AN L BAND ADAPTIVE DIGITAL PREDISTORTER FOR POWER AMPLIFIERS USING DIRECT I-Q MODEM

Ernesto G. Jeckeln, Fadhel M. Ghannouchi and Mohamad A Sawan

Department of Electrical and Computer Engineering
Ecole Polytechnique de Montréal
C.P. 6079, Station Centre-Ville, Montréal, Canada H3C 3A7

Abstract

This paper presents an L band experimental implementation of an adaptive digital predistorter (ADP) using direct I-Q modem for power amplifiers suitable to spectrally efficient mobile communication equipments. The linearizer, which is implemented in digital signal processor (DSP) environment, performs the real time modeling (RTM) of the power amplifier to supply its AM-AM and AM-PM non-linearities characteristics. Experimental results demonstrate that the spectral spreading is reduced by of 20 dB. The ADP achieve both power and spectral efficiencies and without the need for complex convergence algorithms and complex circuit.

Introduction

Linearization techniques become a useful way to compensate the distortion effects and spectral spreading caused by the amplifier non-linearities on the linear modulation method. In other words, linearization techniques permits to achieve both power efficiency and spectral efficiency while signal degradation is compensated. These parameters are important in design consideration of modern wireless radio systems allowing to extend the portable's battery life, to maximize the output power emission and to satisfy the restriction on the available limited spectrum. Thus, linear modulation, which has a high envelop variation, is adopted to maximize the spectral efficiency. In addition, the power amplifier (PA) is operated close to saturation (non-linear region) to achieve both high power efficiency and high output power emission.

Various linearization methods have been reported and many different ways can be used to segment this topic. But in general, all these techniques are, by any measure, derived from three main types named: i) Feed-forward [1], ii) Feedback [2] and iii) Predistortion [3]. The last technique, that has historically been the most common method in analog implementation, now can be well suited to digital implementation using digital signal processor (DSP) environment. The benefits of fast computational engine from this technology in several applications motivate the designers to focus toward the DSP/RF-Microwave integration. In this way, predistortion became one of the most robust linearization techniques that can be suited within this segment and dedicated for narrow frequency band system.

Important experimental results of this technique have been reported [4], [5], [6] demonstrating the capability in reducing the spectral spreading and how adaptive correction for drift, aging and temperature variation can be achieved. All algorithms of these previous work are based on iterative procedure [7], where the adaptation is exposed to critical condition such as stability and convergence rate. In this sense, this paper presents an experimental implementation of an ADP for PA operating near to saturation and without the need for complex convergence algorithms in the adaptation update step. This work validate the theoretical analysis presented by authors in [8], where the Real Time Modeling (RTM) algorithm models the Memoryless Complex Gains (MCG) of the PA to supply the knowledge of the non-linearities. The prototype is implemented with a DSP where both the RTM algorithm and the ADP are performed.

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

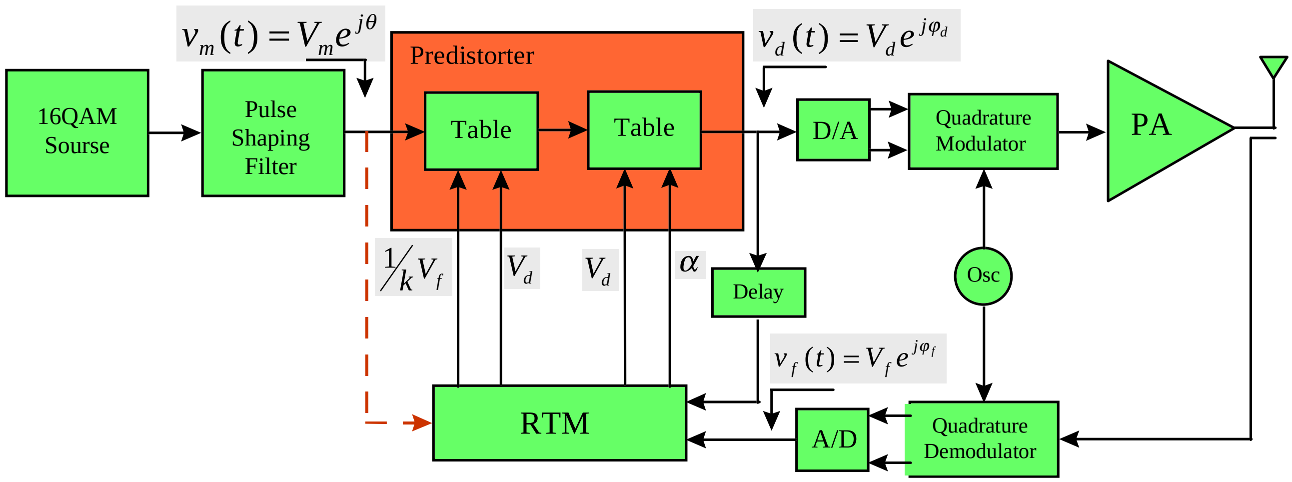

Fig. 1. Adaptive predistorter diagram.

The adaptive digital predistorter

General description

A simplified block diagram is shown in Fig.1. The signal source is the 16-QAM modulation schema, which is passed through a pulse shaping filter. In the RTM algorithm, the input $V_d e^{j\varphi_d}$ and output $V_f e^{j\varphi_f}$ equivalent lowpass complex envelope signals of the amplifier are oversampled and scaled to model the MCG. Then, a number q of complex data are sampled and sorted in order following an ascending list of values of the input signal's amplitude V_d. The sequences of complex samples can be written as following:

$$\sum_{i=1}^{q} V_{di} e^{j\varphi_{di}} \gamma(n-iT), \qquad \sum_{i=1}^{q} \frac{1}{k} V_{fi} e^{j\varphi_{fi}} \gamma(n-iT) \tag{1}$$

where $\gamma(n\text{-}iT)$ represents the impulse sampling at the signaling intervals iT (i = 1,2,3,...), T is the sampling period, k is the gain of the feedback loop of the equivalent baseband system and V_{di}, φ_{di} and V_{fi}, φ_{fi} are the discrete amplitudes and phases of both signal trajectories in the signal-space diagram. Now, letting the power amplifier be considered as a zero memory system and exploiting the rotational invariance of the amplifier nolinearity [7]. Then, the input-output relationship of such system can be written as follows :

$$v_f(t) = T\{v_d(t)\}, \tag{2}$$

where the complex transfer function is given by :

$$T\{v_d(t)\} = \left|T\{V_d(t)\}\right| e^{j\phi\{V_d(t)\}}. \tag{3}$$

Note that $\left|T\{V_d(t)\}\right|$ and $\phi\{V_d(t)\}$ determine the amplitude and phase nonlinearity respectively. Based on equations (2) and (3) and using equation (1), the modeling of the MCG can be performed straightforward where $\phi = \varphi_f - \varphi_d$. From this model, the inverse function of the AM-AM characteristic is performed and the AM-PM conversion factor is complemented according to obtain gain expansion and phase advance.

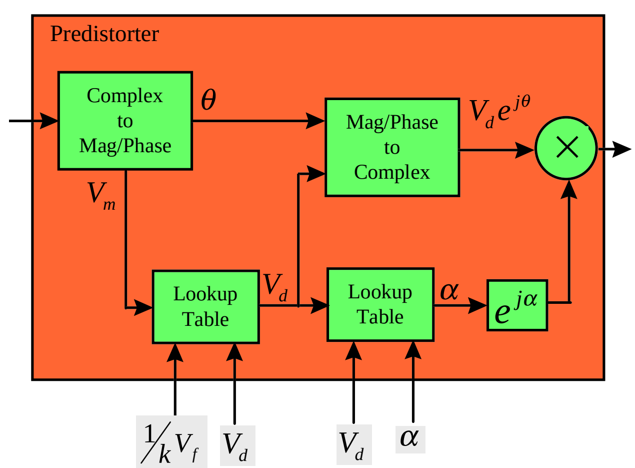

Fig. 2. Lookup tables using polar representation of processed signal.

Then, The set of data from the RTM is loaded into the predistorter where the predistorted signal is provided using one-dimensional lookup table technique (LUT). Note that pipeline structure is employed in the LUT technique to generate amplitude predistortion V_d and phase predistortion α (Fig. 2). An important feature to be considerate is the adaptability dedicated to drift correction. Adapting the predistorter requires a feedback path through which the linearizer can be notified of this change. In this case, mean error criterion between the desired and the distorted feedback signals is used to shoot adaptability. After each adaptation and during normal data transmission, the feedback loop is opened until new significant drifts have occurred and new data has to be entered in the LUT.

Prototype

The entire system has been built as shown in Fig.3. The system boards is a LSI card, running on a PC, including a TMS320C40/50 MHz device and a module with 16 bit/60-200 KHz dual DA/AD converters. The power amplifier was a 1 W class AB driven at 1,780 GHz. The 16QAM modulation method is used as the signal source with a baud rate of 6 kHz. The pulse shaping filter is a raised cosine having a roll off (α) of 0.35, and the oversampled rate was 10 samples/symbol. Careful attention has been paid to reduce the local oscillator carrier feedthrough from the QM, [6]. It was reduced by using a cancellation loop which include an attenuator and phase shifter in parallel with the QM.

Experimental results and discussion

Results

To evaluate the predistorter performance, the PA was driven near saturation with 1 dB peak back-off (the radio of the saturation output power and peak output power) [7]. From the experimental results, as shown in Fig. 4, it is demonstrated that the spectral spreading may be reduced in excess of 20 dB. A further reduction can be achieved by improving the compensation of the feedback loop impairments (carrier leak, gain and phase imbalance, etc.,). Note that the degradation on spectral magnitude from these impairment limits the out of band spectral reduction obtained from the linearizer (Fig. 4).

Advantage

This technique uses the benefits that any mathematics function is easy to be performed by software and therefore, significant improvements can be obtained using inverse nonlinearities from the RTM algorithm. Due to its operating principle, the proposed linearizer performs adaptation without the need of complex convergence algorithms and can supply correction for any order of nonlinearity and any modulation format.

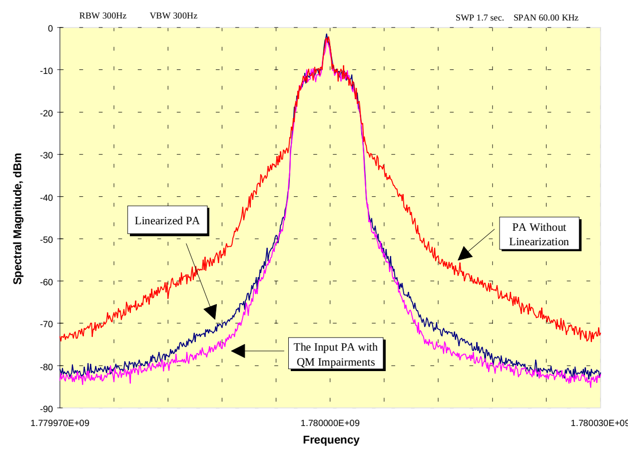

Fig. 4. Power spectrum showing the effect of the linearization and the QM impairment.

Limitation

A quite examination revealed that the precision of the RTM in modeling the non-linearities have a critical dependence of the feedback loop impairments. The distortion, due to imperfection from other components are added to the signal limiting the accuracy when the non-linearities are sounded. Also, a limitation in bandwidth is imposed to the system. In fact, the processor performs its task in real time where data are presented to the system by the external environment and whether the processor is ready or not. Therefore, if the algorithm cannot process data adequately because of time consuming, it may lose input data resulting a failure in the system.

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

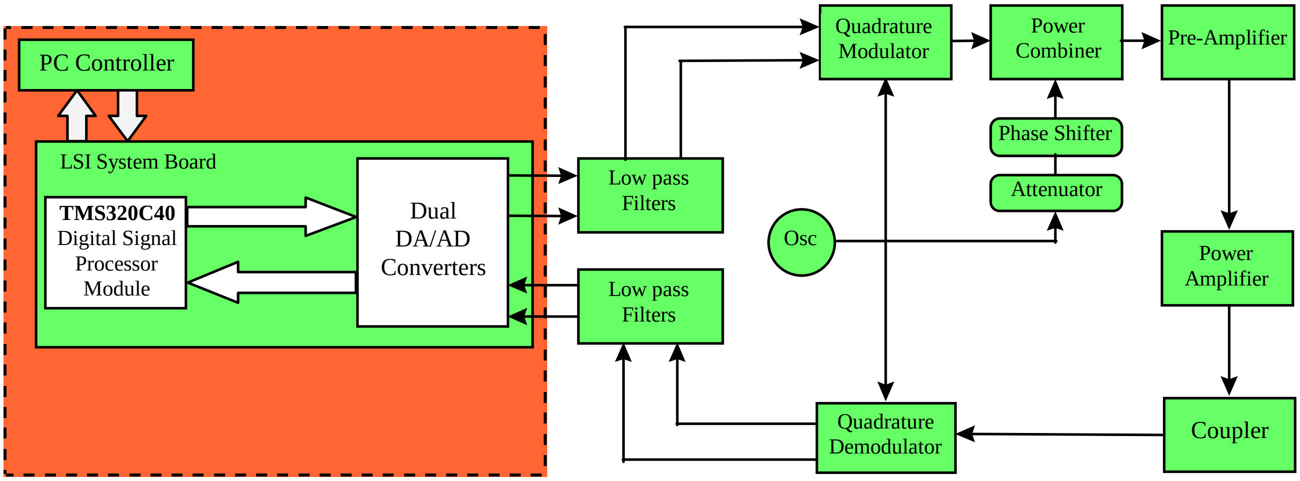

Fig. 3 Simplified block diagram of the hardware.

Conclusion

In this paper, an experimental validation of new method dedicated to ADP with real time modeling of AM-AM and AM-PM characteristics is presented. The RTM algorithm has demonstrated to be a powerful tool for sounding and modeling the memoryless complex gains during normal data transmission. Its ability is in eliminating the need for complex convergence algorithms in the adaptation update step. The predistorter can be self corrected for any drift in the operating points and also, any order of nonlinearity and any modulation format can be supported. Finally, although the technique is limited in bandwidth, the evolution of DSP technology, that improves the speed of digital processing, will allow researchers to handle higher bandwidth signal.

Acknowledgments

This work is supported by the "Programme Synergie" of the Quebec government through the AMPLI project in collaboration with Advantech Inc. and NSI Communications.

References

[1] R. Meyer, R. Eschenbach and W. Edgerley, Jr." A Wide-Band Feedforward Amplifier", IEEE J of Solid-State Circuits, vol.sc-9, no. 6, pp. 442-428, December 1974.

[2] C. C. Hsieh and E. Strid. "A S-band high power feedback amplifier", IEEE MTT-S International Microwave Symposium, San Diego, CA, June 21-23, 1977, pp. 182-184.

[3] N. Imai, T. Nojima and T. Murase, "Novel Linearizer Using Balanced Circulators and Its Application to Multilevel Digital Radio Systems", IEEE Transactions on Microwave Theory and Techniques, vol. 37, no 8, pp. 1237-1243, August 1989.

[4] Y. Nagata, "Linear Amplification Technique for Digital Mobil Communications", in Proc. IEEE Veh. Technol. Conf., San Francisco, CA, 1989, pp. 159-164.

[5] M. Faulkner, T. Mattsson and W. Yates, "Adaptive Linearization Using Predistortion" in Proc. 40th IEEE Veh. Technol. Conf. 1990. pp. 35-40.

[6] A. S. Wright and Willem G. Durtled, "Experimental Performance of an Adaptive Digital Linearized Power Amplifiers", IEEE Transactions on Vehicular Technology, vol. 41, no 4, pp 395-400, November 1992.

[7] J. Cavers, "Amplifier Linearization Using a Digital Predistorter with Fast Adaptation and Low Memory Requirement", IEEE Transactions on Vehicular Technology, vol. 39, no 4, pp 374-382, November 1990.

[8] E.G. Jeckeln, F.M. Ghannouchi and Mohamad Sawan, "Adaptive Digital Predistorter for Power Amplifiers with Real Time Modeling of Memoryless Complex Gains", IEEE MTT-S 1996 International Microwave Symposium, San Francisco, CA, June 1996.