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Improvement of Compensation Effect for Frequency Characteristics Distortion of Antenna by Approximately Inverse Filter

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1. Introduction

In recent years, the demand on a large capacity, high-reliability and high quality are remarkable in the wireless communication system. UWB (Ultra Wide Band) wireless communication can transmit at the speed of several G bit/s by using the pulse with extremely short in time width. An antenna which has wideband characteristics is required for the system because very wide frequency band is utilized in the UWB. However, it is difficult to obtain the antenna which has uniform characteristics in all frequency band of UWB.

A pre-distortion technology that is used to compensate the distortion due to the antenna characteristics before transmission has been proposed by the authors [1], [2]. To compensate the gain characteristics distortion of the antenna, a method of the inverse filter has been proposed [1]. However, the compensation effect of the inverse filter was not enough when the distortion of the antenna gain characteristics was severe.

This paper proposes a compensation method of an approximately inverse filter in order to improve the compensation effect. And the effectiveness of the proposed method for the severe distortion is verified through computer simulation.

2. Compensation method for distortion using pre-distortion filter and the problem

2.1 Concept of pre-distortion

Figure 1 shows the concept of the compensation for distortion using the pre-distortion filter. To make the amplitude spectrum of the signal from the antenna be constant, the gain characteristics of filter, $G_f(f)$,are set to the inverse of the antenna gain characteristics, $G_a(f)$, as shown in equation (2)[1]. On the other hand, to make the total phase characteristics, $\theta_{total}(f) = \theta_f(f) + \theta_a(f)$, to be "linear phase", the phase characteristics of the filter, $\theta_f(f)$, are decided as equation (3)[2].

$$G_f(f) = 1/G_a(f), \qquad (2)$$

$$\theta_f(f) + \theta_a(f) = \tau_c f, \quad \tau_c : \text{constant}. \qquad (3)$$

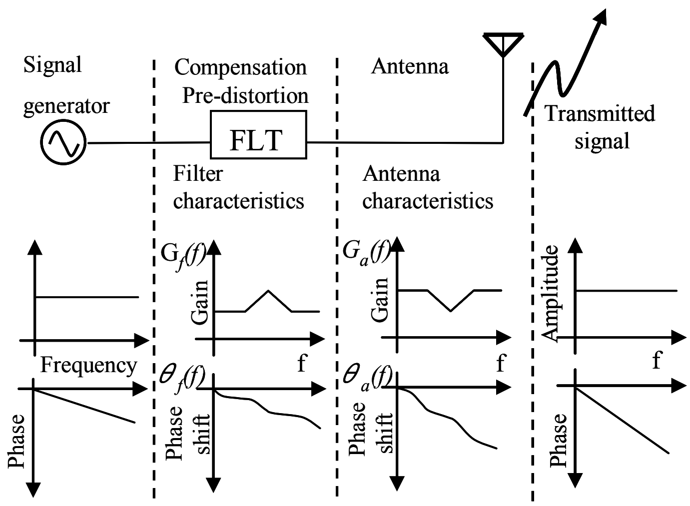

Figure 1: Concept of Compensation for Distortion Using Pre-Distortion Filter

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2.2 Problem of inverse filter

The frequency distortion cannot be compensated adequately by the inverse filter when the distortion of the gain characteristics of the antenna is severe as shown in Fig.2. Because when the gain characteristics of the antenna is extremely small, the gain characteristics of the inverse filter become extremely large and the compensation effect is not obtained adequately. It has been reported that the compensation effect is improved by limiting the filter gain adaptively [3]. But it is difficult to determine the appropriate limiting level because the distortion of the antenna characteristics is varied by surrounding environment.

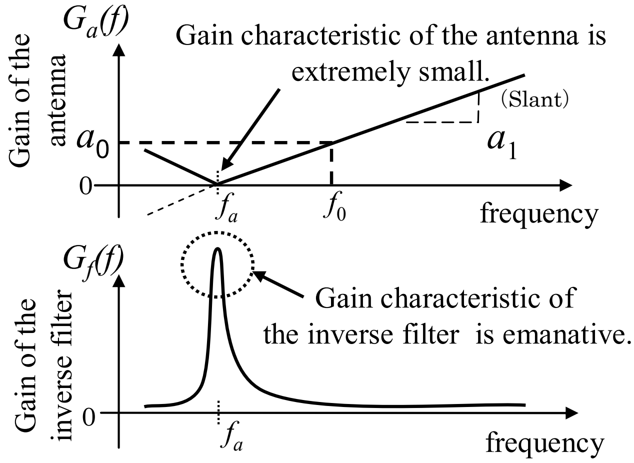

Figure 2: Problem of Inverse Filter

3. Approximately inverse filter (Proposed method)

To avoid the emanation of the coefficient of the filter, we propose the approximately inverse filter. The gain characteristics of the filter, $G_f(f)$,are determined by equation (3).

$$G_f(f) = \frac{G_a(f)}{|G_a(f)|^2 + \alpha} \qquad \alpha\text{: constant} \quad (3)$$

Here, $G_a(f)$ is the gain characteristics of an antenna, and, α is a small constant coefficient to avoid the emanation. Namely, the approximately inverse filter becomes almost the same characteristics as the inverse-filter when gain $G_a(f)$ of an antenna is large enough. On the other hand, the gain of the approximately inverse filter becomes almost 0 in the band when $G_a(f)$ is very small as shown in Fig.3. In the proposed filter, the small constant α in the equation (3) corresponds to a noise level in Wiener filter.

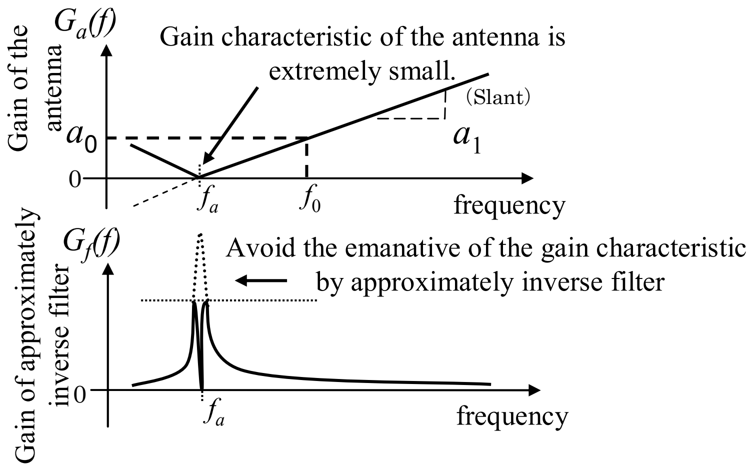

Figure 3: Approximately Inverse Filter (Proposed Method)

4. Simulation condition

4.1 Antenna characteristics

The antenna gain characteristics in the simulation shown in Fig.4 are determined using equation (4). Parameters a_0 and a_1 shown in Fig.4 are the gain at the central frequency and the distortion

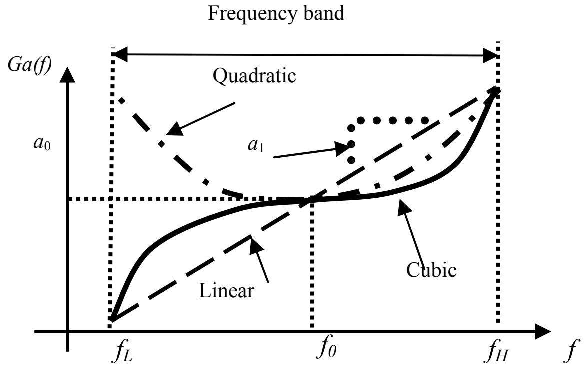

Figure 4: Antenna Gain Characteristics

coefficient of the gain characteristics, respectively [1].

$$G_a(f) = a_1 x^n + a_0, \quad x = \frac{2(f - f_0)}{f_H - f_L}, \quad n = 1,2,3. \tag{4}$$

It was supposed that the antenna has sign wave group delay as equation (5) [4]. Here, T_a, BW, A, n and φ is the average group delay, the band width treated in the simulation, the maximum fluctuation of group delay, the frequency of the fluctuation in the band and the initial phase, respectively. The influence of n on the effect of the filter is investigated when T is 2ns, A is 0.5ns and ϕ are uniformly distributed from 0 to 2π.

$$\tau(f) = A\sin(2\pi fn / BW + \phi) + T_a, \quad 0 \le f \le W, f: frequency, BW: bandwidth. \tag{5}$$

4.2 Composition and evaluation method of pre-distortion filter

We assumed that the pre-distortion filter comprises a transversal filter [5]. The inverse Fourier transform of the objective frequency characteristics is used for the coefficient of the filter in order to form the inverse of the antenna frequency characteristics.

We evaluate the effectiveness of the pre-distortion filter using the MSE (Mean Squared Error) ratio, which is the difference between the original signal and transmitted signal from the antenna. The MSE ratio is calculated using equation (6).

$$MSE\_Ratio = 10 \times \log_{10}\left(\frac{\text{MSE w/o pre-filter}}{\text{MSE with pre-filter}}\right). \tag{6}$$

5. Compensation effects by approximately inverse filter

5.1 Decision of the coefficient of the approximately filter

Figure 5 shows the change of the ratio of MSE as a function of the value of the coefficient α in the approximately inverse filter. The parameter is the distortion coefficient, a_1, the gain at the central frequency, a_0. When α is about 10^{-2}, the ratio of MSE becomes almost peak and it does not depend on the antenna characteristics so much.

5.2 Comparison with conventional technique

Figure 6 shows the comparison of the effect of the filter as a function of the distortion coefficient a_1. The performance of the conventional technique such as the inverse characteristic filter [1], the optimality limiting gain filters [3], and the simple limiting gain

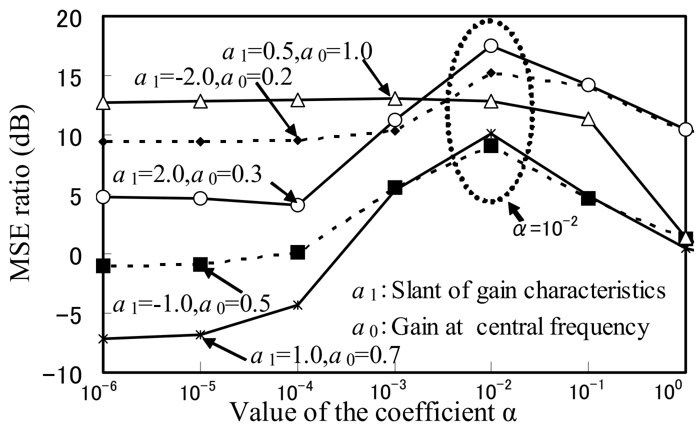

Figure 5: Decision of Coefficient of Approximately Filter

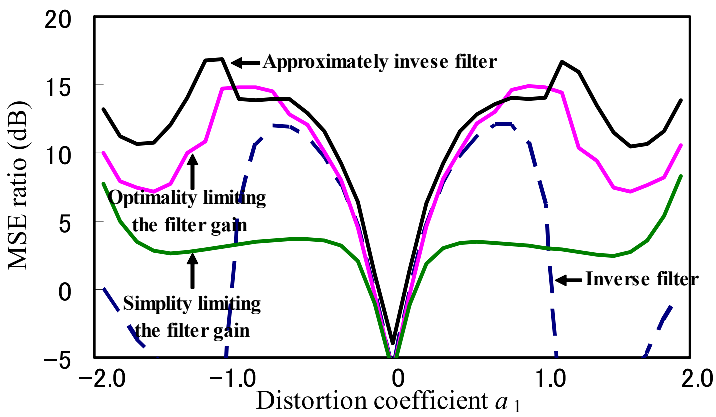

Figure 6: Comparison with Conventional Technique

filter, is shown for comparison. The coefficient α of the approximately inverse filter is 0.01. It is found form Fig.6 that larger MSE ratio can be obtained by the approximately inverse filter compared with case of conventional filters when the distortion coefficient a_1 is large. That is, the proposed method can work well even if the distortion of the antenna characteristics is very severe.

5.3 Influence of number of taps and SNR on compensation effect

The relationship between the number of taps and the average value of the compensation effect of the filter is shown in Fig.7, when the number of the fluctuation of the group delay is changed from 1 to 10 and the distortion coefficient of the gain is changed within the range from -3 to 3. It is understood that about 20 taps are required to obtain the essential performance of the proposed method, and it is almost the same with conventional method. It is also understood that the compensation effect of the approximately inverse filter overcomes than the effect of the inverse filter.

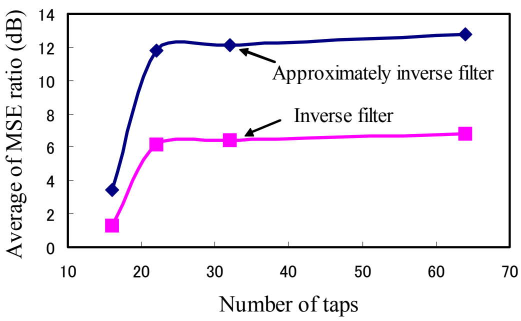

Figure 8: Relationship between SNR and Ratio of MSE

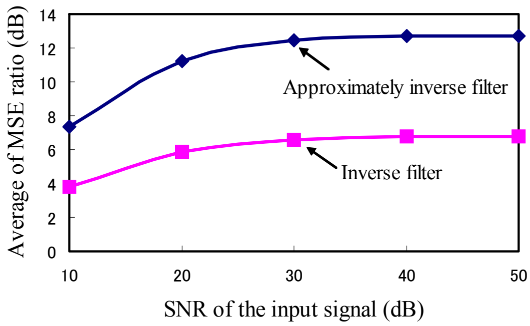

Figure 7: Number of Taps and Ratio of MSE

Figure 8 shows the relationship between the SNR of the input signal and the average of the compensation effect. From Fig. 8, when the SNR is greater than 30 dB, the effect of the filter is almost the same as the case of without noise. But, it is understood that the compensation effect can be improved more than 5dB by introducing the approximately inverse filter.

6. Conclusion

The approximately inverse filter was proposed to improve the compensation performance of pre-distortion filter. It was shown that enough compensation effect was obtained by the approximately inverse filter even when the gain distortion of the antenna was severe, and it was shown that 10^{-2} was most suitable for the coefficient α in the approximately inverse filter.

It was also shown that about 20 taps were required to obtain the enough performance for the proposed method, and the effect of the filter was almost the same as the case without noise when the SNR was grater than 30 dB.

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