Design and Manufacture of X-Band Waveguide Slot Array Antenna using the Probe Feeding Structure

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Abstract—This paper suggests a probe feeding structure to enhance the performance of X-band waveguide slot array antenna. The antenna was designed with a probe feeding structure instead of the slot feeding structure. This paper applied both types of feeding structures to the slot array antenna, and analyzed and compared their electromagnetic property through electromagnetic simulation. The probe feeding design enhanced the sidelobe level of Azimuth direction by approximately 3.5 dB (@Fc) and the bandwidth by 14%, relative to the original slot feeding design. In addition, the antenna using the probe feeding structure is fabricated and measured.

Keywords— Antenna arrays, Slot antennas, Antenna feeds, Near-field radiation pattern

I. INTRODUCTION

Due to an increase in demand for high resolution aerial imaging for various purposes and interests, the demand for radar systems on airplanes and satellites have also escalated. High resolution radar imaging is made possible through Range Resolution by short pulse and Azimuth Resolution by antennas that have narrow beams, and antennas constructed for this purpose is called Synthetic Aperture Radar (SAR). The waveguide broad-wall slot array antenna, known for its low loss, lightweight and mechanical robustness, is mainly utilized for SAR. [1]-[5]

The waveguide broad-wall slot array antenna is made of largely three parts, radiation waveguide, feed waveguide, and waveguide power divider. The bandwidth of each parts and the matching between the parts determines the antenna's bandwidth. This paper applied the probe feeding structure instead of the slot feeding structure, and thus enhanced the bandwidth of the antenna that used to have a relatively narrow banded quality, and the sidelobe level of Azimuth direction. The following chapters record the EM Simulation results of the two feeding structures and the performance results of the antenna designed with the probe feeding structure.

II. ELECTRICAL DESIGN

A. Antenna design

Antennas are functionally divided into radiation waveguide, feed waveguide, and waveguide power divider. The radiation waveguide have an array of radiation slots that have conductance values according to Taylor distribution, at regular intervals. The feed waveguide has inclined slots that match the subarray of radiation slots and can feed signals. The waveguide power divider is constructed as an unequal power divider to divide power to each feeding waveguide, and its output is connected to feeding waveguide. This paper suggests a design for the antenna that shows the performance of a bandwidth of 600MHz, sidelobe level of Azimuth direction of −26dB, and sidelobe level of elevation direction of −13dB at X-band.

1) Radiation waveguide: The radiation waveguide is an array of wide offset slots. The length and offset intervals of slots are determined though the conductance values that depend on the amount of energy that must be radiated in each slot. I applied $\Pi=2$, Taylor 14.5dB to the power distribution of radiation slots, considering the performance target of the antenna and the quality degradation due to manufacturing tolerance. A total of 288 slots (24 slots in the Azimuth direction and 12 slots in the elevation direction) were positioned, at the interval of half wavelength of the center frequency. The radiation slots are vertically symmetrical with respect to the elevation centerline in order for a 180° phase difference compensation.

Figure 1. The wide offset slot array element
2) Feeding waveguide: The feeding waveguide plays the role of transferring the signals from the waveguide power divider to each radiation waveguide through inclined slots, according to the power ratio. More inclined slots inside a feeding waveguide means narrower bandwidth, so the feeding waveguide is divided every four inclined slots. Thus the feeding waveguide consists of a total of 12 waveguides, 6 waveguides in the Azimuth direction and 2 waveguides in the elevation direction. The feeding waveguide is a vertically and horizontally symmetrical structure, so in order for a 180° phase difference compensation, three feeding waveguides are designed to have a power distribution of $\pi = 5$, Taylor 30dB, considering the performance target of the antenna and the quality degradation due to manufacturing tolerance.

3) Waveguide power divider: The incoming signals at the waveguide power divider are distributed each to six output terminals, and each terminal is linked to feeding waveguide. According to the power distribution of inclined slots, each output terminal of divide waveguide must have different power and identical phases, thus the position and size of power iris and matching iris at junctions are modulated to realize the performance target.

B. Feeding

Generally, slot feeding structures that apply slanted slots have been used to transfer the power from the waveguide power divider to the feeding waveguide. This slot feeding structure makes it difficult for a power distribution to the left and right inclined slots of the feeding point. This has a larger effect when the power ratio of the left and right side is large, and leads to a performance degradation of the Azimuth direction's sidelobe level of slot array antennas. Recognizing such problems, this paper suggests a feeding structure utilizing Probe Pins.

1) Slot feeding structure: Slot feeding structures have slanted slots between the waveguide power divider and the feeding waveguide, such as in figure 2. This results in the coupling between inclined slots and feeding slots, causing the following problems.

- The difficulty in distributing power among inclined slots adjacent to the feeding slots and those that are not.
- Performance degradation of phase balance of inclined slots.
- Increase in returning power to the divide waveguide due to performance degradation of Amplitude balance of inclined slots.

In addition, slot feeding structures have the phase of their signals to the left and right side reversed, based on the position of the feeding. The phase of the inclined slots, at the interval of half wavelength of the center frequency, must be identical. So there must be further manipulation of the slope of the inclined slot for a 180° phase difference compensation.

2) Probe feeding structure: To solve the problems of the slot feeding structure, mentioned above, I suggest a probe feeding structure that feeds through an inserted Probe Pin inside the waveguide. The probe feeding structure inserts a probe inside a waveguide power divider and transfers power through the Probe Pin to each the left and right side of the feeding waveguide. Here a transition block will be inserted to the inner wall of the waveguide power divider, for matching, and a hole for Probe Pin will be made in the waveguide power divider and the feeding waveguide. The electrical performance results of probe feeding structure is as follows.

- Design of wideband is easier and has a lower return loss compared to slot feeding structure.
- As in figure 2, the phases of signals distributed to the left and right side of the feeding waveguide are identical. This means the inclined slots can be placed at an angle as they were constructed, with no need for manipulation.
- As there is no structure that can enable coupling, the design of amplitude and phase balance is easier.
- As the quality of amplitude balance of inclined slots increases, the transfer of power to the radiation waveguide will become more efficient, and the return of power to the waveguide power divider decrease.

![Figure 2. Output phase of the feeding structure](image-url)
3) Simulation results: These are the electrical simulation results of the feeding structure. The conditions of the simulation was that the radiation waveguide and power divider be identical, and in the case of feeding waveguides, modified inclined slots were applied according to each feeding structure. Figure 3 is the EM simulation form that has integrated the waveguide power divider and feeding waveguide, excluding the radiation waveguide from the slot array antenna, and figures 4 denote the electrical performances. Figure 4(a) represents the power of the signal fed from the waveguide power divider at the inclined slots of each feeding waveguide. I calculated the power ratio of the inclined slots in the Azimuth direction to the largest-powered inclined slot, and it was possible to confirm that the probe feeding attained a stable rate similar to the theoretical Taylor curve. Figure 4(b) denotes the phase difference of inclined slots. The best outcome is that the phase of all ports are identical, the phase balance of probe feeding is markedly better than that of slot feeding. Figure 4(c) shows the R/L of the waveguide power divider's input port. When comparing the two feeding structures at -10dB, probe feeding is more stable than slot feeding in the desired bandwidths. The probe feeding structure has less shift in bandwidth when the feeding waveguide and divide waveguide are combined, whereas in the case of slot feeding structure, the R/L of the waveguide power divider's input port shifts to the upper band frequency.

**Figure 3.** EM simulation form of feeding waveguide/waveguide power divider.
(a) Slot feeding structure (b) Probe feeding structure

**Figure 4.** Simulation result
(a) Power rate (b) Phase difference (c) Bandwidth
Figures 5–6 demonstrate the EM simulation form and electrical performance of the slot array antennas including the radiation waveguide. Simulation results show that in the case of sidelobe levels in the Azimuth direction, probe feeding structure performs better than the slot feeding structure within the bandwidth, and the gap amounts up to 3.5dB(@Fc), as in figure 6(a). Figure 6(b) is a graph of the return loss of the slot array antenna's input port, and shows that probe feeding structure an increase in bandwidth of about 14% at 10dB, compared to slot feeding structure.

![Figure 5. EM simulation form of the slot array antenna](image)

![Figure 6. Results of slot array antenna by feeding structure](image)

III. MECHANICAL DESIGN

The manufacturing of antenna designed through simulation is as follows. The radiation waveguide, feeding waveguide, and waveguide power divider is manufactured and put together at once. The radiation waveguide is a flat plate, and the feeding waveguide is manufactured to include the waveguide and inclined slots. Waveguide power divider can be separated into a cover and a waveguide power divider without a back page, with the Probe pin and transition block in the inside of the cover page.

The fusion is conducted by brazing. Brazing is a method that fills the gap between two base metals with a filler material that has a lower melting temperature that the base metals. This takes place at a high temperature over 450 ℃. This ensures appropriate strength of the product and prevents its alteration or damage from the melting temperature.

IV. ELECTRICAL PERFORMANCE

To confirm the electrical performance of slot array antenna, Near-Field measurement facilities are utilized. Figure 7 shows a Near-Field Measurement Set-up inside an anechoic chamber, and figure 8~9 is a 2D distribution of amplitude/phase of the Near-Field plane of slot array antenna. Amplitude distribution is highest at the physical center of the antenna and decreases towards the edge, while the Phase distribution is an even inphase distribution.

![Figure 7. Near-field measurement set-up](image)

The comparison between the Simulation and measurement results are as follows.

Graphs in figure 10 compare the measurement and simulation results of the slot array antenna with probe feeding structure. In general, the measurement results are similar to the predicted performance in the simulation. Figure 10(a) shows the return loss of the slot array antenna's input port. Figure 10(b)–(c) show the sidelobe level (SLL) in the Azimuth and elevation direction. The difference between the simulated predictions and measurement results stem from the manufacturing error of the slots and whether the waveguide is joined through brazing.
Figure 8. Near-field test (Amplitude)
(a) 2D Distribution  (b) X axis cut pattern

Figure 9. Near-field test (Phase)
(a) 2D Distribution  (b) X axis cut pattern

Figure 10. Simulation vs Measure results
(a) Return Loss (b) SLL_Az. (c) SLL_El.
V. CONCLUSION

This paper suggested a probe feeding structure to enhance the bandwidth and SLL performance of slot array antenna. By eliminating the problem of coupling between inclined slots and feeding slots, the design of amplitude and phase balance of inclined slots in the feeding waveguide is made easier. Also, the insertion loss itself of the probe feeding structure is quite efficient, so there is little shift of bandwidth when joining the feeding waveguide and power divider. The slot array antenna is designed based on the EM simulation, and is manufactured through precise processing of the slots and brazing method. Near-Field measurement was utilized to confirm the electrical performance of the manufactured slot array antenna. In general, the measurement results were similar to the predicted performance in the simulation.

REFERENCES