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Test bed for power amplifier behavioral characterization and modeling

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ABSTRACT

Traditional test bed of power amplifier (PA) behavioral characterization and modeling based on vector signal analyzer (VSA) and often equipped with specialized software is both expensive and inflexible to modify to suit different scenarios. In this paper, a new test bed based on an oscilloscope or other general purpose data acquisition systems, which works as analog to digital converter (ADC) with a proper (radio frequency) RF bandwidth and maximum sampling rate, is proposed. The common impairments, e.g. transmitter IQ imbalances, channel delay, frequency offset, and carrier phase offset, are all well compensated. The accurately recovered envelopes of the PA's input and output signals are used for a PA behavioral characterization and modeling. Furthermore, Relative envelope error (REE) parameter is proposed to evaluate the accuracy of envelope recovery. The experiment shows a very accurate RF signal envelope recovery, and a good performance of PA behavioral modeling.

1. Introduction

An accurate, efficient, and flexible test bed is critical to PA behavioral characterization and modeling. Since PA AM/AM and AM/PM characterization and behavioral modeling are only concerned with the envelopes of the corresponding radio frequency (RF) signals, the test bed is required to accurately recover the envelopes of the PA's input and output signals in the form of digital samples. The test bed requires almost all the functions of a physical receiver, e.g., down conversion, ADC, demodulation, and baseband signal processing. Moreover, it should perfectly compensate all kinds of impairments occurring in the channels while leaving the PA nonlinear memory influence untouched, e.g., channel delay, frequency offset, or IQ imbalances, etc. Meanwhile, the test bed also needs a flexible signal generator which can output enough linear power to drive the PA and generate all kinds of signal forms, such as two-tone, OFDM, and white Gaussian signals, to facilitate the PA behavioral characterization and modeling.

Currently a typical test bed is based on a specialized instrument called vector signal analyzer (VSA) [1–3], often equipped with a specialized digital signal analysis software, e.g., Agilent 89600 VSA software. Meanwhile, real-time spectrum analyzer (RSA) works in the similar way as the VSA [4], and can serve as the receiver in a test bed. However, the major drawback is their high price. Moreover, all the functions are packed into the instrument and embedded analysis software. Little modification can be made, rendering it inflexible or unable to work for scenarios which require different test methods to compensate for the various kinds of impairments present in the test bed. Large signal network analyzer (LSNA) is used in [5] to model the PA behavior over a wide range of frequency span. However, Fager et al. [6] argues that LSNA requires the modulation to be periodic, which limits the type of testing signals. Moreover, whether it can measure PA's instantaneous behavior or not is still unknown.

Instead of using specific instruments or software, the oscilloscope or other general purpose data acquisition

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systems, which works as analog to digital converter (ADC) with a proper RF bandwidth and maximum sampling rate, is a good alternative for a PA behavior test bed. If the RF bandwidth of the oscilloscope is higher than the signal's carrier frequency, the signal can be acquired directly; otherwise, an external down-converter is required. It turns out to be low cost, more flexible to implement different signal recovery methods, and with no limitation on the type of input signals. There are several PA behavior test beds based on oscilloscope [7,6]. However, none of them give details on how the test bed is implemented, nor compensated for different kinds of impairments of the channel. The authors in [8] show a detailed WiMAX system test bed based on oscilloscope and the steps to implemented and compensate channel impairments. However, the test bed is only for WiMAX system quality measurement, and not demonstrated for PA behavioral characterization and modeling.

In this paper, a PA behavior test bed based on general purpose oscilloscope is proposed, and detailed steps on how to implement it is shown.The major impairments such as IQ imbalances, channel delay, frequency offset and phase offset, are considered, analyzed and compensated. After compensating all the impairments, the envelopes of the PA's input and output signals are accurately recovered in the form of digital samples for behavioral modeling. Moreover, to quantify the nonlinearity and memory effects of the PA – memory effects refer to the phenomenon that the PA output is determined not only by the simultaneous input signal but also by the past ones – both adjacent channel power ratio (ACPR) and error vector magnitude (EVM) are measured. Welch method [9] is employed to numerically estimate the spectrum and compute the ACPR performances with arbitrary resolution.

The structure of the paper is organized as follows: In Section 2, the overall test bed structure is presented, followed by detailed steps and explanations of software signal processing implementation to compensate the major channel impairments. In Section 3, performance metrics are designed, and the performance of the test bed is assessed by experiments, and the results are presented. Finally, Section 4 gives the conclusion.

2. Proposed test bed and signal processing

2.1. Test bed overall structure

Fig. 1 shows the overall structure of the Test Bed. Here the RF bandwidth of the oscilloscope is assumed to be lower than the carrier frequency of the RF signals, so two external down converter channels are used to convert the signals to intermediate frequency (IF). If the RF bandwidth of the oscilloscope is high enough, the external down conversion can be omitted. Throughout the paper, it is assumed that external down converters are required.

Agilent E4438C ESG is a vector signal generator that can generate arbitrary waveform and up-convert it to RF signal. In cases where the RF frequency of the signal generator is lower than the required carrier frequency, an up-converter may be used. In order to characterize its nonlinear

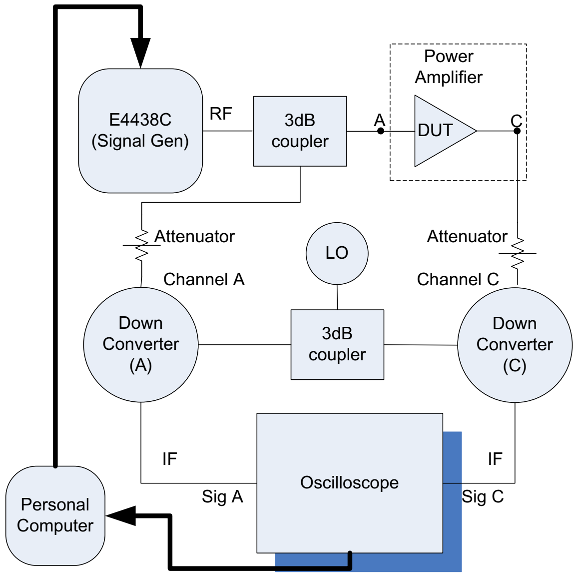

Fig. 1. Overall structure of test bed for PA behavioral modeling.

behavior, the RF signal power level should be high enough to drive the device under test (DUT: high power amplifier) to work in its nonlinear zone. The input and output signals of the DUT pass through separate down conversion channels – Channel A and Channel C. In each channel, the signal passes through a variable attenuator before down conversion. This ensures that the input signal level presented to the down-converter is within its linear zone.

Finally, the PA input and output signals in IF frequencies, denoted as Sig A and Sig C, are acquired by two channels of the oscilloscope. The signals from the oscilloscope are digitized and are passed to a personal computer (PC) for digital demodulation, impairments compensation, and other digital signal processing. The accurately recovered DUT input and output signals in baseband forms are used to characterize and model the DUT behavior.

2.2. Software overall structure

The overall structure for digital signal processing which are implemented in software running on the PC is shown in Fig. 2. At the transmitter, the baseband waveform of the test signal is generated, followed by IQ imbalances linear pre-distortion. At the receiver, channel delay, frequency offset, and phase offset are compensated.

2.3. TX IQ imbalances compensation

In our test bed, IQ imbalances in the demodulator are avoided by the use of heterodyne structure and digital demodulation. However, IQ imbalances are present in the modulator (Agilent E4438C ESG VSG) due to its analog direct up conversion structure. Although they do not influence the relationship between the envelopes of the PA's input and output signals, where they suffer from the same IQ imbalances, IQ imbalances in the modulator degrade the performance of PA behavioral characterization and