Design of a X-Band Waveguide Slot Antenna for Radar Applications with Low Side Lobes and Back Lobe Reduction

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Abstract

In this paper a Waveguide Slot Antenna working in X-Band (9.410-9.495 GHz) is presented. In the proposed configuration, a Taylor distribution in the slot excitation voltages and the insertion of a metallic shield allow to obtain a very low side lobe level and a significant reduction of radiating back lobe. The design has been developed using CST MICROWAVE STUDIO, a general purpose and specialist tool for the 3D electromagnetic simulation of microwave high frequency components.

1. Introduction

Radar systems are well known since the end of World War II and are still currently used in a wide range of civil and military applications.
The basic concept of radar is relatively simple: the system uses the propagation characteristics of electromagnetic waves and works by radiating electromagnetic energy in the space and detecting the echo reflected by the targets. The information related to the target is available in the echo signal: the range, or distance of the target from the receiver station, is computed considering the time taken by the radiated energy to travel to the target and back; the angular location is instead detected using directive antennas with narrow radiated beams.
The ability to discern about the characteristics and size of the target depends on the radar resolution, strictly related to the operating bandwidth and the electrical size of the radar antenna [1]. A typical radar system uses directive antennas with high gains and low-level side lobes, such as mechanically steered parabolic reflectors, planar arrays and waveguide slot antennas (WSA), in order to concentrate the radiated energy in a small region of the surrounding space [2].
WSA combine the low-losses propagation features of the waveguide with the performance of radiating slot antennas [3]. A single WSA is characterized by a 90° fan-radiated beam in the elevation plane, while the width of the radiated beam in the azimuth plane is determined by the number of radiating slots. Depending on the applications, one or more waveguide slot antennas can be “combined” together in a planar array in order to obtain a radiated beam with specific features [4-7].
In this paper, we present the design of a single standing wave WSA [8] for radar applications, having low side lobes and a satisfying back radiation: the antenna works in the X-band (from 9.410 to 9.495 GHz) and is characterized by about 3° half-beam width in the azimuth plane. The antenna has been designed using CST MICROWAVE STUDIO, a commercial general-purpose software for the electromagnetic simulation of three-dimensional high-frequency components. The designed antenna has been realized and measured, showing a very good agreement with simulations.

2. Antenna Design

In this section, the WSA has been designed in order to operate within the X-band (9.410-9.495 GHz bandwidth, central frequency 9.452 GHz). The waveguide has been implemented using a commercial aluminum profile with internal dimensions $a=27$ mm and $b=12$ mm; the radiating slots are milled in the wider side of the structure.
Generally, the design parameters of a waveguide slot antenna are the length l of the slots, their spacing s_1 and the offset s_2 from the center of the waveguide broad wall, as shown in figure 1:

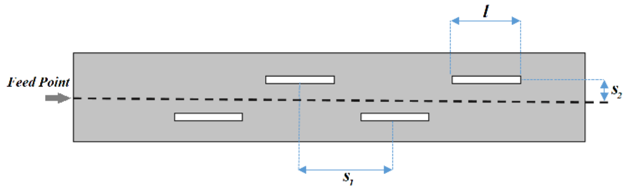

Figure 1. Main geometrical parameters of a Waveguide Slot Antenna.

The number of slots N is strictly related to the desired radiated half-beam width on the azimuth plane: as a first approximation, N can be calculated using the following expression [9]:

$$N = 50.77 \frac{\lambda_0}{HBW * \lambda_g/2} \qquad (1).$$

Where HBW is the desired radiated half-beam width on the azimuth plane (namely 3°), while λ_0 and λ_g are respectively the free space wavelength at the central design frequency and the guided wavelength [10]. Assuming $\lambda_0=31.74\ mm$ and $\lambda_g=39.23\ mm$ we obtain $N=28$.

The results of preliminary simulations using N=28 for a uniform WSA gives a half-beam width on the azimuth plane slightly greater than 3°, therefore we incremented to 30 the value of N, in order to achieve the desired HBW of 3°.

Typically, in radar applications the antennas are characterized by a side lobe level (SLL) lower than -25 dB [11]. In a WSA with uniform displacement, all slots are located at the same distance from the center of the broad wall [12]: this configuration corresponds to a uniform array, where all the radiating slots have the same excitation, resulting in a SLL of -13 dB approximately.

The desired SLL≤-25dB can be obtained using a slot displacement according with a Taylor amplitude distribution [12]. Therefore, following the design procedure indicated in [6] and [7], the slot lengths and offsets have been calculated and the corresponding values are reported in table 1.

Table 1. Slot Lengths and offsets for a Taylor distribution with SLL equal to -25 dB.

Slot n.	*Length (mm)*	*Offset (mm)*
1	14.40	0.83
2	14.36	1.00
3	14.35	1.13
4	14.38	1.31
5	14.41	1.55
6	14.44	1.80
7	14.49	2.07
8	14.53	2.32
9	14.57	2.56
10	14.62	2.77
11	14.65	2.94
12	14.69	3.09
13	14.71	3.21
14	14.73	3.28
15	14.73	3.33
16	14.73	3.33
17	14.73	3.28
18	14.71	3.21
19	14.69	3.09
20	14.65	2.94
21	14.62	2.77
22	14.57	2.56
23	14.53	2.32
23	14.49	2.07
25	14.44	1.80
26	14.41	1.55
27	14.38	1.31
28	14.35	1.13
29	14.36	1.00
30	14.40	0.83

3. Results

The resulting waveguide slot antenna has been fed by a coaxial probe (figure 2) and simulated with CST MICROWAVE STUDIO.

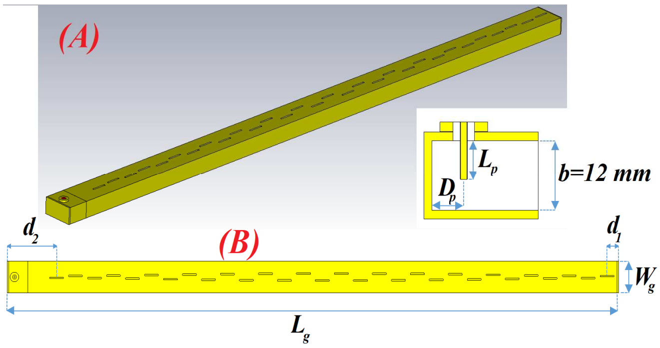

Figure 2. (A) Antenna layout and waveguide feed transverse section. $L_p=6.7\ mm$, $D_p=6\ mm$. (B) Top view. $L_g=630.53\ mm$, $Wg=15\ mm$, $d_1=10.8\ mm$, $d_2=50.92\ mm$.

The width of the slots is less than $\lambda_0/20$ [13] and set equal to 1.55 millimeters. The length L_p and position D_p of the coaxial probe have been optimized in order to obtain a good matching at the operating frequency band [14].

The designed antenna has been manufactured (figure 3) and characterized.

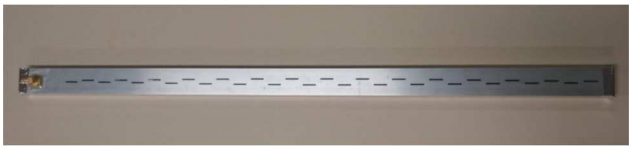

Figure 3. Photo of the designed Waveguide Slot Antenna.

Figure 4 shows the simulated and measured frequency responses of the input reflection coefficient: as apparent, the bandwidth specification between 9.410 and 9.495 GHz is fulfilled with a good agreement between simulation and measurements.

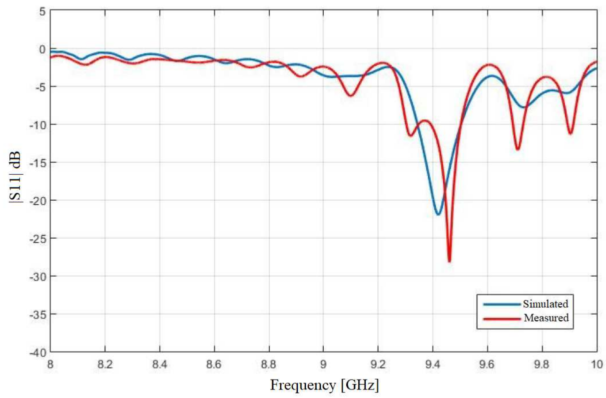

Figure 4. Reflection coefficient of Waveguide Slot Antenna.

In figure 5 the simulated gain radiation pattern at the central frequency (9.452 GHz) both in the azimuth and elevation plane are reported. In the azimuth plane, the SLL obtained with the Taylor amplitude distribution is -28 dB.

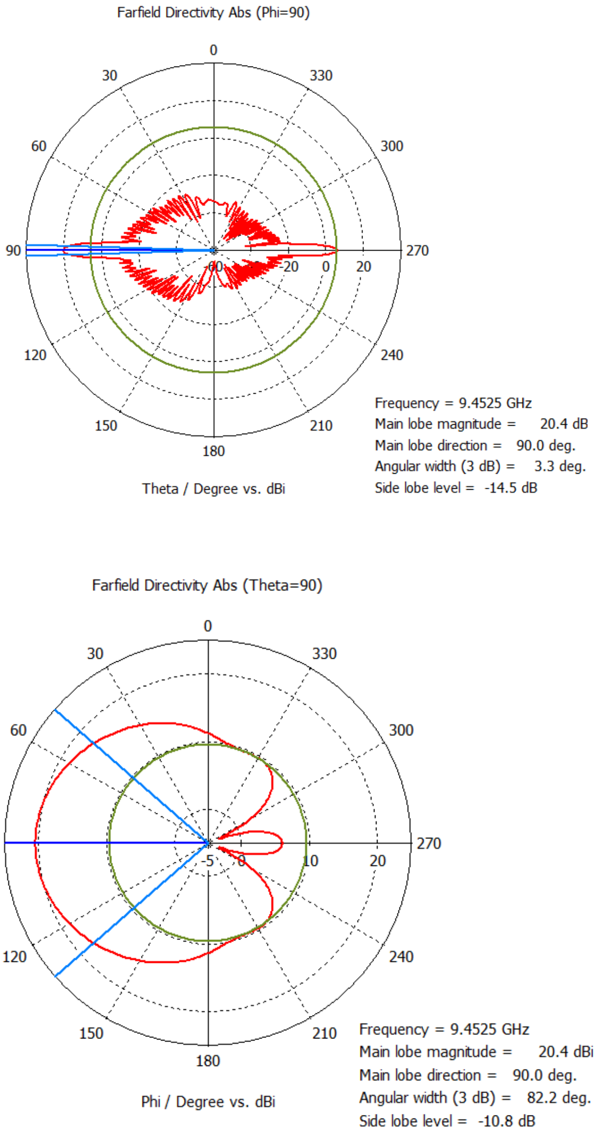

Figure 5. Simulated gain radiation pattern of the designed Waveguide Slot Antenna.

The back lobe level in the azimuth plane is equal to -14.5 dB, which can be too high for radar applications and causes a significant waste of power dissipated in undesired directions. Therefore, in order to reduce the back radiation, a metallic shield has been placed on the back of the antenna (figure 6). The length and the width of shield are optimized to reduce the back lobe to the SLL value. This solution allows to obtain an improvement in the reflection coefficient (figure 7) and a significant reduction of the back lobe level, as shown in figure 8.

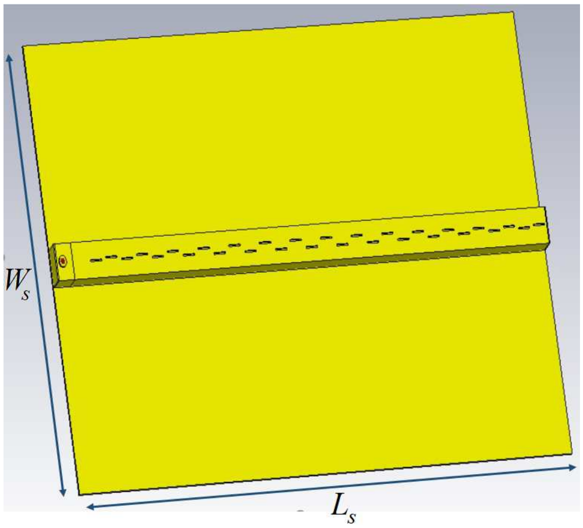

Figure 6. Waveguide Slot Antenna after the insertion of a metallic back shield. L_s=L_g=*630.53 mm*, W_s=*705 mm*.

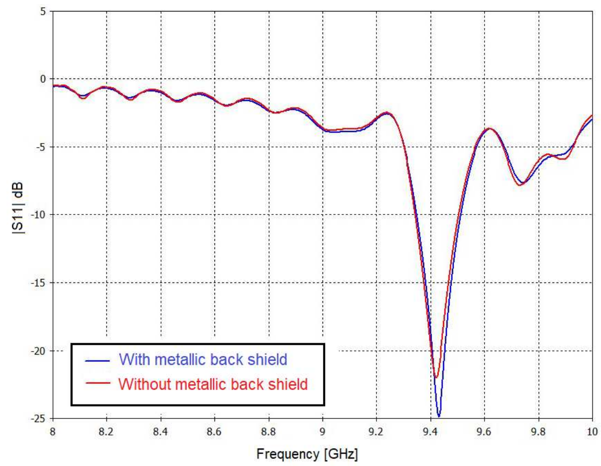

Figure 7. Comparison of the WSA reflection coefficient with and without the metallic back shield.

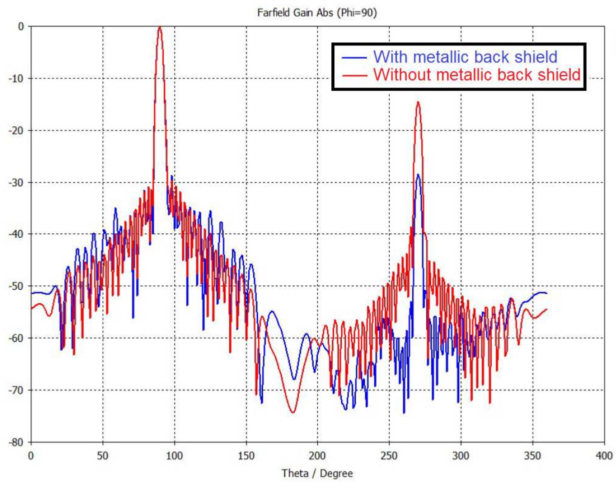

Figure 8. Normalized Cartesian plot of the WSA gain in the azimuth plane with and without the metallic back shield.

Conclusions

A waveguide slot antenna (WSA) operating in the X-Band has been designed and analyzed using CST MICROWAVE STUDIO. The simulated results show that the proposed WSA can be successfully used in radar applications in the whole operating bandwidth (9.410-9.495 GHz) thanks to its low side and back lobe levels. The designed WSA has been manufactured and characterized, obtaining a good agreement between numerical and experimental results.

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