Dielectric Properties of different materials by Microwave using Klystron

M.Sc. Physics 3rd Sem Lab Report

by

Hrishit Das

Entry No.: 2024PHS7170

Group - B

Allotment Date: July 29, 2025

Experiment No.: 10

Submitted to: Prof. Saswata Bhattacharya

M.Sc. Physics Laboratory, Dept. of Physics

INDIAN INSTITUTE OF TECHNOLOGY DELHI

IIT Delhi, Hauz Khas, Delhi, 110016, India

Date of Submission: August 8, 2025

Aim:

① Experiment 1 : study of the characteristics of klystron Tube and to determine its electronic tunning range.

② Experiment 2 : To determine the frequency & wavelength in a rectangular wave-guide working on TE_{10} mode

③ Experiment 3: To measure the dielectric constant of different materials using Klystron.

Apparatus Required:

(i) Microwave source, Klystron power supply
(ii) Klystron tube with Klystron mount.
(iii) Isolator,
(iv) Frequency meter, variable attenuator, detector mount, wave guide stand
(v) VSWR Meter and DSO
(vi) Tunable probe, connecting cables (BNC cables).

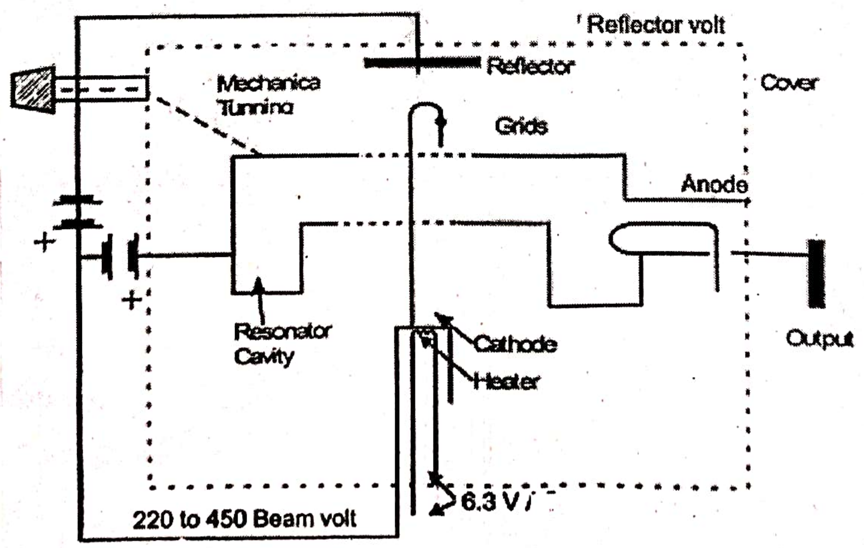


Fig.1 Schematic Diagram of Klystron 2K25

Experiment 1:

To study the characteristics of the Reflex Klystron Tube and to determine its electronic tunning range.

Theory:

The Reflex klystron makes the use of velocity modulation to transform a continuous electron beam into microwave power. Electrons emitted from the cathode are accelarated and passed through the positive resonator towards negative reflector, which retards and finally, reflects the electrons and the electrons turn back through the resonator. Suppose an RF-field exists between the resonators the electrom travelling forward will be accelarated, or retarded, as the voltage at the resonator changes in amplitude. The accelarated electrons leave the resonator at an increased velocity and the retarded electrons leave at the reduced velocity. The electrons leaving the resonator will be needed different time to ~~run~~ return, due to change in velocities. As a result, returning electrons group together in bunches, as the electron bunches pass through resonator, they interact with voltage at resonator grids. If the bunches pass the grid at such a time that the electrons are slowed down by the voltage then energy will be delivered to the resonator; and klystron will oscillate. Fig. 2 shows the relationship between output power, frequency and reflector voltages.

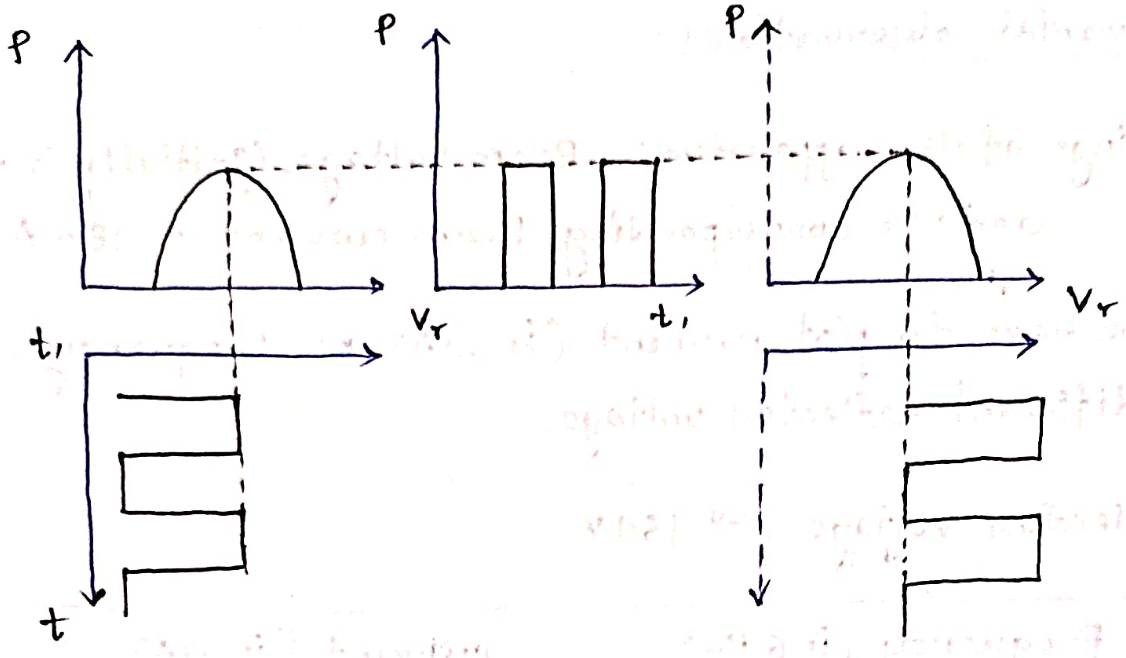


Fig.2 square wave modulation of Klystron.

The frequency is primarily determined by the dimensions of resonant cavity. Hence, by changing the volume of resonator, mechanical tunning of klystron is possible. Also, a small frequency change can be obtained by adjusting the reflector voltage. This is called Electronic Tunning

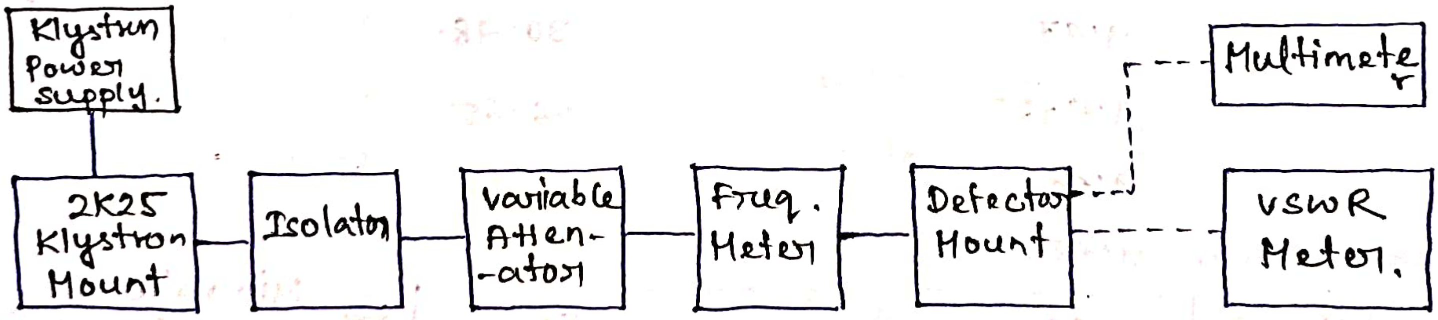


Fig.3 setup for study of klystron tube.

Freq

Experimental observation :

(*) Settings of the apparatus : . Beam voltage (Initially) = 300V.
and the corresponding Beam current = 18mA.

(*) Now we have to plot current (in μA) vs Frequency (in GHz)
for different reflector voltage

(i) Reflector voltage, = 164V.

Frequency (in GHz)	current (in μA)
9.4	47.20
9.42	46.96
9.44	45.60
9.445	42.42
9.455	42.02
9.46	38.63
9.465	34.05
9.47	30.48
9.475	26.65
9.48	15.68
9.485	14.65
9.49	8.26
9.495	10.75
9.5	17.85
9.505	25.95
9.51	34.62
9.515	36.05
9.52	39.46

→ Min value of current and its corresponding frequency which is being absorbed.

B

Frequency (in GHz)	Current (in μA).
9.525	43.5
9.53	45.05
9.535	48.48.

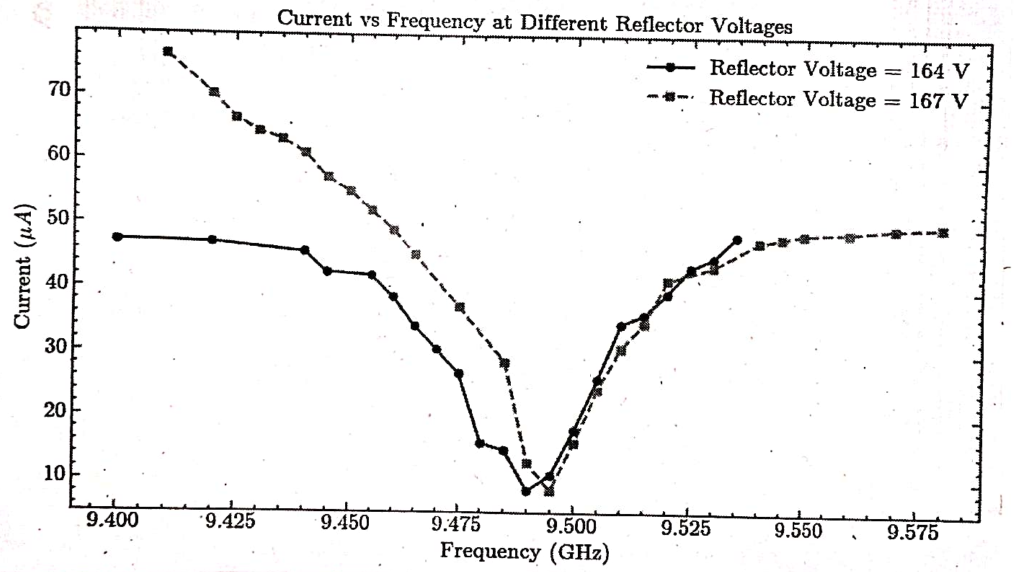
(ii) Reflector voltage, = 167 V.

Frequency (in GHz)	Current (in μA)
9.41	76.3
9.42	70.3
9.425	66.5
9.43	64.5
9.435	63.3
9.44	61.1
9.445	57.3
9.45	55.17
9.455	52.19
9.46	49.13
9.465	45.29
9.475	37.18
9.485	28.45
9.49	12.62
$\boxed{9.495}$	$\boxed{8.31}$
9.5	15.89
9.505	24.22
9.51	30.78
9.515	34.68
9.52	41.48.

Min value of current and its corresponding frequency which is being absorbed.

Frequency (in GHz)	Current (in μA)
9.53	43.68
9.54	47.6
9.545	48.2
9.55	48.9
9.56	49.2
9.57	49.9
9.58	50.2.

Plotting of Data Points:



xperiment 2

To determine the frequency & wavelength in a rectangular waveguide working on TE_{10} Mode.

Theory:

Mode represents in wave guide as either.

TE_{mn} or TM_{mn}

where, TE ≡ Transverse Electric.

TM ≡ Transverse Magnetic

m = Number of half wave length variation in broader direction.

n = Number of half wave length variation in shorter direction.

$$\boxed{\frac{\lambda_g}{2} = (d_1 - d_2)}$$

where, d_1 and d_2 are the distance between two successive minima/maxima. It is having highest cutoff frequency hence dominant mode. for dominant TE_{10} mode in rectangular wave guide λ_0, λ_g and λ_c are related as below.

$$\boxed{\frac{1}{\lambda_0^2} = \frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}}$$

where, λ_0 = free space wavelength.

λ_g = guided wave length.

λ_c = cutoff wavelength.

for TE_{10} mode, $\lambda_c = \frac{2a}{m} = 2a$ [where, m = 1]

and 'a' is the broad dimension of waveguide

Output

Experimental observation:

- Beam Voltage = 300V
- Beam current = 18 mA
- Reflector voltage = − 250V.
- Observed value in the frequency meter = 9.5 GHz.
- Speed of light, $c = 3\times10^8$ m/s.

In this case $a = 22.86$ mm.

Therefore, $\lambda_c = 2a = 2\times 22.86$ mm $= 45.72$ mm

$\Rightarrow \lambda_c = 0.04572$ m.

Table : 1

First minima (d_1)	2nd Minima (d_2)	$\lambda_g = 2(d_2 - d_1)$ λ_g (in m)
11.5	13.91.	0.0472
13.91	16.30	0.0478
16.30	18.50	0.044
18.50	21.05	0.051

Now, the average value of $\lambda_g = 0.0475$ m.

Calculation.

$$\frac{1}{\lambda_0^2} = \frac{1}{\lambda_c^2} + \frac{1}{\lambda_g^2}$$

$\Rightarrow \lambda_0 = 3.29\times10^{-2}$ m. [calculated wavelength]

and the calculated frequency is –

$$f = \frac{c}{\lambda_0} = 9.11\times10^9 \text{ Hz} = 9.11 \text{ GHz}$$

$$\Rightarrow \boxed{f = 9.11 \text{ GHz}}$$

Error:

Percentage Error is $= \left(\frac{9.5-9.11}{9.5}\times100\right)\% = 4.11\%$.

Output in DSO :

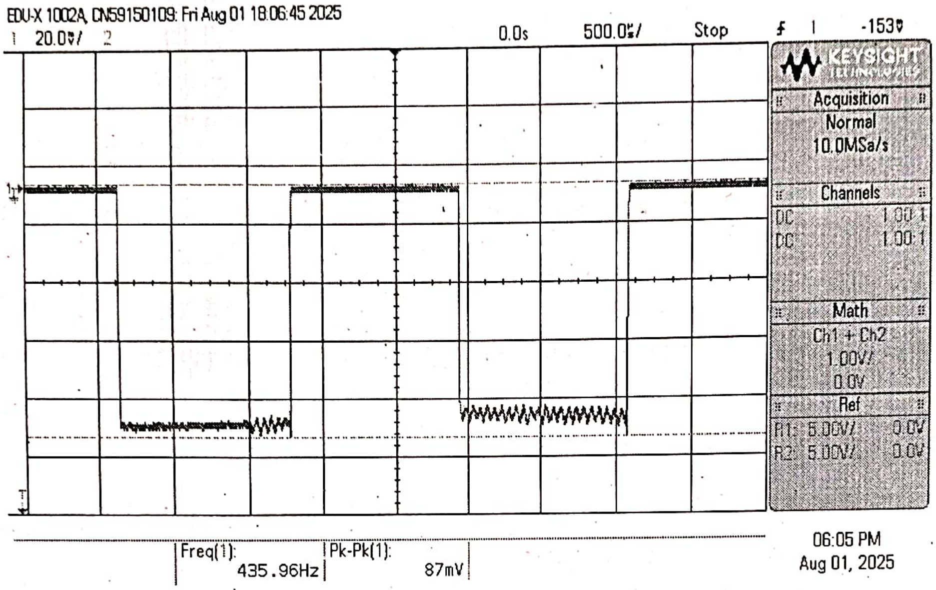


Fig. Tunable probe at distance $d_1 = 11.5$ cm.

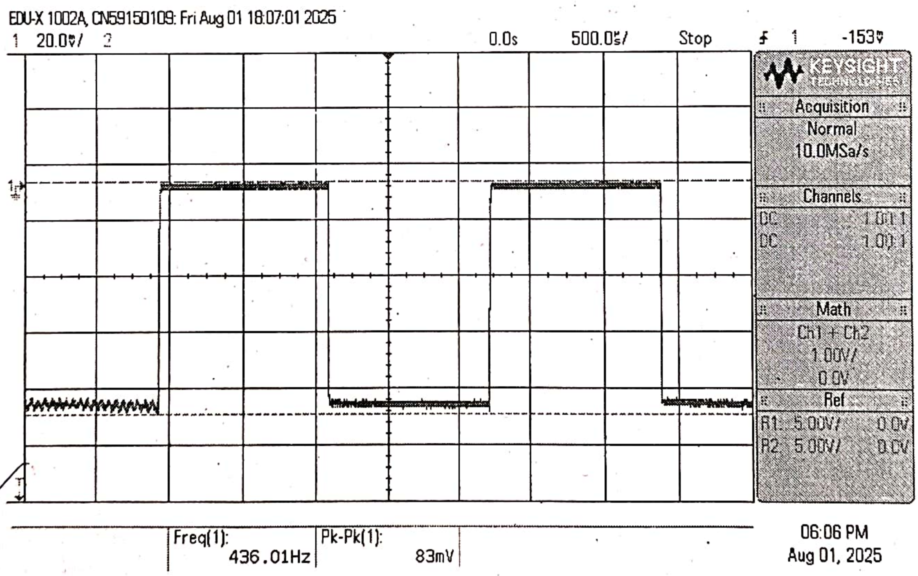


Fig. Tunable probe at distance $d_2 = 13.91$ cm.

Experiment 3

To measure the dielectric constant of different materials using Klystron.

Theory:

Dielectric constant is defined as the ratio of perimitivity of a substance (ϵ) to the permittivity of free space (ϵ_0). It is a measure of how a material is electrically polarized by an externally applied electric field. However, the polarization process also heats up a material, dissipating energy. The real component of dielectric constant measures the polarization response while the imaginary component of dielectric constant measures the energy loss.

$$\epsilon_r = \epsilon_r' - j\epsilon_r'' \quad (j = \sqrt{-1})$$

where, ϵ_r = dielectric constant.

we define the dielectric loss factor or loss tangent as

$$\delta = \frac{\epsilon_r''}{\epsilon_r'}$$

$$\epsilon_r = \epsilon_r' \left(1 - j\frac{\epsilon_r''}{\epsilon_r'}\right)$$

$$\Rightarrow \boxed{\epsilon_r = \epsilon_r' (1 - j\tan\delta)}$$

Now, $\epsilon = \epsilon_r \epsilon_0 = \epsilon_0 (\epsilon_r' - j\epsilon_r'')$

$$\Rightarrow \boxed{\epsilon = \epsilon_0 \epsilon_r' (1 - j\tan\delta)}$$

Several methods are devised for measuring the dielectric constant at microwave frequencies. High frequency electro-magnetic field analyser simulates the electromagnetic phenomena in a structure using the wavelength of the signal of the same order of magnitude or smaller than the dimensions of the model. The method of measurement involves short circuiting the wave guide with a nearly perfectly reflecting surface and peaking the dielectric against the reflecting surface when microwaves travelling through the medium strike the another medium, a part of it is reflected and a part of it gets transmitted. A standing wave pattern is formed in first medium when a wave reflects. A TE mode of oscillaton was used for measurements. i.e. the direction of electric field was maintained perpendicular to the direction of propagation of radiation. The strength of the standing wave is measured by VSWR meter. To generate microwaves, we use klystron tube. For proper transmission of microwaves we ~~use~~ use isolator in the setup.

The sample dielec

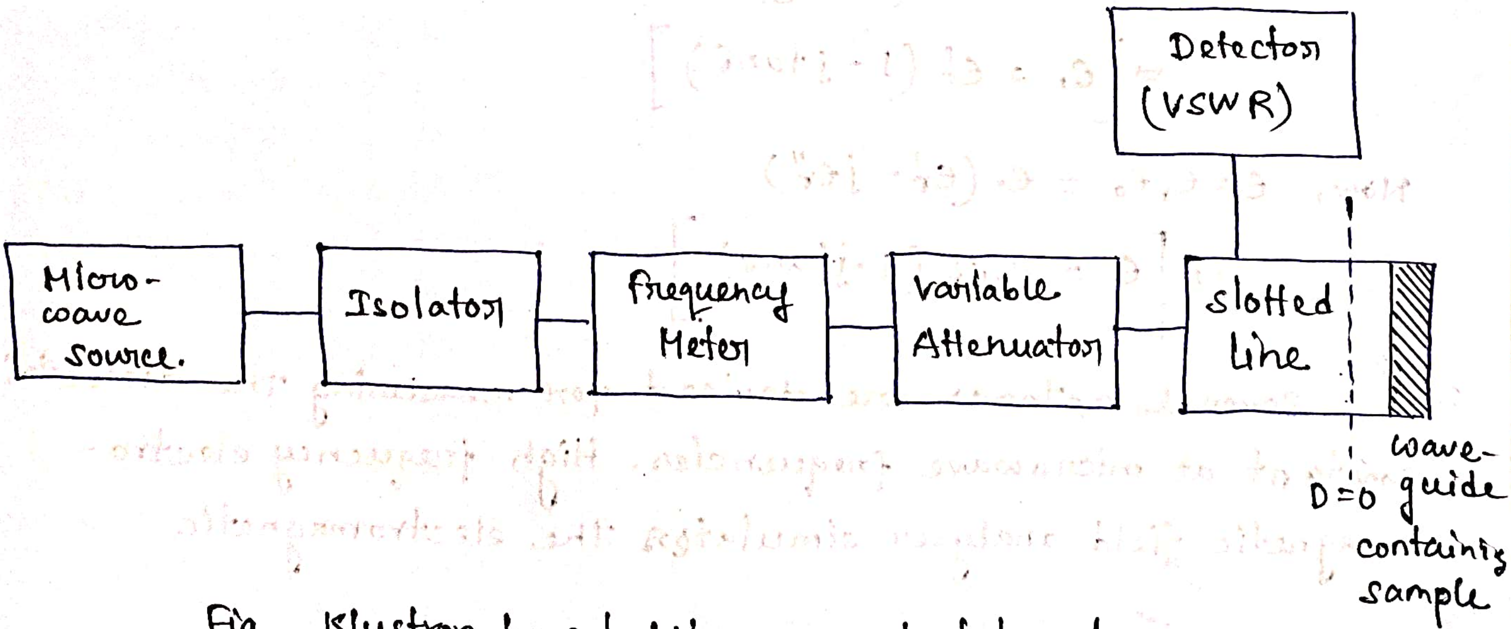


Fig. Klystron based Microwave test bench.

The separation of the first minima from the face of the sample depend upon the wavelength of the wave in the dielectric sample. and the thickness of the sample. The minimum without dielectric is an integral no of half wavelengths. Insertion of dielectric shifts the minima towards termination because the wavelength in the dielectric media is less than in vaccum.

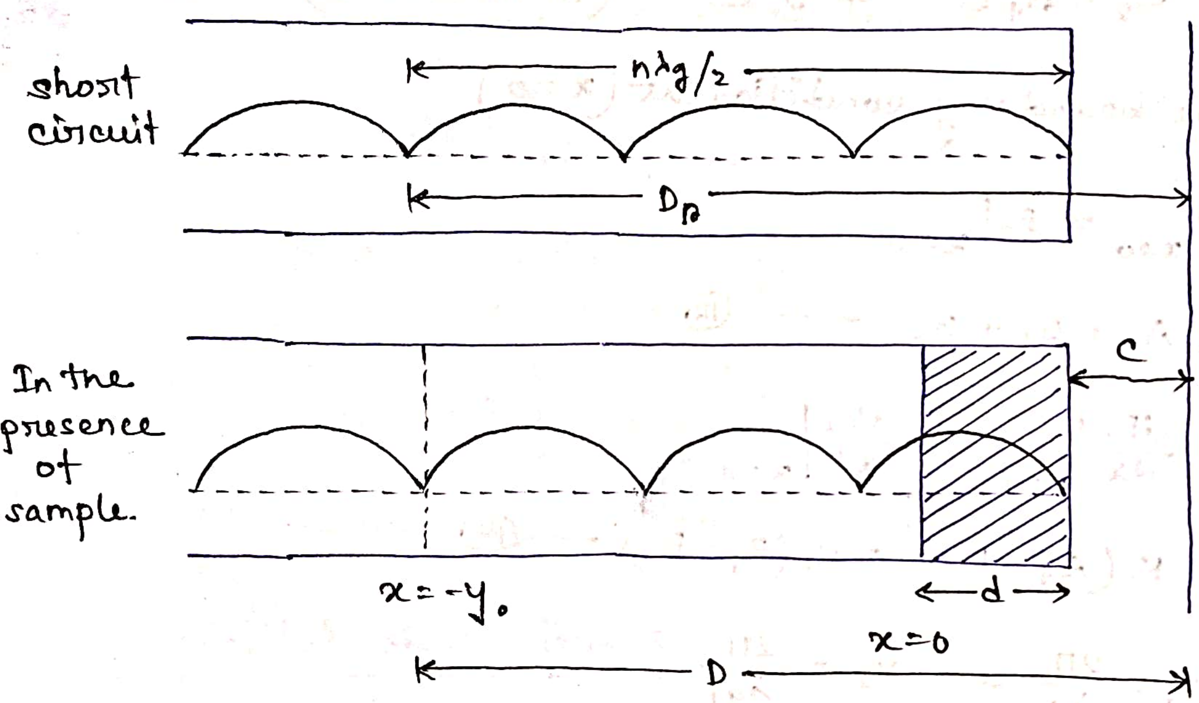


Fig. Resultant electric field inside the waveguide.

$$D_r = C + \frac{n\lambda_g}{2} \quad ; \quad D = C + y_0 + d.$$

where, $\boxed{y_0 = D - D_r - d + \frac{n\lambda_g}{2}}$

D_r = First minima in the short circuit mode

D = First minima in the presence of sample

d = Diameter of the sample.

n = Integer

λ_g = guided wavelength.

Consider an EM wave through medium 1 striking normally at medium 2 (dielectric), a part of it is reflected and the rest gets transmitted. A standing wave pattern is thus produced.

The transverse electric field component in this partial reflection case is given by,

$$E_1 = A_+ e^{jK_1 x} + A_- e^{-jK_1 x} \quad \text{(in medium 1)} \text{ ——— (I)}$$

$$E_2 = B_+ e^{jK_2 x} + B_- e^{-jK_2 x} \quad \text{(in medium 2)} \text{ ——— (II)}$$

applying the boundary condition at $(x=0)$

$$E_1\Big|_{x=0} = E_2\Big|_{x=0}$$

$$\Rightarrow A_+ + A_- = B_+ + B_- \text{ ——— (III)}$$

and,

$$\frac{dE_1}{dx}\Big|_{x=0} = \frac{dE_2}{dx}\Big|_{x=0}$$

$$\Rightarrow K_1(A_+ - A_-) = K_2(B_+ - B_-) \text{ ——— (IV)}$$

where, $K_1 = \frac{2\pi}{\lambda g}$ and $K_2 = \frac{2\pi}{\lambda_{gd}}$

As, $x = -y_0$ in the position of a minima from the interface, electric field at this point is zero.

$$A_+ e^{-jK_1 y_0} + A_- e^{jK_1 y_0} = 0 \text{ ——— (V)}$$

and at $x = d$, $E_2\Big|_{x=d} = 0$

$$\Rightarrow B_+ e^{jK_2 d} + B_- e^{-jK_2 d} = 0 \text{ ——— (VI)}$$

Solving equations (iii), (iv), (v) and (vi) we get,

$$\frac{\tan(K_2 d)}{K_2} = -\frac{\tan(K_1 y_0)}{K_1}$$

Let, $x = K_2 d$

$$\Rightarrow \frac{\tan x}{x} = -\frac{\lambda_g}{2\pi d}\tan\left(\frac{2\pi}{\lambda_g} y_0\right) \quad \text{—— (vii)}$$

Here equation (vii) is the transcendental equation. So, solving graphically, we can calculate x.

The dielectric constant of the medium is given by,

$$\epsilon_r = \frac{K_2^2}{K_1^2} = \frac{\lambda_0^2}{\lambda_{od}^2}$$

and, $$\frac{1}{\lambda_{od}^2} = \left(\frac{1}{\lambda_{gd}^2} + \frac{1}{\lambda_c^2}\right)$$

$$\therefore \epsilon_r = \left[\left(\frac{x}{2\pi d}\right)^2 + \frac{1}{\lambda_c^2}\right]\lambda_0^2 \quad \text{—— (viii)}$$

where λ_c = cut off wavelength.

Experimental observations:

least count = 0.01 cm.

without sample:

No. of Minima.	Total reading (R to L)	distance between two minima.	Total reading (L to R)	distance between two minima.
1	9.04		9.17	
2	11.17	2.13	11.45	2.28
3	13.52	2.35	13.75	2.3
4	15.81	2.29	15.87	2.12
		2.256		2.233

For R to L → Average value   For L to R → Average value.

Now, the average distance between two consecutive minima is 2.245 cm.

$$[d = 2.245 \text{ cm.}]$$

$\therefore$ guided wavelength, $\lambda_g = 2(d_1 - d_2)$

$$= 2d$$

$$\Rightarrow \lambda_g = 2 \times 2.245 \text{ cm}$$

$$\Rightarrow \boxed{\lambda_g = 4.49 \text{ cm}}$$

width of wave guide, $a = 2.286$ cm.

and the cutoff wavelength, $\lambda_c = 2a$

$$\Rightarrow \lambda_c = 2 \times 2.286$$

$$\Rightarrow \boxed{\lambda_c = 4.572 \text{ cm}}$$

Thickness of dielectric sample, $d = 1$ cm.

Therefore the wavelength in vaccum is,

$$\frac{1}{\lambda_0^2} = \frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}$$

$$\Rightarrow \frac{1}{\lambda_0^2} = \frac{1}{(4.49)^2} + \frac{1}{(4.572)^2}$$

$$\Rightarrow \boxed{\lambda_0 = 3.202 \text{ cm.}}$$

- With sample:

(i) Backelite sample.

(ii) Nylon sample.

(iii) Teflon sample.

Backe.

No of mi

Backelite sample!

No of min.	Total Reading. R to L	L to R	distance between two min R to L	L to R
1	8.37	8.33		
2	10.57	10.51	2.2	2.18.

Therefore the average of first minima = 8.35 cm.

$D_1 = 8.35$ cm,

Calculations:

where,
D_r = first min without sample = 9.105 cm
d = thickness of dielectric sample
λ_g = guided wavelength.

$$y_0 = D_r - D_1 + \frac{n\lambda_g}{2} - d.$$

$$= 9.105 - 8.35 + n \cdot \frac{4.49}{2} - 1$$

for, n=1, $\boxed{y_0 = 2\text{cm}}$

$$\frac{\tan K}{K} = -\frac{\lambda g}{2\pi d} \tan\left(\frac{2\pi}{\lambda g} \times y_0\right)$$

$$\Rightarrow \frac{\tan K}{K} = 0.255$$ By solving graphically, we get, $\boxed{K = 3.927}$

$$\epsilon_r = \left[\left(\frac{K}{2\pi d}\right)^2 + \frac{1}{\lambda_c^2}\right] \lambda_0^2$$

$$\Rightarrow \epsilon_r = 4.495 \simeq 4.5$$

$\Rightarrow \boxed{\epsilon_r \simeq 4.5}$ → Dielectric constant of Backelite.

(ii) Nylon sample:

No of min.	Total Reading R to L	Total Reading L to R	Distance between two min. R to L	Distance between two min. L to R
1	8.25	8.17		
2	10.51	10.49	2.26	2.32.

Therefore the average of first minima ⇒ $D_1 = 8.21$ cm

Calculations:

$$y_0 = D_r - D_1 + \frac{n\lambda_g}{2} - d$$

$$= 9.105 - 8.21 + \frac{4.49}{2} - 1$$

$$\Rightarrow \boxed{y_0 = 2.14 \text{ cm}} \quad \text{for, } n = 1$$

$$\frac{\tan K}{K} = -\frac{\lambda_g}{2\pi d} \tan\left(\frac{2\pi}{\lambda_g} \cdot y_0\right)$$

$$\Rightarrow \frac{\tan K}{K} = 0.105$$

By solving graphically, $\boxed{K = 3.493}$

$$\epsilon_r = \left[\left(\frac{K}{2\pi d}\right)^2 + \frac{1}{\lambda_c^2}\right]\lambda_0^2$$

$$\Rightarrow \boxed{\epsilon_r = 3.659}$$

Dielectric constant of Nylon.

Teflon Sample!

No of min	Total Reading R to L	Total Reading L to R	Distance between two min. R to L	Distance between two min. L to R
1	8.49	8.51		
2	10.75	10.61	2.26	2.1

Therefore the average of first minima, $D_1 = 8.5$

Calculations.

$$y_0 = D_r - D_1 + \frac{n\lambda_g}{2} - d$$

$$= 9.105 - 8.5 + \frac{4.49}{2} - 1$$

$$\Rightarrow \boxed{y_0 = 1.85 \text{ cm}} \quad \text{for, } n = 1$$

$$\frac{\tan K}{K} = -\frac{\lambda_g}{2\pi d} \tan\left(\frac{2\pi}{\lambda_g} \cdot y_0\right)$$

$$\Rightarrow \frac{\tan K}{K} = 0.441$$ By solving graphically.

$$\boxed{K = 4.22}$$

Therefore,

$$\epsilon_r = \left[\left(\frac{K}{2\pi d}\right)^2 + \frac{1}{\lambda_c^2}\right] \lambda_0^2$$

$$\Rightarrow \boxed{\epsilon_r = 5.12}$$

Dielectric constant of Teflon.

DSO

Conclusion:

Name of material.	Dielectric constant
Backelite.	4.49
Nylon	3.659
Teflon.	5.12.

Gourav

Error calculations:

(i) For Backelite,

Theoretical $\epsilon_r = 4.9$

Experimental $\epsilon_r = 4.49$

$$\text{Percentage Error} = \frac{4.9 - 4.49}{4.9} \times 100\%$$

$$= 8.37\%.$$

(ii) For Nylon,

Theoretical $\epsilon_r = 3.4$

Experimental, $\epsilon_r = 3.659$

$$\text{Percentage Error.} = \frac{3.659 - 3.4}{3.4} \times 100\%.$$

$$= 7.62\%.$$

(iii) For Teflon,

Theoretical $\epsilon_r = 2.1$

Experimental $\epsilon_r = 5.12$

$$\text{Percentage Error} = \frac{5.12 - 2.1}{2.1} \times 100\%$$

$$= 143.81\%.$$

DSO outplot of square wave :

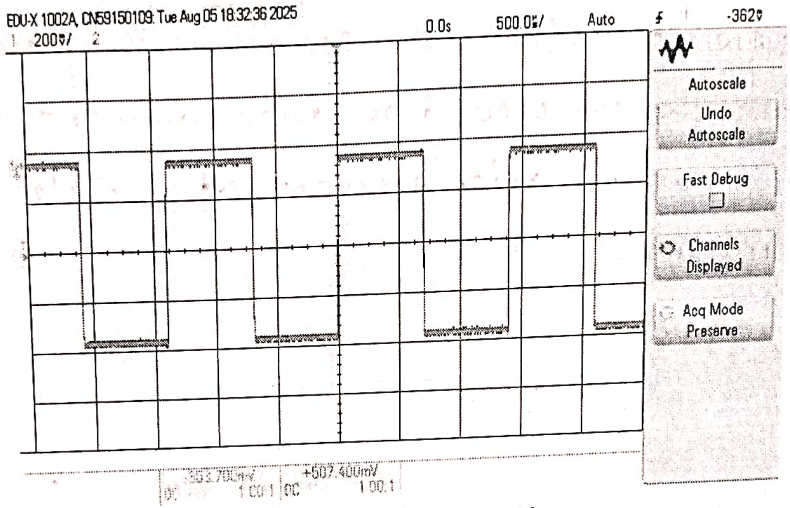


Fig. for Backelite sample

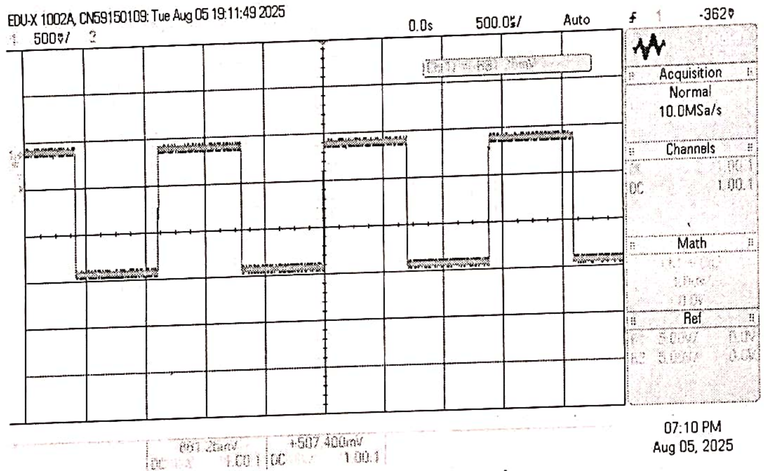


Fig. for Nylon sample.

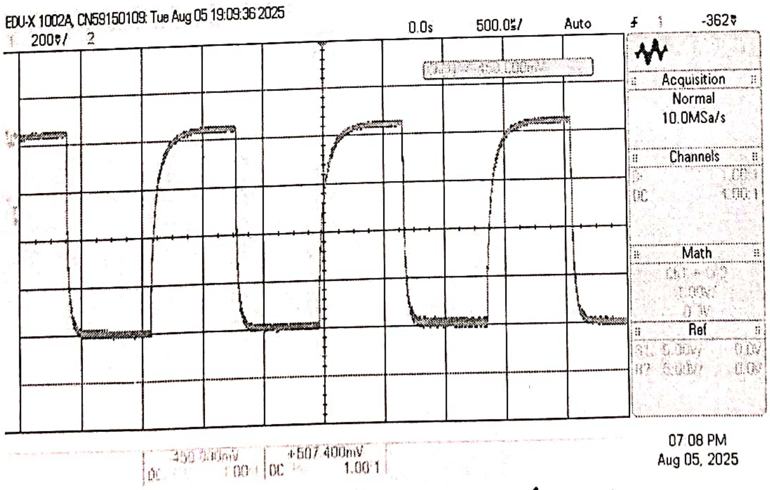


Fig. for Teflon sample.

Source of Error:

(1) Backelite and Nylon has fairly close value of dielectric constant with errors less than 10%..

(2) But in case of Teflon the error is very high. (~144%). May be there ~~woted~~ would be measurement error or setup error. Or it can be misplacement of sample inside the detector mount.