Fabrication and Measurement of a Micro strip-Array Antenna for the Electronic Toll Collection System (ETCS)

JoongHan Yoon[1], Sang Mok Lee[2], Hwa Choon Lee[3] and KyungSup Kwak[4]
Su Mi Chun[5], Woo Sub Byun[5], Myung Nam Jung[5] and Dong Hun Shin[5]

[1]Department of Electronic Engineering, Inha University,
253, YongHyun-dong Nam-gu, Inchon 402-751, Korea
E-mail: g9641095@inhavision.inha.ac.kr
Tel: +82-2-860-8854 Fax: +82-2-868-3654
[2]Department of Information and Communication Engineering, Jeanung College
[3]Department of Information and Communication Engineering, Chodang University
[4]School of Information and Communication Engineering, Inha University,
[5]Access Network Laboratory, Korea Telecomm,

Abstract

This paper describes the design, fabrication, and measurement of a sequential-rotation microstrip-array antenna for the Electronic Toll Collection System (ETCS). The ETCS is made possible by using roadside equipment with radiation pattern that can accurately pinpoint the designated communication area, without interference from other lanes. The sequential-rotation microstrip-array antenna was applied to the absorber to reduce the side lobe level (SLL). Results showed that the antenna yields a return loss at a center frequency of -20.675 dB, an axial ratio of 1.15 dB, and a gain of 20.26 dBi.

I. Introduction

Problems caused by transport systems such as road congestion, traffic accidents, and environmental pollution are on the rise, adversely affecting our industrialized societies. To solve these problems, the Intelligent Transport System (ITS) was introduced specifically to enhance traffic safety, smooth traffic flow, and preserve the environment [1]. The Electronic Toll Collection System (ETCS) is one of the ITS applications that automatically collects tolls at toll roads using vehicle-to-roadside communications technology[2]. Wireless communication is possible between roadside equipment (RSE) installed at tollgates and onboard equipment (OBE) attached to the dashboard of a car at an approximate distance of 5 meters. Taking this into consideration, it is unlikely that serious fading problems would happen during a typical ETC operation. Nevertheless, a roadside communication antenna requires communication reliability to carry out toll collection transactions via wireless communication. Likewise, radio wave propagation at multi-lane tollgates has to be fully considered. One of the most critical requirements for a roadside communication antenna is the antenna radiation pattern. This allows the antenna to efficiently cast a beam with a width equal to that of the designated communication area. In Korea, a 5.8-GHz active DSRC system was specified by the Telecommunications Technology Association (TTA) for the wireless communication of the ETCS[3]. Table 1 shows the specifications of the antenna for RSE.

Table 1. Antenna specifications for RSE [3]

Item	Roadside Equipment
Frequency	5.795 GHz ~ 5.815 GHz 5.855 GHz ~ 5.875 GHz
Radiating Element	Patch
Polarization	RHCP
Gain	22 dBi
Radiation Pattern	Pen Beam
3-dB Bandwidth	20°
Main/Side Lobe Ratio	20 dB

Based on the specifications set by the TTA, this study designed an RSE microstrip-array antenna. Since the microstrip patch antenna was introduced in 1972 [4], patch antennas have been extensively investigated because of their low profile, low weight, lower cost, and ease of manufacture [5][6]. Circular polarization was used to reduce their effect on the environment and receive the reflected signals through multi-path and scattered and diffracted signals. Likewise, a cutting radiated element was generated through circular polarization by one feeding. To make an array using this model, the sequential rotation method structure was adopted. Sequential rotation of circularly polarized array feeding involves applying both physical rotation to the element feed point and an appropriate phase offset to the element excitation. This method leads to significant improvements in both the bandwidth and polarization purity [7][8].

As described in this paper, a cutting radiator was employed as the antenna element in designing a polarized antenna array, using the sequential rotation method with shortened phase delay. Right-hand Circular Polarization (RHCP) was used, with required gain set as22 dBi and the radiation pattern obtained using a pinpoint beam. Moreover, the antenna beam should have a width that is similar to that of the designated communication area, with the side lobe level (SLL) value not allowing communication with adjacent lanes. In addition, the received transmission power ratio of the desired wave to the undesired waves should be 20 dB. The low-cost 4×4 microstrip-array antenna was designed to operate in 5.8-GHz band, with a directivity > 22 dBi and main-lobe widths (3 dB) ≈ 20° and SLL ≈ 20 dB.

2. Design of Sequential Array Antenna

Figure 1 shows the top view of the main layer design and measures of an RHCP 4×4 sequential-rotation microstrip-array antenna with shortened phase delay. The patch dimensions are $W = L = 16.6\ mm.$ and $S_1 = S_2 = 21.52\ mm$. To obtain circular polarization, the truncated corner length was set at $C = 2.6\ mm.$ with four sub-arrays. For each sub-array, the elements were separated by distances of $21.49\ mm.$ and $21.52\ mm.$ in the x and y directions, respectively. Likewise, the ground plane had a size of $500 \times 500\ mm.^2$. The antenna was matched with impedance using a $\lambda/4$ transformer. The array antenna that was fed by a simple microstrip-line network was tuned to attain impedance close to 50 Ω of the line feed. At the same time, the antenna was adopted using the shortened phase delay from the feed point, in order to obtain the current distribution in the same direction. The behavior of this array was simulated with a tool based on the method of moment in the frequency domain (Ensemble 5.0 (c) from Ansoft Corporation). After achieving optimum design, the antenna was fabricated on a 0Taconic TLY-5A-0620-C1/C1 substrate with a 1.54-mm. thickness and $\varepsilon_r = 2.17$.

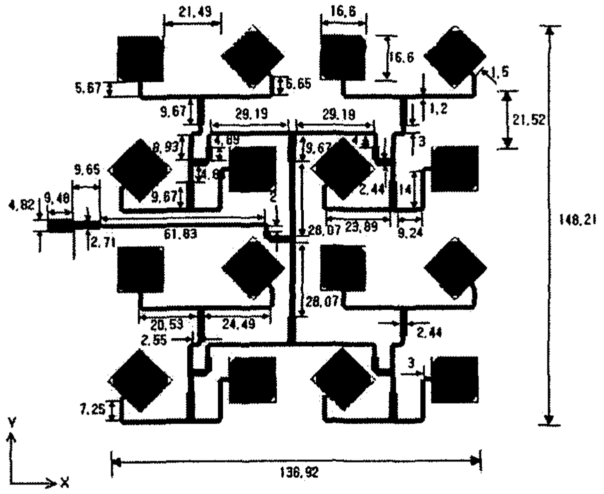


Figure 1. Structure and design parameters of antenna (in millimeters)

3. RESULTS

Based on the proposed design described above, this study designed, fabricated, and measured an RHCP 4×4 sequential-rotation microstrip-array antenna with shortened phase delay. The return loss of the antenna was measured with an HP8510 network analyzer, with the far-field patterns and gain measured inside a compact range available from the ACE Antenna Corporation and the Agency for Defense Development (ADD). Figure 2 shows the return loss against frequency. The impedance bandwidth was less than -10 dB in the operating frequency band.

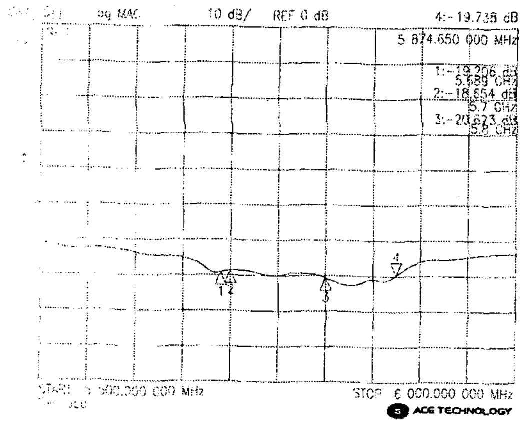


Figure 2. Return loss of RHCP 4×4 sequential-rotation microstrip-array antenna

Figure 3 shows the results of the experiment in determining the axial ratio. Results indicate that the axial ratio was less than 3 dB in the operating frequency band. The first and second operating frequency bands were 5.795 ~ 5.815 GHz

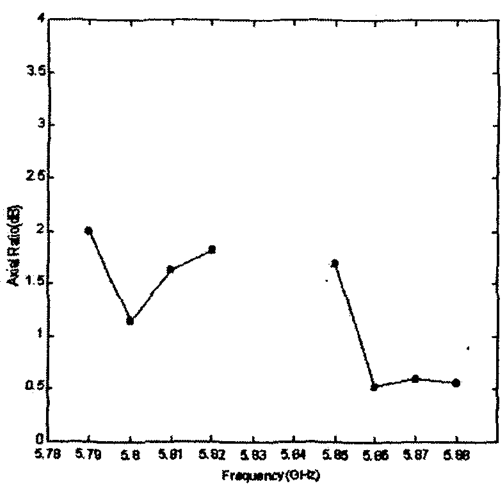


Figure 3. Axial ratio of RHCP 4×4 sequential-rotation microstrip-array antenna

and 5.855 ~ 5.875 GHz, respectively. Likewise, the antenna was measured to determine its radiation pattern at the center frequency $f = 5.8$ GHz. The radiation pattern at the far field was also measured after calibration using a horn antenna. Figure 4 shows the radiation pattern of an RHCP 4×4 sequential-rotation microstrip-array antenna. Results indicate that the difference between the level of the main beam and the level of the side lobe was found to range from -10 dB to -15 dB.

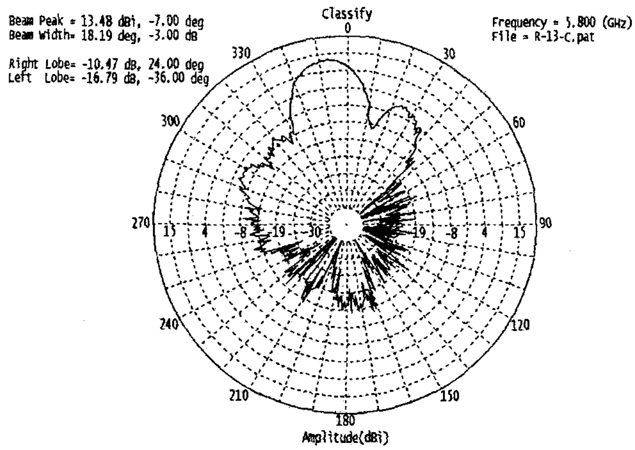


Figure 4. Experimental radiation pattern of RHCP 4×4 sequential-rotation microstrip-array antenna in azimuth

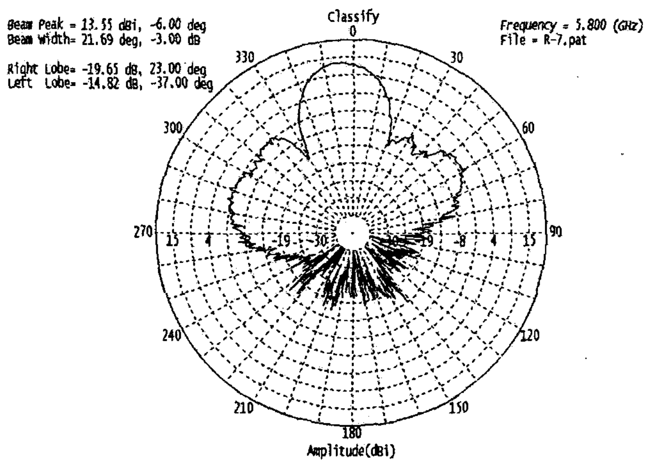
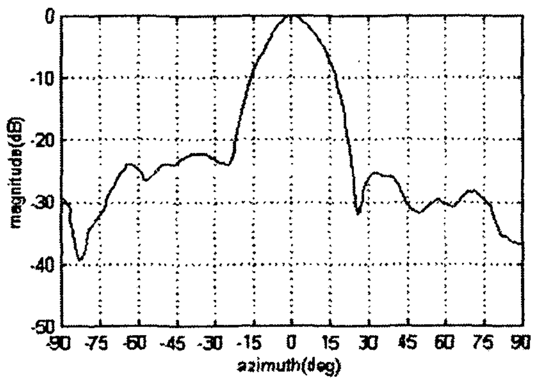
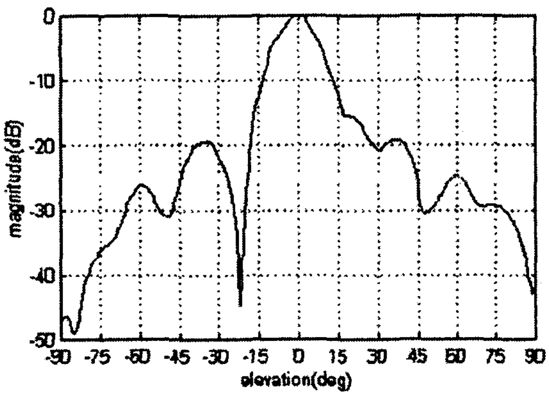


Figure 5. Experimental radiation pattern of RHCP 4×4 sequential-rotation microstrip-array antenna in elevation

To decrease SLL in order to significantly reduce the interferences from adjacent lanes in the tollgate, the sequential rotation array antenna was applied to the absorber that was made of Korean paper with Chinese ink. The radiation patterns of the array antenna with the absorber were measured across the operating frequency. However, for purposes of brevity, only the radiation patterns at a frequency of 5.8 GHz are shown in Figure 6. On the other hand, (a) and (b) in Figure 6 show the azimuth and elevation patterns. Results show that that the gain was 20.26 dBi and the SLL less than –20 dBi. Compared to the antenna without an absorber, the SLL in the antenna with an absorber decreased by about 8 to 10 dB.



(a)



(b)

Figure 6. Radiation pattern at 5.8-GHz (a) azimuth and (b) elevation

IV. CONCLUSION

The proposed sequential-rotation microstrip-array antenna with shortened phase delay was found to have a reduced SLL for the 5.8-GHz band. An antenna with an absorber was fabricated to match the TTA specifications. The measured data confirmed that the gain was 20.26 dBi, with SLL at 20 dB and axial ratio at 1.15 dB. These values indicate that the sequential-rotation microstrip-array antenna is very suitable for the ETCS.

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