IMS2017 Power Amplifier Linearization through DPD Student Design Competition (SDC): Signals, Scoring & Test Setup Description

I. Introduction

The objective of the IMS2017 SDC is to design an appropriate DPD algorithm for the linearization of a power amplifier (PA) with dynamic supply to be used in 4G handsets. The complete transmitter chain to be linearized comprises the following devices and instrumentation:

- The Texas Instruments LM3290-91 evaluation board (LM3290-91-EVM). In envelope tracking (ET) mode, the envelope modulator (EM) follows the envelope reference input signal delivered by the RFIC to the LM3291 via a differential analog input. The output is a single-ended power supply signal which is provided to the Skyworks SKY77621 Multimode Multiband (MMMB) PA installed in the board.
- A Rohde and Schwarz Vector Signal Generator (VSG): The R&S SMW200A will be used to generate the baseband I/Q and power supply waveforms/signals and provide RF up conversion.
- A Rohde and Schwarz Signal and Spectrum Analyzer (SSA): The R&S FSW8 will provide RF down conversion and waveform acquisition.

The participants will be able to access via world wide web (www) the remoteUPCLab (depicted in Fig.1) by uploading: i) the predistorted baseband I/Q signals and ii) the supply waveform to the corresponding VSG (taking into account of the necessary delay compensation between both I/Q and supply signals). The PA response will be retrieved by the SSA and the baseband I/Q output signal made available to the participants. The details on the signals being used as well as the scoring procedure are explained in section II and III of this document, respectively.

In the DPD-Competition, to be held in the IMS2017, the same or similar hardware test setup will be made available to the participating students, where they will be able to tune their DPD algorithms and upload their predistorted and supply signals. Each team will have a period of 15 minutes to tune its DPD model. When ready (or at the end of that 15 minutes period) the target input signal will be given to the team and its DPD will generate the predistorted and bias supply signals, which will be uploaded to the signal generator and supply modulator. At that moment, the jury will measure (and register) the performance metrics used to compute the overall score achieved by the team.
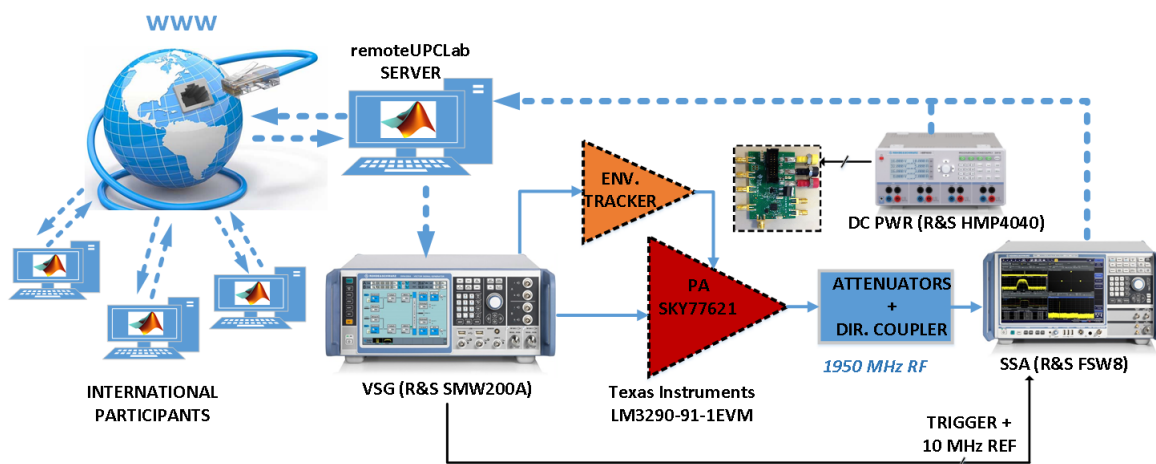

Fig. 1. Block Diagram of the remoteUPCLab.

II. Signals

The ET PA will be excited with a dual-band signal as shown in Fig. 2, centered at 1950 MHz RF frequency. The lower band will handle an OFDM signal of 10MHz bandwidth, while the upper band will be excited by an OFDM signal of 5MHz bandwidth. The separation between their center frequencies will be 80 MHz.

Instead of using a supply signal based on the original envelope, whose bandwidth (around 5x the composite dual-band signal bandwidth, according to the widely used rule-of-thumb) cannot be followed by the typically slew-rate limited envelope modulator, a supply signal based on a slow version of the original dual-band signal's envelope will be generated, as depicted in Fig. 3. The slow envelope generation is described in [Gil15]. Fig. 4 shows an oscilloscope capture of both the RF dual-band signal and the supply signal waveforms.

The Matlab function that creates the dual-band signal and the supply envelope is provided by the organizers. Further information on the required Matlab functions for the DPD competition is provided in section IV of this document.
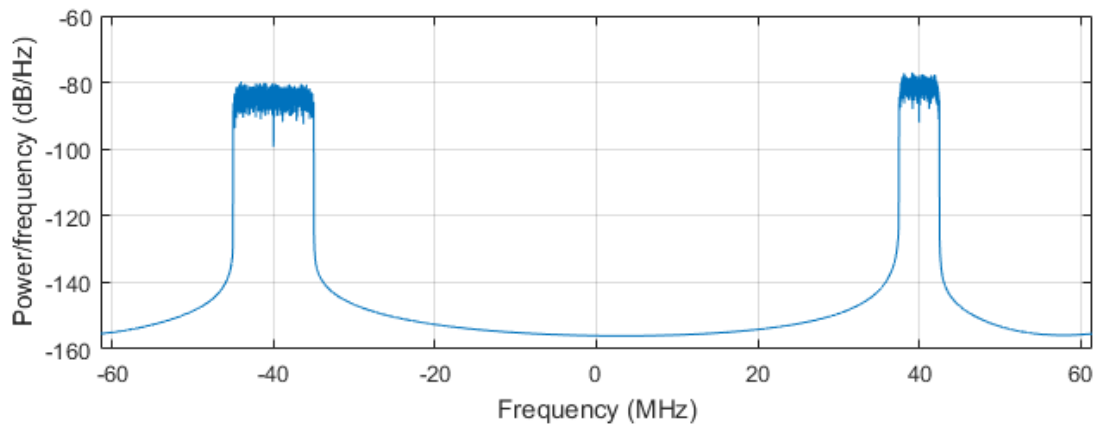

Fig. 2. Spectra of the dual-band signal consisting of a 5 MHz OFDM signal at 40 MHz and a 10 MHz OFDM signal at -40 MHz.
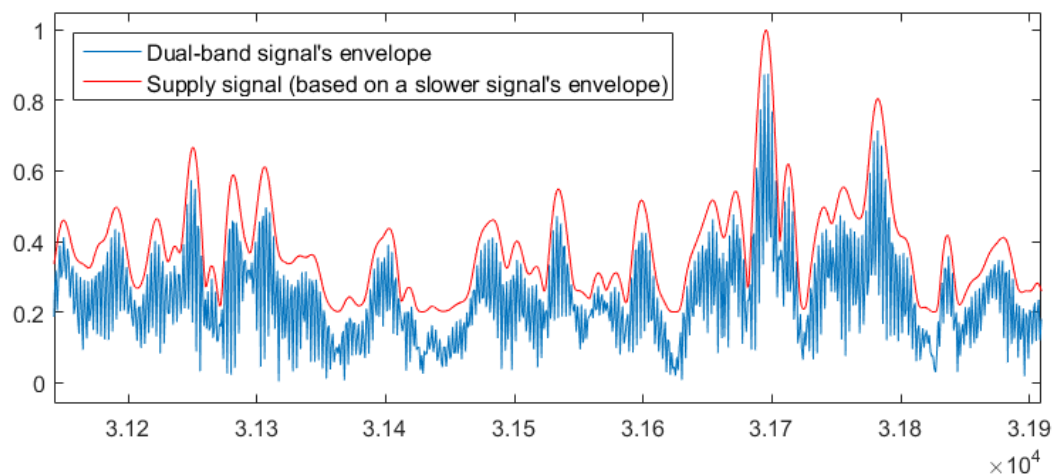

Fig. 3. Waveforms of the original dual-band signal's envelope (blue), and the supply signal, based on a slow version of the original dual-band signal's envelope [Gil15].
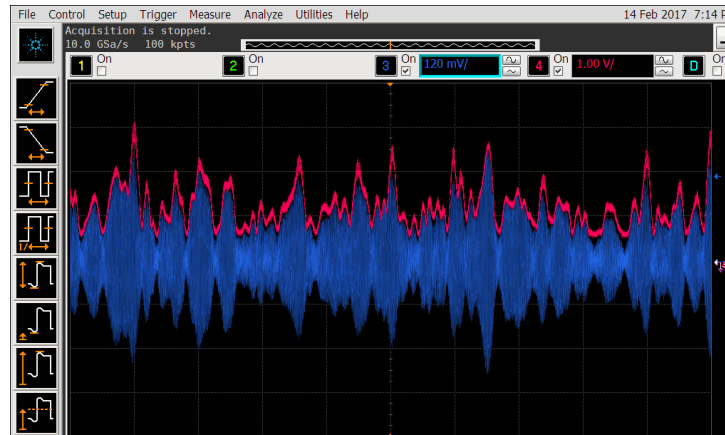
Fig. 3. Oscilloscope capture showing the RF dual-band waveform (blue) at center frequency of 1950 MHz and the supply envelope waveform (red).

III. Scoring

At each iteration, the DPD linearizer performance will be scored taking into account four different quality metrics:

- The total output power, considering both bands.

- The out-of-band linearity, *ACPR*, on each band.

- The error, *NMSE*, on each band.

- The PA efficiency

The average output power is measured in dBm, the PA efficiency in percentage (%) and the ACPR and NMSE are measured in dB. The out-of-band linearity is measured in terms of the adjacent channel power ratio (ACPR), computed for each band as the difference (in dB) between the integrated in-band power (i.e. considering 10 MHz in band 1 and 5MHz in band 2) and the highest between the right and left, adjacent, integrated out-of-band powers (within the same bandwidth). The time-domain error is measured as the normalized mean square error (NMSE) in dB between the reference signal (being originally generated) and the measured output signals at each band.

Scoring trends:

- ACPR values below -45 dBc improve the score while ACPR values above -45 dBc reduce it.

- Similarly, NMSE values below -33 dB improve the score while NMSE values above -33 dB reduce it. However, the contribution of the NMSE to the score is only considered when the minimum ACPR value (i.e., <=-45 dBc) is met. The NMSE is weighted by a factor of 0.5.

- Average output powers in excess of 20 dBm improve the score and powers below 20 dBm reduce the score. However, the contribution of the average output power to the score is only considered when the minimum ACPR (<= -45 dBc) and NMSE (<= -33 dB) requirements are met, and if the initial power ratio between each of the bands is kept. The average output power is weighted by a factor of 10.

- The value of the power efficiency is added only when the minimum ACPR (<= -45 dB) and NMSE (<= -33 dB) requirements are met, and if the initial power ratio between each of the bands is kept.

The total score formula is:

$$SCORE = mean\left(\left[-45 - ACPR_{Band1}, -45 - ACPR_{Band2}\right]\right) + 0.5 \cdot mean\left(\left[-33 - NMSE_{Band1}, -33 - NMSE_{Band2}\right]\right) \cdot \alpha$$
$$+ \left(10 \cdot \left(P_{out} - 20\right) + PA\_efficiency\right) \cdot \alpha \cdot \beta \cdot \gamma$$

with

$$\alpha = \begin{cases} 1 & if \ \min\left(\left[-45 - ACPR_{Band1}, -45 - ACPR_{Band2}\right]\right) \geq 0 \\ 0 & if \ \min\left(\left[-45 - ACPR_{Band1}, -45 - ACPR_{Band2}\right]\right) < 0 \end{cases}$$

$$\beta = \begin{cases} 1 & if \ \min\left(\left[-33 - NMSE_{Band1}, -33 - NMSE_{Band2}\right]\right) \geq 0 \\ 0 & if \ \min\left(\left[-33 - NMSE_{Band1}, -33 - NMSE_{Band2}\right]\right) < 0 \end{cases}$$

$$\gamma = \begin{cases} 1 & if \ \left|P_{out}^{Band1}(dBm) - P_{out}^{Band2}(dBm)\right| \leq 0.5 \\ 0 & if \ \left|P_{out}^{Band1}(dBm) - P_{out}^{Band2}(dBm)\right| > 0.5 \end{cases}$$

The day of the competition at the IMS venue in Hawaii, each test will be performed 3 times. The average of these three realizations will be your final SCORE.

IV. Matlab Functions Description

NOTE: A MATLAB VERSION R2014b OR HIGHER IS REQUIRED.

The necessary Matlab files for the signal generation, scoring and accessing the remoteUPCLab can be found in the following link: **IMS2017 DPD competition**.

A zip file containing three Matlab functions and an Example (`Example_test_IMS2017.m`) showing how to call them will be made available to the participants. The three main Matlab functions will be found inside the "toolbox.IMS" folder, and are described in the following:

- **[gBB,xsupply,PARAM] = IMS2017_generate_signal(GainBB)**

Inputs:

- `GainBB` – is the gain value ranging from 0 to 1 to set the amplitude of the dual-band signal. The absolute value of the dual-band signal to be sent to the remoteUPCLab cannot exceed 1. The dual band signal power may be increased but **the initial power ratio between each of the bands must be kept.**

Outputs:

- `gBB` - is a dual band signal composed by 2 OFDM signals (of 10 MHz and 5 MHz bandwidth) at -40MHz and 40MHz, relative to the center frequency of the PA.

- `xsupply` - is the "slow envelope" supply signal used to dynamically supply the PA.

- `PARAM` - is a *structure array* containing relevant information on the baseband signal processing, for example: OFDM signals bandwidth, frequency bands, length of the data vectors, the sampling frequency.

- **[SCORE]= IMS2017_meas_score_May2017(RX,gBB,PARAM)**

Inputs:

- `RX` - is a *structure array* containing, among other fields, the measured output of the PA.

- `gBB` - is the original generated dual-band signal (reference signal).

- `PARAM` - is the *structure array* containing the relevant information on the remoteUPCLab parameters.

Outputs:

- `SCORE` - is the numerical value calculated as defined in section III.

- **[RX]= IMS2017_PA_meas(xBB,xsupply)**

Inputs:

- `xBB` - is the dual-band input to the power amplifier sampled at 122.88 MHz.

- `xsupply` - is the "slow envelope" supply signal used to dynamically supply the PA.

Outputs:

- `RX` - is a *structure array* with the following fields:

    - - `RX.yBB` – is the measured I/Q-data sampled at 122.88 MHz and has the same number of samples as xBB. The sampling process is started in a completely random fashion so synchronization is required before using the output data.

    - - `RX.Rfpower`- provides information on the measured output power (peak and mean values in W and dBm) and power efficiency (%).

    - - `RX.PARAM`- is a *structure array* containing relevant information regarding the remoteUPCLAB settings and transmitted and received signals.

IMPORTANT: Generation of the supply signal (`xsupply`)

As explained before, the generation of the supply signal to be sent to the remoteUPCLab is carried out inside the function "`IMS2017_generate_signal.m`", by calling the following Matlab function:

- **[xsupply]=Supply_Envelope_Generation(gBB,PARAM)**

    Inputs:

- `gBB` - is a complex I/Q dual-band signal.

- `PARAM` - is a *structure array* containing the relevant information on the remoteUPCLAb parameters.

Outputs:

- `xsupply` - is the "slow envelope" supply signal used to dynamically supply the PA.

The participants **MUST AVOID MODIFYING** the way the `xsupply` function is calculated, i.e., they are not allowed to modify the "`Supply_Envelope_Generation.m`" function. If the participants need to recalculate the supply signal from a different dual-band I/Q signal than the original `gBB` (for example, after applying CFR techniques to the original `gBB` signal), they must use the aforementioned function to generate the new `xsupply` signal to be sent to the remoteUPCLab. Finally, the participants may optionally consider time-alignments between the supply envelope and the dual-band I/Q signal sent to the remoteUPCLab.

REFERENCES

[Gil15] P. L. Gilabert and G. Montoro, "3-D Distributed Memory Polynomial Behavioral Model for Concurrent Dual-Band Envelope Tracking Power Amplifier Linearization," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 63, no. 2, pp. 638-648, Feb. 2015.

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