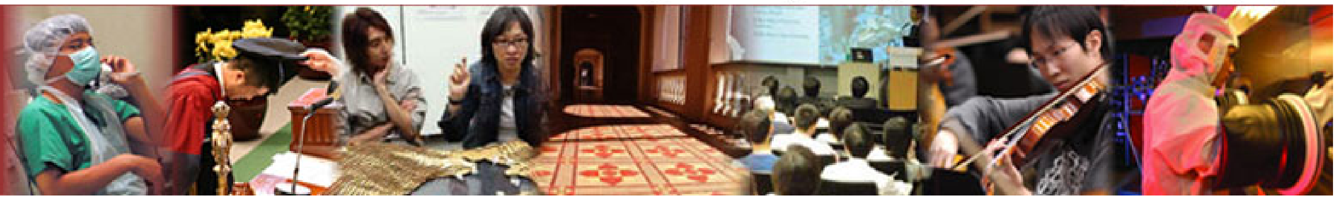

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Design of 5th-Order Analog Predistorter

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Abstract— **This paper presents the design of a 5th-order analog predistorter to suppress the 3rd-and 5th-order intermodulation distortion products (IMDP3 and IMDP5) at the output of a base-station power amplifiers (PAs). The predistorter consists of two mixers: one mixer generating the 3rd-order intermodulation (IM3) products and another mixer of same configuration generating the 5th-order intermodulation (IM5) products using the IM3 products generated by the other mixer, thus simplifying the design and hardware implementation. The predistorter is implemented and tested using two-tone and the CDMA (IS-95) signals at 2.2GHz in a practical 10W-PA. The two-tone test results show that the proposed predistorter can suppress the IMDP3 and IMDP5 by 17dB and 11dB, respectively. For the CDMA (IS-95) test, results show that the predistorter can improve the adjacent channel power ratio (ACPR) by 10 dB at ± 887 kHz from the center frequency.**

I. INTRODUCTION

In the modern wireless communications systems such as the GSM, IS-95 (CDMA), CDMA2000, WCDMA and TD-SCDMA systems, there are great demands on the linearity of the power amplifiers used in the base stations. As a result, diverse techniques have been studied and proposed in recent years to improve the linearity of PAs [1-8]. Among these techniques, predistortion is extensively used in repeaters and base stations. When compared with its counterpart of digital predistortion (DPD), analog predistortion (APD) has a moderate linearity improvement with much simpler circuits and lower cost.

The dominant distortion components at the output of a PA are the 3rd-intermodulation distortion products (IMDP3). However, when the PA is operating in the highly nonlinear region of the characteristic in order to have a higher output power, the 5th–order intermodulation distortion products (IMDP5) become significant. Thus both the IMDP5 and IMDP3 are needed to be suppressed through predistortion to achieve a good linearity of the PA.

APD can be implemented by feeding either the inband intermodulation (IM) signals [4], the difference-frequency signals (known as the difference-frequency technique) [5] or the harmonic-frequency signals (known as the harmonic-injection technique) [6] of the fundamental signal to the input of the nonlinear PA. However, the difference-frequency signals have a relatively low frequency and the harmonic-frequency signals have a relatively high, so the use of these two techniques is limited to the PAs with very wide bandwidths. In this paper, we propose to use the inband IM signals for predistortion of PAs. The predistorter employs two IM generators to generate the 3rd- and 5th-order intermodulation (IM3 and IM5) signals to cancel the IMDP3 and IMDP5 at the PA output. These two IM signal generators have identical configuration which simplifies the design and implementation. The proposed predistorter has been implemented and tested using the two-tone signal and CDMA (IS-95) signals in a practical base-station 10W-PA. Results show that the predistorter can linearize the PA effectively

II. THEORY ANALYSIS

A. Model of Power Amplifier (PA) and Predistortion

The nonlinear characteristic of a PA can be represented using the standard power series [7]:

$$v_o = a_1 v_i + a_2 v_i^2 + a_3 v_i^3 + a_4 v_i^4 + a_5 v_i^5 + ... + a_n v_i^n \qquad (1)$$

where v_o is output signal, v_i is input signal and a_1, ..., a_n are the coefficients used to fit the characteristic.

In general, the input signal is composed of different frequency components, so at the output of the PA, there are the fundamental signal, the high order harmonics and the intermodulation distortion products (IMDPs). The harmonics of the fundamental signal components are not our concern because they are outside the operating frequency band of the PA and can be easily removed by filtering. Among the IMDPs, the IMDP3 and IMDP5 are close to the frequency of the fundamental signal and are difficult to remove. These IMDPs have relatively high amplitudes and so are interference and cause signal distortion.

A 3rd-order analog predistorter using the inband IM signals was discussed and studied in [8], where the IM3 signal was generated using an IM3 signal generator and then fed together with the fundamental signal to the PA to cancel the IMD3 at the output. Here in our proposed predistorter, the IM3 and IM5 signals are generated and used to cancel the IMDP3 and IMDP5 at the output of the HPA. The basic idea of this approach can be found in [8].

B. Predistorter

The block diagram of our proposed IM signal generator is shown in Fig. 1. It consists of a 3-dB 90 degree-hybrid coupler, a pair of anti-parallel Schottkey diodes, a *λ/4*-length transmission line, a variable capacitor and a variable resistor. In Fig. 1, RF_{in} and RF_{out} are the input port and output port, respectively. The anti-parallel Schottkey diodes work like a mixer. Its current flow can be represented as:

$$I(t) = I_s\{\exp[kV(t)]-1\} - I_s\{\exp[-kV(t)]-1\}$$
$$= I_s\left\{2kV(t) + \frac{[kV(t)]^3}{6} + ... + \frac{[kV(t)]^{2n+1}}{(2n+1)!} + ...\right\} \quad (2)$$

where $V(t)$ is the signal applied to the diodes at node 5, k is a constant and I_s is the saturation current.

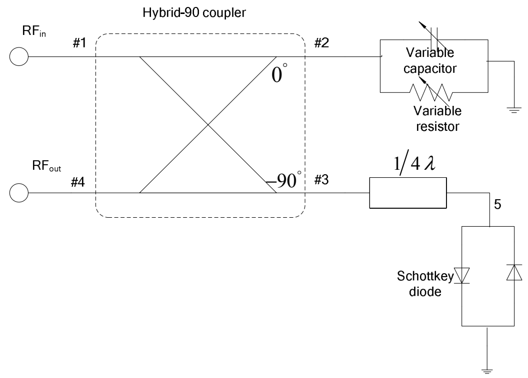


Figure 1. Block diagram of IM signal generator

In Fig. 1, if the input signal is a fundamental signal:

$$V_1(t) = a\cos\omega_1 t + a\cos\omega_2 t \quad (3)$$

and $V_1(t)$ has a relatively low power level, then the generator is an IM3 signal generator. This is because the 1st-order and 3rd-order terms in (2) are dominant and other higher order terms will have much lower levels. The mixer produces mainly the IM3 signal and the fundamental signal at the output. By appropriately adjusting the variable capacitor and the variable resistor in Fig. 1, the fundamental signal at the output port can be cancelled off by the signals reflected from port #2, thus leaving only a strong IM3 signal at the output.

This IM3 signal can be combined with the fundamental signal in (3) to form the signal:

$$V_2(t) = a\cos(\omega_1 t) + a\cos(\omega_2 t) + b\cos[(2\omega_1-\omega_2)t] + b\cos[(2\omega_2-\omega_1)t] \quad (4)$$

which is then used as the input to a IM signal generator having the same configuration of Fig. 1. Thus, the signal applied to the Schottky diodes, which has a half power of (4), can be represented as:

$$V_3(t) = c\left\{\begin{array}{l} a\left(\cos\omega_1 t + \cos\omega_2 t\right) \\ +b\left[\cos(2\omega_1-\omega_2)t + \cos(2\omega_2-\omega_1)t\right]\end{array}\right\} \quad (5)$$

The generator output can be obtained by substituting (5) into (2) and expanding the 3rd-order term and is consisting of the fundamental signal, IM3, IM5, IM7 and IM9 signals given by, respectively, :

$$\frac{I_s\cdot k^3}{6}\left(\frac{9}{4}a^3c^3 + \frac{9}{4}a^2bc^3 + \frac{9}{2}ab^2c^3 + \frac{12}{k^2}ac\right)\left(\cos\omega_1 t + \cos\omega_2 t\right) \quad (6)$$

$$\frac{I_s\cdot k^3}{6}\left(\begin{array}{l}\frac{9}{4}b^3c^3 + \frac{3}{4}a^3c^3 \\ +\frac{9}{2}a^2bc^3 + \frac{12}{k^2}bc\end{array}\right)\left[\cos\left(2\omega_1-\omega_2\right)t + \cos\left(2\omega_2-\omega_1\right)t\right] \quad (7)$$

$$\frac{I_s\cdot k^3\cdot c^3}{6}\left[\frac{9}{4}(a^2b+ab^2)\right]\left\{\cos[(3\omega_1-2\omega_2)t] + \cos[(3\omega_2-2\omega_1)t]\right\} \quad (8)$$

$$\frac{I_s\cdot k^3\cdot c^3}{6}\left(\frac{9}{4}ab^2\right)\left\{\cos[(4\omega_1-3\omega_2)t] + \cos[(4\omega_2-3\omega_1)t]\right\} \quad (9)$$

$$\frac{I_s\cdot k^3\cdot c^3}{6}\left(\frac{3}{4}b^3\right)\left\{\cos[(5\omega_1-4\omega_2)t] + \cos[(5\omega_2-4\omega_1)t]\right\} \quad (10)$$

It can be seen in (8)-(10) that, if a is much larger than b, say 5 dB, the IM5 signal will have a much higher power level than those of IM7 in (9) and IM9 signals in (10) which therefore can be neglected. Then, same as in the IM3 signal generator, by appropriately adjusting the variable capacitor and the variable resistor in Fig. 1, we can cancel off the fundamental signal of (6) or the IM3 signal of (7) at the output port using the signals reflected back from port #2. However, we cannot cancel off both signals of (6) and (7) simultaneously. This is because we cannot adjust the fundamental and IM3 signals separately in port #2. For example, if we adjust the fundamental signal in port #2 to cancel the fundamental signal of (6) reflected from port #3 at port #4, then the same adjustment for the IM3 signals in port #2 will not cancel off the IM3 signal of (6) reflected from port #2 to port #4, and vice versa. Thus, only one of the signals can be cancelled off in an adjustment. In our design, we make the adjustment to cancel the IM3 signals, so there will be a strong IM5 signal of (8) and fundamental signal at the generator output. However, it will be seen later these two signals from the IM5 generator will be combined with a very strong fundamental signal (and an IM3 signal) and fed to the PA for predistortion, so there is no need to suppress fundamental signal from the generator output. Thus the generator in Fig. 1 can be used as an IM5 signal generator for our predistorter.

Fig. 2 shows the block diagram of the predistorter which consists of the IM3 and IM5 signal generators.

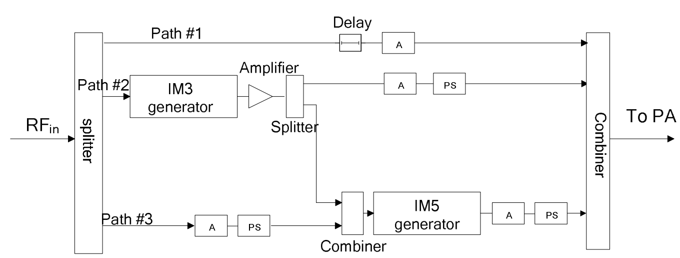


Figure 2. Block diagram of 5th-order predistorter

At the input of the predistorter, the signal is divided into three paths—path #1, path #2 and path #3. The time delay in path #1 which is the main path is used to compensate for the overall time delay in the other two paths. The attenuator in the main path is used to control the input power to the PA. Path #2 directs the signal to the input of the IM3 signal generator which generates the IM3 signal and feed it to an amplifier to obtain a proper power level to the splitter. In path #3, the signal is adjusted by a set of attenuator and phase shifter, combined with the IM3 signal from the IM3 signal generator and then fed to the IM5 signal generator. The amplitudes and phases of the IM3 and IM5 signals are adjusted by using the associated attenuators and phase shifters for cancellation of the IMDP3 and IMDP5 at the PA output.

III. RESULTS

The predistorter has been designed, optimised using the simulation tool ADS2009 and fabricated on a PCB for testing in a practical base-station PA used in the cellular mobile system.

The IM signal generator in the predistorter was first tested using a two-tone signal with 2 MHz spacing. Fig. 3 and Fig. 4 show the output spectra from the IM3 and IM5 signal generators, respectively. The results in Fig. 3 show that the IM3 signal is more than 20 dB higher than the fundamental signal (i.e., the two-tone signal) and the other high-order signals. In Fig. 4, the results show that the IM5 signal is more than 10 dB higher than the other high-order signals. However, the fundamental signal is not suppressed significantly, for the reason described previously. However, Fig. 4 shows that this fundamental signal can be neglected when compared with the fundamental signal having a strong power level in the main path.

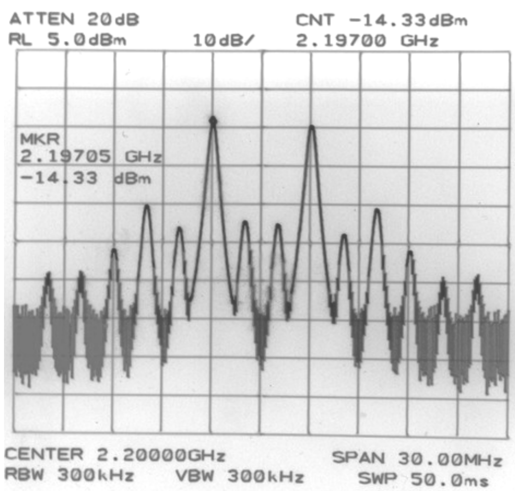


Figure 3. Output spectrum from IM3 signal generator

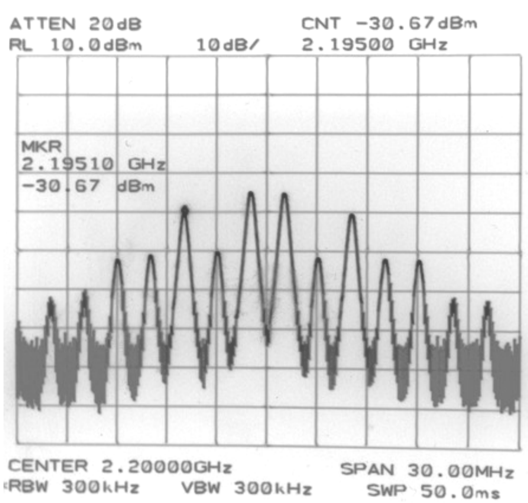
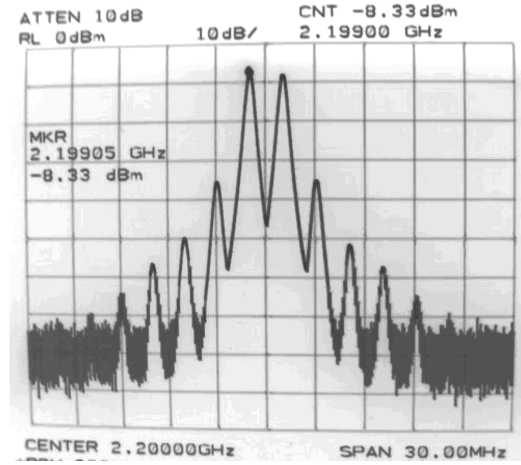
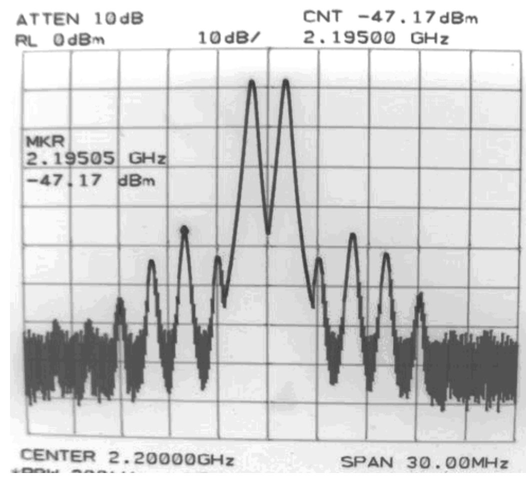


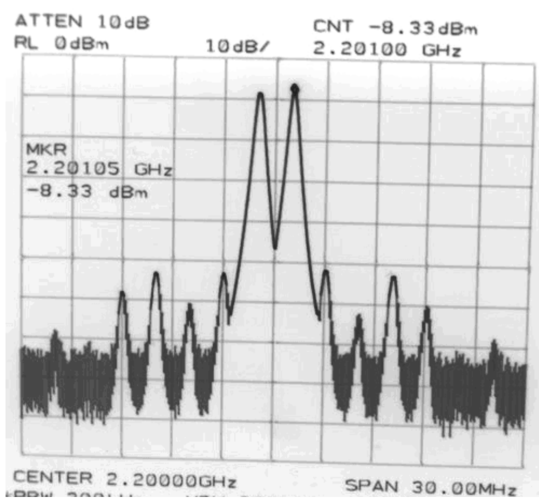
Figure 4. Output spectrum from IM5 signal generator



(a)



(b)



(c)

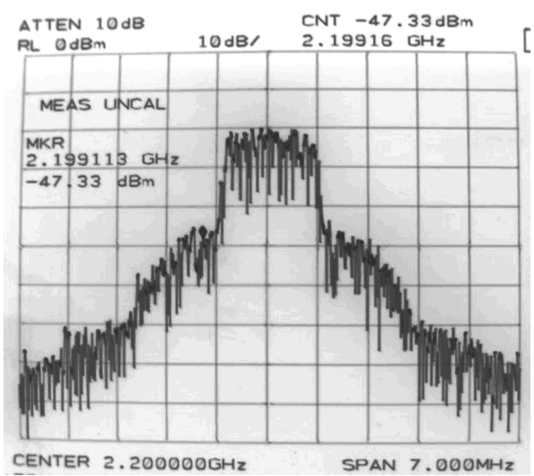
Figure 5. Two-tone test: Spectrum from PA (a) without predistortion, (b) with 3rd-order predistortion and (c) with 5th-order predistortion.

The predistorter has been tested in a 10W-PA manufactured by Bravotech inc. China, using a two-tone single and a CDMA (IS-95) signal. In these tests, the output signals were obtained via a 40-dB coupler in the PA module. The signal spectra from the PA in the two tone tests without predistortion, with 3rd-order predistortion and with 5th-order predistortion are shown in Fig. 5. It can be seen that, without predistortion, the power levels of the IMDP3 and IMDP5 at the PA output are -35 dBm and -50 dBm, respectively. With 3rd-order predistortion, the IMDP3 and IMDP5 have the power levels of -52.17 dBm and -47 dBm. Thus the predistorter has reduced the IMDP3 by about 17 dB, but enhanced the IMDP5 by nearly 3 dB, which is due to the mixing process the IM3 signal with the fundamental signal. With 5th-order predistortion, Fig. 5(c) shows that the IMDP3 and the IMDP5 are suppressed to -52.17 dBm and -61dBm. Thus, the proposed 5th-order predistorter has suppressed the IMDP3 and IMDP5 components by 17 and 11dB, respectively, relatively those without using predistortion.

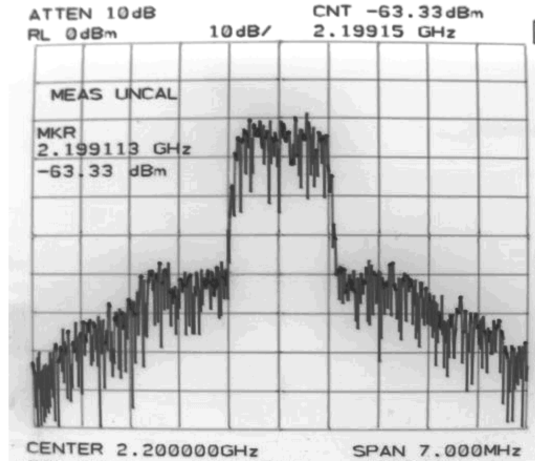
Fig. 6 shows the results for a CDMA (IS-95) signal centered at 2.2 GHz. It can be seen that a substantial improvement can be obtained by using the 5th-order predistorter. Without predistortion, the adjacent channel power ratio (ACPR) at ± 887 kHz from the center frequency of 2.2 GHz is about 25 dB below that at the center frequency. With the proposed predistorter, the ACPR is reduced by 10 dB.

IV. CONCLUSIONS

A 5th-order analog predistorter has been proposed and designed using an IM3 and IM5 signal generators. The predistorter has been implemented and tested in a practical 10W-PA. Results of the two-tone tests have shown that the predistorter can suppressed the IMDP3 and IMDP5 are suppressed by 17dB and 11dB, respectively. While in the CDMA (IS-95) signal tests, it has been shown that the predistorter can improve the ACPR by 10 dB at the ± 887 kHz of the center frequency of 2.2 GHz.



(a)



(b)

Figure 6. CDMA (IS-95) signal spectrum from PA: (a) Without predistortion and (b) With 5th-order predistortion

REFERENCES

[1] Sung Won Chung, Jack W. Holloway, and Joel L. Dawson, "Energy-Efficient Digital Predistortion With Lookup Table Training Using Analog Cartesian Feedback," IEEE Trans. MTT., vol. 56, no. 10, pp. 2248-2258, 2008.

[2] S. Bounmaiza, and F. M. G.ahnnouchi, "Realistic Power Amplifiers Characterization with Application to Baseband Digital Predistortion for 3G Base Stations," IEEE Trans. Microw. Theory Tech. vol. 50, no. 12, pp. 3016-3021, Dec. 2002.

[3] Gokceoglu, A. H., Ghadam, A. S. H. and Valkama, M., "Effects of power amplifier memory on adaptive feedforward linearizers," ISWCS 2008, pp. 304-308.

[4] Yong-Sub Lee, Mun-Woo Lee, Sang-Ho Kam, and Yoon-Ha Jeong, "A Transistor Based Analog Predistorter with Unequal Delays for Memory Compensation," IEEE Microwave and Wireless Components Letters, vol. 19, pp. 743-745, Nov. 2009.

[5] Modeste, M., Budimir, D., Moazzam, M.R. and Aitchison, C.S., "Analysis and practical performance of a difference frequency technique for improving the multicarrier IMD performance of RF amplifiers," Technolofies for Wireless Applications, 1999. Digest. 1999 IEEE MTT-S Symposium, pp. 53-56.

[6] Matsubara, H., Ishihara, K., Miyadai, N. and Nojima, T., "Anovel 3rd- and 5th-order predistortion circuit for 2 GHz band WCDMA amplifier," APMC 2007, pp. 1-4.

[7] S. C. Cripps, "RF Power Amplifiers for Wireless Communications," Norwood, MA: Artech House, 2006.

[8] M. X. Xiao, S. W. Cheung, and T. I. YUK, "An RF Predistorter for Base Station HPAs of NADC System," PIMRC 2009, Japan, pp. 1587-1591.