A Fast AM/AM and AM/PM Characterization Technique

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Abstract – **In this paper a novel AM/AM and AM/PM power amplifier characterization technique is presented, exploiting signals interference properties. Key features of the proposed measurement technique are the simplicity, requiring basic scalar power measurements only, and the low cost of the utilized set-up; moreover, it allows a power amplifier distortion characterisation in a very short time if compared with a more conventional method utilizing a Vector Network Analyzer. A description of the measurement set-up used to perform AM/AM and AM/PM characterisation is given. Lastly, in order to validate the measurement technique, comparisons with vector network analyzer measurements, for a 2W, 2GHz power amplifier, are reported.**

I. INTRODUCTION

Modern radio-communication systems, including UMTS cellular phones, require high spectral efficiency modulation schemes. Microwave power amplifiers (PA) generate an amplified but distorted output signal, suffering from spectral regrowth and intermodulation effects. The impact that this phenomenon has on the communication system may be heavy. For narrow band applications, the non linear behaviour of the PA is usually described using the AM/AM compression and the AM/PM conversion curves [1]. This approach is widely accepted and generally used in order to estimate the impact that the power amplification can bring over the communication system [2] [3]. If AM/AM curve may be obtained executing basic power measurements, phase conversion curve determination requires a suitable approach, based on vector network analyzer (VNA) measurements, performed for different input power signal to the PA [4], or using other two-tone test criteria [5],[6]. These methods usually require expensive measurement equipments (VNA or Spectrum Analyzer) and are time consuming. The proposed measurement technique utilizes a synthesized generator and a couple of power meters only, thus avoiding the use of a costly vector network analyzer and allowing the reduction of time needed to the characterization.

II. Measurement Theory

Assuming a general narrow band modulated input signal *x(t)*

$$x(t) = m(t)\cdot\cos\big(\omega t + \varphi(t)\big) \qquad (1)$$

where *m(t)* and *φ(t)* are the instantaneous amplitude and phase, the in band output signal of the PA, taking into account its non linear behaviour, can be expressed as:

$$y(t) = F\big[m(t)\big]\cdot\cos\big(\omega t + \varphi(t) + \psi\big[m(t)\big]\big) \qquad (2)$$

where *F[m(t)]* and *ψ[m(t)]* are the PA compression and conversion characteristics respectively.

The proposed technique exploits the properties arising from the interference of two sinusoidal waveforms, allowing the determination of both *F[m(t)]* and *ψ[m(t)]* by simple power measurements.

Assuming a sinusoidal input signal:

$$x(t) = A\cdot\cos(\omega t) \quad [V] \qquad (3)$$

the signal at the output of the PA, according to (2), becomes

$$y(t) = F[A]\cdot\cos\big(\omega t + \psi[A]\big) \quad [V] \qquad (4)$$

The sum of *x(t)* and *y(t)* can be expressed as:

$$z(t) = x(t) + y(t) = Z\cdot cos(\omega t + \xi) \quad [V] \qquad (5)$$

where:

$$Z = \sqrt{A^2 + F[A]^2 + 2A\cdot F[A]\cdot cos\big(\psi[A]\big)} \qquad (6)$$

$$\xi = arctg\left[\frac{F[A]\cdot\sin\big(\psi[A]\big)}{A + F[A]\cdot\cos\big(\psi[A]\big)}\right] \qquad (7)$$

The average power of *z(t)* over 1Ω load is given by

$$\begin{aligned} P_z &= \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} z^2(t)dt = \\ &= \frac{1}{2}\cdot A^2 + \frac{1}{2}\cdot F[A]^2 \qquad [W] \qquad (8) \\ &\quad + A\cdot F[A]\cdot cos\big(\psi[A]\big) \end{aligned}$$

On the other hand the average powers of *x(t)* and *y(t)* over 1Ω load are:

$$P_x = \frac{1}{2} \cdot A^2 \quad [\mathrm{W}] \tag{9}$$

$$P_y = \frac{1}{2} \cdot F[A]^2 \quad [\mathrm{W}] \tag{10}$$

so (8) may be written in the following form:

$$P_z = P_x + P_y + 2 \cdot \sqrt{P_x P_y} \cdot cos(\psi[A]) \tag{11}$$

As a consequence (9), (10) and (11) allow the extraction of both *F[A]* and *ψ[A]*. The former can be obtained comparing P_x and P_y measured values, while the latter can be inferred inverting (11).

III. MEASUREMENT SET-UP

The adopted measurement set-up is schematically depicted in Fig. 1. It is composed by a synthesized generator (MG3692A from Anritsu), two dual channel power meters (8542C from Giga-tronics). Moreover, directional couplers and attenuators are used to sample the signal power and to limit the power level at the input of the diode sensors respectively. Power splitters are used to divide the signal power at the input and to recombine it at the output of the PA.

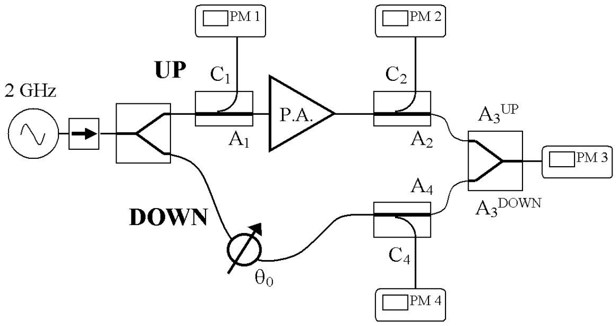


Fig. 1: Measurement set-up schematic.

According to the previous section, the single-tone from the microwave source is splitted by a power divider in two branches, called *UP* and *DOWN* in Fig. 1.

The *UP* signal flows into the PA, which distorts it at the output; the signal in the *DOWN* path flows into a coaxial cable and then is recombined with the output signal delivered by the PA.

Two power sensors, PM_1 and PM_2, measure the input and output power levels, thus obtaining the AM/AM characteristic. In fact, the PA input and output power may be expressed by:

$$P_{in,dBm} = P_{1,dBm} + C_{1,dB} - A_{1,dB} \tag{12}$$

$$P_{out,dBm} = P_{2,dBm} + C_{2,dB} \tag{13}$$

and the AM/AM characteristic is given by (12) and (13); in the expressions above, C_i and A_i represent the coupling and attenuation factors (dB) of the directional coupler at the input (*i=1*) and output (*i=2*) ports of the PA respectively, while P_i is the power level (dBm) measured by the power sensor PM_i.

Exploiting (11), the power recombined at the output of the combiner, P_{TOT}, may be written as:

$$\begin{aligned} P_{TOT} &= P_{UP} + P_{DOWN} + \\ &+ 2\sqrt{P_{UP} \cdot P_{DOWN}} \cdot cos[\varphi_0 + \psi(P_{in})] \end{aligned} \quad [\mathrm{W}] \tag{14}$$

where:

$$\varphi_o = \varphi_{UP} - \varphi_{DOWN} \tag{15}$$

is the phase difference between the linear (without PA) upper and bottom paths, that is independent on the input power level, and *ψ(P_{in})* is the phase shift due to the PA, that is clearly variable with the input power level P_{in}.

The P_{DOWN} and P_{UP} are computed from PM_4 and PM_2, while P_{TOT} is measured by PM_3:

$$P_{UP,dBm} = P_{2,dBm} + C_{2,dB} - A_{2,dB} - A^{UP}_{3,dB} \tag{16}$$

$$P_{DOWN,dBm} = P_{4,dBm} + C_{4,dB} - A_{4,dB} - A^{DOWN}_{3,dB} \tag{17}$$

where C_i and A_i represent the coupling and attenuation factors (dB) of directional coupler on the up (*i=2*) and down (*i=4*) paths respectively, A_3^{UP} and A_3^{DOWN} are the attenuations of the output power combiner for up and down paths respectively, and P_i is the power level (dBm) measured by the power sensor PM_i (*i=2,4*).

Relative phase imbalance of the output combiner is not relevant since contributes only to the fixed phase terms φ_o. Source power sweeping and power measurements are computer controlled by a Matlab® developed program and standard GPIB instrument interface commands.

Once collected the four set of power measurements, it is possible to solve (14) for *ψ(P_{in})*:

$$\psi(P_{in}) = acos\left[\frac{P_{TOT} - P_{UP} - P_{DOWN}}{2\sqrt{P_{UP} \cdot P_{DOWN}}}\right] - \varphi_0 \tag{18}$$

It is to underline that the absolute phase shift due to the PA, *ψ(P_{in})*, can be determined only if the linear term φ_o is known. However, taking into account the small signal (SS) PA behaviour, it is possible to write

$$\psi(P_{in}) = \psi_{SS} + \Delta\psi(P_{in}) \tag{19}$$

where ψ_{SS} is the small signal phase shift in the PA output signal

$$\psi_{SS} = \psi\left(P_{in}\big|_{small-signal}\right) \tag{20}$$

and *Δψ(P_{in})* represents the AM/PM characteristic:

$$\begin{aligned} \Delta\psi(P_{in}) = acos\left[\frac{P_{TOT} - P_{UP} - P_{DOWN}}{2\sqrt{P_{UP} \cdot P_{DOWN}}}\right] - \\ acos\left[\frac{P_{TOT} - P_{UP} - P_{DOWN}}{2\sqrt{P_{UP} \cdot P_{DOWN}}}\right]\Bigg|_{Small-Signal} \end{aligned} \tag{21}$$

It is to note that the AM/AM and AM/PM characteristics are measured simultaneously and independently.

In order to reduce numerical errors, mainly related to the inversion of (14), the power levels from the two paths should be comparable and the linear phase $\varphi_o+\psi_{SS}$ should be placed far from 0 and 180 degree. The first condition can be obtained by the insertion of attenuators in the PA path. The condition on the phase can be controlled through a phase shift (θ_o) inserted on the down path.

IV. EXPERIMENTAL RESULTS

The proposed measurement technique has been applied for the characterisation of a 2W PA (CPA02063230 from Cernex), at a frequency of 2 GHz. The relevant amplifier figures are listed in Table.1

POWER GAIN [dB]	45.8
GAIN FLATNESS	+/- 1.70 dB
P1dBm (min)	30.9
Noise Figure dB (max)	5.5
Input VSWR (max) Output VSWR (max)	2.0:1 2.0:1
DC Power	15V @ 934 mA

Table 1: Data Sheet of the PA (CPA02063230 from Cernex).

The amplifier has been also characterised by a VNA [4], and the results of such characterization have been used as reference quantities in order to validate the proposed measurement technique. The VNA used is a HP 8510C.

Since the gain of the amplifier is very high (45dB) a 30dB attenuator is added between its output and the VNA test port in order to protect the built-in receiver. The adopted VNA set-up is shown in Fig. 2.

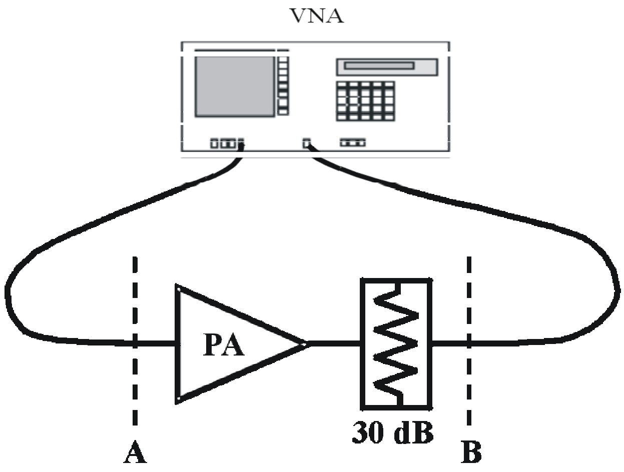


Fig. 2: Measurement set-up for Am-Am and Am-Pm characterization utilizing a VNA.

A full two-port calibration (TRL [7]) is required for each input power level imposed by the synthesized source. As a consequence, the reference planes are shifted at the PA input (A) and at the attenuator output (B). The PA S-parameters are obtained de-embedding the attenuator S-parameters, that have to be separately measured. The procedure is very time consuming, since a new TRL calibration is required every time the power level is increased.

The new proposed experimental set-up is depicted in Fig. 3.

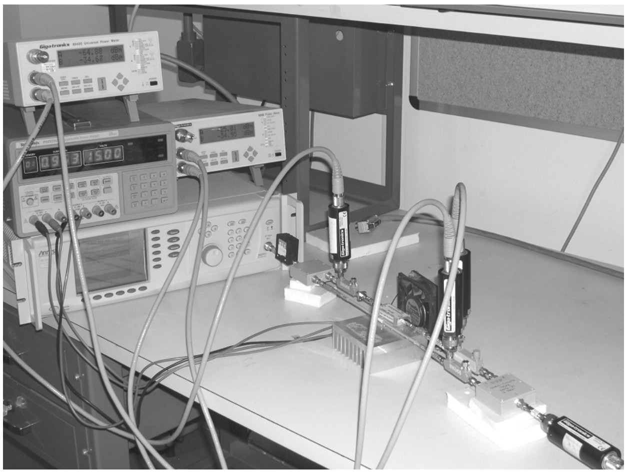


Fig. 3 : Photo of the measurement set-up for the Am-Am and Am-Pm characterization.

Power levels used in (14) are reported in Fig. 4, as functions of the PA input power P_{in}.

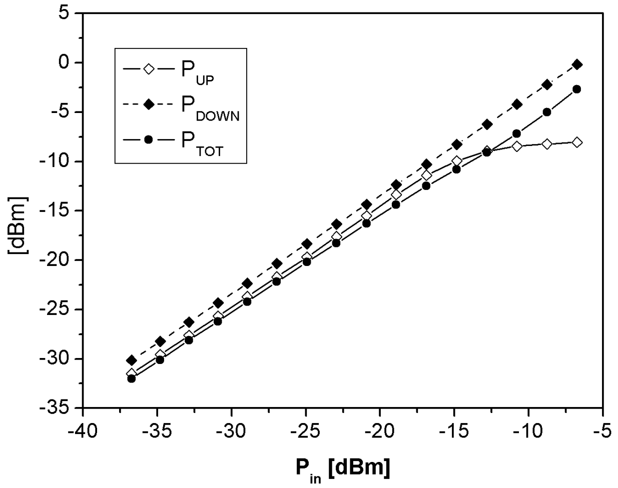
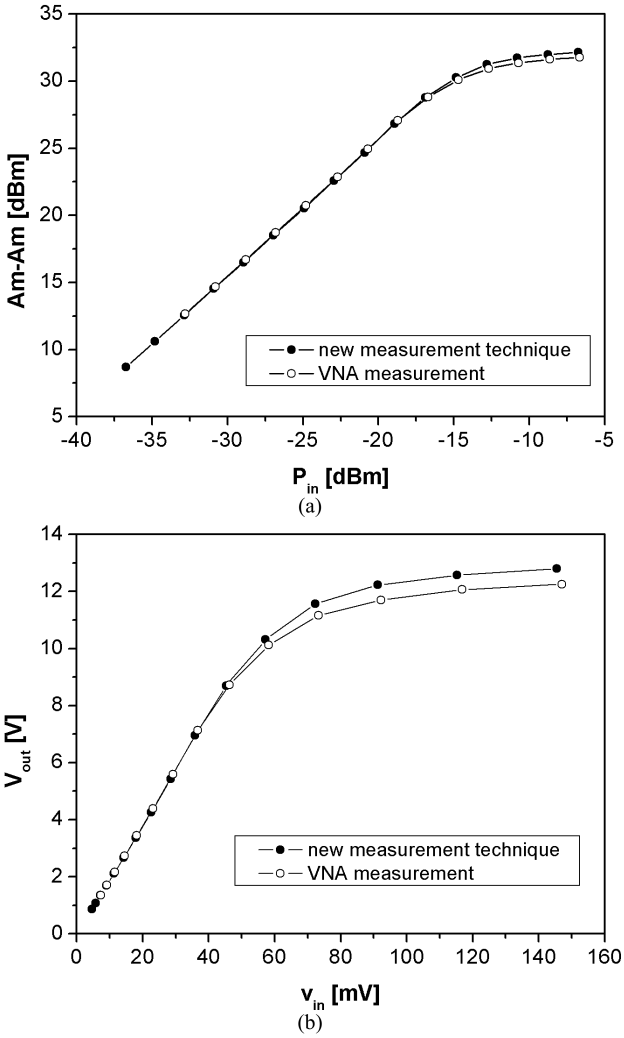


Fig. 4 : Measured power levels, P_{UP}, P_{DOWN} and P_{TOT}, as a function of P_{in}.

As can be noted from this figure, the power level that flows into the down path, P_{DOWN}, increase linearly with P_{in}, while the power that flows into the PA, P_{UP}, saturates. Results obtained with the proposed measurement technique has been compared with the same quantities carried out by VNA measurements, as reported in Fig. 5 and Fig. 6:

From these figures, the good agreement between the proposed fast and low-cost approach and the results obtainable by conventional VNA measurements can be noted.

The main drawback of the proposed approach is related to the harmonic distortion generated by the PA. In fact, the measured power is affected by harmonic components generated from PA, due to total power measurements performed by the power sensors. In the presented measurements, the PA harmonic components measured are lower than 30dBc, thus the error introduced is negligible. In any case, in order to further reduce this error, the signal from PA could be filtered or a Spectrum Analyzer could be used, instead of power meters, in order to measure the power levels required.



(a)

(b)

Fig. 5: Experimental results for the AM/AM compression curve: power in log scale (a) and voltage (50Ω) in linear scale (b).

V. CONCLUSIONS

In this paper a new method for simultaneous power amplifiers AM/AM and AM/PM distortion curves measurements has been presented. Key features of the proposed set-up are its low-cost, simplicity and measurement speed, requiring only power meters. Results obtained are in a good agreement with those obtainable with a conventional VNA set-up.

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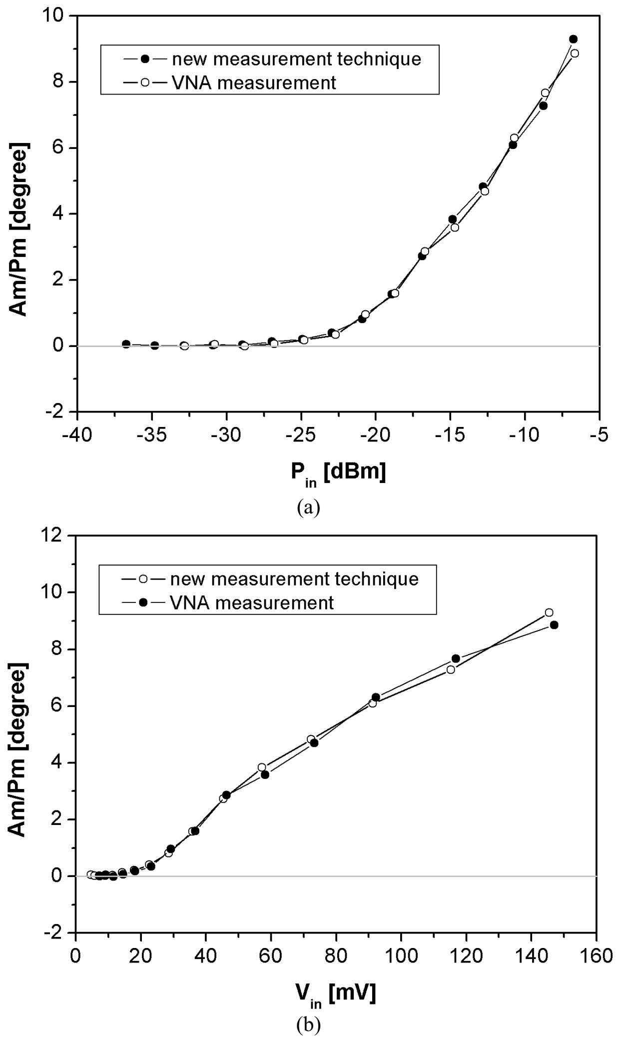

(a)

(b)

Fig. 6 : Experimental results on AM/PM compression curve: degree as a function of P_{in} (a) and of V_{in} (b).

VI. REFERENCES

[1] Peter B. Kennington, *High-Linearity RF Amplifier Design*, Artech House 2000.

[2] S. V. Schell, “Implementation Effects on GSM's EDGE Modulation”, Tropian Inc., Cupertino, CA.

[3] R.G.Medhurst, J.H.Roberts, and W.R.Walsh, “Distortion of SSB Transmission due to AM-PM Conversion,” *IEEE Transaction on Communication Systems*, pp. 166-176, June 1964.

[4] Agilent Technologies, “Using a Network Analyzer to characterize high-power components”, *Application Note 1287-6*, 1998.

[5] C.J.Clark, C.P.Silva, A.A.Moulthrop, and M.S.Muha, “Power-Amplifier Characterization Using a Two-Tone Measurement Technique,” *IEEE Transaction on Microwave Theory and Technique*, vol. MTT-50, n.6, pp. 1590-1602, June 2002.

[6] C.F.Campbell, and S.A.Brown, “Application Of The Unequal Two-Tone Method For AM-AM and AM-PM Characterization Of MMIC Power Amplifier”, *2001 IEEE Symp. on Emerging Technologies*, pp. 103-106, Sept. 2001.

[7] Agilent Technologies, “HP 85052C 3.5mm precision calibration kit”, Operating and service manual, 1987.