Power Amplifier Memory-less Pre-distortion for 3GPP LTE Application

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Abstract— **A new and simple Power Amplifier (PA) linearization method is proposed and demonstrated using a very high efficiency yet inherently nonlinear inverse class-F PA. This was conducted in the presence of a generic variable envelope RF signal in order to extract its AM-AM and AM-PM characteristics. Deducing the polynomial pre-distortion parameters from the AM-AM and AM-PM characteristic has resulted in the successful linearization of the PA in the presence of 3GPP Long Term Evolution (LTE) signals. The results obtained for the PA - a 12W GaN HEMT inverse Class-F structure designed to operate at 900MHz - demonstrate the proof of concept and the efficiency of the proposed linearization technique with significant advantageous reduction in base-band resources for 3GPP LTE applications.**

I. Introduction

The 4th generation of wireless communication systems is to be deployed in the near future. This 3GPP LTE based protocol allows users to access various multimedia services by receiving up to 100Mbps download speeds. The possibility of achieving such high bit rates is only possible due to the use of a spectrally efficient complex modulation technique; Orthogonal Frequency Division Multiplex (OFDM). According to the recently updated 3GPP LTE technical specifications [1], the 3GPP LTE signal's dynamic range is given by the minimum values showed in Table I. The relative Peak-to-Average Power Ratio (PAPR) is variable and depends on the channel bandwidth and the number of allocated resource blocks. Clearly, the transmitter block, in the 4th generation wireless communication infrastructure, has to handle 3GPP LTE downlink signals which are variable in terms of bandwidth and PAPR.

TABLE I
3GPP LTE Downlink Characteristics

channel bandwidth (MHz)	Total power dynamic range (dB)
1.4	7.7
3	11.7
5	13.9
10	16.9
15	18.7
20	20

In the transmitter block, RF power amplifiers are known for their strong non-linear behaviour, and have to be designed to target a minimum linearity of 45dBc in terms of adjacent channel leakage ratio ACLR [1]. In order to achieve that level of linearity, several linearization techniques can be applied. One form of linearization used is digital (base-band) pre-distortion (DPD) [2][3][5]-[9]. The DPD intentionally distorts the input signal of a power amplifier in order to compensate for its non-linear behaviour. Pre-distorting the input signal requires the extraction of the inverse transfer function of the power amplifier in terms of AM-AM and AM-PM characteristics. Therefore, the quality of the linearization depends on the accuracy of the power amplifier AM-AM and AM-PM measurements. Moreover, the AM-AM and AM-PM characteristics depends on the RF signal used in the measurement procedure; i.e. the AM-AM and AM-PM profiles depend on the dynamics of the test signal in terms of bandwidth and PAPR [5]. In a 3GPP LTE context, the variability of the RF signals presents a challenge, and trying to characterize an amplifier for all the possible scenarios is difficult and time consuming. On the other hand, implementing in the base-band infrastructure several pre-distortion parameters, to compensate for all possible scenarios, results in large baseband memory requirements. Therefore, in order to achieve a reasonable base-band cost implementation, it is important to be able to linearize a power amplifier in such a way that this linearization can be applied in the presence of various 3GPP LTE signals. The scope of this paper is the implementation of a pre-distortion procedure, in the presence of several 3GPP LTE signals that linearises the power amplifier.

The proposed method extracts the pre-distortion parameters from the AM-AM and AM-PM characteristics obtained by driving the power amplifier using a generic, variable envelope signal. The use of the generic test signal allows the extraction of the “static” nonlinearities of the power amplifier, so that a memory-less polynomial pre-distortion method can be applied. The advantage of the proposed method is its simplicity and its suitability to a manufacturing environment.

The approach presented in this paper has been validated by linearizing a highly efficient 10W inverse Class-F PA .This 900 MHz structure uses a CREE 10W GaN HEMT and is particular interesting as this type of PA is typically considered unsuitable for use in modern communications systems due to its perceived inherent nonlinearity. The measurement setup and the linearization procedure are described in section II. The results are discussed in section III.

II. Measurement Setup and Linearization Procedure

A. Setup Description

Figure 1 shows the measurement setup used for the power amplifier AM-AM and AM-PM characterization. The RF generator (R&S SMATE200A) feeds the driver with a 3GPP LTE or a pre-distorted signal. The LZY-2 amplifier is able to deliver a suitably high output power level (47dBm) such that it can remain linear while driving the power amplifier over its entire dynamic range. The Device Under Test (DUT) comprises the inverse Class-F GaN HEMT PA followed by a 13 dB attenuator.

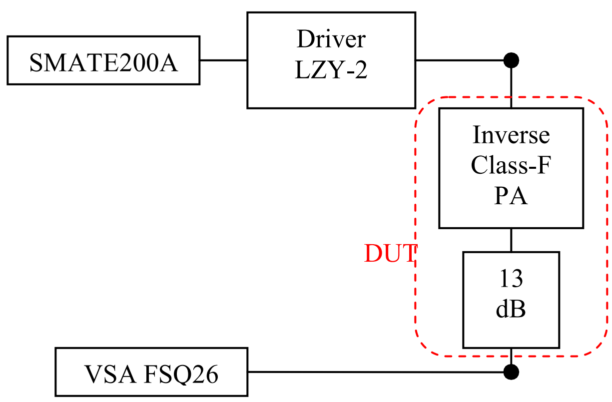

Fig. 1 Measurement setup for AM-AM and AM-PM Characterization

The inverse class-F PA was realised using a waveform-based design procedure [10]. This approach combines active high-power harmonic load-pull with high-frequency time domain measurement, and enabled the device output waveforms to be measured and 'engineered' for optimised inverse class-F mode behaviour, minimising overlap between the current and voltage waveforms and thus reducing dissipated energy. This technique enabled operation with peak Power Added Efficiency (PAE) of 80%, whilst delivering 12W from a 10W rated device. Figure 2 depicts measured current and voltage waveforms at the drain current generator of the DUT for several output power levels, and clearly show the expected square current waveform along with a half-rectified voltage waveform indicative of this mode of operation.

The PA operates with a 28V drain rail voltage and has a peak output power of 12W. Since the inverse class-F mode must operate at a high level of gain compression in order to achieve its high efficiency, the potential for nonlinear operation is very high. This has tended to limit practical application of inverse class-F in modern, linear communications systems. At the DUT terminations input and output complex envelopes are measured and the AM-AM and AM-PM characteristics are extracted using a vector signal analyser (VSA) (R&S FSQ26).

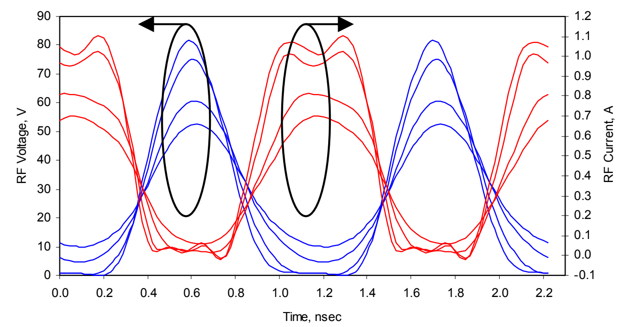

Fig. 2 Current and Voltage waveforms at the Drain current generator of the inverse Class-F power amplifier for several output power levels

B. Linearization Procedure

The generic signal used to extract the polynomial pre-distortion parameters is an RF signal with a repetitive triangle magnitude. The peak value of the triangle magnitude varies as shown in Figure 3. The period repetition of the generic RF signal magnitude is chosen to avoid the generation of some memory and thermal effects [2]. So that "true" static nonlinearities of the DUT can be measured accurately. The relative slow envelope variation of the generic signal (500kHz), allows the use of a reasonable acquisition speed and make delay compensation relatively simple.

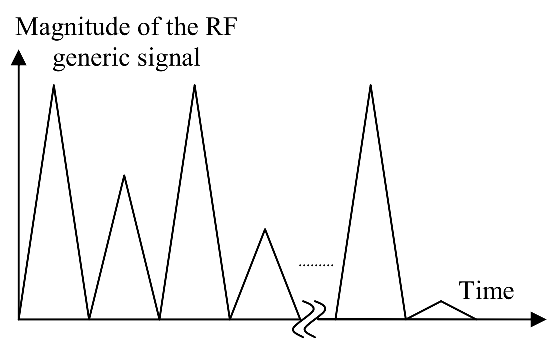

Fig. 3 Magnitude of the RF generic signal

Performing the same measurements in presence of wide band 3GPP LTE signals requires high frequency sampling, careful delay estimation and non-negligible data processing in order to estimate the static nonlinearities [5]. Figures 4 and 5 show AM-AM and AM-PM characteristics of the DUT using the generic RF signal and some 3GPP LTE signals. Results show that the obtained static nonlinearities, while the generic signal is applied, can be considered as a good approximation to those obtained in the presence of LTE modulated signals. Therefore, extracting polynomial pre-distortion parameters from the "generic" AM-AM and AM-PM should yield to good linearization performance in the presence of various 3GPP LTE signals. In fact, due to memory effects [5] and in the case of coarse delay estimations [4], AM-AM and AM-PM curves exhibit hysteresis behaviour. Therefore, extracting the polynomial pre-distortion parameters from the measurements performed in presence of the generic signal is a much easier task than doing this in presence of the wideband LTE signals.

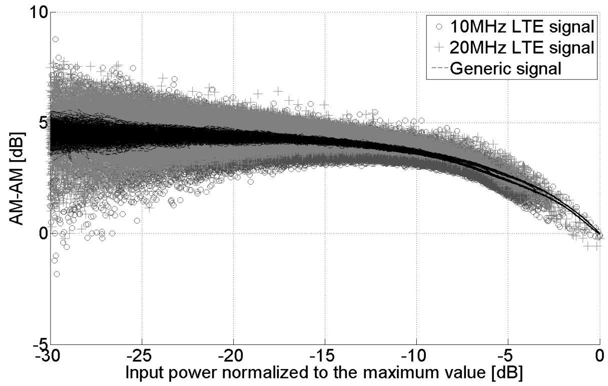

Fig. 4 AM-AM of the PA in presence of the generic signal and some 3GPP LTE signals

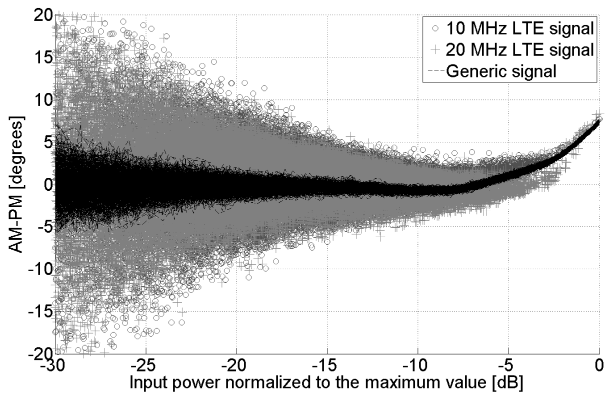

Fig. 5 AM-PM of the PA in presence of the generic signal and some 3GPP LTE signals

The accuracy and the efficiency of the pre-distortion rely strongly on the modelling of the true static nonlinearities of the DUT. But the use of a good approximation of these nonlinearities allows a linearization good enough to meet the 3GPP LTE linearity requirements (45dBc of ACLR).

III. Measurement Results

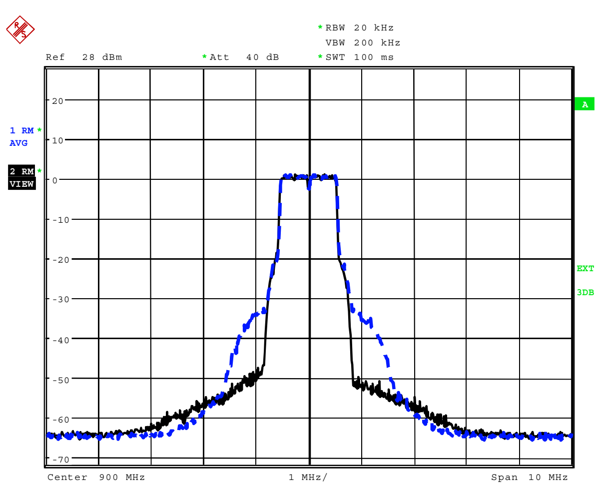

Fig.6 PA Linearization in presence of 1.4 MHz 3GPP LTE signal using a generic signal for AM-AM and AM-PM measurement.

Figures 6 and 7 show the spectrum of the output signal of the DUT with (solid curves) and without (dashed curves) pre-distortion. The pre-distortion parameters were extracted from the AM-AM and AM-PM characteristics obtained in the presence of the generic triangle envelope RF signal. Results show the efficiency of the proposed linearization procedure since more than 15dB and 5dB improvements in terms of ACLR are obtained in the presence of 1.4MHz and 20MHz 3GPP LTE signals, respectively. The reason for the small amount of linearity improvement for the 20MHz LTE signal is that the PAPR is around 15dB, so, further back-off is needed to drive the PA within its input dynamic range, and obviously the single ended PA tested in this study is less nonlinear at such back-off input power. Figure 8 shows the linearity improvement (10 dB in term of ACLR) of the DUT when a 10MHz LTE signal is applied and pre-distorted with the proposed method (solid curve). In order to verify the accuracy of the linearization with the generic signal, the 10 MHz LTE input signal is also pre-distorted using the AM-AM and AM-PM characteristic measured in presence of the 10MHz LTE signal (dashed curve). Similar performances are obtained when classic and generic linearizations are applied. This observation demonstrates that the generic signal is suitable for the extraction of memory-less polynomial pre-distortion parameters. In Figures 6, 7 and 8, the residual nonlinearities observed in the output signals after pre-distortion are attributed to memory effects, but all the results show that the linearized signals meet the 3GPP LTE standard linearity requirement.

IV. Conclusions

A generic linearization procedure is proposed in this paper. The proposed method is based on the use of a generic variable envelope RF signal applied to the DUT in order to extract its AM-AM and AM-PM characteristics for static nonlinearity compensation. The proposed method was validated on an inherently nonlinear inverse Class-F RF PA and successful linearization results are obtained enabling the very high efficiency RF power amplifier to meet the 3GPP LTE standard linearity requirements. This linearization strategy is simple, cost effective and suitable for a production environment for the following reasons:

- Simple extraction of the pre-distortion parameters due to the use of a relatively slow variable envelope RF signal.
- Less sensitivity to a coarse delay estimation of the AM-AM and AM-PM measurements.
- Pre-distortion parameters are valid in the presence of various LTE signals which relax the requirements on base band resources.

The main disadvantage of the proposed method is the fact that memory effects are not taken into account. This results in residual nonlinearities in the output signal after linearization, but good linearity performance was obtained for the PA measured for this paper.

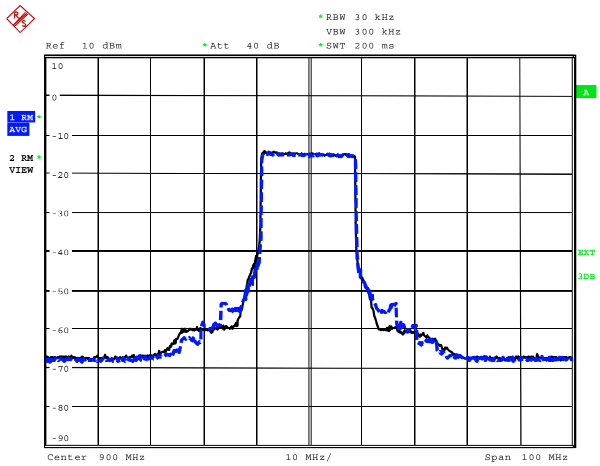

Fig. 7 PA Linearization in presence of 20 MHz 3GPP LTE signal using a generic signal for AM-AM and AM-PM measurement.

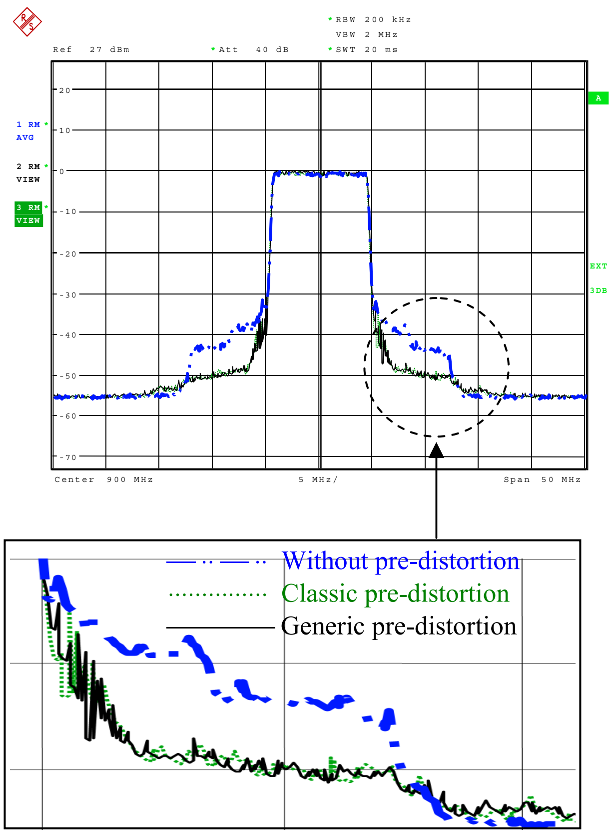

Fig. 8 PA Linearization in presence of 10 MHz 3GPP LTE signal using a generic (solid line), and 10MHz 3GPP LTE (dashed line) signal for AM-AM and AM-PM measurement.

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REFERENCES

[1] 3GPP technical specification, TS 36.104 V8.4.0. [Online]. Available: http://www.3gpp.org/ftp/Specs/latest/Rel-8/36_series/

[2] O. Hammi, S. Carichner, B. Vassilakis, and F.M. Ghannouchi, "Power Amplifiers' Model Assessment and Memory Effects Intensity Quantification Using Memoryless Post-Compensation Technique," *IEEE Microwave Theory and Techniques Trans.,* Vol.56, pp:3170-3179, Dec. 2008.

[3] O. Hammi, F.M. Ghannouchi, and B. Vassilakis, "On The Sensitivity of RF Transmitters' Memory Polynomial Model Identification to Delay Alignment Resolution," *IEEE Microwave and Wireless Components Lett.*, Vol.18, pp:263-265, Apr. 2008.

[4] J. Lees, T. Williams, S. Woodington, P. McGovern, S. Cripps, J. Benedikt, and J. Tasker, "Demystifying Device related Memory Effects using Waveform Engineering and Envelope Domain Analysis," *European Microwave Conf.* pp:753-756, Oct. 2008, Amsterdam.

[5] S. Boumaiza, M. Helaoui, O. Hammi, T. Liu, and F.M. Ghannouchi, "Systematic and Adaptive Characterization Approach for Behavior Modeling and Correction of Dynamic Nonlinear Transmitters," *IEEE Instrumentation and Measurements Trans.,* Vol.56, pp:2203-2211, Dec. 2007.

[6] G.I. Abib, S. Bensmida, E. Bergeault, and B. Huyart, "A source-pull/load-pull measurement system including power amplifier linearization using simple instantaneous memoryless polynomial base-band predistortion," *European Microwave Conf.* pp:252-254, Sept. 2006, Manchester.

[7] S. Bensmida, O. Hammi, and F.M. Ghannouchi, "High efficiency digitally linearized GaN based power amplifier for 3G applications," *IEEE Radio and Wireless Symp.*, pp:419-422, Jan 2008.

[8] N. Safari, T. Roste, P. Fedorenko, and J.S. Kenney, "An Approximation of Volterra Series Using Delay Envelopes, Applied to Digital Predistortion of RF Power Amplifiers With Memory Effects," *IEEE Microwave and Wireless component Lett.,* Vol.18, pp:115-117, Feb. 2008.

[9] D.R. Morgan, M. Zhengxiang, J. Kim; M.G. Zierdt, J. Pastalan, "A Generalized Memory Polynomial Model for Digital Predistortion of RF Power Amplifiers," *IEEE Signal Processing Trans.,* Vol.54, pp:3852-3860, Oct. 2006.

[10] Wright, P. et al., "Highly Efficient Operation Modes in GaN Power Transistors Delivering Upwards of 81% Efficiency and 12W Output Power," *IEEE MTT-S Int. Microwave Symp.* Digest, June 2008, pp. 1147-1150.