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Wide-Range Waveform Measurement System with Load-Pull Capability for the Characterization of RF Devices

Walid S. El-Deeb

Department of Electronics and Communications Engineering, Faculty of Engineering, Zagazig University, Egypt.

Abstract: In this paper, a simple, effective, and time saving measurement setup for nonlinear RF power amplifier characterization is presented. This setup gives the ability of measuring AM-AM, AM-PM and waveforms for SISO, SIMO, and MIMO RF power amplifiers in one measurement step. The system incorporates the advantages of high-speed MTA for waveform measurements and the advantages of using Focus load-pull setup for the characterization of RF devices. Several measurements of multiport balanced amplifier at 1 GHz, using the proposed measurement setup, are presented.

Keywords: AM-AM, AM-PM, MIMO, Power amplifier characterization, RF measurements, SIMO, SISO.

I. Introduction

The Nonlinearity of radio frequency (RF) power amplifiers (PA) is one of the major concerns in the design of modern radio communication systems. The key point in the design of such communication systems is the achieving the highly linear power amplification with simultaneous high conversion efficiency.

To improve the power amplifier efficiency without compromising its linearity, power amplifier linearization is essential. Digital predistortion is one of the most effective techniques for the linearization of power amplifiers. With the predistorter, the power amplifier can be utilized up to its saturation point while still maintaining a good linearity, thereby significantly increasing its efficiency. The design of the predistorter requires knowledge of the amplitude modulation to amplitude modulation (AM-AM) and amplitude modulation to phase modulation (AM-PM) conversions of the power amplifier.

Many research works have been presented for AM-AM, AM-PM and waveform characterization of PA. Usually, AM-AM and AM-PM characteristics are extracted with a Vector Network Analyzer (VNA) [1]. Some other techniques have been presented for the same purpose using six-port reflectometers [2], [3].

In the last decades, the time-domain waveform measurement technique becomes one of the most important tools for the design and optimization of RF PAs [4]. In fact, the classification of the RF PAs according to their modes of operation is mainly based on the voltage and current waveforms at the device terminals [4]. This makes the waveform based design approach the emerging solution as the accurately measured voltage and current waveforms at the device ports comprise the magnitudes and phase of all spectral components generated by the nonlinear operation of microwave devices.

Other waveform measurement systems based on high-speed scope have been presented for waveform monitoring of RF PAs.

All of the above techniques were presented only for the characterization of SISO PA. In this paper, a multiport measurement system suitable for AM-AM, AM-PM and waveform characterization of SIMO and MIMO PAs in a single measurement step is presented.
Using single shot of measurements for the characterization of multi-port PA gives accurate results and time saving for the whole measurement process [5].

II. Description of The Measurement System

The large-signal waveform measurement system consists of two main systems. The first one is the multiport measurement system for large-signal characterization of RF devices. This system is based around the microwave transition analyzer (MTA) as multi-harmonic receiver from RF up to 40 Ghz. It incorporates the advantages of the vector network analyzer (VNA) and the high-speed scope for frequency-domain and time domain characterizations, respectively. The second system is the Focus load-pull system. The Focus system is integrated with the large-signal waveform measurement system as shown in Fig. 1 to provide the source and load variation capability to the system.

III. Calibration Algorithm

In the proposed measurement system, the calibration process is performed in two different steps. The first step is based on performing OSLT to calculate the error box parameters between port 1 and 2 for the DUT and the measuring plane of the MTA. Theses raw measurements have to be de-embedded to get the true measurements at the plane of the DUT.

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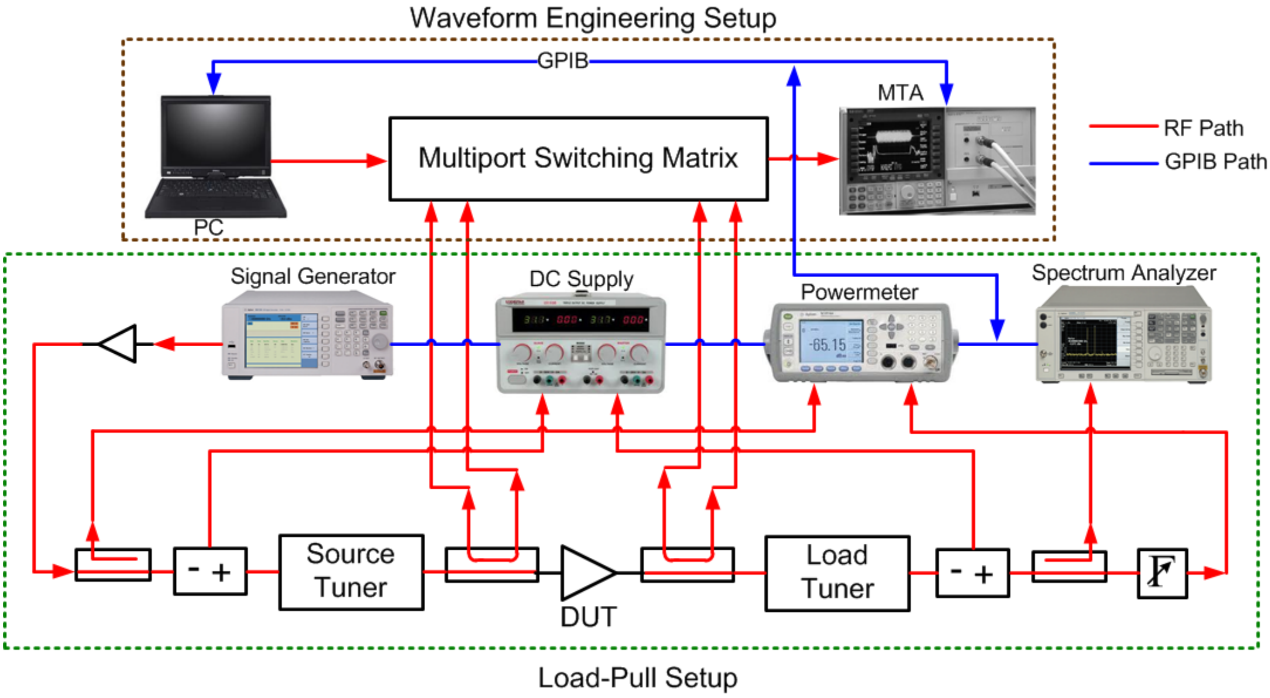

Fig. 1. Wide-range measurement system with load-pull capability

The first calibration step can also be performed using several calibration algorithm proposed for the multiport VNA [6]-[8]. The calibration algorithm used in this multiport measurement system is based on making full calibration for port 1 using open-short-load (OSL) standards and then making two-port calibration using a (THRU) standard connected between port 1 and the other ports of the multiport system [6].

Fig. 2 shows the flow chart of the first calibration step. This calibration algorithm has the advantage of taken the cross talk between ports into consideration, which leads to accurate results compared to other calibration algorithm.

The second calibration step is performed for waveform measurements. The second step can be performed using the power de-embedding technique described in [9]. This step is very important to calculate the normalized waves the DUT plane as a function of the measured waves MTA plane. The power de-embedding technique described in [9] gives a clear idea about the absolute magnitude of the waveforms at the DUT plane.

IV. EXPERIMENTAL RESULTS

A four port balanced power amplifier designed at 1 GHz, shown in Fig. 3, was characterized using the proposed measurement system. The balanced amplifier consists of two amplifier branches based on the FLL351ME high power GaAs FET transistor from Fujitsu with input and output matching circuits. Two baluns were also designed at 1 GHz, one of them is used to distribute out of phase the input signal to the two inputs of the amplifier and the second is used to combine the two outputs of the amplifier into single output such that the two branch PA can be operated as a class D RF amplifier as shown in Fig 3.

A. Characterization of single input single output (SISO) PA

In this case the multiport measurement system was calibrated for two ports only at 1GHz and the balanced amplifier was characterized as a whole amplifier with the baluns connected at the input and the output of the two amplifier branches.

The two amplifier branches (Amp1 and Amp2) of the balanced amplifier were biased at V_{DS}=8 V and V_{GS}=-1.8 V and the input power was swept over the dynamic range of the amplifier. Fig. 4 shows the AM-AM and AM-PM conversions of the balanced amplifier as a whole with single input and single output accesses. The balanced amplifier reaches the saturation region at 30 dBm input power with 36 dBm output power. The phase of the balanced amplifier remains constant, around -150°, in the nonlinear region and starts to increase, up to -120°, in the nonlinear region of the amplifier.

B. Characterization of single input multi output (SIMO) PA

In this setup the output balun which combines the output signals from the two outputs of the balanced amplifier was removed. In this case the DUT has three ports, one at the input and two at the output. The measurement system was calibrated for three ports at 1 GHZ. Port 1 was connected to the input of the amplifier, port 2 to the output of the first branch, and port 3 to the output of the second branch.

The AM-AM and AM-PM conversions of the two amplifier branches under the same biasing conditions are shown in Fig. 5. The outputs of Amp1 and Amp2 start to saturate at 26 dBm input power with 32 dBm output power. The phase shift between the output of Amp1 and

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Amp1 is about 180° due to the balun effect at the input.

C. Characterization of multi input multi output (MIMO) PA

In this case, the characterization of the balanced PA started by calibrating the multi-port measurement system at 1 GHz, herein having four ports after removing the input and output baluns. Port 1 and port 2 of the measurement system were connected to the inputs, while port 3 and port 4 were to the outputs of Amp1 and Amp2, respectively.

Fig. 6 presents the AM-AM and AM-PM of the MIMO PA. It is clear from Fig.6 that, the two branches of the balanced amplifier are not exactly similar. There is a difference of 1dB in there AM-AM characteristics and about 6° in their AM-PM characteristics.

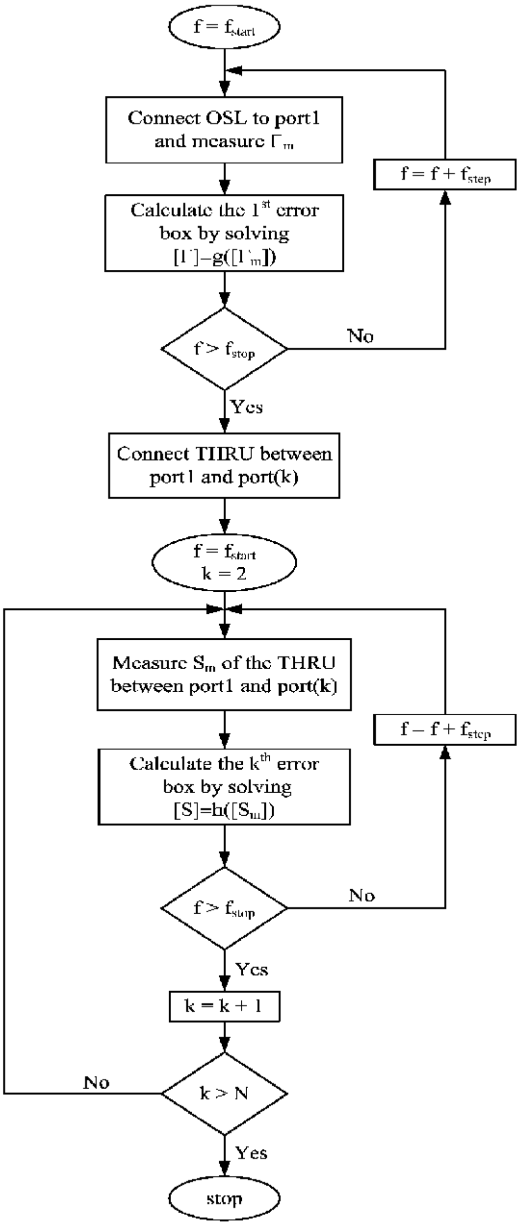

Fig. 2. Flow chart of the multiport calibration algorithm

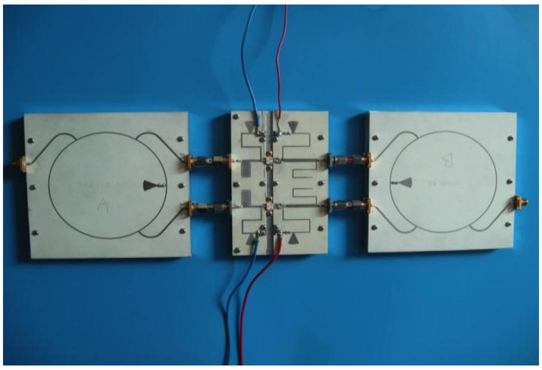

Fig. 3. Two-branch Balanced amplifier with input and output baluns designed at 1GHz frequency

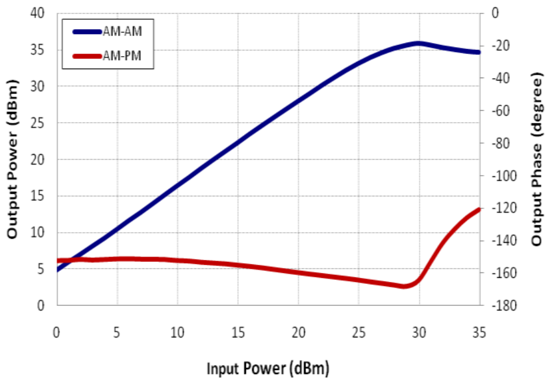

Fig. 4. AM-AM and AM-PM conversions of SISO balanced amplifier

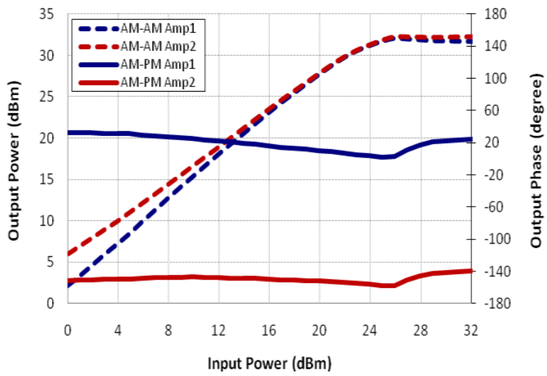

Fig. 5. AM-AM and AM-PM conversions of SIMO of the balanced amplifier branches

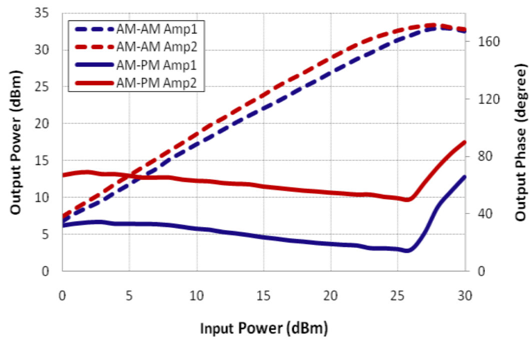

Fig. 6. AM-AM and AM-PM conversions of MIMO of the balanced amplifier branches

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D. Waveform Measurements of ZFL-2500 PA

The following results show the waveform measurements for the ZFL-2500 medium power amplifier at 0.5 GHz frequency and 3 Harmonics at Pin= 5dBm.

The measurements have been performed at different tuner positions of the load-pull system to provide different impedance at the input and the output terminals of the device.

Fig. 7 shows the measured output voltage and current waveforms at the output of the amplifier with the tuner position that gives 50 Ω impedance to achieve perfect match at the output. Due to the matching condition at the output, the voltage and current waveforms appear without any kind of distortion.

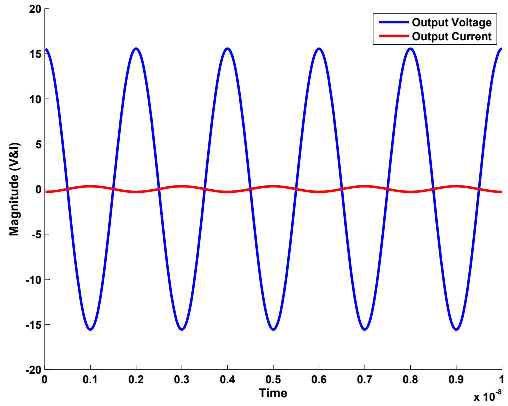

Fig.7. Output voltage and current waveform at the initial position of the tuners (50Ω Impedance)

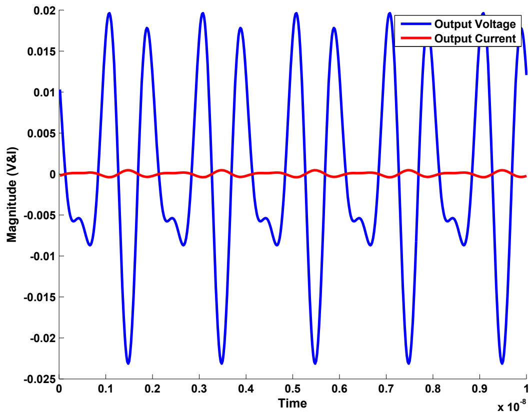

Fig.8. Output voltage and current waveform at the final position of the tuners (0.9 reflection)

Fig. 8 describes the effect of mismatch at the output on the voltage and current waveforms. The tuners of the load-pull setup have been adjusted to give reflection coefficient of 0.9 at the output of the PA. The measured output voltage and current waveforms illustrates the distortion due to the mismatch at the output terminal of the PA.

V. CONCLUSION

A wide-range waveform measurement system with load-pull capability suitable for large signal characterization of MIMO RF PA has been presented. As described in the measurement results, the system has the ability of measuring AM-AM and AM-PM conversions for SISO, SIMO, and MIMO RF PA in one measurement step without the need of reconnection or recalibration, which gives more accuracy to the measurement results. The measurement system offers also the load-pull capability in measuring the waveforms measurements to help in selecting the proper impedances while designing the PAs. This advantage decreases the time required to design the input and output matching circuits of PAs for maximum power transfer.

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BIOGRAPHY

Walid S. El-Deeb received the M.Sc. degree in Electronics and Communications Engineering from the University of Zagazig, Egypt, in 2004. He joined iRadio lab, University of Calgary, Calgary, Canada as PhD student and research and teaching assistant in Jan. 2011. He received his PhD in Electrical and Computer Engineering from University of Calgary in Mar 2011. Dr. El-Deeb worked as Post-Doctoral Fellow in University of Calgary till Aug. 2011. He is currently an Assistant Professor with the Department of Electronics and Communications Engineering, Faculty of Engineering, Zagazig University, Egypt.