AM and AM/PM measurement test set

The PM null method requires the following equipment:

1) a PM demodulator with $\leqslant 0.05°$/dB AM–PM and $\geqslant 30$ dB AM suppression;
2) an AM demodulator with > 30 dB PM suppression;
3) an AM modulator with < 0.001 radian peak residual PM;
4) a down-converter with $< 0.05°$/dB AM–PM and < 0.05 dB AM–AM.

An HP 8901A modulation analyzer was used as both the AM and PM demodulator. The 8901A has excellent AM and PM suppression and negligible AM–PM. The modulation frequency must be 100 kHz or less when using the 8901A. If a higher modulation rate is required, a different PM demodulator, such as the 4A FM receiver [4] used by Moffatt, must be used. The down-converter can be made with a commercially available, double-balanced wide-band mixer. The RF input to the mixer is kept backed off from its 1-dB compression point so that the mixer AM–AM and AM–PM will be very small.

The PM null technique requires a modulator with nearly ideal characteristics. Stremler [5] suggests modulators generating AM and narrow-band PM signals. By adding a variable phase shifter of the type shown in Fig. 1, the modulation format can be changed from AM to PM simply by adjusting the phase shifter.

The modulator operation can be explained as follows: A signal at the carrier frequency F_c is split into two arms. One arm contains a phase shifter and an attenuator. The other arm contains a wide-band double-balanced mixer. The mixer up-converts the modulation frequency F_B, producing sidebands at $F_C - F_B$ and $F_C + F_B$. The carrier frequency level at the double-balanced mixer output will be very low compared to the sideband levels because of good local oscillator (LO) suppression. The two arms are recombined at the modulator output. The output spectrum contains a carrier at F_C and sidebands at $F_C - F_B$ and $F_C + F_B$. If the phase shifter is adjusted so that the sidebands are in phase with the carrier, a pure AM signal is generated. If the modulation index is $\ll 1$ and the phase shifter is adjusted such that the sidebands are 90° out of phase with respect to the carrier, a pure narrow-band PM signal is generated. The modulation index can be adjusted with attenuator A1. It is important to maintain the modulation index at 0.1 or less so that the narrow-band approximation is valid.

The phase shifter can be adjusted by demodulating the modulator output in a PM receiver. When the phase shifter is adjusted for a maximum baseband response, a pure PM signal is being generated. If the phase shifter is adjusted for a null or minimum of the baseband response, a pure AM tone is being

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generated, since the receiver responds only to the PM component. Hence, the name for this method is the PM null technique.

II. Calibration and Measurement

To calibrate the measurement system, the DUT must be removed. As shown in Appendix I for an amplitude modulation index $M = 0.1$, the sideband-to-carrier ratio is -26 dBc. Attenuator A3 is adjusted to keep the RF input to the down-converter constant. Attenuator A1 is first adjusted to that the sidebands are -26 dBc. The down-converted signal is then applied to the AM detector. The phase shifter is adjusted for a null on the AM detector (maximum for the PM detector). The baseband response (in dBm) of the PM detector is recorded R_0. Since the sidebands are -26 dBc, the peak phase deviation is $X_1 = 0.1$ rad. The baseband response (in voltage) r_0 is related to X_1 by a constant, S_{PM}. Thus,

$$r_0 = 10^{\frac{R_0}{20}} \qquad r_0 = S_{PM} X_1.$$

Next, the phase shifter is adjusted for a null on the PM detector and the baseband response of the AM detector, R_A, is recorded. The AM modulation index M_1 is related to R_A as follows:

$$r_A = 10^{\frac{R_A}{20}} \qquad r_A = S_{AM} M_1.$$

With the phase shifter set for a PM null, the input signal is of the form

$$S_{in} = (1 + M_1 \cos 2\pi F_B t)\cos(2\pi F_c t).$$

The system is calibrated and ready to measure the DUT.

The DUT is placed in the measurement system. Attenuator A2 should be adjusted for the desired input or output level at the DUT. Attenuator A3 is adjusted for the same input power to the down-converter as during calibration. The DUT causes both AM–AM and AM–PM distortion of the input signal. The output signal will be of the form

$$S_{out} = [1 + M_2 \cos 2\pi F_B t]\cos(2\pi F_c t + X_2 \cos 2\pi F_B t).$$

The baseband responses of the AM and PM demodulators will be as follows.

AM response:

$$R_B \text{ dBm} \qquad r_B = 10^{\frac{R_B}{20}} \qquad r_B = S_{AM} M_2$$

PM response:

$$R_1 \text{ dBm} \qquad r_1 = 10^{\frac{R_1}{20}} \qquad r_1 = S_{PM} X_2.$$

From the calibration data we know

$$S_{AM} = \frac{r_A}{M_1} \qquad S_{PM} = \frac{r_0}{X_1}.$$

Thus,

$$M_2 = \frac{r_B}{r_A} M_1 \quad \text{or} \quad M_2 = M_1 10^{\frac{R_B - R_A}{20}}$$

and

$$X_2 = \frac{r_1}{r_0} X_1 \quad \text{or} \quad X_2 = X_1 10^{\frac{R_1 - R_0}{20}}$$

The AM–AM conversion coefficient can be defined as $a = M_{out}/M_{in}$, where M_{in} and M_{out} are the input and output amplitude modulation indices, and $M_{in} \ll 1$. Thus, $a = M_2/M_1$, and the AM compression in dB is $C = -20\log[a]$, where $C = R_B - R_A$.

The magnitude of the AM–PM conversion coefficient is defined as $k = \pm X_{out}/M_{in}$, where X_{out} is the output PM index in radians. The sign of k can be either positive or negative and is given by the sign of the slope of the phase characteristic of the device.

It can be shown [6] that the AM–PM conversion in degrees per dB is equal to

$$K = \frac{k(180/\pi)}{20\log(1+M_1)} (^\circ/\text{dB}), \qquad \text{where } k = \pm\frac{X_2}{M_1}.$$

Thus,

$$K = \pm\frac{6.6}{M_1} X_1 10^{\frac{R_1 - R_0}{20}} \; (^\circ/\text{dB}) \qquad \text{for } M_1 \ll 1.$$

A device with a positive k produces PM having the same phase as in the input AM. To determine the sign of k, the phase of the demodulated PM signal is compared to the modulating signal phase on an oscilloscope. If the delay through the modulator and DUT is much less than one period at the modulation frequency, the two signals will be in phase for positive k and 180° out of phase for negative k.

III. Accuracy of Results

Appendix II shows that if the data readings are within ± 0.1 dB, the value of k will be within 5 percent of the correct value. The value of C will be within ± 0.2 dB. The accuracy of these results is independent of modulation or carrier frequency.

IV. Comparison with Parabolic Phase Method

Figs. 2(a) and 2(b) show AM–AM and AM–PM measurements using the PM null technique for an 8-GHz amplifier. Also shown are data taken using the parabolic phase method developed by Moffatt [1]. As can be seen, the two methods give very similar results. However, the PM null method has the following practical advantages over the parabolic phase method.

1) The PM null method does not require an up-converter, thus eliminating it as a possible source of unwanted AM–AM and AM–PM.
2) The parabolic phase method requires a band-pass filter at the output of the up-converter. To change the carrier frequency, this band-pass filter must also be changed. The PM null method uses wide-band components, so the carrier frequency can be changed very easily.
3) The accuracy of the results is independent of the modulating frequency for the PM null method. For the parabolic phase method, the accuracy is dependent on the modulation rate.

Note, in Figs. 2(a) and 2(b) that a 10-MHz modulation rate was used for the parabolic phase method and a 100-kHz modulation rate was used for the PM null technique. A 10-MHz rate was selected for the parabolic phase method to maintain the measurement accuracy. A 100-kHz rate was selected for the PM null technique because of the limitations of the HP 8901A modulation analyzer. The PM null technique was repeated using a 4A FM receiver as the demodulator at modulation frequencies of 100 kHz and 10 MHz. The results using the 4A receiver are essentially identical to the results obtained using the HP 8901A.

V. Conclusions

A new method of measuring AM–AM and AM–PM nonlinearities in microwave components has been explained. This method can be implemented easily with practical coaxial compo-

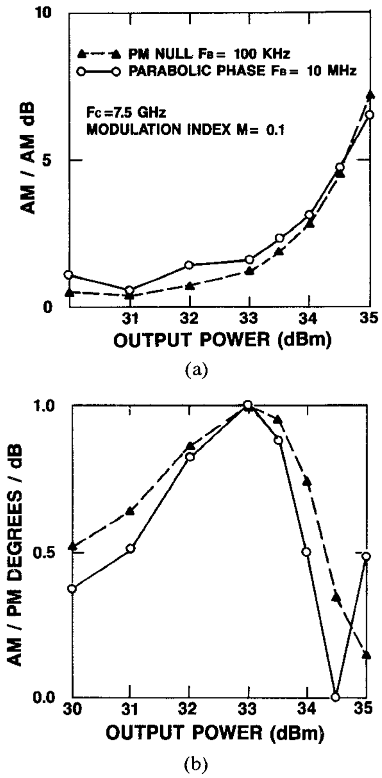

Fig. 2. (a) Measured data comparing PM null and parabolic phase methods: AM/AM versus output power. (b) Measured data comparing PM null and parabolic phase methods· AM/PM versus output power.

nents and readily available test equipment. The carrier and modulation frequency may be changed easily. Good agreement has been found between this technique and the parabolic phase method used by Moffatt.

Appendix I
Relation between Carrier-to-Sideband Level and Modulation Index

For an AM signal,

$$S(t) = A(1 + M\cos 2\pi F_B)\cos 2\pi F_c t.$$

The average power in $S(t)$ is

$$\int_0^T [S(t)]^2\, dt = \frac{A^2}{2} + \frac{1}{4}M^2A^2$$

$$\text{Carrier Power} = \frac{A^2}{2}$$

$$\text{Sideband Power} = \frac{1}{4}M^2A^2.$$

The power in only one sideband is $= \frac{1}{8}M^2A^2$.

The ratio of single sideband power to carrier power in dBc becomes

$$\frac{P_{\text{SSB}}}{P_c} = 10\log\left[\frac{\frac{1}{8}M^2A^2}{\frac{1}{2}A^2}\right] = 20\log M - 6\text{ dB}$$

$$\text{or } M = 2\left[10^{\frac{P_{\text{SSB}}}{20}}\right] \qquad \text{if } M = 0.1$$

$$P_{\text{SSB}} = -26\text{ dBc}.$$

A similar argument holds for a narrow-band PM signal.

$$S(t) = A\cos[2\pi F_c t + X_1\cos 2\pi F_B t]$$

For $X_1 \ll 1$,

$$s(t) = A[\cos(2\pi F_c t) - X_1\sin(2\pi F_B t)\sin(2\pi F_c t)]$$

$$P_{\text{SSB}} = 20\log X_1 - 6\text{ dBc}$$

$$\text{or } X_1 = 2\left[10^{\frac{P_{\text{SSB}}}{20}}\right].$$

Appendix II
Error Analysis

If there is a function $Y = f(X_1, X_2, \cdots, X_n)$ where X_1 through X_n are independent variables, then the change in Y due to a change in all X_i's is approximately

$$\frac{\Delta Y}{Y} = S_{X_1}^Y\frac{\Delta X_1}{X_1}\cdots S_{X_n}^Y\frac{\Delta X_n}{X_n}$$

where $S_{X_i}^Y$ is defined as

$$S_{X_i}^Y = Y'_{X_i}\frac{X_i}{Y}$$

and Y'_{X_i} is the partial derivative of Y with respect to X_i.

For the function

$$K = 6.6\, 10^{\frac{R_1 - R_0}{20}}\, 10^{\frac{R_{\text{PM}}}{20}}\, 10^{\frac{-R_{\text{AM}}}{20}}$$

R_{AM} and R_{PM} are the ratios of single sideband to carrier levels, in dBc, which are used to set M_1 and X_1.

We find

$$\frac{\Delta K}{K} = \frac{\ln 10}{20}[\Delta R_1 - \Delta R_0 + \Delta R_{\text{PM}} - \Delta R_{\text{AM}}].$$

So if all the values are off 0.1 dB in the worst direction, then

$$\frac{\Delta K}{K} = 4.6\%.$$

Acknowledgment

The author wishes to acknowledge T. Lentine and G. Alley for suggesting the approach taken to this problem. Thanks go to J. Moffatt for his discussions on AM–PM measurements. Thanks also go to W. E. Schroeder for supporting this work and D. Russo for his careful measurements.

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