Effects of Hands on the 4-Branch MRC Diversity Gain for Terrestrial Digital Broadcasting Portable TV

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1. Introduction

Digital broadcasting terrestrial services have been spread all over the word, including Europe, North and South America. In Japan, Terrestrial Integrated Services Digital Broadcasting (ISDB-T) system has been adopted. ISDB-T system has a unique feature in that it offers not only high definition television (HDTV) services for fixed reception, commonly referred to as 'Full segmentation', but also mobile multimedia services for mobile reception, called 'One segmentation'. Initially, ISDB-T system was started to primarily provide fixed reception services. However, currently there is an increasing demand for mobile reception services, even for HDTV Full segmentation reception with small handheld digital broadcasting TV receivers, including a notebook size portable LCD TV set and a cellular phone type handset receiver, using all built-in antennas.

In order to achieve performance required for HDTV reception, maximum ratio combining (MRC) diversity system is a promising technology since an MRC can reduce the required signal-to-noise ratio (SNR) for receiving broadcasting signals compared to a single antenna receiver system. However, to extract the desired performance of an MRC, some technical obstacles must be overcome because some diversity branches comprising an MRC array experiences a significant antenna gain reduction due to a tightly volume-constrained condition. In addition, in the case of a handset receiver, the electromagnetic interaction between the branch antenna elements and the user, especially due to the hand and fingers of an operator, can cause a further severe gain reduction. In this situation, the difference in antenna gain, leading to the power imbalance of received signals, is a major source of cause in the degradation of MRC performance since fading correlation between branches tends to be low due to a wide angular power spread of incident waves in azimuth. Hence, the diversity gain of an MRC decreases predominately due to the power imbalance of received signals.

This paper studies on effects of hands on the diversity gain for a 4-branch MRC array implemented in a terrestrial digital broadcasting TV set. In the first step, using a four-element dipole array antenna, the relationship between decrease in the diversity gain and reduction of the receive power, and decrease in the diversity gain and the number of branches to be reduced received power, was investigated by means of a Monte Carlo simulation. Then using the simulated results, a simple method of predicting the diversity gain under the power imbalance condition is given. The goal is to know the criterion with respect to the gain reduction for achieving a required system performance. Finally, the proposed method is confirmed by the analysis using a model of a typical portable digital broadcasting TV set held with both hands simulating the power imbalance condition.

2. Analysis of an MRC Dipole Array under Power Imbalance Condition

Fig. 1 shows the MRC diversity antenna model used for the simulation considering the power imbalance problem. As shown in the figure, attenuators are connected at the input port of each element, and thus the received signals can be intentionally reduced by ΔG. With this configuration, we can simulate the received power imbalance conditions for MRC antennas. Although, in practice, the human body and electrical devices in the immediate vicinity of an antenna cause the radiation pattern of antennas to change, which, for example, may lead to changes in the mutual coupling between branches, this effect is not part of the study conducted in this paper.

The analysis is conducted using a channel model of a two-dimensional angular power spectrum (2D-APS) simulating a Rayleigh fading environment [1]. Using the model, a Monte Carlo simulation has been carried out, in which the MRC function is achieved using the MMSE algorithm. By applying the MMSE condition to the output signal of the array, the optimum weight vector is calculated at each snapshot during the sequence of moving the array in a fading environment. In the simulation, the channel response is created in consideration for both vertical and horizontal components of radiation patterns of the antenna elements, and the cross polarization power ratio (XPR) in a fading environment. Finally, the average BER over the entire traveling distance is calculated by summing all the instantaneous BER, in which the coherent detection of phase shift keying signals is assumed. In this paper, QPSK signals, used for the one-segmentation ISDB-T system, and 64QAM signals, used for the full-segmentation ISDB-T system, are adopted.

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3. Analytical Results for an MRC Dipole Array

As a basic study, we considered array antennas comprising two and four vertically oriented half-wavelength dipole antennas with half-wavelength spacing in free space. The radiation and impedance characteristics are calculated by means of the method of moments. Fig. 2 shows the average BER characteristics as a function of the average input SNR with the reduction of antenna gain $\Delta G=\Delta G_k$ as parameters, assuming the 64QAM modulation. In the case of a two-branch MRC, the antenna gain of branch #1 is reduced, and in the case of a four-branch MRC, the gains of branches #1 and #2 are reduced with the same values. As a reference case, the BER for a single dipole is also shown in the figure. Frequency for the simulation is 600MHz and XPR is assumed to be infinity. The traveling distance is 50λ, and the distance between two successive points in the simulation Δd is set to be 0.01λ.

Now the diversity gain is defined as the difference between the average SNR of an antenna under consideration and that of a single dipole antenna when BER is achieved at a prescribed value, $P_{ave}=P_o$, by the following equation

$$G_{div} = \frac{SNR_{SingleDipole}}{SNR_{Pave=Po}} \qquad (1)$$

Fig. 2 shows that, when $P_o=10^{-3}$ and ΔG=0dB, the diversity gains for the two-branch and four-branch MRC are found to be G_{div}=10.6dB and 17.3dB, respectively. Furthermore, as can be seen from the figure, the BER characteristics are degraded with increasing ΔG. Consequently, as a limiting case of sufficiently large ΔG, the BER of the two-branch MRC is converged to that of a single dipole, whereas the BER of the four-branch MRC is converged to that of the two-branch MRC with ΔG=0dB.

Fig. 3 shows the relationship between the diversity gain G_{div} of the four-branch MRC and the antenna gain reduction ΔG for the QPSK (Fig. 3(a),(b)) and 64QAM (Fig. 3(c),(d)) modulation, in which (a, c) and (b, d) show the diversity gain when ΔG is reduced by between 0 and 30 dB for branches (#1 and #2) and (#1, #2 and #3), respectively. It was confirmed by other simulations that other combinations, for example (#1 and #4), give similar results. In the figures, the three lines indicate the cases when P_o equals 10^{-2}, 10^{-3} and 10^{-4}. It can be seen from Fig. 3 that the diversity gain decreases in proportion to ΔG in the region where ΔG is less than 10dB. In addition, Fig. 3 shows that in each case the diversity gain converges to a certain constant value for ΔG greater than 20dB. The three symbols plotted at ΔG=30dB in Figs. 3(a)-(d), show the results of calculations with P_o being equal to 10^{-2}, 10^{-3} and 10^{-4} when a 2-branch antenna is used in Figs. (a) and (c), and a 1-branch antenna is used in Figs. (b) and (d). In each figure, it can be seen that the three curves converge to the corresponding symbols.

Table 1 shows the gradient of the plots in the region where ΔG is less than 10dB, in which the gradients for QPSK and 64QAM are averaged. It can be seen in Table 1 that, in the case of three-element gain reduction (#1,#2,#3) the gradient is equal to 6.2, 6.7, and 7.3 dB per 10dB reduction in ΔG as the BER (P_o) is reduced, indicating that the received power imbalance has a greater influence on diversity gain for smaller P_o. Table 1 also shows that, in the region where P_o is small, say $P_o=10^{-4}$, the gradient increases with the number of elements with reduced received power.

Using the results obtained from the analyses, the reduction of diversity gain can be estimated in a simple manner by knowing the number of elements with reduced received power and the value of gain reduction. For example, for a 64QAM-MRC array, when the gain of two elements are reduced by ΔG=6dB, the reduction of the diversity gain is estimated to be $\Delta G_{div}=5.5\times 6/10=3.3$dB at $P_o=10^{-3}$.

4. Consideration on a Portable TV Set

Fig. 4 shows the analytical model for a portable TV set held with both hands, comprising two monopole antennas and two inverted L antennas (ILA). The analysis is conducted with the model being placed in the horizontal configuration, representing a practical use condition when a user watches TV. The hand is modeled by a simple parallelepiped holding a portable TV set with a palm thickness of 15 mm, assuming biological human tissue parameters. The location of the hands can be varied with respect to the TV set in order to obtain knowledge about a way how the proximity of the hands to ILAs creates the power imbalance condition, and consequently the reduction of the diversity gain.

Fig. 5 shows the VSWR characteristics as a function of the location of hand at 600MHz. As can be seen from the figure, VSWR of the monopoles changes moderately, whereas VSWR of ILAs increases significantly when the hand location, h1=h2, is 5 cm. This is because the ILAs have a small frequency bandwidth compared with the monopoles. Fig. 6 shows the difference between the MEG of ILA and that of monopole in the horizontal plane with XPR of -6dB, indicating the power imbalance between the two antennas. It can be seen from Fig. 6 that a power imbalance of 9dB is given when the hand location, h1=h2, is 2.5 cm, which is close to the location of VSWR degradation, as described in Fig. 5. Fig. 7 shows the required average SNR as a function of the location of hand for the 64QAM when BER equals 10^{-2}, 10^{-3} and 10^{-4}. It can be understood from Fig. 7 that the required average SNR increases at around h1=h2=2.5 cm due to the power imbalance condition shown in Fig. 6. Fig. 8 shows the diversity gain as a function of the location of hand for (a) QPSK and (b) 64QAM. The diversity gain is defined as the value when a reference antenna, meaning the numerator in Eq. (1), is chosen as a single monopole antenna (MONO #1). It can be seen from the Fig. 8 that the diversity gains are reduced by 5.5dB and 5.3dB at $P_o=10^{-3}$ for QPSK and 64QAM, respectively. Now, let's consider those decreases in diversity gain from the gradient of the diversity gain for a dipole array shown in Table 1 (5.5dB for the two-element gain reduction (#1, #2) at $P_o=10^{-3}$) and the power imbalance of 9dB shown in Fig. 6. Hence, the reduction of the diversity gain is estimated to be $\Delta G_{div}=5.5\times 9/10=5$dB. It is confirmed from this fact that the reduction of the diversity gain for an actual digital TV set can be successfully predicted using the gradient of the diversity gain shown in Table 1.

5. Conclusion

This paper presents a basic investigation on the power imbalance problem with regard to an MRC antenna for a digital broadcasting portable TV, and a simple method of estimating the reduction of diversity gain has been proposed.

References

[1] K. Ogawa, A. Yamamoto, and J. Takada: "Multipath Performance of Handset Adaptive Array Antennas in the Vicinity of a Human Operator," IEEE Trans. Antennas Propagat. AP-53, No. 8, pp. 2422-2436, Aug. 2005.

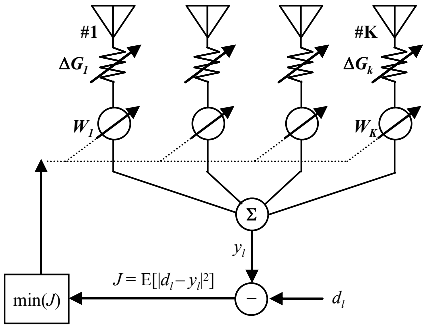

Fig. 1 MRC diversity antenna model

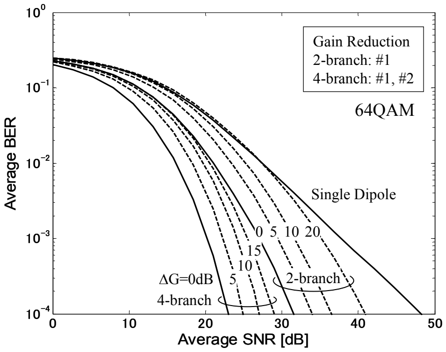

Fig. 2 Average BER characteristics of a dipole MRC array

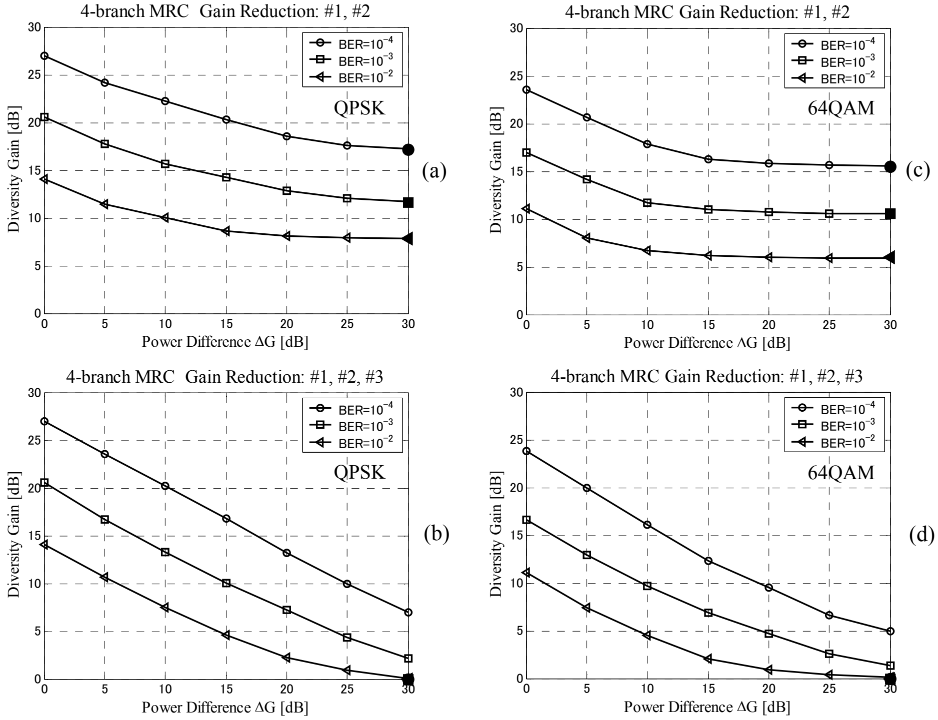

Fig. 3 Relationship between the diversity gain G_{div} and the antenna gain reduction ΔG of a dipole MRC array

Table 1 Gradient of the average diversity gain per 10dB reduction of ΔG shown in Fig. 3 in the region ΔG<10dB

	Branches with the gain reduction		
BER (P_o)	#1	#1,#2	#1,#2,#3
10^{-2}	2.2 dB	4.9 dB	6.2 dB
10^{-3}	2.3 dB	5.5 dB	6.7 dB
10^{-4}	2.4 dB	6.1 dB	7.3 dB

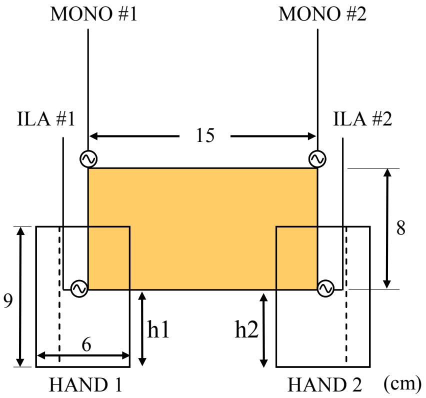

Fig. 4 Model for a portable TV set held with both hands

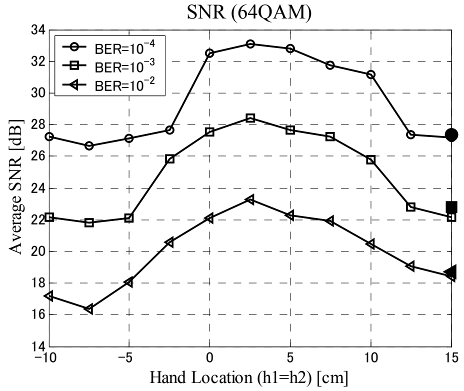

Fig. 7 Required Average SNR vs. Hand Location

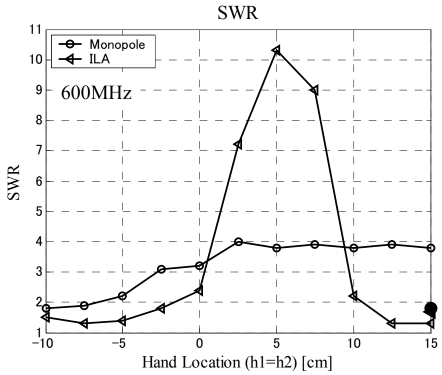

Fig. 5 VSWR vs. Hand Location

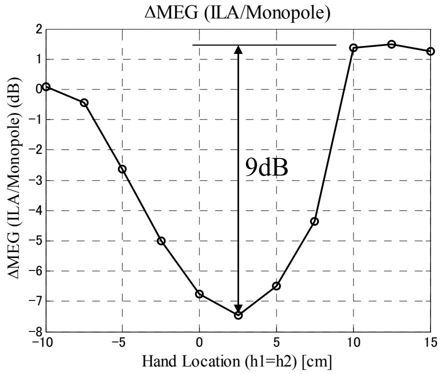

Fig. 6 ΔMEG vs. Hand Location

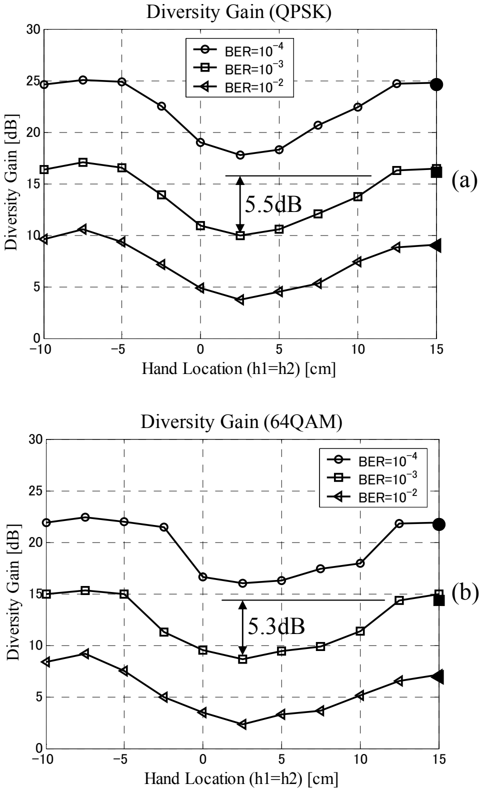

Fig. 8 Diversity Gain vs. Hand Location