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Enabling Baseband and Radio-Frequency Characterization of Supply-Modulated Power Amplifiers Using a Wideband Nonlinear Measurement Platform

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ABSTRACT:

The use of spectrum-efficient digital modulation techniques and the cost advantage of utilizing a single power amplifier in multi-carrier radio communication systems are the two major contributors to the increase in the linearity requirements during the processing of a signal. The simplest technique to improve the linearity of a power amplifier is to reduce its output power, so the device is operated in its linear region. Though this approach is valid, it severely degrades the power efficiency. Because the remaining components in a communications system usually consume little power compared to the final power amplifier, the efficiency of the latter becomes of extreme importance. Any systematic method for improvement of linearity (or nonlinear distortion reduction) is called linearization. Because baseband signal generation in modern communications systems is performed digitally, it makes sense to implement the linearization right at baseband, in the form of one more stage in the baseband generation process. The predistortion method of nonlinear distortion correction is the most suitable technique for this purpose, because the whole process is carried out before the power amplifier and immediately after the modulation takes place. This thesis generically analyses the predistortion method of nonlinear distortion reduction, and applies the concepts to implement a practical wideband digital predistorter. Methods for the cancellation of imperfections in the linearizer itself are developed, and its performance evaluated as a function of a variety of system parameters. The cancellation of memory effects in the power amplifier is also considered. Experimental results are shown for various signals, and for traveling wave tubes or solid-state power amplifiers, demonstrating correction bandwidths of up to 100 MHz, and cancellation of distortion products of up to 25 dB. These results are considered state of the art for today's standards. The bandwidth is only limited by the processing speed of the available digital processing devices; wider bandwidths are certainly possible in the near future without changes to the algorithms developed.

1. INTRODUCTION

This doctoral thesis is on the reduction of non-linear distortion in communications systems by using digital signal processing. Distortion can be understood as a measure of the difference in shape between the input and output signals of a system. If the distortion does not generate additional signals at the output of the system, it is called linear distortion, and it can be reduced by using an equalizer. However, if the distortion is such that new signals (with new frequencies) appear at the output of the system, it is called non-linear distortion. This type of distortion is of concern because those additional signals may interfere with other communications systems. Non-linear distortion was not much of a problem many years ago when communications systems utilized frequency modulation; this type of modulation does not introduce amplitude variations in the envelope of the signal being transmitted, for which power amplifiers could be operated in class-C, achieving high efficiencies. Today's communication systems make use of spectrum-efficient modulations that have variable envelope. At the same time, the tendency is to use a single power amplifier for multi-carrier transmissions. In both cases, any amplitude or phase distortion of the signal as a function of its level will generate additional undesired signals called intermodulation distortion products (IMD). The gain of a Radio Frequency (RF) power amplifier is typically not a constant at all output power levels. The magnitude of the gain decreases when the output power approaches the saturation level (which is the maximum achievable output power), and the phase of the gain could either increase or decrease, depending on the type of active device utilized by the power amplifier. The major contribution to non-linear distortion occurs in the high power region. Hence, one method to minimize the non-linear distortion consists of the reduction of the input power in order to operate the power amplifier in its low power region. Unfortunately, the reduction of the output power, also called back-off, degrades the power efficiency. Low distortion and high efficiency go in opposite ways, and therefore a compromise solution is often found. Many systematic methods of non-linear distortion reduction, often called linearization, have been developed [Katz, Ref. 47 and 67]. Among all methods, predistortion and feed-forward are the two that provide the best results. Feed-forward linearization consists of the cancellation of the distortion products at the output of the power amplifier. To achieve this, a small portion of the input signal to the power amplifier is subtracted from a sample of the output of the power amplifier, obtaining in this way a third signal that only contains the distortion products of the amplifier. Then, the distortion signal is amplified by a low distortion auxiliary amplifier and subtracted from the output of the power amplifier, canceling out the distortion. Feed-forward linearization has been successfully employed in many communication systems, but it is difficult to add to existing amplifiers, and can only provide good results if the output back-off level of the power amplifier is in the order of 6 to 7 dB. Predistortion linearization has been in use for many years as well, particularly in the satellite and microwave industries. A predistorter is a device that precedes a non-linear device such as an RF power amplifier. The magnitude of the predistorter gain increases when the magnitude of the power amplifier gain decreases, and the phase of the predistorter gain is the negative of the phase of the power amplifier gain. The net result is that the magnitude and phase of the gain of the two devices in cascade becomes approximately a constant until the power amplifier reaches saturation. Predistortion linearization can provide good results (50 dB of signal to IMD ratio) even at output power levels close to saturation..

2. REVIEW OF THE LITERATURE

A - Digital pre distortion The most relevant publications on digital predistortion, including overview papers.

B - Linear distortions Papers on the analysis and correction of linear distortion that can degrade the performance of the digital predistorter.

C - Memory effects Papers on the analysis and correction of memory effects of the non-linear device that can degrade the performance of the predistorter.

D - Characterization of non-linear devices Literature on methods to measure the complex gain of a non-linear device as a function of power.

E – Digital predistorter performance vs. system parameters Publications on the performance of a digital predistorter as a function of a variety of parameters that must be chosen during the design process.

2.1. REVIEW OF LITERATURE ON DIGITAL PREDISTORTION There have been a good number of publications on digital predistortion in the last twenty years. The first papers dealt with the improvement of the constellation points of a digital transmitter, more than on the spectrum regrowth [Grabowski, Ref. 72, Shanmugan, Ref. 74, Saleh, Ref. 75]. When the occupancy of adjacent channels became more of a problem, the research was focused more on the Intermodulation Distortion (IMD) products than the bit error rate. The first practical implementation of a gain based digital predistorter was proposed by James Cavers [Ref. 37] in 1990. Before this method, the majority of the digital predistorters were based on the mapping predistorter principle, in which each possible signal level was directly mapped to another output level. Not much improvement was achieved over the basic idea of the gain based predistorter, because it seems to be practical and efficient. However, the reduction of distortion and the frequency range over which the distortion is corrected, often called signal correction bandwidth was far from the need of most applications, and digital predistorters remained as laboratory experiments. As an example, signal correction bandwidths of 8 KHz were reported in Ref. 37. Table 2.1.1 reviews the weaknesses and strengths of the most relevant publications on digital predistortion. Very few of the proposals perform corrections of memory effects or linear distortions; this is, in fact, one of the key issues in obtaining greater bandwidths while still maintaining good distortion cancellation. As a way of showing how the distortion cancellation and the signal correction bandwidth interact, Figure 2.1.1 depicts a plot of the distortion reduction as a function of the linearization bandwidth for the most relevant papers in which real implementations of digital predistorters, and not simulations, were carried out in practice. There have been no published experimental results, to this date, that make an outstanding improvement and break with this apparent trend.

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Ref. Number - Author	Topic	Weakness	Strength
2 – Jeckeln, et al	Digital predistorter using analog IQ modulator	-Not 100% digital approach	
7 – Ren, et al	Simulation of a digital mapping predistorter	-Only simulation results -The mapping predistorter requires large memory size	
9 – Stapleton	Complex gain predistorter	-Overview paper	
10 – Sills	Digital predistorter	-Wideband, but only 5 dB distortion cancellation	
18 – Zavosh, et al	Digital predistorter for CDMA	-20 dB improvement across 3 MHz	
19 – Wright, et al	Complex gain predistorter	-Very narrowband (8 KHz) -Few details provided	
20 – Goeckler	Simulation of a digital predistorter	-Only simulated results shown	
26 – Jeckeln, et al	Adaptive digital predistorter	-20 dB distortion cancellation -Narrowband (60 KHz)	
28 – Zavosh, et al	Digital predistorter	-Narrowband	-Analyses performance versus table size and quantization level, but not the combined effects
31 – Andreoli, et al	Digital predistorter	-10 dB improvement across 10 MHz -Few details provided	
36 – Stapleton, et al	Adaptive predistorter using complex spectral convolution	-Narrowband (8 KHz) -11 dB distortion cancellation	-Introduces the concept of periodic update
37 – Cavers	Gain based predistorter		-Introduces the gain based predistorter concept
38 – Davis, et al	Digital predistorter	-Non-linear device static gain measurement -10 dB improvement across 1 MHz	
45 – Kenington, et al	GSM-EDGE predistorter	-Not 100% digital -800 KHz bandwidth	
89 – Hammi, et al	Digital predistorter using sub-band technique	- Only simulation results shown - No other memory effects compensation	- Filters used to compensate for temperature changes
93 – Ding, et al	Digital predistorter with memory polynomials	- Only simulation results shown -Polynomial approach is hard to implement -No other memory effects correction	- Uses filters to correct for frequency memory effects

Table 2.1.1 – Analysis of the literature on digital predistortion linearization

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CONCLUSION As a result of the research work carried out for this doctoral thesis, the following can be concluded: 1. Digital predistortion linearization is a well established method of distortion reduction. It has been used for over 20 years in a wide variety of communications systems. The gain based predistorter is the most effective method for the implementation of a digital predistorter. 2. The performance of the digital predistorter is severely affected by any linear distortions that may appear either in the feedback or the forward paths, for which careful equalization is necessary. 3. The major contributors to the linear distortions are the quadrature modulator, the quadrature demodulator, the reconstruction filters, and the anti-alias filters. 4. The non-linear distortion introduced by the quadrature modulator can be cancelled with the predistorter, as long as the modulator is characterized together with the RF power amplifier. 5. The non-linear distortion introduced by the quadrature demodulator in the feedback path cannot be reduced with the predistorter, therefore, the demodulator must be operated at small signal levels. Any increment in the signal to noise ratio can be minimized by averaging. 6. The quantization level plays an important role not only in setting the noise floor as in any communications systems, but it also affects the cancellation of non-linear distortion. The effect of the quantization level on the distortion cancellation depends on the probability density function of the signal.

REFERENCES AND LINKS

1. A. Katz, S. Moochalla, J. Klatskin, “Passive FET MMIC Linearizers for C, X and KU-Band Satellite Applications”, IEEE MTT International Microwave Symposium Digest, 1993.

2. E. Jeckeln, F. Beauregard, “Adaptive Baseband/RF Predistorter for Power Amplifiers Through Instantaneous AM-AM and AM-PM Characterization Using Digital Receivers”, IEEE MTT International Microwave Symposium Digest, 2000.

3. A. Katz, “Measuring AM-to-PM Effects in a GaAs FET Power Amplifier”, RCA AstroElectronics Technical Report.

4. C. Clark, C. Silva, A. Moulthrop, M. Muha, “Power - Amplifier Characterization Using a Two - Tone Measurement Technique”, IEEE Transactions on Microwave Theory and Techniques, Vol. 50, No. 6, June 2002.

5. W. Jenkins, A. Khanifar, “A Multicarrier Amplifier with Low Third–Order

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Intermodulation Distortion", IEEE MTT International Microwave Symposium Digest, 2000.

6. Y. Hu, J. Mollier, J. Obregon, "A New Method of Third – Order Intermodulation Reduction in Nonlinear Microwave Systems", IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-34, No. 2, February 1986.

7. Q. Ren, I. Wolff, "Improvement of Digital Mapping Predistorters for Linearising Transmitters", IEEE Transactions on Microwave Theory and Techniques, June 1997.

8. R. McMorrow, S. Yates, "Evaluating Iridium Amplifiers with a New Noise Power Ratio Technique", Hewlett Packard Application Note.

9. S. Stapleton, "Amplifier Linearization Using Adaptive Digital Predistortion", Applied Microwave & Wireless, February 2001.

10. J. Sills, "Application of Digital Predistortion to BWA", Intersil Wireless Networking Products System Engineering, Scottsdale, August 20, 2001.

11. M. Faulkner, M. Johansson, "Correction of Mixer Nonlinearity in Quadrature Modulators", IEEE MTT Electronics Letters, Vol. 28 No. 3, 30th January 1992.

12. Q. Ren, I. Wolff, "Effect of Demodulator Errors on Predistortion Linearization", IEEE Transactions on Broadcasting, Vol. 45, June 1999.

13. K.Voudouris, J. Noras, "Effects of Amplitude, Phase, and Frequency Imperfection on the Performance of a Direct Conversion Receiver (DCR) for Personal Communication Systems", IEEE Microwave and Guided Wave Letters, Vol. 3, September 1993.

14. M. Heutmaker, J. Welch, E. Wu, "Using Digital Modulation to Measure and Model RF Amplifier Distortion", Applied Microwave &Wireless, March/April 1997.

15. J. Staudinger, "Specifying Power Amplifier Linearity Via Intermodulation Distortion and Channel Spectral Regrowth", Applied Microwave & Wireless.

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