Adaptive RF Cartesian Predistorter Based on the Low Frequency Even Order IM Terms

Youngoo Yang, Young Yun Woo, and Bumman Kim

Department of Electronic and Electrical Engineering and Microwave Application Research Center, POSTECH, Korea

Abstract — **A new adaptive predistortion method of high power class AB amplifier is presented. The 2nd order harmonics(f2-f1) is generated in the properly filtered drain bias circuits of small amplifier with proper drive level to have relatively high 2nd order and low 4th order IM components. The 4th order component(2f2-2f1) is generated by multiplying the 2nd order component. These low frequency even harmonics modulates the main signal in I/Q channel form to generate the 3rd and 5th IM components. This PD is very compact and has low insertion loss and capability to independently control the amplitudes and phases of the 3rd and 5th IM components, which are very important to achieve higher performance without having local minima in the adaptive control. A 2.15GHz high power amplifier has been linearized for the 4.5MHz broad band CDMA signal. The results prove that this adaptive predistorter could achieve a drastic improvement of ACP and has excellent adaptivity.**

I. Introduction

Predistortion technique has been very popular for the SCPA(Single Carrier Power Amplifier) of the base station and relay of mobile communication systems since it has relatively simple topology, good performance, and low cost [1]-[4]. For the base station of the 3G systems, broad band high power amplifiers with highly linear characteristics are demanded [5], and predistorters focusing on the cancellation of the 3rd order distortion term or having narrow band characteristics would not be suitable for the 3G systems. In addition to the broad band and linear characteristics, the adaptive control of predistorters is very important because of their open loop structures. Adaptive control should track long term variations of the amplifier due to the temperature variation, device drift, and etc. as well as short term variations caused by AM-AM and AM-PM to maintain the optimum nonlinearity cancellation.

In this paper, we present a new adaptive predistortion method using Cartesian type diode modulator to generate IM3 using the low frequency 2nd IM component(f2-f1 for two-tone case) and IM5 using 4th order component(2f2-2f1). It's well known feature in Volterra series analysis that the 3rd order IM components(2f2-f1, 2f1-f2) can be generated by modulating the fundamental components(f2, f1) and 2nd order component(f2-f1) and the 5th order IM terms(3f2-2f1, 3f1-2f2) by modulating the fundamental components and 4th order component(2f2-2f1) [6]-[8]. This predistorter has the freedom to control the amplitudes and phases of the IM3 and IM5 independently, which means that it can position the IM3 and IM5 in any point of the Cartesian coordinate by adjusting only 4 parameters: gains of the in-phase and quadrature low frequency 2nd and 4th order IM components. DSP is used to adaptively control the long term gain and phase variations of the overall RF path and to optimize the ACP cancellation. We have linearized a 2.15GHz class AB high power amplifier with 120W PEP. The two-tone linearization results and adaptive control results of the cancellation of ACP will be presented. A broad band CDMA signal with a chip rate of 4.096Mcps and peak to average ratio of 11dB is applied. The results will be compared with both no predistorter and no adaptive control cases, respectively.

II. System Description

Fig. 1 shows the system schematic diagram including adaptation circuits. The adaptation circuits are aimed at the compensation of both the long term fluctuations of gain and phase due to the temperature, aging, average input power level, and etc. and the short term fluctuations due to the gain(AM-AM) and phase(AM-PM) variation by canceling the IM3 and IM5 components.

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

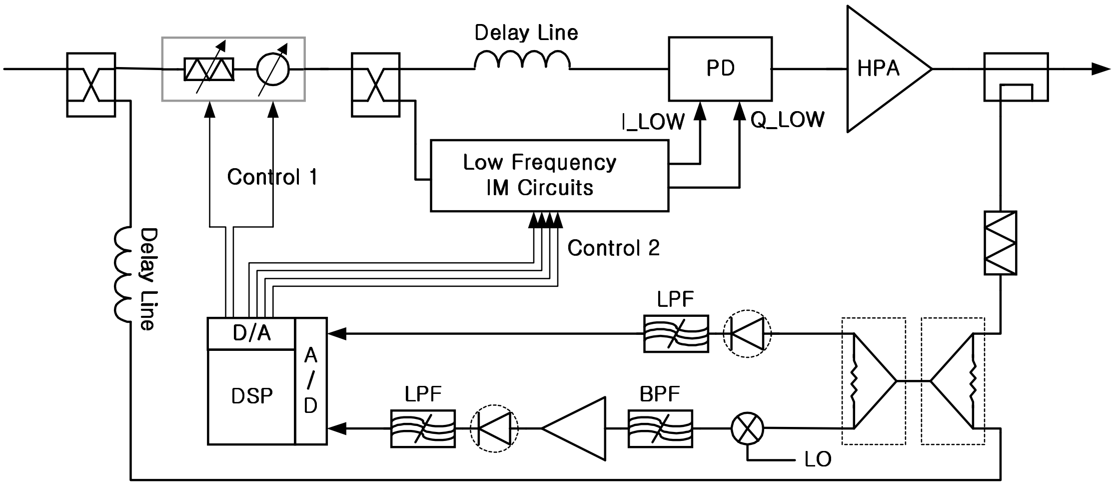


Fig. 1. System schematic diagram with adaptation circuits for compensating both long term and short term variations

For compensating long term fluctuations, a polar vector modulator is used. For the reference of the optimum compensation for the long term variations, the signal cancellation method similar to the first loop cancellation of feed-forward amplifier is used. A split and delayed input signal is combined with the tapped and attenuated output signal to have minimum signal level by adjusting the polar vector modulator. This vector modulator can compensate the long term fluctuations of the main path parameters because the maximum signal cancellation can be achieved for the accurate balance between the reference path and main path parameters.

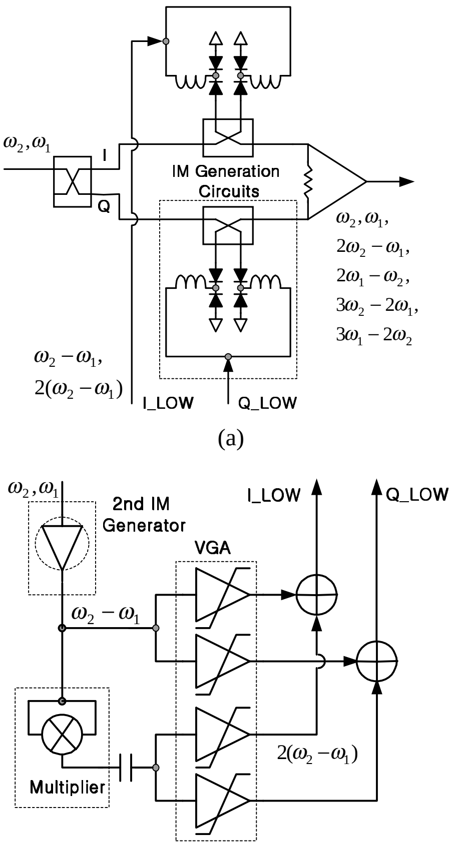
For compensating the short term variations(AM-AM and AM-PM), the signal is split into two paths: low frequency and RF paths. In the low frequency path, low frequency even order terms are generated and injected into RF Cartesian type predistorter to generate IM3 and IM5 components. The amplitudes and phases of IM3 and IM5 are controlled by adjusting the VGAs. For the control, the distortion level is directly detected at a low frequency by down conversion and the VGA's for the 3rd order and 5th order distortion components are independently adjusted to minimize the distortion level of the output signal. The timing difference between two paths can be compensated using RF delay line.

A. Operation of Predistorter

A circuit diagram of the RF Cartesian predistorter is shown in Fig. 2(a) and its low frequency circuit diagram shown in Fig. 2(b). RF input signal is split to the signal path and harmonic generation path. In the harmonic generation path, the 2nd order component is generated using the nonlinearity of small size FET amplifier and is extracted at the drain bias circuitry with proper filtering. The 4th order component is generated by multiplying the 2nd order term using analog multiplier. The 2nd and 4th components are split into respective in-phase and quadrature parts and separately amplified using VGAs. Then, the in-phase part of the 2nd order and 4th order components are added and compose I_LOW signal and the comparable quadrature components compose Q_LOW signal. In the signal path, input is split into in-phase and quadrature signals by 90 degree hybrid power splitter. This provides the axes of the Cartesian coordinate. The intermodulation terms of predistorter are generated by the 2nd order nonlinear coefficient of the reflective diodes by modulating the fundamental and 2nd and 4th order low frequency components. The detailed operation of the predistorter is described in reference [8].

B. Adaptive Control Circuits

In the adaptive control circuits shown in Fig.1, the main signal is cancelled and the output is split into two paths. In the upper path, the remaining main signal is detected using log detector and low pass filter. The DSP chip produces the control signals of the polar vector modulator to maintain the minimum detected power level. In the way, the gain and phase variations of the HPA can be compensated and constant average gain and phase can be maintained. In the lower path, the error signal is down-converted to an intermediate frequency (45MHz in our case). At the low



(b)

Fig. 2. Circuit diagram of RF Cartesian type predistorter with injecting low frequency even order IM terms: (a) RF part with in-band IM generation circuits and (b) low frequency part including 2^{nd} and 4^{th} order components generation blocks

frequency, the error signal can be easily detected using a sharp band pass filter, eliminating the residual main signal and thermal noise. The error signal is detected using log detector and is converted to a digital signal. To minimize the distortion level, DSP provides four control signals for VGAs: two for the 3^{rd} order and other two for the 5^{th} order distortions. For the compensations of the long term and short term variations, the adaptive delta modulated power gradient algorithm, which was previously demonstrated to have improved characteristics over general steepest descent based methods, is used [9].

III. Experiments and Results

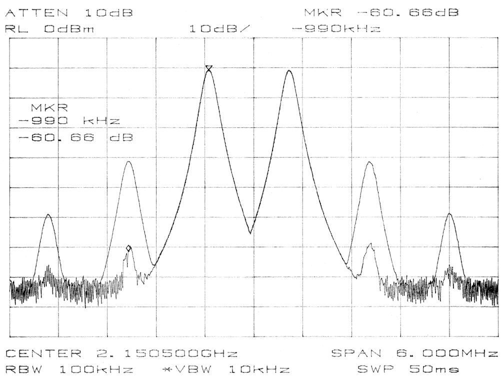
In the experiment, a class AB power amplifier having 120W PEP at 1dB gain compression point using Motorola's LDMOSFET MRF21120 is used as a final stage. It is driven by a class AB driver amplifier having 30W PEP at 1dB gain compression point. Overall HPA module has 45.5dB of gain. For generating 2^{nd} order IM term, Mini-Circuit's ERA5SM is used as a nonlinear amplifier and the 2^{nd} order IM component is extracted from its drain bias circuits.

Two-tone linearization results show a large improvement of IM3 and IM5 as shown in Fig. 3(a). At the average output power of 44dBm, IM3 is improved by more than 28dB and IM5 is improved by more than 17dB to near noise level. As applying broad band CDMA signal, which has chip rate of 4.096Mcps and peak to average ratio of 11dB, the ACP improvement is about 14.84dB at the average output power level of 40.5dBm and 2.5 MHz offset point as shown in Fig. 3(b). The adaptive control results of the ACP cancellation with applying the CDMA signal show a drastic improvement compared to both no predistorter and no adaptive control(with predistorter manually optimized at average output power of 40.5dBm) cases, which is shown in Fig. 4. The adaptive control algorithm has been rapidly converged to the minimum ACP point with respect to varying average output power of the broad band CDMA signal.

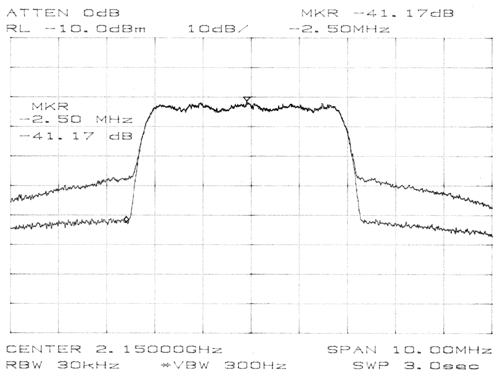
IV. Conclusions

We have presented a new adaptive RF Cartesian predistorter with injecting low frequency even order components. This predistorter has some advantages: first, the predistorter could be very compact size because it has simple RF circuits and is mainly based on compact low frequency circuits using multi-layer PCB artwork. A simple micro-controller can be substituted for DSP due to running very simple algorithm. Second, predistorter has low RF insertion loss of less than 3dB. Third, this predistorter has only 4 control parameters to independently control the 3^{rd} order and 5^{th} order distortion components, which makes it easy for controller to converge to the optimum point.

For validation, a 2.15GHz HPA module of 120W PEP at 1dB compression point, predistorter, detection circuits, and control circuits have been implemented. The linearization results have shown significant cancellation of IM3 and IM5 at two-tone input and drastic improvement of ACP at broad band CDMA test. Adaptation using DSP makes it possible to maintain improvement of ACP through a broad range of average output power level.



(a)



(b)

Fig. 3. Linearization results: (a) two-tone input with average output power of 44dBm and (b) broad-band CDMA signal with average output power of 40.5dBm

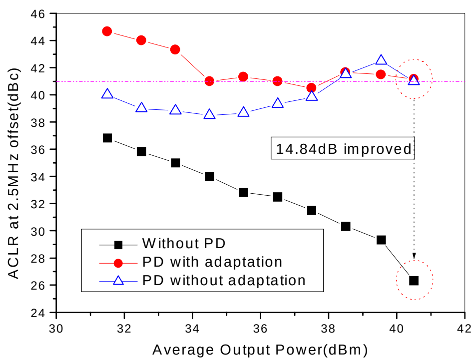


Fig. 4. Adaptive control results of ACP improvement compared to both no predistortion and no adaptation cases.

ACKNOWLEDGEMENT

This work has been supported by the Agency of Defense Development and BK21 project of the ministry of education in Korea.

REFERENCES

[1] J. S. Kenney and A. Leke, "Design Considerations for Multi-Carrier CDMA Base Station Power Amplifiers," *Microwave Journal*, Vol. 42, No. 2, pp. 76-83, 1999.

[2] P. B. Kenington, S. J. Gillard, and A. E. New, "An Ultra-Broadband Power Amplifier Using Dynamically Controlled Linearization," *IEEE MTT-S Int. Microwave Sympo. Dig.*, pp. 355-358, 1999.

[3] A. Katz, "SSPA Linearization," *Microwave Journal*, Vol. 42, No. 4, pp. 22-44, 1999

[4] J. Yi, Y. Yang, M. Park, W. Kang, and B. Kim, "Analog Predistortion Linearizer for High Power RF Amplifier," *IEEE MTT-S Int. Microwave Sympo. Dig.*, pp. 1511-1514, 2000.

[5] E. G. Jeckeln, F. Beauregard, M. A. Sawan, and F. M. Ghannouch, "Adaptive Baseband/RF Predistorter for Power Amplifiers Through Instantaneous AM-AM and AM-PM Characterization Using Digital Receivers," *IEEE MTT-S Int. Microwave Sympo. Dig.*, pp. 489-492, 2000.

[6] S. A. Maas, and A. Crosmun, "Modeling the Gate I/V Characteristics of a GaAs MESFET for Volterra-Series Analysis," *IEEE Trans. Microwave Theory Tech.*, Vol. 37, No. 7, pp. 1134-1136, 1989.

[7] J. C. Pedro and J. Perez, "Accurate Simulation of GaAs MESFET's Intermodulation Distortion Using a New Drain-Source Current Model," *IEEE Trans. Microwave Theory Tech.*, Vol. 42, No. 1, pp. 25-33, 1994.

[8] Y. Yang, Y. Y. Woo, and B. Kim, "New Predistortion Linearizer Using Low Frequency Even Order Intermodulation Components," submitted to *IEEE Trans. Microwave Theory Tech.*.

[9] Y. Yang, Y. Kim, J. Yi, J. Nam, B. Kim, W. Kang, and S. Kim, "Digital Controlled Adaptive Feedforward Amplifier for IMT-2000 Band," *IEEE MTT-S Int. Microwave Sympo. Dig.*, pp. 1487-1490, 2000.