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

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Introduction

Terrestrial digital TV broadcasting in Japan (ISDB-T) was started in three metropolises of Tokyo / Osaka / Nagoya in 2003, and nationwide broadcasting was launched in 2006. In ISDB-T, Orthogonal Frequency Division Multiplexing (OFDM) is adopted as a modulation scheme. The communication performance of OFDM is known to be superior especially to that of a single carrier in a multipath environment. However, multipath fading caused by many reflected signals seriously deteriorates the quality of digital communication at the mobile reception in actual fact. For overcoming this problem, to perform beam-forming and null-steering adaptively by adaptive array antenna technology reduces the effect of fading. It enables the stable reception even if radio environment changes with time at the mobile reception. In this paper, we propose the system configuration in consideration of antenna directivity when four antennas are mounted on a vehicle and we experimentally demonstrate that the ISDB-T reception probability is improved while the vehicle moves at high speed.

Implemented algorithms

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

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

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

Then, the combined output of the array is given by

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

Here, the superscripts T and H represent the transpose and the conjugate transpose, respectively. Figure 1 shows the OFDM modulated signal with the 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.

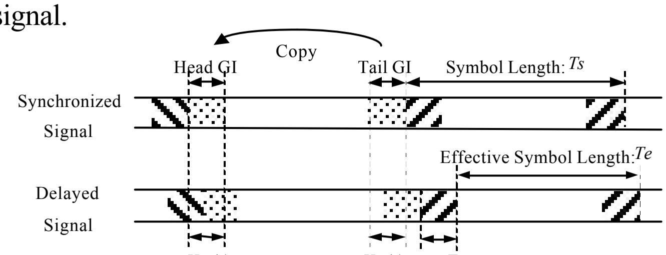

Figure 1. OFDM modulated signals

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The extracted signals from Head GI and Tail GI are expressed in a vector as

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

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

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

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

In this paper, we adopted 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,

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

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],

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

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

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

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

System Configurations

In this paper, we examine three types of system configuration in case that four antennas are mounted on a vehicle (Front:2 antennas, Rear:2 antennas). Figure 2 shows a position of the antennas on a vehicle. Figure 3 shows the most basic configuration where the OFDM modulated signal is demodulated after signals from four antennas are combined. Here, it is referred to as "System Configuration A".

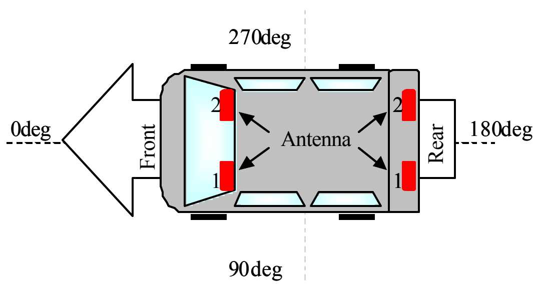


Figure 2. Antenna position on the vehicle

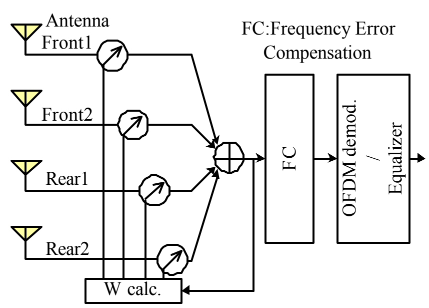


Figure 3. System Configuration A

The 2 front antennas mainly receive the radio waves arriving from front direction of the vehicle because of their directivities. Similarly, the 2 rear antennas mainly receive the radio waves from back direction of the vehicle because of their directivities. Figure 4 shows the configuration, in which the reception signals are combined independently in the front and the rear of a vehicle. Subsequently, these signals are applied to frequency error compensations, and the signals in front and in rear are combined again and this combined signal is demodulated. It is referred to as "System Configuration B". Figure 5 shows the configuration referred to as "System Configuration C" which has the purpose of improving System Configuration B. After performing adaptive array of two elements, each of adaptive array output signals is demodulated. In addition, this system features performing the carrier diversity every subcarrier, as shown in Figure 5.

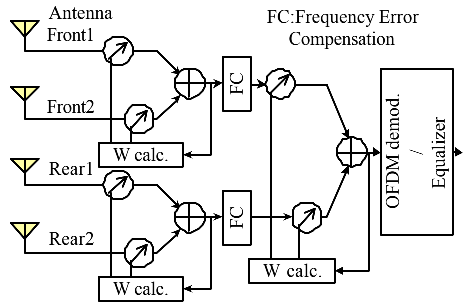


Figure 4. System Configuration B

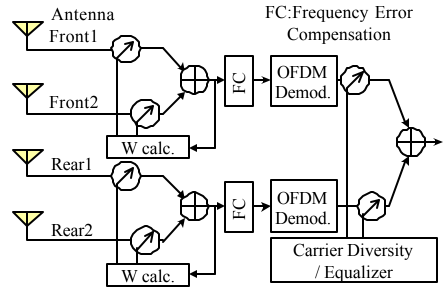


Figure 5. System Configuration C

Simulation Results

Using computer simulation, we evaluated the BER performances of above three configurations for Doppler shift. HPBW of each antenna is 120degrees and Table 1 shows their central angles with maximum directivity. Figure 6 shows the directional patterns of four antennas. Table 2 shows the condition of OFDM signal. Table 3 shows the simulation condition of 6-arrival wave environment.

Table 1. Antenna center angles

Front1	30(deg)
Front2	330(deg)
Rear1	150(deg)
Rear2	210(deg)

HPBW[Half Power Beam Width] = 120(deg)

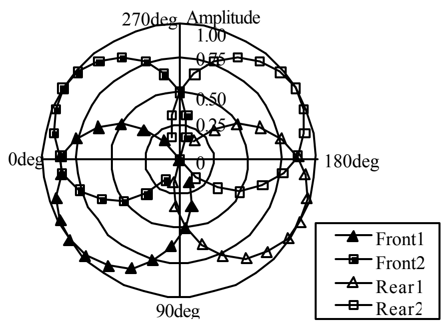


Figure 6.Directional patterns of four antennas

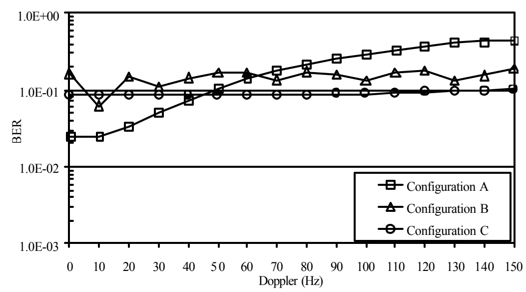
Table 2. Condition of OFDM signal

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

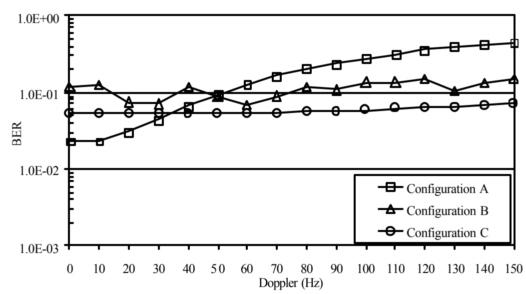
Table 3. Simulation condition

Paths	angle(deg)	D/U (dB)	Delay(μs)
#1	30	0	0
#2	90	5	2.5
#3	150	0	4.1
#4	190	0	130.8
#5	270	3	2.1
#6	0	0	90.5

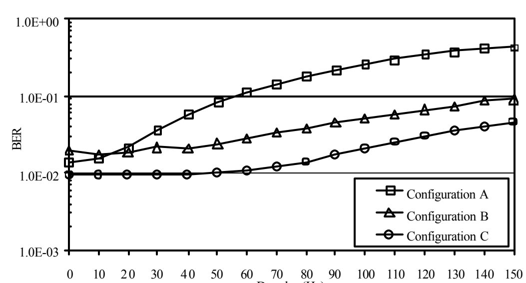
CNR[Carrier to Noise Ratio]=30dB



(a)BER performance with MRC



(b)BER performance with AMBF



(c)BER performance with MMSE

Figure 7. BER performances of three configurations

Figure 7 shows the BER performances of three configurations with the algorithms of MRC, AMBF and MMSE. When comparing BER performances based on the algorithms, BER performance of AMBF is superior to that of MRC, and BER performance of MMSE is superior to that of AMBF. In all algorithms, the BER performance of System Configuration B is better than that of System Configuration A, moreover we can find that the BER performance of System Configuration C is the best in the condition that Doppler shift is large.

Experimental results

We built two prototypes of System Configuration A that is the most basic and System Configuration C that is the best in the simulation results, and we evaluated the two systems in real radio environments. In the course of Figure 8, we evaluated the ISDB-T reception probability while the vehicle moves at high speed. Nagoya Expressway City Center Loop Road of the evaluation course is about 20km away from Seto digital tower transmitting the ISBD-T broadcast signals. Figure 9 shows the experimental results. In all algorithms, the reception probabilities of System Configuration C are greatly superior to those of System Configuration A.

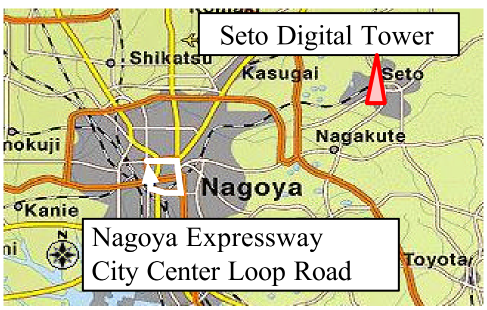


Figure 8. An evaluation course

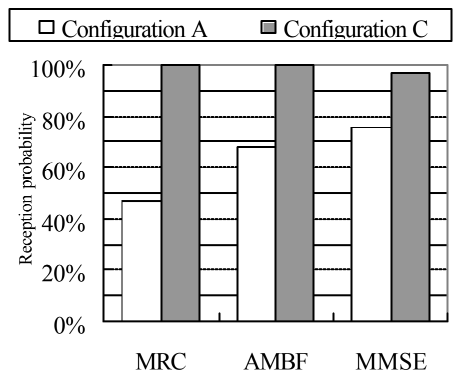


Figure 9. Reception probabilities

Conclusion

We did the comparative study of System Configurations A, B, and C. From the results of the simulation and the experiment, it has been shown that System Configuration C is improved in performance over System Configurations A and B. The dominant waves received by the front antennas and those by the rear antennas are different because of their directivities. Therefore, it is considered that System Configurations B and C which combine the two signals individually at the front and the rear are better for actual automobile reception than System Configuration A which simultaneously combines all the signals of 4 antennas. We will analyze in detail the usefulness of the carrier diversity by comparing it with System Configuration B in future. Some of this research was conducted by a grant from Chubu Bureau of Economy, Trade and Industry in Japan.

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[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.