Patch Array Antenna Using a Dual Coupled Feeding Structure for 79 GHz Automotive Radar Applications

Sungjun Yoo, Yaroslav Milyakh, Heeyoung Kim, Choulhee Hong, and Hosung Choo

***Abstract*—This letter proposes a novel design for a patch array antenna using a double indirect coupled feeding structure to achieve broad matching and gain bandwidths for automotive radar applications. The proposed radar antenna consists of a microstrip line, a rounded rectangular radiator, and a waveguide feeding structure. The indirect coupled feeding mechanism is first applied to the rounded rectangular radiator, which is placed at an adjacent distance from the microstrip line. To further improve the broad matching and gain characteristics, another indirect coupled feeding structure is applied to the transition between the microstrip line and the waveguide feeding network. To verify the proposed antenna performance, including impedance matching, bore-sight gain, and the radiation pattern, the proposed antenna is measured in a compact antenna test range chamber. The results confirm that the proposed patch array antenna using a double indirect coupled feeding structure is suitable for the 79 GHz radar array.**

***Index Terms*—79 GHz wideband antenna, automotive radar, radar antenna array.**

I. Introduction

THE W-band has been widely adopted in automotive radar systems in recent years [1]–[4]. In particular, for autonomous driving vehicles, the importance of radar sensors is gradually increasing due to their excellent performances even under extreme weather conditions. In general, automotive radar sensors simultaneously detect information in real time, including distance, speed, and angles of multiple targets. The detection is enabled using the transmit (Tx) and receive (Rx) antennas, and the detection performance can be improved as the number of the Tx and Rx antennas increases [5]. However, such increased antenna elements may not achieve the expected performance improvement due to mutual coupling between adjacent elements, resulting in pattern distortions and unwanted frequency shifts. This degradation effect can be even worse in an extremely high frequency of the W-band, because even a minor defect in the design can cause a significant change in antenna performance. Therefore, it is important to employ individual elements for W-band arrays that achieve broad matching and gain bandwidths against the performance distortion. Extensive efforts have been devoted to optimizing the radiator shape to improve the performance of individual elements in the radar arrays, for example, using a grid array structure [6], a thin film [7], or an additional lens [8]. However, such research alone has limitations in obtaining a wide matching bandwidth while maintaining a broad-gain bandwidth characteristic. Recently, there have been many studies on a low-temperature co-fired ceramic (LTCC) in the design of radar array antennas to improve an antenna performance. However, this approach requires the insertion of additional structures, such as a via cavity to suppress surface waves, resulting in increased design complexity with a high fabrication cost. In addition, the radiation efficiency is very low, usually less than 30%, due to the high loss associated with the LTCC substrate materials [9], [10].

In this letter, we propose a novel design for a patch array antenna using a double indirect coupled feeding structure to achieve broad matching and gain characteristics for automotive radar applications. The proposed radar antenna consists of a microstrip line, a rounded rectangular radiator, and a waveguide feeding structure. To obtain broad matching and gain characteristics, the array with rounded rectangular radiators is first placed at an adjacent distance from the microstrip line. A radiator with a rounded rectangular shape is adopted to reduce the manufacturing error in fabrication process [11], and the coupled feeding between the rounded rectangular radiator and the microstrip line can increase the matching bandwidth. Another indirect coupled feeding structure is, then, applied to the transition between the microstrip line and the waveguide feeding network to further improve the matching bandwidth. In order to verify the proposed antenna in terms of impedance matching and the radiation pattern, the optimized array antenna is fabricated, and its performances are measured in a compact-antenna test range (CATR) chamber. Radiation characteristics such as the gain and front–back (F/B) ratio are observed as the distance between the array with rounded rectangular radiators and the microstrip line is varied. The results verify that the patch array antenna using a double-indirect coupled feeding structure is suitable for the 79 GHz radar array.

II. Proposed Antenna Design

Fig. 1 shows the proposed patch array antenna using a double indirect coupled feeding structure to obtain broad matching and

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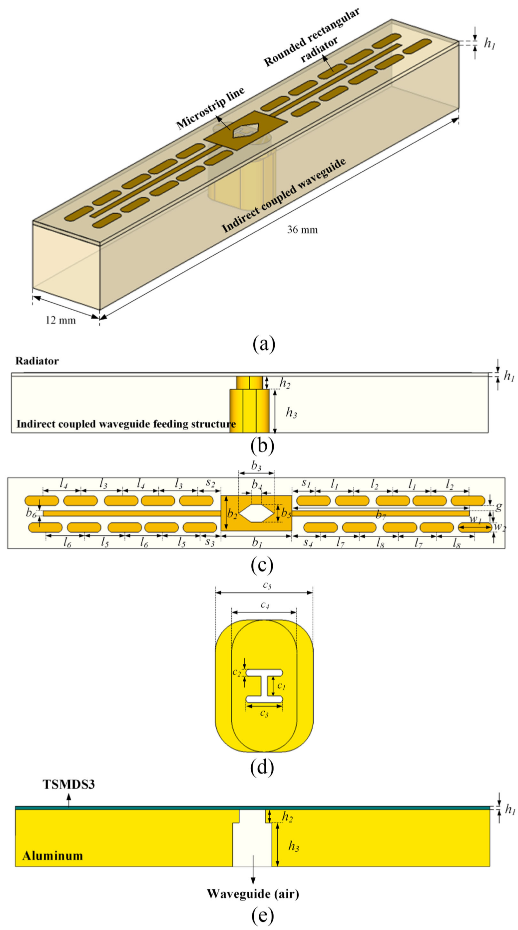

Fig. 1. Geometry of the proposed array antenna. (a) Perspective view. (b) Side view. (c) Top view of the radiator. (d) Top view of the indirect cavity resonator. (e) Cross-section view of the proposed array antenna.

TABLE I
OPTIMIZED VALUES OF THE PROPOSED ANTENNA

Parameters	Values	Parameters	Values
s_1	0.96 mm	b_1	4.4 mm
s_2	0.88 mm	b_2	0.84 mm
s_3	0.96 mm	b_3	2.22 mm
s_4	0.88 mm	b_4	1.2 mm
l_1	2.36 mm	b_5	0.64 mm
l_2	2.60 mm	b_6	0.2 mm
l_3	2.60 mm	b_7	11.32 mm
l_4	2.28 mm	c_1	0.68 mm
l_5	2.36 mm	c_2	0.16 mm
l_6	2.60 mm	c_3	0.79 mm
l_7	2.60 mm	c_4	1 mm
l_8	2.28 mm	c_5	1.6 mm
w_1	1.13 mm	h_1	0.13 mm
w_2	0.28 mm	h_2	1.7 mm
g	0.1 mm	h_3	7 mm

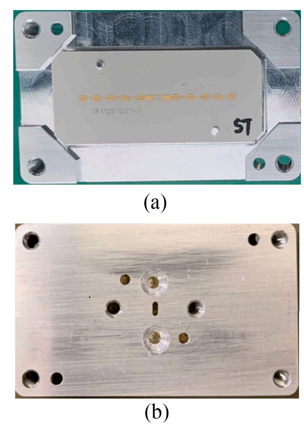

Fig. 2. Photographs of the fabricated array. (a) Top view of the proposed array antenna. (b) Bottom view of the proposed array antenna.

gain characteristics. The proposed radar antenna consists of a microstrip line, a rounded rectangular radiator, and a waveguide feeding structure as shown in Fig. 1(a) and (b). The array has 20 rounded rectangular radiators, which are located at a distance (g) from the microstrip line. This is to achieve wide matching and gain bandwidth characteristics from the current induced in the rounded rectangular radiator by electromagnetic coupling. We design the radiator with a rounded rectangular shape instead of a rectangle shape to minimize the manufacturing error during the fabrication process, which allows the proposed array antenna to have higher tolerance to fabrication errors. According to our parametric investigation, the rounded rectangular shape of the radiator has a relatively small change in resonance characteristics, even with the fabrication error. The rounded rectangular radiators with microstrip lines are printed on a TSMDS3 substrate ($\varepsilon_r = 3.12$, tan$\delta = 0.01$ from Taconic) with a height h_1. The radiators are designed to have a length (w_1) of $0.5\lambda_g$ and a width (w_2) of $0.13\lambda_g$, and they are placed above and below the microstrip line. The length of the microstrip line is determined by b_1 and b_7, and the front part of the microstrip line using a slot is designed by b_3, b_4, and b_5 to strongly induce the field strength from the waveguide feeding network, as shown in Fig. 1(c). To further improve the matching bandwidth, another indirect coupled feeding structure is implemented in the transition between the microstrip line and the waveguide feeding network. Fig. 1(d) shows the top view of another indirect coupled feeding structure. Herein, the I-shaped slot transition should be carefully tuned to induce the strong fields on the microstrip line in the operating frequency band from 76 to 81 GHz. The optimized design parameters are obtained using a genetic algorithm [12] with the FEKO electromagnetic (EM) simulator [13], and the finalized values are listed in Table I. Fig. 2 shows a photograph of the fabricated W-band radar antenna, in which the top and bottom views of the fabricated antenna are shown in Fig. 2(a) and (b). As can be seen, the proposed antenna can be connected to a waveguide source, which is fixed by a supporting jig.

Fig. 3 shows a photograph of the CATR chamber, which consists of a transmit horn, a parabolic reflector, a positioner, and the proposed antenna. To demonstrate the suitability of the proposed radar sensor, antenna characteristics, such as the reflection coefficient, bore-sight gain, and 2-D radiation patterns, are measured in the CATR chamber.

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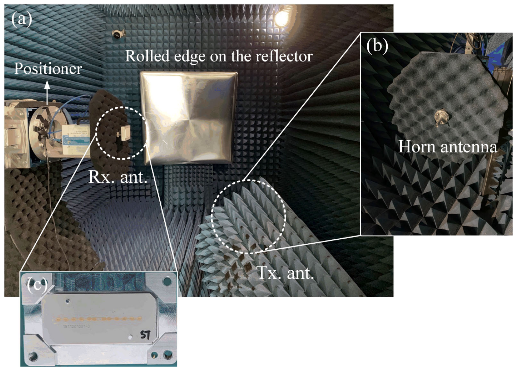

Fig. 3. Photographs of a full anechoic chamber. (a) Components inside the chamber. (b) Transmit horn antenna. (c) Proposed array antenna.

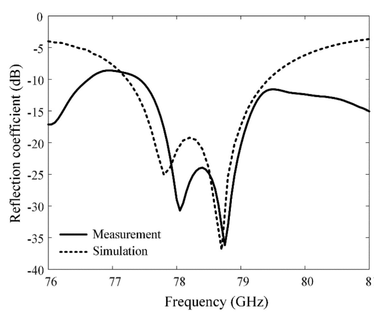

Fig. 4. Reflection coefficients of the proposed antenna. Solid and dashed lines indicate measured and simulated results, respectively.

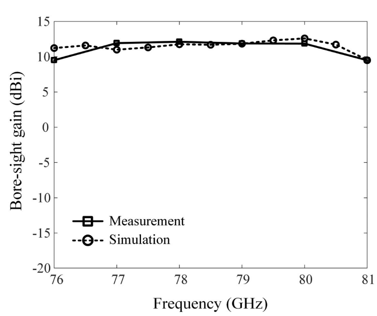

Fig. 5. Bore-sight gain of the proposed antenna. The dashed line indicates simulated results compared to the measured data obtained from the full anechoic chamber.

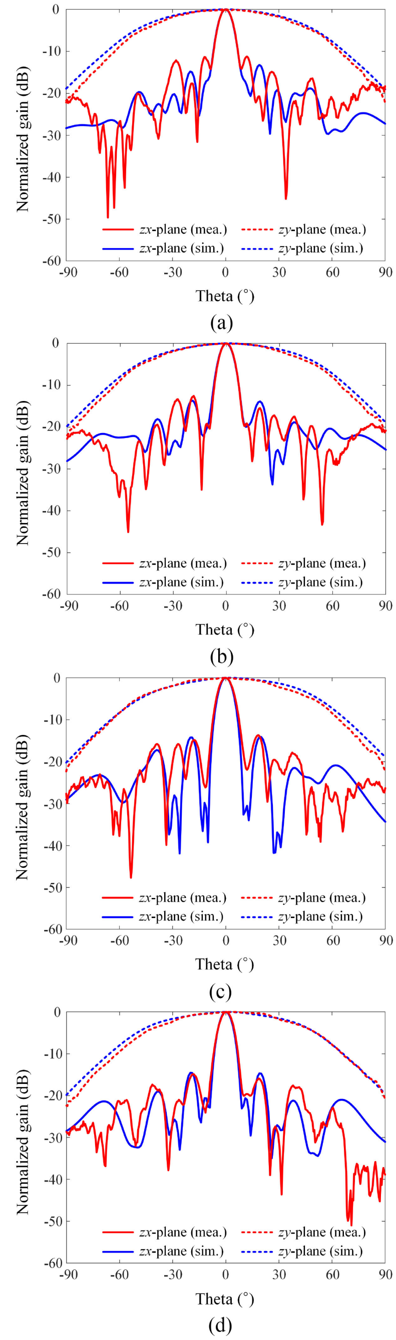

Fig. 6. Measured and simulated 2-D radiation patterns of the proposed array antenna. (a) 76, (b) 77, (c) 78, and (d) 79 GHz.

III. Measurement and Analysis

Fig. 4 shows the simulated and measured reflection coefficients according to a function of frequency. The measured reflection coefficient is specified by the solid line and has an average value of −16.1 dB over the 5 GHz bandwidth from 76 to 81 GHz. The dashed line indicates the simulation result, which shows a trend similar to the measurement, with an average value of −11.7 dB.

Fig. 5 shows the measured bore-sight gain (solid line with square markers) obtained in the full-anechoic chamber. The measured value at 79 GHz is 11.8 dBi, and the average gain is 11.5 dBi in the 5 GHz bandwidth, which is similar to the simulated data (dashed line with circular markers).

The measured radiation patterns in the *zx* and *zy* planes are also in a good agreement with the simulated result, as shown in Fig. 6(a)−(d). In the entire operating frequency band from 76 to 81 GHz, the proposed antenna shows a stable radiation pattern, with a half-power beamwidth (HPBW) of 8.1° in the *zx* plane and a maximum measured sidelobe level (SLL) of 15.9 dB at 79 GHz. In the *zy* plane, the HPBWs are greater than 70°, and these measured radiation patterns demonstrate that the proposed

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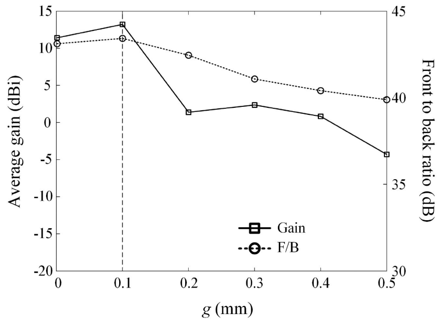

Fig. 7. Variation of the simulated average gain and F/B ratio according to g.

TABLE II
COMPARISON OF PERFORMANCE TO EXISTING RESULTS IN LITERATURE

No.	Frequency	Gain	SLL (peak)	Features
Ref. [1]	77/79 GHz	9.3 dBi	12 dB	SIW bridge
Ref. [2]	77 GHz	9.5 dBi	18 dB	Multi stub radiator
Ref. [5]	77/79 GHz	10.5 dBi	14 dB	Multi-layer grid structure
Ref. [9]	77/79 GHz	7.5 dBi	13 dB	12-layer of LTCC
Proposed	77/79 GHz	11.5 dBi	15.9 dB	double indirect coupled feeder

antenna does not exhibit any serious pattern distortion in the upper hemisphere.

To further verify the effectiveness of the proposed indirect coupled structure, we observe the variations in the average gain and F/B ratio when the distance (g) between the rounded rectangular radiators and the microstrip line is varied from 0.001 to 0.5 mm as shown in Fig. 7. The solid line with square markers indicates the average gain, and the maximum gain is observed at a distance of 0.1 mm, because the coupled field is strongly induced on the radiating array elements. The F/B ratio is also observed in relation to the distance, and the F/B value tends to decrease as the distance varies from 0.1 to 0.5 mm. The results demonstrate that the proposed indirect coupled structure is properly designed to achieve optimal performance in the operating frequency range from 76 to 81 GHz.

Table II shows the target frequency, gain, SLL, and characteristic in comparison with other existing research presented in [1], [2], [5], and [9]. The resulting high gain and SLL of the proposed antenna support the effectiveness of the proposed approach.

In order to examine the performance when the proposed single sub-array column is extended to multiple array configuration, the proposed antenna is arranged in two columns. The extended array with two columns shows the simulation gain of 17.2 dBi, SLL of 12.9 dB, and HPBW of 5.7°.

IV. CONCLUSION

We have investigated the novel design for a patch array antenna that implemented a double indirect coupled feeding structure to obtain broad matching and gain bandwidths. The proposed radar antenna consists of a microstrip line, a rounded rectangular radiator, and a waveguide feeding structure. To achieve broad matching and gain characteristics, the rounded rectangular radiators were placed at an adjacent distance from the microstrip line. Another indirect coupled feeding structure was then applied to the transition between the microstrip line and the waveguide feeding network. The reflection coefficient was -20.4 dB at 79 GHz, and the average value was -16.1 dB over the 5 GHz bandwidth. The measured bore-sight gain was 11.8 dBi at 79 GHz with, the average gain of 11.5 dBi in the operating frequency, which implies that the proposed radar array antenna has a broad matching bandwidth while maintaining a broad gain bandwidth characteristic. The results demonstrated that the proposed patch array antenna using a double indirect coupled feeding structure is suitable for the 79 GHz radar array.

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