Communications and Electromagnetic Waves

Design of a Slotted Waveguide Array

Cristhian Quezada Riofrio
ID: 001113297

***Abstract*— This research explores the applications and design approaches of slotted waveguide antennas through MATLAB simulations. Radar, satellite communications, and wireless networking are some of its versatile applications. The focus is on WR90 waveguide antennas in the X-band frequency range. Results highlight slot's parameters impact on antenna performance, guiding personalized designs.**

I. INTRODUCTION

This report highlights the benefits and applications of slotted waveguide antennas and the process of designing such antennas to meet specific requirements. The report demonstrates how software simulators such as MATLAB are useful in graphically representing and validating the behaviour of designed antennas in an ideal environment. Slotted waveguide antennas have numerous applications, including radar systems, satellite communications, wireless networking, and broadcasting. By describing the design process and simulation techniques, the report emphasizes the practical utility and effectiveness of slotted waveguide antennas in modern communication systems.

II. APPLICATIONS

Slotted waveguide antennas are indispensable in a variety of applications. They offer high directivity and wideband performance in radar systems, allowing for precise target detection and tracking. These antennas for satellite communications ensure reliable transmission over long distances, preserving connectivity while reducing size and weight. In wireless networking, they provide seamless device connectivity, high-speed data transfer, and extensive coverage. Furthermore, slotted waveguides help to transmit television and radio signals clearly and consistently. Their versatility and efficiency make them essential components of modern communication systems, enabling critical functions such as target detection, connectivity, and signal transmission across multiple industries.

III. DESIGN

A. Material

When designing an antenna, selecting the appropriate material that meets the specific requirements is critical. These properties include choosing a conductive material, such as metals, determining permeability and permittivity, ensuring resistance to oxidation, and ease of handling. For this project, aluminium has been chosen as the preferred material.

B. Slot Orientation

Different research on slotted antennas provides a good understanding of the recreation of the equivalent circuit of the rectangular waveguide slot, as shown in Fig.1. According to these studies, this configuration can be determined by the current. Common configurations are longitudinal slots on the wide side of the antenna that cause a sudden change in the longitudinal current, transversal slots on the wide side of the antenna that cut off the longitudinal current, forming a voltage change and lastly, inclined slots, which intensity depends on its angles.

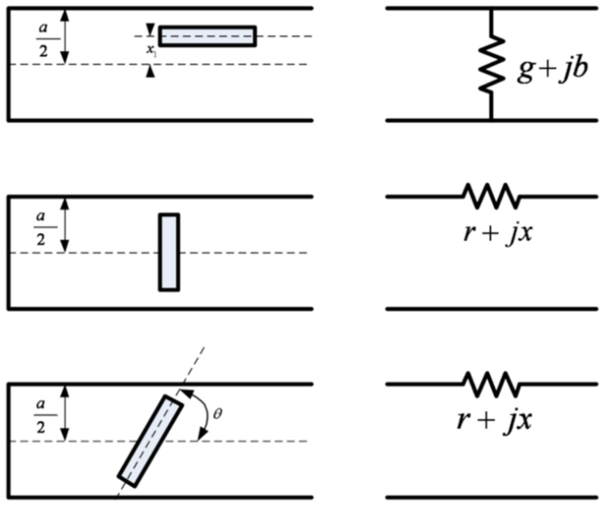


Figure 1: Equivalent circuit of the slot antenna [1].

C. Waveguide Antenna

This project aims to create an antenna that operates inside the X band frequency range, which ranges from 8 GHz to 12 GHz, following IEEE standards [2]. Extensive studies and experiments have shown that a rectangular waveguide antenna has a superior performance compared to antennas of other shapes [3]. As a result, a WR90 waveguide antenna was chosen to build the needed slotted waveguide antenna, which aligns with the project's frequency parameters, as shown in Table 1, by operating within the appropriate frequency band of 8.20GHz to 12.40GHz.

Table 1: WR90 Specifications.

Frequency Range (GHz)	Frequency Band	Dimension
8.20 - 12.40	X Band	22.86mm x 10.16mm

D. Slots

According to the parameter proposed for the antenna design, it is possible to obtain the wavelength of the frequency that the antenna is going to operate, as shown in

Eq.1; knowing the speed velocity and frequency, a wavelength of 3cm is obtained.

$$\lambda = \frac{C}{f}$$
$$\lambda = 3\ cm$$

Equation 1: Wavelength.

Where:

λ = Wavelength

C = Speed of Light

f = Frequency

Theoretically, the antenna length should ideally be half the wavelength to resonate at the desired frequency to achieve optimal antenna efficiency. For a slotted antenna, this principle extends to the length of the slot, which should also be half of the calculated wavelength, as shown in Eq.2. This ensures that the antenna operates efficiently and effectively within the desired frequency range,

$$l = \frac{\lambda}{2}$$
$$l = 1.5\ cm$$

Equation 2: Slot length.

Another important factor to consider is the wavelength within the waveguide. This number is critical for establishing the distance between slots in the antenna design [4]. By properly calculating the wavelength within the waveguide, as shown in Eq. 3, designers can determine the distance between the centre point of one slot and the next one, resulting in optimal antenna performance and resonance within the specified frequency range.

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{2*a}\right)^2}}$$
$$\lambda_g = \frac{0.03}{\sqrt{1-\left(\frac{0.03}{2*0.02286}\right)^2}}$$
$$\lambda_g = 3.97\ cm$$

Equation 3: Wavelength inside the waveguide.

Where:

λ_g = Wavelength in the Waveguide

λ = Wavelength

a = Width of the WR-90

To obtain the separation between slots, the value obtained previously for the wavelength inside the material can be used to obtain a separation of approximately 2 cm, as shown in Eq.4.

$$S_s = \frac{\lambda_g}{2}$$
$$S_s \approx 2\ cm$$

Equation 4: Slot separation.

In order to obtain a reference value for the offset separation between the slots, its electrical equivalent circuit was used, as shown in Fig.2.

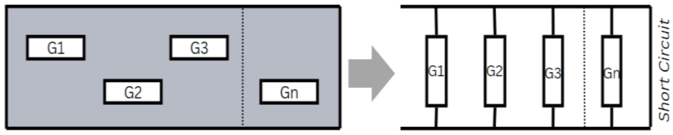


Figure 2: Longitudinal resonant arrays and their electrical equivalent.

The waveguide slotted antenna is designed to operate broadside; this means that the radiation produced by the antenna is perpendicular to it. To obtain this radiation, all the slots must be excited in phase [5]. The number of slots is important to obtain the slot offset, as shown in Eq.5. The number of slots can be modified according to the project requirements.

$$G_{slot} = \frac{1}{N}$$
$$X = \left(\frac{a}{\pi}\right) * arc\ sin\left(\sqrt{\frac{G_{slot}}{G_{wg}}}\right)$$

Equation 5: Calculations to obtain the offset distance.[4]

Once the initial parameters have been set up, as shown in Fig.3 the antenna can be designed using MATLAB in order to carry out different tests. These tests will be used to optimize the performance of the antenna.

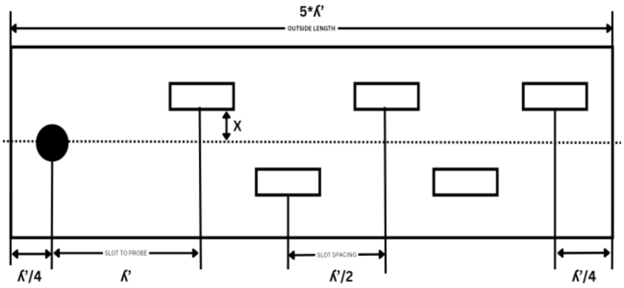


Figure 3: Initial conditions for a waveguide slotted antenna.

IV. SIMULATION

A. Number of Slots

The number of slots is an important element in the design of slot antennas as it directly affects the antenna's performance. As shown in Table. 2, two antennas were created in MATLAB with similar characteristics to explore the effect of the number of slots on antenna functionality; antenna A uses the parameters obtained from the equations, and antenna B follows the same equations but varies the number of slots. As previously stated, choosing the optimum number of slots is critical for precisely setting the slots' offset values during the antenna design phase.

Table 2:Parameters used for test one.

Antenna A		***Antenna B***	
Parameter	***Value***	***Parameter***	***Value***
Width	22.28mm	Width	22.28mm
Length	198mm	Length	198mm
Height	10.16mm	Height	10.16mm
Width *(Slot)*	1.5mm	Width *(Slot)*	1.5mm
Length *(Slot)*	15mm	Length *(Slot)*	15mm
N of Slots	8	N of Slots	3
Slot offset	3.1mm	Slot offset	5.4mm

The graph produced from the scattering parameters presented in Fig.4 shows that increasing the number of slots has a better frequency response obtaining a value of -9.5dB. Contrary, limiting the number of slots increases the antenna attenuation obtaining a value of -5dB.

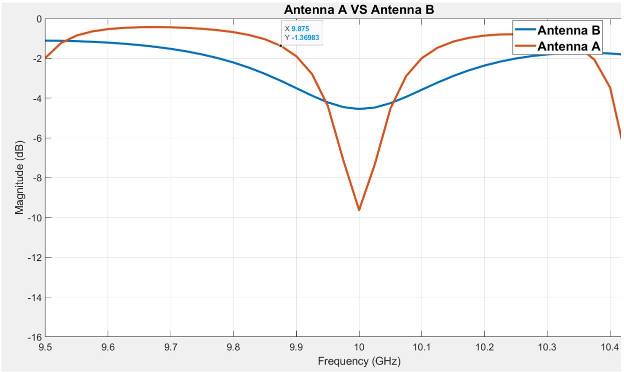
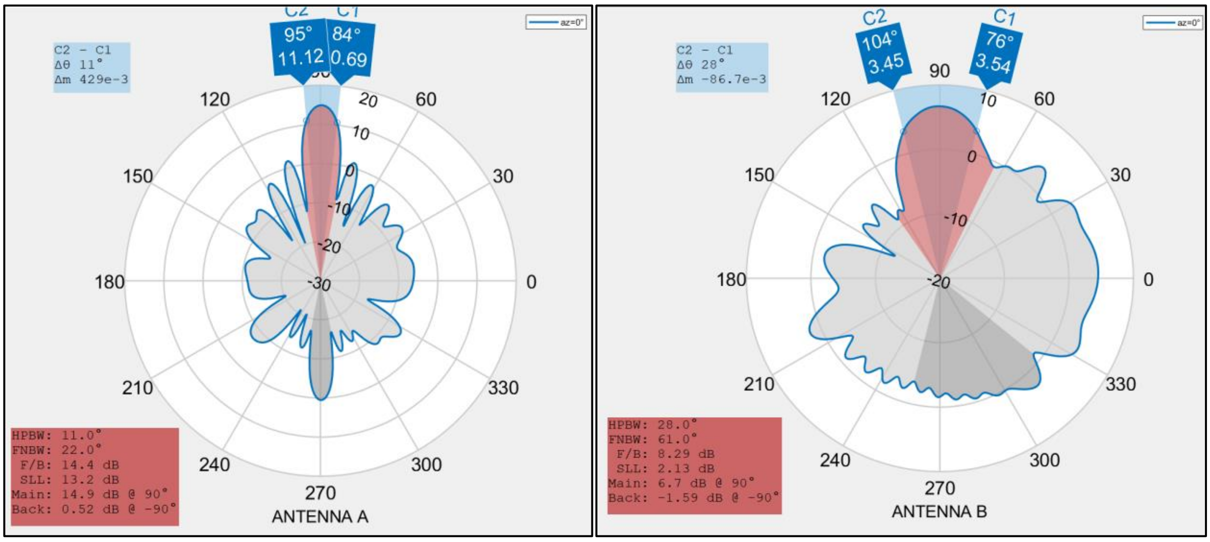


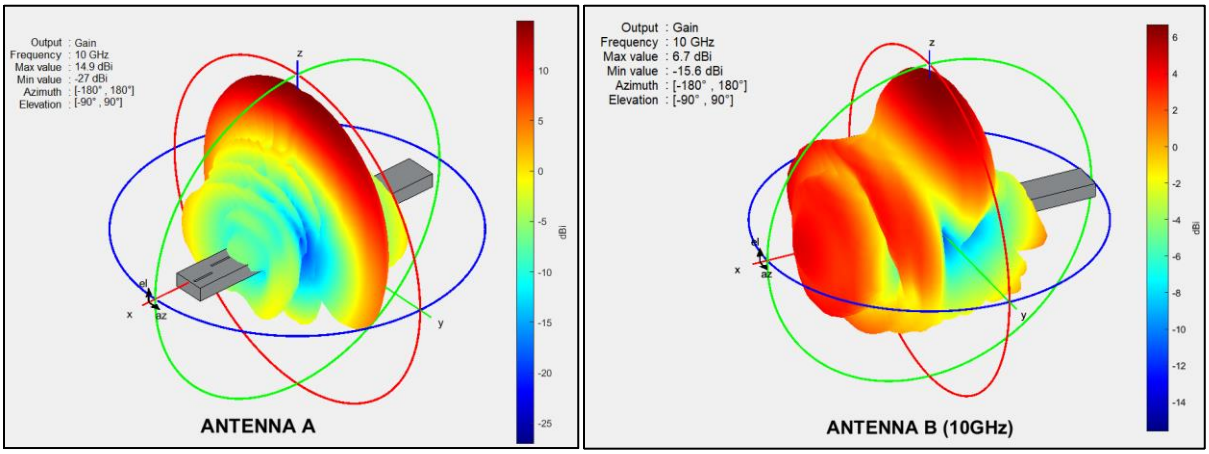
Figure 4: Scattering parameters for different number of slots.

The number of slots in the antenna considerably impacts its directivity. As evident from the elevation pattern shown in Fig.5, the directivity of Antenna A is notably higher compared to Antenna B. Engineers may have preferences for antennas with either high or low directivity depending on specific application requirements. Furthermore, changing the number of slots has a discernible influence on the gain provided by each antenna. Antenna A exhibits a gain of up to 14.9 dBi, whereas Antenna B achieves a maximum gain of 6.7 dBi as shown in Fig.6.



[a] [b]

Figure 5: Polar radiation pattern. (a) Antenna A, (b) Antenna B



[c] [d]

Figure 6: Radiation pattern. (a) Antenna A, (b) Antenna B.

B. Slot Width.

Another critical parameter for a slotted antenna is the width of its slots. In this experiment, two antennas with different slot widths were built, as shown in Table 4. All other parameters used in the design remained identical except for the slot width. Examining the scattering parameter graphs displayed in the Fig.7 reveals that increasing the width of the slots improves the matching between the antenna and the source, but it also produces a frequency shift from 10GHz to 10.1GHz.

Table 3: Parameters used for test two.

Antenna A		Antenna B	
Parameter	**Value**	**Parameter**	**Value**
Width	22.28mm	Width	22.28mm
Length	198mm	Length	198mm
Height	10.16mm	Height	10.16mm
Width *(Slot)*	1.8mm	Width *(Slot)*	1.2mm
Length *(Slot)*	15mm	Length *(Slot)*	15mm
N of Slots	8	N of Slots	8
Slot offset	3.1mm	Slot offset	3.1mm

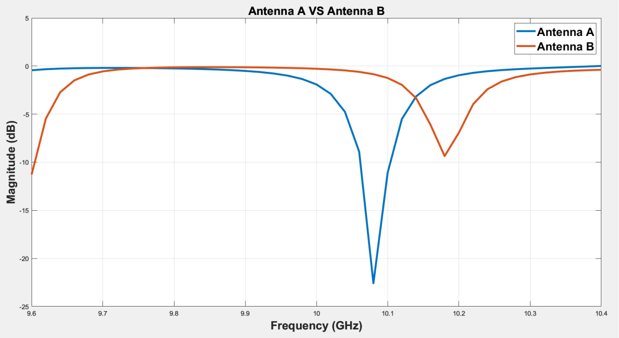


Figure 7: Scattering parameters for different slot widths.

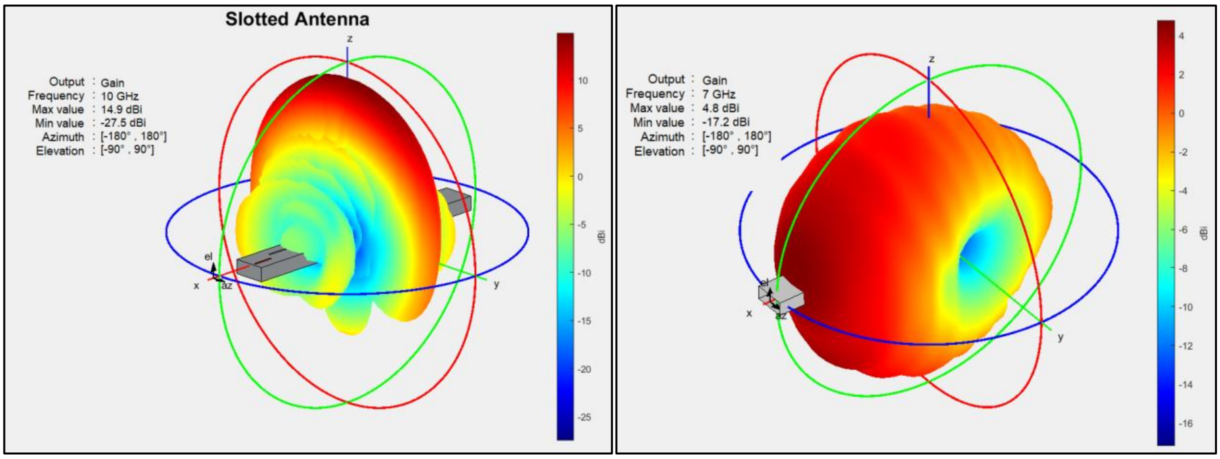
C. Comparison

A different antenna type with similar characteristics was selected to compare the performance of the slotted antenna, as shown in Table 8. For this simulation, a waveguide antenna was chosen as an alternative option.

Figure 8: Parameters used for test three.

Slotted Antenna		Waveguide Antenna	
Parameter	**Value**	**Parameter**	**Value**
Width	22.28mm	Width	22.28mm
Length	198mm	Length	198mm
Height	10.16mm	Height	10.16mm
Width *(Slot)*	1.5mm	Width *(Slot)*	/
Length *(Slot)*	15mm	Length *(Slot)*	/
N of Slots	8	N of Slots	/
Frequency	10GHz	Frequency	7GHz

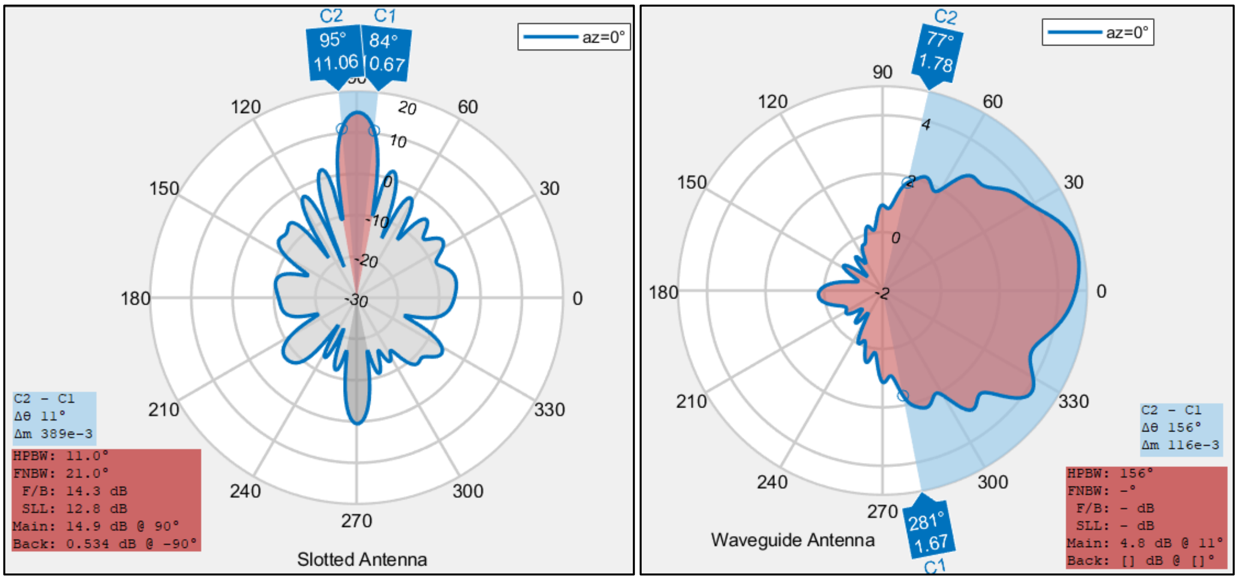
The simulation reveals significant differences between these antennas. Whereas the slotted antenna's radiation pattern is perpendicular to it, the waveguide antenna emits radiation in the same plane, as shown in Fig.9. This discrepancy could be due to the waveguide antenna's lack of slots and open-side configuration. Another important observation comes from the directivity produced for each antenna; while the directivity of the slotted antenna is more narrow, the one obtained from the waveguide antenna has a bigger angle, as shown in Fig.10. This is caused by the width side of the waveguide antenna.



[a] [b]

Figure 9: Radiation pattern (a) Slotted antenna, (b) Waveguide antenna.

.



[c] [d]

Figure 10: Polar pattern radiation, (c) slotted antenna elevation view, (d) Waveguide antenna elevation view.

V. CONCLUSION

Modifying factors such as slot width, number of slots, and slot offset substantially impact antenna performance, particularly resonant frequencies. Adjustments can be made from the initial values obtained from the equations. Initially, the antenna exhibited a return loss of -9.5 dB. The return loss improved to -11dB upon incrementing the slot width, as observed in Fig.11. This indicates enhanced impedance matching, highlighting the impact of slot width on antenna performance. Future works can include different parameters in order to obtain a deeper understanding of this type of antenna and relate them to specific applications.

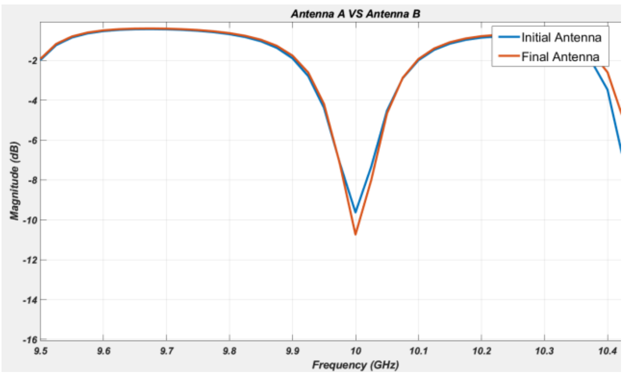


Figure 11: Improvement in the Scattering Parameters.

REFERENCES

[1] Isabel Zeng, 'Basic knowledge of slot antenna, rectangular waveguide, and slotted waveguide antenna', Yingcomm. Accessed: Mar. 24, 2024. [Online]. Available: https://www.linkedin.com/pulse/basic-knowledge-slot-antenna-rectangular-waveguide-slotted-zeng-ggesc/?trackingId=ZqrsicBoTa6QptdUktezqg%3D%3D

[2] Standard Association, *521-2019 - IEEE Standard Letter Designations for Radar-Frequency Bands*. IEEE, 2020.

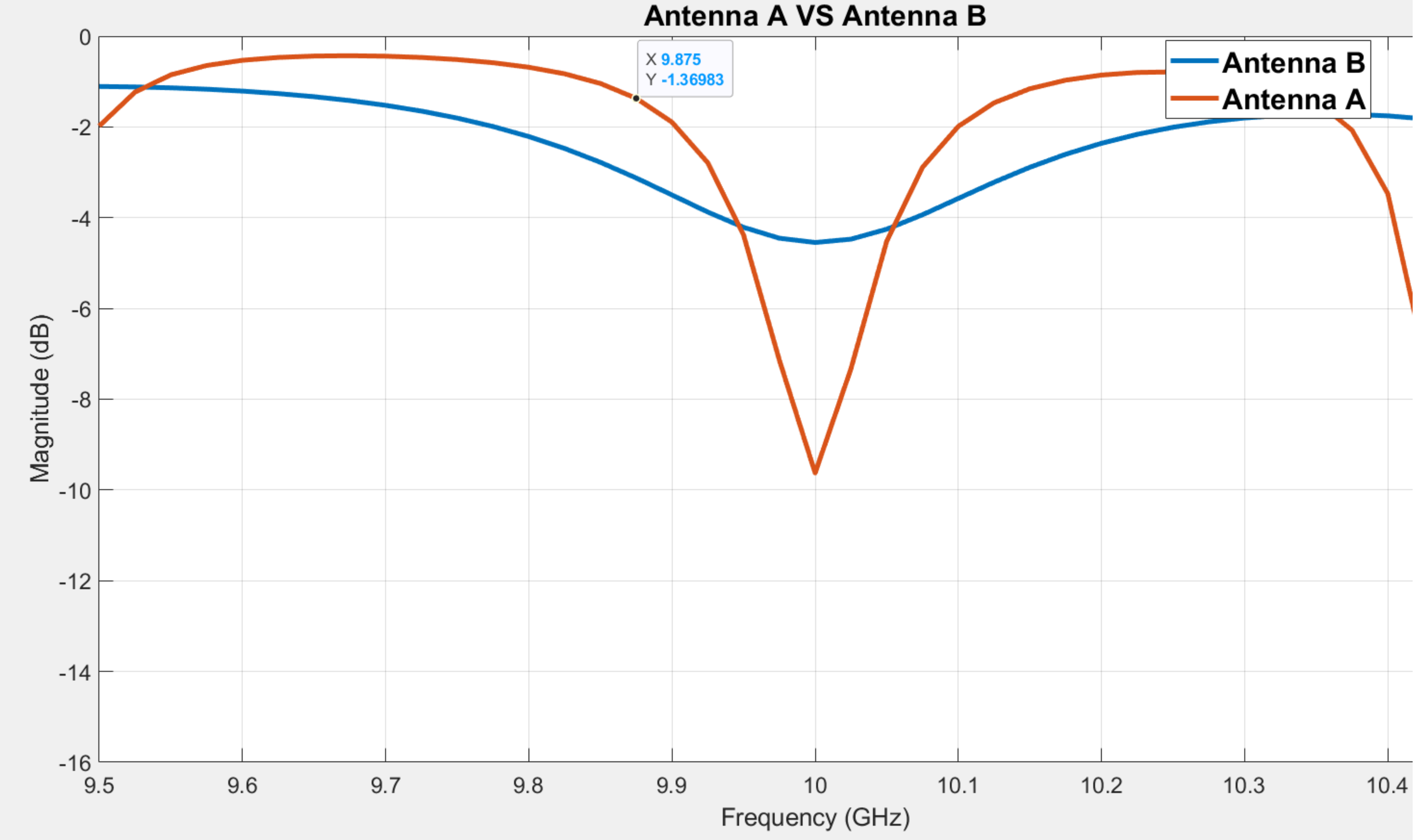
[3] Baselios Mathews, *ICETT - 2016 : proceedings of IEEE International Conference on Emerging Technological Trends in Computing, Communications and Electrical Engineering : on 21st and 22nd October, 2016*. 2016.

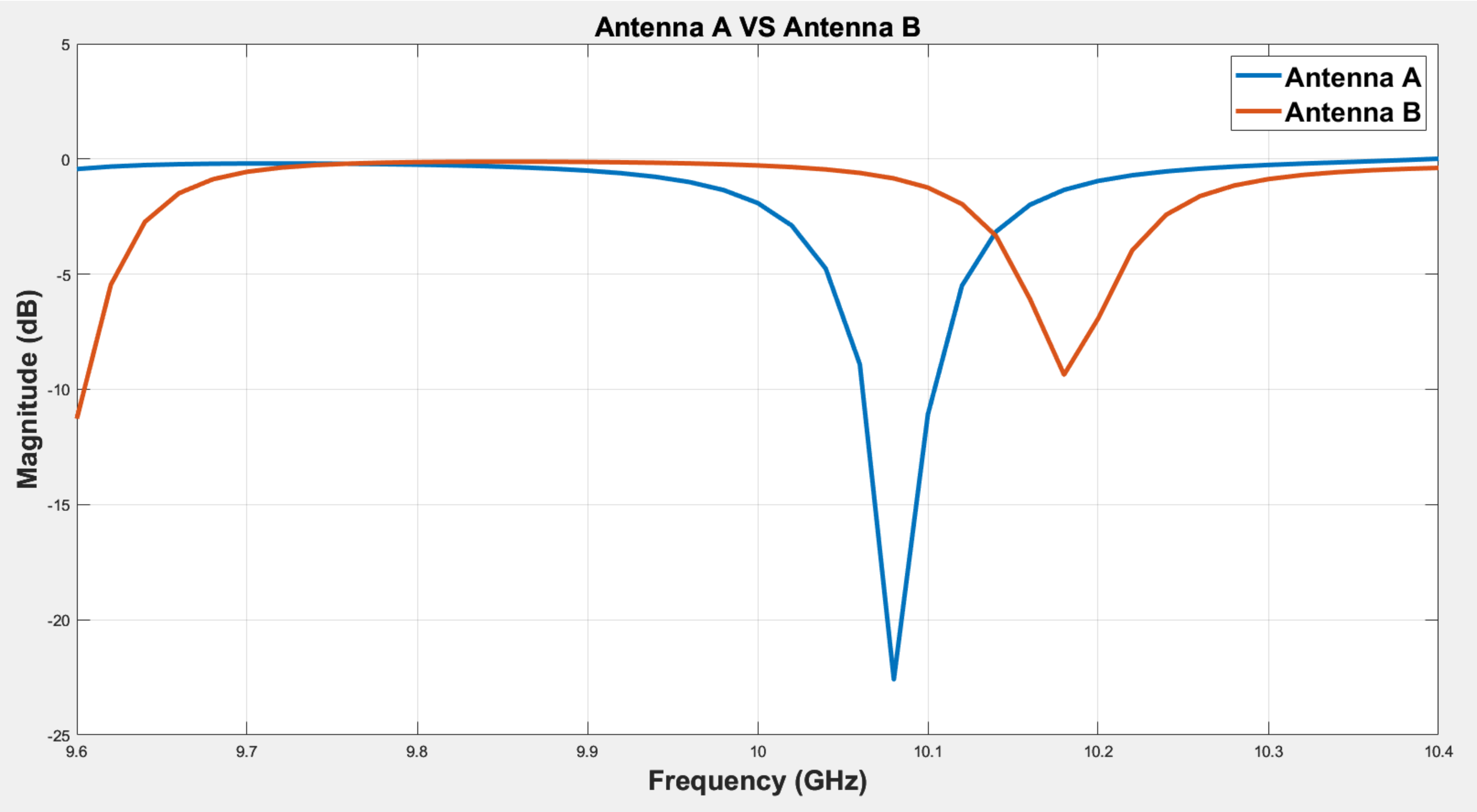
[4] N. Bethart Rodríguez, T. E. Cordoví Rodríguez, R. Jiménez Hernández, and D. B. Casanova, 'PROPUESTA DE ANTENA DE GUÍA DE ONDA CON RANURAS RESONANTES PARA APLICACIONES WLAN WAVEGUIDE ANTENNA PROPOSAL WITH RESONANT SLOTS FOR WLAN APPLICATIONS', *Revista Telemática*, vol. 19, no. 2, pp. 55–66, 2020, [Online]. Available: http://revistatelematica.cujae.edu.cu/index.php/tele

[5] L. Ripoll and L. Valdez, 'Design and Simulation of a Slot Waveguide Array Antenna (SWAA) for Satellite Communications', *IOP Conf Ser Mater Sci Eng*, vol. 519, no. 1, p. 012035, May 2019, doi: 10.1088/1757-899X/519/1/012035.

VI. APPENDIX

PLOTS





Antenna A VS Antenna B
Antenna A
Antenna B
Magnitude (dB)
Frequency (GHz)
5
0
-5
-10
-15
-20
-25
9.6
9.7
9.8
9.9
10
10.1
10.2
10.3
10.4

CODE (Slotted & Waveguide)

```
% Create a waveguide antenna
% Generated by MATLAB(R) 9.13 and Antenna Toolbox 5.3.
% Generated on: 10-Mar-2024 17:38:05
%% Dialogue box %%
dlgtitle = 'Antenna 1 Value';%% Name of the dialogue box
prompt={'Number of Slot A','Slot Width A %:','Frequency GHz',}; %% Name of each data
dims=[1 35]; %% Dimensions of the text box
answer = inputdlg(prompt,dlgtitle,dims); %% user data
%% Convert from string to N %%
NS = str2num(answer{1}); %% Number of Slots
WSP = str2num(answer{2})/100; %% Width Slop Percentage
F = str2num(answer{3})*10^9; %% Freq in GHz
%% COMMON
C=3*10^8 %% Speed of ligth
L=C/F; %% Length of the wavelength
W = 0.02286; %% Height
H = 0.01016; %% Width
Ls = L*0.5; %% Length Slot
G=L/(sqrt(1-(L/(2*W))^2)) %% Wavelength in the antenna
SL = G * 5 %% Antenna Length
STT = G/4  %% Slot to Top
FeedP = G/4; %% Feeder point
FeedL = SL/2; %% Feeder location
POSFeed = -FeedL + FeedP;
%% ANTENNA 1 PARAMETERS
Ws = Ls*WSP; %% Width Slot
Sp = G/2; %% Slot Separation
Gslot = 1/NS; %%
Gwg = ((2.09*W*G)/(H*L))*(cos((0.464*pi*L)/G)-cos(0.464*pi))^2 %% Wavelength inside antenna
X = (W/pi)*(asin(sqrt(Gslot/Gwg))) %% Offset distance
%% ANTENNA 1
ant = waveguideSlotted
ant.Width = W;
ant.Height = H;
ant.Length = SL; %% Antenna Length
ant.NumSlots = NS %% Number of Slots
ant.Conductor.Name = 'Aluminium'; %% Antenna Material
ant.Conductor.Conductivity = 3.77*1e7;
ant.Conductor.Thickness = 0.00254; %% Thickness of the antenna0
ant.Slot.Length = Ls; %% Slot Length
ant.Slot.Width = Ws; %% Slot width
ant.SlotToTop = STT;
ant.SlotSpacing = Sp;
ant.SlotOffset = X*0.99 %% Offset value
ant.ClosedWaveguide = 1
%% ANTENNA 1 END
%% ANTENNA 2 (Similar dimensions)
ant2 = waveguide;
ant2.Length = 0.2;
ant2.FeedWidth = 0.0009;
ant2.FeedHeight = 0.005;
ant2.FeedOffset = [-0.085, 0];
ant2.Conductor.Name = 'Silver';
ant2.Conductor.Conductivity = 6.3*1e7;
ant2.Conductor.Thickness = 2e-07;
%% ANTENNA 2 END
%% FEEDER 1 and 2
ant.FeedOffset = [POSFeed,0]
ant.FeedHeight = 0.005;
ant.FeedWidth = 0.0009;
%% DISPLAY ANTENNA PLOTS
azimuth_angles = 0:1:360;
%% ANTENNA DISPLAY
figure(1) %% Display antenna
show(ant)
title('ANTENNA SLOT');
%%Antenna 2
```

```
figure(2) %% Display antenna
show(ant2)
title('ANTENNA WAVEGUIDE')
%% ANTENNA DISPLAY END
%% ANTENNA RADIATION PATTERN
figure(3)
pattern(ant,10e9)
title('Antenna Slot');
%%Antenna 2
figure(4)
pattern(ant2,7e9)
title('Antenna Waveguide');
%% ANTENNA RADIATION PATTERN END
%% PATTERN PLOTS
figure(5)
patternElevation(ant,10e9)
title('Antenna Slot');
%%Antenna 2
figure(6)
patternElevation(ant2,7e9)
title('Antenna Waveguide');
```