A Novel Predistorter using a Balanced Type IM3 Generator

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Abstract **— This paper presents a novel linearization scheme for a nonlinear RF amplifier. It is based on the amplitude modulation with envelope signal. The 3rd order distortion generator is composed of two FETs and it adopts a balanced structure for the purpose of main carrier cancellation. The amplitude and phase of the IM3 components can be controlled at RF band. This predistorter is implemented and tested at the KOREA PCS Tx. band (1840~1870MHz). Experimental results of two-tone test show that the IM3 cancellation is achieved about 30-40 dB for the wide dynamic range. The adjacent channel power ratio is improved by over 10 dB at the CDMA signal with a peak to average power ratio of 10dB, and this improvement is maintained over a wide range of output power levels.**

I. INTRODUCTION

Modern digital communication systems use the band-limited modulation schemes, such as multi-level quadrature amplitude modulation (QAM) and quadrature phase shift keying (QPSK). In those systems, high efficiency linear amplifiers are required to prevent adjacent channel interference.

There are several solutions to overcome this problem. One possible solution is a feedforward technique. It is generally adopted because of its unconditional stability and extremely linear characteristics. However, it requires an additional amplifier and a complex adaptive control circuit. The other solution is a predistorton technique. Predistorton is the simplest form of linearization for an RF power amplifier. It simply involves the creation of a distortion characteristic that is precisely complementary to the distortion characteristic of power amplifier and cascading the two in order to ensure that the resulting system has little output distortion.

Among the various types of predistorter, recent trend is using second order nonlinear components instead of in-band IM component.[1]-[3] There are several types of predistorter using second order nonlinear component such as second harmonic injection technique, harmonic feedback technique, harmonic feed-forward technique etc.

But the phase control of low frequency second order component is a serious problem. And injection of high frequency second order harmonic component is not easy due to the matching problem. Therefore the IM3 improvement using the second harmonic injection technique is relatively low. Moreover this technique can be applicable only in small signal transistor. It only operates on low input power level with narrow dynamic range.

In this paper, we present a novel predistorter using a balanced type IM3 generator. The balanced type IM3 generator is composed of two FETs. The in-band IM3 component is generated by amplitude modulation with envelope signal, which is generated by four Schottky diodes. The operation and analysis of the proposed circuit is presented in section II. Finally, the experimental results of linearization for a power amplifier are presented in section III.

II. DESIGN METHOD

Fig. 1 shows the whole block diagram of predistorter using a new balanced type IM3 generator. The input signal is divided into the main path, IM3 generation block and envelope detector. The input power level of envelope detector and IM3 generator is maintained constant by the Automatic Level Control (ALC) circuit. So the generated in-band IM3 component is also constant and stable.

The envelope detector generates $\cos(\omega_1-\omega_2)t$ signal from the RF two-tone signal with frequency ω_1 and ω_2. The structure of envelope detection circuit is reflection type with four different Schottky diodes. For two-tone case we can find the essential point of the $\cos(\omega_1-\omega_2)t$ component by adjusting the bias of each four Schottky diodes. Then the amplitude of detected signal can be adjusted by variable gain amplifier(VGA). Next the VGA, envelope signal is split into 0° and 180° by transformer.

The type of the 3rd order distortion generator is a balanced structure. 0° and 180° envelope signals are injected into the balanced type IM3 generator. Then IM3 component is generated by amplitude modulation. If there is only one 3rd order distorter, amplified main carrier signal is also generated with IM3 component. This main carrier signal causes gain losses, so main carrier cancellation circuit is required. The balanced type IM3 generator operates as a main carrier cancellation circuit, so the additional main carrier cancellation circuit is not

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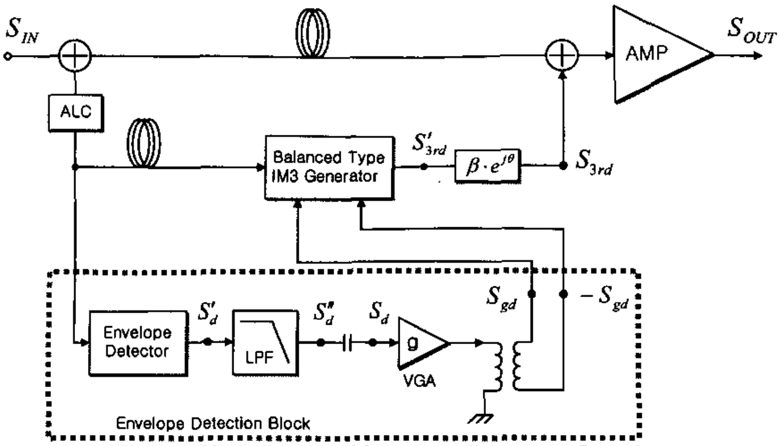


Fig. 1. Block diagram of the new predistorter configuration.

required. And the amplitude and phase of IM3 component are adjusted at the RF band. Then IM3 signal is combined with the main carrier signal and linearization is achieved.

A. Envelope Detector

Fig. 2 shows the reflection type of the envelope detector circuit using four Schottky diodes [4]. The optimum point of envelope signal can be obtained by adjusting the bias of each four Schottky diodes.

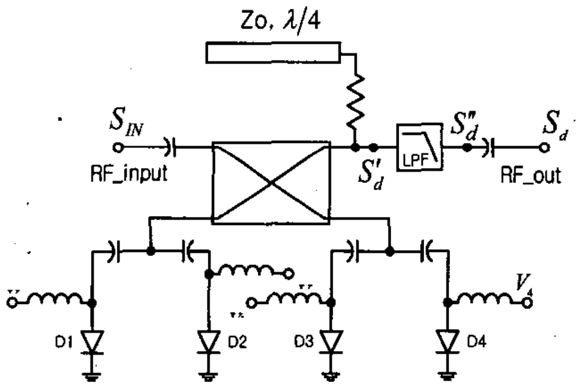


Fig. 2. A diagram of an envelope detector

The RF signal is isolated by $\lambda/4$-open stub and 50Ω resistor at the output .Only envelope signal is remained after low pass filtering.

If input signal is two-tone signal:

$$S_{IN} = \cos\omega_1 t + \cos\omega_2 t = \frac{1}{2}A(t)\cos\omega_c t \qquad (1)$$

where, $A(t) = \cos\omega_m t, \omega_m = \frac{\omega_1 - \omega_2}{2}, \omega_c = \frac{\omega_1 + \omega_2}{2}$

Then output signal S'_d consists of the second order terms due to the nonlinearity of Schottky diodes.

$$\begin{aligned} S'_d &= k(S_{IN})^2 \\ &= \frac{k}{4}\left[A^2(t)\cdot\cos^2\omega_c t\right] \\ &= k'\cdot A^2(t)\left[1+\cos 2\omega_c t\right] \end{aligned} \qquad (2)$$

After low pass filtering, high frequency term is removed, then:

$$\begin{aligned} S''_d &= k'\cdot A^2(t) \\ &= k''\left[1+\cos 2\omega_m t\right] \end{aligned} \qquad (3)$$

DC component is blocked by capacitor, then:

$$S_d = k''\cdot\cos(\omega_1 - \omega_2)t \qquad (4)$$

Then amplitude of S_d is controlled by VGA.

$$S_{gd} = g\cdot S_d = gk''\cos(\omega_1 - \omega_2)t \qquad (5)$$

where, g is a gain of VGA.

B. 3rd Order Distortion Generation

Fig. 3 shows the block diagram of the proposed 3rd order distorter. It is a part of balanced type IM3 generator (fig. 4).

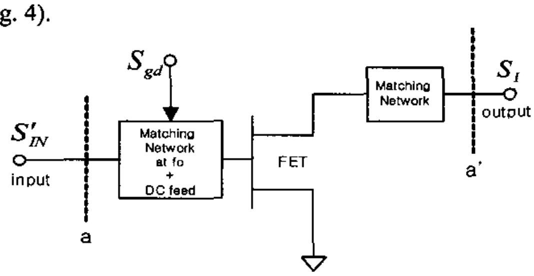


Fig. 3. 3rd order distorter using gate modulation

If two-tone signal S'_{IN} and envelope signal S_{gd} from (5) are injected into gate:

$$S'_{IN} = \frac{1}{\sqrt{2}} S_{IN} = \frac{1}{\sqrt{2}} (\cos \omega_1 t + \cos \omega_2 t) \quad (6)$$

$$\begin{aligned} S_I &= g_f \cdot S'_{IN} + S'_{IN} \cdot S_{gd} \quad (7) \\ &= g_f \cdot S'_{IN} + \frac{gk''}{\sqrt{2}} S_{IN} \cdot \cos(\omega_1 - \omega_2)t \\ &= g_f \cdot S'_{IN} + \frac{gk''}{2\sqrt{2}} [\cos(2\omega_1 - \omega_2)t + \cos(2\omega_2 - \omega_1)t] \end{aligned}$$

Then RF signal is modulated at the gate by envelope signal and it makes IM3 component at the output of FET.

From (7), IM3 component as well as main carrier signal $g_f \cdot S'_{IN}$ is included, where g_f is the gain of a FET. So as to remove the main carrier signal, the balanced type IM3 generator is suggested.

The balanced type IM3 generator is composed of two 3rd order distorters. The structure of two 3rd order distorters is exactly same. Fig. 4 is the balanced type IM3 generator.

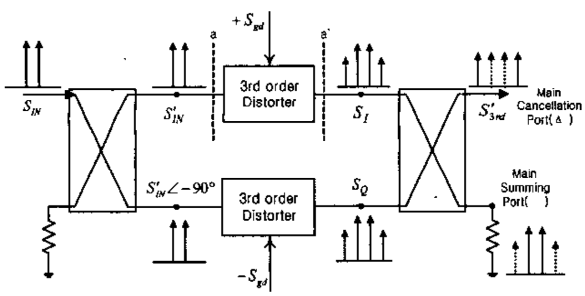


Fig. 4. Balanced type of IM3 generator for main carrier cancellation

From (7), in-phase component S_I is:

$$S_I = g_f \cdot S'_{IN} + \frac{gk''}{2\sqrt{2}} [\cos(2\omega_1 - \omega_2)t + \cos(2\omega_2 - \omega_1)t]$$

Similarly, quadrature component S_Q is:

$$\begin{aligned} S_Q &= g_f \cdot S'_{IN}\angle -90° + S'_{IN}\angle -90° \cdot (-S_{gd}) \quad (9) \\ &= g_f \cdot S'_{IN}\angle -90° \\ &+ \frac{-gk''}{\sqrt{2}} [\cos(\omega_1 t - 90°) + \cos(\omega_2 t - 90°)] \cdot \cos(\omega_1 - \omega_2)t \\ &= g_f \cdot S'_{IN}\angle -90° \\ &+ \frac{-gk''}{2\sqrt{2}} \{\cos[(2\omega_1 - \omega_2)t - 90°] + \cos[(2\omega_2 - \omega_1)t - 90°]\} \end{aligned}$$

In the following, S_I and S_Q are combined. At the cancellation port Δ, fundamental signal is cancelled due to the balanced structure. From (10), only IM3 component is remained.

$$\begin{aligned} S'_{3rd} &= \frac{1}{\sqrt{2}} (S_{I_{3rd}} + S_{Q_{3rd}}) \quad (10) \\ &= g_f \cdot S'_{IN} + g_f \cdot S'_{IN}\angle -180° \\ &+ \frac{gk''}{4} [\cos(2\omega_1 - \omega_2)t + \cos(2\omega_2 - \omega_1)t] \\ &- \frac{gk''}{4} \{\cos[(2\omega_1 - \omega_2)t - 180°] + \cos[(2\omega_2 - \omega_1)t - 180°]\} \\ &= \frac{gk''}{2} [\cos(2\omega_1 - \omega_2)t + \cos(2\omega_2 - \omega_1)t] \end{aligned}$$

III. Experimental Results

In this experiment, 10W Class AB amplifier (STA1800-37 manufactured by Sewon Teletech) is used. It is designed for Korean PCS Tx. Band (1840~1870MHz).

Fig.6 shows the experimental result of the IM3 components using balanced type IM3 generator. Main carrier signal cancellation is about 35dB.

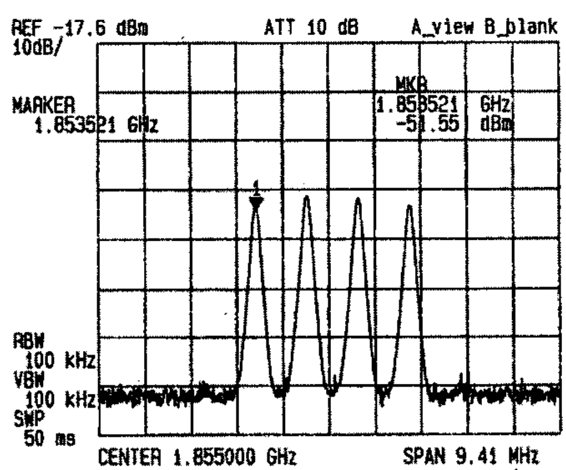
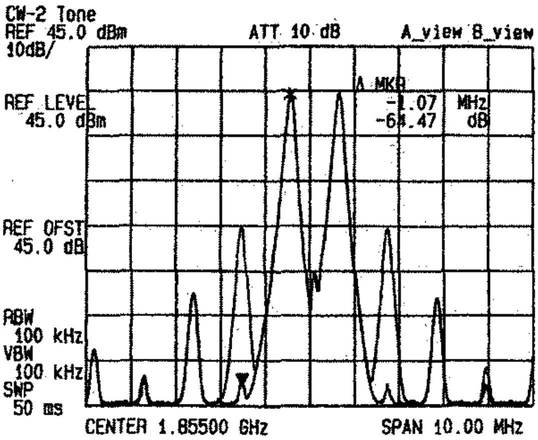
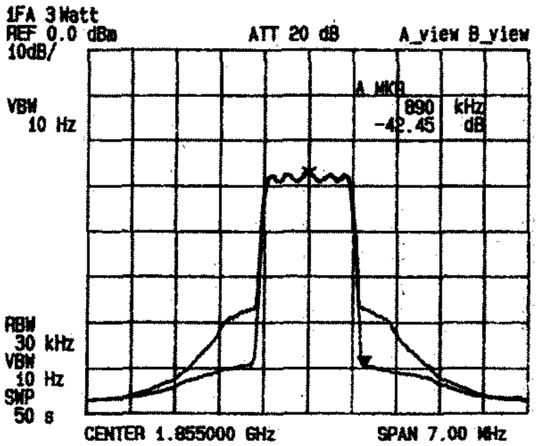


Fig. 6. Output spectrum of 3rd order distortion generator

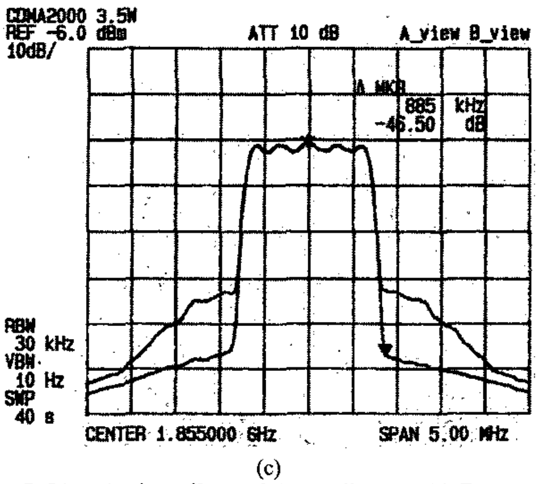
Fig.7 shows the experimental result of proposed predistorter and Fig.8 shows the ACPR improvement versus output power of CDMA 1FA signal.



(a)



(b)



(c)

Fig. 7. Linearization effects of the predistorter. (a) For a two-tone test at output power =5W. (b) For a IS-95 CDMA test at output power =3W (c) For a CDMA2000 test at output power = 3.5W

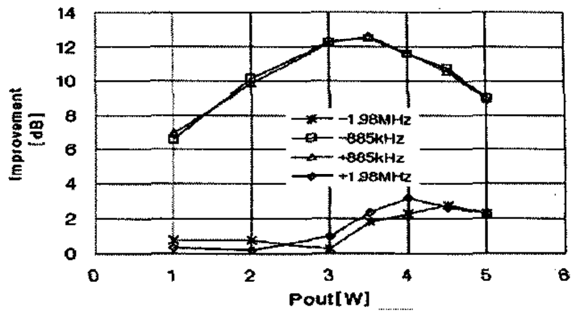


Fig. 8. Improvement of IMD versus average channel output power of IS-95 CDMA 1FA signal (peak-to-average power ratio =10dB)

VI. Conclusions

In this paper, a novel predistorter using envelope signal and a balanced type IM3 generator has been proposed. The balanced type IM3 generator has two IM3 distorters. And the structure of IM3 distorter is composed of FET. With the balanced structure, additional main carrier cancellation circuit is not required. Compare to conventional second-harmonic injection method, amplitude and phase of IM3 components can be controlled at RF band.

The experiments are performed at Korean PCS-band of 1.855GHz for a two-tone test and IS-95 CDMA signals. The experimental results show that sufficient cancellation is achieved for IM3 component. The CDMA test shows that the ACPR is improved by over 10dB and the improvement is maintained over the broad range of the power levels.

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