A Mirror Predistortion Linear Power Amplifier

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***Abstract* — We propose a new type of predistortion linearization technique: "Mirror Predistortion". In a regular predistortion power amplifier (PA), the AM-AM and AM-PM distortion (Or IMD3, Third Order Inter-modulation Distortion, and IMD5) of the PA are not known before measurement. In the Mirror Predistortion technique, we choose a PA with identical design as, but smaller than the main PA, as a Mirror Predistorter (PD). Since this Mirror PD's nonlinear characteristics tracks the main PA, there is no need for nonlinear characterization for the PD or the PA. We have reduced this concept to practice and have built a mirror predistortion linear PA having 23 dB improvement in IMD3, at a 2-tone total output power of 34 dBm, with 7.5 dB back off from P1dB of 41.5dBm.**

***Index Terms* — Power Amplifier, Linearization, Predistortion, Intermodulation.**

I. INTRODUCTION

The current wireless communication standards require high data rate to carry voice, data and video. In order to carry high data rate in a given finite bandwidth, efficient modulation techniques such as OFDM 64QAM are employed. In this type of modulation, there are probabilities that at certain time, the voltages of the multi carriers are in phase and their amplitudes add up to create very high peak to average ratio (PAR) that may reach 15 dB. This high PAR will drive a conventional PA into saturation; causing signal distortion and generating out-band interference. One way to solve this problem is to use a high power PA in Class A mode and back off (BO) 10-12 dB. But this technique results in a very inefficient PA.

There are various linearization techniques that are used to increase the linearity of the PA allowing the use at lower BO values and consequently having higher efficiency. These techniques include Feedback, Feedforward, and Digital and Analog Predistortion [1]-[2]. Amongst all, the analog predistortion (Fig. 1) tends to provide a good compromise between complexity, bandwidth and linearity improvement.

Different ways are used to implement the analog predistorter circuit. One way is to use a simple diode circuit in front of the PA and to choose its size and bias to compensate for its AM-PM nonlinearity. Although this technique is simple and could be easily integrated with a PA in one package, the linearity improvement reported is very limited and does not track well with higher output power levels [3]-[4]. Another way is to use Cuber Predistortion [5]-[6] where higher improvement in IMD3 could be achieved, but with an increase in the fifth and higher order nonlinearities. In [7]-[9] the IMD3 and IMD5 are independently improved by using two Cuber Predistorter circuits but with an increased level of complexity. A simpler technique is suggested in [10] to improve both of IMD3 and IMD5 by using new Cuber PD design.

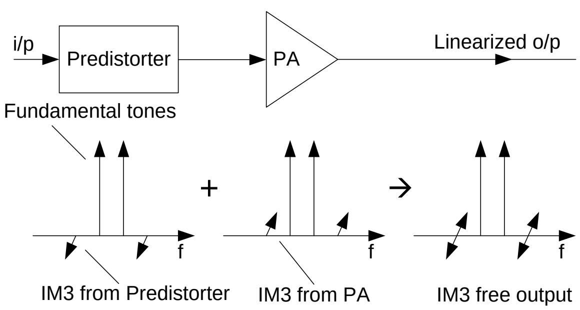

Fig. 1. Intermodulation cancellation concept by using a Predistorter.

All of the predistortion techniques require a full nonlinear characterization of the phase and magnitude of the IM3 and IM5 for both the predistorter circuit and the power amplifier. This characterization requires a special measurement techniques like those reported in [11]-[12].

The Feedforward linearization provides higher levels of IMD improvement up to the P1dB but requires the use of an additional Error Amplifier (EA) that is required to be very linear and consequently consumes a lot of power, resulting in reduction in the overall efficiency of the PA. We propose here a pseudo predistortion linearization technique that mitigate the deficiencies of both Predistortion and Feedforward techniques.

We suggest using a low power PA in front of the main high power PA. This low power PA has the identical construction as the main PA. Therefore, it has

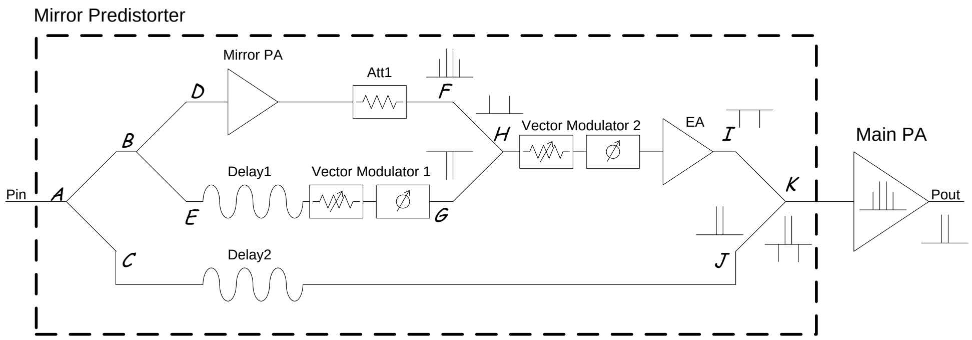

Fig. 2. Mirror Predistortion Linearization.

the same distortion characteristics, but at a lower power level. Because this low power PA's third and higher order nonlinearities mirror those of the main PA in magnitude and phase, we call this low power PA a "Mirror Predistorter". The nonlinearities generated by the mirror PD are properly fed to the input of the PA, so that it appears at its output in the same magnitude but out of phase with the internally generated PA nonlinearities, resulting in IM cancellation as shown in Fig. 1

II. Implementation

In order to prove the concept of the proposed mirror PD, we have designed a mirror predistortion PA as described in this Section. Fig. 2 shows the block diagram of the proposed Mirror PD linearization technique. It is required to feed the intermodulation terms coming from the mirror PD to the input signal of the PA so that they cancel the intermodulation generated at the output. So the magnitudes of paths *ABDFHIK* and *ACJK* have to be equal whereas the phases have to be 180° shifted. Both the magnitude and the phase are controlled by *Vector Modulator 2*, whereas *Delay 2* is used to equalize the delays of the two paths.

Also it is required to cancel the carrier coming out from the mirror PA. This is done by adding path *EG* to path *DF* with the same delay and magnitude but 180° phase shifted. Again this is controlled by using *Vector Modulator 1* and *Delay 1* to get broadband cancellation. Any carrier leakage at point *H* will result in reduced gain since paths *ABDFHIK* and *ACJK* are 180° out of phase, and also will result in non optimum predistorter tracking to the AM-AM and AM-PM of the PA.

The main advantage of the Mirror PD over Feedforward linearization is that the size of the Error Amplifier (EA) could be much smaller in terms of size and power consumption because the EA is in the input (low power) side. This is accomplished by feeding the intermodulation terms at the input of the PA rather than its output. So the power requirement of the EA is lower by an amount that is equal to the gain of the main PA. Moreover by changing the coupling ratio of coupler *IKJ* we can farther decrease the requirement on the output power of the EA. However by doing so, the total loss of the PD will increase. For instance if we are using a 10 dB coupler instead of a 3 dB coupler, we will get 7 dB higher in the total loss of the predistorter.

Fortunately the total gain of the PA with the predistorter could be boosted by using a low power driver amplifier before the predistorter.

The mirror PA is an AMCOM MMIC PA, AM204437WM-BM. It has 30dB gain with 36dBm output power from 2.0 to 4.4GHz. The main PA is the power combining of four of the same MMICs as shown in Fig. 3. Therefore, the DC power consumption of the mirror PA is only ¼ of the main PA. The overall efficiency can be improved if the main PA is power combining of eight MMICs. The input power of the MMIC used in the mirror PA has to be equal to the input power of each of the same MMICs used in the main PA ($P_{A0} = P_{A1-4}$), otherwise the nonlinear performance will be different. This could be adjusted by an additional fixed attenuator in front of the mirror PA according to the coupling factors of the different couplers used in the design.

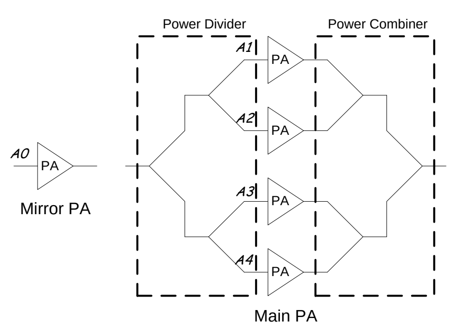

Fig. 3. Realizing a Mirror PA that has the same nonlinear characteristics as the main PA.

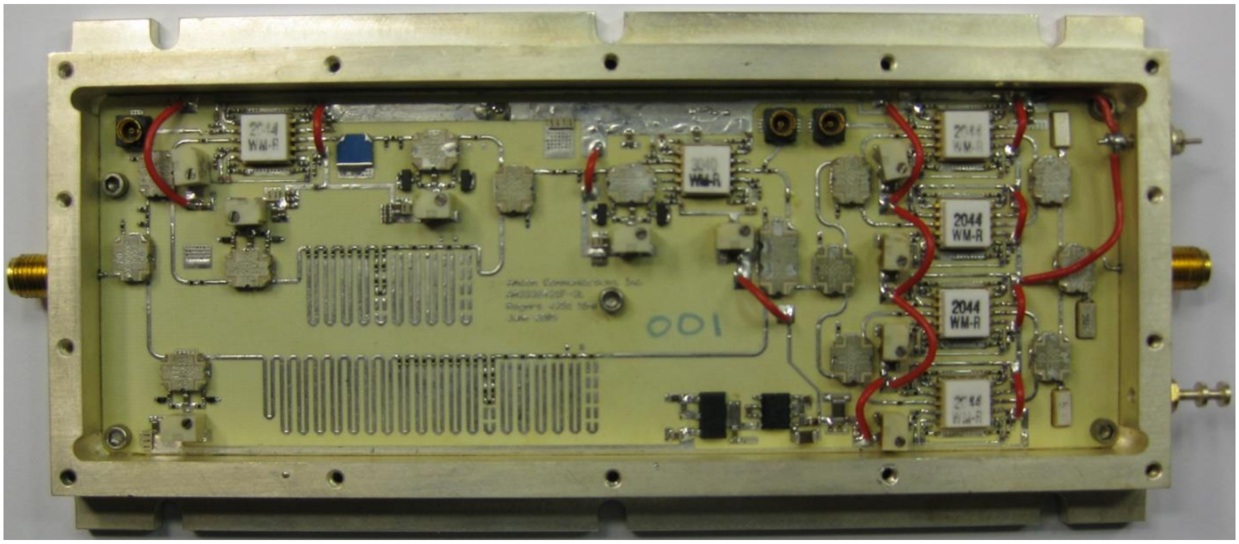

Fig. 4. Picture of the implemented Hybrid Module.

The mirror predistortion PA was integrated in a hybrid module that is 6.1” x 2.9” as shown in Fig. 4. A low-power AMCOM MMIC AM304031WM-BM was used as the EA and consumes only 22% of the mirror PA DC power, i.e. only 5.5% of the main PA power. Surface mount 3 dB hybrid couplers with a frequency band of 3.3 to 3.7 GHz were used everywhere in the design except for coupler *IKJ* where a 10dB coupler was used to lower the output power from the EA at the expense of higher PD loss. The vector modulators consist of analog voltage attenuators and analog phase shifters. Both of them were designed using 3dB hybrid coupler and 2 pin diodes for the variable attenuator, 2 varactors for the variable phase shifter by using the reflective topology as in [7].

III. Experimental Results

Fig. 5 and Fig. 6 show the IMD3 and IMD5 versus two-tone total output power for this mirror predistortion PA with and without linearization. The linearization is being activated and deactivated by turning on and off the EA. The frequency separation of the two tones is 10 MHz. We are able to optimize the performance at different back off levels, by controlling the vector modulators. For the shown results, the performance is optimized at 34dBm which is 7.5dB back off from the output 1dB compression power of 41.5dBm. At a two-tone total output power of 34dBm, the IMD3 is 46dBc where the IMD5 is 72dBc when the linearization is deactivated. The IMD3 is 69dBc and the IMD5 is 75dBc when the linearization is activated. This represents IMD3 and IMD5 improvements of 23dB and 3dB, respectively.

Since the main purpose of linearization is to operate the PA at lower BO values with the same linearity, we plot the efficiency and output power of the PA versus the IMD3 level with and without linearization as shown in Fig. 7. We notice that for higher levels of linearity requirements, i.e. |IMD3| > 60 dBc the increase in Efficiency is more than four times. This means that we can get output power that is four times higher for the same DC input power. At |IMD3| value of 40 dBc the Efficiency values with and without linearization are equal. This is because the amount of improvement in linearization at that level is not high enough to justify for the use of extra PAs for the mirror and the EA.

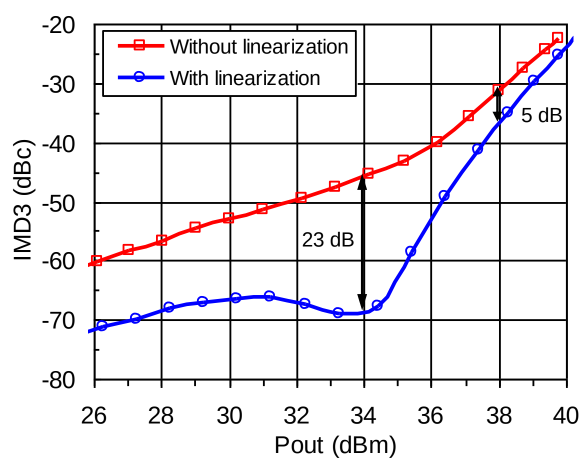

Fig. 5. IMD3 vs. output power with and without linearization.

The reason that the linearity improvement degrades with higher power levels could be explained as follows: Although the mirror and the main PA are tracking each other, *Vector Modulator 1* is not tracking the mirror PA when it start compressing, so the carrier cancellation at *H* becomes non perfect. This resulting carrier leaks and arrives at the input of the PA out of phase with the main input carrier causing non optimum PD performance and consequently lower linearity improvement.

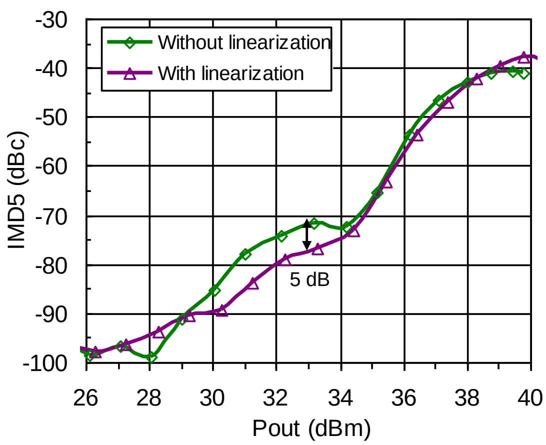

Fig. 6. IMD5 vs. output power with and without linearization.

The measurements were repeated with different frequency separations: 1MHz, 10 MHz (as shown in Fig. 5,6,7), and 20 MHz where the same performance was achieved, indicating broadband capability. This is because by equalizing *Delay 1* and *Delay 2*, high bandwidth could be achieved depending on the gain and phase flatness of the different components and on the bandwidth of the couplers. A bandwidth of 20 MHz is enough for a WiMax channel.

IV. Conclusion

We have proposed a "New" Predistortion Linearization concept that mitigates the deficiencies of regular Predistortion and Feedforward linearization techniques. We call this "Mirror Predistortion Linearization". We have reduced this concept into practice. We have developed a Mirror Predistortion PA and have achieved an IMD3 of 69dBc, a 23dB IMD3 improvement at back off value of 7.5 dB.

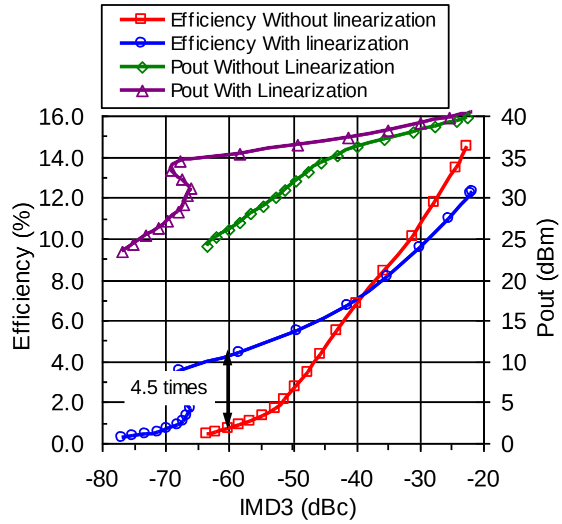

Fig. 7. Efficiency & Pout vs. IMD3 with and without linearization.

References

[1] S. C. Cripps, *RF power amplifiers for wireless communications*. Boston: Artech House, 1999.

[2] S. C. Cripps, *Advanced techniques in RF power amplifier design*. Boston: Artech House, 2002.

[3] K. Yamauchi, K. Mori, M. Nakayama, Y. Itoh, Y. Mitsui, and O. Ishida, "A novel series diode linearizer for mobile radio power amplifiers," *IEEE MTT-S Int. Microwave Symp. Dig.*, Vol. 3, pp. 831-834, June 1996.

[4] C. Haskins, T. Winslow, and S. Raman, "FET Diode Linearizer Optimization for Amplifier Predistortion in Digital Radios," *IEEE Microwave Guided Wave Letters*, Vol. 10, pp. 21-23, January 2000.

[5] T. Nojima and T. Konno, "Cuber Predistortion Linearizer for Relay Equipment in 800 MHz Band Land Mobile Telephone System," *IEEE Transactions on Vehicular Technology*, VT-34, n 4, pp. 169-177, November 1985.

[6] K. Morris and P. Kenington, "Power amplifier linearisation using predistortion techniques," *IEE Colloquium on RF and Microwave Components for Communication Systems*, Bradford UK, 1997.

[7] J. Yi, Y. Yang, M. Park, W. Kang, and B. Kim, "Analog predistortion linearizer for high-power RF amplifiers," *IEEE Trans. Microwave Theory & Tech.*, Vol. 48, no. 12, pp. 2709-2713, 2000.

[8] S. Y. Lee, Y. S. Lee, S. H. Hong, H. S. Choi, and Y. H. Jeong "Independently controllable 3rd- and 5th-order analog predistortion linearizer for RF power amplifier in GSM," *Proceedings of 2004*

IEEE Asia-Pacific Conference on Advanced System Integrated Circuits, pp. 146-149, 2004 .

[9] Y. S. Lee, K. I. Jeon, and Y. H. Jeong "Linearity Improvement of RF Power Amplifiers Using a Simple High-Order Predistorter for WCDMA Applications". *Proceeding of 2006 Asia-Pacific Microwave Conference*, vol. 2, pp. 887-890, 2006

[10] Y. S. Lee, S. Y. Lee, K. I. Jeon, and Y. H. Jeong "Highly linear predistortion power amplifiers with phase-controlled error generator," *IEEE Microwave & Wireless Components Letters*, vol. 16, no. 12, pp. 690-692, December 2006.

[11] S. Y. Lee, Y. S. Lee, and Y. H. Jeong, "A novel phase measurement Technique for IM3 Components in RF Power Amplifiers," *IEEE Trans. Microwave Theory & Tech*, vol. 54, no. 1, pp. 451–457, January 2006.

[12] J. Dunsmore, and D. Goldberg, "Novel Two-Tone Intermodulation Phase Measurement for Evaluating Amplifier Memory Effects," 33rd *European Microwave Conference*, pp. 235-238, October 2003.