

High-gain *S*-band Slotted Waveguide Antenna Arrays with Elliptical Slots and Low Sidelobe Levels

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Abstract— Slotted waveguide antenna arrays offer clear advantages in terms of their design, weight, volume, power handling, directivity and efficiency. Slots with rounded corners are more robust for high power applications. This paper presents a slotted waveguide antenna with elliptical slots made to one broadwall of an *S*-band rectangular waveguide. The antenna is designed for operation at 3 GHz. The slots length and width are optimized for this frequency, and their displacements are determined for a 20 dB sidelobe level ratio. Two rectangular metal sheets are then symmetrically added as reflectors to focus the azimuth plane beam and increase the gain.

1. INTRODUCTION

Slotted waveguide antennas (SWAs) [1] radiate energy through slots cut in a broad or narrow wall of a rectangular waveguide. They are attractive due to their design simplicity, since the radiating elements are an integral part of the feed system, that is the waveguide itself. This removes the need for baluns or matching networks. They also offer significant advantages in terms of weight, volume, high power handling, high efficiency and good reflection coefficient [2]. Thus, they have been ideal solutions for many radar, communications, navigation, and high power microwave applications [3].

SWAs can be realized as resonant or non-resonant according to the wave propagation inside the waveguide (respectively standing or traveling wave) [4, 5]. The design of a resonant SWA is generally based on the procedure described by Elliot [4, 6, 7], by which the waveguide end is short-circuited at a distance of a quarter-guide wavelength from the center of the last slot, and the inter-slot distance is one-half the guide wavelength. For rectangular slots, the slot length should be about half the free-space wavelength. Slot shapes that avoid sharp corners are more suitable for high power applications, since sharp corners aggravate the electrical breakdown problems. Elliptical slots are an excellent candidate for such applications [8].

As with all antenna arrays, the resulting sidelobe level is related to the excitations of the individual elements. In SWAs, the excitation of each slot is proportional to its conductance. For the case of longitudinal slots in the broadwall of a waveguide, a slot conductance is controlled by its displacement from the broadface centerline [9]. Thus, for a desired sidelobe level, the corresponding set of slots displacements should be determined.

In this paper, an SWA designed for operation at 3 GHz is presented, where ten elliptical slots are made to one broadface of an *S*-band rectangular waveguide. The slot displacements from the centerline are determined to obtain a sidelobe level ratio of 20 dB. Later, two metals sheets are attached to the SWA edges to focus its azimuth plane beam. The reflection coefficient, pattern plots and gain results of the antenna are reported.

2. ANTENNA CONFIGURATION

The target frequency is 3 GHz, so a WR-284 waveguide having $a = 2.84''$ and $b = 1.37''$ is used to construct the SWA. The waveguide is shorted at one end and fed at the other. Ten elliptical slots are cut into one of its broadsides. The slots are spaced at half the guide wavelength, center to center, where in this case the guide wavelength $\lambda_g = 138.5$ mm. The slots are positioned such that the center of the first one, *Slot1*, is at a distance of $\lambda_g/4$ from the waveguide feed, and the center of the last slot, *Slot10*, is at $\lambda_g/4$ from the waveguide's short-circuited side. The total length of the waveguide is thus $5\lambda_g$.

The width of each slot, which is 2 times the minor radius of the ellipse, is fixed at 5 mm. This is calculated as follows: for *X*-band SWAs, which the literature is full of, the adopted width of a rectangular slot is $0.0625''$, corresponding to $a = 0.9''$. By proportionality, the width of the elliptical slot for this *S*-band SWA is computed from $2.84'' \times 0.0625/0.9$, which is $0.197''$ or 5 mm. Because of their elliptical shape, the length of the slots (double the major radius) is expected to be larger than half the free space wavelength. Simulations using ANSYS HFSS are done to optimize the slot

length for resonance at 3 GHz. For these simulations, it is assumed that all slots are at the same spacing from the broadside centerline, in an alternating fashion. The resonant slot length is found to be 54.25 mm.

For a desired sidelobe level ratio (SLR) of 20 dB, a heuristic method is used to obtain the required set of slots displacements. The slots near the two waveguide edges are closest to the broadface centerline, whereas those toward the waveguide center have the largest displacement. The detailed displacements values are given in Section 3.

Two metal sheets are then attached symmetrically, as shown in Fig. 1, at an angle of 60° with respect to the XZ plane. These 2 sheets act as reflectors, thus leading to beam focusing in the azimuth plane and as a result to a gain increase. The width of each metal sheet, L , is $3''$.

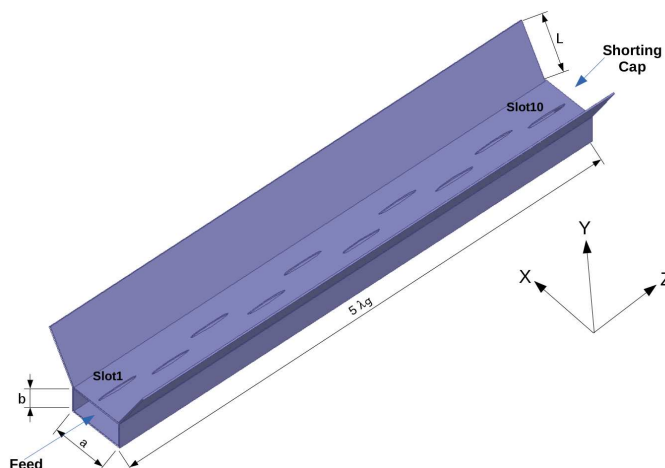


Figure 1: Slotted waveguide with 10 elliptical slots with two reflectors added.

3. RESULTS

The uniform slots displacement that leads to a good reflection coefficient at 3 GHz is calculated using

$$d_u = \frac{a}{\pi} \sqrt{\arcsin \left[\frac{1}{N \times G} \right]}, \quad (1)$$

where

$$G = 2.09 \times \frac{a}{b} \times \frac{\lambda_0}{\lambda_g} \times [\cos(0.464\pi \times \lambda_0/\lambda_g) - \cos(0.464\pi)]^2. \quad (2)$$

In (1), N is the number of slots, which is equal to 10, and in (2), λ_0 is the free-space wavelength. At 3 GHz, $\lambda_0 = 100$ mm. For this SWA, $d_u = 7.7$ mm. This displacement value is used in the HFSS simulations to obtain the resonant elliptical slot length, which is found to be 54.25 mm. For this slot length and this uniform displacement of all ten slots, the resulting SLR is around 13 dB, which is as expected. The reflection coefficient S_{11} and the YZ -plane gain pattern in this case are given in Fig. 2. A peak gain of about 17 dB and an SLR of 13.2 dB are recorded. The half-power beamwidth (HPBW) in this plane is 7.2 degrees. These values are obtained using CST Microwave Studio, but are also verified with HFSS.

Since better SLRs are desirable, the slots displacements are changed, to non-uniform, using a heuristic method, which will not be detailed in this paper. For an example SLR of 20 dB, the displacement values are given in Table 1. The alternating pattern about the centerline is respected. The length of all slots is kept at 54.25 mm, as in the uniform case. Simulations have proven that the resonating length of these elliptical slots is not very sensitive to the distance from the centerline. For these values, the antenna still resonates at 3 GHz, the SLR is 20 dB, the peak gain is 16.8 dB, and the YZ -plane HPBW increases to 8.4 degrees. The broadening of the main beam is expected when the sidelobes are forced to go lower.

When the two reflectors are added, a gain increase of about 3 dB is obtained due to a focus of the azimuth plane beam. The antenna retains its resonance at 3 GHz, and the SLR remains around

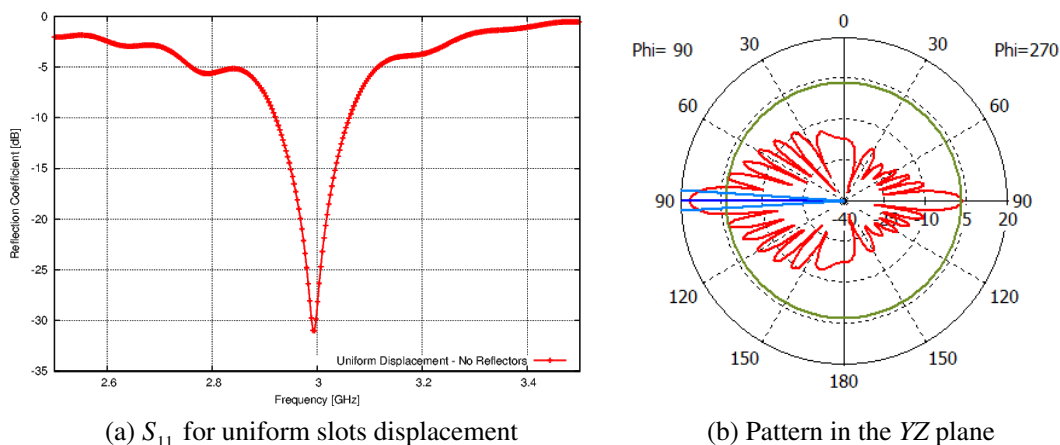


Figure 2: Antenna's reflection coefficient and YZ-plane pattern for the case of uniform slot displacement and before attaching the two reflectors.

Table 1: Displacement of slot centers for an SLR of 20 dB.

Slot number	1	2	3	4	5	6	7	8	9	10
Displacement (mm)	3.74	5.42	7.11	8.4	9.11	9.11	8.4	7.11	5.42	3.74

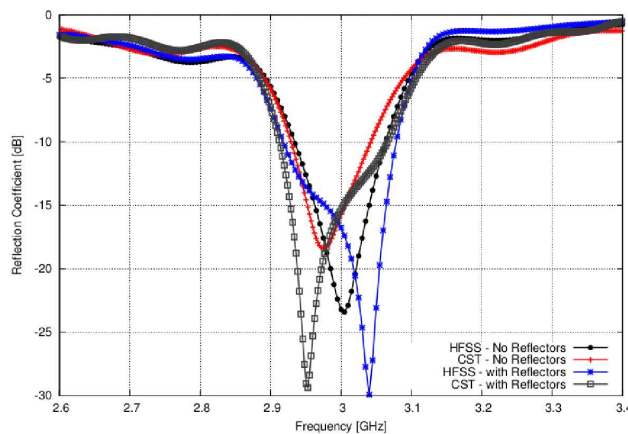


Figure 3: Reflection coefficient without and with the reflectors.

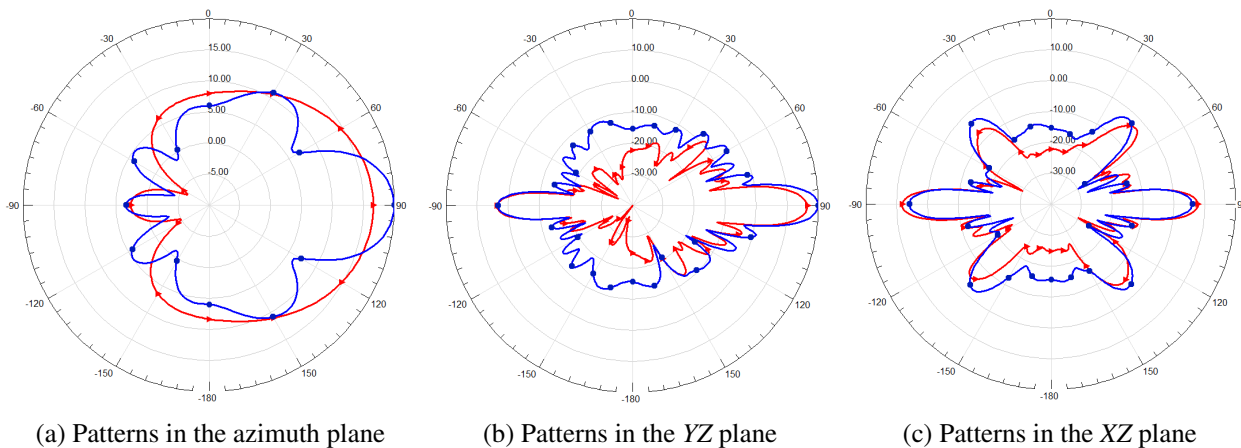


Figure 4: Antenna's gain patterns in the three principal planes (red line: no reflectors, blue line: with reflectors).

20 dB. The back lobe level stays about the same, so the main-to-back lobe level ratio also increases by about 3 dB. The S_{11} and pattern results of the two cases, with and without the reflectors, are shown in Fig. 3 and Fig. 4, respectively. All results generated in HFSS were verified in CST Microwave Studio, where a good match is observed.

4. CONCLUSION

A 3 GHz slotted waveguide antenna was presented. It has 10 elliptical slots, with optimized dimensions, made to one broadwall and displaced around its centerline so as to obtain a 20 dB sidelobe level ratio. The antenna has a very broad azimuth plane beam and a peak gain of about 17 dB. Upon adding two reflectors to the antenna's edges, the beam is focused and the gain is increased to about 20 dB.

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