Basic Study of a Monopulse DOA Estimation Circularly Polarized Array Antenna Integrated with Magic-Ts

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Abstract: In this paper, a monopulse direction of arrival (DOA) estimation circularly polarized microstrip array antenna integrated with magic-Ts is proposed and its characteristics are investigated. The proposed antenna based on the monopulse system has a compact structure effectively utilizing an integration technology with microwave circuits. As the DOA estimation with a monopulse system is one of the attractive methods to realize a tracking function, the proposed antenna is suitable for communication systems which require the tracking function, such as the vehicle-to-vehicle (V2V) direct communications.

Keywords: DOA, monopulse, magic-T, antenna
Classification: Antennas and propagation

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1 Introduction

Recently, a wide variety of radar and sensor systems have been developed. In these systems for mobile communications such as the V2V direct communications [1, 2], the high functionality and compactness are required. The monopulse method with simple configuration is a useful technology to be applied to the tracking antennas for the communications. In this paper, a novel advanced compact planar circularly polarized (CP) antenna based on a monopulse DOA estimation is proposed.

In the monopulse DOA estimation process, the arrival angle is determined by the sum and difference of received signals of two antenna elements [3]. Because of the simple structure of the monopulse system, many researches for mobile communications have been reported [3-6]. We have presented the monopulse DOA estimation antennas which consist of microstrip antennas and magic-Ts [7], as well. Generally, the monopulse DOA estimation antennas consist of two antennas and a sum and different network. As these proposed antennas are designed based on the integration concept [8], the two antennas and the network are combined into one two-port array antenna. Therefore, the proposed DOA estimation function is achieved with an even more compact configuration.

The antenna which we have proposed [7] receives a linear polarization (LP) wave. For V2V direct communication, if a CP wave is applied, influences of reflected waves from other objects can be reduced. However, there are no reported works for monopulse DOA estimation CP array antennas with very compact configuration such as this proposed antenna. In this paper, in order to improve the function of the monopulse DOA estimation antennas, a CP antenna element is applied. The characteristics of the monopulse DOA estimation CP array antenna are simulated and its performances are investigated with a comparison of the measured results.

2 Antenna structure

The proposed antenna is shown in Fig.1. The antenna consists of four CP microstrip antenna elements, an orthogonal two-port feed circuit and magic-Ts. The feed circuit is combined with microstrip lines and a slot line. The magic-Ts...
The proposed monopulse DOA estimation antenna is compactly configured on a single-layer substrate by effectively utilizing the double-sided MIC technology [9]. In this design, a Teflon fiber ($\varepsilon_r = 2.15$, thickness = 0.8 mm) is used as a substrate. The design frequency is 5.8 GHz ($\lambda = 51$ mm), the size of the antenna is 110 × 110 mm, and the antenna element size is 16.9 × 16.9 mm. The antenna element separation $d$ is $1.0 \lambda$.

**3 Monopulse system**

A block diagram and a signal vector diagram of the monopulse system are shown in Fig. 2 (a) and (b), respectively. The monopulse system basically consists of two blocks, which are an antenna block and a sum and difference network one. When an arrival wave with an angle $\theta_a$ (in x-z plane) is received, the signals (RF$_{13}$, RF$_{24}$) with the same amplitude and $\varphi$ phase difference are output from the antenna elements. The sum signal ($\Sigma$) and the difference signal ($\Delta$) are obtained from the two signals (RF$_{13}$, RF$_{24}$) by using the network. The arrival angle $\theta_a$ is denoted by the following equations.

$$\varphi = 2 \tan^{-1}(|\Delta|/|\Sigma|)$$  \hspace{1cm} (1)

$$\theta_a = \sin^{-1}(\varphi \lambda / 2\pi d)$$ \hspace{1cm} (2)

The arrival angle $\theta_a$ is estimated by the amplitude ratio of the $\Sigma$ and $\Delta$ signals.

In the proposed antenna, the magic-Ts operate as the sum and difference network.
When an arrival wave with the angle $\theta_a$ (x-z plane) is received by the elements #1, 3 and #2, 4, the $\Sigma$ and $\Delta$ signals are generated from the signals ($RF_{13}, RF_{24}$) by utilizing the magic-Ts. And, the $\Sigma$ and $\Delta$ signals observed at Port 1 and Port 2, respectively. Consequently, the arrival angle $\theta_a$ is estimated by the amplitude ratio of the $\Sigma$ and $\Delta$ signals which are output from Port 1 and Port 2.

4 Characteristics

Characteristics of the proposed antenna are simulated by ADS (Keysight) and measured for comparison. The CP antenna gain (in x-z plane) for the arrival angle $\theta_a$ are shown in Fig. 3. The (a) and (b) show the gains for the $\Sigma$ (Port 1) and $\Delta$ (Port 2) signals, respectively. Directional and dual-beam patterns are observed. For both the $\Sigma$ and $\Delta$ signals, the maximum gains of more than 10 dBi are obtained. When the gain is more than 0 dBi, the AR less than 3 dB is observed. The simulated and measured amplitude ratio $|\Delta|/|\Sigma|$ of the output signals for the arrival angle $\theta_a$ are shown in Fig. 3(c). The amplitudes of the $\Sigma$ and $\Delta$ signals are calculated from the CP antenna gains. The simulated arrival angle $\theta_a$ is calculated using the Eqs. (1) and (2). It is observed that the amplitude ratio $|\Delta|/|\Sigma|$ varies according to the arrival angle $\theta_a$. In the range of 0 to 30 deg., the arrival angle $\theta_a$ can be estimated by the amplitude ratio $|\Delta|/|\Sigma|$. The estimation range is obtained according to the element distance $d$ as shown Eq. (2). The estimation range increases as the distance $d$ decrease. The AR characteristics depend on the element distance $d$, as well.
this design, because the minimum AR is observed at $d=1\lambda$, the element distance $d$ is set to $1\lambda$. Therefore, the estimation range of the proposed CP antenna is narrower than one of the antenna [7] with the distance $d=0.8\lambda$. The difference of simulation and measurement is caused by the limited dynamic range of our measurement system and the ground plane condition of the antenna (simulation: infinite, measurement: finite).

5 Conclusion

In this paper, the characteristics of the monopulse DOA estimation circularly polarized array antenna integrated with magic-Ts are proposed and its characteristics are investigated. It is confirmed that the monopulse DOA estimation function utilizing CP wave is realized. In the vehicle-to-vehicle (V2V) direct communications such as truck platooning [1, 2], a tracking function is required for the V2V communication antennas because antenna alignment must be adjusted according to lane changes and curves. The proposed monopulse antenna with simple configuration is a useful technology to be applied to the tracking antennas for the V2V direct communications in platooning.