Linearized Mixer Using Predistortion Technique

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***Abstract*—A predistortion technique has been proposed to reduce intermodulation distortion (IMD) generated from the conversion process of a mixer. In this technique, the IMD generated from a mixer in IF band was canceled by the controlled RF error signal, which is generated by a predistorter. The magnitude and phase of the RF error signal were properly adjusted through a vector modulator. This linearization technique has been verified by experiment of a down conversion mixer in cellular band. A two tone test has been performed at the frequency of 836 MHz with 442 KHz separation. The results show that this method improves about 16 dB of IMD3 at −18 dBm IF output power in 10 MHz frequency band and increases about 3.5 dB of P1 dB of the mixer. Simple topology and good performance in linearization of IF signals renders this technique suitable for highly linear frequency conversion in communication systems.**

***Index Terms*—IM3, linearization, mixer, predistortion.**

I. Introduction

LINEARITY is a critical requirement in modern communication systems where the signal envelopes are varying with time [1]. The intermodulation performance of a RF receiver is often limited from that of the mixer, which is a key component in the frequency translation in communication system. A mixer with high IP3 and P1 dB is necessary to achieve a large dynamic signal range. For high linearity, a number of linearization techniques have been developed in a mixer that are analogous to linearization techniques used in power amplifiers [2], [3]. However, the predistortion (PD) technique has not been investigated in a mixer until now. The PD techniques have been popularly used for the amplifier linearization because of their simple topology, good performance, and low cost [4]. In a power amplifier, the predistored RF input signal linearizes the RF output signal. On the hand, we demonstrate that the predistorted RF signal linearizes the IF signals in a mixer. This work describes a linearized mixer with a predistorted RF input, and investigates its effect on the reduction of intermodulation distortion from a mixer.

II. Theory and Circuit Design

Fig. 1 shows the proposed mixer block diagram with predistortion circuit. In this circuit, there are a distortion-path and a delay-path. In the distortion-path, the IMD error signals are generated, and modified in magnitude and phase by a vector modulator. And then, the error signal is added to the delay-path signal.

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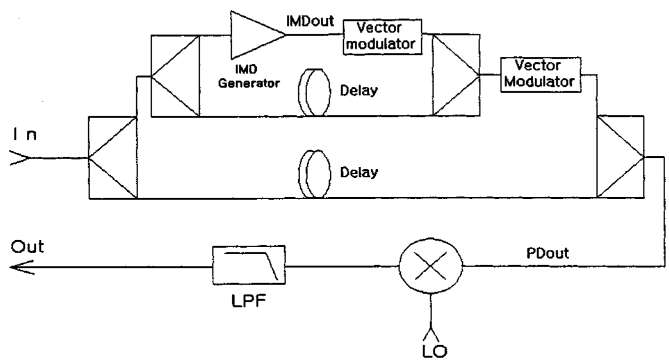


Fig. 1. Schematic of predistortion circuit with mixer.

The output of the IMD generator, IMD_{out}, may be expressed as follows:

$$IMD_{out} = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3 + a_4 \cdot x^4 + \cdots \quad (1)$$

where a_n is the Taylor coefficient of the transfer function of the IMD generator, and x is the input signal of RF signal. When a two tone RF input signal of $x = A\cos(\omega_1 t) + A\cos(\omega_2 t)$ is applied to the PD circuit, intermodulation signals are generated. In order to figure out the dominant intermodulation terms, the output of IMD generator was arranged as follows:

$$IMD_{out} \approx a_0 + a_1 A(\cos(\omega_1 t) + \cos(\omega_2 t)) + \frac{3}{4} a_3 A^3 \cdot(\cos(2\omega_1 t - \omega_2 t) + \cos(2\omega_2 t - \omega_1 t)) + \cdots. \quad (2)$$

The error signal is obtained by removing the fundamental signal components from the IMD_{out} signal using vector modulator. This error signal and the original signal from the delay-path are combined at the end of the PD, and then PD_{out} becomes as follows:

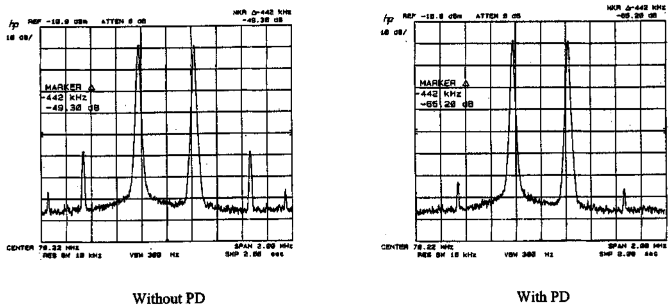
$$PD_{out} \approx b_0 + b_1(\cos(\omega_1 t) + \cos(\omega_2 t)) + b_2 \cdot(\cos(2\omega_1 t - \omega_2 t + \alpha) + \cos(2\omega_2 t - \omega_1 t + \alpha)) + \cdots \quad (3)$$

where b_n is variable and α is phase change in vector modulator. This PD_{out} is applied to a mixer with the LO signal, i.e., $L\cos(\omega_L t)$. Then, the mixer output, M_{out}, may be expressed by

$$M_{out} = c_0 + c_1 \cdot x + c_2 \cdot x^2 + c_3 \cdot x^3 + c_4 \cdot x^4 + \cdots \quad (4)$$

where c_n is Taylor coefficients of mixer and x is $PD_{out} + LO$. When IF signals from the mixer are filtered by a LPF, the mixer output signals are given as follows:

$$\begin{aligned} IF_{out} \approx\, & b_1 c_2 L\cos(\omega_1 t - \omega_L t + \theta_1) \\ & + b_1 c_2 L\cos(\omega_2 t - \omega_L t + \theta_1) \\ & + b_2 c_2 L\cos(2\omega_1 t - \omega_2 t - \omega_L t + \theta_2) \\ & + b_2 c_2 L\cos(2\omega_2 t - \omega_1 t - \omega_L t + \theta_2) \\ & + \frac{3}{4} c_4 b_1^3 L\cos(2\omega_1 t - \omega_2 t - \omega_L t + \alpha + \theta_3) \\ & + \frac{3}{4} c_4 b_1^3 L\cos(2\omega_2 t - \omega_1 t - \omega_L t + \alpha + \theta_3) \\ & + \cdots \end{aligned} \quad (5)$$



(a) (b)

Fig. 2. IF signal spectrum when output power is -18 dBm, (a) is without PD and (b) is with PD.

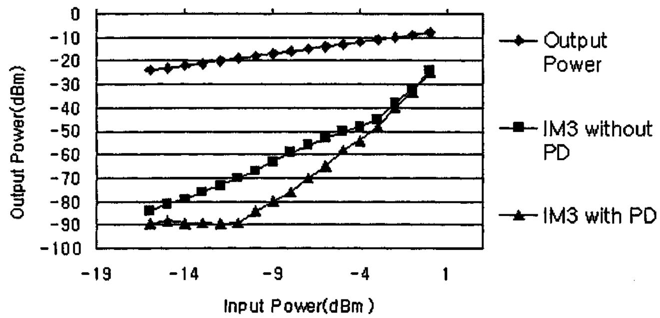


Fig. 3. IMD3 level with power sweep.

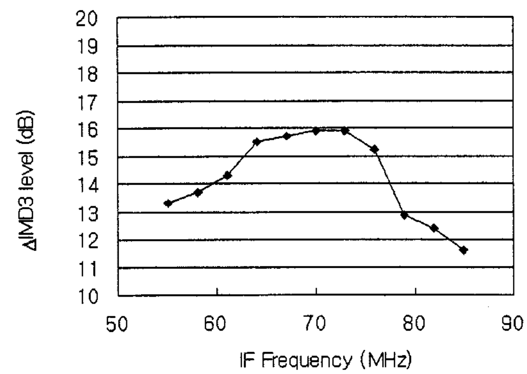


Fig. 4. IM3 reduction versus frequency for PD ($P_{out} = -18$ dBm).

where θ_1, θ_2, θ_3 are phase delay. From the above equation, the IM3 component can be canceled under the following conditions.

$$\begin{aligned} &Amplitude\ Condition: \quad b_2c_2 = \frac{3}{4}c_4b_1^3 \\ &Phase\ Condition: \quad \theta_2 = \alpha + \theta_3 + 180^\circ. \end{aligned} \tag{6}$$

III. Experiment and Results

A predistortion circuit has been fabricated and tested in the cellular band of 800 MHz. Hybrid couplers were used for power dividing and power combining, and the vector modulator was made of pin diodes and hybrid couplers. The IMD generator was selected considering IP3 and insertion loss of the mixer because IM3 level of the PD should be higher than that of the mixer. As for the mixer, a mini-circuit's SCH-2500LH balanced mixer was used, which operates up to 2.5 GHz and is rated up an RF level of 7 dBm and a LO level of 10 dBm. The two tone test was performed with 836 MHz and 836.442 MHz signals, the LO frequency was used 766 MHz, and the IF output frequency was 70 MHz and 70.442 MHz.

The IF IM3 level of the mixer has been reduced by adjusting the magnitude and phase of the input error signals using the vector modulators. In this work, the vector modulators were controlled to lower intermodulation products over the wide power range rather than a great deal of IM3 cancellation at a particular power level. Representative two tone test results are shown in Fig. 2. The results show that the third order intermodulation products were cancelled about 16 dB in the power range up to 10 dB back off from P1 dB of the mixer. The IM5 level of the mixer was also reduced, but the IM5 level was not dominant compared to the IM3 level all over the tested power range. The measured results of power sweep in the mixer are displayed in Fig. 3. As to P1 dB of the mixer, it was shown to increase 3.5 dB from -7 dBm to -3.5 dBm. The conversion loss of the mixer is 5.9 dB without PD, and the conversion loss with PD was measured as 8.3 dB including 2.4 dB loss of the predistortion circuit. The IM3 level could not be measured correctly below the output power of -20 dBm, because the IM3 level was lower than the noise floor of the spectrum analyzer. To testing the bandwidth of the predistortion circuit, the IM3 level was measured by IF sweep, which is shown in Fig. 4. The IF was sweeped by sweeping the RF with fixed LO frequency. The proposed predistortion circuit shows a good frequency response from 65 MHz to 75 MHz.

IV. Conclusion

A predistortion technique was applied to a mixer to improve the linearity in frequency conversion. This is analogous to the techniques used in power amplifier linearization. The unique feature of the present work is that down converted IF signals are linearized with the predistorted RF signals in the mixer. The measured data showed that IM3 products are reduced by about 16 dB at -18 dBm output power level in 10 MHz band. In addition, P1 dB of the mixer is improved by 3.5 dB. The measured results show that this predistortion technique is effective in the linearization of a mixer, and this technique will be helpful to improve the intermodulation performance of a mixer in multi-carrier communication systems.

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