Microwave Experiments with Vidyut Yantra Setup

A Lab Report submitted in partial fulfilment for 8th semester for the Degree

INTEGRATED MSC

in

PHYSICS

by

B RAJESH ACHARI

Roll Number- 1811047

under the supervision of

Prof. Ritwick Das and Dr. Gunda Santosh Babu

Course code - P443, P444

SCHOOL OF PHYSICAL SCIENCES

NATIONAL INSTITUTE OF SCIENCE EDUCATION AND RESEARCH BHUBANESWAR

2022

Abstract

Light is the visible part of the electromagnetic wave spectrum. Similarly, Microwave is also a part of electromagnetic wave spectrum. Previously we have verified so much property of light such as reflection, refraction, polarization and so many. This experiment will verify whether those property will be applicable for microwave range or what changes can be made to the setup to behave microwave of similar kind. This report is based on the theoretical aspects of the experiments by giving qualitative approach to the experiments which will be performed physically afterward in the lab.

Contents

List of Figures

Chapter 1

Introduction

Light is the visible part of the electromagnetic wave spectrum. Similarly Microwave is also a part of electromagnetic wave spectrum. We have studied different properties of light earlier such as reflection, refraction, diffraction, interference etc. Now we are going to examine those properties for microwave. Does the same property works or is there any other deviation can be seen?

1.1 Gunn Diode and Microwave Production

A Gunn diode is a passive semiconductor device with two terminals, which composes of only an n-doped semiconductor material. Mainly GaAs, InP are used for the fabrication. Gunn diodes is a 3 layer device in which a lightly doped n-type semiconductor is placed between two highly doped materials as shown in the Fig.1.1.

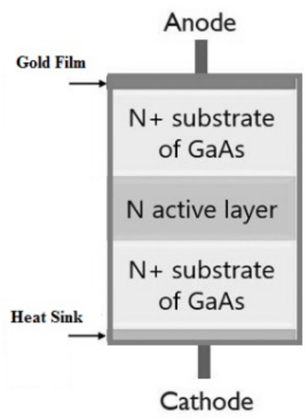


Figure 1.1: Gunn Diode construction

1.1.1 Gunn diode working Principle

The working principle of a Gunn diode mainly depends on the Gunn Effect. In some materials like InP and GaAs, once a threshold level is attained through an electric field within the material, then electrons mobility will decrease concurrently. When the electric field enhances then negative resistance will be generated.

Once the intensity of an electric field for GaAs material reaches its significant value on the negative electrode, then low electron mobility region can be formed. This region moves through the average electrons speed to the +ve electrode. Gunn diode includes a negative resistance region on its IV characteristics as shown in the Fig.1.2. Once the significant value is attained through the negative electrode, then there will be a region through the mobility of low electrons. After that, it will shift to the positive electrode. Once it meets a strong electric field domain through the positive electrode on the negative electrode, then a cyclic type of the region for less electron

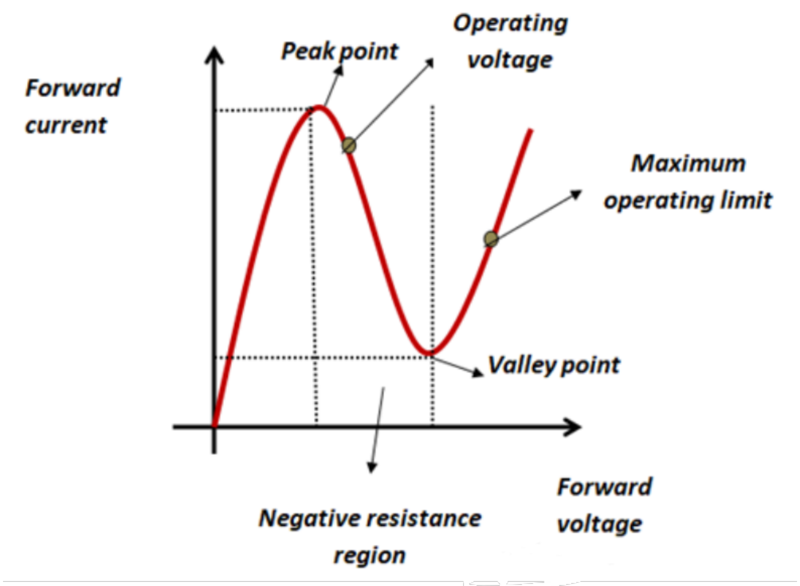


Figure 1.2: IV characteristics of gunn diode

mobility as well as the high electric field will begin to re-create.

The cyclical nature of this incident produces oscillations with microwave frequencies. Once this value exceeds, then oscillations will begin to disappear quickly.

1.2 Antenna

An Antenna is a transducer that provides a transition between electromagnetic field into alternating current or vice versa. There are several types of antenna which are of varied size and strength. Depending upon the required frequency at which the antenna has to be operated, the type of antenna is chosen. An antenna can usually handle this transition in both direction(i.e. transmitting and receiving E.M waves). This property of antenna is known as reciprocity.

An isotropic antenna radiates equally in all directions and it is considered to be 100% efficient. Most of the properties of an antenna is described with respect to the properties of an isotropic antenna. It is often easier to calculate the properties of transmitting antennas and to measure the properties of receiving antennas.

1.2.1 Field Region

The field surrounding an antenna are divide into 3 primary regions.

- **Reactive Near Fields:** In the immediate vicinity of the antenna, we have the reactive near field. In this region, E-fields and H-fields are out of phase by 90 degrees to each other.
- **Radiative Near Fields:** The far field is the region far from the antenna.The further away from the antenna the observation point is, the antenna looks like a point source. In this region, the radiation pattern does not change shape with distance(R).

However, the Electric and Magnetic fields die off as 1/R, and thus the power dies off as $1/R^2$.

- **Far Field:** This is the region between the near and far fields. The shape of radiation pattern may vary appreciably with distance.

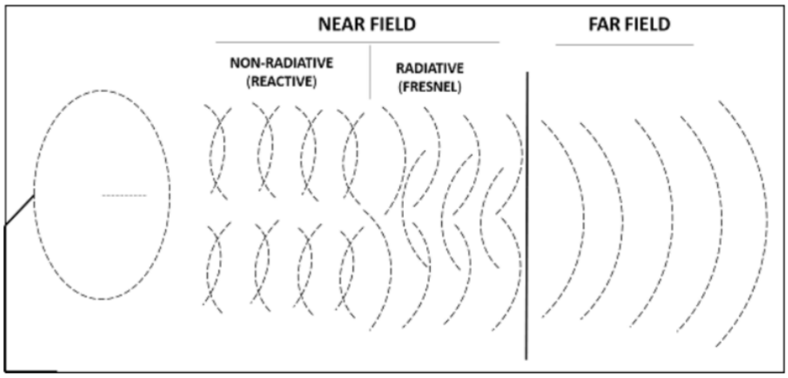


Figure 1.3: Field region

1.2.2 Imepdence Matching

Impedance matching is considered when the approximate value of impedance of a transmitter is equal to the approximate value of the impedance of a receiver. The antenna must be impedance matched when assembled for the end-user environment so that it operates in the desired frequency band with maximum efficiency. A resonant devices give better output at certain narrow band of frequencies. If antenna impedance matches with the free space impedance, the power radiated by an antenna will be effectively radiated. If the impedance is not matched, the signal reached the load and reflect back to the source. It will produce a standing wave.

1.3 Waveguide

Waveguides are used to transfer electromagnetic power efficiently from one point in space to another. They are hollow metal tubes.They are capable of directing power precisely to where it is needed, can handle large amounts of power and function as a high-pass filter. The waveguides are of varied structures. Since this experiment is focused on rectangular waveguides, more of rectangular waveguide is discussed further.

Rectangular waveguides has length "a" in the x-direction and width "b" in the y-direction with a > b. The z-axis is in the direction in which the waveguide carry power. A diagram of a waveguide is shown in the Fig:1.4. At the conducting walls, the parallel component of any electric field inside the waveguide must be zero.

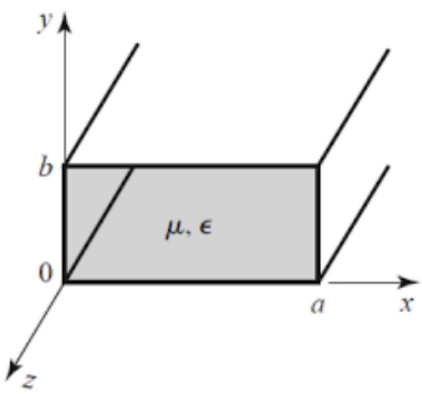


Figure 1.4: Dimensions of waveguide

Depending upon the longitudinal component of the electric field or magnetic field rectangular waveguide can be operated in two different modes i.e., Transverse Electric (TE), Transverse Magnetic (TM) mode. TE mode indicates that the Electric field is orthogonal to the axis of the waveguide, that is $E_z = 0$. The TM mode indicates that the Magnetic field is orthogonal to the axis of the waveguide, that is $H_z = 0$. The modes can be further classified as TE_{ij} , where i and j indicate the number of wave oscillations for a particular field along the length (a) and along the width (b). The field pattern are shown in the Fig:1.5. The TE modes of a parallel plate waveguide are preserved if perfectly conducting walls are added perpendicularly to the electric field. As our experiments will be done with TE mode, TE mode are studied in

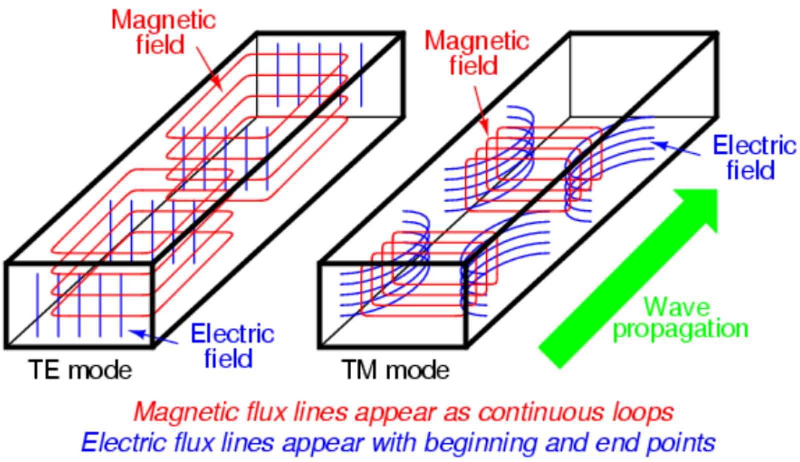


Figure 1.5: Field pattern of different mode in rectangular waveguide

details. By solving the Maxwell's equation by applying the boundary conditions for TE mode, we get,

$$H_z(x, y, z) = H_0 \cos(k_x x) \sin(k_y y) e^{-ik_z z} \tag{1.1}$$

where k_i are wave number along the i-axis and $k_x = m\pi/a$ and $k_y = n\pi/b$. And the relation between these k_i is

$$k_x^2 + k_y^2 + k_z^2 = k^2 = \omega^2 \mu \epsilon = \omega^2/c^2 \tag{1.2}$$

For propagation to occur, the wavenumber along z-axis (k_z) has to be real. This can lead to a constraint on eq.1.2. Thus we obtain the cut-off frequency for each mode in TE as

$$\omega_{mn}^c = \sqrt{k_x^2 + k_y^2} = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \tag{1.3}$$

Particularly, for rectangular waveguides, the TE_{10} mode has the lowest cutoff frequency and so, called the dominant mode. This implies that at the frequency-band of operation only the dominant mode is propagating, while all higher-order modes are cut-off.

In general, an excitation of the guide at its cross-section excites all possible waveguide modes. The modes with cutoff frequencies higher than the frequency of excitation decay away (evanescent) from the source. Only the dominant mode has a sinusoidal dependence upon distance and thus possesses fields that are periodic in space and dominate the field pattern far away from the source, at distances larger than the transverse dimensions of the waveguide.

If several modes can propagate simultaneously, one has no control over which modes will actually be carrying the transmitted signal. This may cause undue amounts of dispersion, distortion, and erratic operation. Thus, mono-mode operation are usually considered. The mono-mode bandwidth depends on the cut-off frequency of the The TE_{10} mode and the second propagating mode. The TE_{10} has the lowest attenuation of all modes, and thus constitute the cut-off frequency as

$$f_{10}^c = \frac{1}{2a\sqrt{\mu\epsilon}} \tag{1.4}$$

Since the dispersion of the velocity has to be minimised, the operating frequency has to be greater than $1.25 f_{10}^c$.

The impedance of a waveguide can be obtained from the following equation,

$$Z = \frac{\omega\mu}{k_z} \tag{1.5}$$

The guide wavelength can be obtained if the cut-off frequency is known. The guide wavelength λ_g is

$$\lambda_g = \frac{\lambda}{\sqrt{1 - (\lambda/\lambda_c)^2}} \tag{1.6}$$

where λ_c is the cut-off wavelength.

1.4 Horn Antenna

The practical way to increase the directivity is to flare out its ends into a horn. Horn antenna is most widely used simplest form of microwave antenna which comes from the aperture antenna family. The typical waveguide had an input impedance of 50Ω. And the free space has an impedance of 377Ω. As signal passes from waveguide to vacuum, the sudden transition cause signals to be reflected back to the waveguide as standing waves. To overcome this issue, the waveguide can be tapered out or flared like the horn. This has the effect of providing a gradual transition from the impedance of the waveguide to that of free space.

There are three types of horns: the H-plane sectoral horn in which the long side of the waveguide (the a-side) is flared, the E-plane sectoral horn in which the short side is flared, and the pyramidal horn in which both sides are flared. Since we require an antenna with higher directivity, horn antenna are usually preferred because of their large dimensions.

The gain of horn antenna is calculated using

$$G_0 = \frac{4\pi AB\epsilon_A}{\lambda^2} \tag{1.7}$$

When Polar plot of far-field radiation of horn antenna is analysed, the following can be observed from Fig.1.7. The main beam is the region around the direction of maximum radiation. The sidelobes are smaller beams that are away from the main beam. These

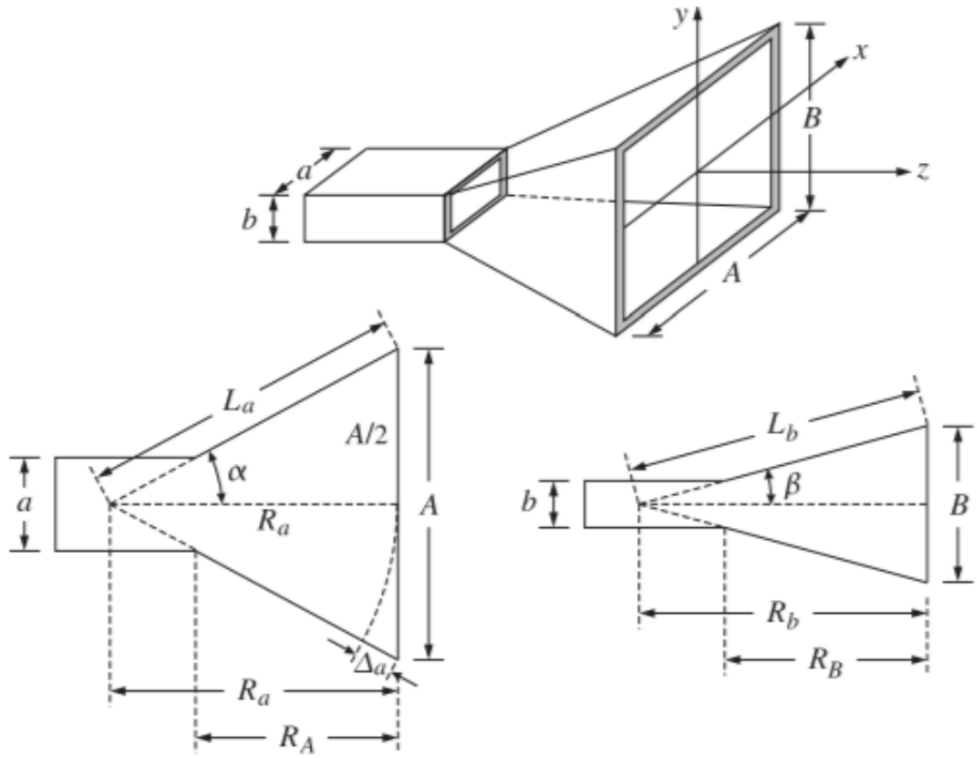


Figure 1.6: Geometrical description of horn antenna

sidelobes are usually radiation in undesired directions which can never be completely eliminated. The Half Power Beamwidth (HPBW) is the angular separation in which the magnitude of the radiation pattern decrease by 50% from the peak of the main beam. The Null Beamwidth is the angular separation from which the magnitude of the radiation pattern decreases to zero away from the main beam.

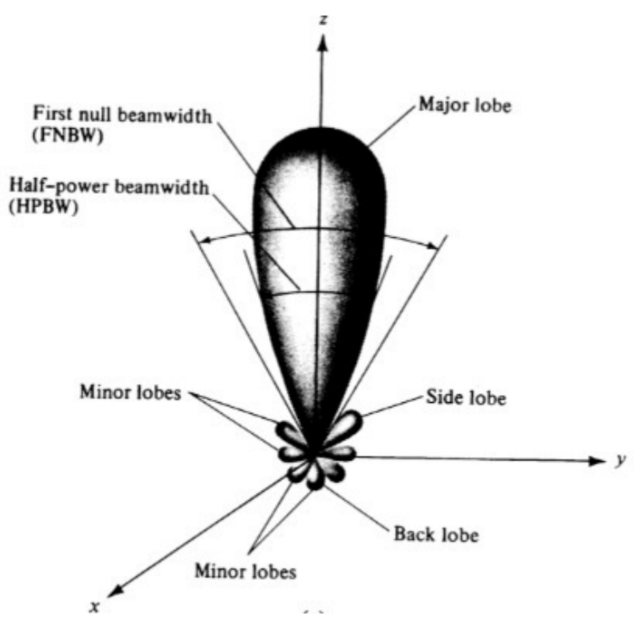


Figure 1.7: Radiation pattern of horn antenna

1.5 Feed antenna

To receive the signal ground-plane vertical antennas are placed inside the horn close to the end of the waveguide. This antenna converts electromagnetic waves in the waveguide to currents. A ground-plane vertical antenna is just half of the dipole above the conducting plane as shown in the Fig.1.8. The mirror-like conducting plane creates the lower half of the dipole as mirror image of upper half. Since both the half are symmetrical, the virtual electric field produced by the lower half have same magnitude as the electric field in the upper half, but are 180 degrees out of phase. The antenna has a height of $\lambda/4$ and is at a distance of about 1/4 of guide wavelength λ_g from the closed end of the waveguide.

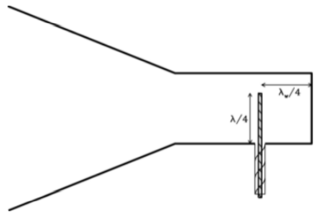


Figure 1.8: The feed antenna inside the horn

1.6 Feko simulation

Feko is a computational electromagnetics software developed by Altair Engineering. It has the capability for calculating the gain, directivity, loss, total power radiated, smith charts, polar graphs, Cartesian graphs which can be used to analyse and optimise the antenna design. The FEKO used the source method to solve the Maxwell equation for the antenna. The surface of the antenna is divided into several segments (descretisation) and the integral form of Maxwell equation is solved. Feko uses Method of Moments (MOM) for solving horn antenna.

1.6.1 Dimensions

The feko simulation is done for the antenna which is in our lab has the following dimension:

- Waveguide has a=2.5cm, b = 1.2cm and h = 25cm.
- Horn has A = 9.7cm, B = 7.5cm and R = 10cm.

1.6.2 Observation

Using the FEKO solver, Separate mesh were created for near field and far field simulations for 10GHz frequency. Current via the waveguide was also implemented to study the flow of electric field current through surface of the antenna. Using post-feko all the features of the designed antenna were studied.

Surface Current

The simulation of current via the surface was used to study the regions of nodes present in electric field. By analysing the aperture of the horn antenna, how electric field is propagating on the aperture was able to determine

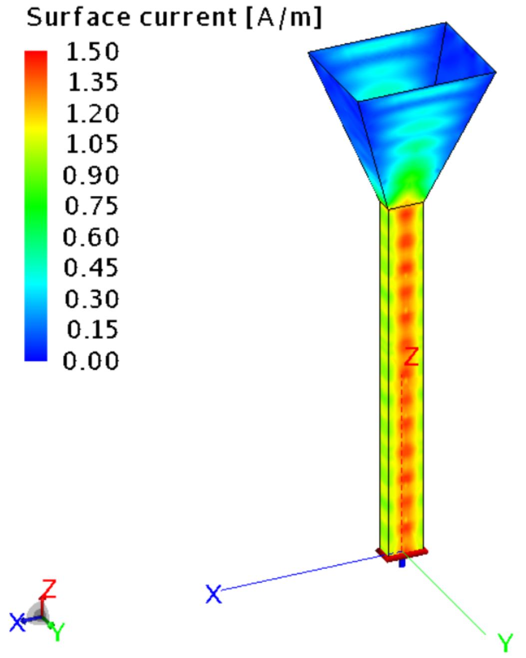
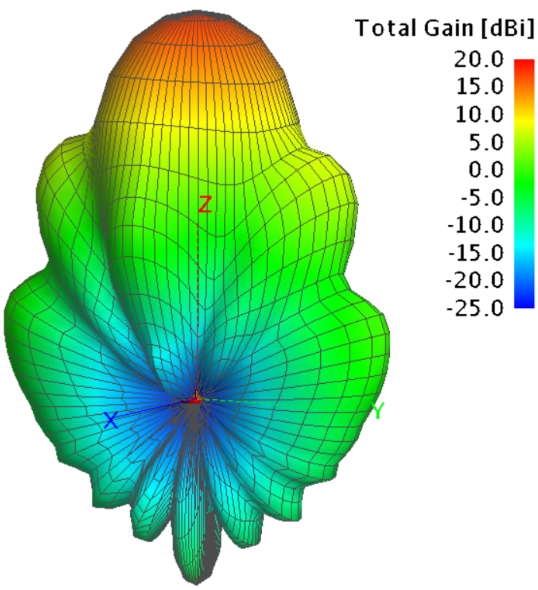


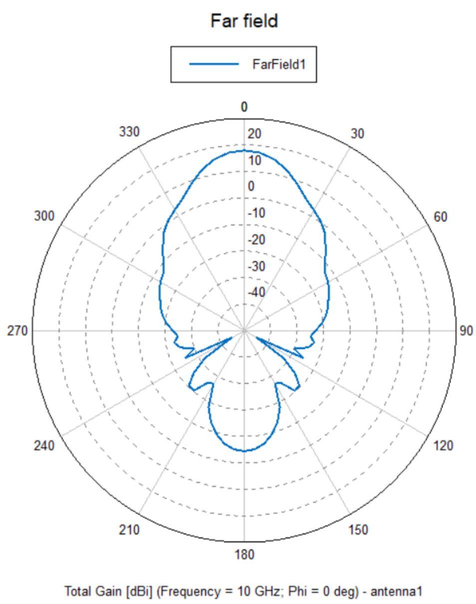
Figure 1.9: The electric current through the surface of waveguide

Far Field

The simulated far field helped to visualise the directivity and expected major lobes and minor lobes.



(a) Far field gain in 3D simulation



(b) The polar plot of far field radiation pattern of horn antenna

Figure 1.10: Far Field simulation

Chapter 2

Experiments

With the concept of waveguide and antenna now we can transmit and receive microwave radiation. By using microwave radiation we are going to verify certain fundamental optics experiments in the microwave setup. This report presents only the theoretical aspects of the experiments to be performed in the lab at a later stage.

2.1 Standing Waves-Measuring Wavelengths

2.1.1 Background

Standing wave are combination of two waves moving in opposite directions, each having the same amplitude and frequency. The phenomenon is the result of interference. So, when waves are superimposed, their energies are either added together to give anti nodes or canceled out to give nodes. The distance between nodes in the standing wave pattern is just half of the wavelength (λ) of the two waves.

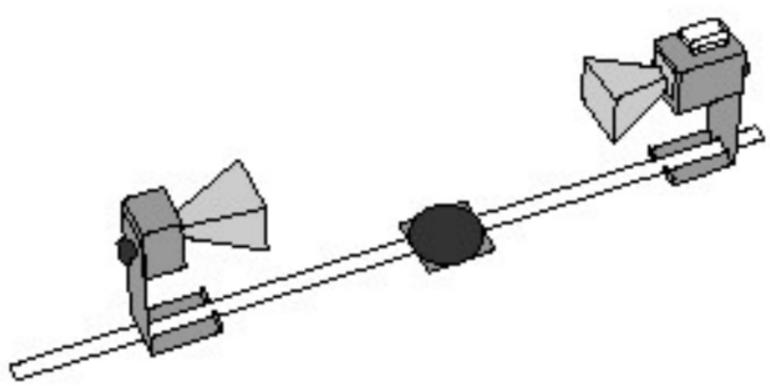


Figure 2.1: Setup for standing waves-measuring wavelength experiment

2.1.2 Approach

- In this set up both transmitter and receiver are kept face to face as in the Fig.2.1. The receiver is not a perfect collector, it reflects some of the microwaves back to the transmitter. That forms a standing wave. the radiation from the Transmitter reflects back and forth between the Transmitter and Reflector horns.

- If the distance between the Transmitter and Receiver diodes is equal to $n\lambda/2$, (where n is an integer) then at the multiply-reflected waves entering the Receiver horn will be in phase with the primary transmitted wave. This results a maximum reading in the meter.
- If we can identify the nth maximum at x_1 distance between them and mth maximum at x_2 distance between them, then the wavelength can be calculated as following:

$$\lambda = 2\left(\frac{x_2 - x_1}{m - n}\right) \tag{2.1}$$

2.1.3 Data Analysis

Table 2.1: Standing wave experiment

Sl. No	Receiver Positions (cm)
1	14.4
2	15.7
3	17.2
4	18.6
5	19.9
6	21.4
7	22.8
8	24.4
9	26
10	27.3
11	28.8
12	30.1
13	31.6
14	32.9
15	34.5

The value of $\lambda/2$ is found to be 1.4414 cm. Therefore, the wavelength of the microwave is found to be 2.8828 cm. As we know v = fλ, where v is the velocity of microwave in air ($3 \times 10^8 m/s$) and f is the frequency of microwave. Therefore, frequency can be calculated as

$$\begin{aligned} f = \frac{v}{\lambda} = \frac{3 \times 10^{10} cm/s}{2.8828 cm} \\ = 1.041 \times 10^{10} Hz = 1.041 GHz. \end{aligned} \tag{2.2}$$

2.2 Reflection

2.2.1 Background

When electromagnetic waves impinge on a surface, different interactions may result: Part of the radiation will be reflected, transmitted, and absorbed (energy will be transferred to

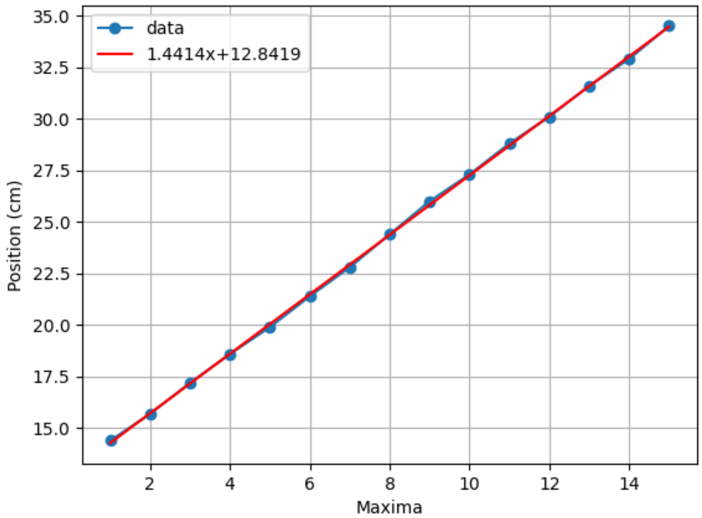


Figure 2.2: Position of receiver at relative maxima while measuring the wavelength of standing wave produced by the microwave antenna

the material). The reflection follows the law of reflection (angle of incidence = angle of reflection). Metal act as reflector for microwave.

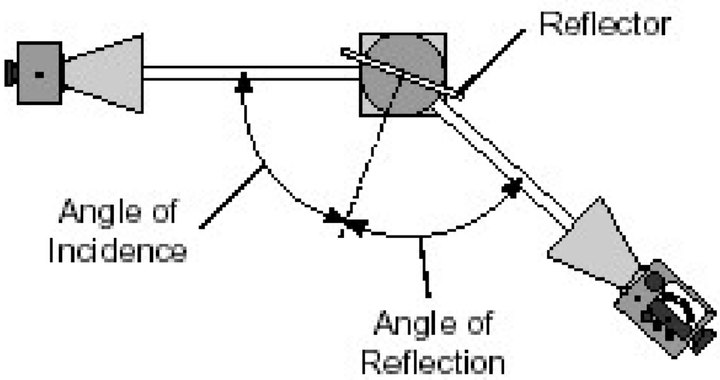


Figure 2.3: Setup for reflection experiment

2.2.2 Approach

- The angle between the incident wave from the Transmitter and a line normal to the plane of the Reflector is called the Angle of Incidence.
- Without moving the Transmitter or the Reflector, rotate the movable arm of the Goniometer until the meter reading is a maximum. Now, the angle between the axis of the Receiver horn and a line normal to the plane of the Reflector is called the angle of reflection.
- There is some chances of direct reading of microwave from the transmitter after some angle this error can be minimized by increasing the directivity of the horn

antenna or can be eradicated by subtracting the direct reading (reading taken without keeping the reflector). With this we can find the relation between angle of incidence and reflection.

2.3 Polarization

2.3.1 Background

The microwave radiation from the Transmitter is linearly polarized along the Transmitter diode axis (i.e., as the radiation propagates through space, its electric field remains aligned with the axis of the diode). If the receiver diode were at an angle θ to the Transmitter diode, it would only detect the component of the incident electric field that was aligned along its axis as shown in the Fig.2.4.

When a polarizer is kept in between the transmitter and receiver the field component along the direction of metal bar will be absorbed by the free electron on the metal surface, however the field component perpendicular to the metal bar will be transmitted through the polarizer.

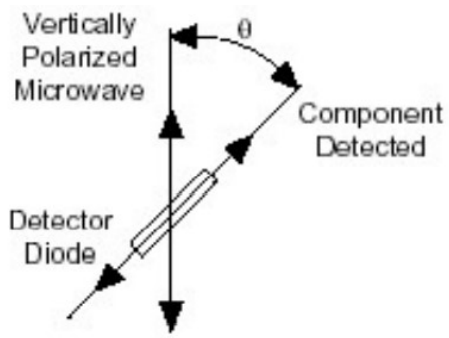


Figure 2.4: Detection of components polarization

2.3.2 Approach

- First without placing the polarizer the data should be taken for various receiver angle.
- The same procedure should be done after putting the polarizer in between to verify the Malu's law:

$$I = I_0 \cos^2(\theta) \tag{2.3}$$

where I is the intensity of the wave at various polarizer angle (θ) and I_0 is the maximum intensity.

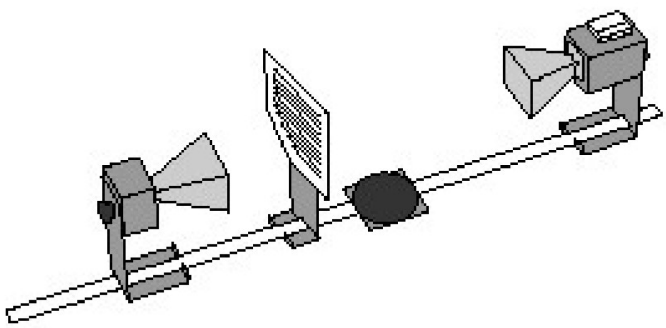


Figure 2.5: Set up with polarizer

2.3.3 Data Analysis

Table 2.2: Polarization

Polarizer angle(deg)	Amplitude (mV)
0	410
10	396
20	352
30	292
40	204
50	140
60	76
70	34
80	8
90	0
100	8
110	33
120	72
130	128
140	192
150	248
160	298
170	340
180	374
190	350
200	312
210	254
220	192
230	126
240	74
250	33
260	9
270	1
280	9
290	36
300	81
310	152
320	226
330	290
340	364
350	400
360	408

The curve best fits with the function $a\cos^2(bx+c)+d$ and comes out to be -390.19cos^2(-1.01x-171.17)+374.16. The absolute value of 'b' is 1.01 which shows that polarization is proportional to $\cos^2(1.01x)$ and rest parameters are there due to the adjustments in the instruments.

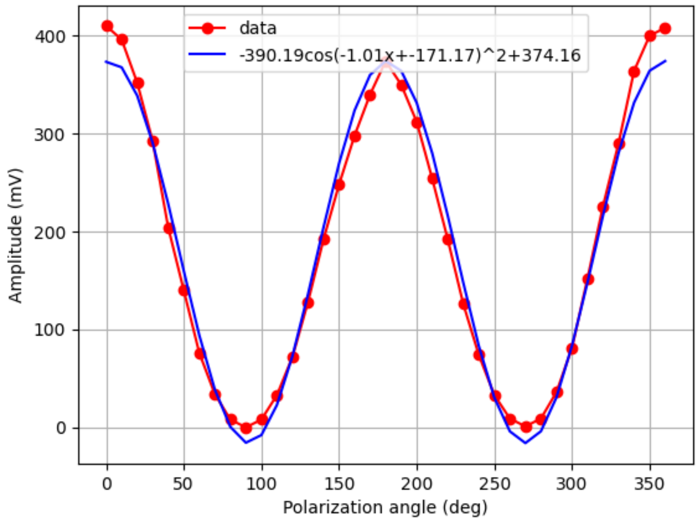


Figure 2.6: Polarization

2.4 Double-slit Interference

2.4.1 Background

When an electromagnetic wave passes through a two-slit aperture. The wave diffracts into two waves which superpose in the space beyond the apertures. Similar to the standing wave pattern, there are points in space where maxima are formed and others where minima are formed. With a double slit aperture, the intensity of the wave beyond the aperture will vary depending on the angle of detection. For two thin slits separated by a distance d, maxima will be found at angles such that

$$d \sin\theta = n\lambda \tag{2.4}$$

where d is the slit width, θ is the angle of detection, λ is the wavelength of incident radiation and n is a integer.

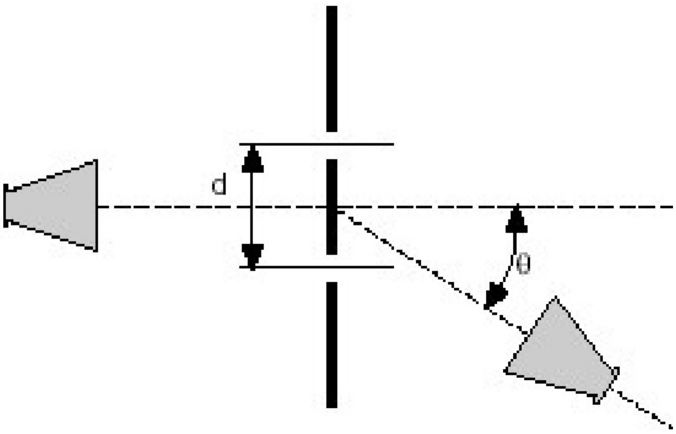


Figure 2.7: Set up for double slit interference

2.4.2 Approach

- Adjust the Transmitter and Receiver for vertical polarization (0°) and adjust the Receiver controls to give a full-scale reading at the lowest possible amplification.
- Find the maximum position of the receiver and then change the angle of the receiver and record the meter reading. By this we can verify the Eq.2.4.

2.4.3 Data Analysis

Table 2.3: slit width = 1.4cm,distance of receiver from the slit = 22 and d=4.1cm

Sl.No.	Angle(deg)	Amplitude(mV)
1	5	1
2	10	3
3	15	5
4	20	11
5	25	32
6	30	74
7	35	122
8	40	208
9	45	284
10	50	372
11	55	304
12	60	216
13	65	50
14	68	2
15	70	36
16	75	168
17	80	540
18	85	864
19	90	952
20	95	848
21	100	620
22	105	528
23	110	200
24	115	52
25	120	4
26	125	78
27	130	174
28	135	294
29	140	252
30	145	212
31	150	146
32	155	72
33	160	38
34	165	18
35	170	11

36	175	4

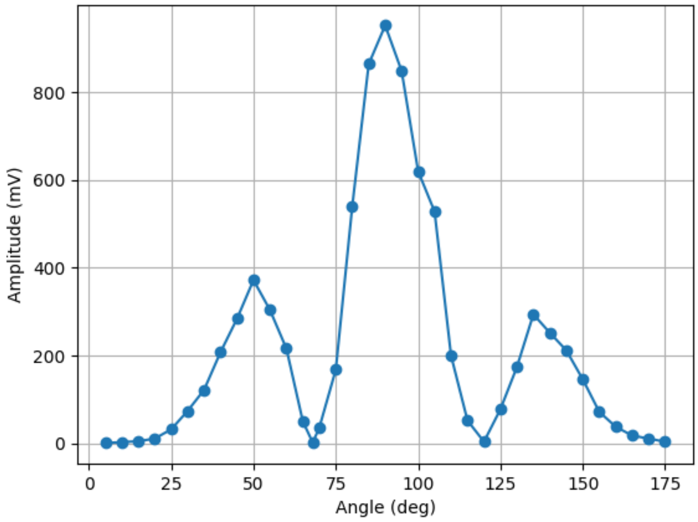


Figure 2.8: Intensity vs angle in double slit interference

2.5 Fabry-Perot Interference

2.5.1 Background

When an electromagnetic wave encounters a partial reflector, part of the wave reflects and part of the wave transmits through the partial reflector. A Fabry-Perot Interferometer consists of two parallel partial reflectors positioned between a wave source and a detector. The wave from the source reflects back and forth between the two partial reflectors. However, with each pass, some of the radiation passes through to the detector.

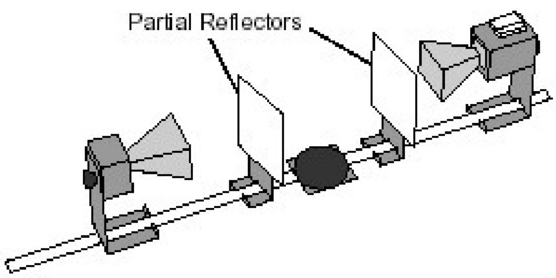


Figure 2.9: Set up for Fabry-Perot experiment

If the distance between the partial reflectors is equal to nλ/2, where λ is the wavelength of the radiation and n is an integer, then all the waves passing through to the detector at any instant will be in phase. In this case, a maximum signal will be detected by the Receiver. If the distance between the partial reflectors is not a integer multiple of λ/2, then some degree of destructive interference will occur, and the signal will not be a maximum. If the nth maxima is found at a distance x_1 and mth maxima at a distance x_2 then the wavelength will be

$$\lambda = 2\left(\frac{x_2 - x_1}{m - n}\right) \tag{2.5}$$

2.5.2 Data Analysis

Table 2.4: Fabry-parot interferometer

Sl. No.	d2(cm)	Amplitude(mV)
1	7.2	368
2	8.6	356
3	10.1	356
4	11.4	332
5	12.7	384
6	14.1	392
7	15.5	400
8	16.9	368
9	18.2	380
10	19.7	348
11	21	356
12	22.3	371
13	23.6	384
14	24.9	344
15	26.3	372
16	27.6	361

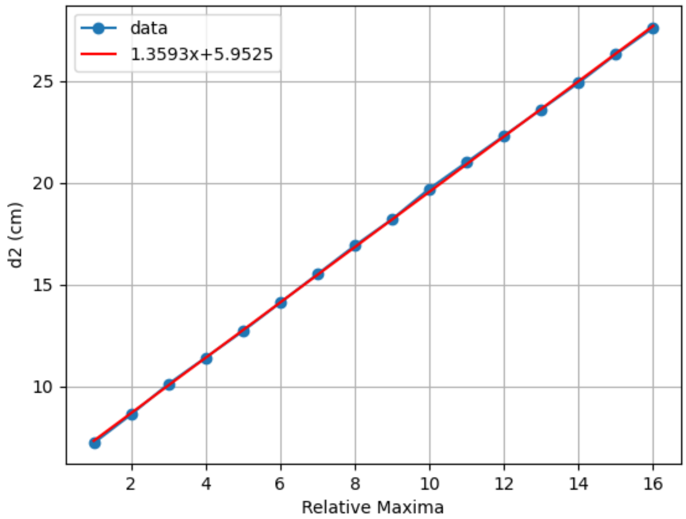


Figure 2.10: Reflector position at relative maxima

The slope of the graph gives the value $\lambda/2$. Therefore, slope = 1.359 cm. So, $\lambda = 2.718cm$.

2.6 Michelson Interferometer

2.6.1 Background

Michelson interferometer splits a single wave, then brings the constituent waves back together so that they superpose, forming an interferometer. A and B are Reflectors and C is a Partial Reflector(Beam Splitter) as shown in the Fig2.11.

Microwaves travel from the Transmitter to the Receiver over two different paths. In one path, the wave passes directly through C, reflects back to C from A, and then is reflected from C into the Receiver. In the other path, the wave reflect from C towards B, then again reflects back to C from B, and then back through C into the Receiver. If the two waves are in phase when they reach the Receiver, a maximum signal is detected. Since each wave passes twice between a screen and the partial reflector, moving the reflector A by a distance $\lambda/2$ will cause a complete 360° change in the phase of one wave at the receiver. This causes the meter reading to pass through a minimum and return to a maximum. If the nth maxima is found at a distance x_1 and mth maxima at a distance x_2 then the wavelength will be same as eq.2.5.

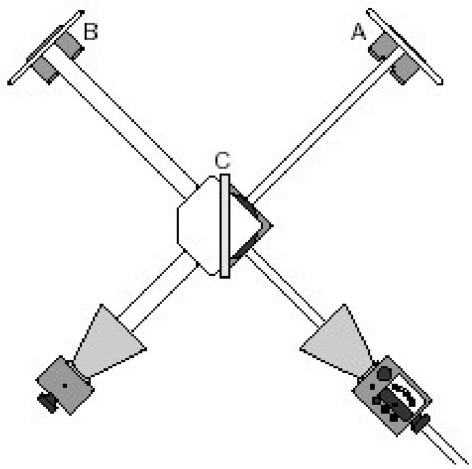


Figure 2.11: Set up for Michelson experiment

2.6.2 Data Analysis

Table 2.5: Michelson interferometer

Sl. No.	Position of reflector(cm)	Position of reflector(cm)	Mean (cm)
1	21.8	21.9	21.85
2	23.2	23.3	23.25
3	24.5	24.6	24.55
4	25.9	25.9	25.9
5	27.3	27.2	27.25
6	28.6	28.6	28.6
7	29.9	29.9	29.9
8	31.3	31.3	31.3
9	32.6	32.6	32.6
10	34	33.9	33.95
11	35.3	35.3	35.3
12	36.7	36.7	36.7
13	38.1	38.1	38.1
14	39.6	39.5	39.55
15	41	39.9	40.45
16	42.3	42.3	42.3
17	43.6	43.6	43.6
18	45	44.9	44.95
19	46.4	46.3	46.35
20	47.8	47.8	47.8

The slope of the graph gives the value $\lambda/2$. Therefore, slope = 1.360 cm. So, $\lambda = 2.720cm$.

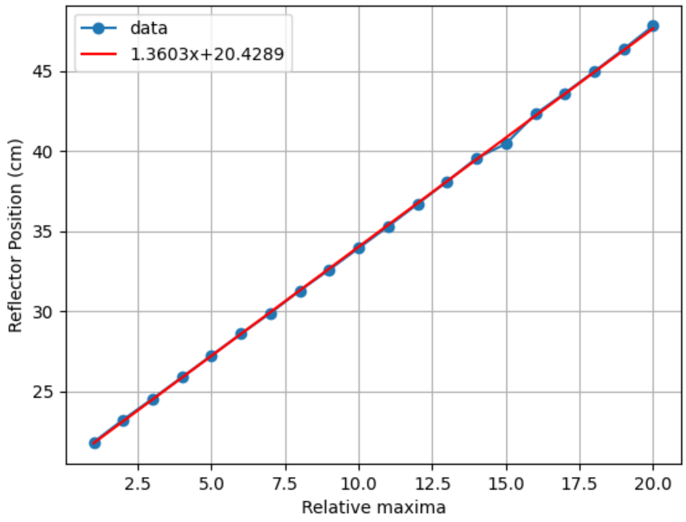


Figure 2.12: Reflector position at relative maxima

2.7 Lyoid's Mirror

2.7.1 Background

An electromagnetic wave from point source A is detected at point C. Some of the electromagnetic wave, of course, propagates directly between point A and C, but some reaches C after being reflected at point B. A maximum signal will be detected when the two waves reach the detector in phase. Assuming that the diagram shows a setup for a maximum signal, another maximum will be found when the Reflector is moved back so the path length of the reflected beam is AB + BC + λ.

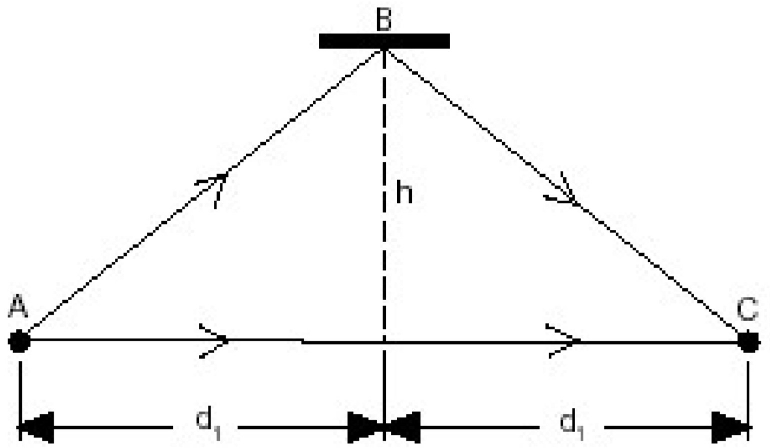


Figure 2.13: Setup for Lyoid's mirror experiment

2.7.2 Approach

2.7.3 Data Analysis

Table 2.6: Lyoid's mirror

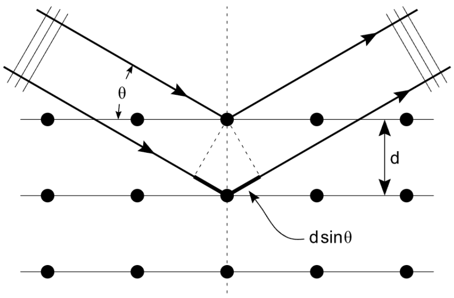
Sl. No.	Position of Reflector at minima(cm)	Wavelength (cm)
1	12.4	2.76
2	17.9	2.84
3	21.9	2.80
4	25.3	2.77
5	27.5	2.60

2.8 Bragg's Diffraction

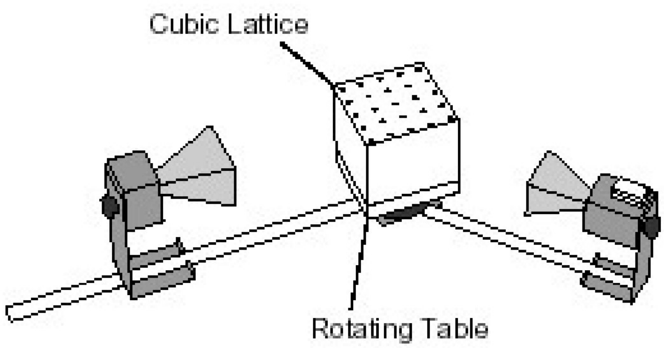
2.8.1 Background

Braggs Law provides a powerful tool for investigating crystal structure by relating the interplanar spacing in the crystal to the scattering angles of incident x-rays. In this experiment, Braggs Law is demonstrated on a macroscopic scale using a cubic crystal consisting of 10-mm metal spheres embedded in an ethafoam cube. Braggs law states that diffraction will occur only when the angle of incidence is equal to the angle of scattering and the path difference is an integer multiple of wavelength as shown in the Fig.2.14a. Mathematically can be represented by

$$n\lambda = 2d \sin\theta \tag{2.6}$$



(a) Demonstration of Bragg law in crystal



(b) Setup for Bragg diffraction experiment

Figure 2.14: Bragg law

2.8.2 Approach

- At first we have to kept the transmitter and receiver in the staright line and then we can place the crystal in between and rotate the crystal to get the maximum reading in the receiver.
- Then for different grazing angle, we can rotate the Goniometer to get the maximum meter reading as to get exact angle of reflection.

- Grazing angle can be changed by rotating thh crystal, we can observe that for every degree of rotation of crystal we have to rotate twice the degree to get the maximum intensity in the receiver.

2.8.3 Data Analysis

Table 2.7: Bragg Diffraction

Plane =100		Plane =110		Fixed crystal at 100 position	
Angle	Voltage(mV)	Angle	Voltage(mV)	Angle	Voltage(mV)
0	116	0	62.4	0	348
1	110	1	62.2	2	304
2	104	2	61.3	4	240
3	96	3	59.2	6	164
4	82	4	50.4	8	96
5	66	5	36.8	10	62
6	52	6	26.4	12	44
7	38	7	15.4	14	35
8	28	8	12.8	16	30
9	20.4	9	10	18	28.8
10	14.4	10	8.6	20	24.8
11	12	11	8.2	22	17.4
12	10.4	12	7.6	24	11.2
13	8	13	6.4	26	5.6
14	4.8	14	5.2	28	3.2
15	1.8	15	3.8	30	4
16	0.2	16	2.2	32	4.8
17	1.5	17	1.8	34	8.8
18	6	18	0.8	36	10.4
19	12.5	19	0.2	38	11.2
20	19.4	20	0.2	40	10.4
21	23.2	21	0	42	9.6
22	25.6	22	0.2	44	4.8
23	25.8	23	0.4	46	1.6
24	26	24	0.6	48	0.24
25	27.4	25	0.4	50	0
26	31	26	0.6	52	0
27	33.4	27	2.2	54	0.2
28	32.2	28	3.8	56	0.2
29	27.2	29	4.2	58	0.8
30	24.2	30	3.8	60	2.6
31	20.2	31	7.2	62	3.6
32	18.4	32	11.4	64	3.8
33	16.6	33	13.8	66	5.4
34	15.8	34	15.4	68	10
35	15.2	35	17.6	70	12.6
36	14.8	36	21.8	72	9.6

37	13.8	37	25.6	74	6.2
38	10.2	38	31.8	76	13.8
39	6.2	39	41.2	78	30.6
40	2.4	40	53.6	80	75.2
41	0.4	41	49.6	82	106
42	0.2	42	48.3	84	124
43	0	43	45.2	86	127
44	0.4	44	37.6	88	114
45	1.8	45	34	90	84.8
46	2.2	46	28	92	57.6
47	2.4	47	22.4	94	28.8
48	3.2	48	16.8	96	10.4
49	0.6	49	14	98	5.6
50	0	50	10.8	100	3.2
51	0.2	51	8	102	2.2
52	0.4	52	6.8	104	0.5
53	0.4	53	4.8	106	0.2
54	0.4	54	4.2	108	0.5
55	0.2	55	3.8	110	2.4
56	0	56	1.2	112	4.6
57	0.2	57	0.6	114	5.3
58	0.6	58	0.6	116	3.5
59	2.4	59	0.2	118	2
60	4.2	60	0.2	120	0.6
61	7.4	61	0	122	0.4
62	11.6	62	0.2	124	0.4
63	21.6	63	0.6	126	0.2
64	29.2	64	0.8	128	0.4
65	41.8	65	0.4	130	1.8
66	48	66	0.2	132	2.4
67	51	67	0	134	3.4
68	51.6	68	0	136	6.4
69	46.6	69	0.2	138	4.6
70	44	70	0	140	4.2
71	43.2	71	0	142	0.6
72	38.4	72	0	144	0.6
73	33.6	73	0	146	0.8
74	28.8	74	0	148	5.8
75	28	75	0	150	11.6

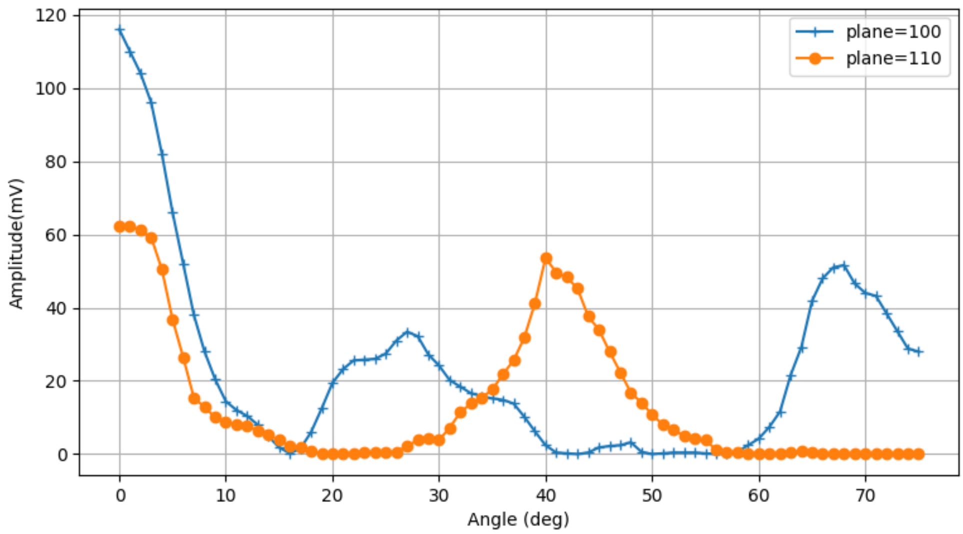


Figure 2.15: Bragg diffraction for 100 and 110 plane

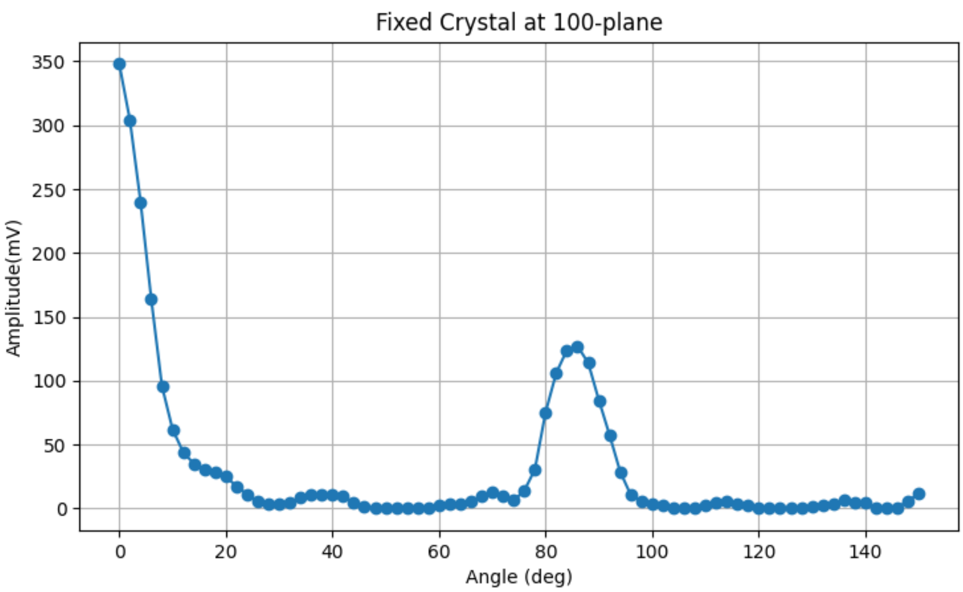


Figure 2.16: Bragg diffraction for fixed crystal position at 100 plane

Chapter 3

Conclusion

This report demonstrates the wave property of microwave in macro scale parameter. At first the wave propagation in the wave guide and antenna were described in brief. The EM field simulation and the surface current were analysed to have the knowledge of wave propagation in the guide. The resulting microwave of 10GHz can now be used to demonstrate the experiments which are already done with visible light. This report theoretically explains that experiments such as reflection, refraction, polarization and many other experiments can be done in laboratory with the Microwave of given 10GHz frequency. Which may give similar property of optics but slight change in instruments is required for higher wavelength as the slit width in double slit experiments and the polarizer dimension. But the results will be more or like similar to visible optics.

Bibliography

[1] *Instruction Manual Antenna and Wave Propagation Trainer*

[2] Gunn Diode. https://www.watelectronics.com/gunn-diode-construction-working-applications/.

[3] "Bragg's law" from wikipedia. https://en.wikipedia.org/wiki/Bragg%27s-law

[4] "Brewster Angle" from wikipedia. https://en.wikipedia.org/wiki/Brewster%27s-angle