Adaptive Control Method for a Feedforward Amplifier

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Abstract

A feedforward amplifier, which is composed of several components, is an open loop system. Therefore, feedforward amplifiers are apt to deteriorate the performance according to the environmental changes even though the cancellation performance and the linearization bandwidth of feedforward systems are superior to other linearization methods. A control method is needed for maintaining the original performance of feedforward amplifiers or to keep the performance within a little error bounds. In this paper, an adaptive control method, which has a good convergence characteristic and is easy to implement, is suggested. The characteristics of the suggested control method compare with the characteristics of other control methods and the simulation results are presented.

Key words : feedforward, cancellation performance, linearization bandwidth

Ⅰ. Introduction

Feedforward has several advantages in the linearization performance and the linearization bandwidth over other linearization methods, such as feedback, predistortion and LINC(Linear amplification with Nonlinear Components)[1]. Therefore, feedforward power amplifiers are widely used in mobile communication systems. Feedforward amplifiers are composed of many components. This architecture causes the performance degradation of linearization loops of a feedforward amplifier especially when the circumstances surrounding the feedforward amplifier and the characteristic of the amplifier's components are changed. Furthermore, since feedforward amplifiers are open loop systems, the performance could be easily deteriorated unless the outputs of linearization loops of the feedforward amplifier are monitored and the amplitude and the phase balance of linearization loops are controlled. It is no doubt that feedfoward amplifiers are recognized to take the observation and control of the output of linearization loops in order to avoid performance degradation.

A controller can adjust the amplitude and the phase of a linearization loop except for the delay time. Fig. 1 shows the configuration of a feedforward amplifier. The two-tone spectrum shown in fig.1 explains the operation principle of a feedforward amplifier. The point of monitoring the operation of linearization loops is also shown in fig. 1. The A' and B' are the observation points of the first and the second linearization loop, respectively. The point A and B are the inputs of the first and the second linearization loop, respectively. The principle of monitoring and controlling a linearization loop is to adjust the amplitude and the phase of the linearization loop so that the minimum power could be detected at the monitoring point. When the first linearization loop ideally operates, the controller detects the minimum power of input signals of the feedforward amplifier at the monitoring point A' shown in fig. 1. And the minimum power of distortion signals is detected at point B' shown in fig.1 when the second loop's operation is ideal.

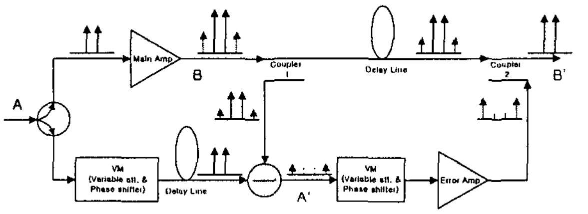


Fig.1 The configuration and the operation principle of a feedforward amplifier

In general, a pilot signal is used for monitoring and controlling linearization loops. A controller can detects input signals and IMD(Intermodulation Distortion) signals when the controller knows the frequency of input signals. If the controller of a feedforward amplifier generates a pilot signal, then the controller already knows the frequency of the pilot signal. Therefore, the feedforward amplifier using a pilot signal in order to control linearization loops need not to interface with the system controller which provides system information, such as the frequency of input signals, on/off signal and so on.

Several control methods are studied[2-5]. [2] uses LMS algorithm and has the advantages of doing the control operation without a pilot and system information, however the step size of control voltages is constant and a time delay is carefully considered to obtain a correct correlation. [5] uses a modified LMS in frequency domain. This method can change the step size of control voltages according to a detected error power and use the simple way of finding a control direction. In this paper, the steepest descent algorithm based on the gradient method in the spectral domain, which has a good convergence characteristic and is easy to implement, is suggested. The characteristics of the suggested control method compare with the characteristics of [5] and the simulation results are presented.

II. Control method

Fig. 2 shows the operation of an adaptive filter. In fig. 2, y(n) is the actual response, d(n) is the desired response and e(n), the difference between d(n) and y(n), is the error signal. W(n) is the tap weight of an adaptive filter. An adaptive filter must adjust the filter's tap weight, W(n), in order to generate the minimum error signal. A system shown in fig. 2 can be the first and the second linearization loop. In a feedforward amplifier, y(n) is the detected power of a pilot(or signal/IMD) signal at the monitoring port and W(n) is the control voltage of a vector modulator(or a phase shifter and a variable attenuator).

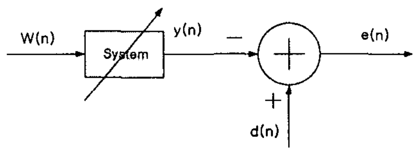


Fig. 2 The operation of an adaptive filter

The steepest descent algorithm based on a gradient method in order to determine an adaptive filter's tap weights can be written as

$$W(n+1) = W(n) - \mu \frac{\partial P(n)}{\partial W(n)} \quad (1)$$

where μ is the step size parameter and $P(n)$ is the detected power of a pilot(or signal/IMD) signal. The voltage control direction of components used for adjusting the amplitude and the phase of a linearization loop is the negative of the gradient of $P(n)$. In eq(1), the filter's tap weights are updated by the gradient of $P(n)$ with a constant increment ΔW_i, which is the initial increment of a filter's tap weight. If the dependence on the detected power of a pilot(or signal/IMD) signal is included in eq(1), then eq(1) can be modified as

$$W(n+1) = W(n) - \mu\alpha(n) \frac{\partial P(n)}{\partial W(n)} \quad (2)$$

where $\alpha(n)$ is the detected error size parameter depending on the detected pilot(or signal/IMD) signal level. The $\alpha(n)$ can be defined as

$$\alpha(n) = P(n) - P_d \quad (3)$$

where P_d is the desired power of a pilot signal when the linearization loop is properly controlled. In eq(2), the step size of control voltages is depending on the detected pilot power, that is, the detected error size parameter $\alpha(n)$. In eq(2), however, the gradient of $P(n)$ is calculated with a constant increment, ΔW_i. Thus the dependence on the detected error signal level isn't included in eq(2) effectively. If the increment of the gradient of $P(n)$ can be changed by the detected error size parameter $\alpha(n)$, then the adaptive increment of a filter's tap weight, ΔW_a, can be written as

$$\Delta W_a(n) = \Delta W_i \alpha(n) \tag{4}$$

And the eq(2) is modified as

$$W(n+1) = W(n) - \mu \frac{\partial P(n)}{\partial W_a(n)} \tag{5}$$

If a controller adjusts the real and the imaginary part of signals in a linearization loop instead of controlling the amplitude and phase of the linearization loop, then the filter's tap weights can be determined by the following equations.

$$W_{re}(n+1) = W_{re}(n) - \mu \frac{P(W_{re}(n) + \Delta W_{a\_re}, W_{im}(n)) - P(W_{re}(n), W_{im}(n))}{\Delta W_{a\_re}(n)} \tag{6}$$

$$W_{im}(n+1) = W_{im}(n) - \mu \frac{P(W_{re}(n), W_{im}(n) + \Delta W_{a\_im}) - P(W_{re}(n) - W_{im}(n))}{\Delta W_{a\_im}(n)} \tag{7}$$

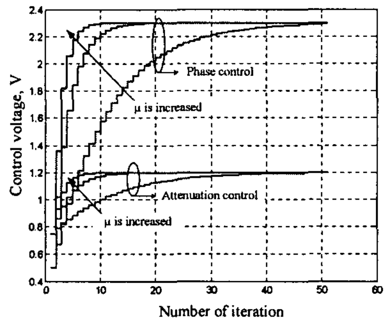
where $W_{re}(n)$ and $W_{im}(n)$ are the real and the imaginary part of a filter's tap weights respectively. $\Delta W_{a\_re}(n)$ and $\Delta W_{a\_im}(n)$ are the adaptive increments of the real and imaginary part which are depended on a detected error power.

Ⅲ. Simulation Results

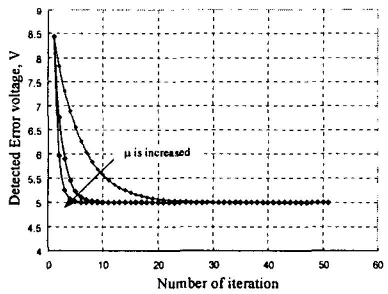
We simulate the performance of the control method mentioned previously. We use the following function for generating the error surface used in the simulation.

$$P(V_p, V_a) = P_{offset} + (V_p - V_{p\_t})^2 + (V_a - V_{a\_t})^2 \tag{8}$$

where $P(V_p, V_a)$ is the detected pilot power when the phase control voltage and the attenuation control voltage are V_p and V_a, respectively. P_{offset} is the offset power of a pilot signal and represents the desired pilot power. V_{p_t} and V_{a_t} are the optimum control voltages for phase and attenuation, respectively. In simulating the performance of control methods described previously, we use P_{offset} =5V, P_{p_t} =2.3V, P_{a_t} =1.2V and the initial phase and attenuation control voltages are 0.5V and 0.75V, respectively.



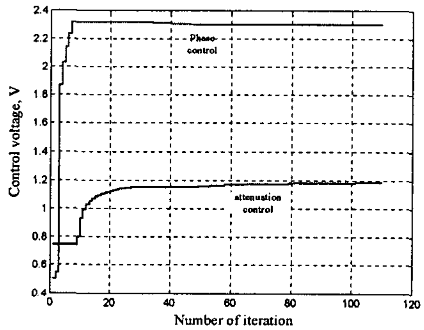
(a)



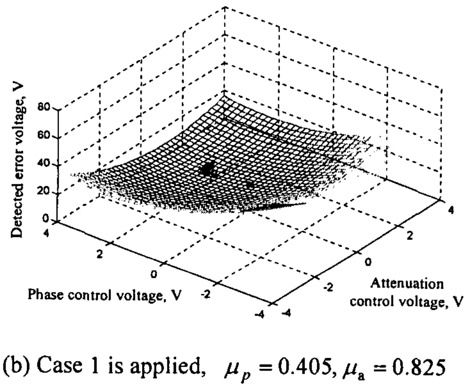
(b)

Fig. 3 The phase and attenuation control voltages of a linearization loop (a) and the detected error voltages (b) when the steepest descent algorithm is used(μ = 0.25, 0.15, 0.05)

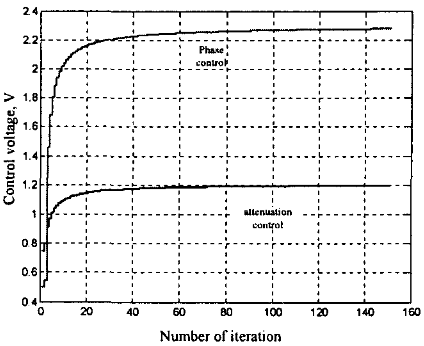
Fig. 3 shows the simulation results of the steepest descent algorithm. The simulation results show that the step size of control voltages is varied by a detected pilot power and μ. As the detected pilot power becomes large, the controller adjusts the voltage step size to a large value. As μ becomes large, the convergence speed becomes fast because of the large step size of a control voltage, but the possibility of being unstable is increased. The simulation results using a modified LMS algorithm are shown in fig. 4. In fig.4, μ_p and μ_a are the step size parameters for phase and attenuation, respectively. In this simulation we use two simulation scenarios. In case 1, the phase of a linearization loop is controlled until the direction of the phase control voltage is changed in twice. And then the amplitude of the linearization loop is controlled until the direction of the attenuation control voltage is changed in twice and so forth. In case 2, the phase and amplitude of the linearization loop are alternatively controlled. The simulation results according to the case 1 are shown in fig. 4 (a) and (b). Fig. 4 (c) and (d) are the simulation results of the case 2. Fig. 4 (c) and (d) are similar to the results obtained by the steepest descent algorithm but the convergence speed is lower than that of the steepest descent algorithm and the stability is very sensitive to μ.



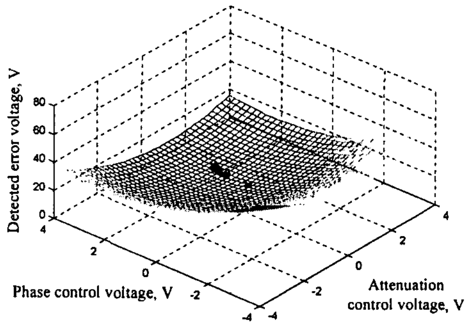
(a) Case 1 is applied, and $\mu_p = 0.405, \mu_a = 0.825$



(b) Case 1 is applied, $\mu_p = 0.405, \mu_a = 0.825$



(c) Case 2 is applied $\mu_p = 0.28, \mu_a = 0.13$



(d) Case 2 is applied, $\mu_p = 0.28, \mu_a = 0.13$

Fig. 4 The phase and attenuation control voltages of a linearization loop, (a) and (c), and the locus of the control voltages on the error surface, (b) and (d), when a modified LMS algorithm is used

Fig.5 (a) shows that the control algorithm operates stably even if the environment is suddenly changed. Fig. 5 (b) shows that the suggested control method needs 6 iterations for convergence. The comparison of the simulation results between eq(2) and (5) is shown in fig. 6. The convergence characteristics obtained by eq(5), which is suggested in this paper for a control algorithm, are better than that by eq(2) because the increment of the gradient is varied by the detected pilot power.

Ⅳ. Conclusions

The performance of the proposed control algorithm is better than the previous control algorithm. And the implementation of the proposed control method is simple because the negative of the gradient of the detected error power directly determines the control direction. The proposed control algorithm can be usefully used in controlling a feedforward amplifier and a predistortion system.

Reference

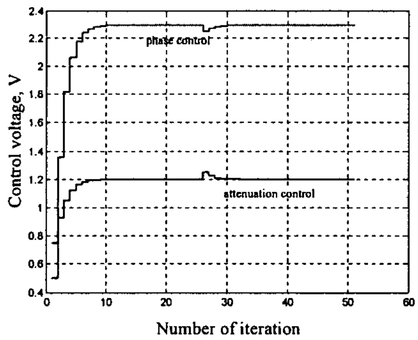
[1] Frederick H. Raab, Peter Asbeck, Steve Cripps, Peter B. Kenington, Zoya B. Popovic, Nick Pothecary, John F. Sevic and Nathan O. Sokal, "Power Amplifiers and Transmitters for and Microwave," IEEE Trans. Microwave Theory Tech., vol. 50, no. 3, pp. 814-826, March 2002.

[2] Stephen J. Grant, James K. Cavers and Paul A. Goud, "A DSP Controlled Adaptive Feedforward Amplifier Linearizer," IEEE conference on Universal Personal Communications, pp. 788 – 792, 1996.

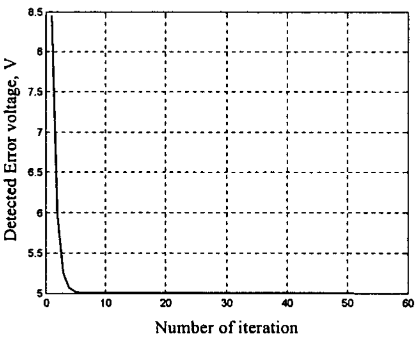
[3] Ki Suk Yoo, Sang Gee Kang, Jae Ick Choi and Jong Suk Chae, "Optimal Control Method for Adaptive Feedforward Linear Amplifier," U.S. Patent 6,232,837, May 15, 2001.

[4] G. Zhao, F. M. Ghannouchi, F.Beauregard and A. B. Kouki, "Digital Implimentions of Adaptive Feedforward Amplifier Linearization Techniques," IEEE MTT-S, pp. 543 – 546, 1996.

[5] Youngoo Yang, Youngsik Kim, Jeahyok Yi, Joongjin Nam, Bumman Kim, Wonwoo Kang and Shinwook Kim, "Digital Controlled Adaptive Feedforward Amplifier for IMT-2000 Band," IEEE MTT-S, pp. 1487 – 1490, 2000.



(a)



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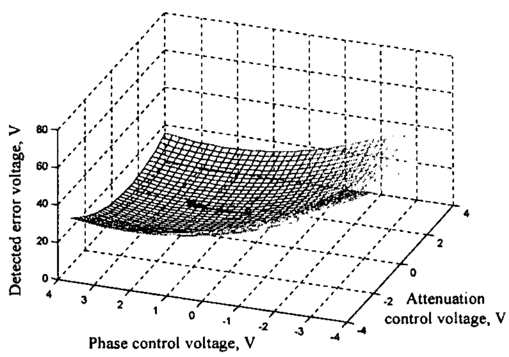
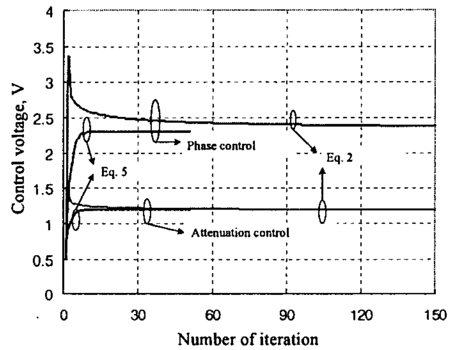
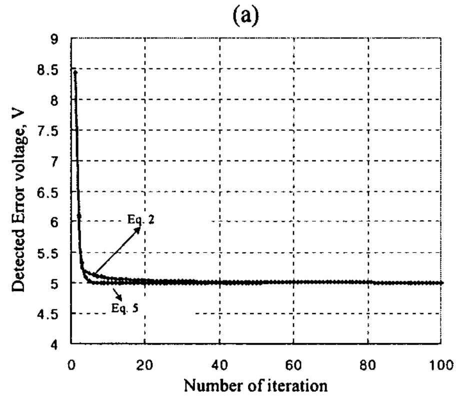


(c)

Fig. 5 The phase and attenuation control voltages of a linearization loop (a), the detected error voltages (b) and the locus of the control voltages on the error surface (c) when the steepest descent algorithm is used(μ = 0.25)



(a)



(b)

Fig. 6 The phase and amplitude control voltages of a linearization loop (a) and the detected error voltages (b) when the steepest descent algorithm is used(μ = 0.25)