Prototype Evaluation of a Beam Tracking Antenna Using Magic-T

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***Abstract*—In this paper, a new beam tracking antenna is proposed. It consists of a magic-T circuit, two antenna elements and two phase shifters and brings a new prototype antenna in wireless communication systems. The main idea for the antenna is to shift the beam by adjusting the phase shifter using the difference of signals received by the two antenna elements. Both-sided MIC technology is effectively used to integrate the magic-T and phase shifters with a simple structure. Radiation pattern and return loss are measured and this concept is experimentally demonstrated.**

***Keywords*—beam tracking antenna; magic-T; phase shifter; both-sided MIC technology;**

I. INTRODUCTION

Nowadays many kinds of advanced wireless technologies are widely used for wireless communication systems based on digital signal processing. To achieve the requirements of higher data rate, larger capacity and higher efficiency, advanced technologies have been developed. Multifunction and high performance microwave and millimeter wave components are also required to promote the wireless technologies [1].

Advanced planar antennas are the new generation of antennas which features as low profile, light weight, low cost, and ease of integration into arrays. These features make them ideal components for radar technology and modern communication systems. Properties of planar antennas have been discussed many times in many journals and proceedings [2, 3]. The radiation properties of the planar antennas were investigated by using photonic crystal as substrate material [4]. The effect of planar array antennas to its backward RCS (Radar Cross Section) and radiation pattern was investigated when it is integrated with dielectric and FSS (Frequency Selective Surface) [5].

Several advanced planar antennas are also developed for RF signal processing [6]. The antennas are constructed with microstrip lines and slot lines on both sides of the substrate and microwave circuits (i.e. a magic-T) are integrated with antenna elements. A direction of arrival estimation antenna [7, 8] and beam steering antenna [9] are already presented based on RF signal processing. A beam tracking antenna proposed in this paper is also a novel antenna in RF signal processing. The antenna is designed, manufactured and the result is also measured experimentally.

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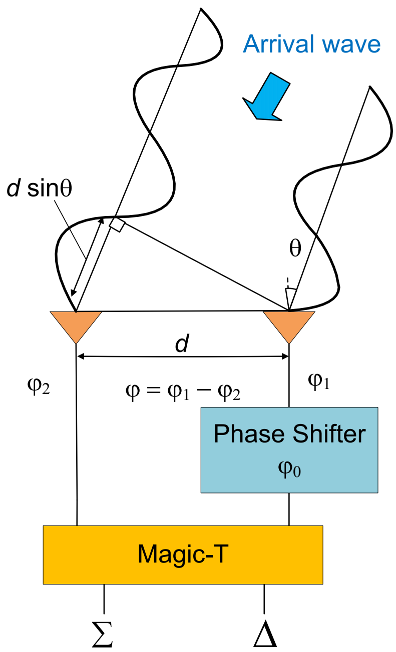

Fig.1. Block diagram of the proposed beam tracking antenna.

This paper is organized as follows. In Section II, a basic concept of the proposed beam tracking antenna is introduced. Structure and design of the antenna which integrates antenna elements and microwave circuits such as a magic-T and phase shifter are described in section III. In section IV, measured results demonstrate the concept of the proposed beam tracking antenna. Finally, section V concludes the paper.

II. BEAM TRACKING PRINCIPLE

Fig. 1 shows a basic concept of the proposed beam tracking antenna. It consists of two antenna elements, a magic-T and a phase shifter. Arrival waves received by the two antennas have a phase difference in general. The relation of the angle of arrival θ and the phase difference φ is expressed in

$$\varphi = \frac{2\pi d}{\lambda}\sin\theta \qquad (1)$$

where d and λ are the antenna separation and wavelength, respectively.

By changing the phase shift value of the phase shifter to compensate the phase difference, maximum power is obtained by combining the two received signals. It corresponds that beam of the antenna array shifts to the direction of the arrival wave. In the proposed antenna, a magic-T is employed to detect the phase difference received by the two antennas. Magic-T is a microwave circuit which provides in-phase or anti-phase power division according to the input port. Hence, the sum (Σ) and difference (Δ) of the received signals are easily obtained using the magic-T and they are expressed in the following expressions.

$$\Sigma = D(\theta)e^{j\frac{\varphi}{2}}e^{-j\varphi_0} + D(\theta)e^{-j\frac{\varphi}{2}} = 2D(\theta)e^{-j\frac{\varphi_0}{2}}\cos\left(\frac{\varphi-\varphi_0}{2}\right) \quad (2)$$

$$\Delta = D(\theta)e^{j\frac{\varphi}{2}}e^{-j\varphi_0} - D(\theta)e^{-j\frac{\varphi}{2}} = 2jD(\theta)e^{-j\frac{\varphi_0}{2}}\sin\left(\frac{\varphi-\varphi_0}{2}\right) \quad (3)$$

where φ_0 and $D(\theta)$ are the phase shift value of the phase shifter and the directivity of the single antenna element, respectively. As shown in these expressions, Σ becomes maximum and Δ becomes 0 when $\varphi_0 = \varphi$. This means that the beam tilts to the direction of the arrival wave by adjusting the phase shifter to make Δ minimum.

III. Structure and Design

Fig. 2 shows the layout of the proposed beam tracking antenna. Two microstrip antennas, a magic-T and two phase shifters are integrated on a substrate. Capacitors are used for DC cut. In this design, two phase shifters are used to tilt the beam to both directions. The magic-T and phase shifters are effectively using the both-sided MIC technology [10]. The input impedance of each antenna element is designed to be 100 Ω and it is converted to the port impedances of 50 Ω using the magic-T and a quarter-wavelength impedance transformer.

Fig. 3 shows the structure of the magic-T used in the proposed antenna. The magic-T is a combination of a microstrip line T junction and a slot line-to-microstrip line branch. As the microstrip line T junction is a parallel branch, the signal fed from port M1 is divided to port M3 and M4 in the same phase. On the other hand, as the slot line-to-microstrip line branch is a series branch, the signal fed from Port M2 is divided to Port M3 and M4 in the anti-phase. Furthermore, isolation between Port M1 and M2 are achieved due to the difference of the propagation modes of the microstrip line and slot line. Then, when RF signals are fed from Port M3 and M4, the sum and difference of the signals are obtained at Port M1 and M2, respectively. However, the sum and difference of the received signals are obtained at Port 1 and Port 2 in Fig. 2, respectively because two microstrip antennas are fed from the opposite side of the patch.

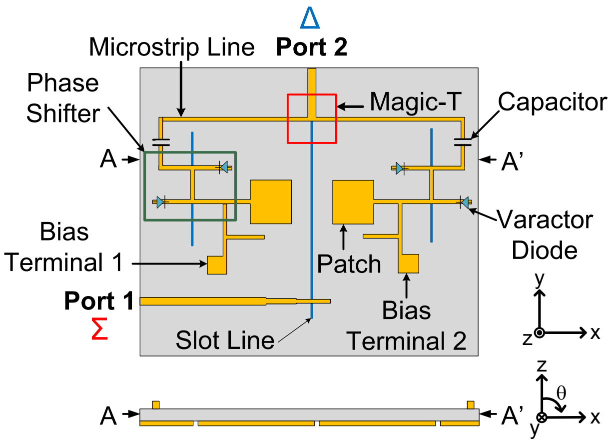

Fig.2. Structure of the proposed beam tracking antenna.

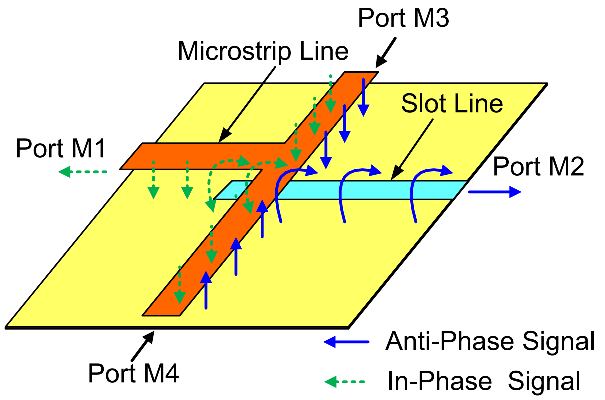

Fig.3. Structure of the planar magic-T constructed with the combination of microstrip T junction and slot line-to-microstrip line branch.

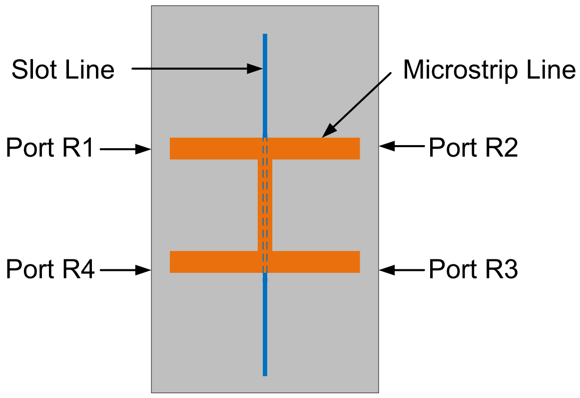

Fig.4. Structure of the de Ronde's coupler used in the phase shifter.

Fig. 4 shows the structure of the de Ronde's coupler [11] used in the phase shifter. The de Ronde's coupler is constructed with a microstrip line and a slot line and it provides a π/2 hybrid function with a simple structure. Two varactor diodes are attached to Port R2 and R4 of the coupler and the phase shift is obtained by changing the bias voltage of the varactor diodes.

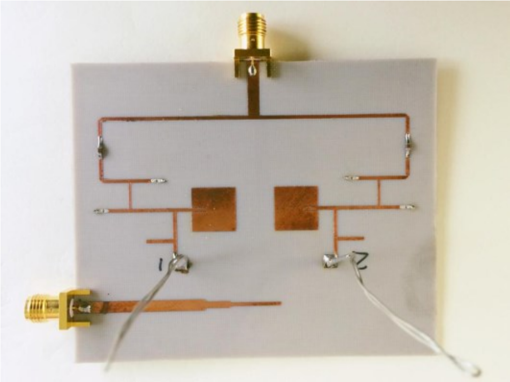

Fig.5. Prototype beam tracking antenna (80 × 65 mm).

IV. Measured Results

Fig. 5 shows a photograph of the prototype beam tracking antenna. Teflon fiber substrate (ε_r =2.15, thickness =0.8 mm) is used. The design center frequency is 10 GHz and the size of the antenna is 80 × 65 mm. The separation of the antenna elements is 0.8λ (= 24 mm).

Figs. 6 and 7 show the return loss of Port 1 and Port 2 measured with different voltages, respectively. The return losses S_{11} and S_{22} do not change regardless of the bias voltage. Better than 10 dB return loss is obtained around 10.2 GHz at both Port 1 and 2. The actual design frequency is 10 GHz but from return loss plot it is seen that the return loss is less in near around 10.2 GHz.

Figs. 8 and 9 show the measured radiation patterns of the Σ and Δ signals, respectively. The measured frequency is 10.2 GHz where better return loss is obtained. The phase shifter is adjusted by changing the bias voltage of the varactor diodes. In this experiment, the bias voltage is applied to the bias terminal 2 shown in Fig. 2 and it is increased from 0 V to 7 V, where the bias voltage of the terminal 1 is fixed to 0 V. As shown in these figures, the beam of the Σ signal tilts to right by increasing the bias voltage. Simultaneously, null of the Δ signal also shifts to right. The beam tilt was 9 degrees at the bias voltage of 7 V. It corresponds to the phase shift of 45 degrees according to (1).

In the proposed configuration, the Δ signal is used to determine the phase shift, i.e., angle of arrival. High detection accuracy is expected because the null of the Δ signal is sensitive to the angle of arrival.

V. Conclusions

A new proposal of beam tracking antenna has been designed, fabricated and experimentally measured. By using a magic-T, the beam tracking function can be achieved in a simple configuration suitable for a planar antenna. The proposed antenna can be used for a wide variety of applications in wireless communications.

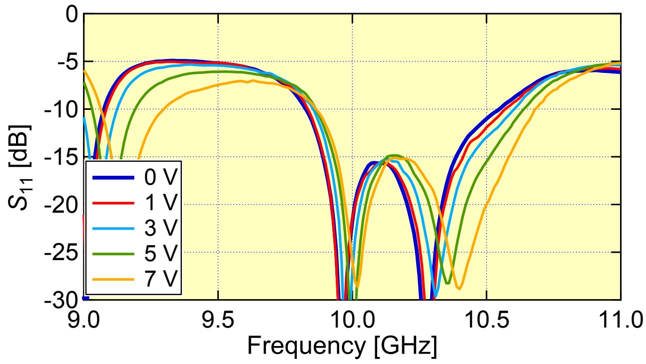

Fig.6. Measured return loss of Σ signal.

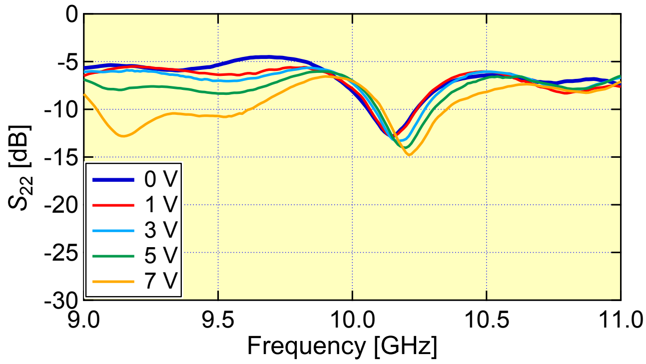

Fig.7. Measured return loss of Δ signal.

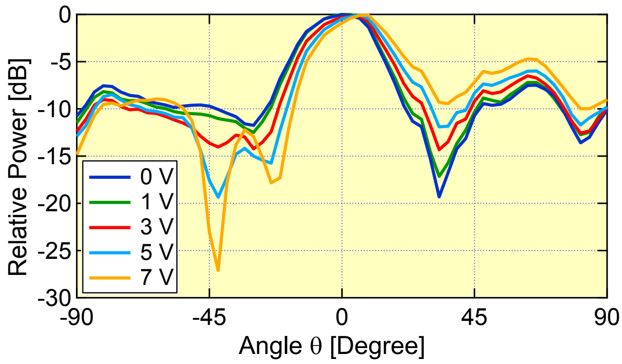

Fig.8. Measured radiation pattern of Σ signal (f = 10.2 GHz).

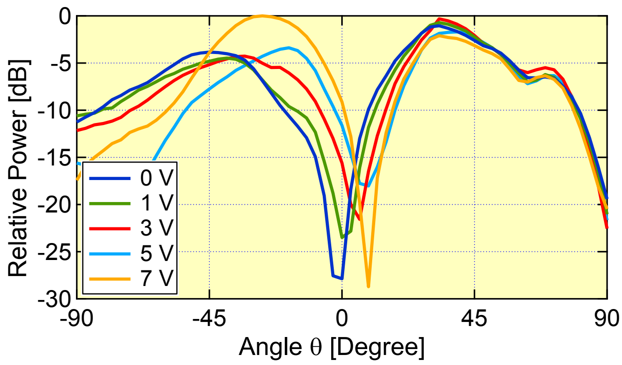

Fig.9. Measured radiation pattern of Δ signal (f = 10.2 GHz).

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