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Design and Development of a Conjoined Narrow Wall Slotted Waveguide Array Antenna with Low Side Lobe Levels

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ABSTRACT

This paper discusses the development of a multipiece narrow wall slotted waveguide array antenna (SWAA) for the X-band frequency range (9.1 GHz - 9.5 GHz). Slots were cut on the narrow wall, and the SWAA operates as a travelling wave type. Slot angles were calculated via polynomial equations, whereas slot depths were determined on the basis of fixed resonance lengths corresponding to slot angles. A 54-slot prototype was developed by joining three waveguide pieces and then cutting the slots. The fabricated prototype was tested for both bench-level measurements and radiation pattern parameters, achieving a return loss better than -34 dB, an insertion loss better than -12 dB, and a side lobe level better than -25.2 dB at 9.3 GHz.

Keywords: Narrow wall slots array; Linear array; X-band; Waveguide; Manufacturing

NOMENCLATURE

SWA : Slotted waveguide arrays
θ : Slot angle
d : Slot depths

1. INTRODUCTION

Radar systems play a critical role in various applications, such as coastal surveillance, aviation navigation, and military operations[1-2]. These applications demand antennas with low loss, high power handling, high gain, and low side lobe levels. Slotted Waveguide Arrays (SWAs), known for their high-power handling capacity and superior RF performance, are ideal for these applications[3]. SWAs radiate through slots cut into the narrow or broad wall of a rectangular waveguide[3], with the slot location determining the polarization of the radiated field-vertical polarization for broad wall slots and horizontal polarization for narrow wall slots[4].

Previous studies[5-6] has developed both resonant and nonresonant antennas on the basis of polynomial equations for slot parameters. A more detailed procedure for the design of narrow wall slotted waveguide array antennas is presented in[7]. These designs, however, are limited to small-length arrays. To achieve high gain for primary radar applications, large antenna lengths are necessary, presenting challenges in maintaining linearity and ease of transportation.

Additively manufactured waveguide slots are used in the case of conformal antennas[8] and slotted waveguides[9], whereas injection moulding[10] is useful for small antennas. To achieve a gain of 30 dBi or more, a 6 meter or longer linear length of the waveguide is required[10]. Handling such large lengths poses significant challenges for maintaining linearity, and transportation is a daunting task. Hence, to make a large single waveguide, it is proposed to use small lengths and join them together. Dip brazing is used for joining aluminium parts as previously described[11].

Existing designs[5-7] have also characterized the slot depth on the basis of conductance, which makes it very difficult to determine the precise slot depths because the size of the array increases as the polynomial equation for depth does not hold. This paper presents improvements over existing designs by characterizing the slot depth on the basis of a fixed slot length. This paper further presents the feasibility and measurement results of a silver-brazed three-piece linear slot waveguide array antenna compared with those of a single-piece waveguide. In this work, a slotted waveguide with 54 narrow wall slots was designed, manufactured by joining three pieces and measuring at the bench, and pattern characterization was performed at X-band frequencies of 9.1 GHz to 9.5 GHz.

2. DESIGN & DEVELOPMENT

2.1 Narrow Wall Slotted Waveguide Array

A detailed design procedure in which a non-resonant linear array is developed[7]. Similarly, in this research, a non-

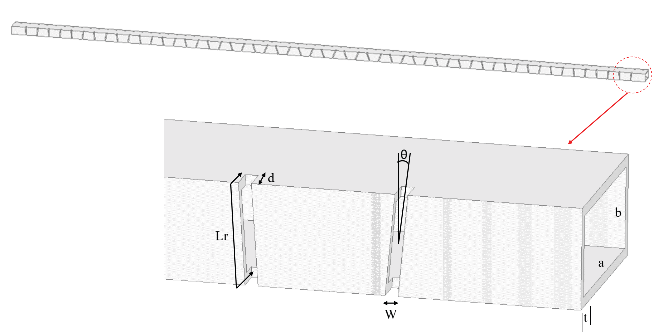

Figure 1. Narrow wall slotted waveguide and its parameters.

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resonant linear array of 54 slots is designed for calculating the slot depth for a fixed resonant length. The same geometry is shown in Fig. 1.

The WR-90 waveguide was chosen because it operates at X-band frequencies ranging from 9.1 GHz to 9.5 GHz, with the dominant mode TE_{10}. The selected waveguide has a thickness (t) of 1.27 mm, and the width of the slots (w) was held constant at ($\lambda_0/20$). The angles of slot inclination (θ) and slot depth (d) are calculated to meet the desired side lobe specifications.

2.2 Array Design

The required excitation amplitudes (a_n) and normalized conductance in each slot for Taylor's aperture field distribution were used to calculate the slot angles (θ) via the polynomial equations proposed in [7]. However, slot depths (d) were calculated via a fixed resonance depth[12] as follows:

$$L_r = \frac{b+t}{\cos(\theta)_n} + 2(d - t/2) \tag{1}$$

In Eqn. (1), the slot resonant length $\underline{L_r}$ was fixed at 0.4625 λ_0[13] for each slot angle (θ_n), and the corresponding slot depth was calculated. A 54-slot SWAA was designed, a 3D model was generated, and simulations were conducted in the 9.1 GHz - 9.5 GHz frequency range.

2.3 Results and Discussion

A 1-meter long, 54-slot waveguide array was designed and divided into three pieces, which were joined via C-type metal clips, as shown in Fig. 2.

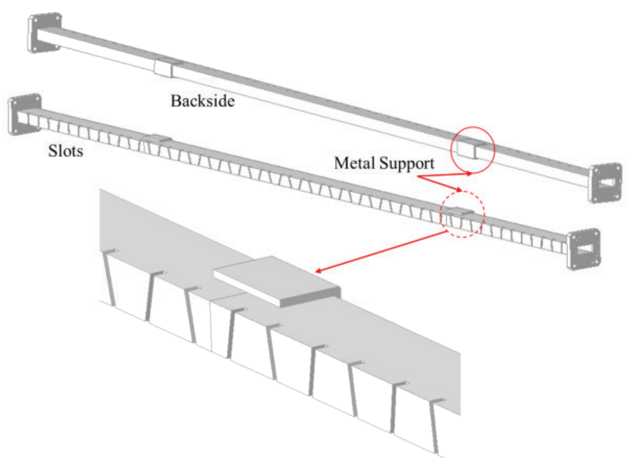

Figure 2. 3D model of the designed SWAA and its joining mechanism.

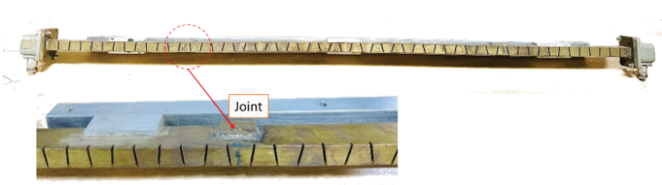

Figure 3. Manufactured array antenna.

The three pieces were joined via silver brazing, and the slots were cut as per the design. The fabricated array antenna is shown in Fig. 3.

The prototype's return loss and insertion loss were measured, as shown in Fig. 4 and Fig. 5.

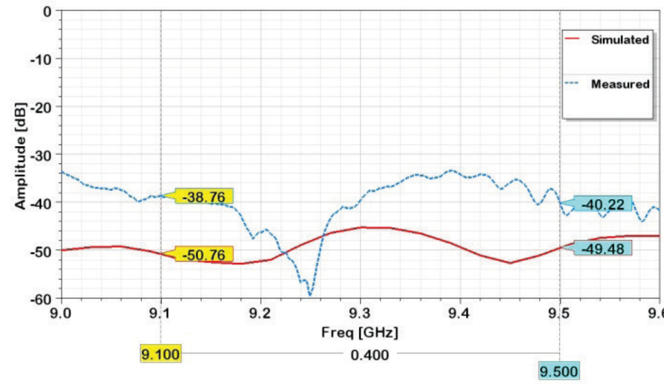

Figure 4. Return loss.

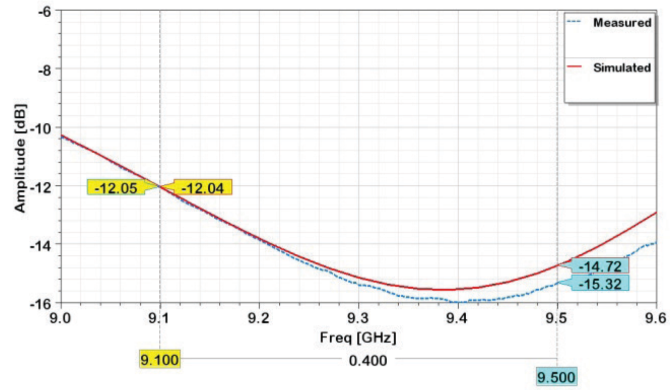

Figure 5. Insertion loss.

The prototype achieved a return loss better than -34 dB within the 9.1--9.5 GHz operating frequency range. The measured insertion loss was better than -12.04 dB over the frequency band of 9.1--9.5 GHz, which is very close to the simulated values, as shown in Fig. 5.

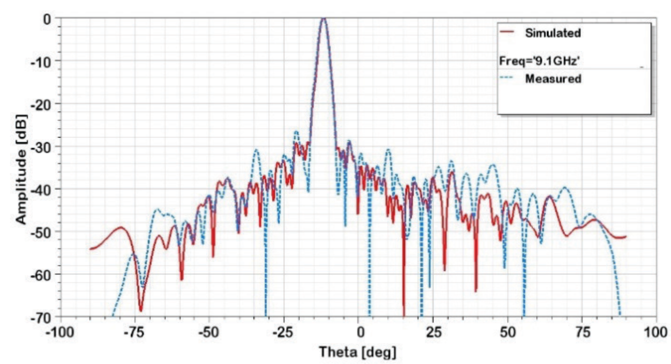

Figure 6. Radiation patterns at 9.1 GHz.

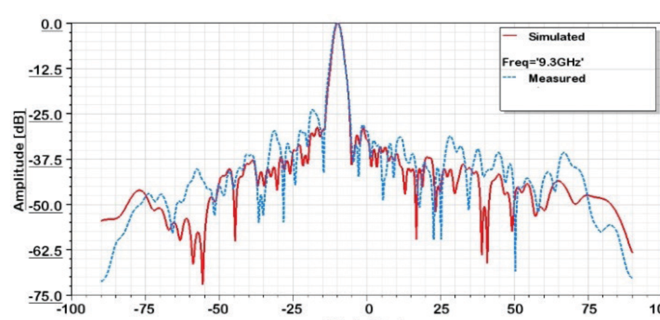

Figure 7. Radiation patterns at 9.3 GHz.

The measured insertion loss was better than -12.04 dB over the frequency band, closely matching the simulated values. Radiation patterns were characterised at the near-field test range (NFTR), with measured results compared with simulated results at different frequencies (Fig. 6 - Fig. 8).

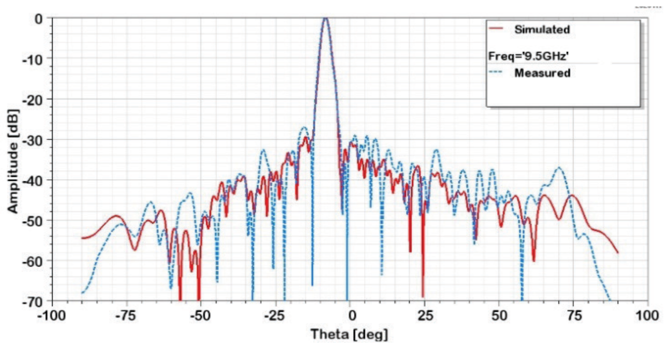

Figure 8. Radiation pattern at 9.5 GHz.

Table 1. Summary of results

Parameter	Simulated values	Measured values (dB)	(dB)
Return loss	≤ -42 dB	≤ -34.2	
Insertion loss	-12.04 dB	-12.05	
First side lobe level SLL	9.1 GHz	-29.1	-26.4
	9.3 GHz	-28.9	-25.2
	9.5 GHz	-29.3	-27.1

Table 2. Measured gain.

Parameter	Measured values (GHz)	
Gain (dBi)	9.1	21.09
	9.3	22.05
	9.5	22.54
Beam peak (Deg.)	9.1	-11.88
	9.3	-9.96
	9.5	-8.34

The measured gains at 9.1 GHz, 9.3 GHz and 9.5 GHz are plotted in Fig. 9. A summary of the results is given in Table 1. The achieved gain and beam peak are shown in Table 2.

The achieved side lobe levels were -26.4 dB, -25.2 dB, and -27.4 dB at 9.1 GHz, 9.3 GHz, and 9.5 GHz, respectively, with gains of 21.09 dBi, 22.05 dBi, and 22.54 dBi, respectively. The marginal differences in the measured results are attributed to manufacturing inaccuracies.

5. CONCLUSIONS

A SWAA prototype with 54 slots was developed by joining three waveguide pieces and cutting the slots. Slot angles were characterized through interpolation for low side lobe levels, and slot depths were calculated for fixed resonance lengths. The prototype was measured for return loss, insertion loss, and radiation pattern characteristics. The results demonstrated an insertion loss of less than -12 dB and a return loss of better than -34.2 dB across the frequency band, with side lobe levels and gains meeting the desired specifications. The study also confirmed the feasibility of developing large linear SWAAs by joining multiple waveguide pieces and cutting slots afterward.

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