A Design of Predistortion Linearizer using 2nd Order Low Frequency Intermodulation Signal Injection

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Abstract — This paper presents a new predistortion methods which injects the 2nd order low frequency intermodulation signal of RF signal into the input bias line of the amplifier. We show this technique can suppress the 3rd IM and the 5th IM apparently by adjusting 2 factors, phase and amplitude, through mathematical analysis, and then confirm it with simulation. And we design digital cellular amplifier to show variation of the optimal performance without additional circuits or controls for the operating range. When the input signal CDMA IS-95 1FA was applied, measured ACPR improvements were 25dBc, 22.5dBc, and 6dBc at 0.855MHz, 1.25MHz, and 2.25MHz offset respectively. Also, when applying the CDMA IS-95 3FA, the measured ACPR improvement showed 16dBc at 0.885MHz offset.

I. Introduction

In recent years, the mobile communication systems have used modulation methods like CDMA, QAM, QPSK etc to use the frequency resource efficiently. However, these methods have high peak to average power ratio and fluctuant envelop of RF signal. Also the power amplifier is operated to extract maximum output in the saturation region. In that region, the nonlinear characteristics such as distortions of amplitude and phase are very serious. These distortions give rise to interferences in adjacent channels. Therefore, it is needed to compensate the nonlinear characteristics by a linearization technique [1]-[3]. Predistortion is a linearization technique which lays a circuit with inverse distortion characteristic at front of the power amplifier to cancel the distortion signals of the power amplifier. Predistortion have many advantages such as a broad bandwidth, wide operation range, light weight and smaller size, but not good linearizing effects than feedforward technique. Recently, several papers using harmonic injection or the 2nd low frequency inter modulation signal have been reported [4]-[6].

In this paper, we can implement a predistortion linearizer using 2nd order low frequency intermodulation signal injection. After detecting the 2nd low frequency inter modulation signal from input signals, it is injected into the input bias line of the power amplifier. In result, we can cancel the distortion components IM3 and IM5 at the same time by generating the inverse distortion characteristic of the power amplifier itself.

II. Theory

Figure 1 shows the proposed linearizer block diagram. The linearizer consists of a power divider, the 2nd low frequency inter modulation signal detector, a variable gain amplifier (VGA), a transformer, an input bias line, a phase shifter, delay line and an amplifier. The input signal is split into the power amplifier path and $LFIM_2$ signal detector path by the power divider. The signal of the power amplifier path goes toward the variable phase shifter. And then, it is amplified and generates the intermodulation components by the nonlinearity of the amplifier. The signal of the detector path goes to the circuit of the $LFIM_2$ signal detector. And then the amplitude of detected signal is change by the VGA. The $LFIM_2$ signal goes to the bias line through the transformer. As shown in figure 1, intermodulation components are generated by the nonlinearity of the amplifier and injection of detected signal. Making the same amplitude and out-of phase of these signals, we can linearize the 3rd intermodulation distortion component of transistor.

We assume that the nonlinearity of the amplifier can be expressed in terms of a power series like (1), which is truncated beyond the 3rd order term.

$$v_{out}(t) = g_1 v_{in}(t) + g_2 v_{in}^2(t) + g_3 v_{in}^3(t) \tag{1}$$

Where g_1, g_2 and g_3 are the coefficients of the nonlinear amplifier. Here, we apply the 2-tone input signal, $v_{in}(t) = a\cos\omega_1 t + a\cos\omega_2 t$. Injection of the $LFIM_2$ signal into the bias line affects input bias so that the output gain has the variation. As a result, we can consider a signal modulation like an AM modulation. So, the input signal, $v_{in}'(t)$, may be expressed as

$$v_{in}'(t) = \{1 + b\cos(\omega_2 - \omega_1)t\} \times a\{\cos(\omega_1 t - \theta_{21}) + \cos(\omega_2 t - \theta_{21})\} \tag{2}$$

Where a is the amplitude of input signal, θ_{21} is the phase component of signal, and b is the $LFIM_2$ amplitude and it can be controlled by the voltage gain amplifier. Substituting (2) into (1), and considering only the 3rd intermodulation distortion components at the low frequency side band, by assuming that $g_1 >> g_3$ and $a >> b$. The large correlative terms are as

$$0.75 G_3 a^3 \cos(2\omega_1 t - \omega_2 t + \theta_{21}) \tag{3}$$

$$0.5 G_1 ab\cos(2\omega_1 t - \omega_2 t) \tag{4}$$

(3) is a component generated by the main signal, (4) is the one generated by the $LFIM_2$ signal injection. If $b = 1.5 G_3 a^2 / G_1$, $\theta_{21} = 180°$ or $-180°$, the IM3 component can be suppressed. And, the IM5 components are generated by the injection of the $LFIM_2$ signal. The dominant term is given by

$$1.125 g_3 a^3 b\cos(3\omega_1 t - 2\omega_2 t) \tag{5}$$

By proper control of the $LFIM_2$, the IM5 components, which are generated by amplifier itself, can reduced. Namely, we can cancel the IM3 and IM5 components with the appropriate choice of amplifier by the injection of the $LFIM_2$ only.

Figure 2 shows the simulation circuit using the ADS of Agilent. Here the power amplifier and the detector of the $LFIM_2$ signal are represented as symbols. Their detail circuits are shown in figure 1. And simulation results are also show in figure 3. Where center frequency is 880MHz and 2-tone spacing is 1MHz. Improvements of IM3 and IM5 characteristics are 36dBc and 17dBc, respectively.

III. Experimental Results

To show the validation of the proposed linearizing method, the circuit has an MRF581 of Motorola with input bias just like figure 1 was fabricated. The measured gain and P1dB are 12dB, 18dBm respectively. The detector circuit consists of an ERA5SM amplifier, coupled parallel lines using open circuited lines, inductor Ls, and capacitor Cs. The amplifier used for extraction of $LFIM_2$ is the ERA-5SM of Minicircuits. The coupler with open stubs cuts off the main frequency like a filter and series LC circuit the $LFIM_2$ signal. Controlling the phase of the power amplifier path and the amplitude of variable gain amplifier at the gain suppression point, we obtained data of the phase and the amplitude with optimal output characteristics. Measured results needed the constant phase and the amplitude variation of 15dBm/7dBm. Then, we investigated the slop variation of the $LFIM_2$ signal detector and matched two slops appropriately. Consequently, an implemented linearizer operated well for wide output range without additional adaptive control circuits.

Figure 4 shows the improvements in characteristics before and after the $LFIM_2$ signal injection at the output power 12.5dBm, when the 2-tone input with center frequency 880MHz and 1MHz spacing is applied. The improvements in IM3 and IM5 are 36dBc and 9dBc, respectively.

Figure 5 shows the total improvement characteristics for the output power 3.3~13.3dBm. As shown in figure 5, IM3 and IM5 are cancelled together for the wide output range. Especially, the IM3 improvement shows 36dBc at the output 12.5dBm, and that of IM5 is 18dBc at output 11.7dBm. At the low output power ranges, output signals are so pure that IM cancellation can be shown somewhat poor.

Figure 6 shows an improvement characteristic when a CDMA IS-95 signal with the center frequency 880MHz and the output power, 13.4dBm, is applied to the amplifier. The ACPR improvement characteristics show 25.1dBc, 22dBc, and 5dBc at 0.855MHz, 1.25MHz, and 2.25MHz, respectively.

Figure 7 shows improvement characteristics for the output power range 4.1~14.3dBm. We measured ACPR improvements at 0.885MHz, 1.25MHz, and 2.25MHz offset from the center frequency, 880MHz. As this figure shows, we can see excellent ACPR improvements for the wide output range.

Figure 8 show experimental results, when CDMA IS-95 3FA with output 13.4dBm and center frequency 880MHz are applied to the amplifier. In figure 8, the ACPR improvement shows 16dBc.

IV. Conclusion

In this paper, we have discussed the proposed predistortion method using the injection of the $LFIM_2$ signal. We have shown the possibility of canceling IM3 and IM5 together and the improved performance in theory, by simulation, and in practice. When CDMA

1FA is applied to a fabricated linearizing amplifier, we obtained the ACPR improvement 25.1dBc in case output level 13.5dBm at 0.885MHz offset. And also, by matched the slop of the required variable gain amplifier and the slop of the $LFIM_2$ signal detector, we have shown optimal improvement results without additional circuits or control for the output range. The proposed method was experimented at the low power. But it has shown a very excellent ACPR cancellation performance. Therefore, we need to apply for the higher power in the next time.

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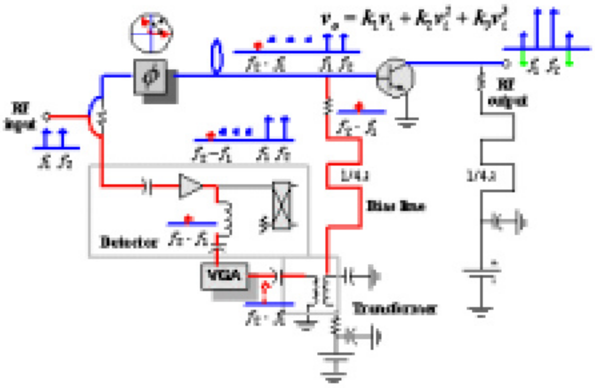


Fig. 1 Proposed linearizer block diagram using the $LFIM_2$ signal injection into a bias line.

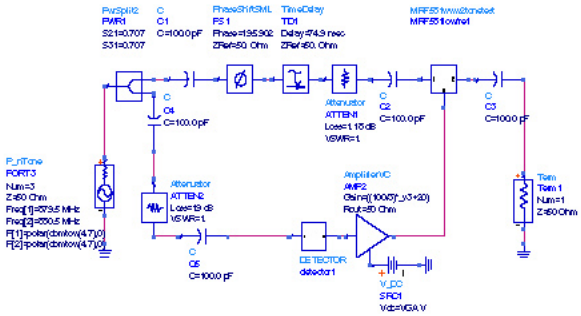


Fig. 2. 2-tone input simulation setup using Agilent ADS

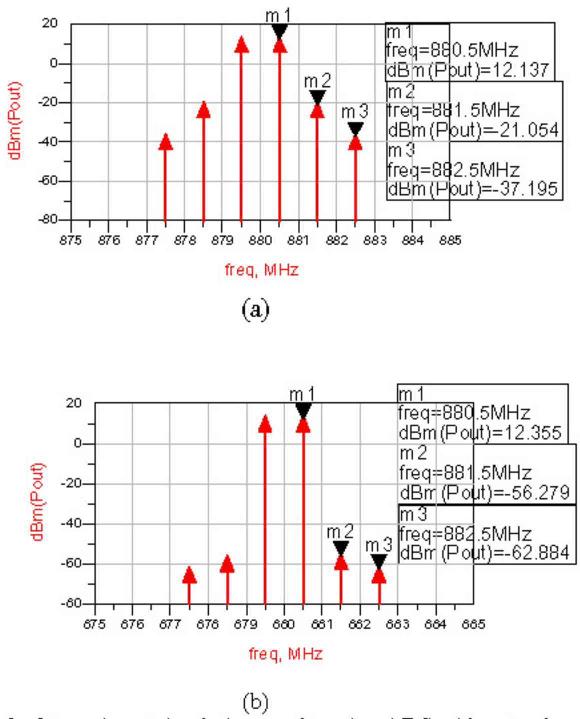
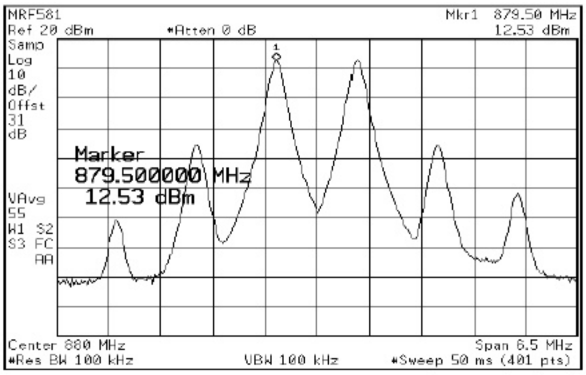
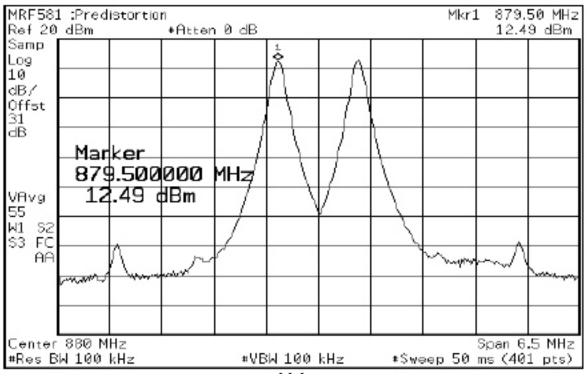


Fig. 3 2-tone input simulation results using ADS without and with $LFIM_2$ signal injection. (a) Without $LFIM_2$ signal injection (b) With $LFIM_2$ signal injection



(a)



(b)

Fig. 4. Linearization results of 2-tone input test with center frequency 880MHz and output power 12.5dBm (a) Before linearization (b) After linearization

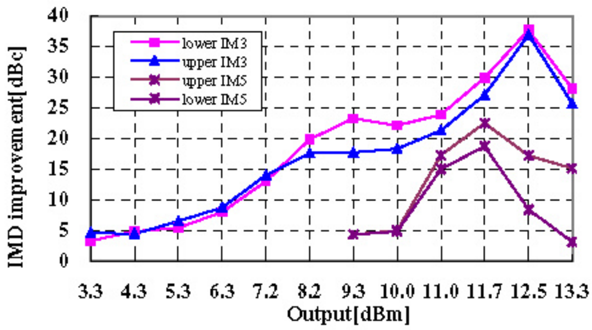


Fig.5. Measured 2-tone improvement characteristics for the output power range 3.3~13.3dBm.

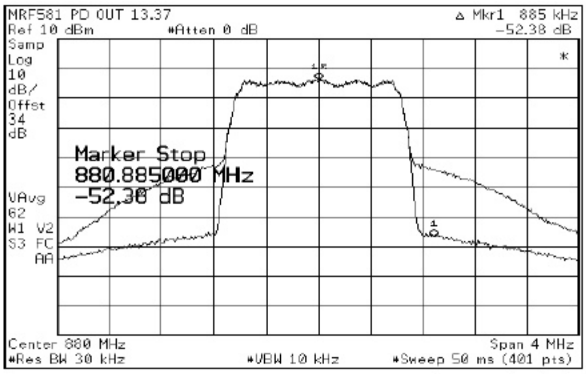


Fig. 6. ACPR improvement is 25.1dBc when a CDMA IS-95 signal with center frequency 880MHz is applied

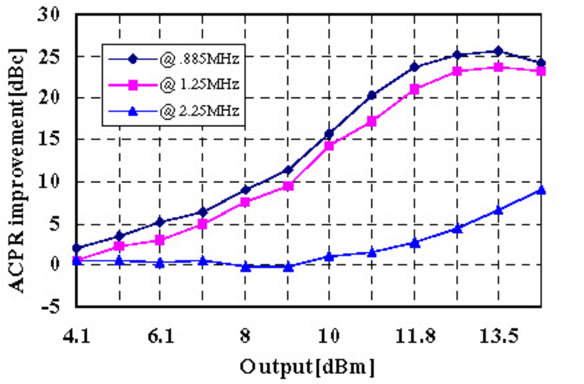


Fig. 7. Measured ACPR improvements at 0.885MHz, 1.25MHz, and 2.25MHz offset respectively.

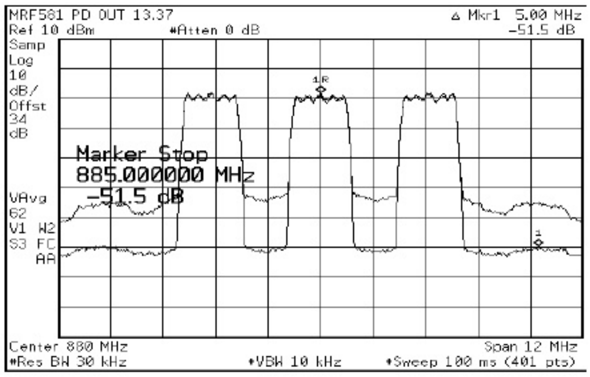


Fig. 8. CDMA IS-95 3FA input test result when output 13.4dBm and 1.25MHz spacing