Feedforward Amplifier for WCDMA Base Stations with a New Adaptive Control Method

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***Abstract* — This paper describes a feedforward amplifier with a new adaptive control method. For the modulated signal with a high peak-to-average ratio, the residual output error level of the feedforward amplifier can be further reduced by adjusting the 1st loop control parameters to have an imperfect signal cancellation since an error amplifier generates less distortion in the case. For verification, a base-band signal simulation and experiments have been performed. A 30W feedforward amplifier for WCDMA base stations at 2.14GHz shows a 4dB improvement of linearization when it is controlled by the proposed method.**

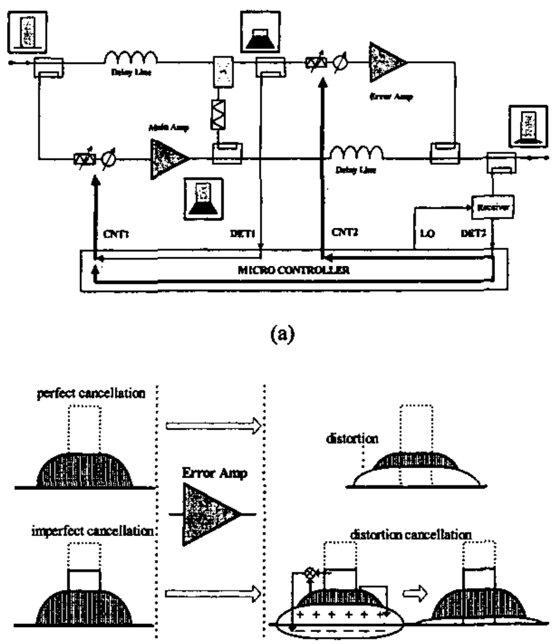
I. Introduction

Feedforward amplifier is one of the most popular linearization techniques for base station power amplifiers [1],[2]. Distortion cancellation in the feedforward amplifiers is based on subtraction of two signals. The degree of cancellation is determined by the amplitude and phase balances of the signals over the bandwidth of interest [3],[4]. The feedforward amplifiers ideally have the capability of perfect cancellation of unwanted in-band IM products. However, a high level cancellation is not easily achieved due to premature saturation of an error amplifier, as well as the gain and phase mismatches. The distortion generated by the error amplifier reduces the error cancellation capability of the feedforward amplifier [4] and it is especially significant for the case utilizing the modulated signals with complex signal statistics and high peak-to-average ratios, such as WCDMA, OFDM, etc.

It was already addressed that the perfect signal cancellation in the 1st loop of the feedforward amplifier is not an optimum for minimizing the output error level [5] since the error amplifier with an imperfectly cancelled input generates less distortion signals and the linearity of the amplifier can be improved. Therefore, we adopt a new merged control method to adjust the signal cancellation level for the best linearity of the feedforward amplifier. We control the cancellation level by monitoring both the signal cancellation level and output error level. In this paper, the operation principle is described and simulation results are presented. For the experiments, a 30W feedforward amplifier for WCDMA base stations at 2.14GHz is implemented. The optimal merged control technique is compared with conventional method [6],[7], which independently controls the 1st loop and 2nd loop cancellations. The linearization performance is further improved, when the new adaptive control is applied.

II. System Description

Fig. 1(a) shows a simplified block diagram of an adaptive feedforward system with the proposed control method. It monitors the output linearization level by directly detecting the power of the error signal after down-converted to a proper IF band and then filtered out the main signal.



(a)

(b)

Fig. 1. (a) schematic diagram of an adaptive feedforward amplifier adopting our new merged control method, and (b) input and output signals of the error amplifier for a perfect signal cancellation (upper) and for an optimum signal cancellation (lower)

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Fig. 1(b) shows the input and output signals of the error amplifier for a perfect signal cancellation and an optimum signal cancellation cases. As shown in the upper part of Fig. 1(b), the pure error signal after a perfect signal cancellation has a high peak-to-average ratio (around 20dB) and the error amplifier with the input generates significant distortions even at a very low average output power. This distortion terms degrade the cancellation performance of the feedforward amplifier. However, for the lower part of Fig. 1(b), the error amplifier with an imperfectly cancelled input signal generates less harmonic distortions due to cancellation of the distortion by the cross modulation term of the error and residual main signals. The cancellation level can be optimized by the adaptive control system shown in Fig. 1(a).

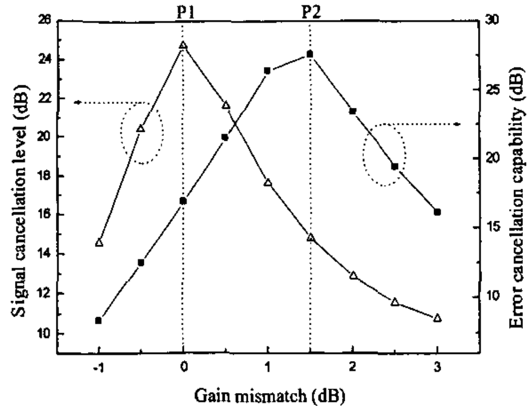
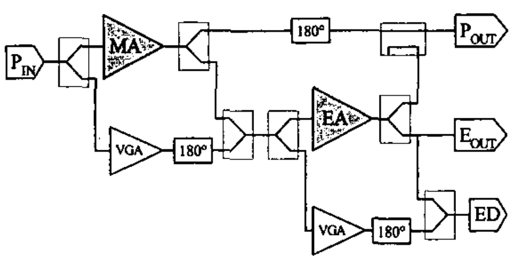
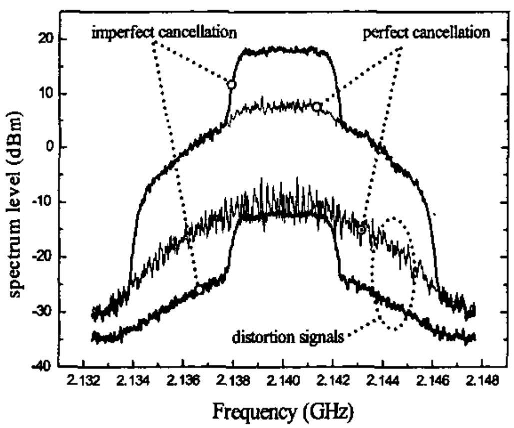


Fig. 3. Error cancellation capabilities of the feedforward amplifier (solid rectangles) and main signal cancellation levels at the error amplifier input (hollow triangles) through various gain mismatches



(a)



(b)

Fig. 2. System simulation results of the feedforward amplifier: (a) schematic diagram for system simulation setup and (b) simulation results – spectra of the output signals of an error amplifier and its respective distortion signals

III. Simulations

For verification of the distortion mechanism described in Fig. 1(b), base-band system simulations are undertaken in Agilent's ADS using 3G WCDMA design library. Fig. 2(a) shows a simplified schematic diagram for ADS system simulation to monitor the error signal(depicted by 'E_{OUT}' in Fig. 2(a)), the final output signal(depicted by 'P_{OUT}'), and the distortion of the error amplifier(depicted by 'ED'). In the simulation, WCDMA signal, which has 9-channel, chip rate of 3.84Mcps, and a peak-to-average ratio 8.6dB at 0.1% CCDF, is used. The main and error amplifiers are modeled using only AM-AM behavior of the designed amplifier to have 5W-PEP. The ratio of main to error amplifiers is set to 4:1 and coupling ratio of the output coupler is laid to be 10dB, which are generally used values. To investigate the distortion level of the error amplifier, another signal cancellation loop at the error signal path is employed as shown in Fig. 2(a). The pure distortion of the error amplifier can be extracted by controlling the VGA to have the minimum correlation between the reference error signal and distortion term of the error amplifier probed in port 'ED'. For the perfect signal cancellation, the main signal is completely suppressed at the 1st cancellation loop and for the imperfect signal cancellation, the 1st loop is adjusted to have minimum distortion from the error amplifier.

The simulated spectra of the output signals and extracted distortion signals for both cases are shown in Fig. 2(b). As shown, there is about 10dB reduction in the distortion signal generated by the error amplifier when the optimum signal cancellation is employed, resulting in substantially better linearity characteristics of the overall feedforward amplifier. Fig. 3 shows the error cancellation capabilities of the feedforward amplifier and residual main signal levels for the error amplifier input through various gain mismatches. The perfect signal cancellation point indicated by 'P1' and optimum cancellation level pointed by 'P2' are separated by gain mismatch of about 1.5dB. And the residual main signal level is increased by about 10dB for the optimum signal cancellation.

IV. Experiments

The adaptive control algorithm described in section I and II is implemented in the feedforward amplifier operated at 2.14GHz. The overall main amplifier module has 65dB gain and delivers 47dBm of average output power at 30dBc IMSR at offset 2.5MHz with WCDMA single carrier signal. The error amplifier module has more than 65dB gain and its power capacity is 0.25 times of the main amplifier. In Fig. 1(a), 'DET1' port detects the signal cancellation level and 'DET2' port detects the residual error level in IF band with proper filtering. For conventional case, the 'CNT1' and 'CNT2' control the vector modulators using 'DET1' and 'DET2' detection signals, respectively.

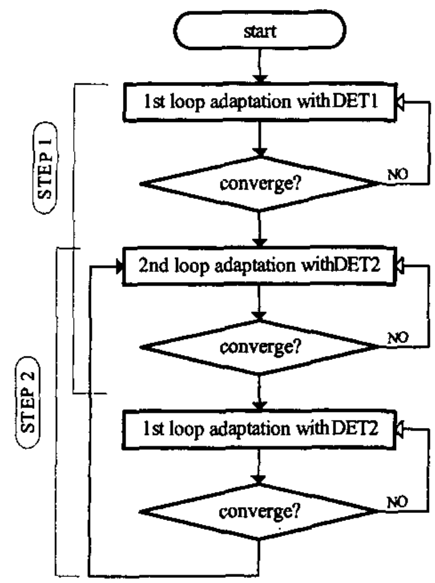


Fig. 4. Simplified flowchart of the adaptive control method

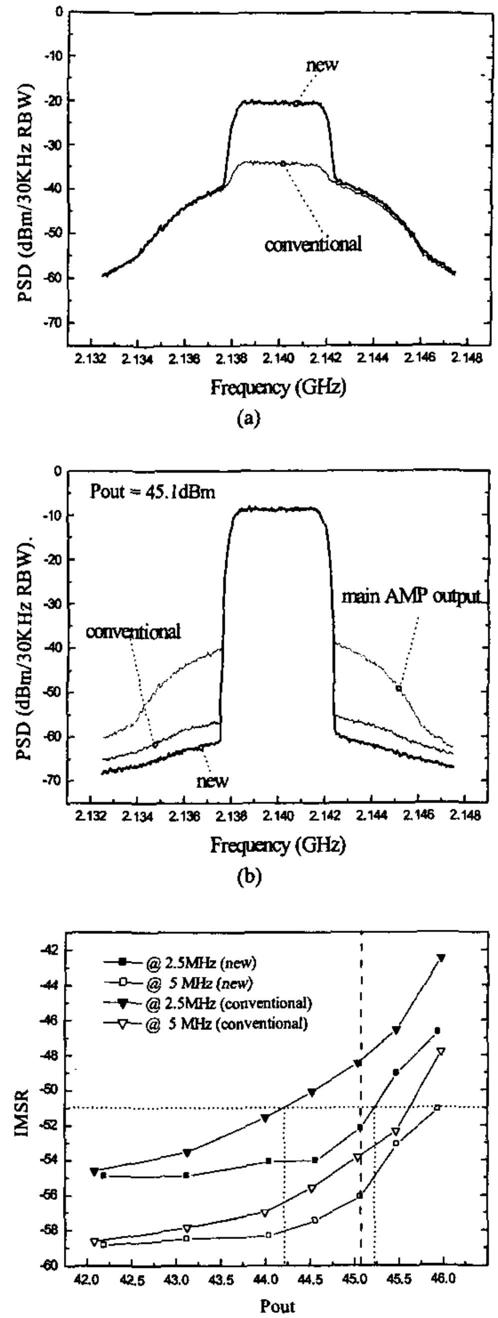


Fig. 5. Adaptive control results with 3G WCDMA signal for the new linearization method and the conventional one: (a) the PSDs of the error amplifier output, (b) the PSDs of the feedforward amplifier output, and (c) output IMSRs (at 2.5 and 5MHz offsets) for average output power sweep

A flow of adaptation process for the proposed linearization method is shown in Fig. 4. The control algorithm is based on the adaptive delta-modulated power gradient [7]. The adaptation method consists of two steps. The step 1 is required to search for initial values of the two vector modulators ('CNT1', 'CNT2') and the 1st loop and 2nd loop adaptations are identical to the conventional case. The step 1 makes a perfect signal cancellation. After convergence of step 1, the control is handed over to step 2. In step 2, the control parameters of both 1st loop and 2nd loop are simultaneously adjusted to optimize the error cancellation level by monitoring 'DET2'. After convergence of step 2, the signal cancellation level is optimized and the error level of output is reduced.

The experimental results for the conventional control and our new adaptation are shown in Fig. 5. The conventional method has only step 1 with pilot tone. The spectra of two cases are quite different, -52dBc of IMSR at 2.5MHz offset for the proposed method and -48dBc for the conventional case (see Fig. 5(a) and (b)), which is about 4dB improvement. Fig. 5(c) compares IMSRs for the two cases with sweeping the average output power. When an IMSR is specified to -51dBc at 2.5MHz offset, the amplifier adapted by the proposed merged control method delivers about 45dBm of the average output power and the amplifier with the conventional method has less than 44dBm, which is about 1dB improvement of average output power. The residual main signal delivered by the error amplifier doesn't seriously perturb the output signal, because it is still substantially lower than the main signal delivered by the main amplifier.

V. CONCLUSIONS

In this paper, a new adaptive control method for feedforward amplifiers using an imperfect signal cancellation has been proposed. The error amplifier with the input generates less distortion and the error cancellation capability of the feedforward amplifier is enhanced. The basic operation mechanism has been explained and verified by system simulation. For experimental verification, an adaptive WCDMA feedforward amplifier with 30W of the average output power at 2.14GHz was implemented. The experimental results showed a superior performance for the proposed method compared to the conventional control. It delivers more than 1dB of output average power for a fixed -51dBc of IMSR at 2.5MHz offset and more than 4dB improvement of IMSR for a fixed average 45dBm. These improvements are achieved without using any additional hardware.

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