Linearity Improvement of Power Amplifier using Modulation of Low Frequency IMD Signals

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Abstract - **In this paper, a new predistortion linearizer for controlling the amplitude of low frequency intermodulation distortion signals is proposed. The low frequency intermodulation distortion(IMD) components are generated by harmonic generator. A vector modulator, modulate fundamental signal with low frequency IMD signals, generates predistortion IMD signals and controls amplitude and phase of them with modulation factors. As a result, this predistorter is suppressed IMD signals of power amplifier effectively. The predistortion linearizer has been manufactured to operate in cellular base-station transmitting band (869~894MHz). The experimental results show that IMD_3 of power amplifier are improved more than 20dB for CW two-tone signals. Also, it's improved the adjacent channel power ratio (ACPR) more than 10dB for CDMA (IS-95) signals.**

Index Terms – **Linearization, predistorter, power amplifier, intermodulation distortion**

I. INTRODUCTION

Recent circumstance in wireless applications puts further stress on the utilization of spectral efficient modulation scheme so as to accommodate more traffic in a limited bandwidth. When this signals are amplified to RF power amplifier, intermodulation distortion (IMD) signals are generated which gives rise to interfering signals in adjacent channels. In addition, this IMD signals increased in-band interference and bit error rate, and decreased the efficiency of power amplifier. In order to recuperate nonlinearity of power amplifier, the variety schemes of linearization such as feedforward, feedback and predistortion have been reported [1]-[4]. Recently, harmonic feedback, harmonic feedforward and baseband feedforward were also reported.

In this paper, a new predistorter that creates inverse transfer characteristics of power amplifier is proposed for linearization of a RF power amplifier. The harmonic generator extracts low frequency IMD signals and then amplitude modulator(AM) is modulated original signal with extracted IMD signals. This process is generating IM signals. Then after the generated IMD signals are combined with original signal inversely, it's cancelled out the third order intermodulation distortion of power amplifier.

II. OPERATING THEORY

We assume that the amplifier nonlinearity can be expressed in terms of a power series like eq. (1).

$$v_o = a_1 v_i + a_2 v_i^2 + a_3 v_i^3 + a_4 v_i^4 + \cdots \qquad (1)$$

where v_i is input and v_o is output signal.

If input signals consist of two-tone, equal amplitude, signals as

$$v_i = A[\cos(\omega_1 t) + \cos(\omega_2 t)] \qquad (2)$$

Unlike other predistorters, desired signals obtained from the harmonic generator are just the second order low frequency intermodulation signals. It's explained below an expression.

$$\begin{aligned} H_2 &= a_2 v_i^2 \\ &= a_2 A^2 + 0.5\, a_2 A^2 [\cos 2\omega_1 t + \cos 2\omega_2 t \\ &\quad + 2\cos(\omega_2 - \omega_1)t + 2\cos(\omega_1 + \omega_2)t] \end{aligned} \qquad (3)$$

The desired signal ($\omega_2 - \omega_1$) is one element of second order harmonics (H_2) as shown Eqs. (1), (2), and (3). Figure 1 shows a detailed circuit of harmonic generator proposed in this paper. The harmonic generator is random controlled bias voltage to generate only desired low frequency IMD signal. Also, its output port is matched with 50 ohm terminated quarter wavelength open stub, so that the main signal is null and only low frequency second order intermodulation signal is passed [5].

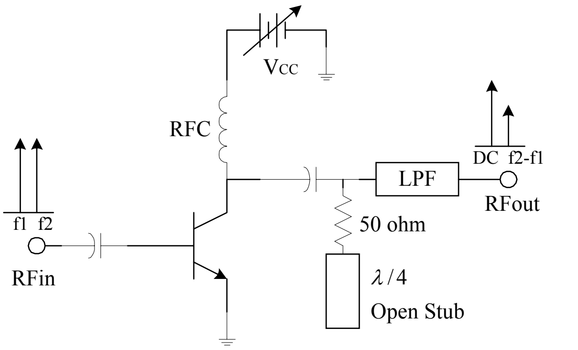
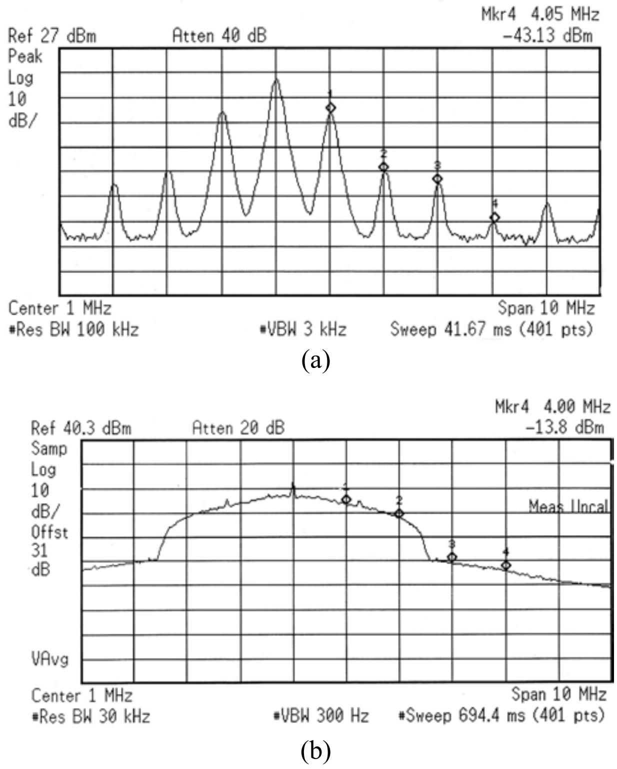


Fig. 1. Block diagram of the low frequency intermodulation signal generator

Figure 2 show low frequency second order intermodulation signal measurement results in case of CW two-tone, CDMA 2FA.



(a)

(b)

Fig. 2. Characteristics of the low frequency intermodulation distortion signal generator (a) two-tone case (b) CDMA 2FA case

The measured conditions are followed that harmonic generator input power is 0dBm, two-tone frequencies are 879.5MHz , 880.5MHz. The level of low frequency intermodulation signal (ω_2-ω_1) generated from the harmonic generator is big enough to modulate with fundamental signal in the AM modulator and the variable gain amplifiers (VGAs) that control modulation factor are used in order to cancel the third order intermodulation of power amplifier.

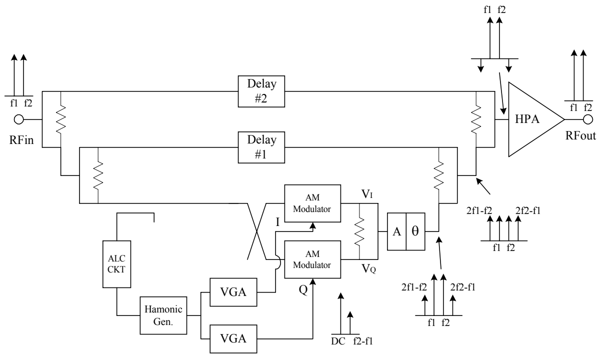
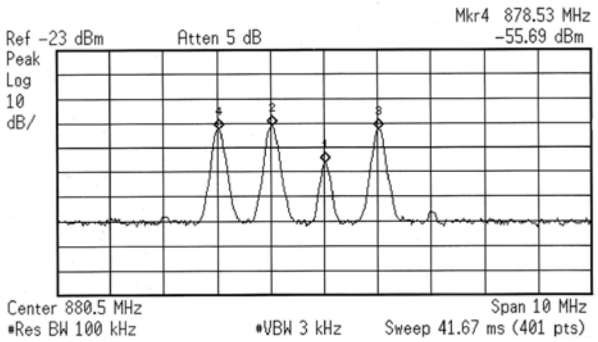
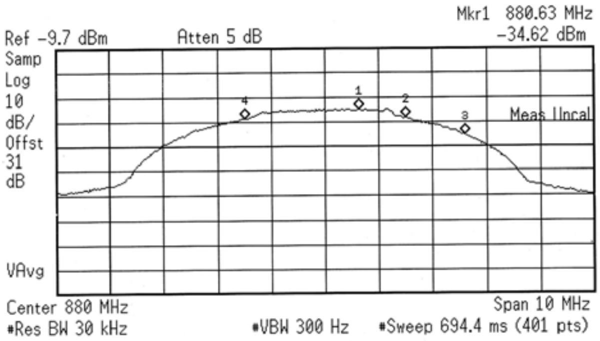


Fig. 3. Block diagram of the proposed linearization power amplifier

Figure 3 shows a block diagram of proposed linearization power amplifier. The proposed linear power amplifier consists of power divider, ALC (Automatic Level Controller), harmonic generator, VGA, AM modulator, variable attenuator, variable phase shifter, delay line and high power amplifier (HPA). The input signals are divided main path and harmonic generation path through the power divider. Also, the harmonic generation path signals are divided delay path and harmonic path through the power divider. Then, harmonic path signals are divided modulation path and ALC path through the 10dB directional coupler. The ALC circuit at the input port stabilizes the device making constant IM signal in spite of sensitivity of incoming power level. The signal (ω_2-ω_1), generated from the harmonic generator under proper bias condition, is modulated with main signal in the AM modulator and the vector modulator output is generated the predistorted IM signals. These modulated signals are eliminated the main carrier signal with controlling the delay line and adjusting the variable attenuator and variable phase shifter. The delay circuit #1, #2 is compensated by coaxial delay line, which is about 7.5ns and 9.2ns. Figure 4 shows the generated IMD signals in case of two-tone and CDMA 2FA. These signals are combined with 180° phase difference of the main signal. The predistorted signals are consisted of in-phase(I) and quadrature-phase(Q) component. So, when we are only changed amplitude of low frequency IM signal, the I and Q components are changed amplitude and phase simultaneously. The modulation factors adjustment of low frequency IM signals controls the phase and amplitude of the predistorted IM components. So, it is omitted variable attenuator and phase shifter at the harmonic generation path.



(a)



(b)

Fig. 4. Generated intermodulation distortion signals (a) CW two-tone case (b) CDMA 2FA case

III. Experimental Result

In order to show validity of the proposed linearizing method, the proposed predistorter and HPA were fabricated. The HPA is designed with Watkins Johnson AH1 and Motorola MHL9838, for which the gain and 1dB compression point are 43dB and 37dBm, respectively. The harmonic generator was used Watkins Johnson AH1 and the AM modulator consist of the 3dB hybrid coupler, varactor diode and power divider. Also, VGA is Analog Device's AD602. Fig. 5 compares carrier to IMD (C/I) ratio of HPA with and without the proposed predistortion circuit in case of CW two-tone, where the output power is 28.27dBm/tone and test frequencies are 879.5MHz, 880.5MHz. The third order intermodulation distortion is improved 21.09dB. Figure 6 shows the nonlinear characteristics comparison of HPA with and without the proposed predistorter according to input level variation. The third order intermodulation distortion is improved about 20dB for CW two-tone signals in the 10dB dynamic range.

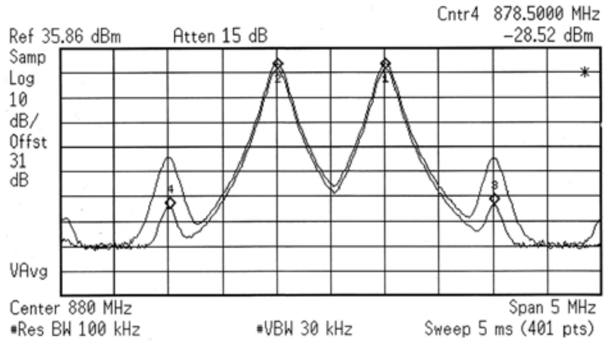


Fig. 5. Nonlinear characteristics comparison of HPA with and without the proposed predistorter (@Po=28.27dBm/tone)

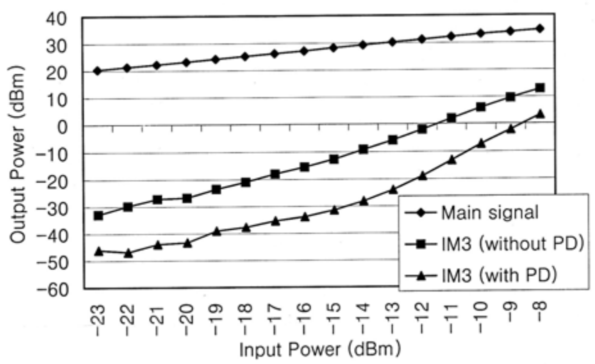


Fig. 6. The nonlinear characteristics comparison of HPA with and without the proposed predistorter according to input level variation

Figure 7 compares adjacent power ratio (ACPR) of HPA with and without the proposed predistorter, where the output power is 25.34dBm and test frequency is 880MHz. The improvements of ACPR are 14.36dB and 10.62dB at f_0±885KHz, f_0±1.23MHz offset frequencies respectively. Figure 8 compares adjacent power ratio (ACPR) of HPA with and without the proposed predistorter, where the output power is 22.3dBm/FA and test frequencies are 878.75MHz, 880MHz, 881.25MHz. Figure 9 shows the ACPR improvements of HPA according to output power variation in case of CDMA IS-95 1FA signal.

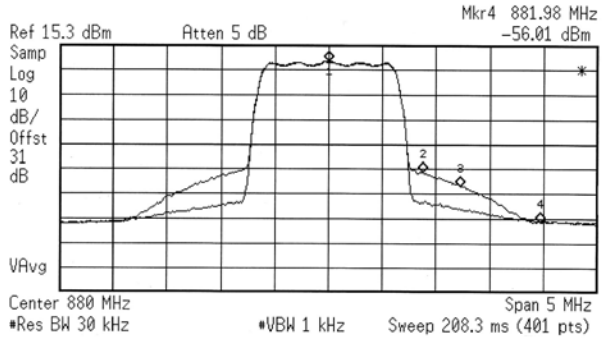


Fig. 7. Nonlinear characteristics comparison of HPA with and without the proposed predistorter in case of CDMA IS-95 1FA signal (@Po=25.34dBm)

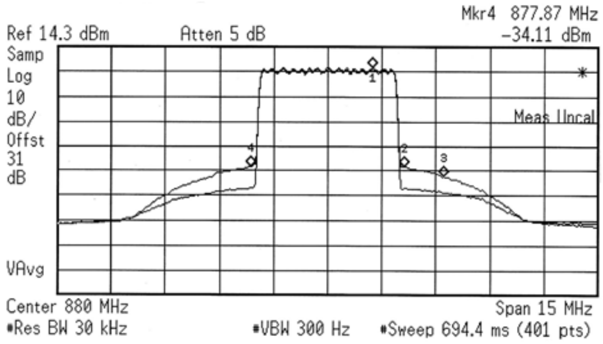


Fig. 8. Nonlinear characteristics comparison of HPA with and without the proposed predistorter in case of CDMA IS-95 3FA signals (@Po=22.3dBm/FA)

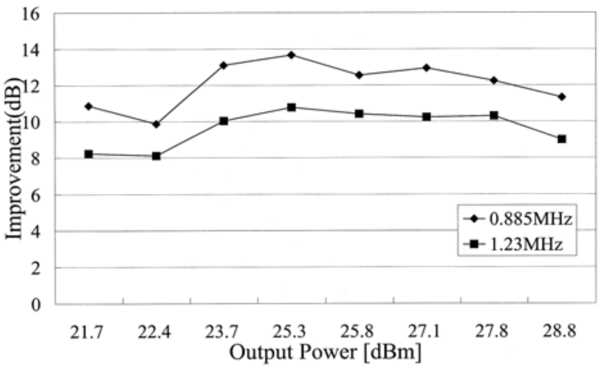


Fig. 9. The ACPR improvements of HPA according to output power variation in case of CDMA IS-95 1FA signal

IV. Conclusion

In this paper, a new predistortion linearizer for controlling the amplitude of low frequency IM signals is proposed and the proposed predistorter was validated. A vector modulator, modulate fundamental signal with low frequency IMD signals, generates predistortion IMD signals and controls amplitude and phase of them with modulation factors. According to this method, IMD signals of HPA are suppressed effectively. Also, the circuit design is simple and small.

In the experiments, good IM cancellation characteristics are obtained for a wide dynamic range and many kind of signals. The suggested predistortion linearizer has been designed to operate in cellular base-station transmitting band. The test results show that IMD_3 of HPA is reduced more than 20dB for CW two-tone signals. Also, it's improved the adjacent channel power ratio (ACPR) more than 10dB for CDMA IS-95 1FA signals.

V. Reference

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