Dual-axis monopulse direction-of-arrival estimation planar antenna employing multilayer structure

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Abstract: A novel multilayer structure of a direction-of-arrival (DOA) estimation antenna is proposed in this paper. This antenna provides dual-axis DOA estimation, while conventional monopulse DOA estimation antennas determine arrival angle in a single plane. The proposed antenna has a multilayer structure and consists of four ring-slot antennas and four magic-Ts. The proposed antenna provides both \(xz\)- and \(yz\)-plane dual-axis DOA estimation by using the monopulse mechanism.

Keywords: dual-axis, DOA estimation, multilayer, ring slot, magic-T

Classification: Antennas and propagation

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1 Introduction

In wireless communication systems, direction-of-arrival (DOA) estimation plays a vital role in order to achieve better reception of incoming signals. The research area in the field of DOA estimation has become wider in the last six decades. It has been applied in various applications including wireless communications, radar, etc. The role of the DOA estimation in wireless communications is essential since it helps to estimate the direction of the incoming signal. The estimated signal direction will be used to point the array beam towards the direction. The DOA estimation of the RF signals has been an interesting area of research as it offers several interesting benefits in terms of improved Quality-of-Service, such as better coverage, more reliable communication and higher data rates [1]. Furthermore, the DOA information can also be used for positioning or localization in a wireless cellular network.

Planar DOA estimation antennas using magic-Ts were already proposed [2-5]. These DOA estimation antennas can determine the angle of arrival in a single plane by employing the phase monopulse mechanism.

In this paper, a new dual-axis DOA estimation antenna which can calculate the angle of arrival signals in two planes is proposed. The basic concept has already discussed in [6]. The proposed antenna employs a multilayer structure and four annular ring-slot antennas are used as antenna elements. The proposed antenna contains both sided microwave integrated feedline circuits including magic-Ts [7]. The ability to measure the direction of arrival waves in dual planes makes the proposed antenna unique.

2 Operating Principle

Fig. 1(a) illustrates the basic block diagram of the proposed antenna. Three antenna elements are arranged along the x- and y-axis with the antenna separation of $d_x$ and $d_y$. The antenna elements along the x- and y-axis connect to Magic-T1 and -T2, respectively. As the magic-T provides in-phase or anti-phase power combination according to the input and output ports, the sum ($\Sigma$) and difference ($\Delta$) of the signals received by the two antenna elements are separately obtained [8]. Therefore, the sum and difference signals in the x-axis, i.e. $\Sigma_{xz}$ and $\Delta_{xz}$ are obtained from Magic-T1. Similarly, $\Sigma_{yz}$ and $\Delta_{yz}$ are obtained from Magic-T2. The arrival angle of the received signals can be determined by the amplitude of the sum ($\Sigma$) and difference ($\Delta$) of the two received signals using the monopulse mechanism.

Fig. 1(b) shows the coordinate system where $\theta_{xz}$ and $\theta_{yz}$ are defined as arrival angles in the xz-plane and yz-plane, respectively. In case of the dual-axis DOA estimation, the arrival angle in xz-plane, $\theta_{xz}$ and yz-plane,
(a) Basic block diagram of the proposed DOA estimation antenna. The magic-T generates the sum (Σ) and difference (∆) of the signals received by two antennas.

(b) Coordinate system.

Fig. 1. Concept of the proposed dual-axis DOA estimation antenna.

\[ \theta_{yz} = \sin^{-1}\left(\frac{\lambda}{\pi d_y}\tan^{-1}\left|\frac{\Delta_{yz}}{\Sigma_{yz}}\right|\right) \]  

where \( \lambda \) is the wavelength. \( \Sigma_{xz} \) and \( \Delta_{xz} \) are the Σ and Δ signals in \( xz \)-plane and \( \Sigma_{yz} \) and \( \Delta_{yz} \) are the Σ and Δ signals in \( yz \)-plane, respectively. Therefore the proposed array antenna provides DOA estimation in both \( xz \)-plane and \( yz \)-plane by using the monopulse mechanism.

3 Antenna Structure

Fig. 2(a) shows the schematic layout of the proposed multilayer dual-axis DOA estimation antenna. The proposed antenna comprises four ring-slot antenna elements and four magic-Ts. The complete structure of the antenna is designed in three metal layers. The ring-slot antennas are formed in Layer 2 and the feed networks are distributed on two different layers (i.e., Layer
(a) Schematic structure. $\Sigma_{xz}$ and $\Delta_{xz}$ signals from port 1 and port 3 are obtained at Layer 1. $\Sigma_{yz}$ and $\Delta_{yz}$ signals from port 2 and port 4 are obtained at Layer 3. Four ring-slot antennas are formed in Layer 2.

(b) Prototype of the proposed dual-axis DOA estimation antenna (size: 88 x 88 mm, $f = 5.8$ GHz)

Fig. 2. Antenna structure of the proposed 5.8-GHz dual-axis DOA estimation antenna.

1 and Layer 3). Two separate feed networks are designed in two separate planes so that the arrival angle estimation operation can be obtained in two orthogonal planes (i.e. $xz$-plane and $yz$-plane). One of the feed networks with Port 1 and 3, which respectively provide $\Sigma$ and $\Delta$ signals in the $xz$-plane is arranged on Layer 1. Layer 3 consists of another feed network with Port 2 and 4, which provide $\Sigma$ and $\Delta$ signals in the $yz$-plane, respectively. Two slot lines arranged orthogonally are also formed with four slot rings in Layer 2. In this structure, Layer 1 detects only horizontal polarization ($x$-polarization) while Layer 3 detects only vertical polarization ($y$-polarization). Therefore, the arriving waves have to have both $x$- and $y$-polarization to properly estimate the arrival angle in the dual-axis. In case of circular polarizations, this antenna works perfectly.

3.1 Prototype antenna

Fig. 2(b) shows the photograph of the fabricated 5.8-GHz dual-axis DOA estimation antenna in three different layers. $\Sigma$ and $\Delta$ signals of the $xz$-plane
(a) Reflection coefficient. Better than 10-dB return loss is obtained at 5.64 GHz for all four ports.

(b) Radiation pattern. Gain of the $\Sigma_{xz}$ is 5.32 dBi and $\Sigma_{yz}$ is 6.84 dBi.

**Fig. 3.** Measured result of the proposed dual-axis DOA estimation antenna.

from Port 1 and Port 3 are obtained at Layer 1, and Port 2 and Port 4 at Layer 3 provide $\Sigma$ and $\Delta$ signals of the $yz$-plane, respectively. In this design, a Teflon fiber ($\varepsilon_r = 2.15$, thickness = 0.8 mm) is used as a substrate material. The size of the prototype antenna is $88 \times 88$ mm. Each ring-slot antenna has an outer radius 7 mm and inner radius 6 mm resulting a slot width of 1 mm.

### 4 Results and discussion

Fig. 3(a) shows the measured reflection coefficient plots of Port 1, 2, 3 and 4 of the designed antenna. Better than 10-dB return loss is observed at 5.64 GHz for all ports.

Fig. 3(b) illustrates the measured radiation patterns of the $\Sigma$ and $\Delta$ signals for the $xz$- and $yz$-plane. The measured gain of this antenna is 5.32 dBi for $\Sigma_{xz}$ and 6.84 dBi for $\Sigma_{yz}$. The arrival angles in $xz$- and $yz$-plane can be determined using the values of the $\Sigma$ and $\Delta$ with eqs. (1) and (2). The concept of the dual-axis DOA estimation can be confirmed by the experimental
result.

5 Conclusion

A multilayer structure of a DOA estimation antenna was discussed in this paper. The proposed antenna can determine the arrival angles of the received signals in two orthogonal planes. The antenna has been fabricated and the performance has been measured to confirm the proposed DOA estimation concept. It is found that the antenna can determine the arrival angles in the $xz$- and $yz$-planes according to the theory.

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