Baseband Digital Predistortion Using Subband Filtering Technique

O. Hammi, S. Boumaiza, M. Jaidane and F. M. Ghannouchi

Poly-GRAMES Research Center, Department of Electrical Engineering, École Polytechnique, Montreal, Quebec, H3V 1A2, Canada

Department of Electrical Engineering, École Nationale d'Ingénieurs de Tunis, Tunisia

Abstract — **This paper proposes a subband baseband digital predistortion architecture for power amplifiers operated in multi-channel wideband applications. The new architecture is composed of a cascade of a fixed nonlinear function and an adaptive linear subband filters bank. It takes advantage of subband filtering for computational complexity reduction and convergence enhancement. This will allow digital baseband predistortion to be applied to wideband signals that traditional architectures fail to handle due to the insufficient processing speed capacity of the available digital signal processors. Power amplifiers non-linear behavior changes versus temperature were used for a first attempt to evaluate this new subband predistorter performances.**

I. Introduction

Power amplifiers are critical and expensive components in the base stations transmitters and satellite transponders. Indeed, their design has to meet a stringent requirement in terms of power and spectrum efficiency and linearity that are generally contradictory. Third generation (3G) emerging wireless systems are particularly concerned with this issue since they employ wideband and high varying envelope signals with high peak-to-average ratio in order to achieve higher data rate and multi-media services. Consequently, PA's linearization techniques represent an unavoidable solution to attain a good trade-off between the linearity and power efficiency. Several linearization techniques have been employed in the literature such as feedback, feedforward and predistortion.

Even though feedforward linearizers are actually widely deployed in wireless BS transmitters thanks to their ultra linearity, they suffer from poor power efficiency, high cost, and complex adaptation architecture. Digital baseband predistortion is perceived as a valuable solution when taking advantage of the steel growing digital signal processors performances. It offers a good linearity, a better power efficiency and especially reduced complexity and cost. However, this technique still admit some limitations especially in the case of multi-carrier signal derive that implies a stringent processing speed requirement for the implementation of the predistortion function and its adaptation algorithm. We applied, in this paper, the subband filtering technique for the realization of the predistorter to get round of the previous limitations.

In this paper we present a baseband digital predistorter technique based on subband processing. In the first section, we introduce the subband processing. In the second one, we show the details of the proposed baseband predistorter scheme. In the third section, we present the simulation results and discuss the performances of the new predistorter.

II. Subband Processing

Subband processing technique is widely used in multirate systems for computational complexity reduction and adaptive filtering algorithms convergence behavior improvement.

In such multirate systems, samples at different points in the scheme are processed at different clock rates. For that, decimators and interpolators functions are respectively used for the clock rate reduction and increase. Figure 1 shows a typical bloc diagram of multi-channel subband filters. It consists of two main parts that are analysis and synthesis stages. The analysis stage decomposes the original input signal spectrum into M subbands. It reduces the clock rate as well by the decimation factor (M). The decomposition filters (H_i) (called anti-aliasing filters) that are of bandpass type limit the input signal spectrum to avoid any aliasing after decimation. The signal (V_i) at the output of each subband is given by equation (1).

$$V_i(z)=\frac{1}{M}.\sum_{r=0}^{M-1}\theta_i\left(z^{\frac{1}{M}}\cdot W^r\right) \qquad (1)$$

where

$$\theta_i\ (z)=H_i(z)\cdot X(z). \quad \text{and} \quad W=e^{\frac{-j2\pi}{M}}$$

An interpolator is used at the input of the synthesis stage for the recovery of the original clock rate. The reconstruction filters (G_i) remove the imaging effect introduced by the interpolation function. The resulting signal at the output of each subband in the synthesis stage is obtained by equation (2).

$$Y_i(z) = G_i(z) \cdot V_i\left(z^M\right) \quad (2)$$

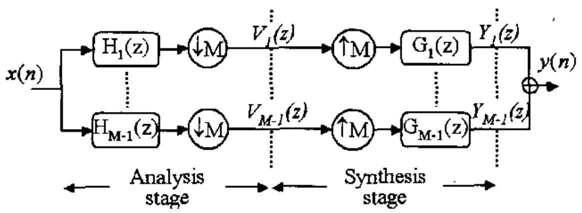

Fig. 1. Multi-channel subband filters.

The output signal $Y(n)$ of the subband can be written as a function of the input signal and the decomposition and reconstruction filters as following:

$$Y(z) = \frac{1}{M} \cdot \sum_{k=0}^{M-1} G_k(z) \cdot \sum_{r=0}^{M-1} H_i(z) \cdot X(z) \quad (3)$$

Reconstruction and decomposition filters functions are determined in [1] so that one can assure a perfect reconstruction and consequently the subband structure behaves as a perfect delay. In the literature, we distinguish several filters types allowing a perfect reconstruction that meet these requirements such as Quadrature Mirror Filters (QMF) [2].

Since input signal decomposition and reconstruction are already performed, subband filters used for signal processing has to be added in between the analysis and synthesis stage. This reduces the computational complexity since the clock rate is the lowest at this level in the scheme.

III. Proposed Baseband Predistorter

The proposed predistorter is based on Hammerstein system, shown in figure 2, which consists of a cascade of a non-linear filter and a linear one. In the literature, this type of predistorter structure has been used to linearize power amplifiers that were modeled by a Wiener system composed of a linear filter followed by a non-linear memoryless one [3] and [4]. Both linear and non-linear filters have to be adapted when the PAs behavior changes [3]. In the case of wideband signals excitation, the adaptation of such filters may give rise to convergence problems such as slow convergence speed and large excess mean-squared errors. Moreover, computation requirements for the implementation of these filters may lead in practice to an unachievable processing speed. In the proposed predistorter structure, the subband technique permits to get round of these problems by decomposing the linear filter in the conventional Hammerstein predistorter into M filters having a complexity reduced by M. Consequently, this allows a faster convergence with a reduced complexity.

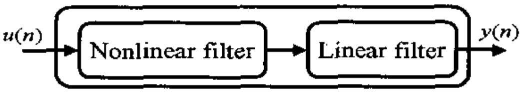

Fig. 2. Hammerstein predistorter structure.

In the proposed predistorter, the non-linear filter corresponds to the PA non-linear memoryless model deduced under reference conditions. The dynamic linear filter is used to take into account for the PA non-linear behavior variations due to aging, biasing conditions and temperature variations. Furthermore, the non-linear filter is fixed in this paper and the adaptation is restricted to the linear filter.

The non-linear fixed predistorter is synthesized based on AM/AM and AM/PM curves obtained using instantaneous complex input and output envelope of the power amplifier. The PA is characterized under realistic signal excitations and a reference temperature. The non-linear filter in this work was implemented using a Look-Up Table (LUT).

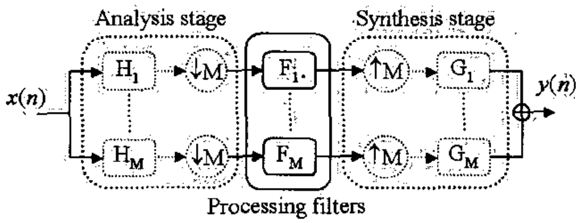

Fig. 3. Linear filters block diagram.

The details of the linear filters block based on subband processing are given in figure 3. The input signal is first decomposed in subband by the analysis stage. Then, each subband is individually adjusted via the processing filters F_i to the desired level (in magnitude and phase). Finally, the subband processing output signals are recombined in the synthesis stage. Subband processing filters are bypassed as long as the power amplifier characteristics, on which the synthesis of the fixed predistorter was based, remain unchanged. If the operation condition of the PA changes and its output fails to pass the linearity requirements, the processing filters are adjusted iteratively until getting the desired PA output.

The adaptation of the processing filters coefficients was done by using M error signals generated from the difference of the input and output signals as shown in figure 4. In other words, the error signal in the k^{th} subband ($e_k(n)$) is computed by comparing the desired signal at the output of the PA in that subband ($d_k(n)$) to the actual output of the PA in the same subband ($z_k(n)$). Since linear amplification is required, the desired signal at the output of the PA is a scaled version of the original input signal. Thus, the subband desired signals other than those corresponding to the in-band components are zero since they represent the distortion introduced by the PA non-linearity. In this way, the problem of identifying a single complex filter at a high speed is changed to that of identifying smaller filters at a lower speed.

IV. Measurements And Simulation Results

The proposed predistortion scheme has been simulated using Advanced Design System software. As a first attempt a two-tones signal with 2 MHz spacing was used for these simulations. The AM/AM and AM/PM characteristics curves used in this work are those of an, 90-Watts peak LDMOS, amplifier having a gain of 58 dB and P1dB output power of 49dBm. The amplifier AM/AM and AM/PM characteristics, shown in figure 5, were obtained using the instantaneous test bed presented in [5] at different case temperatures.

The non-linear fixed predistorter has been derived from the measured curves at a case temperature of 30°C that was used as a reference temperature. The simulation of the cascade of PA model and the fixed predistorter corresponding to the same reference temperature (30° C) was done by setting the subband filters coefficients to the unity. Figure 6 shows the output spectrum of the PA at these conditions. After substitution of the PA model corresponding to 30°C by that corresponding to 85°C, we observe linearity degradation in the spectrum at the output of the PA as shown in figure 7. Figure 8, shows the output spectrum of the PA without any linearization. Based on figure 7 and 8, one can concludes that even though the fixed predistorter in figure 7 does not correspond to that of the amplifier it was possible to reduce the inter-modulation level by almost 10 dB. In order to compensate for the mismatching between the power amplifier non-linear characteristics and that of the fixed non-linear predistorter, the subband filters coefficients were changed in the sense of minimizing the error defined in the previous section. Following the activation of sub-band pre-processing of the predistorter which result in updating the subband filter's coefficients, one can clearly observe the inter-modulation level reduction at the output of the PA as given in figure 9. The IMD improvements when compared to those in Figure 7 are evaluated to better than 40dB for both the IMD3 and the IMD5. We can conclude, by comparing figures 6 and 9, that the cascade of the fixed predistorter and the subband processing behaves as the matched predistorter.

Performances evaluation of this predistorter with multi-channel W-CDMA signal is under way.

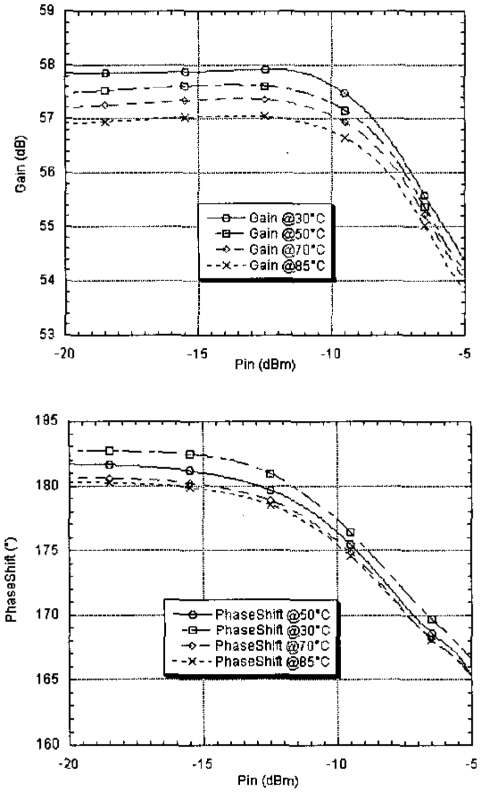

Fig. 5. AM/AM and AM/PM measured curves of the PA at different case temperature.

V. Conclusion

This paper proposes a new architecture for adaptive baseband predistortion suitable for multi-channel wideband applications. This new predistortion calls for the use of subband processing technique, which allow reducing the speed requirement of the DSP. This is accomplished by synthesizing multiple linear short filters in place of a very long linear and/or non-linear filter. Initial results were obtained for an LDMOS 90 Watts PA with a two-tone signal. Satisfactory results were obtained.

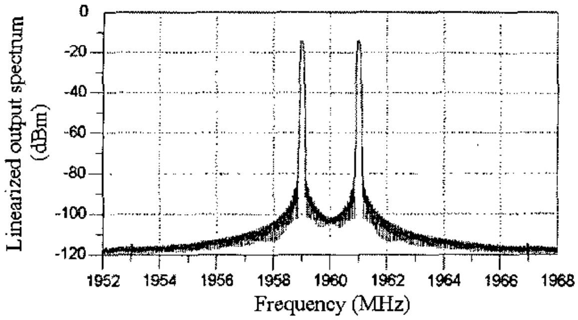

Fig. 6. Linearized Output Spectrum @ 30° C.

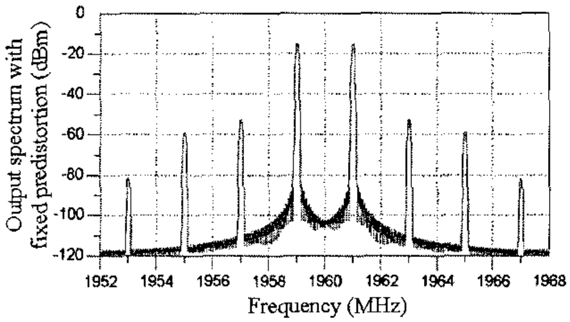

Fig. 7. Linearity degradation after temperature variation from 30° C to 85° C.

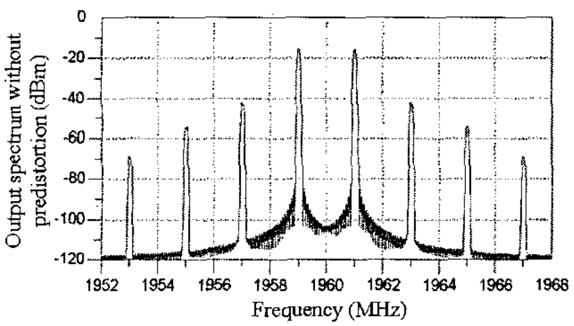

Fig. 8. Output spectrum without predistortion @ 85° C.

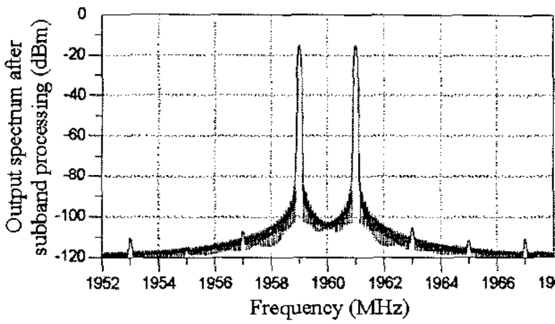

Fig. 9. Output spectrum after subband processing

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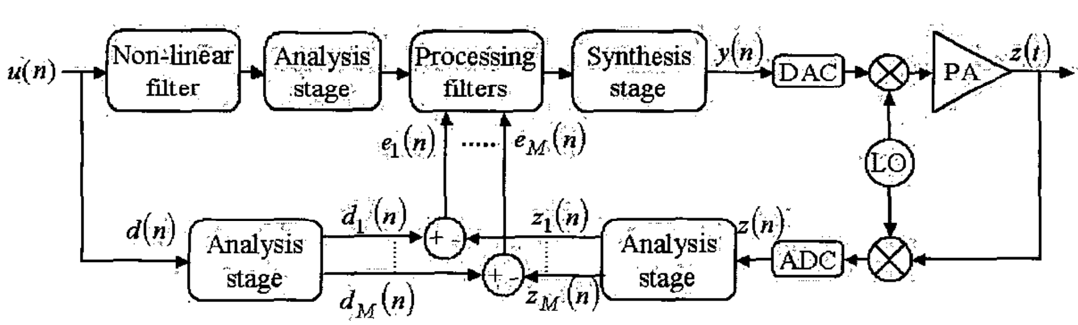

Fig. 4. Subband processing filters adaptation architecture.