Verification of Compensation Effect of Quasi-Inverse Filter in Wideband Communication System

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1. Introduction

In recent years, the demands on a large capacity, high-reliability and high quality are remarkable in the wireless communication system. UWB (Ultra Wide Band) wireless communications can transmit at a speed of several gigabits per second [1]. A wideband antenna is required for the system because a very wide frequency band is utilized in UWB. However, it is difficult to obtain an antenna that has uniform characteristics in all UWB frequency bands.

Pre-distortion technology to compensate for the distortion due to the antenna characteristics before transmission was proposed in [2]. To compensate for the distortion in the gain characteristics of the antenna, a method of inverse filtering was proposed [3] [4]. However, the compensation effect of the inverse filter was not sufficient when the distortion of the antenna gain characteristics was severe.

The authors have proposed a quasi-inverse filter (QIF) in order to improve the compensation effect and an effectiveness of the proposed filter has been indicated through computer simulation [5]. In the simulation, a simple model for antenna characteristics was employed, however, real antenna characteristics are very complex in general.

In this paper, the QIF is applied to two antennas as a concrete example of a broadband antenna; one is a disc monopole antenna, and the other is a square loop antenna.

2. Compensation Method for Wideband Communication System

2.1 Concept of Compensation and Problem Facing Conventional Inverse Filter

Figure 1 shows the concept of compensation system using a pre-filter and a post-filter. The total characteristics, $H_{\mathrm{Total}}(f)$, between the input of transmission antenna and output of receiver antenna are expressed in Eq. (1). Here, $H_{\mathrm{tx}}(f)$ represents the gain characteristics of the transmitter antenna, $H_{\mathrm{rx}}(f)$ represents the gain characteristics of the receiver antenna, and $H_{\mathrm{space}}(f)$ represents the propagation characteristics of the radio channel.

$$H_{\mathrm{Total}}(f) = H_{\mathrm{tx}}(f) \times H_{\mathrm{space}}(f) \times H_{\mathrm{rx}}(f). \qquad (1)$$

To make the transmission characteristics from the signal generator to the receiver constant, the gain characteristics of the conventional filter, $G_{\mathrm{IF}}(f)$, are set to the inverse of $H_{\mathrm{Total}}(f)$ as Eq. (2).

$$G_{\mathrm{IF}}(f) = \frac{1}{H_{\mathrm{Total}}(f)} \qquad (2)$$

The conventional inverse filter cannot compensate distortion adequately when the distortion of the gain characteristics of the antenna is severe [4]. This is because when the antenna gain is extremely low as shown in Fig. 2(a), the gain of the inverse filter becomes extremely high as shown in Fig. 2(b).

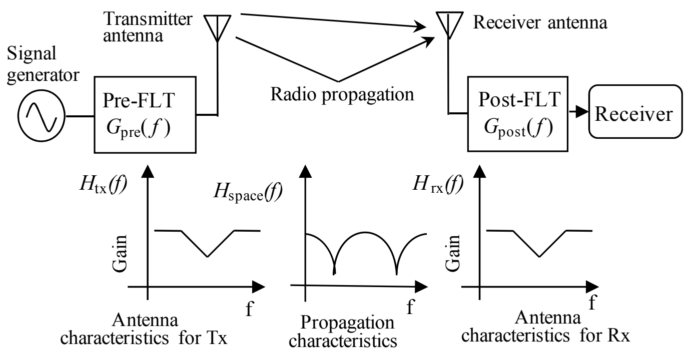


Figure 1: Communication system using compensation filters

2.2 Quasi Inverse Filter (QIF)

To avoid the extreme high gain characteristics of the inverse filter, the authors have proposed QIF. The gain characteristics of the QIF, $G_{QIF}(f)$, are determined by Eq. (3).

$$G_{\mathrm{QIF}}(f) = \frac{H_{\mathrm{Total}}(f)}{\left|H_{\mathrm{Total}}(f)\right|^2 + \alpha} \qquad (3)$$

Here, α is a small constant coefficient to avoid the extreme high gain characteristics. Namely, the QIF has almost the same characteristics as the inverse-filter when $H_{\mathrm{Total}}(f)$ is sufficiently high. On the other hand, the gain of the QIF becomes almost 0 in the band when $H_{\mathrm{Total}}(f)$ is very low as shown in Fig. 2(c). In the QIF, the small constant, α, in Eq. (3) corresponds to a noise level in the Wiener filter [6]. Square root characteristics of the $G_{QIF}(f)$ is used for the pre-filter and post-filter as shown in following equation.

$$G_{\mathrm{pre}}(f) = G_{\mathrm{post}}(f) = \sqrt{G_{\mathrm{flt}}(f)}\,. \qquad (4)$$

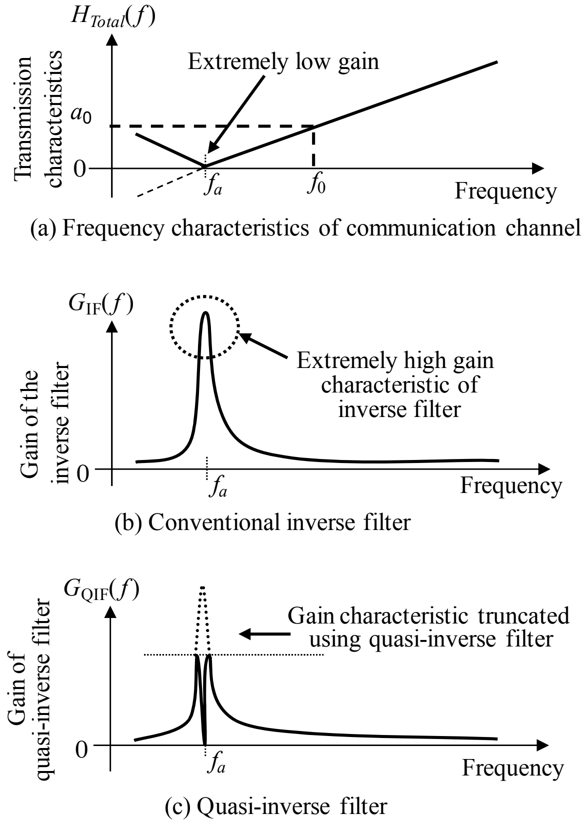


Figure 2: Frequency characteristics of compensation filter

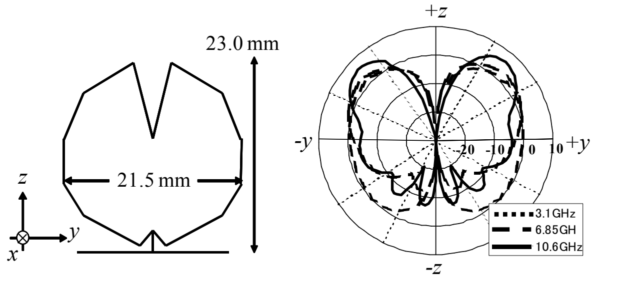
3. Antenna Characteristics and Evaluation Conditions

3.1 Antenna Characteristics and Arrangement

We applied the compensation filter to two types of antennas; one is a disc monopole antenna [7] and the other is a square loop antenna [8].

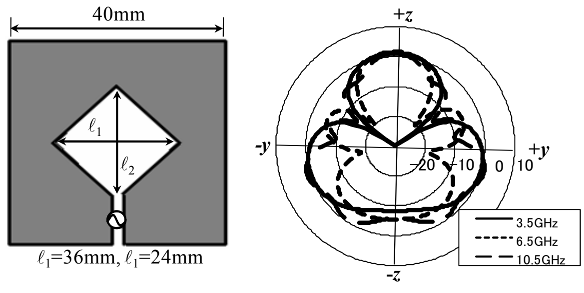
Figure 3 shows the structure and radiation patterns of the disc monopole antenna. The radiation element is mounted on a ground plane and it is fed from the back of the ground plane. Radiation patterns of the antenna in the vertical plane are shown in Fig. 3(b). The radiation pattern around zenith is greatly changed.

Figure 4 shows the structure and radiation patterns of the square loop antenna. The radiation element is composed of thin metal and it is fed by parallel feeding line. Radiation patterns of the antenna are shown in Fig. 4(b). Since the radiation patterns depend on the frequency, we can find that the gain in a specific direction is considerably distorted. The patterns in Fig. 3(b) and Fig. 4(b) are calculated results based on the moment method.



(a) Shape of antenna (b) Radiation patterns

Figure 3: Disc monopole antenna



(a) Shape of antenna (b) Radiation patterns

Figure 4: Square loop antenna

We applied the same antenna to both the transmission side and reception sides and evaluated the compensation effect through computer simulation. Figure 5 shows the relative location of the antennas. We assume that the transmitter antenna was attached under a ceiling and the receiver antenna was located on a desk or fixture. We also assume that only direct wave arrived at the receiver antenna.

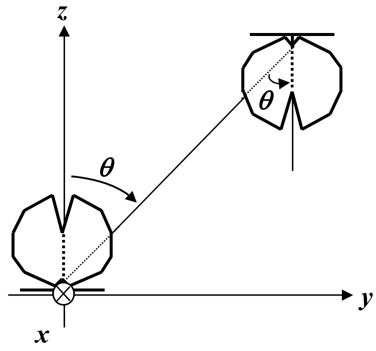


Figure 5 : Antenna arrangement

3.2 Evaluation Method

RMSE (Root Mean Square Error) between the original signal and radiated signal from the antenna are calculated for evaluation. We evaluate the effectiveness of the filter using the RMSE ratio, which is the ratio in dB between the RMSE with the filter and the RMSE without the filter. The RMSE ratio is calculated using Eq. (5). If the RMSE ratio is a positive value, the filter is effective, and if the RMSE ratio is a negative value, then the filter is ineffective.

$$RMSE\ ratio = 10\log_{10}\left(\frac{\text{RMSE w/o filter}}{\text{RMSE with filter}}\right). \qquad (5)$$

4. Verification of Compensation Effects using Concrete Antenna Characteristics

4.1 Compensation Effect for Wideband Disc Monopole Antenna

Figure 6 shows the frequency characteristics when the angle θ in Fig. 5 is 45 degrees which correspond to the direction of the maximum radiation of the antenna. The gain characteristics of conventional inverse filter, G_{IF}, and the gain of QIF, G_{QIF}, are determined by Eq. (2) and Eq. (3), respectively. As we can see in the figure, the compensated characteristics by G_{IF} are perfectly flat because G_{IF} is just the inverse of H_{Total}. However, noises must be enhanced in the frequency when the H_{Total} is very small. On the other hand, the peak of gain characteristics of QIF is reduced. Although the transmission characteristics are not compensated perfectly, the effect of noise enhancement might be reduced.

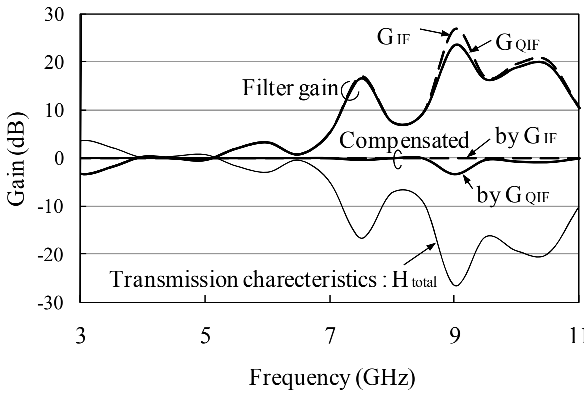


Figure 6 : Frequency characteristics compensation by the filters

Figure 7 shows the compensation effects of the filters when the disc monopole antennas are used for both transmitting and receiving side. The horizontal axis represents the direction of the direct path and the vertical axis indicates the RMSE ratio. Figure 7 shows that the QIF achieves a higher RMSE ratio than that for the conventional inverse filter. The QIF greatly improves the RMSE ratio especially where angle θ is small. This is because the gain of the antenna at these angles is very small and greatly changes as shown in Fig. 3(b).

4.2 Compensation Effect for Square Loop Antenna

Figure 8 shows the compensation effects of the filters when the square loop antennas are used. The horizontal axis and the vertical axis are the same as Fig. 7. It can be found in Fig. 8 that the

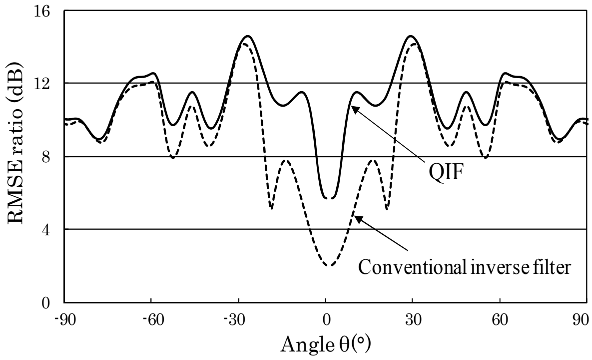


Figure 7 : Compensation effect for disc monopole antenna

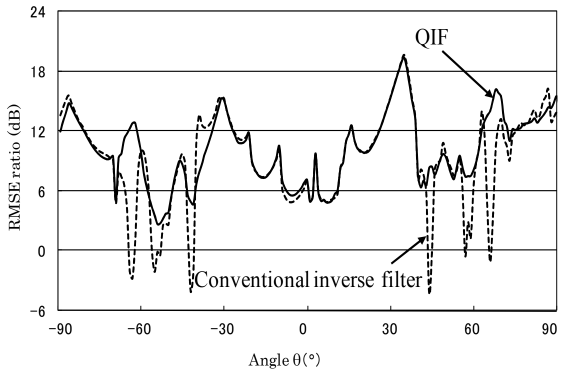


Figure 8 : Compensation effect for square loop antenna

RMSE ratio is approximately the same between QIF and conventional inverse filter in almost angle. In the several specific angles, however, RMSE ratio for conventional inverse filter is greatly decreased and it became negative value. Such angles are corresponding to that the square loop antenna has null in radiation pattern as shown in Fig. 4(b). By utilizing the QIF, the RMSE ratio is improved and the value is always positive.

5. Conclusion

In this paper, the QIF which has been proposed by the authors was applied to two antennas as a concrete example of a broadband antenna; one was a disc monopole antenna, and the other was square loop antenna. It was indicated that the compensation effects were greatly improved by using quasi-inverse filter (QIF).

For both antennas, higher RMSE ratio was obtained by the QIF compared to that of the conventional inverse filter in the several specific angles. Such angles were corresponding to null in radiation pattern. Through the results, effectiveness of the QIF for concrete antennas was verified. Especially, it was clarified that significant compensation effects were obtained when frequency characteristics are very severe.

Acknowledgement

The authors would like to thank Ms. Haiyan Zhao for her valuable work when she was student in Graduate school of engineering, University of Fukui.

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