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Mutual Interactions Between Holding Angle and Broadcasting Waves Polarization on the Sensitivity of a Portable DTV MRC Array

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Abstract— **This paper presents an analysis of the mutual interactions between holding angle and broadcasting waves polarization on the sensitivity of a 4-branch MRC array used for a digital broadcasting portable TV set. First, we have measured a way of holding a portable TV set in order to investigate statistical properties of the holding angle. Characteristics of broadcasting waves polarization are also quantitatively examined through propagation measurements. Based on the measured results, the sensitivity of an MRC array was examined to clarify the mutual interactions in terms of the radiation power ratio (RPR). The results show that the holding angle has a significant impact on the sensitivity of an MRC array, and that there is a possibility of achieving a high-performance MRC array antenna by optimizing the RPR characteristics of an MRC array.**

I. INTRODUCTION

Digital broadcasting terrestrial services have spread all over the world. Digital TV was commonly watched inside housing by the use of a Yagi-Uda array antenna standing on the top of a roof. In recent years, however, there has been a great demand for an outdoor usage with the emergence of a notebook-sized portable LCD TV set, commonly referred to as a tablet type handset. Because people watch a tablet TV set both indoors and outdoors, we must consider two types of radio wave environments encountered in these scenarios, where there would be a great discrepancy in the polarization characteristics of broadcasting waves.

There is a variety of styles about a way of people holding a tablet type TV set. Particularly, the holding angle of a tablet TV set is easy to change because we usually adjust the holding angle in order to watch a clear video picture on a display. In this situation, the polarization characteristics of antennas are significantly influenced by the holding angle of a tablet TV set. Hence, there may be the mutual interactions between the holding angle and broadcasting waves polarization, and consequently the performance of a tablet TV set is considered to be strongly affected by the mutual interactions.

This paper presents an analysis of the mutual interactions between the holding angle and broadcasting waves polarization on the sensitivity of a 4-branch MRC array used for a digital broadcasting tablet type portable TV set. In the first step of our investigation, we have measured a way of holding a portable TV set in order to gain useful knowledge about statistical properties of the holding angle. Secondly, characteristics of broadcasting waves polarization are quantitatively examined through propagation measurements. Based on the measured results, the sensitivity of an MRC array was examined. Finally, extensive considerations on the radiation power ratio (RPR) of the MRC array antenna are given in order to clarify the mutual interactions. The results show that the holding angle has a significant impact on the sensitivity of an MRC array. More importantly, it is suggested from the study on the mutual interactions that there is a possibility of achieving a high-performance MRC array antenna by optimizing the RPR characteristics of an MRC array.

II. HOLDING STYLE OF PORTABLE TV SETS

In cellular handsets, studies were conducted on statistical measurements of the geometrical relationship between the handsets and an operator [1]. However, digital TV sets treated in this paper have the structure that is quite different from that of a cellular handset, particularly in the size of the display, which leads to a different way of holding a handset. Based on this background, we have measured a way of holding a portable TV set in order to investigate statistical properties of the holding angle. Measurements were done by sampling two regions of the human body using thirty-seven 10 to 20-year-old men holding a portable TV set.

Fig. 1 shows the measured region. In Fig. 1, α represents the holding angle from the horizontal plane, and β indicates the location of hands from the bottom of a portable TV set. Table I shows the measured results for each region. In the table, σ is the standard deviation and μ is the average value.

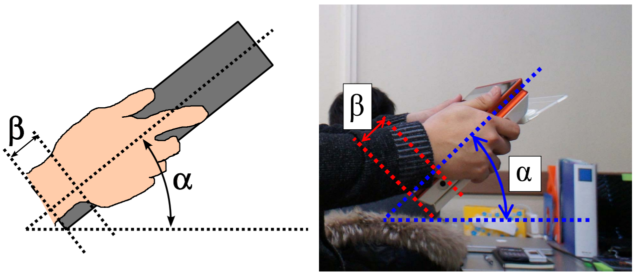


Fig. 1. Measured region that shows the relationship between the portable TV set and the human body

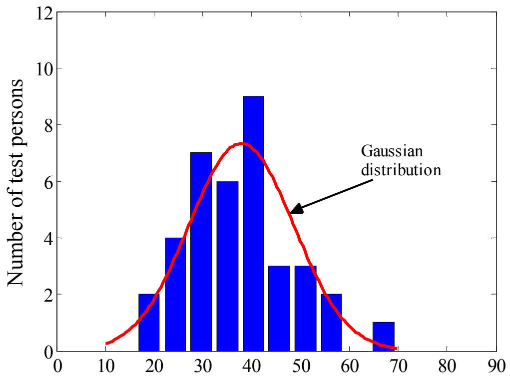
Table I
Measured results

Measured region	Min	Max	μ	σ
Angle of Handset α [degree]	19	67	38	11
Hand Location β [cm]	-5.6	5.1	-0.9	2.3

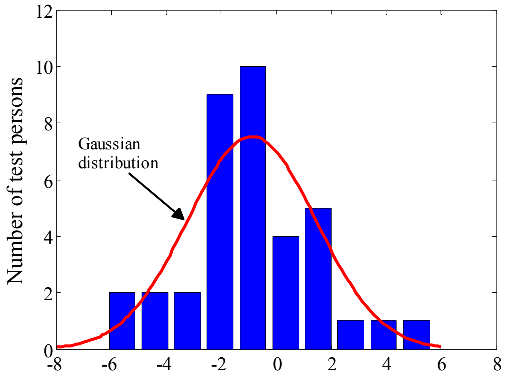
Fig. 2 shows the histograms of the measured results. In Fig. 2, the Gaussian distribution curve is also plotted using Eq. (1), indicated by the solid lines.

$$f(x)=\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (1)$$

As shown in the figures, the histograms agree approximately with the Gaussian distribution. It can be seen from Fig. 2(a) that the holding angle α ranges from 19° to 67° because the holding angle is adjusted in order to watch a clear video picture on a display. In contrast, Fig. 2(b) shows that the hand location β is concentrated on β = 0. This is probably due to the fact that the portable TV set used in the experiment has a relatively large weight, and thus a test person is likely to hold the bottom of the portable TV set so as to support it in a stable position.



(a) Angle of handset α [degree]



(b) Hand location β [cm]

Fig. 2. Histograms of the measured data

III. PROPAGATION MEASUREMENTS

Fig. 3 shows the site of the propagation measurements at the Toyama University. In Fig. 3, the symbols A–O indicate the locations for the measurements. The locations A–C mean that they are situated under the line-of-sight (LOS) condition because a broadcast station (horizontal polarization transmission) is visible directly from the measurement site. On the other hand, the locations L–O are situated under the non-line-of-sight (NLOS) because these locations are present well inside the building and completely surrounded by walls and furniture. A sleeve dipole antenna was used to receive the vertical component (P_V) of broadcasting radio waves, and a cylindrical slot antenna was used to receive the horizontal component (P_H). The frequency for the measurement was 539MHz (UHF24ch).

Fig. 4 shows the received power of P_V and P_H as a function of the measured locations. In Fig. 4, the dotted lines indicate the received power of −60 dBm that corresponds to the threshold level of the full-segmentation reception. We see in Fig. 4 that the received power, P_V and P_H, decreases when the measurement site moves from outdoor to indoor locations. The received power is lower than −60 dBm at the locations J–O, which means that the full-segmentation reception is not performed at these locations but only the one-segmentation reception is possible.

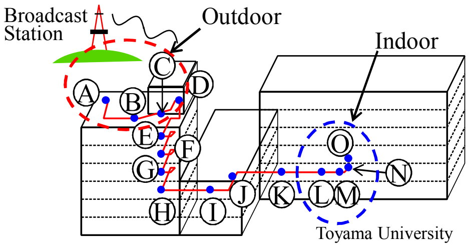


Fig. 3. Measurement site

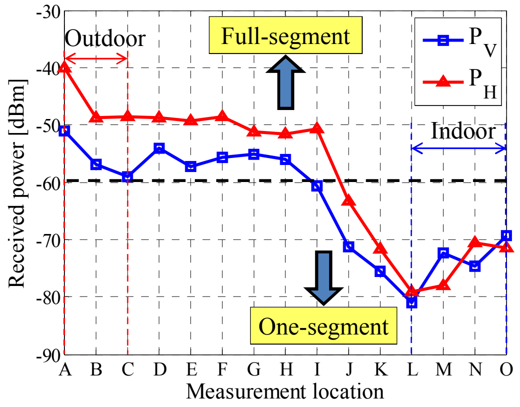


Fig. 4. Received power vs. measurement locations

It should be noted in Fig. 4 that the received power of P_H is approximately 10 dB greater than that of P_V in the outdoor locations A–C. In contrast, the received power of P_H is almost same as that of P_V in the indoor locations L–O. There is a possibility of utilizing these features to compensate the reduction in the received power in the indoor locations L–O by receiving both polarization components, so that the full-segmentation reception can be achieved. Hence, we have examined the cross-polarization power ratio (XPR), as shown in Fig. 5. XPR can be calculated using Eq. (2)

$$XPR = \frac{P_V}{P_H} \qquad (2)$$

It can be seen from Fig. 5 that the XPR at locations A–C is approximately −10 dB. It can be seen from this fact that the horizontal component is dominant at these locations, and the horizontal polarization transmitted from the base station is well conserved. On the other hand, the XPR at locations L–O is larger than 0 dB caused by the emergence of cross polarization components due to many objects surrounding the sleeve and slot antennas. It is concluded from Fig. 5 that the XPR varies from −10 dB in an outdoor environment to 6 dB in an indoor environment.

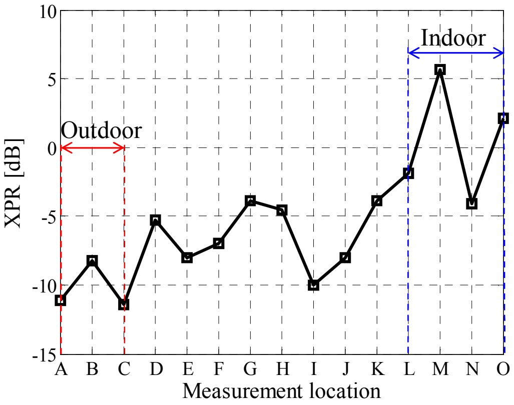


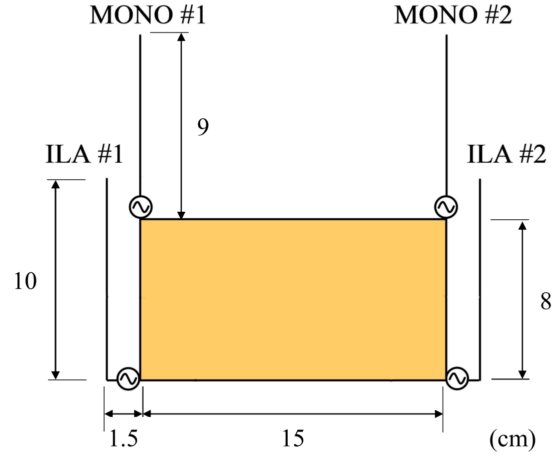
Fig. 5. XPR vs. measurement locations

IV. CONSIDERATION ON MRC ARRAY ANTENNAS

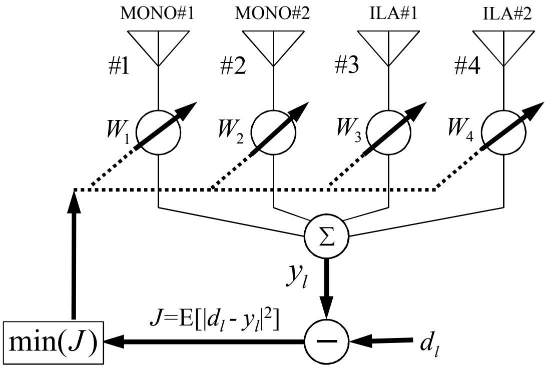
Based on the measured results described in Sec. II and III, signal bit error rate (BER) characteristics of an MRC array were examined. In this paper, 64QAM signals used for the full-segmentation in the digital broadcasting terrestrial system are adopted.

Fig. 6(a) shows the analytical model for a portable TV set, comprising two monopole antennas and two inverted L antennas (ILA). The frequency for the simulation is 600MHz. Electromagnetic analysis was carried out by the method of moments. Fig. 6(b) shows the minimum mean square error (MMSE) adaptive array antenna model used for the simulation.

As shown in Fig. 7, the analysis is conducted using a channel model of the two-dimensional angular power spectrum simulating a Rayleigh fading environment [2]. The MRC function is achieved by the MMSE adaptive array algorithm without interference signals. 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 Rayleigh 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 XPR in a fading environment is taken into account.



(a) Portable TV set



(b) MMSE adaptive array antenna

Fig. 6. Analytical model

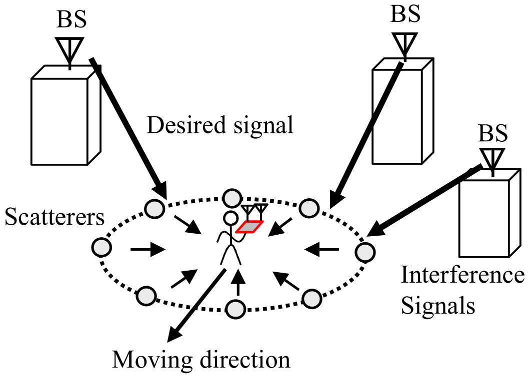


Fig. 7. Radio propagation model

Fig. 8 shows the average SNR required for achieving BER = 10^{-3} as a function of XPR. It is shown in Fig. 5 that the XPR of an outdoor environment is assumed to be −10 dB to −5 dB, and the XPR of an indoor environment is assumed to be 0 dB to 6 dB. Hence, the XPR is varied from −10 dB to 10 dB in the analysis conducted here.

In Fig. 8, an inset is provided to show the definition of the inclination angle α of a handset. In the figure, the open circle symbols show the case where the model is placed in the horizontal configuration (α = 0°). The open square symbols indicate the case where the model is held by α = 40° (the average value shown in Table I). The open triangle symbols show the case where the model is placed in the vertical configuration (α = 90°). The dotted lines indicate the average SNR = 28 dB that is assumed to be the threshold level for achieving the full-segmentation reception.

Fig. 8 shows that when the XPR ranges from −10 dB to −5 dB (outdoor environment) the angle of α=0° yields a lower SNR than the angles of α = 40° and 90°. In contrast, when the XPR ranges from 0 dB to 6 dB (indoor environment) the angle of α = 90° provides a lower SNR than the angles of α = 0° and 40°. As a result, the angles of α = 40° gives a compromise solution that achieves a robustness performance against the two environments. This phenomenon would suggest an idea realize a high-sensitivity MRC array antenna. Hence, in order to clarify this mechanism, we will investigate the radiation power of the vertical and horizontal polarization components separately for all the array elements in the next section.

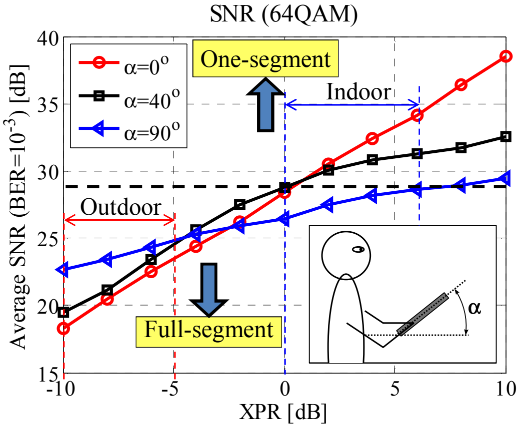


Fig. 8. Average SNR required for achieving BER = 10^{-3} as a function of XPR

V. CONSIDERATIONS ON RADIATION POWER RATIO

In this section, considerations on the radiation power ratio [3], referred to as RPR, of the MRC array antenna are given. The PRPs of the vertical and horizontal polarization components, R_V and R_H, are defined as follows:

$$R_V = \int_0^{2\pi}\int_0^{\pi} G_\theta(\Omega)d\Omega \qquad (3)$$

$$R_H = \int_0^{2\pi}\int_0^{\pi} G_\phi(\Omega)d\Omega \qquad (4)$$

where Ω denotes components (θ, ϕ) in spherical coordinates and $d\Omega = \sin\theta d\theta d\phi$. $G_\theta(\Omega)$ and $G_\phi(\Omega)$ are the θ and ϕ components of the antenna power gain pattern, which take account of the impedance mismatch loss.

Fig. 9 shows the RPR as a function of the holding angle α at 600MHz. It can be seen from Fig. 9 that there is a crossover behavior between R_H and R_V; R_H decreases with increasing the holding angle, whereas R_V increases with increasing the holding angle. Consequently, it is considered from this result that this crossover behavior shown in Fig. 9 creates the sensitivity response against the XPR shown in Fig. 8.

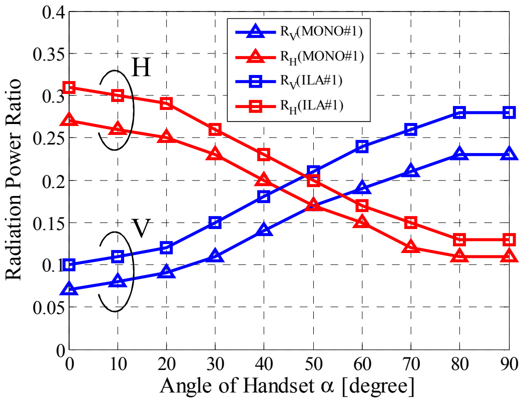


Fig. 9. Radiation power ratio vs. angle of handset α

In more specific terms, because when α = 0° the radiation power of the horizontal component is considerably greater than that of the vertical component, α = 0° exhibits a lower SNR than α = 40° and 90° in the outdoor environment. Conversely, because, in the case of α = 90°, the radiation power of the vertical component is superior to that of the horizontal component, α = 90° gives a lower SNR than α = 0° and 40° in the indoor environment. As a consequence of this behavior, Fig. 9 shows that when α = 50°, R_H is almost identical with R_V. This fact explains the reason that α = 40° gives the robustness performance against the two environments, as shown in Fig. 8.

It is concluded from the above considerations that if a method of changing the RPR arbitrarily is developed there is a possibility of achieving a high-performance MRC array antenna in both outdoor and indoor radio wave environments by optimizing the RPR characteristics of an MRC array.

VI. CONCLUSION

In this paper, an analysis was given on the mutual interactions between the holding angle and broadcasting waves polarization on the sensitivity of a 4-branch MRC array used for a digital broadcasting portable TV set. The results show that the holding angle has a significant impact on the sensitivity of an MRC array, and that there is a possibility of achieving a high-performance MRC array antenna by optimizing the RPR characteristics of an MRC array.

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