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Adaptive Control Method for a Feedforward Amplifier

피드포워드 증폭기의 적응형 제어 방법

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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 its 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 desired performance within a little error bounds. In this paper, an adaptive control method using the steepest descent algorithm, 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.

요 약

피드포워드 증폭기는 선형화 성능이 우수하고 선형화 대역폭이 넓은 장점이 있다. 그러나 피드포워드 증폭기는 다양한 소자들로 구성되는 개루프 시스템이기 때문에 주변 환경의 변화에 의해서 성능 저하가 일어나기 쉽다. 따라서 피드포워드 증폭기가 허용하는 범위 내에서 원하는 성능을 유지하기 위해서는 선형화 루프의 이득과 위상을 조정하기 위한 제어 방법이 필요하다. 본 논문에서는 steepest descent 알고리즘을 이용한 새로운 적응형 제어 방법을 제안하였다. 제안한 방법은 기존의 제어 방법에 비해 수렴 속도가 빠르고 구현하기가 쉬운 장점이 있음을 시뮬레이션을 통해 확인하였다.

Key words : Feedforward, Control, LMS Algorithm, The Steepest Descent Algorithm

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, its 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 feedforward amplifiers are recognized to take the observation and control of the output of linearization loops in order to avoid performance degradation.

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A controller can adjust the amplitude and the phase of a linearization loop except for the delay time. Fig. 1 shows the basic configuration of a feedforward amplifier. The two-tone spectrum shown in Fig. 1 explains the operation principle of the 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 linearization loop's operation is ideal.

In general, a pilot signal is used for monitoring and controlling linearization loops. A controller can detect 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, output power on/off and so on.

Several control methods are studied [2]~[6]. [2] uses

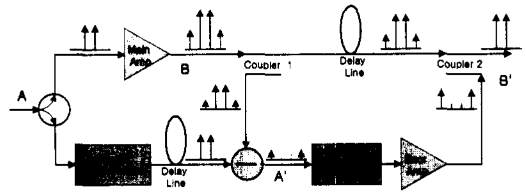


Fig. 1. The basic configuration of a feedforward amplifier.

the correlation between the input and the output signals of linearization loops. This method has the DC offset generated in correlating two bandpass signals and the slow convergence speed in controlling the second linearization loop. [3] uses LMS(Least Mean Square) algorithm to overcome the problems in [2]. [3] has the advantage of doing the control operation without a pilot signal and system information, however, a time delay is carefully considered to obtain a correct correlation. [4] uses a power detection 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. [5] suggests the steepest descent algorithm based on a gradient method in time domain. In this method, the power of error signals is determined by the time average of the limited number of sampled ADC output signals. Therefore, the detected error power may be inaccurate and the limited performance is obtained from this method. [6] is suggeted to avoid an error included in the power detection procedures. In this method, a controller just uses the detected error power for deciding the direction and the step size of control voltages. However, this method has the large variation in the performance near the optimum control points particularly when the slope of an error surface close to an optimum control point is steep.

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 other control methods 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

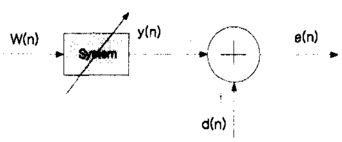


Fig. 2. The operation model of an adaptive filter.

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).

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

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

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 (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 the filter's tap weight. If the dependence on the detected power of a pilot(or signal/IMD) signal is included in (1), then (1) can be modified as

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

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

$$\alpha(n) = P(n) - P_d \tag{3}$$

where P_d is the desired power of a pilot signal when the linearization loop is properly controlled. In (2), the step size of control voltages is depending on the detected pilot power, that is, the error power parameter $\alpha(n)$. In (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 effectively included in (2) especially when the value of the gradient of $P(n)$ is small. If the increment to calculate the gradient of $P(n)$ can be changed by the error power parameter $\alpha(n)$, then the adaptive increment ΔW_a to calculate the gradient of $P(n)$ can be written as

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

And the (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.

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

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

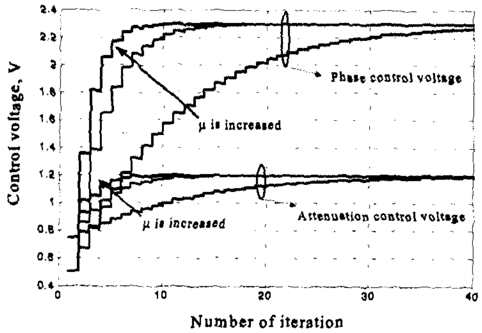
where $W_{re}(n)$ and $W_{im}(n)$ are the real and the imaginary part of a filter's tap weights respectively. $\Delta W_{a\_re}(n)$ and $\Delta W_{a\_im}(n)$ are the adaptive increments of the real and imaginary part which are depended on a detected error power.

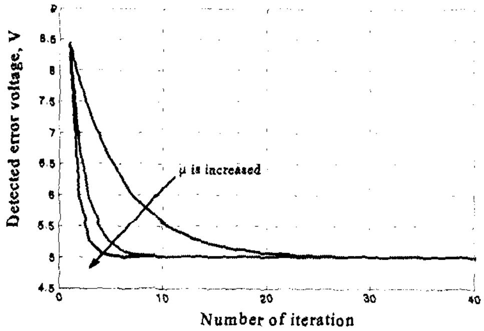
Ⅲ. Simulation Results

We simulate the performance of the control method mentioned previously. The following equation is used 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

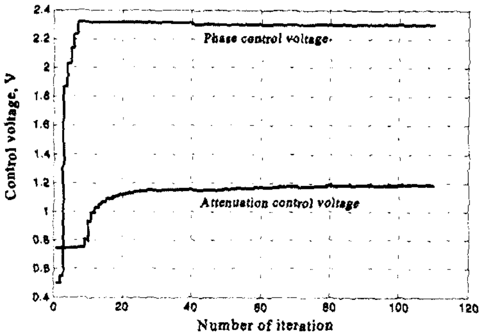


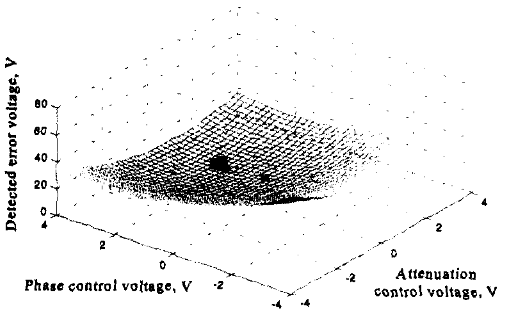


(a) The phase and attenuation control voltages of a linearization loop

(b) The detected error voltage

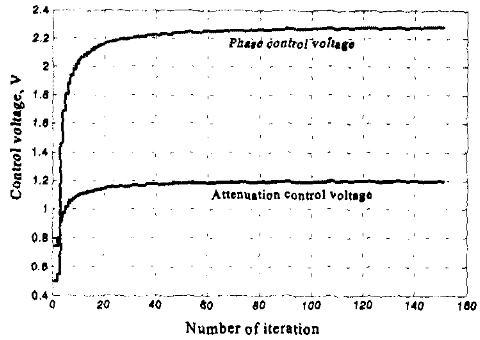
Fig. 3. The control performance according to μ(steepest descent algorithm : μ =0.25, 0.15, 0.05).

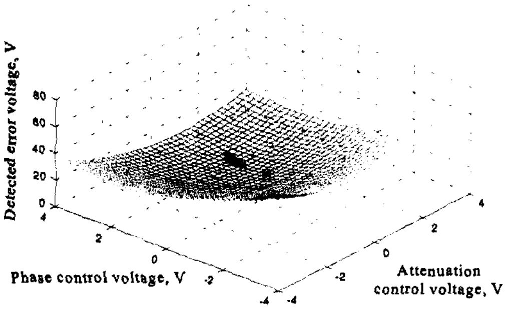




(a) The phase and attenuation control voltages of a linearization loop(Case 1: μ_p=0.405, μ_a=0.825)

(b) The locus of the control voltages on the error surface (Case 1: μ_p=0.405, μ_a=0.825)





(c) The phase and attenuation control voltages of a linearization loop(Case 2: μ_p=0.28, μ_a=0.13)

(d) The locus of the control voltages on the error surface (Case 2: μ_p=0.28, μ_a=0.13)

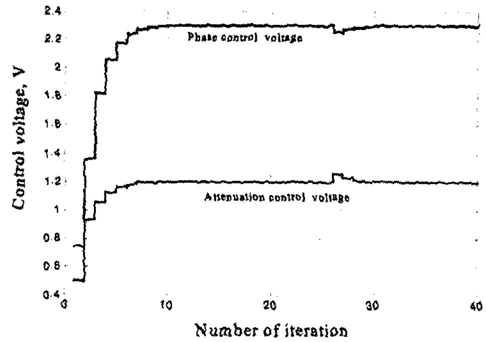
Fig. 4. The modified LMS control algorithm.

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} = 5 V, P_{p_t} = 2.3V, P_{a_t} = 1.2 V and the initial phase and attenuation control voltages are 0.5 V and 0.75 V, respectively.

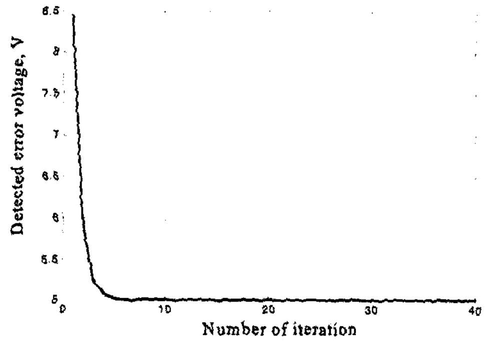
Fig. 3 shows the simulation results of the steepest descent algorithm. The simulation results show that the step size of control voltages is varied by a detected pilot power and μ. As the detected pilot power becomes large, the controller adjusts the voltage step size to a large value. As μ becomes large, 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 attenuation 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 attenuation 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 for case 2. From the locus of the control voltage shown in Fig. 4(b), the control direction is zigzag for case 1. Therefore the convergence speed of case 1 is slower than that of the steepest descent algorithm. Fig. 4(c) and (d) are similar to the results obtained by the steepest descent algorithm. However, Fig. 4(c) shows that the phase control voltage does not reach the optimum control voltage. Therefore the convergence speed is slower than that of the steepest descent algorithm and the stability is very sensitive to μ in case 2.

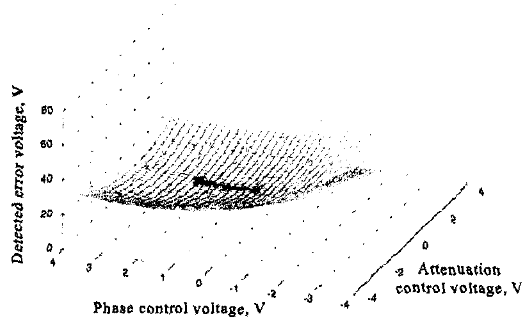
Fig. 5(a) shows that the control algorithm operates stably even if the environment is suddenly changed. Fig. 5(b) shows that the suggested control method needs 6 iterations for convergence. And Fig. 5(c) shows that the locus of control voltages is straight. Therefore, the convergence speed of this case is faster than the zigzag case shown in Fig. 4(b). The comparison of the simulation results between (2) and (5) is shown in Fig. 6. The convergence characteristics obtained by (5), which is suggested in this paper for a control algorithm, are better than that by (2) because the increment of the gradient is varied by the detected pilot power.



(a) The phase and attenuation control voltages of a linearization loop



(b) The detected error voltage

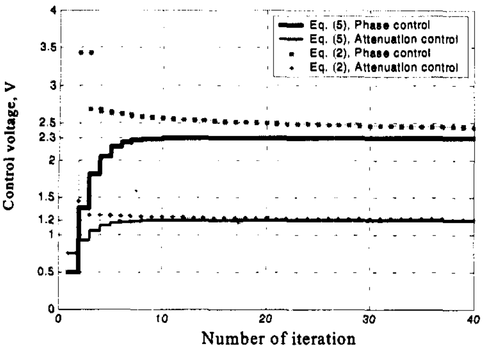


(c) The locus of the control voltages on the error surface

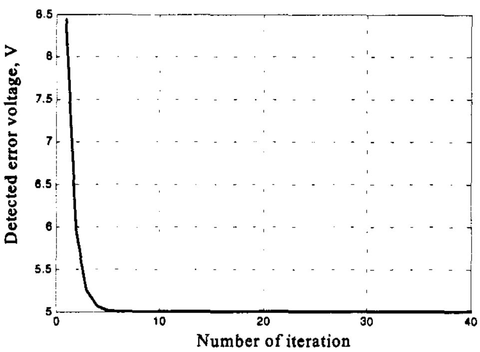
Fig. 5. The steepest descent control algorithm(μ=0.25).

Ⅳ. Conclusions

The performance of the proposed control method using steepest descent algorithm is better than the previous control algorithm. And the implementation of the proposed control method is simple because the



(a) The phase and attenuation control voltages of a linearization loop



(b) The detected error voltage

Fig. 6. The steepest descent control algorithm(μ=0.25).

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.

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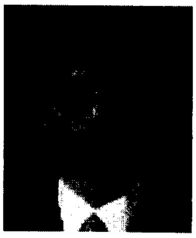

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