Weighted-polarization MRC adaptive vehicular antenna for secure communication in rollover accident

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Abstract: In this paper, we investigate the signal bit error rate (BER) characteristics of a vehicle-borne weighted polarization maximum ratio combining adaptive array antenna for secure communications. The array comprises orthogonally arranged dipole elements, which are combined using weight functions determined by the cross-polarization power ratio in the propagation environment and the angle of inclination of the antenna. The experimental results show that the required signal-to-noise ratio for the proposed antenna to achieve the prescribed BER is lower than that for a conventional dipole array even in vehicle rollover accidents.

Keywords: MRC adaptive array, weighted polarization combining, bit error rate, 3-dimensional OTA apparatus

Classification: Antennas and Propagation

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1 Introduction

Forthcoming connected cars need two technological breakthroughs [1]. One is the realization of a transmission rate of over-10 Gbps using higher order multiple-input multiple-output (MIMO) antenna technologies [2, 3, 4]. The other is the achievement of secure communication with high reliability in the event of an extreme emergency, such as a serious car accident or road rage. In this radio system, the required transmission rate is relatively low, but no discontinuity in communication is allowed. In particular, in the event of a serious car crash resulting in vehicle rollover, the polarization characteristics of a vehicular antenna change significantly. This results in considerable degradation in the signal level when an ordinary roof-mounted dipole-like antenna is used.

This paper presents a weighted-polarization maximum ratio combining (MRC) adaptive array antenna that can be mounted on the roof of a vehicle for secure emergency communications [5]. The experimental results using signal bit error rate (BER) over-the-air (OTA) tests show that the required signal-to-noise ratio (SNR) for the proposed antenna to achieve a prescribed BER for a quadra phase-shift keying (QPSK) signal is lower than that for a conventional dipole array, even in the case of rotation of the antenna by 90 degrees, which is encountered in car accidents involving vehicle rollover.

2 Weighted-polarization MRC adaptive array antenna

Currently, a connected car has a communication system that automatically makes an emergency call to the police in the event of an accident. In the case of vehicle rollover, it may be difficult to make an emergency call because the polarization characteristics of the vehicular antenna change significantly. With regard to an antenna attached to the arm in wearable radio applications, on the other hand, a method of eliminating the reduction of antenna gain due to inclination of the arm has been proposed [6]. These studies led the authors to suggest that the method described in [6] can be applied to solve the problem for vehicular antennas.

Fig. 1 shows the configuration of a weighted polarization MRC adaptive array antenna to be mounted on the roof of a vehicle [5]. In [7], it was found that a simple model comprising a roof presents a radiation pattern within a tolerable error in comparison with the radiation pattern using a model of the whole vehicle. The
The dimensions of the roof are $g_x = 60 \text{ cm}$ and $g_y = 50 \text{ cm}$. In Fig. 1(a), the angle $\alpha$ represents anticlockwise rotation of the car about the $x$-axis. Thus, $\alpha$ denotes the angle of inclination of the antenna.

Fig. 1(b) shows the configuration of the weighted-polarization antenna which consists of orthogonally arranged half-wavelength dipole elements [6]. This antenna comprises two dipole elements aligned in the $z$ and $y$ directions, and excludes the element lying in the $x$ direction because the polarization characteristics of this element do not change depending on $\alpha$. The height $H$ of the array from the surface of the roof is set to a half-wavelength ($H = 7.5 \text{ cm}$), which enhances the radiation field emitted from element $A_y$ at low elevation angles owing to the electromagnetic image created by the roof. The frequency for the measurements was $2 \text{ GHz}$. Each signal received ($s_V, s_H$) is modified by multiplying by weight functions. The weight functions ($W_V, W_H$) are determined by the cross-polarization power ratio (XPR) and the angle of inclination, $\alpha$, and are given by the following equations:

$$a = \frac{W_V}{\sqrt{W_V^2 + W_H^2}} s_V + \frac{W_H}{\sqrt{W_V^2 + W_H^2}} s_H e^{j\frac{\alpha}{2}},$$  

(1)

$$W_V = \sqrt{\frac{XPR}{1 + XPR}} |\cos \alpha| + \sqrt{\frac{1}{1 + XPR}} |\sin \alpha|,$$  

(2)

$$W_H = \sqrt{\frac{XPR}{1 + XPR}} |\sin \alpha| + \sqrt{\frac{1}{1 + XPR}} |\cos \alpha|.$$  

(3)

Fig. 1(c) shows a photograph of the fabricated MRC adaptive array antenna.
based on the analytical model. An aluminum plate with a thickness of 1 mm was used as a simple model for the roof of the vehicle. The antenna was placed on an acrylic jig so that the array was at a height $H$ from the surface of the roof.

3 Radiation characteristics

Fig. 2 shows the radiation patterns in the $xy$-plane of subarray #1. The weighted-polarization antenna can be optimized for directivity based on the variations in $XPR$ and $\alpha$. Figs. 2(a) and (c) show the case of $\alpha = 0^\circ$, indicating the upright position of the car, whereas Figs. 2(b) and (d) exhibit the case of $\alpha = 90^\circ$, indicating a rollover situation. The solid and broken lines represent the measured and analytical results, respectively. The blue and red lines indicate the vertical and horizontal polarization components, respectively.

![Radiation pattern of the adaptive array (subarray #1).](image)

It can be seen from Fig. 2 that the measured radiation patterns are in good agreement with the analytical results.

In the upright position shown in Figs. 2(a) and 2(c), as $XPR$ increases from 0 to 10 dB, the vertically polarized component in the radiation pattern becomes larger, whereas the horizontally polarized component becomes smaller, in accordance with the dominant incoming wave polarization component.

In the rollover position shown in Figs. 2(b) and 2(d), the vehicle roof is parallel to the $x$-axis, as shown in the inset. Thus, the element $A_z$ is parallel to the ground, while the element $A_y$ is perpendicular to it. The weight functions are determined considering the angle of inclination, $\alpha$, and contrast with those in the upright position,
so the radiation patterns of the proposed antenna suitable change depending on $\alpha$. These results clarify that the weight functions work properly according to XPR and $\alpha$.

4 BER characteristics

To evaluate the weighted polarization MRC adaptive array antenna, the BER characteristics for QPSK signals with coherent detection were measured using three-dimensional OTA apparatus [8]. The MRC was performed using the minimum mean square error (MMSE) algorithm [9]. The signal to interference power ratio (SIR) was set to 50 dB, meaning that there were no interference signals when measuring the performance of the MRC using the MMSE scheme.

In this paper, the propagation environment is assumed to be a macrocell environment, with uniform distribution in azimuth and a Gaussian distribution in elevation. The average elevation angle is assumed to be 0° with an angular spread of 20°.

When the BER characteristic is measured, SNR is determined by

$$
SNR = \frac{REF}{N}
$$

where $REF$ is defined as the power received by an isotropic antenna for all radio waves from the scatterers. $N$ is the noise power. However, since the ideal isotropic antenna does not exist, compensation must be made for the received power measured using other antennas. A half-wavelength dipole antenna was used for measuring the received level of the fading emulator, and the radiation gain of the dipole antenna was taken into consideration and calibrated [8].

Fig. 3(b) shows the BER characteristics of the proposed and conventional dipole array antennas for the QPSK signals as a function of $\alpha$ when XPR = 10 dB. The
dipole array comprises two half-wavelength dipole antennas which are positioned as a \( z \)-directed dipole array \((A_z)\) with the same structure as shown in Fig. 1. The solid curves represent the measured results, whereas the broken curves show the results from Monte Carlo simulation. The theoretical curves for the Rayleigh fading channel and MRC using isotropic antennas are shown by the magenta dotted lines in the graph for comparison.

As shown in Fig. 3(b), there is good agreement between the measured and calculated results. The required SNR for the adaptive array to achieve a prescribed BER for a QPSK signal is approximately the same regardless of the inclination angle of the antenna, \( \alpha \). In contrast, the required SNR for the dipole array to achieve a prescribed BER increases with increasing \( \alpha \). Specifically, with regard to the average BER of \( 10^{-3} \), the required SNR for the proposed antenna when \( \alpha = 90^\circ \) is 4.6 dB smaller than that for the conventional dipole array. This is attributed to the fact that when \( \alpha = 90^\circ \) a large signal power is achieved due to the optimum allotment to the theta and phi components of the radiation power.

Fig. 3(c) shows the average SNR characteristics when \( \text{BER} = 10^{-3} \) as a function of XPR in vehicle rollover accidents. The red and blue curves indicate the results of the proposed and dipole array antennas, respectively.

As shown in Fig. 3(c), the required SNR of the proposed antenna does not vary with XPR because the weight functions work well considering the XPR. Conversely, the required SNR of the dipole array antenna increases with increasing XPR. The reason for this is that the directivity of the dipole antenna coincides with the dominant propagation component when \( \text{XPR} = -10 \text{ dB} \), whereas it does not coincide with the dominant propagation component when \( \text{XPR} = 10 \text{ dB} \) because the element \( A_z \) is parallel to the ground.

5 Conclusion

In this paper, we proposed a vehicle-borne weighted-polarization MRC adaptive array antenna that can realize an emergency call in the event of a vehicle rollover accident. We evaluated the communication performance using BER–OTA apparatus. It was clarified from the OTA measurement results that, by controlling the signal using weight functions based on the XPR and the angle of inclination of the antenna, the proposed antenna can realize highly reliable communication compared to a conventional dipole array.

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