Multi-Order Predistortion of Power Amplifiers Using a Second Harmonic Based Technique

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***Abstract*—A novel multi-order predistortion linearizer is proposed to achieve independent control of the third- and fifth-order intermodulation products in high power amplifier. The approach is based on a combination of the second harmonic technique and the difference frequency technique. The second harmonic and difference frequency terms are generated using an envelope detector and two frequency multipliers. The RF predistorter has the advantage of low insertion loss and the requirement of a short delay line. Experimental results demonstrate an adjacent channel power ratio (ACPR) reduction of 11 dB for W-CDMA, at 2140 MHz.**

***Index Terms*—Multiplier, power amplifiers, predistortion.**

I. Introduction

HIGH-POWER amplifiers (HPA) have been widely used in conjunction with RF predistortion techniques, in base station and repeater applications for mobile communication systems. The RF predistorter technique [1]–[4] has two distinct advantages over other approaches: 1) the correction is applied before the power amplifier where insertion loss is not as critical and 2) the correction architecture is less bandwidth limited. RF predistortion using either a harmonic frequency technique [5] or a difference frequency technique have been presented [6]. Predistortion using a harmonic frequency technique has the advantage of not attenuating the power amplifier's output power. The disadvantages are the high predistorter insertion loss, long delay line and requirements of a lowpass filter (LPF) and bandpass filter (BPF). It also must be driven sufficiently hard to yield a reasonable level of second harmonics, in order to improve high levels of intermodulation distortion in the power amplifier. Predistortion using a difference frequency technique has the advantage of flexible control of the intermodulation products and ease of implementation. The disadvantage is the instability due to the feedback technique. In this paper, we propose a multi-order predistortion technique which uses a novel combination of the second harmonic technique and the difference frequency technique to achieve independent control of the third- and fifth-order intermodulation products generated by the power amplifier.

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II. Multi-Order Predistortion Alanlysis

Fig. 1 shows the block diagram of the approach used in this paper. The predistorter consists of three main sections: linear path, nonlinear path I and nonlinear path II. When two signals at frequencies ω_1 and ω_2, with respective amplitudes A_1 and A_2, is applied at the input of the RF predistorter, the output signal $\mathrm{x(t)}$ of the hybrid coupler can be written as shown in (1)

$$x(t) = A_1 \cos(\omega_1 t + \phi_1) + A_2 \cos(\omega_2 t + \phi_2). \qquad (1)$$

The output signal $b(t)$ of the frequency multiplier in the nonlinear path I can be expressed by

$$b(t) = A_{11} \cos(2\omega_1 t + 2\phi_1) + A_{22} \cos(2\omega_2 t + 2\phi_2) + A_{33} \cos(\omega_1 t + \omega_2 t + \phi_1 + \phi_2) \qquad (2)$$

where $A_{11} = (1/2)A_1^2$, $A_{22} = (1/2)A_2^2$, $\mathrm{A}_{33} = \mathrm{A}_1\mathrm{A}_2$.

The combined signals at the diplexer output, of the fundamental frequency in the linear path and second harmonics in the nonlinear path I, can be obtained as

$$c(t) = A_1 \cos \omega_1 t + A_2 \cos \omega_2 t + b(t). \qquad (3)$$

In the nonlinear path II, the output signal $d(t)$ of the frequency multiplier can be written as

$$\mathrm{d(t)} = \mathrm{A}_{33} + \mathrm{A}_{33} \cos(2\omega_2 t - 2\omega_1 t + \phi_3) \qquad (4)$$

where $\mathrm{A}_{33} = (1/2)\mathrm{A}_1^2\mathrm{A}_2^2$.

The input signal of the main amplifier $p(t)$ becomes $c(t) + d(t)$. Finally, the output signal of the main amplifier $y(t)$ is written as

$$y(t) = y_1 p(t) + y_2 p(t)^2 + y_3 p(t)^3. \qquad (5)$$

Substituting into (5), the third-order IMD products can be written as shown in (6) and (7)

$$h_2 A_1 A_{22} \cos(2\omega_2 t - \omega_1 t + 2\phi_2) + \frac{3}{4} h_3 A_1 A_2^2 \cos(2\omega_2 t - \omega_1 t) + \frac{3}{2} A_2 A_{22} A_{33} h_3 \cos(2\omega_2 t - \omega_1 t + \phi_2 - \phi_1) \qquad (6)$$

$$h_2 A_2 A_{11} \cos(2\omega_2 t - \omega_1 t + 2\phi_1) + \frac{3}{4} h_3 A_2 A_1^2 \cos(2\omega_1 t - \omega_2 t) + \frac{3}{2} A_1 A_{11} A_{33} h_3 \cos(2\omega_1 t - \omega_2 t + \phi_1 - \phi_2) \qquad (7)$$

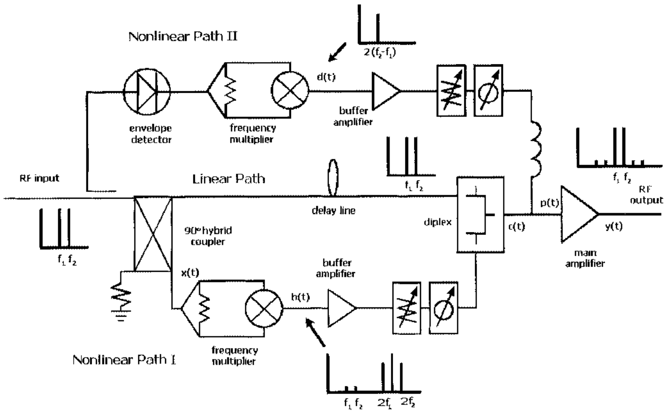

Fig. 1. Block diagram of multi-order predistortion technique using second harmonic and difference frequency terms.

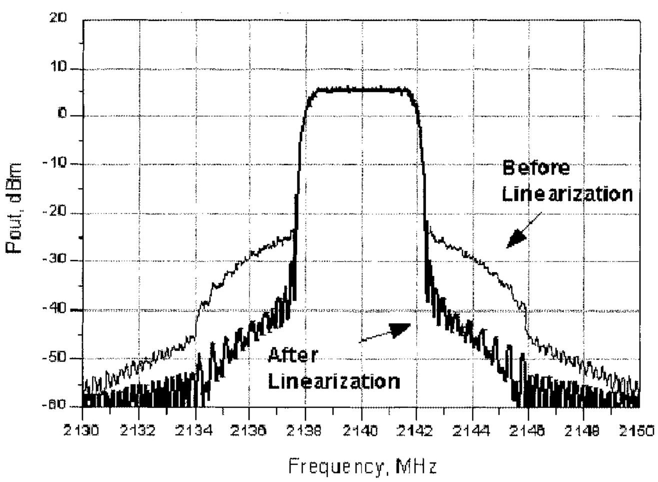

Fig. 2. Simulated ACPR characteristics before and after linearization.

and the fifth-order IMD products are

$$\frac{1}{2}h_2A_1A_{33}\cos(2\omega_2 t - 3\omega_1 t + \phi_3) + \frac{5}{8}h_5A_1^3A_2^2\cos(2\omega_2 t - 3\omega_1 t) \quad (8)$$

$$\frac{1}{2}h_2A_2A_{33}\cos(2\omega_1 t - 3\omega_2 t + \phi_3) + \frac{5}{8}h_5A_2^3A_1^2\cos(2\omega_1 t - 3\omega_2 t). \quad (9)$$

The third terms in (6) and (7) are small in comparison to the others and then can be ignored. When $|\phi_1| = |\phi_2| = 90$, the 3rd order IMD products can be ideally cancelled. The 5th order IMD products cancellation can also be achieved by the condition of $|\phi_3| = 180$. To verify the operational principle of the RF predistorter, simulation of the circuit shown in Fig. 1 was performed using Agilent ADS. From the simulation results, the ACPR reduction of 13 dB was obtained at the offset frequency 5 MHz for a single 30 dBm W-CDMA carrier of 2140 MHz (Fig. 2).

III. Experimental Results

An experimental hybrid MIC (microwave integrated circuit) test circuit was fabricated on a Teflon substrate with 2.52 dielec-

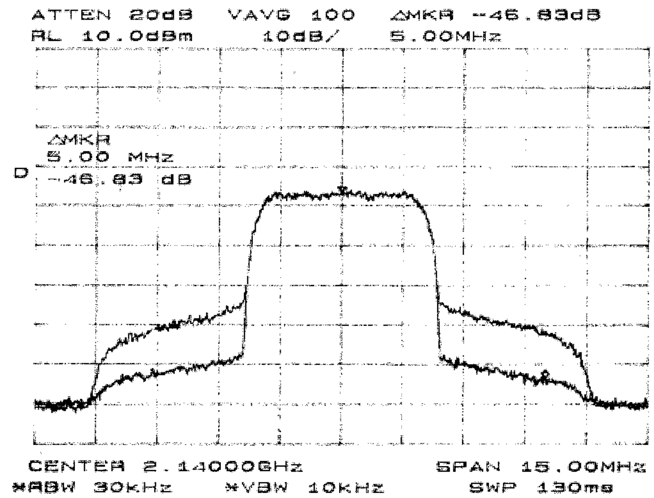

Fig. 3. Linearization result for 30 dBm W-CDMA carrier.

TABLE I
Comparison of Simulated and Measured Results

Parameter	Simulated (2137.5 – 2142.5 MHz)		Measured (2137.5 – 2142.5 MHz)	
Before Linearization	3rd IMD	-31.05 dBc	3rd IMD	-32.05 dBc
	5th IMD	-51.31 dBc	5th IMD	-51.34 dBc
After Linearization	3rd IMD	-51.65 dBc	3rd IMD	-50.34 dBc
	5th IMD	-62.60 dBc	5th IMD	-61.50 dBc
Total IMD Reduction	20 dB		18 dB	
ACPR Reduction (*fos =5 MHz)	13 dB		11 dB	

* fos is the offset frequency

tric constant and 0.54 mm thickness. A Motorola MHL21336 transistor used for the main amplifier is operated at an average power of 1 W with a 3 W peak power capability. From the measurement results, over the frequency band 2137.5 MHz to 2142.5 MHz, a total IMD reduction of 18 dB was obtained. Also, the ACPR reduction of 11 dB was achieved at the offset frequency 5 MHz for a single 30 dBm W-CDMA carrier, as shown in Fig. 3. Table I shows the comparison of simulated and measured results. It is clear that the 3rd and 5th order intermodulation products are suppressed simultaneously. The measured results are in good agreement with the simulated results.

IV. Conclusions

A multi-order predistortion technique is investigated by using a novel combination of the second harmonic technique and the difference frequency technique. Using the 90° hybrid coupler, we achieved minimization of the phase shifter sensitivity in the nonlinear path. The diplexer reduced the insertion loss and maximized the isolation effect between the linear and nonlinear path. The simulated and measured results show that this predistorter is suitable for independently improving both the third- and fifth-order IMD products of a power amplifier.

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