Compensation for Frequency Characteristics Distortion of Antenna Using Pre-distortion Filter

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Abstract

High speed wireless communication system attracts much attention in recent years. To realize the high speed wireless communication system utilizing ultra-wide-frequency bands, a broadband antenna must be required. However, it is difficult to obtain the antenna which has uniform characteristics in broad frequency band. Thus, the communication quality tends to become worse because of distortion of the gain characteristics and the group delay characteristics of the antenna.

To compensate the gain characteristics of the antenna, a pre-distortion technology has been proposed by the authors [1]. This paper proposes the compensation method for frequency characteristics distortion of antenna using pre-distortion filter, under considering both gain and group delay characteristics of antenna. And the effectiveness of the method is verified by the simulation results.

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 Gbit/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.

In this paper, pre-distortion method to compensate the distortion due to the antenna characteristics before transmission is proposed, and the effectiveness in compensating for distortion is shown through numerical results.

2. COMPENSATION METHOD FOR DISTORTION USING PRE-DISTORTION FILTER

A. Distortion by group delay characteristics of antenna

The group delay is defined as the rate of change of the phase with respect to angular frequency, as shown in equation (1). It shows the change of the phase characteristics in frequency.

$$\tau_g(\omega) = -\frac{d\theta(\omega)}{d\omega}, \qquad (1)$$

ω : *augular frequency* , $\theta(\omega)$: *phase* .

If the phase characteristics of the antenna change linearly in frequency, the group delay characteristics are constant. Therefore, the delay time of all the frequency components is the same, and the distortion is not caused in the signal wave. On the other hand, the shape of signal in time domain will be distorted when the phase characteristics of the antenna change nonlinearly as usual antennas.

B. Concepts of compensation for distortion using pre-distortion filter

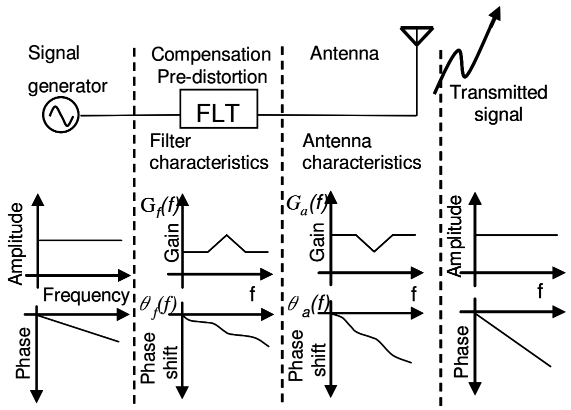


Fig.1 Concept of compensation for distortion using pre-distortion filter

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 "linear phase", the phase characteristics of the filter, $\theta_f(f)$, are decided as equation (3)[2].

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

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

C. Design of phase characteristics of the filter

The phase characteristics of the filter are decided as equation (3). That is, $\theta_f(f)$ is decided so that the total of $\theta_f(f)$ and $\theta_a(f)$ become a straight line as shown in Fig.2. Here, following two conditions must be satisfied to realize the filter.

(1)The slant of the phase is negative so that the group delay becomes always positive.

(2)The phase value is negative so that the phase delay becomes always positive.

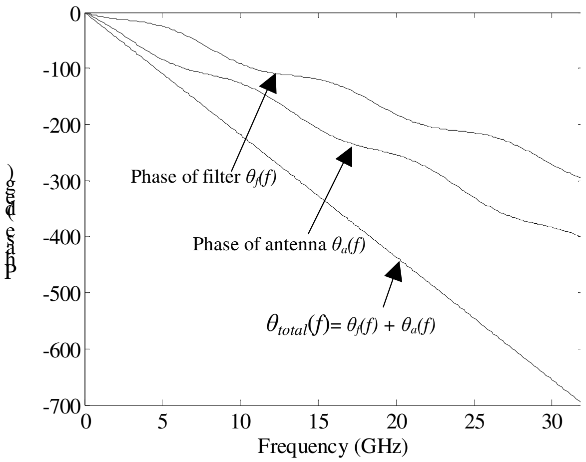


Fig.2 Phase characteristics for the filter

3. SIMULATION MODEL

A. Gain characteristics of antenna

The antenna gain characteristics in the simulation shown in Fig.3 are determined using equation (4). Parameters a_0 and a_1 shown in Fig.3 are the gain at the central frequency and the distortion coefficient of the gain characteristics, respectively [1].

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

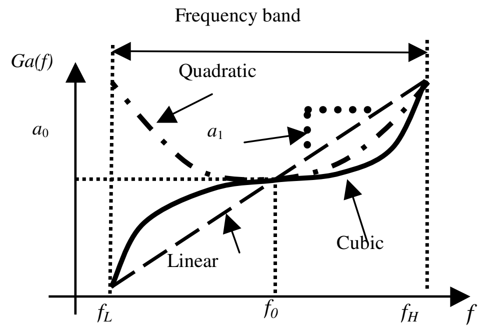


Fig.3 Gain characteristics of antenna

B. Group delay characteristics of antenna

It was supposed that the antenna has sign wave group delay as equation (5) [3]. 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 and A on the effect of the filter is investigated when the average group delay T is 2ns and the initial phase φ are set at random.

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

C. Pre-distortion filter composition

We assumed that the pre-distortion filter comprises a transversal filter [4]. 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.

4. Compensation Effects by Pre-Distortion Filter

A. Influence of gain and group delay characteristics on compensation effect

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).

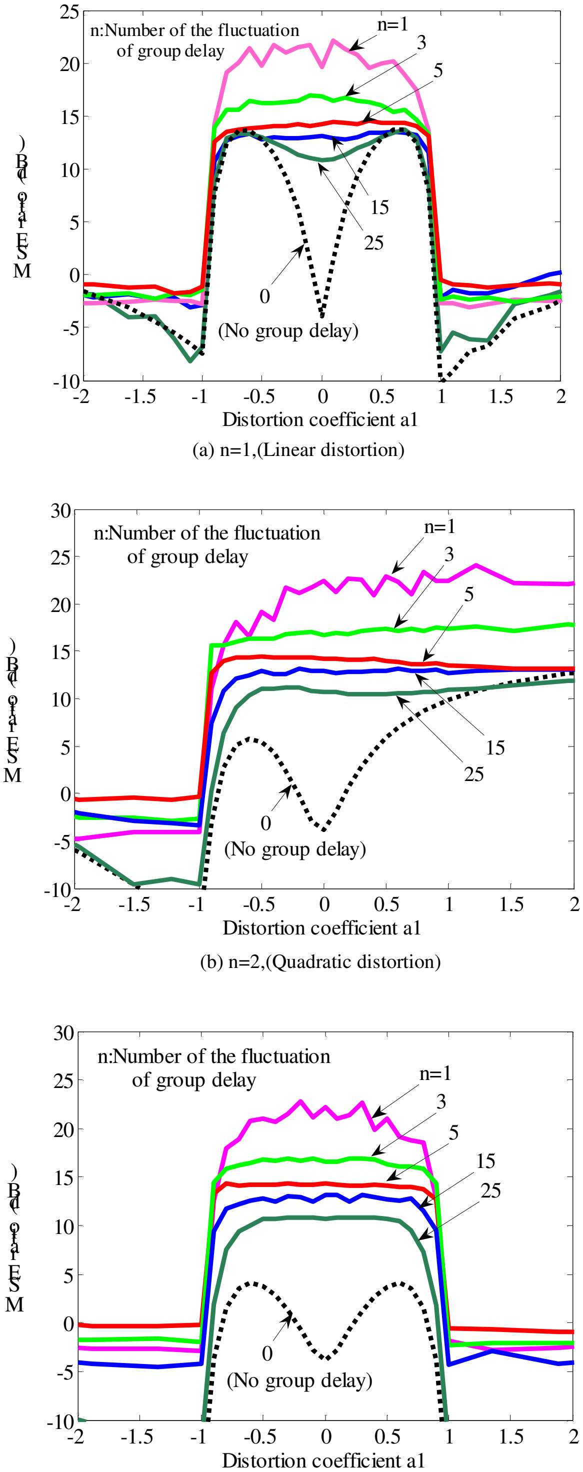
$$MSE\_Ratio = 10 \times \log_{10}\left(\frac{\text{MSE without the pre-filter}}{\text{MSE with the pre-filter}}\right) \quad (6)$$

Figure 4 shows the influence of the gain distortion on the effect of compensation when the number of taps of the filter is 64, the SNR is 50 [dB] and the gain at the central frequency, a_0, is 1. The horizontal axis indicates the distortion coefficient, a_1, while the vertical axis shows the MSE ratio, respectively. The MSE ratio when only the gain characteristics is considered, is shown by the dotted line, and the result when both the group delay and gain characteristics are considered is shown by the solid line, respectively.

"n" in Fig.4 is the number of the fluctuation of the group delay. It is found from Fig.4 that the effect of compensation is higher than the case of only the gain distortion when not only the group delay distortion but also the gain distortion exists. Moreover, it is understood that the ratio of MSE is increased and stabilized and not depend on the gain distortion coefficient so much, if the absolute value of gain distortion coefficient a_1 is small.

Figure 5 shows the influence of the group delay distortion on compensation effect. The horizontal axis indicates the number of the fluctuation of group delay and the vertical axis shows the value of MSE. The MSE with the filter is shown by the solid line and the MSE without the filter is shown by the dotted line, respectively.

The value of MSE is suppressed small as the number of the fluctuation of the group delay, n, is increasing. The compensation effect is obtained when the distortion coefficient a_1 is small. However, the filter falls into counter effect when a_1 is increased.



(a) n=1,(Linear distortion)

(b) n=2,(Quadratic distortion)

(c) n=3,(Cubic distortion)

Fig.4 Influence of gain distortion on compensation effect

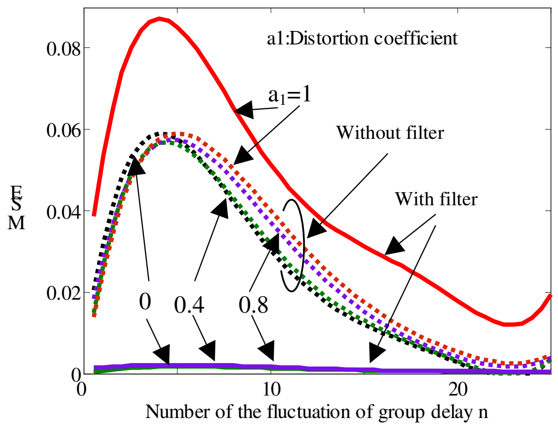


Fig.5 Influence of the group delay distortion on compensation effect

B. Influence of number of taps on compensation effect

Figure 6 shows the relation between the number of taps and MSE. The horizontal axis shows the number of the taps and the vertical axis indicates the value of MSE. It is found from Fig. 6 that the performance of the filter is raised as the number of the taps is increased. The more number of taps are required when both of the gain and group delay characteristics should be compensated.

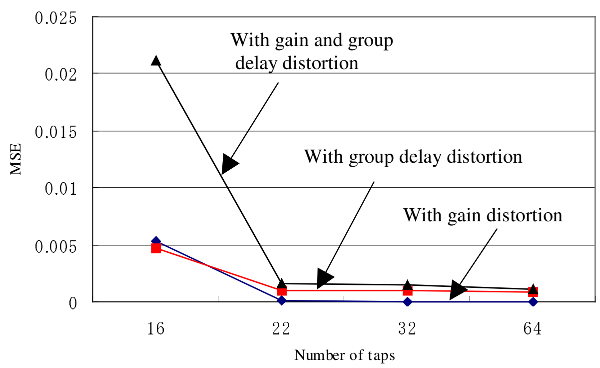


Fig.6 Number of taps and MSE

5. Conclusion

In this paper, pre-distortion method to compensate the distortion due to the antenna characteristics before transmission was proposed, and the effectiveness in compensating for distortion was shown through numerical results.

The simulation results showed that the distortion compensation effect on the transmitted signal waveform could be obtained for not only the gain distortion but also the group delay distortion due to the antenna frequency characteristics.

It was shown that compensation effect of the filter depended on the gain distortion coefficient and the number of the fluctuation of the group delay. It was also found that the performance of the filter was raised as the number of the taps was increased.

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