Experimental Study of Adaptive Array Antenna System for ISDB-T Mobile Reception

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1. Introduction

In Terrestrial digital TV broadcasting in Japan (ISDB-T), Orthogonal Frequency Division Multiplexing (OFDM) is adopted as a modulation scheme. The communication performance of OFDM is known to be superior to that of a single carrier in a multipath environment. However, multipath fading caused by a large number of reflected signals seriously deteriorates the quality of digital communication at the mobile reception. For overcoming this problem, we utilize the adaptive array antenna technology which can perform beam-forming and null-steering adaptively against multipath fading. Therefore, it would enable the stable reception even if the radio environment changes with time at the mobile reception.

In this paper, we compare Pre-FFT (Fast Fourier Transform) adaptive array antenna with Post-FFT carrier diversity when 4 antennas are mounted on a vehicle. The 4 antennas consist of 2 front antennas and 2 rear antennas with 2 cases of antenna intervals. The maximum gain directions of those antennas are different in either front or rear of the vehicle. From an experimental result, it is proved that the adaptive array antenna has superior BER performance in the case where OFDM signals arrive with delay exceeding the Guard Interval (GI) length.

2. System Configurations

In this paper, we examine system configuration in case that four antennas are mounted on a vehicle (Front:2 antennas, Rear:2 antennas). Figure 1 shows the top view of the antenna position on a vehicle and the directional patterns of 4 antennas. For each antenna, F/B (Front/Back) is defined as shown in Figure 1.

In this paper, we propose Pre-FFT adaptive array antenna and compare with Post-FFT carrier diversity (4FFT) through experiments.

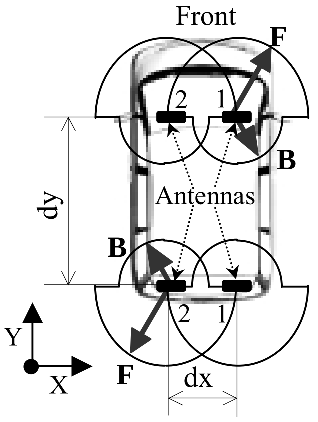


Figure 1: Antenna conditions

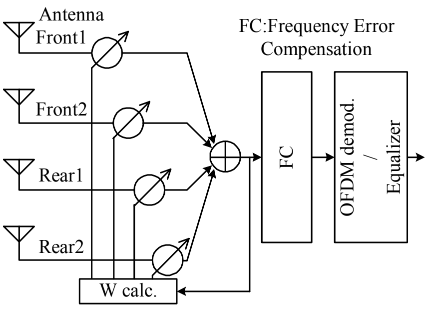


Figure 2: Proposed System
(Pre-FFT type)

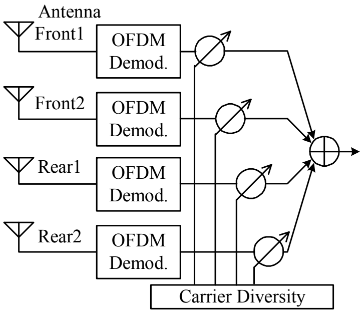


Figure 3: 4FFT System
(Post-FFT type)

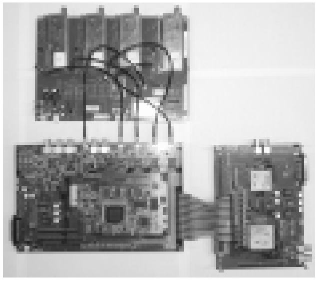


Figure 4: Prototype
(for both systems)

Figure 2 shows the block diagram of the proposed system (Pre-FFT type), and Figure 3 shows 4FFT system (Post-FFT type). Both systems have been implemented in the prototype which is shown in Figure 4.

3. Implemented algorithms

Suppose that array antenna is equipped with K-element. The received signals and weight coefficients are expressed in a vector as follows,

$$\boldsymbol{X}(t) = [x_1(t), x_2(t), \ldots, x_K(t)]^T \tag{1}$$

$$\boldsymbol{W} = [w_1, w_2, \ldots, w_K]^T \tag{2}$$

Then, the combined output of the array is given by

$$y(t) = \boldsymbol{W}^H \boldsymbol{X}(t) \tag{3}$$

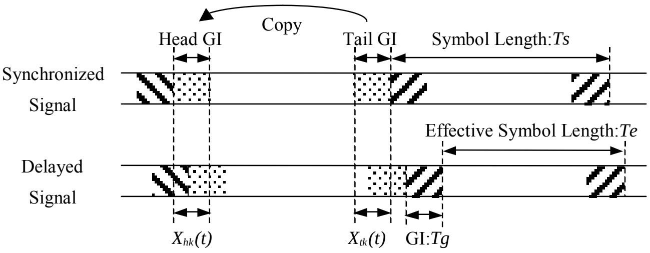


Figure 5: OFDM Modulated Signals

Here, the superscripts T and H represent the transpose and the conjugate transpose, respectively. Figure 5 shows the OFDM modulated signal with one delayed signal in time domain. The signal consists of the GI (T_g) and the effective symbol length (T_e). Let $x_{hk}(t)$ ($k = 1, 2, \ldots, K$) express the input signals extracted from the received signal during the Head GI (T_g) of the synchronized signal. In a similar manner, $x_{tk}(t)$ ($k = 1, 2, \ldots, K$) express the input signals extracted from the received signal during the Tail GI of the synchronized signal. The extracted signals from Head GI and Tail GI are expressed in a vector as

$$\boldsymbol{X}_h(t) = [x_{h1}(t), x_{h2}(t), \ldots, x_{hK}(t)]^T \tag{4}$$

$$\boldsymbol{X}_t(t) = [x_{t1}(t), x_{t2}(t), \ldots, x_{tK}(t)]^T \tag{5}$$

Hence the combined outputs of the extracted signals from Head GI and Tail GI are given by

$$y_h(t) = \boldsymbol{W}^H \boldsymbol{X}_h(t), \; y_t(t) = \boldsymbol{W}^H \boldsymbol{X}_t(t) \tag{6}$$

In this paper, we adopt three kinds of algorithms with different characteristics. The first one is Maximum Ratio Combining (MRC), and the weight coefficient vector $\boldsymbol{W}_{MRC}$ is expressed as follows,

$$\boldsymbol{W}_{MRC} = E[\boldsymbol{X}_h(t) y^*_h(t)] \tag{7}$$

where E[ ] denotes the expected value calculation. The second one is Array Main Beam Former (AMBF), and the weight coefficient vector $\boldsymbol{W}_{AMBF}$ is expressed as follows [1],

$$\boldsymbol{W}_{AMBF} = E[\boldsymbol{X}_h(t) y^*_t(t)] \tag{8}$$

The third one is Minimum Mean Square Error (MMSE), and the weight coefficient vector $\boldsymbol{W}_{MMSE}$ is expressed as follows [2],

$$\boldsymbol{W}_{MMSE} = R^{-1}_{XhXh} \boldsymbol{W}_{AMBF} \tag{9}$$

where $R_{XhXh} = E[\boldsymbol{X}_h(t) \boldsymbol{X}_h^H(t)]$.

4. Experimental Conditions

Using the fading simulator, we evaluated the BER performances and the directional patterns. The measuring frequency is 35ch (The center frequency: 605.143MHz), and Table 1 shows the OFDM signal condition. Table 2 shows the element spacing for Fig.1. Case 1 and Case 2 correspond to the ideal antenna interval and the practical interval when the antennas are mounted on a vehicle, respectively. The F/B of antennas is varied from 0dB through 15dB.

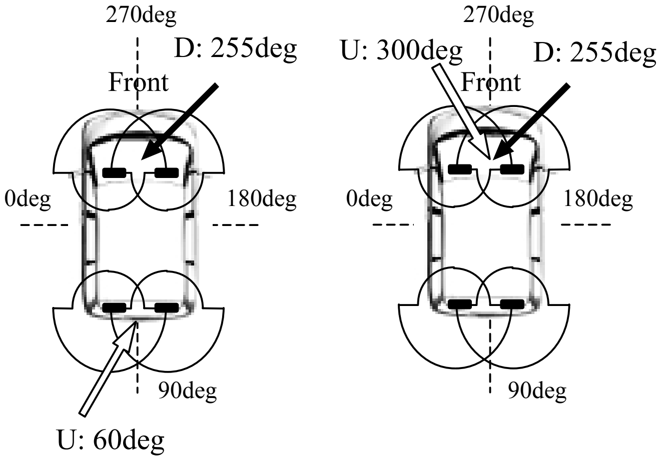
We evaluated in a 2-arrival wave environment. The D/U was 3dB(D: Desired signal, U: Undesired signal). Moreover, the delay time of the undesired signal to the desired signal was 21 (1/6*GI) or 147 (7/6*GI) [μs]. Figure 6 shows the radio environments.

Table 1: Condition of OFDM Signal

Number of carriers	5617
Effective symbol length	1008μs
Carrier interval	0.992kHz
GI length (1/8)	126μs
Moduration scheme	64QAM

Table 2: Element Spacing

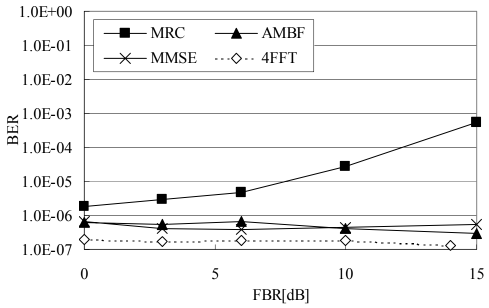
	dx	dy
Case1	0.5λ	0.5λ
	0.25m	0.25m
Case2	3.0λ	8.0λ
	1.50m	4.00m



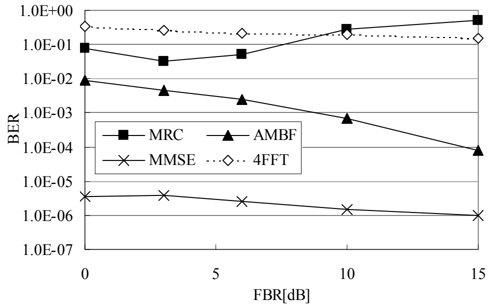
Radio Environment (A) Radio Environment (B)

Figure 6: Radio Environments

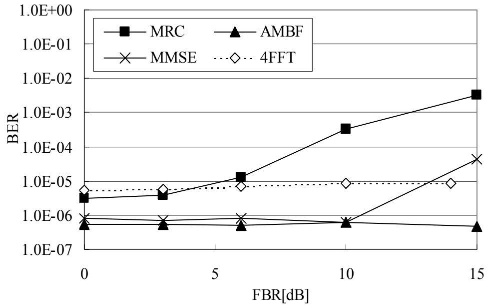
5. Experimental Results



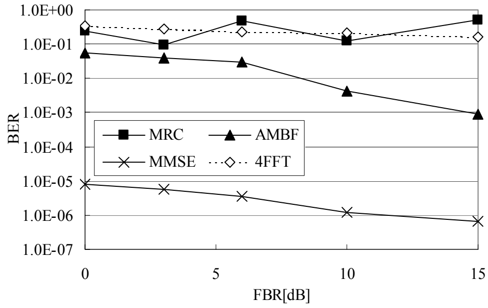
(a) Conditions: Case1, 21μs , (A)



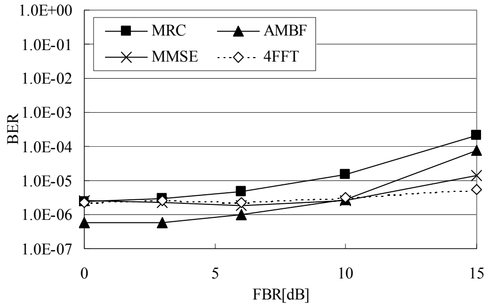
(b) Conditions: Case1, 147μs , (A)



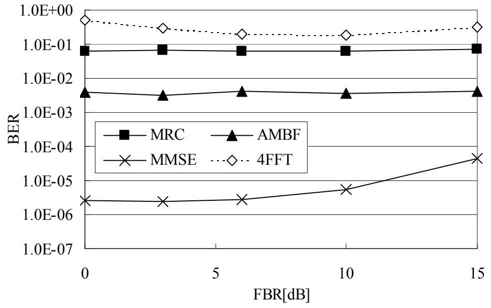
(c) Conditions: Case2, 21μs , (A)



(d) Conditions: Case2, 147μs , (A)



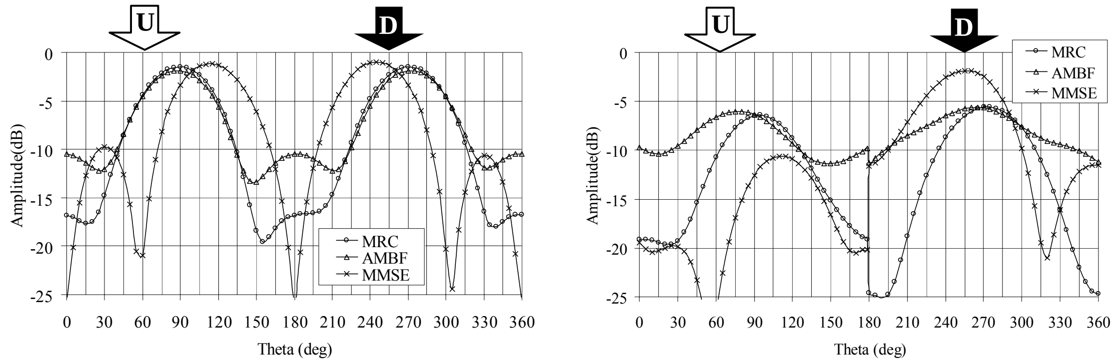
(e) Conditions: Case1, 21μs , (B)



(f) Conditions: Case1, 147μs , (B)

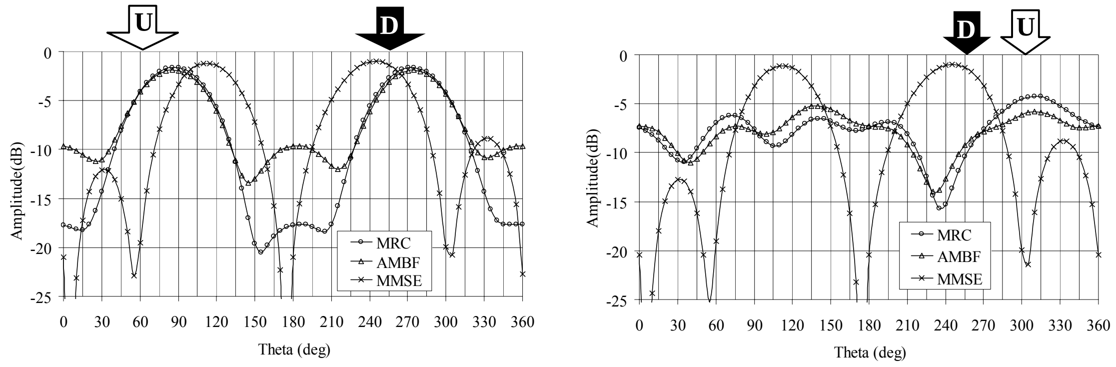
Figure 7: BER Performances
(Conditions: Element Spacing, Delay, Radio Environment)

Figure 7 shows the BER performances of each experimental condition. The influence of the antenna position on the BER performances is only slight in comparison between Fig.7 (a) and (c), and between Fig.7 (b) and (d). Similarly, the influence of the radio environment is not so much in comparison between Fig.7 (a) and (e), and between Fig.7 (b) and (f). The BER performances of MRC, AMBF and 4FFT are deteriorated when the delay time of the undesired signal is 147 (7/6*GI) [μs] in Fig.7 (b), (d) and (f). On the other hand, the BER performance of MMSE is excellent with the same conditions. Further, Figure 8 shows the directional patterns for Case 1, thereby demonstrating a much better performance of the MMSE.



(a) Conditions: 0dB, 21μs, (A)

(b) Conditions: 15dB, 21μs, (A)



(c) Conditions: 0dB, 147μs, (A)

(d) Conditions: 0dB, 21μs, (B)

Figure 8: Directional patterns for antenna position of Case1
(Conditions: F/B, Delay, Radio Environment)

6. Conclusion

In this paper, we compared the BER performances of Pre-FFT adaptive array antenna with those of Post-FFT carrier diversity. When the delay time of the undesired signal is within GI, the BER performances of AMBF, MMSE and Post-FFT diversity are almost the same. However, when the delay time of the undesired signal is over GI, the BER performance of MMSE is superior to that of Post-FFT diversity, because the undesired signal is suppressed significantly.

References

[1] S.Hori, N.Kikuma, T.Wada, M.Fujimoto, "Experimental Study on Array Beam Forming Utilizing The Guard Interval in OFDM," International Symposium on Antennas and Propagation (ISAP05), pp.257-260, Vol.1, 2005.

[2] S.Hori, N.Kikuma, N.Inagaki, "MMSE adaptive array utilizing Guard Interval in the OFDM systems," Electronics and Commun. in Japan, Pt.1, Wiley Periodicals, Inc., Vol.86, No.10, pp. 1-9, 2003.