A Design of Predistortive High Power Amplifier using Carrier Complex Power Series Analysis

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***Abstract* – In this paper, a new carrier complex power series for linearizing the distortion effects of a HPA(High Power Amplifier) is proposed. Amplitude(AM-to-AM) and phase(AM-to-PM) nonlinear characteristics of HPA are combined to generate carrier complex power series. Inverse carrier complex power series of predistortor is also proposed. The fabricated HPA of IMT- 2000 band with a measured gain and P_{1dB} are 34.06dB and 35.4dBm. With proposed series, C/I(Carrier to Intermodulation) ratio of HPA is improved by 17.01dB(@Pout = 25.43dBm/tone) with 2-tone at 2.1375GHz and 2.1425GHz.**

I. INTRODUCTION

Transmitter in a mobile communication system or satellite communication system amplifies carrier signals with HPA and transports them to antenna. In a weakly nonlinear amplifier, its input and output voltage can be expressed using the power series. If input signals consist of two, equal-amplitude, in-band RF signals, whose frequency spacing is much smaller than their RF frequency, there are many distortion signals besides amplified input signals in output port. It is so difficult to eliminate distortion signals because of close to amplified input signals. Particularly, in a communication system which has several transmitting channels, distortion signals interfere adjacent channels. There are several methods for reducing distortion signals : input power level back-off, feedforward, feedback, predistortion, etc.

In this paper, carrier complex power series including AM-to-AM and AM-to-PM nonlinear characteristics of HPA is proposed, and inverse carrier complex power series of predistortor for linearizing HPA is also proposed.

II. Carrier Complex Power Series Analysis

Because HPA is not a linear device, output signals of HPA are not linear scaled input signals. Let consider the amplifier as two port network, it can be modeled by a power series. If two port network is memory-less, the output voltage can be represented by a power series of the input voltage as :

$$v_o = k_1 v_i + k_2 v_i^2 + k_3 v_i^3 + \cdots \qquad (1)$$

k_i in equation (1) is real number and equation (1) is obtained from amplitude distortion(AM-to-AM) of HPA. But nonlinear characteristics of HPA have amplitude and phase distortion (AM-to-PM) and equation (1) can't explain phase distortion [1][2]. If power series represent amplitude and phase distortion of HPA, linearizng method for HPA can be much simple [3]. In this paper, carrier complex power series which represent amplitude and phase distortion of HPA is derived.

To drive this approach, an IMT-2000 band HPA is designed, and AM-to-AM and AM-to-PM characteristics of HPA are obtained using CW power sweep. Consider a single unmodulated CW carrier as the input signal and than the input voltage(amplitude A, frequency ω_1, phase θ) has the form :

$$\begin{aligned} v_i &= A\cos(\omega_1 t + \theta) \\ \Rightarrow v_{is} &= Ae^{j\theta} = A\angle\theta \end{aligned} \qquad (2)$$

The input signal can be changed phasor form or exponential form. Consider a single unmodulated CW carrier as the output signal and than the output voltage (amplitude $A^\bullet$, frequency ω_1, phase $\theta^\bullet$) has the form :

$$\begin{aligned} v_o &= A^\bullet\cos(\omega_1 t + \theta^\bullet) \\ \Rightarrow v_{os} &= A^\bullet e^{j\theta^\bullet} = A^\bullet\angle\theta^\bullet \end{aligned} \qquad (3)$$

Equation (4) shows the proposed carrier complex power series of HPA and inhere f_i are complex number. In the case of a weak non-linearity, the output voltage can be represented by first three terms. And only odd-order terms of the carrier complex power series are considered.

$$v_{os} = f_1 v_{is} + f_2 v_{is}^2 + f_3 v_{is}^3 + \cdots\cdots \quad (4)$$

Output signal can be represented in complex signal domain as shown in fig. 1. Inhere input signal can be shown in real axis.

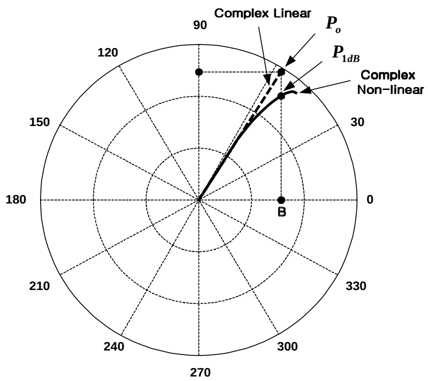

Fig. 1. Complex domain characteristics

The f_1 of equation (4) is the linear gain of complex scale which is combined fixed gain and phase shift. So, the first coefficient of the carrier complex power series is obtained from small input power level as equation (5).

$$f_1 = \frac{v_{os}}{v_{is}} = \frac{A^{\bullet}\angle\theta^{\bullet}}{A\angle\theta} \quad (5)$$

When output power level is operated in 1dB compression point (P_{1dB}), let assume input signal as $v_{is-1dB} = A_{1dB}e^{j\theta_{1dB}}$. Then ideal linear complex output signal is defined as :

$$v_{os} = f_1 \times v_{is-1dB} = f_1 \times A_{1dB}e^{j\theta_{1dB}} \quad (6)$$

And assume that real output signal is $v_{os-1dB} = A_{1dB}^{\bullet}e^{j\theta_{1dB}^{\bullet}}$ and a relationship between v_{os} and v_{os-1dB} is defined as :

$$Q = \frac{v_{os-1dB}}{v_{os}} = \frac{A_{1dB}^{\bullet}\angle\theta_{1dB}^{\bullet}}{f_1 A_{1dB}\angle\theta_{1dB}} \quad (7)$$

where v_{os-1dB} is amplitude($A^{\bullet}_{1dB}$) and phase($\theta^{\bullet}_{1dB}$) of the output signal at 1dB compression point. 1dB compression point is the point where the linear scale gain value is lower than 1dB compared to its value in the linear region.

$$f_1 + \frac{3}{4} f_3 {v_{is-1dB}}^2 = Q \times f_1$$

$$f_3 = \frac{4}{3}\frac{(Q-1)f_1}{{v_{is-1dB}}^2} \quad (8)$$

So, the carrier complex power series is written as

$$v_{os} = f_1 v_{is} + f_3 v_{is}^3 \quad (9)$$

In this paper, we propose predistortion type linearizer which transfer function is inverse carrier complex series. Fig. 2 shows the block diagram and the proposed predistortion linearizer mechanism[4].

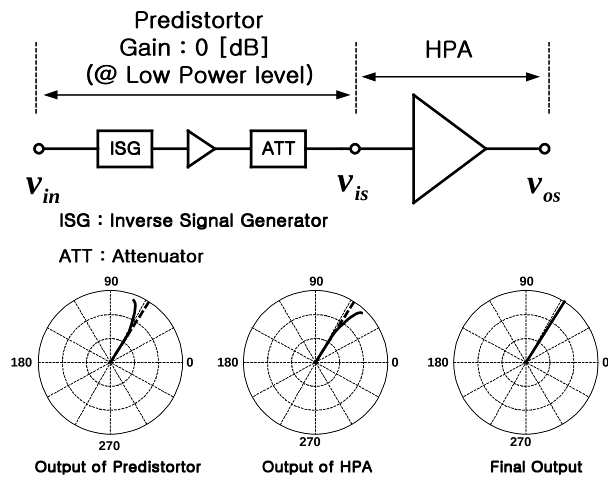

Fig. 2 The operation of the proposed predistortion method

Assume that inverse carrier complex power series is equation (10) which is transfer function to linearizing HPA, substituting equation (10) into equation (9) yields

$$v_{is} = a_1 v_{in} + a_3 v_{in}^3 \quad (10)$$

We can write equation (10) and equation (11) in the form

$$v_o = f_1 a_1 v_{in} + (f_1 a_3 + f_3 a_1^3)v_{in}^3 + 3f_3 a_1^2 a_3 v_{in}^5 + 3f_3 a_1 a_3^3 v_{in}^7 + f_3 a_4^4 v_{in}^9 \quad (11)$$

If the gain of the predistortor is 0dB at low power level, the complex linear gain of the inverse signal is defined as

$$f_1 a_1 = f_1 \quad \Leftrightarrow \quad a_1 = \frac{f_1}{f_1} = 1 \quad (12)$$

If predistorted HPA has linear complex gain, the 3rd term of equation (13) is zero. Equation (13) shows the 3rd term of inverse carrier complex series.

$$f_1 a_3 + f_3 a_1^3 = 0 \quad \Rightarrow \quad \therefore\ a_3 = -\frac{f_3}{f_1} \quad (13)$$

Inverse carrier complex power series of predistortor using carrier complex power series has the form ;

$$v_{is} = v_{in} - (\frac{f_3}{f_1})v_{in}^3 \qquad (14)$$

Inhere 3rd term is obtained from carrier complex power series of HPA. So inverse carrier complex power series of predistortor depend on carrier complex power series of HPA.

III. SIMUATION AND IMPLEMENTATION EXPERIMENTS

In this paper, we implemented 3.5watt power amplifier module whose line-up is AH1 of Watkins-Johnson, FLL171ME, FLL105MK of Fujitsu. Fig. 3 shows gain characteristics of HPA using frequency sweep. Fig. 4 shows the nonlinear characertistics of HPA using CW power sweep. The measured gain is 34.6± 0.1dB and the measured P_{1dB} is 35.4dBm.

The nonlinear output result of the modeled HPA using FFT are shown in Fig. 5, and from this figure, we can predict the distortion effect of nonlinear HPA at 2-tone or multi-tone.

The used diode in ISG(Inverse Signal Generator) is HS

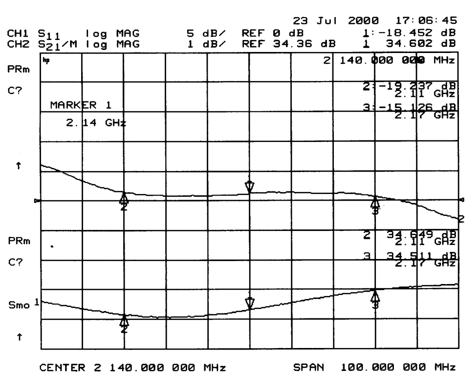

Fig. 3. S_{11}, S_{21} of HPA

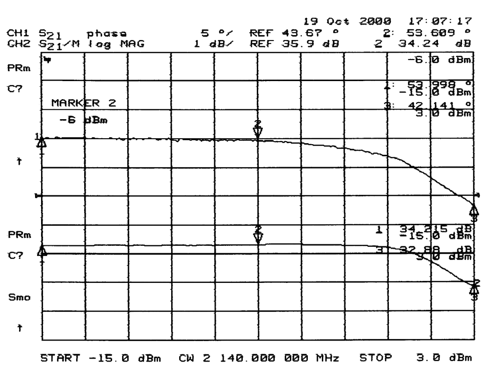

Fig. 4. The CW power sweep characteristics of HPA

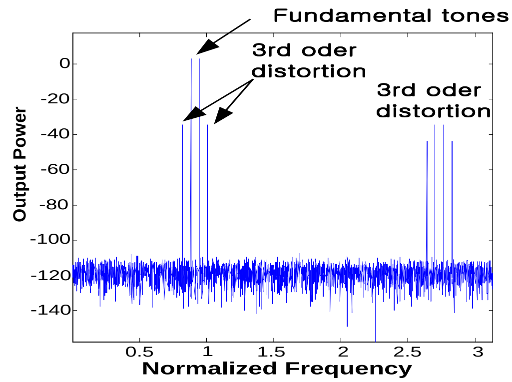

Fig. 5. Simulation result of the modeled HPA using FFT

MS-2852 of HP, the used 3-dB hybrid coupler is JX503 of Anaren. Fig. 6 shows the detail circuit of ISG. And Fig. 7 shows calculated and measured inverse carrier complex power series characteristics.

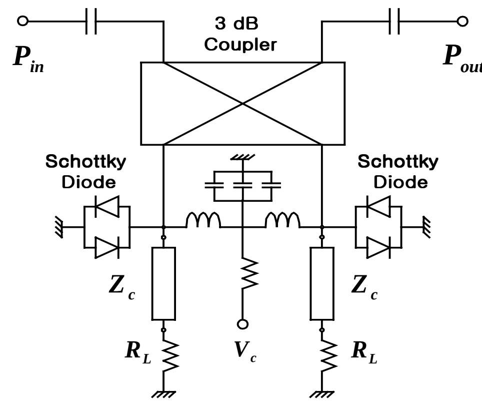

Fig. 6. The detail circuit of inverse signal generator

To confirm improvement, we perform CW power sweep and 2-tone test. Fig. 8 shows CW power sweep characteristics of HPA with predistortor. When compared with Fig.4, variation of gain and phase is much decreased. Fig. 9 and 10 show 2-tone output characteristics of HPA with and without predistortor. 2-tones frequency are 2.1375GHz, 2.1425GHz, respectively. When the output power level is 25.43dBm/tone, the improvement is about 17dB. Fig. 11 shows the improvement by comparing intermodulation distortion characteristics of HPA with and without predistortor when output level changes from 21.43dBm/tone to 28.43dBm/tone, the improvement of C/I is 5~13.34dB.

IV. CONCLUSION

In this paper, carrier complex power series including amplitude(AM-to-AM) and phase(AM-to-PM) nonlinear characteristics of HPA is proposed and inverse carrier complex power series of predistortor using the proposed carrier complex power series is also proposed. With these series, C/I of 3.5watt HPA in IMT-2000 band is improved 5~13dB. If the coefficient of power series more than 3rd order can derived, the performance of linerizer will be obviously improved.

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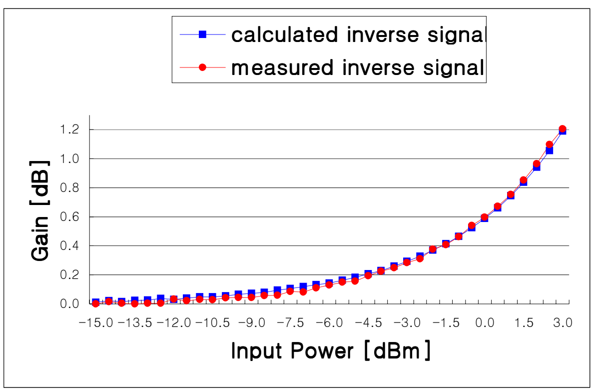
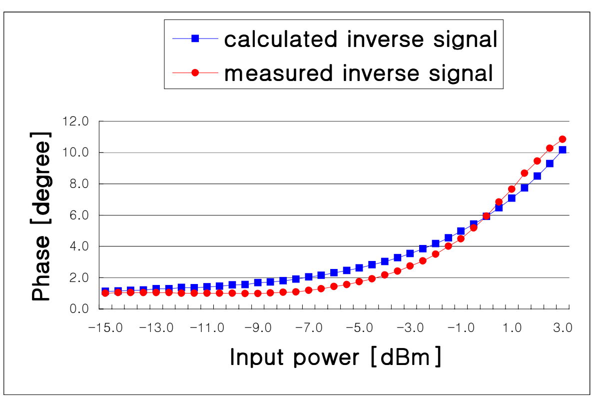


(a) Gain characteristics of inverse signal



(b) Phase characteristics of inverse signal

Fig. 7. The calculated inverse signal and the measured inverse signal

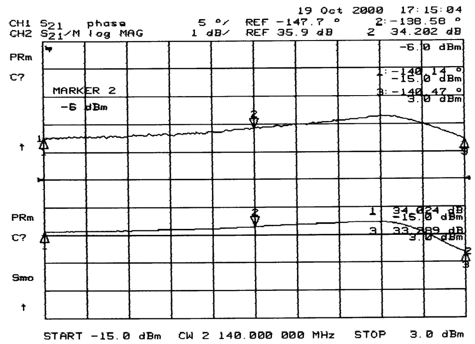


Fig. 8. The CW power sweep characteristics of HPA with predistortor

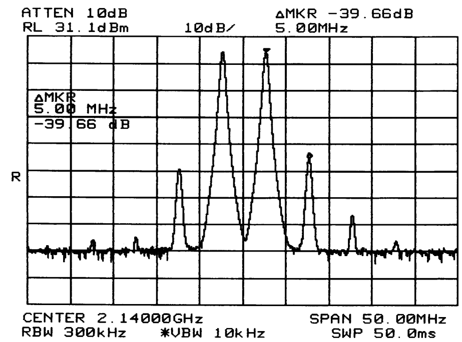


Fig. 9. The output characteristics of HPA without predistortor(@P_{out} = 25.43dBm/tone)

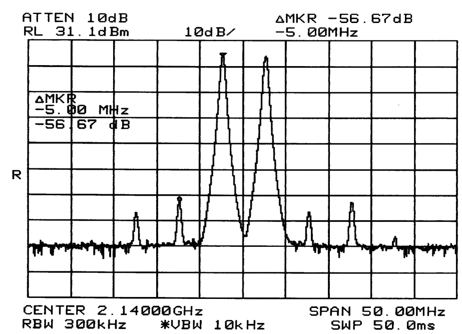


Fig. 10. The output characteristics of HPA with predistortor(@P_{out} = 25.43dBm/tone)

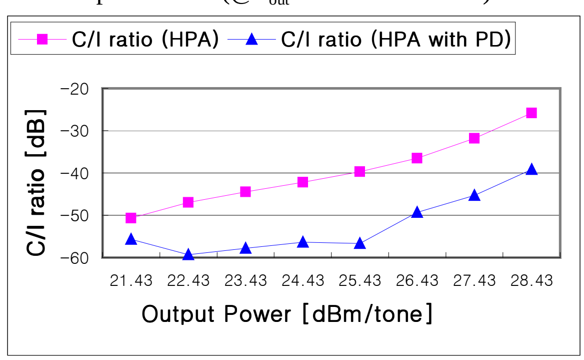


Fig. 11. The improvement characteristics of the proposed predistortor