Design of Ridge Waveguide Array Antenna for Radar

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Abstract— In this paper, we suggest a wide-angle waveguide array antenna for radar operation and designed a ridge waveguide antenna to enlarge the beam steering angle. A miniaturization rate of 48.2% was obtained compared to the WR-90 waveguide. Using this, a 1×8 array antenna was designed and manufactured. The average beam-width of each antenna was 120°. A number of phase shifters corresponding to the beam steering angle were fabricated, and it confirmed that the measured beam steering angle was consistent with the designed beam steering angle. Accordingly, the designed antenna has characteristics suitable for beam steering of a hexagonal array structure.

Keywords— Ridge waveguide Antenna; Beamforming; Wide angle Scanning, Anti-jamming

I. Introduction

The receiving echoes of electromagnetic waves reflected from the surface of the target object and collected target information is significant in radar. In recent years, advances in RF devices and digital technologies have made radar more high precision, high mobility, and multifunctional mission performance.

Therefore, the method of beam operation is also being replaced from mechanical rotation to electronic beam steering using phased array antenna[1]. Although this method has disadvantages in terms of economics, it is possible to have a function capable of detecting multiple targets as well as target detection speed and accuracy[2]. However, it is difficult to arrange the radars due to the limit of the allowable range of the beam steering angle. For example, beam steering antennas on the warship usually consist of four sets. If one set is damaged from enemies attack while operation, a 90° blind area is created on the horizontal plane. Each individual element of the array antenna must have a wide-angle beam-width in order to compensate for beam steering by a partial angle on each side.

In this paper, we present a new concept of three-dimentional radar beam operation method to compensate for these shortcomings. First, a designed ridge waveguide antenna that has wide-angle beam steering, with this, we aim to obtain a wide-angle characteristic of 120° on the horizontal plane of the 1 × 8 array antenna. Next, we set the 8 × 8 plane array as a sub-array, defining and analyzing the performance that can represent the radiation element properties at any location. To analyze this, we perform simulation and measurement on active element patterns and active return loss of array antennas. Details of the antenna design are presented with the simulations and measurements.

II. Ease of Use

A. A New Concept of three-dimentional Radar Operation

Existing warship-mounted three-dimentional radars were operated so that antennas are placed on four sides at 90° intervals and can detect all directions in azimuth. However, even if even one of the four sides becomes inoperable, the 90° region cannot be detected. The inoperable sides are either from its own internal malfunction or external mechanical damage caused by exposure from high power jamming [3].

The three-dimensional radar beam operation method proposed in this paper is a hexagonal array structure as shown in Fig. 1(a). Assuming that it has steering area of 120° per side, it is possible to detect 360° in all directions on three sides. As shown in Fig. 1(b), if the operation error occurs at maximum 3 sides, it can be operated by replacing with another neighboring antenna. In addition, it is possible to maximize the gain in a specific direction by forming 6 overlapping beams when all 6 sides are operated. Accordingly, the radar adopting this method can increase the reliability of operation because the blind spot due to inoperability can be covered from both side antennas when on side in inoperable.

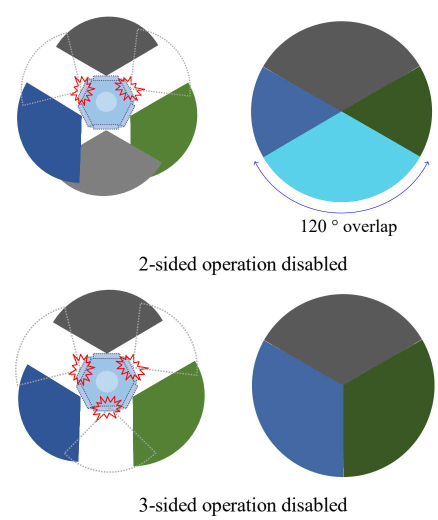


Fig. 1. Beam operation of hexagonal flat array by inoperability.

B. *Design of ridge waveguide antenna*

To improve the beam wide-angle characteristics, a ridge structure was applied for the aperture of the waveguide to reduce the size. The miniaturized ridge waveguide antenna can be seen shown in Fig. 2 by perturbation theory[4-5]. If the ridge is located in a waveguide where the electric field energy is strong, the width of the waveguide can be reduced as the resonance frequency is lowered. The narrower the gap between the ridges, the more the waveguide width can be reduced. In this way, the height and width of waveguide can be significantly reduced.

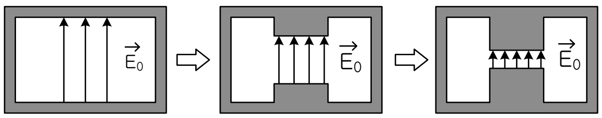
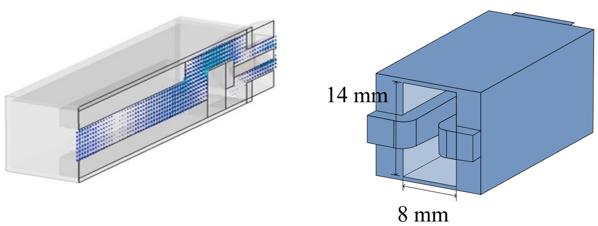
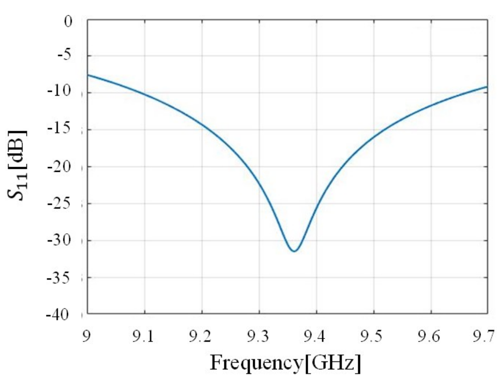


Fig. 2. Variation of electric field distribution by the ridge size.

As shown in Fig. 3(a), a double ridge was inserted into the waveguide, and the height b of the waveguide was reduced to 8mm, and the width a was reduced to 14mm. Fig. 3 shows the cross-sectional structure, electric field distribution, dimensions, and return loss simulation results of the ridge-inserted waveguide antenna. As a result of the simulation, -30dB was obtained at the center frequency of 9.375 GHz.



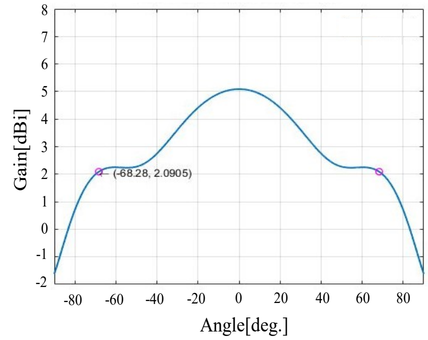
a



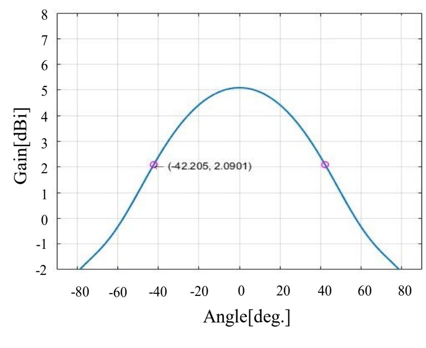
b

Fig. 3. End-launch feeding[6] ridge waveguide antenna(Simulation)
a. E-filed distribution and antenna structure.
b. Return loss

Fig. 4 shows the simulation results of the radiation pattern of the ridge waveguide antenna. The beam width was 136° in the E-plane direction and 84.4° in the H-plane. It was confirmed that compared to the standard waveguide(WR-90) antenna that wide-angle beam width was obtained.



E-plane

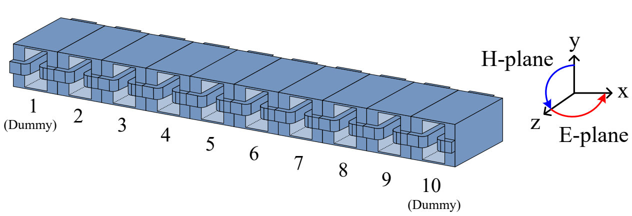


H-plane

Fig. 4. Radiation patterns of ridge waveguide antenna(Simulation)

C. *Design of 1 × 8 array ridge waveguide antenna*

As shown in Fig. 5(a), eight ridge-inserted waveguide antennas in Fig. 3(a) were arranged at 16 mm intervals in the horizontal direction. The dummy antennas were additionally placed at both ends to prevent distortion of the beam. Fig. 5 shows the antenna array structure and the simulation result of the fifth antenna return loss. As a result of the simulation, the -10 dB bandwidth was obtained from 9.3 GHz to 9.55 GHz (2.7%).



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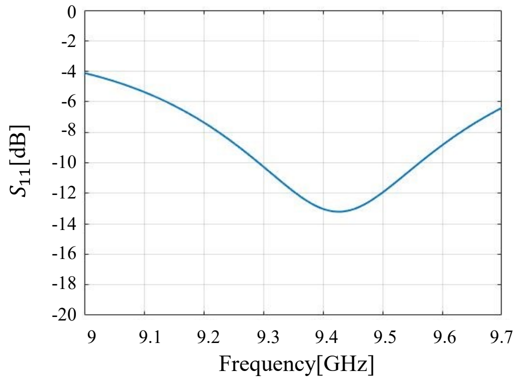
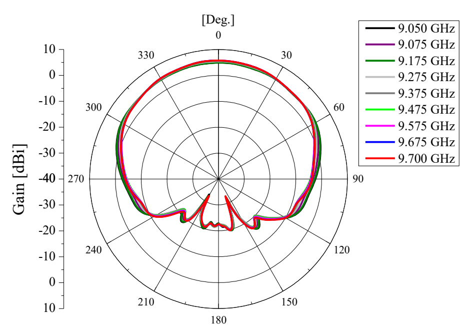


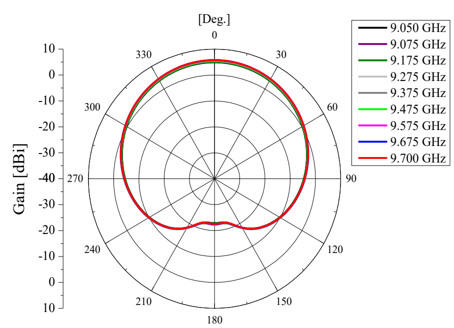
b

Fig. 5. Structure and return loss of ridge waveguide 1 × 8 array antenna(Simulation).
a. E-filed distribution and antenna structure.
b. Return loss

Fig. 6 shows the simulated radiation patterns from 9.05 GHz to 9.70 GHz for the fifth antenna element. The gain of simulated result was 5.53 dBi, the E-plane beam width was 118.4°, and the H-plane beam width was 93.2 °.



E-plane



H-plane

Fig. 6. Radiation patterns of fifth element in ridge waveguide 1 × 8 array antenna (Simulation).

Fig. 7 shows the result of steering from -72° to 72° by placing a phase difference on each of the 8 array radiation elements of the ridge waveguide array antenna.

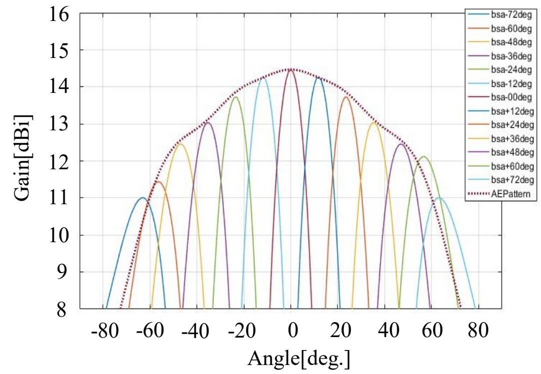
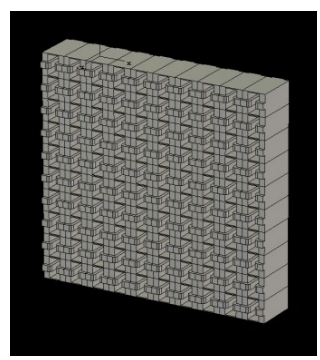


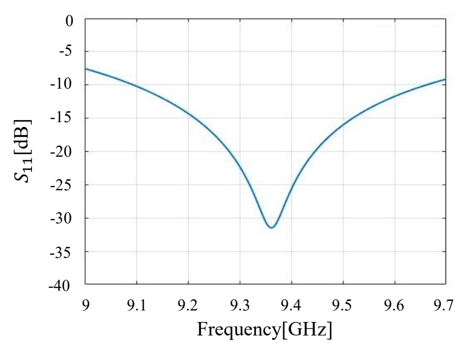
Fig. 7. Active element and beam steering radiation patterns of ridge waveguide 1 × 8 array antenna (Simulation)

D. *Sub-array ridge waveguide antenna*

Radar antennas basically have a large number of arrays. Therefore, it is possible to define and analyze the performance which can represent the characteristics of the radiation element at any location. Here, the 8 × 8 plane array was set as the sub array.



Antenna structure



Return loss

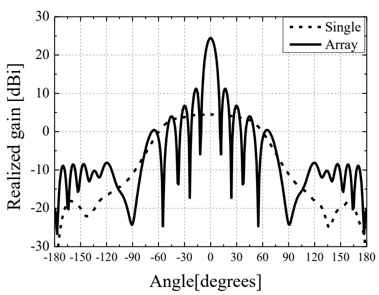
Fig. 8. Structure of sub-array ridge waveguide antenna and return loss (Simulation)

In the figure above, it shows the simulated array antenna structure, and how the triangular array is applied. The graph shows the self-return loss in the array. The matching characteristics were changed due to the change of the load impedance, mutual coupling, and the input impedance was adjusted and optimized. The load impedance value changed due to mutual coupling, resulting in a change in matching characteristics, and this was optimized by adjusting the input impedance.

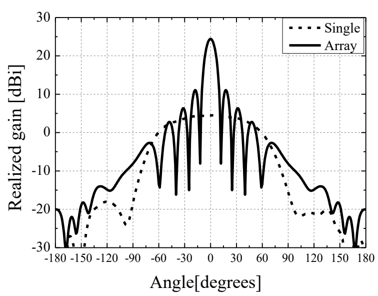
Among the 8 × 8 sub-array elements, 8 rows and 8 columns were used as feeding elements, and the remaining edge ports were terminated.

The element separation of E-plane (horizontal) was 16mm and the element separation of vertical was 17.8mm.

Fig. 9 shows the active element patterns of the E-plane and H-plane. The beam width of E-plane was 117.2 °, and H-plane was 106.6 °. The gain of the 8 × 8 array antenna was 24.4 dBi, and beam width of E-plane was 10.2°



E-plane



H-plane

Fig. 9. Radiation patterns of sub-array ridge waveguide antenna (Simulation)

E. Measured results

A ridge waveguide 1 × 8 array antenna was fabricated, assembled and measured as shown in Fig. 10. The thickness of the narrow side wall of the antenna was 4 mm, and the wide side wall was made of 0.5mm of aluminum. Fig. 11 shows the measurement result of the return loss of the fifth antenna. As a result of the measurement, the -10 dB bandwidth was obtained from 9.16 GHz to 9.66 GHz (5.3%).

Fig. 10. Measurement set-up of ridge waveguide 1 × 8 array antenna

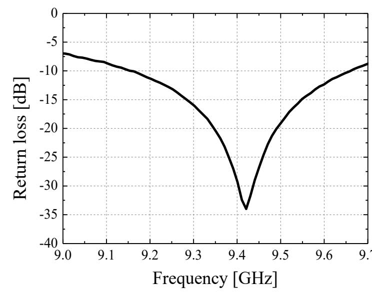
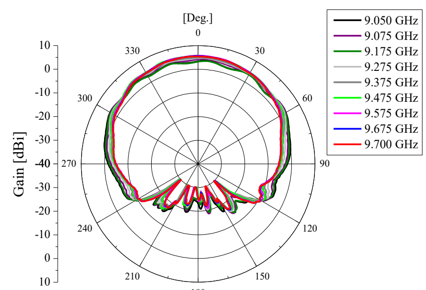
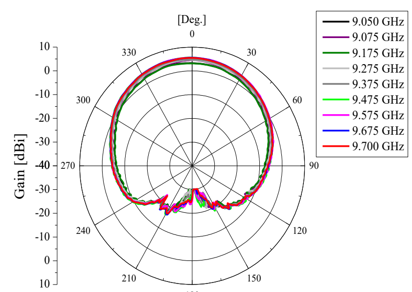


Fig. 11. Return loss of ridge waveguide 1 × 8 array antenna

As shown in Fig. 12, the gain of measured result was 5.08 dBi, the E-plane beam width was 120.9°, and the H-plane beam width was 89.7 °.



E-plane



H-plane

Fig. 12. Radiation patterns of fifth element in ridge waveguide 1 × 8 array antenna

As shown in Fig. 13, the characteristics of beam steering for the 1 × 8 radiation element were measured by applying a power distributed phase shifter.

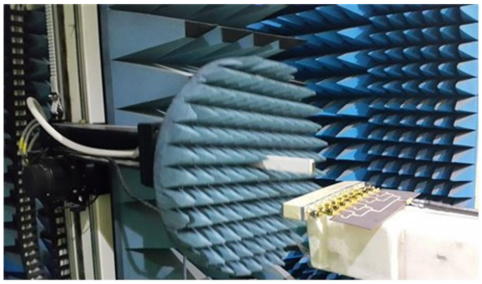
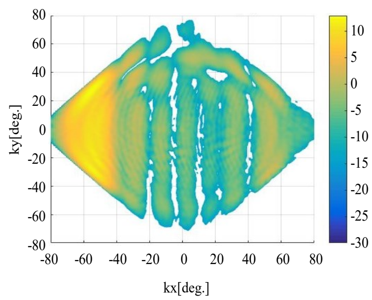
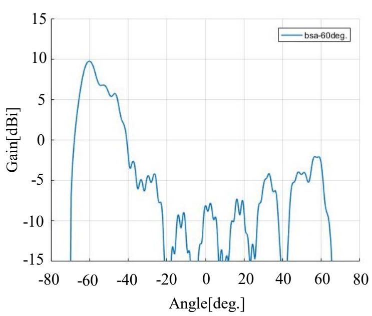


Fig. 13. Beam steering measurement set-up of ridge waveguide 1 × 8 array antenna

Figure 13 shows the results for a beam steering angle of 30 ° (BSA = 30 °) as a 3D far-field radiation pattern and an E-plane pattern. The simulated gain was 13.4 dBi and the measured gain was 11.3 dBi. The average insertion loss of the power distributed phase shifter was 1.6 dB. Given the 0.4 dB connector loss and the amplitude/phase error, the 2.1 dB gain difference was a predictable range.



3D-pattern



E-plane

Fig. 14. Radiation patterns of ridge waveguide 1 × 8 array antenna (Measurement)

Fig. 15 shows the measurement results of the beam steering patterns. The beam steering patterns showed maximum values at 0°, 15°, and 30°, and had a good steering characteristic.

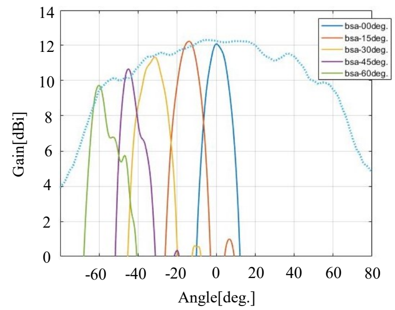


Fig. 15. Active element and beam steering radiation patterns of ridge waveguide 1 × 8 array antenna

III. Conclusion

In this paper, a new concept of radar operation using the overlap beam was proposed. To implement this, a miniaturized ridge waveguide antenna capable of steering a wide-angle beam was designed and measured. The size of the ridge waveguide radiation element was reduced to 14 mm in width and 8 mm in height for wide-angle beam steering. Next, a 1 × 8 array antenna was designed and manufactured, and beam width of E-plane was 120°, H-plane beam width of 89.7° was obtained. In addition, the measurement result of beam steering characteristics using a power distributed phase shifter, it was confirmed that the steering angle were well matched for 0°, 15°, 30°, 45° and 60°. Finally, the possibility of application as a radar antenna was secured by expanding the ridge waveguide antenna into a 8 × 8 sub-array form and confirming the characteristics of a single radiating element in the array through simulation. Therefore, it was confirmed that if the array antennas are arranged on each of the six sides, when one side is inoperable, it can be supplemented from both sides, and a gain increase effect can be obtained in normal times. Considering the radar's operational plan and future ecomomics, this can be applied to ultra-wide-angle beam steering radar.

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