A New Adaptive Feedforward Amplifier Using Imperfect Signal Cancellation

Bumman Kim, Young Yun Woo, Youngoo Yang, Jaehyok Yi, Joongjin Nam, and Jeonghyeon Cha

Department of Electronic and Electrical Engineering and Microwave Application Research Center, Pohang University of Science and Technology, San 31 Hyoja-Dong, Nam-Gu, Pohang, Kyungbuk, 790-784, Republic of Korea
e-mail: bmkim@postech.ac.kr

Abstract—**This paper describes a new adaptive feedforward amplifier for WCDMA system using an imperfect signal cancellation. Due to the complicated signal statistics, the distortion generated by the error amplifier is significantly reduced by the imperfect signal cancellation. Therefore, the performances of feedforward amplifier are improved with this new adaptation technique, especially for the modulated signals with a high peak-to-average ratio. For verification, a 2.14 GHz feedforward amplifier with 80 W output power has been implemented and tested with digital control circuits. The results, compared to the perfect signal cancellation, show more than 7 dB improvement of ACLR at 80 W output power. The efficiency is also improved from 7.5 % to 9 % at the same ACLR's.**

I. Introduction

As wireless system evolves from second-generation to third- or fourth-generation, the linearity, efficiency, and bandwidth requirements for the power amplifiers become tighter. Many techniques, including feedforward, envelope feedback, manifold types of predistorters, etc., have been employed to effectively satisfy these performance requirements and to reduce production cost for various system applications. Feedforward is generally known as the best performing linearization technique for linear power amplifiers at RF band. Many previous works for various implementations and analyses of the feedforward type linearizers have been reported [1]-[12]. Distortion cancellation in the feedforward amplifiers is based on the subtraction of two signals. The degree of cancellation is mainly determined by the amplitude and phase balances of the signals over the bandwidth of interest [2],[3]. However, due to the high peak-to-average ratio of the error signal extracted at the first loop, the error amplifier is easily saturated and the distortion generated by the error amplifier limits the error cancellation capability of the feedforward amplifier [4]. This problem becomes more serious as the peak-to-average ratio of a signal or number of carriers are increased. Hence, a larger-size error amplifier is required to amplify the error signal without generating any significant distortion. But, the large-size error amplifier causes many problems with cost, heating, efficiency, etc.

It was already addressed that the perfect signal cancellation in the first loop of the feedforward amplifier is not an optimum for minimizing the output error level [5]. This means, in other words, that the error amplifier can generate less distortion signals, when the input signal with imperfect signal cancellation is applied. To utilize this benefit, a new merged *adaptive control method*, which optimizes the signal cancellation level for the best linearity of the feedforward amplifier, has been implemented. For the experiments, a 2.14 GHz digitally controlled feedforward amplifier with 80 W output power for WCDMA base stations has been built and tested. The optimally merged control technique has been compared with conventional method [6],[7], using down-link 16-channel WCDMA signal.

II. New Adaptive Control Scheme

To adopt the beneficial effects of the imperfect signal cancellation on suppressing the distortion generated by the error amplifier with very simple manner, the usual 4 adaptive control parameters(2 for the 1st loop and other 2 for the 2nd loop controls) of the feedforward amplifier are sequentially adjusted to minimize the final output error level. Fig. 1 shows the simplified block diagrams to compare a new adaptation technique using the im-

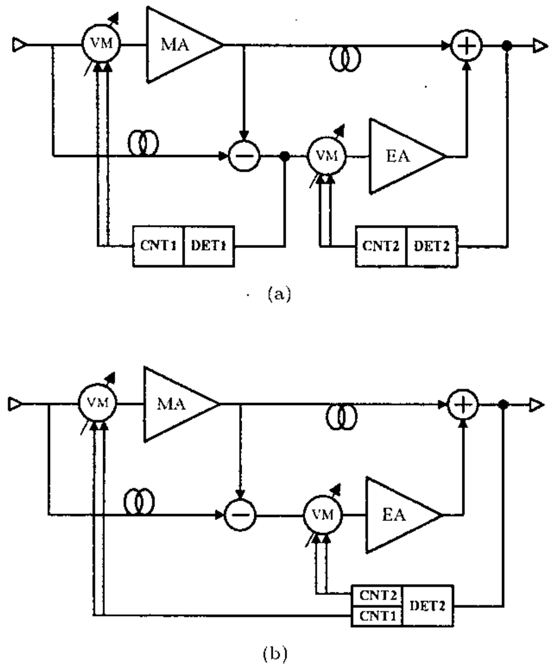

Fig. 1. Simplified block diagrams of adaptive feedforward amplifiers with (a) the conventional and (b) the new adaptation methods.

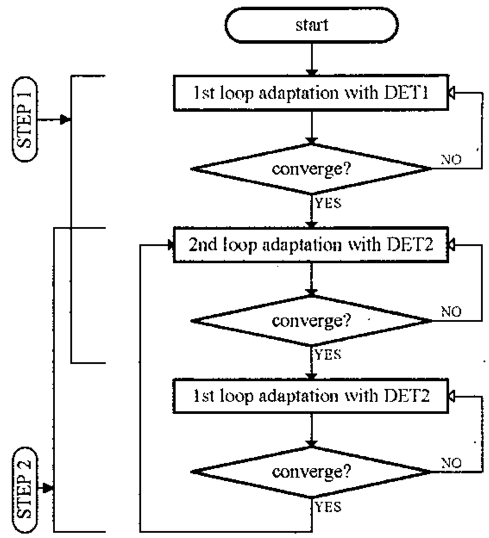

Fig. 2. Flowchart of the proposed adaptation process.

perfect signal cancellation with a conventional one. The conventional method in fig. 1(a) is also used to get an initial adaptation step for the new adaptation technique shown in fig. 1(b).

An execution flow of the proposed adaptation process is shown in fig. 2. The algorithm used in this experiment is based on the modified power gradient with an adaptive delta-modulation [6]. The adaptation flow consists of two steps. Step 1 is required to search for the initial control voltages of the two vector modulators, and is identical to the conventional adaptation. After convergence of step 1, the control is handed over to step 2. Then, all control parameters of both 1st loop and 2nd loop are sequentially adjusted to optimize the error cancellation level monitored using **DET2**.

III. Implementation and Experimental Results

A. *Implementation*

To validate the proposed adaptive control scheme, a 2.14 GHz adaptive feedforward amplifier with 80 W average output power for down-link 16-channel WCDMA signal has been implemented. The overall main amplifier module has been designed to deliver more than average 100 W WCDMA signal with 30 dBc IMSR at 2.5 MHz offset and 65 dB of gain. The final stage of the main amplifier has been configured to have 720 W PEP by 4-way combination of 180 W PEP amplifiers using motolola's MRF21180 LDMOSFETs. The error amplifier module has more than 65 dB of gain and its power capacity is 4 times less than that of the main amplifier.

For the system, the vector modulator has been fabricated by the series connection of a reflection type attenuator and a phase shifter using 3 dB hybrid couplers, PIN diodes, and varactor diodes. The 1st loop delay has been compensated by a coaxial delay line and the 2nd loop delay has been compensated by a delay filter, which has about 15 ns of delay and 0.9 dB of loss. For the conventional and new adaptation controls, a pilotless error power detection method is employed. For the detection, the RF signal is down-converted to a proper IF band to filter the main signal components out. The adaptation algorithms described in section II were coded and installed. The adaptive control programs have been run using a low cost micro-controller based on intel's 80C196KC CPU, 2-channel ADC's, and 4-channel DAC's. Many other digital in/out ports are also controlled to detect faults, to control PLL frequency synthesizer for error detection, to provide alarm and protection signals, and so on.

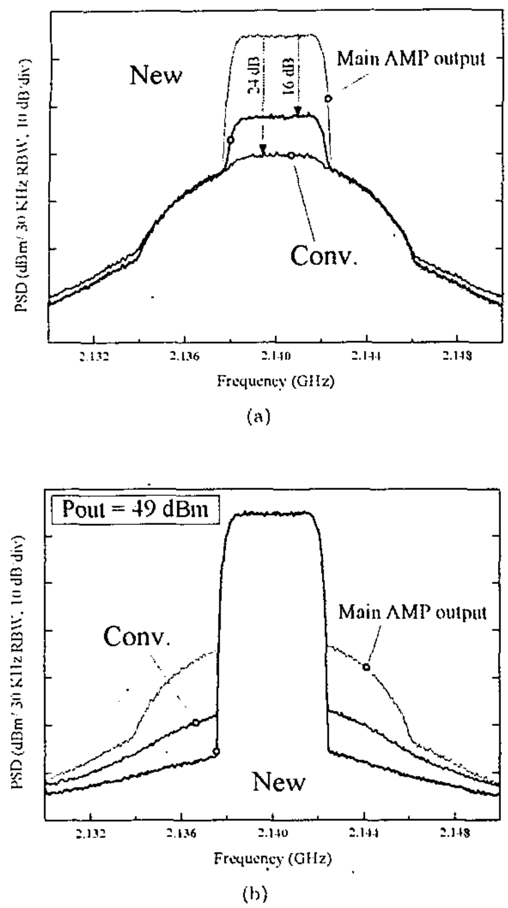

Fig. 3. PSD's with single-carrier WCDMA signal for both the new and the conventional adaptation methods at 49 dBm output power: (a) the signal cancellation level and (b) the error cancellation level.

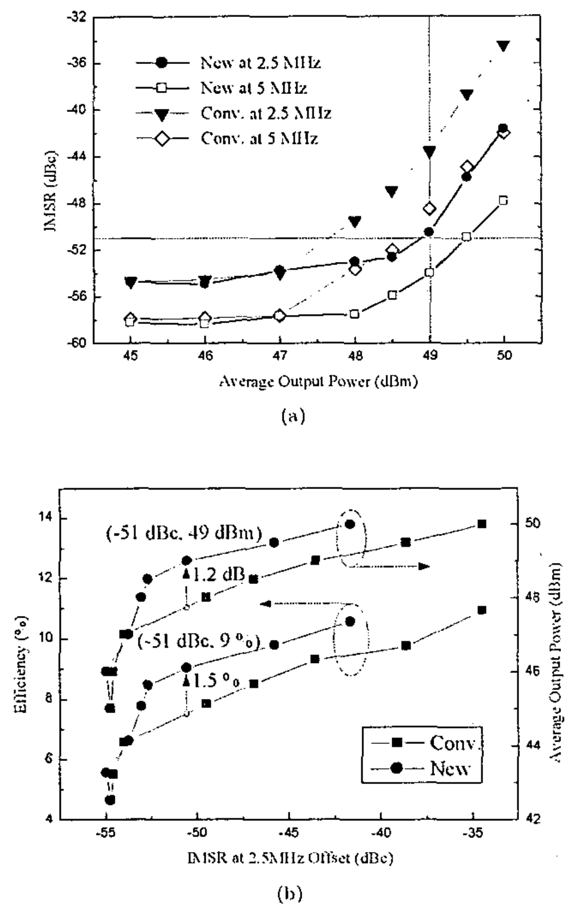

Fig. 4. Adaptive control results (a) for IMSR's at 2.5 and 5 MHz offsets versus average output power and (b) for efficiency and average output power versus IMSR at 2.5 MHz offset.

B. Experimental Results

Experiments have been performed to verify the new adaptive control scheme based on the imperfect signal cancellation. Conventional and new adaptive control algorithms have been executed to optimize the linearity of a 2.14 GHz feedforward amplifier with 80 W output power using WCDMA signal. The results for the conventional and new adaptation controls are compared in fig. 3 and fig. 4. Fig. 3 shows the PSD's of two cases, which are visualizing signal cancellation levels at fig. 3(a) and error cancellation levels at fig. 3(b). Due to the imperfect signal cancellation, the PSD of the new adaptive control method is 8 dB higher than that of the conventional case (see fig. 3(a)). The error cancellation is improved by 7 dB to -51 dBc from -44 dBc of IMSR's at 2.5 MHz offset at 49 dBm of the average output power (see fig. 3(b)). Fig. 4 summarizes the overall adaptation experiments with single-carrier WCDMA signal. Fig. 4(a) compares IMSR's at 2.5 MHz and 5 MHz offsets of the two cases for the various average output power levels. The amplifier adopting the proposed merged control method delivers about 49 dBm of the average output power with -51 dBc IMSR specification, which is about 1.2 dB improvement of average output power compared with the conventional case. Fig. 4(b) shows the efficiency and average output power for the various IMSR's at 2.5 MHz offset. The efficiency of the new method at IMSR -51 dBc is about 9 %, while that of the conventional control is 7.5 %. The optimum imperfect cancellation point can be easily found by referring to the minimum output error level during the adaptive control and the new adaptation algorithm always converges to the optimum point.

IV. Conclusions

For the signals with a high PAR, the premature saturation of the error amplifier of the feedforward system can be a major performance degrading source. Due to the interaction between the signal and IM terms, the distortion signal generated by the error amplifier are affected by the main signal cancellation level and can be significantly reduced with a properly imperfect signal cancellation. To adopt the benefit of the imperfect signal cancellation to linearization, a new adaptive control method for feedforward amplifiers with merged control of the 1st and 2nd loops has been proposed.

To validate the new adaptive control method, a 2.14 GHz digitally-controlled feedforward amplifier with 80 W output power for the WCDMA base stations has been designed and implemented. The optimal merged control technique has been compared with the conventional method using WCDMA signal. The new method can improve the linearity to a considerable amount, which backs up the proposed adaptation method. This significant linearity improvement using the proposed control scheme can be easily acquired without any additional hardware. This adaptation method can be applied to any feedforward amplifiers transmitting the signals with a high PAR.

Acknowledgement

The authors would like to thank Charles Gentzler and Ki-Young Nam at Paradigm Wireless Systems for donating the delay filter and Doo Hun Choi at Danam Communications for many helpful informations. This work was supported by the Agency for Defense Development and BK21 project of the Ministry of Education in Korea.

References

[1] J.K. Cavers, "Adaptation Behavior of a Feedforward Amplifier Linearizer," *IEEE Trans. Vehicular Technology*, Vol. 44, No. 1, Feb. 1996.

[2] Y.K.G. Hau, V. Postoyalko, and J.R. Richardson, "Sensitivity of distortion cancellation in feedforward amplifiers to loops imbalances," *in IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1695-1698, June 1997.

[3] R.J. Wilkinson, and P.B. Kenington, "Specification of Error Amplifiers for Use in Feedforward Transmitters," *in IEE Proc-G.*, Vol. 139, No. 4, pp. 477-480, Aug. 1992.

[4] Y. Yang, Y. Y. Woo, J. Cha, and B. Kim, "Linearity Optimization of the Feedforward Amplifier for WCDMA System Using a Mathematical Model Based on the Base-Band Signal Simulation," *submitted to 2002 European Microwave Conf.*, 2002.

[5] C.L. Larose and F.M. Ghannouchi, "Pilotless adaptation of feedforward amplifiers driven by high-stress signals," *in IEEE RAWCON Dig.*, pp. 81-84, Aug. 2001.

[6] Y. Yang, Y. Kim, J. Yi, J. Nam, B. Kim, W. Kang, and S. Kim, "Digital Controlled Adaptive Feedforward Amplifier for IMT-2000 Band," *in IEEE MTT-S Int. Microwave Sympo. Dig.*, pp. 1487-1490, Jun. 2000.

[7] G. Zhao, F.M. Ghannouchi, F. Beauregard, and A.B. Kouki, "Digital implementations of adaptive feedforward amplifier linearization techniques," *in IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 543-546, June 1996.

[8] J.S. Kenney and A. Leke, "Design Considerations for Multicarrier CDMA Base Station Power Amplifier," *Microwave Journal*, Vol. 42, No. 2, pp. 76-86, Feb. 1999.

[9] R.G. Meyer, R. Eschenbach, and W.M. Edgerley, "A Wide-Band Feedforward Amplifier," *IEEE Journal of Solid State Circuits*, Vol. 9, No. 6, pp. 422-428, Dec. 1974.

[10] A. Katz, "SSPA Linearization," *Microwave Journal*, Vol. 42, No. 4, pp. 22-44, 1999.

[11] S. Narahashi and T. Nojima, "Extremly Low-Distortion Multi-Carrier Amplifier Self-Adjusting feedforward(SAFF) Amplifier," *in IEEE Int. Commun. Conference Proceedings*, pp. 1485-1490, 1991.

[12] K. Horiguchi, M. Nakayama, Y. Sakai, K. Totani, H. Senda, Y. Ikeda, and O. Ishida, "A High Efficiency Feedforward Amplifier with a Series Diode Linearizer for Cellular Base Stations," *in IEEE MTT-S Int. Microwave Sympo. Dig.*, pp. 797-800, May 2001.