USE OF MATLAB IN SIGNAL PROCESSING LABORATORY EXPERIMENTS

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Abstract:
This paper describes the use of the MATLAB in the laboratory experiments in our Signal Processing Laboratory. One of the most important applications that we are currently working on is the algorithms verification for the linearization of power amplifiers using digital baseband adaptive predistortion. In order to test the operation of the predistorter on digitally modulated signals, the experimental workplace has been realized.

1 Introduction

Recent communication systems widely employ digital modulations, often with non-constant signal envelope. On the other side, for the reason of efficiency, transmitter power amplifiers work often in nonlinear region. The nonlinearities present in power amplifiers (PA) cause amplitude and phase distortions of the PA output signal. These distortions are at the origin of undesirable spectral regrowth and constellation point's deformation.

That's why many more or less efficient approaches to combat the power amplifier nonlinearity problem are employed. The easiest solution is to use the nonlinear PA only in its linear region far from saturation (PA back-off). The inconvenience of this approach is the reduced amplifier efficiency. More sophisticated methods how to minimize the effect of power amplifier nonlinearities without significant efficiency reduction can be divided into two main groups – linearization of power amplifiers (feedback, feedforward, predistortion, etc.) and special transmitter architectures (EER, Doherty). A publication [1] represents good overall description of the methods for amplifier linearization and transmitter architectures.

Most of the hardware as well as software tools used in this experiment serve also for the students experimental work in the undergraduate courses on Signals and Systems and Communications taught in our department. This paper will not concentrate only on the digital predistortion itself, but will also describe developed tools for the practical experiments like preparation of modulation signal, its sampling, synchronization etc.

2 Digital predistortion

Digital baseband predistortion is a special case of general linearization technique called predistortion. As can be intuitively derived from its name, predistortion technique is based on the additional signal distortion introduced before power amplifier to assure that the combination of predistorting device and power amplifier exhibits linear behavior. In other words, predistorter has to model the inverse of PA characteristics. In general, it can be implemented in radio frequency, intermediate frequency or baseband domain. The baseband predistortion is especially suitable for digital implementation and that's why we are focusing on. An adaptive predistortion is often used in order to follow the PA changes due to the temperature, aging etc. The principle of adaptive baseband predistortion is depicted in Fig. 1. In this case, a part of PA output is downconverted into baseband and used for PA inverse characteristic estimation that is subsequently used in the predistorter.

3 Experiment description

The hardware configuration of our currently built experimental workplace is shown in Fig. 2. This section will be devoted to description of its components. Evaluation of baseband predistortion systems consists in a few steps:

1. Digital modulated signal (QPSK) is generated in a data vector form in Matlab. The vector is then converted into an ASCII file and sent to the arbitrary waveform generator LeCroy LW410 through USB to GPIB converter.
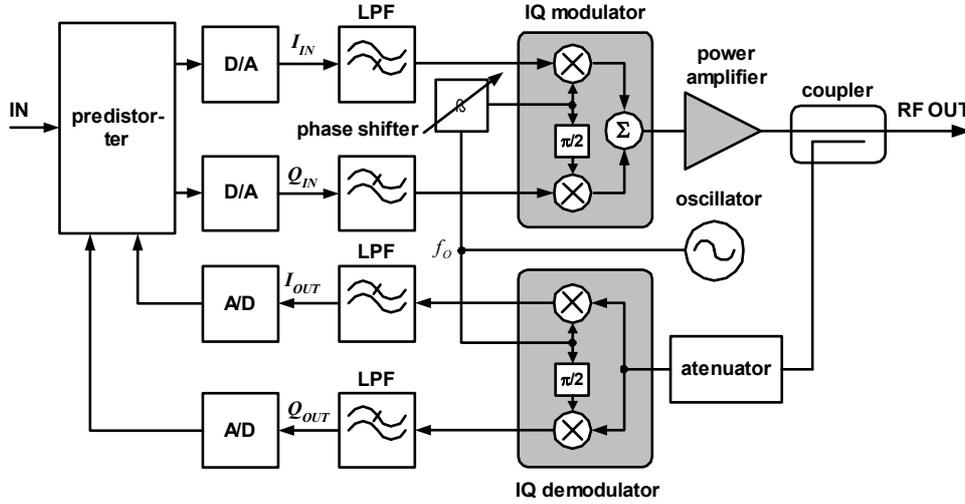

Fig. 1: Adaptive digital baseband predistortion principle

Data transmission is handled by the Matlab Instrument Control Toolbox functions. The appropriate amplitude of the modulated signal can be adjusted in programmable attenuator Tesla BM670.

2. Both modulated signals from the generator output and amplifier output are then sampled using CompuScope 1250 card and processed with application "Synchronization" written in Matlab. It ensures the data acquisition, carrier recovery, demodulation and visualization. Furthermore, the measured amplifier data are used as the data for the adaptation of several power amplifier models. One of the simplest solutions is the polynomial approximation given by:

$$z_a(n) = z \sum_{k=1}^{K} f_k |z(n)|^k \, , \tag{1}$$

where z, z_a, are PA input complex envelope and output complex envelope and f_k are the complex polynomial coefficients. More sophisticated model is polynomial with memory that can be expressed as:

$$z_a(n) = \sum_{k=1}^{K} \sum_{l=0}^{L} z(n - l \cdot n_0) f_{kl} |z(n - l \cdot n_0)|^{k-1} \, , \tag{2}$$

where L is the length of memory and n_0 is an elementary delay.

3. Simultaneously the amplifier output signal is processed in real time analyzer Sony/Tektronix 3086 in order to evaluate the EVM and depict the spectrum and vector diagram of modulated signal.

4. Digital predistorter function is calculated for example using algorithm described in [2] and applied to the modulation signal. Predistorted modulated signal is sent again to the arbitrary waveform generator through HPIB interface.

5. Amplified signal is processed in real time analyzer and results with and without predistorters are compared.

3.1 Communication with LW410 generator

Data transfer from MATLAB consists of these 5 steps:

1 Calculation of signal to send. It is either original modulated signal or modulated signal modified using predistortion function.
2 Conversion of signal to ASCII format, storing the result to .asc file.
3 Calling the routine 'lwconv.exe' provided by LeCroy, converting the .asc file to .dif file that is an internal data format used for LW410 data transfer. Matlab function `dos(command),` where the parameter command means the name of converting function plus conversion parameters, has been used.
4 Opening a handle for LW410 instrument using `g = visa('AGILENT', 'GPIB0::ADRESS::INSTR')` command and setting the parameters for communication through HPIB. Here, `ADRESS` is the GPIB address of the generator. Instrument Control Toolbox is used to handle the communication between PC and LW410.
5 Reading the .dif file and sending its contents to the instrument using following command sequence: `command = ['WAVE:DATA',data];write(g,command,'char').` A `'WAVE:DATA'` string is the specific LW410 command for data transfer.

Duration of steps 2-5 in the case of file to transfer of the length of 512KB requires only few seconds that is very advantageous comparing with data transfer using built-in floppy disc.

3.2 Power amplifier
Power amplifier (PA) is based on the BJT preamplifier (A class) and MOSFET power amplifier. PA operates at 3.5 MHz band with the maximum RF output power 5 W. The gate bias voltage has to be supplied from an external source. The change of it allows PA operation in A, B or C classes and then the resulting nonlinearity and output power can be adjusted. This will give us a great possibility to test the linearization algorithms for various working conditions. The splitters divide output power into two identical impedance matched outputs, whereas the coupler has adjacent path attenuation 40 dB. In presented experiment the PA was operating near A class with proper input power level allowing to obtain noticeable envelope distortion.

3.3 Compuscope Card
COMPUSCOPE 1250 is an analog input card for PCI bus. It uses two analog to digital converters providing a dual-channel or a single-channel real-time sampling rate of 25 MS/s or 50 MS/s respectively with 12 bit resolution.

3.4 Data acquisition and Synchronization
A software used in our application is based on our previous work [3]. It is possible to choose the sampling frequency, number of channels, carrier frequency and modulation parameters like useful bit rate etc. Systems for carrier recovery are used for many years in coherent systems. Their basic building block is the Phase-Locked Loop. In practice, a Costas loop has been used.

3.5 Arbitrary waveform generator & Real time analyzer
LeCroy LW410B WaveStation is a single-channel, 400 MS/s arbitrary waveform generator. It provides 6 kHz to 400 MHz sample clock with 1 Hz resolution, 8-bit vertical resolution and up to 1 Mbyte waveforms. It can be programmed via GPIB port and SCPI protocol.

A real time analyzer Sony/Tektronix 3086 serves as a reference and for the evaluation of results (power amplifier output). It operates from DC to 3 GHz in RF, baseband or IQ mode. Constellation diagram, eye diagram and RF spectrum can be displayed. Moreover, the quality of amplifier output signal can be also evaluated by EVM value.
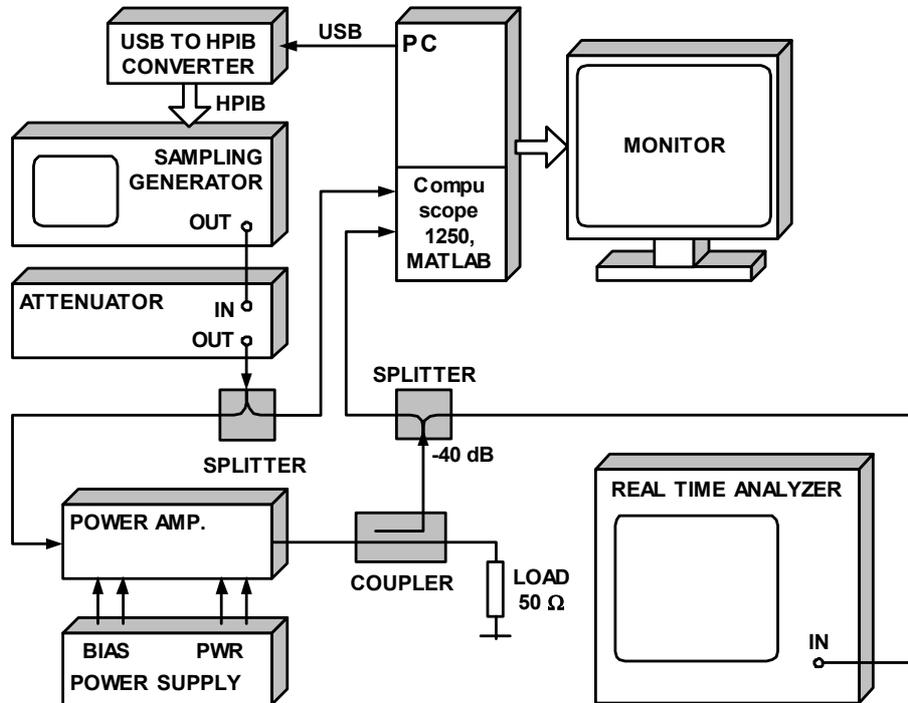

Fig. 2: Experimental workplace overall schematics

4 Measurement results

In this section, the measurement results for the QPSK modulated signals (symbol rate 5 ksymbols/s) modulated on 3.5 MHz carrier will be presented, although the proposed workplace is able to be used for various modulated signals and standards.
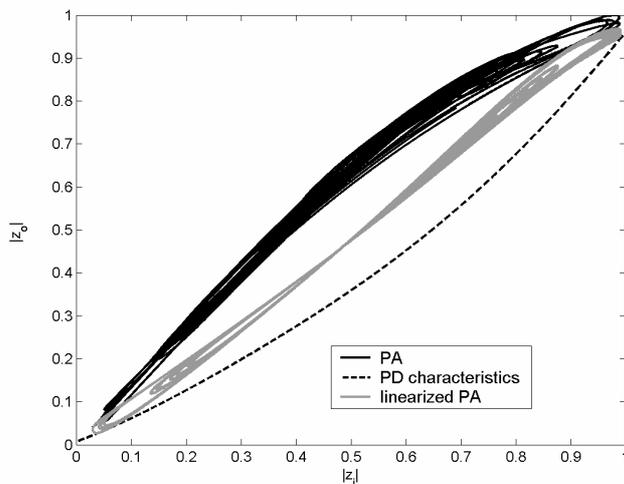

Fig. 3: Normalized amplitude characteristics of PA before and after linearization together with predistorters (PD) characteristics

The sampling frequency for both channels was 25 MHz. Fig. 3 shows the effect of digital predistortion on measured amplitude characteristics of above described amplifier. Here z_I denotes the input and z_o the output signals. For the simplicity, only the simple predistorter based on memoryless polynomial [2] has been used. As evident from this figure, polynomial predistorter can improve the linearity but cannot compensate the PA dynamics. Fig. 4 shows the PA output spectrum for PA without and with polynomial predistortion.
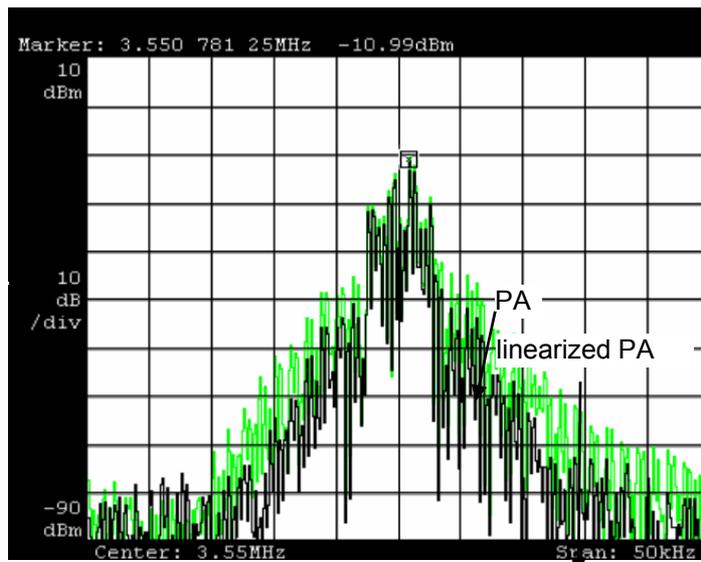
Fig. 4: Spectrum of PA output signal with and without predistortion.

5 Conclusion

In this paper we have presented our measurement setup that can be used for the power amplifier baseband characterization and for testing of power amplifier predistortion algorithms. It allows to capture the signals at the amplifiers input and output and to use such data to create a behavioral model of measured amplifier. Software tools used in the above described experiment with digital predistortion are planned to be used for students experiments in the laboratory of Signals and systems and Communication.

References:
[1] Cripps, S. *RF power amplifiers for wireless communications*, Artech House 1999.
[2] Marsalek, R., Jardin, P., Baudoin, G. From postdistortion to predistortion for power amplifier linearization, *IEEE Communication Letters*, Vol. 7, July 2003, pp. 308-310
[3] Prokopec, J. Prokes, A. Software tool for simulation of carrier recovery for MPSK and MQAM signals using MATLAB GUI, *In Proceedings of Electronic Devices and Systems Conference 2004*, Brno 2004, pp. 232-236.