

# Cross Cancellation Technique Employing an Error Amplifier

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**Abstract**—In this letter, we propose a new distortion cancellation mechanism for a balanced power amplifier (PA) structure using the cross cancellation technique employing an error amplifier. The proposed cross cancellation balanced linear PA is implemented in the IMT-2000 ( $f_0 = 2.14$  GHz) band. With commercial PAs with a peak power of 240 W for base-station application, the proposed system shows 18.6 dB improvement at an average output power of 40 dBm for adjacent channel leakage ratio measurement with wideband code division multiple access 4FA signal. The efficiency of the proposed structure is about 2% higher than the conventional feedforward amplifier for modulated carrier.

**Index Terms**—Balanced power amplifier (BPA), cross cancellation, feedforward technique (FFW), linearization.

## I. INTRODUCTION

HIGH power amplifiers (HPA) are the most important devices in mobile communication systems, specifically for base-station applications. However, HPA presents nonlinearities generating amplitude and phase distortions on the PA output signal due to the non-constant envelope modulations used to achieve better spectral efficiency. There are many linearization techniques to satisfy the rigid linearity requirement of the base-station HPA. Feedforward technique (FFW) is one of the most widely used techniques with excellent linearity improvement over broad bandwidth, and its signal cancellation mechanism has been used for various applications [1]–[5]. Also, there is a patent reported to reduce the nonlinear distortion of a balanced amplifier [6]. The output of a PA is sampled, and then the sampled signal is injected to the input of the other PA, linearizing total output signal based on the mechanism of pre-distortion (PD) technique. However, additional intermodulation distortion can be generated by the interaction between the injected signal and the intermodulation from the HPA itself due to the nonlinearity of the target HPA, limiting the linearizing performance.

In this letter, we propose a cross cancellation technique employing an error amplifier (CCE), of which distortion cancellation mechanism can be explained with the balanced power am-

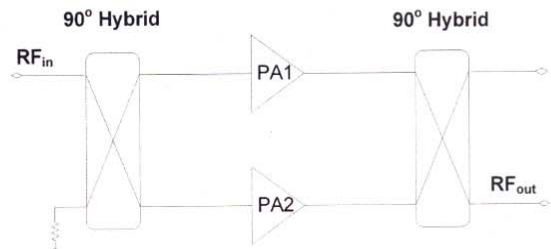


Fig. 1. Conventional balanced PA structure.

plifier (BPA) structure using the carrier cancellation loop of the FFW and cross post-distortion technique. Also a brief analysis of cancellation mechanism, main power amplifier (PA) and error power amplifier (EPA) power capability relation between CCE and FFW are presented with some experimental results.

## II. CROSS CANCELLATION TECHNIQUE EMPLOYING AN ERROR AMPLIFIER

### A. Circuit Configuration and Theory of Operation

A conventional two-way BPA structure is shown in Fig. 1. Two transistors or PAs are combined in parallel with a power divider and combiner. This structure is commonly used when higher output power is required. Since the two transistors or PAs normally have identical electrical characteristics if we have the same transistor, bias condition, and the matching network, we can infer that the samples of the distortion signal generated from PA<sub>1</sub> can be used to cancel the distortion generated by both part of the BPA when it is injected into the output of PA<sub>2</sub>.

Fig. 2 shows the whole block diagram of the proposed CCE. It consists of three major loops: the carrier cancellation loop (first loop), the BPA loop (second loop), and an error-signal injection loop (third loop). The first loop extracts the error signal from the amplified signal generated at an output of PA<sub>1C</sub> using an equal group delay signal canceller [5]. The second loop amplifies the input signal and contributes to output power. The third loop receives error signals from the first loop, injecting these distortion signals into the output of PA<sub>2C</sub> after adequate gain and phase adjustment.

The main advantage of this structure is that any error signal generation circuit such as PD is not required, since PD has limitation in predicting the transfer function of HPA, resulting in the degradation of linearization performance [7]. Also, due to the fact that two PAs of the BPA have the same nonlinearity, perfect distortion cancellation is possible over broad bandwidth.

Moreover, because of the structural similarity with FFW, this configuration has linearity improvement through wide output dynamic range. And as compared with the conventional FFW

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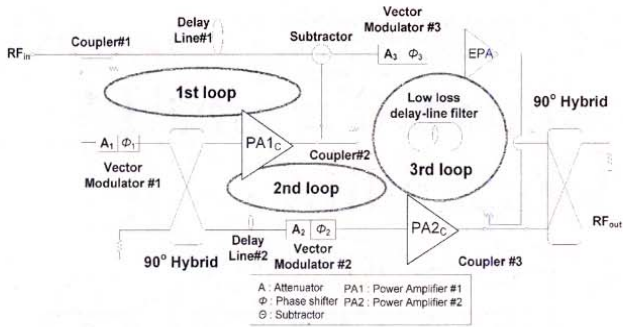


Fig. 2. Whole block diagram of the proposed CCE.

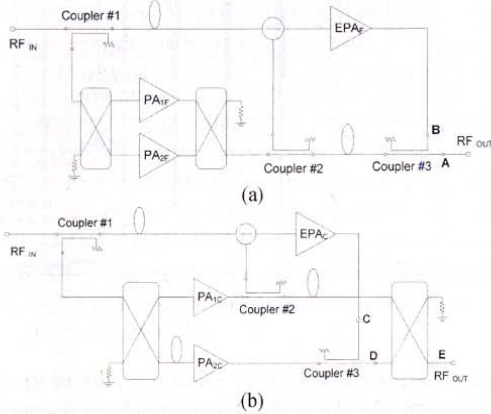


Fig. 3. Simplified block diagram. (a) Conventional FFW LPA. (b) Proposed CCE.

which has a lossy delay-line filter and couplers at the output of all main PAs introducing considerable power loss, the proposed CCE has a lossy delay-line filter (0.2 dB loss) and couplers only at the output of one part of the BPA, reducing the total output power loss considerably.

**B. Comparison of FFW LPA and CCE**

For simple and clear analysis, we simplified the block diagram of Fig. 2 as the one shown in Fig. 3. All of the directional couplers are assumed to have the same coupling coefficients of 10 dB with 0.5 dB insertion loss as a rule of thumb. From the block diagram analysis, the power capacity relation between FFW linear power amplifier (LPA) (PA<sub>1F</sub>) and CCE (PA<sub>1C</sub>) for the same total output power can be extracted as follows:

$$P_{PA1C} = P_{PA1F} - \alpha_3. \tag{1}$$

Where the subscript *C* and *F* denote cross of CCE and feed-forward, respectively.  $\alpha_3$  is an insertion loss of coupler #3. The CCE experiences smaller PA output power loss than the FFW LPA by the amount of the insertion loss of coupler #3 ( $\alpha_3$ ) for the same system output power. The loss of  $\alpha_3$  is considerable and should not be neglected because it reduces by as much as 10% (equal to 0.5 dB loss) the total system power. Therefore we could conclude that the CCE is more efficient in the sense of PA requirement than the conventional FFW LPA. From the EPA point of view, the result is opposite. That is, the required EPA output power is slightly higher for CCE than the conventional FFW LPA. However, it can be ignored because EPA power capacity is very smaller than PA in the real design.

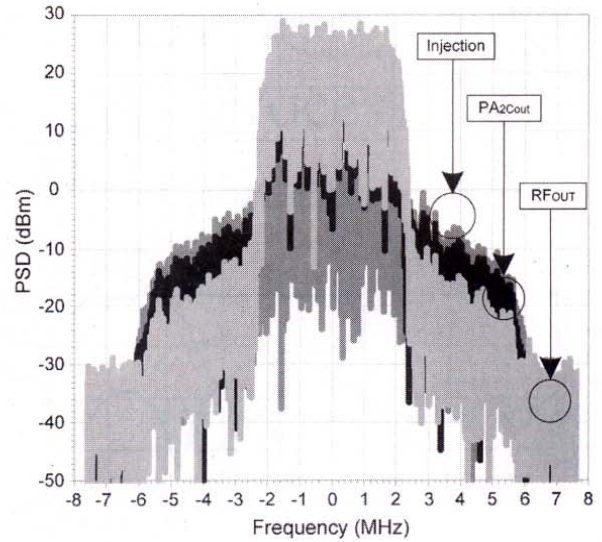


Fig. 4. ADS simulation result showing power spectral density for WCDMA 1FA signal (64DPCH).

**III. SIMULATION AND MEASUREMENT**

System simulation has been done using Agilent’s ADS2006U2. For simple verification, all of the active and passive devices are ideally modeled, except for the output power of each main PA being 120 W peak envelope power (PEP). Test signal is WCDMA 1FA (Test model 1, 64DPCH) for IMT-2000 band. Linearization result is shown in Fig. 4. Injection, PA<sub>2Cout</sub>, and RF<sub>out</sub> mean injection signal through coupler #3, PA<sub>2C</sub> output before linearization, total system output after linearization, respectively. Injection signal is from the output of the EPA. It is observed that the injection signal power is slightly higher than the adjacent channel power of output of PA<sub>2C</sub>. It is the objective of this operation for the residual component from injected error signal after cancelling distortion of PA<sub>2</sub> to cancel the distortion from the PA<sub>1</sub> at the total system output port, resulting in linear output.

We implemented the CCE for IMT-2000 band and measured the performance of the implemented linearization system with the commercial PAs of total power of 240 W PEP for base-station. PAs used in this configuration were STA2100 series commercial base-station PA of 120 W PEP of Sewon Teletech, Inc.

Fig. 5(a) shows the loop suppression result of the first loop measured with network analyzer. The equal group delay signal canceller cancels input signal more than 23.6 dB for 2.11 ~ 2.17 GHz. Bandwidth of signal cancellation could be broader than the result shown here since the operation bandwidth of the PA is limited to 60 MHz in this case. Fig. 5(b) shows the loop suppression result of the second loop monitored at the signal cancellation port (isolation port of the BPA output hybrid) with a network analyzer. It shows over 28 dB cancellation for 2.11 ~ 2.17 GHz. From the result, we can conclude that the second loop is well-balanced and operates as the BPA.

We have measured the output power spectral density of the CCE with and without an error signal injection loop using a WCDMA four-carrier signal for IMT-2000 band. Adjacent channel power ratio (ACPR) measurement results are shown in Fig. 6. Adjacent channel leakage ratios (ACLR) at a 5 and



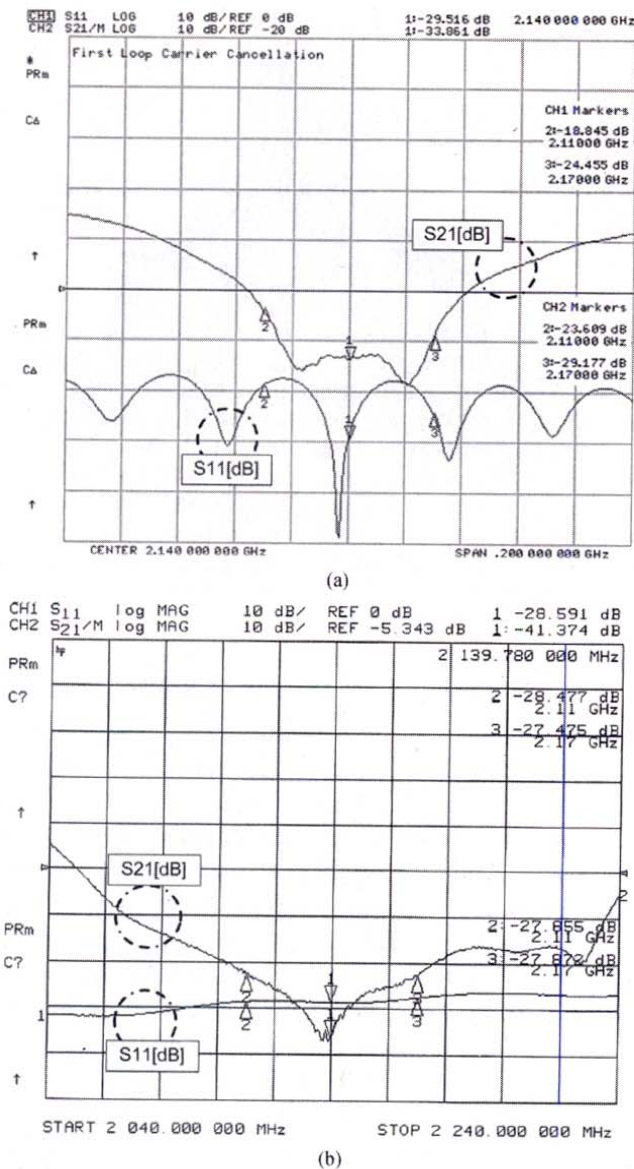


Fig. 5. Loop cancellation results measured with network analyzer. (a) Carrier cancellation loop. (b) Balanced PA loop.

10 MHz offset are shown through output dynamic range in Fig. 6(a). The proposed system shows excellent linearity throughout the dynamic range. Fig. 6(b) shows the measured power spectral density of the implemented CCE at an average output power of 40 dBm before and after cancellation. The ACLR at 5 MHz offset is  $-46.6$  dBc, an improvement of about 18.6 dB by the cancellation. Because of limitation in the spectrum measurement setup, we think that the real ACPR characteristic would be better than the measurement results.

For the WCDMA signal which has PAR of roughly 10 dB, the measured efficiency of the proposed CCE shows 9.2%, about 2% higher than the conventional FFW LPA, although the amount of improvement would be higher for the CW signal. However, the result is similar to the one that is analyzed in Section II.

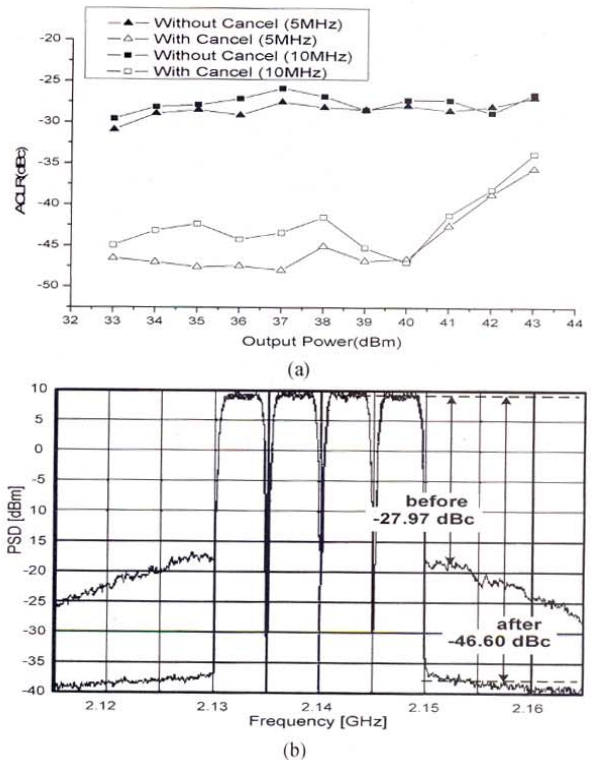


Fig. 6. ACLR characteristic and power spectral density of the CCE before and after linearization. (a) ACLR characteristics through the output dynamic range. (b) Power spectral density at an average output power of 40 dBm.

#### IV. CONCLUSION

The proposed design method of CCE can be extended to the BPA structure with more than two PAs to cancel the distortion generated by all parts of a BPA. Therefore, it is expected that the proposed system would show its superior ability as a base-station HPA in the broadband multimedia communication environment. There are several additional advantages such as relative high efficiency, excellent linearity improvement, wide dynamic range, and simple structure.

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