A Circularly Polarized Dual-Axis Dual-Beam Array Antenna Employing a Dual-Feed Network with Diagonal 90° Phase Shift

Thet Paing Phyoe¹a), Eisuke Nishiyama¹, and Ichihiko Toyoda¹

¹ Saga University
1 Honjo-machi, Saga-shi, Saga 840-8502, Japan
a) thet@ceng.ec.saga-u.ac.jp

Abstract: A 2×2 circularly polarized array antenna integrating a dual-feed network is proposed to provide a dual-beam radiation patterns for the wide-angle rectennas. The two diagonal antenna elements of the array antenna are quarter-wavelength ahead of another diagonal antenna elements. The planar magic-Ts are effectively used to obtain the desired radiation patterns with a simple structure. The design and performance of the array antenna is confirmed with experimental results and the proposed antenna have the same radiation patterns in the x-z and y-z planes. The measured gain of the proposed antenna is more than 9 dBi and 3-dB axial ratio bandwidth is 0.86%. The 10-dB impedance bandwidth of the antenna is better than 4.4%.

Keywords: dual-feed network, wide-angle rectenna, planar magic-T

Classification: Antenna and Propagation

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1 Introduction

Circularly polarized (CP) antennas are widely used for many modern wireless communication applications to reduce the polarization misalignment between the transmitters and receivers. The microstrip patch array antennas for circular polarization are very attractive in microwave communication applications due to its simple structure, small volume, low profile and easy fabrication [1]. The array antennas for wide-angle reception capability become popular in wireless power transfer system because of its higher output DC power [2]. Generally, antennas are connected as an array to improve the gain, and the conventional RF array antennas have a narrow beam. Therefore, the conventional RF power combining rectennas degrade the performance at the angles away from the boresight and only provide the highest power at the boresight. On the other hand, the DC power combining technique provides more power for the wide-angle range of the incident electromagnetic waves, and obtains less power at the boresight due to the non-linearity of the rectifying circuits[3–4].

The performance degradation of the RF power combining technique is discussed and it can be recovered by using the anti-phase signals of the re-
received RF waves [5]. We also proposed many advanced linearly polarized array antennas for different applications such as a direction of arrival (DOA) estimating antenna [6], beam steering antenna [7], repeater antenna [8], antennas for wide-angle rectenna [9–10] by using the in-phase and anti-phase signals. The array antennas [6–9] have the dual-feed networks, and they provide the desired radiation patterns in one plane only. A circularly polarized array antenna was proposed to solve the polarization and main-beam misalignment for the $x$-$z$ and $y$-$z$ planes [11]. Although the antenna provides the same radiation patterns in both planes, a triple-feed network is required.

In this paper, a new circularly polarized array antenna integrating a dual-feed network with diagonal 90° phase shift is proposed to provide the same radiation patterns in the $x$-$z$ and $y$-$z$ planes. The two diagonal antenna elements of the array antenna are quarter-wavelength ahead of the other two antenna elements to obtain the dual-beam radiation patterns in both planes.
The performance of the proposed antenna is experimentally confirmed and the brief description of the proposed antenna has been discussed in [12].

2 Antenna Structure and Operating Mechanism

Figure 1 (a) shows the structure of the proposed circularly polarized dual-axis dual-beam array antenna integrating a dual-feed network. The array antenna consists of four circularly polarized microstrip antenna elements, two feed networks, two magic-Ts and two additional quarter-wavelength microstrip lines. The microstrip lines of the antenna elements #1, #2 and #3, #4 are connected to the magic-T1 and magic-T2, respectively. The microstrip lines of magic-Ts are combined and connected to the Port 2. On the other hand, the slot lines of the magic-Ts are connected to the Port 1 via a slot line microstrip line transition. In this structure, the two diagonal antenna elements are directly connected to the magic-Ts and the other two diagonal antenna elements are connected to the magic-Ts via additional quarter-wavelength transmission lines. Each magic-T is constructed with the microstrip and slot lines using the both-sided MIC technology. All microstrip antenna elements and microstrip lines are located on the front side of the substrate, whereas the slot line is designed at the back side of the substrate.

Figure 1 (b) shows the block diagram of the proposed array antenna integrating the planar magic-Ts. The solid and broken arrows in the figures mean the resultant phase for each antenna element of the array antenna. The magic-T has four ports and it generates the in-phase and anti-phase signals for the incoming RF waves, and fulfills the requirements of anti-phase signals for the array antenna. The 90° phase difference in the figure represents the additional quarter-wavelength microstrip line and it provides the dual-beam radiation patterns in all planes. When the signal is fed from the Port 1 to Port E of the magic-Ts, anti-phase signals are generated. However, all antenna elements of the array antenna are excited with in-phase signals because the antenna elements #1, #2 and #3, #4 have opposite feed points. The additional 90° phase shift of the signal changes the phases and the antenna elements #1, #2 and #3, #4 are excited with same amplitude with 90° phase difference. Therefore, the phases of antenna elements #1, #3 and #2, #4 become in-phase shown by the red arrows. The radiation patterns have a peak in the center for the x-z and y-z planes and a pencil-beam radiation pattern is achieved. On the other hand, the signal is fed from Port 2 to the Port H of magic-Ts and in-phase signals are generated. The phases of antenna elements #1, #3 and #2, #4 become anti-phase shown by the blue arrows. The radiated waves have a null at the center for both planes and a conical-beam radiation pattern is obtained.

3 Results and Discussion

Figure 2 (a) shows photographs of the prototype 5.8-GHz band RHCP dual-feed array antenna. Teflon glass fiber substrate with a thickness of 0.8 mm, relative dielectric constant of 2.15 and loss tangent of 0.001 is used. The
antenna separation is 0.9\(\lambda_0\) (46 mm) and the size of the antenna is 130 mm \(\times\) 120 mm.

Figure 2 (b) shows the measured and simulated S-parameters of the proposed array antenna. The antenna is designed and optimized by using the Keysight Technologies’ Momentum. The return loss of the antenna is better than 10 dB and the 10-dB impedance bandwidths of the antenna for Port 1 and Port 2 are more than 4.4\%. The isolation between the two ports is better than 28 dB.

Figure 2 (c) shows the measured and simulated axial ratio (AR) performances of the antenna. The measured axial ratio is optimum at 5.77 GHz with the arrival angle of \(\theta = 0^\circ\) and \(\theta = 24^\circ\), where peak gain is observed for Port 1 and Port 2, respectively. The measured 3-dB AR bandwidth of the RHCP antenna is 0.86\%.

Figure 3 (a) and (b) show the simulated and measured RHCP radiation patterns of the proposed array antenna for Port 1. The antenna measurement is done at the frequency where the best AR ratio is obtained. The solid and broken lines in these figures indicate the measured and simulated radiation patterns of the RHCP antenna for 5.77 GHz and 5.83 GHz, respectively. The measured gain of the Port 1 is 9.5 dBi for the \(x\)-\(z\) and \(y\)-\(z\) planes. The cross-polarization level of better than 20 dB is obtained in both planes.
in both planes. The proposed phase shift is proposed. Planar 
ashi-zplanes. Measured and simulated radiation patterns of the proposed 
array antenna.

Figure 3 (c) and (d) show the simulated and measured CP radiation patterns of the antenna for Port 2. When the signal is fed from Port 2, the peak gain of the antenna is obtained at $\theta = \pm 24^\circ$ in both planes. The measured gain of the antenna is 6.6 dBi and the cross polarization level is better than 17 dB.

4 Conclusion

In this paper, a circularly polarized dual-axis dual-beam array antenna employing a dual-feed network with diagonal 90$^\circ$ phase shift is proposed. Planar magic-Ts and additional quarter-wavelength transmission lines are used to provide the same radiation patterns in the $x$-$z$ and $y$-$z$ planes. The proposed antenna has been measured to confirm the concept of the proposed dual-beam radiation patterns. The proposed array antenna achieves the good antenna performance and it can be used for a wide-angle rectenna by connecting the rectifying circuit of each feeding network in series or parallel.

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