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ABSTRACT

In recent years, the mobile communication systems have used linear modulation methods like CDMA, QAM, QPSK etc. to use the frequency resources efficiently.

However, these modulation methods have drawbacks of high peak to average power ratio and fluctuant envelop of RF signal. So, they require a power amplifier with good linearity.

Also, the power amplifier operates in saturation region to obtain high efficiency and maximum output power.

In this region, nonlinear characteristics such as the distortion of amplitude and phase are generated. When multi-tone signals are amplified in the power amplifier, unwanted harmonics and intermodulation(IM) distortion signals in addition to amplified signals are generated simultaneously by nonlinear characteristics of power amplifier.

These IM signals increase bit error rate of data and adjacent channel interferences, and decrease the efficiency of power amplifier.

Therefore, the power amplifier has to operate with linearizer for compensation of the nonlinear characteristic [1]-[3]. Predistortion is a linearization technique that lays a circuit having inverse distortion characteristic in front of the power amplifier to cancel the distortion signals of the power amplifier. And predistortion method has many advantages such as broader bandwidth, wider operation range, smaller size and lighter weight. In the past year, several papers using injection of harmonic or the second low frequency intermodulation signal ($LFIM_2$) has been reported[4]-[6].

In this paper, a new predistortion method is proposed, that $LFIM_2$ of RF input signal is extracted by using a new $LFIM_2$ detector and then injected it into the input bias line of the amplifier. Also we propose three type injection methods of $LFIM_2$ to input bias line of drive and power amplifier.

As a result, we can obtain the optimum $LFIM_2$ injection method and cancel the distortion components of the power amplifier effectively. The proposed linearizer has the advantages of the simpler circuit and better performance not less than the feedforward linearizer.

A DESIGN OF THE SECOND ORDER LOW FREQUENCY INTERMODULATION SIGNAL INJECTION PREDISTORTIVE LINEARIZER FOR CASCADE POWER AMPLIFIER

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Abstract - This paper presents a new predistortion method, injecting the second order low frequency inter- modulation signal(LFIM2) of RF input signal into the input bias line of the cascade power amplifier. We showed the suppression of IM3 and IM5 apparently by adjusting phase and amplitude. Also, we confirmed the verification of mathematical analysis. And we tested several LFIM2 injection methods in cascade power amplifier to obtain the optimum nonlinearity improvement performance. When CW 2-tones are applied as input signals, improvements of IM3 and IM5 are 35dB and 6dB, respectively. Also, when input signal CDMA IS-95 1FA is applied, we showed the improvement of ACPR is over 18dB in the operation band.

1. Introduction

In recent years, the mobile communication systems have used linear modulation methods like CDMA, QAM, QPSK etc. to use the frequency resources efficiently. However, these modulation methods have drawbacks of high peak to average power ratio and fluctuant envelop of RF signal. So, they require a power amplifier with good linearity.

Also, the power amplifier operates in saturation region to obtain high efficiency and maximum output power. In this region, nonlinear characteristics such as the distortion of amplitude and phase are generated. When multi-tone signals are amplified in the power amplifier, unwanted harmonics and intermodulation(IM) distortion signals in addition to amplified signals are generated simultaneously by nonlinear characteristics of power amplifier. These IM signals increase bit error rate of data and adjacent channel interferences, and decrease the efficiency of power amplifier.

Therefore, the power amplifier has to operate with linearizer for compensation of the nonlinear characteristic [1]-[3]. Predistortion is a linearization technique that lays a circuit having inverse distortion characteristic in front of the power amplifier to cancel the distortion signals of the power amplifier. And predistortion method has many advantages such as broader bandwidth, wider operation range, smaller size and lighter weight. In the past year, several papers using injection of harmonic or the second low frequency intermodulation signal ($LFIM_2$) has been reported[4]-[6].

In this paper, a new predistortion method is proposed, that $LFIM_2$ of RF input signal is extracted by using a new $LFIM_2$ detector and then injected it into the input bias line of the amplifier. Also we propose three type injection methods of $LFIM_2$ to input bias line of drive and power amplifier. As a result, we can obtain the optimum $LFIM_2$ injection method and cancel the distortion components of the power amplifier effectively. The proposed linearizer has the advantages of the simpler circuit and better performance not less than the feedforward linearizer.

2. Theory of operation

Figure 1 shows the block diagram of the proposed amplifying system. In practice, power amplifier module of an RF front-end is usually composed of a chain of cascade amplifiers to achieve sufficient output power and signal gain[7]. The proposed block diagram consists of a power divider, $LFIM_2$ detector, variable gain amplifier (VGA), transformer, input bias line, delay line, the drive amplifier and the power amplifier.

The input signal is split into RF path and $LFIM_2$ detector path by the power divider. If the RF signal of $LFIM_2$ detector path passes through the small signal amplifier, we can obtain $LFIM_2$ except output signals of the operation band. The signals of the operation band are consumed at the termination load through the λ/4 coupled line. However, $LFIM_2$ can be extracted from inductor port by reflection characteristic of the λ/4 coupled line in the low frequency band. The amplitude of $LFIM_2$ is controlled with the small signal amplifier and VGA.

Out of phase control of $LFIM_2$ is obtained by virtue of transformer of the input port and delay line. The input signal of the RF path and the $LFIM_2$ from detector path are amplified at the drive amplifier simultaneously. Output signals of the drive amplifier and $LFIM_2$ from detector path are injected into the power amplifier. Commonly, the output of the amplifier consists of a infinite series of nonlinear products, which are added to the linear gain represented by the first term. It can be described by the power series Eq. (1). The amplifier with weak nonlinear characteristic, generally, is expressed by using first three terms of the power series[8].

$$v_{out}(t) = k_1 v_{in}(t) + k_2 v_{in}{}^2(t) + k_3 v_{in}{}^3(t) \tag{1}$$

If the input signal is $v_{in}(t)=a(\cos\omega_1 t+\cos\omega_2 t)$, then $LFIM_2$ can be obtained at the second term of the Eq. (1) and it can be represented as $C_1\cos(\omega_2-\omega_1)t$, where C_1 is a constant. And, after controlling the amplitude of $LFIM_2$, we inject it into input bias line of the amplifier. It affects the input bias as an AM modulation, so the gain is affected. This process can be expressed as Eq. (2).

$$v_{in}(t) = \{1 + b\cos\Delta\omega t\} \times a\{\cos(\omega_1 t - \theta_1) + \cos(\omega_2 t - \theta_2)\} \tag{2}$$

Where $\Delta\omega=\omega_2-\omega_1$ and $\theta_2 \neq \theta_1$. And θ_1 and θ_2 are phases of the RF signal. The amplitude of $LFIM_2$, b, is adjusted by VGA. Substituting Eq. (2) into Eq. (1), we can distinguish the third order intermodulation distortion signals(IM_3) into IM_3 generated by pure input signals and IM_3 generated by $LFIM_2$ injection. Since it is assumed that $k_1 >> k_3$ and $a >> b$ in power series, we can express the generated IM_3 by pure input signals, eq. (3), and IM_3 by $LFIM_2$, eq. (4), respectively.

$$0.75k_3a^3\cos\{(2\omega_2-\omega_1)t-(2\theta_2-\theta_1)\} \tag{3}$$

$$0.5k_1ab^*\cos\{(\omega_2+\Delta\omega)t-(\theta_2-\Delta\theta')\} \tag{4}$$

Where $\Delta\theta'$ means the phase variation of $LFIM_2$. If the magnitude is same and the phase is out of phase, we can cancel IM_3 generated by pure input signals. In other words, if the amplitude of b is $1.5k_3a^2(k_3/k_1)$ and $\Delta\theta'$ is $\pm 180^o$, we can remove IM_3. By the same process, we can eliminate the fifth order intermodulation signal(IM_5). Eq. (5) and Eq. (6) express IM_5 generated by pure input signals and generated by $LFIM_2$, respectively.

$$k_5C_2\cos\{(3\omega_1-2\omega_2)t-(3\theta_1-2\theta_2)\} \tag{5}$$

$$(2/32)k_3a^3b^3\cos\{(3\Delta\omega-\omega_2)t-(3\Delta\theta'-\theta_2)\} \tag{6}$$

Where C_2 is a constant.

3. Measured results

In order to show the validity of the proposed linearizing method, we designed to 2-stage cascade amplifier. Transistors of the drive stage and the power stage are MRF581, MRF891 of Motorola Co., respectively. The gain of designed cascade power amplifier is 18.8dB and P_{1dB} is 20.51dBm. The operation band is 869~894MHz. The used frequencies of CW 2-tone signals are 879.5MHz and 880.5MHz.

In this paper, we tested the four kinds of bias processing and measured carrier to intermodulation(C/I) at the output of the power amplifier. First, we didn't inject $LFIM_2$ into the input bias port of each transistor. Secondly, we injected $LFIM_2$ into the input bias port of drive amplifier, so that the linearized output signals of drive amplifier is fed to power amplifier. In here, $LFIM_2$ is not injected into power amplifier. Thirdly, the drive amplifier, injected $LFIM_2$, is operated as predistortor stage of the power amplifier. Fourthly, we injected $LFIM_2$ into both the drive amplifier and the power amplifier.

Figure 2 shows IM_3 levels according to output signal level variation for four experiments. The measured results confirm the best C/I characteristics when the drive amplifier is used as utilizes the predistortor circuit in a low output power level range. And the best C/I characteristics are obtained when $LFIM_2$ is injected into all stages of amplifier in high output power level range. Figure 3 shows IM_5 levels according to output signal level variation for four experiments. The measured results confirm the best C/I characteristics when $LFIM_2$ is injected by all stages of amplifiers. Figure 4 shows C/I characteristics with and without $LFIM_2$ injection. Where $LFIM_2$ is injected to input bias line of the drive and the power amplifier. The output level is 20.59dBm/tone, which is P_{1dB}. Improvements of IM_3 and IM_5 are 35dB and 6dB, respectively. Figure 5 shows the IMD improvements of the cascade power amplifier in the output dynamic range. IM_3 is improved about 35dB at 2.6dBm/tone and IM_5 is improved about 10dB at 1.6dBm/tone. Figure 6 shows the ACPR characteristics of cascade amplifier with and without $LFIM_2$ injection for CDMA IS-95 1FA signal. The output power level is 20.35dBm and the center frequency is 880MHz. ACPR improvements at 0.75MHz and 1.98MHz offset from center frequency are about 18dB and 10dB, respectively. Figure 7 shows the ACPR improvements of the cascade power amplifier in the input dynamic range in case of CDMA IS-95 1FA signal. This figure shows that the ACPR improvement at 0.75MHz offset is over 15dB for wide operation range. Figure 8 shows the result of the ACPR improvement as CDMA IS-95 3FA signal at 20.35dBm. The ACPR of the measured result is improved about 10dB.

Conclusion

In this paper, we proposed the new predistortion method that extract $LFIM_2$ from the input signals and then inject into the input bias of the amplifiers. We suggest the possibility of IMD improvement of the power amplifier from the mathematical approach. It is superior to the IMD improvement to the drive and power amplifier injection scheme among the various $LFIM_2$ injection method. When the CW 2-tone signals are applied, IM_3 improvement is 35dB and IM_5 improvement is 6dB. Also, when the input signal CDMA IS-95 1FA is applied, we showed the ACPR improvement over 18dB in the operation band.

The suggested circuit is simpler than other linearizing method and the improvement is excellent. Moreover, in case of cascade power amplifier, this scheme is easily applicable.

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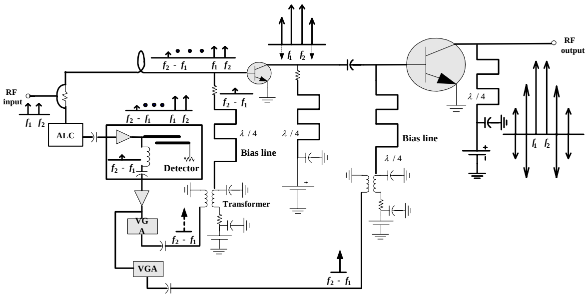

Fig. 1. Configuration system of the proposed cascade amplifier

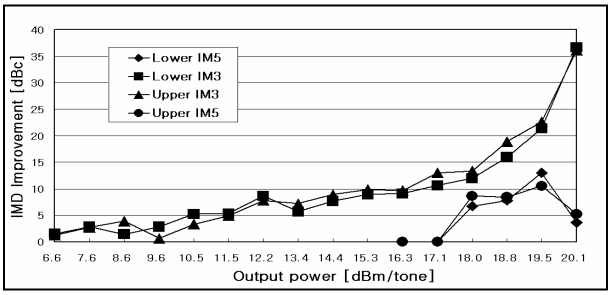

Fig. 4 The output spectrum comparison with and without the proposed linearizer in case of 2-tone input signals (@Po=26dBm/tone)

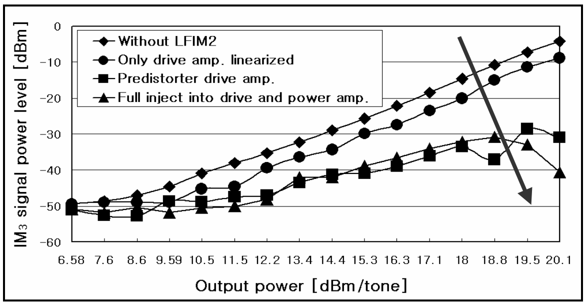

Fig. 2. IM_3 levels variation for four experiments

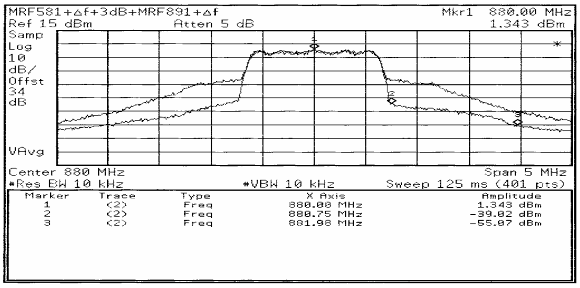

Fig. 6. ACPR improvement of CDMA IS-95 1FA signal (@P_o = 20.37dBm)

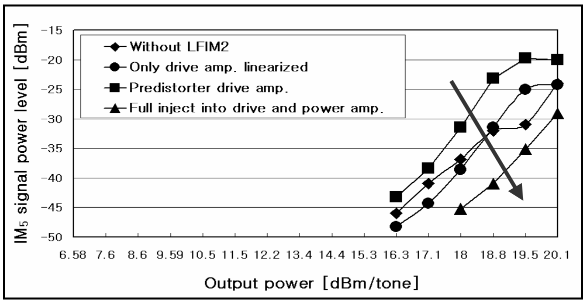

Fig. 3. IM_5 levels variation for four experiments

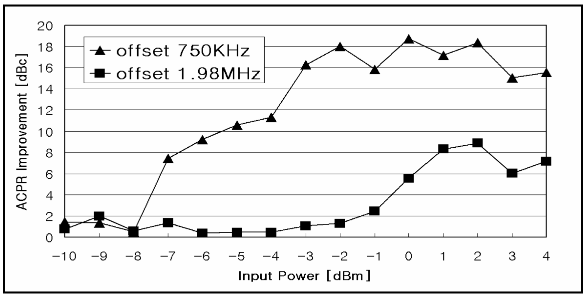

Fig. 7. ACPR improvements for CDMA IS-95 1FA signal

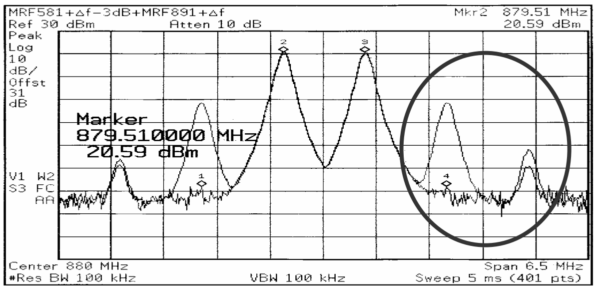

Fig. 4. C/I characteristics with and without $LFIM_2$ injection (@P_o=20.59dBm/tone)

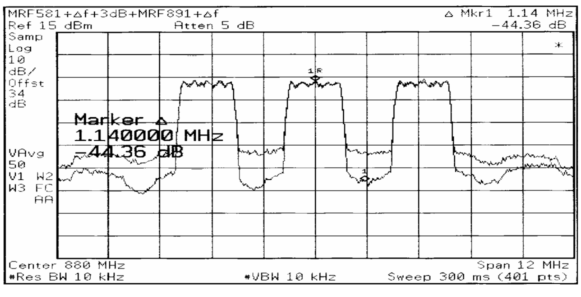

Fig. 8. ACPR improvement for CDMA IS-95 3FA signal (@P_o = 20.35dBm)