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E4 Wave Transmission & Reflection

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Summary

In this experiment, we study the general properties of travelling waves and the creation of standing waves. We first measure the wavelength and velocity of microwaves in air of the standing wave in coaxial line. We also investigated the refractive index of three other solid materials. Finally, we investigated a microwave resonator and plot its response. The frequency response for two different lengths is then studied.

Results and Discussions

3.1 Measurement of wavelength and phase velocity on the slotted line.

Experimental method:

1) We used standing waves of different frequencies (3.0 GHz and 4.0GHz) through air.
2) Wavelengths were calculated by Q1-P1 (the left most rise and the right most fall) and divided by half the number of maxima counted.
3) The speed of light in the medium, u, was calculated by the multiplication of frequency and wavelength.

Frequency/GHz ±0.0005GHz	P_1 (mm) ±0.5 mm	Q_1 (mm) ±0.5 mm	Number of max.	Wavelength (mm)	Velocity (mm/ns)
3.0	43	448	9	100.44	301.33
4.0	8	496	13	75.08	300.31

Table 1: Calculated values of wavelength and velocity of light from standing wave

The velocity that we obtained was close to the theoretical value of the speed of light as we expected. This was generally true for all two frequencies we measured with minimal error.

- Sources of error includes:
  Length measured by ruler: uncertainty of ±0.5 mm.
- Difficult to determine value of P1and Q1 from graph due to uncertainty in peak and trough, estimated error ±2.5 mm.
- Frequency measured by device: Error of ±0.0005GHz.

Relative error is then obtained from this formula:

$$\frac{\delta u}{u} = \frac{\delta \lambda}{\lambda} + \frac{\delta f}{f} \approx 3.0\%$$

(1)

The largest uncertainty is found in the measurements from 3.0 GHz, which is calculated to be +0.84% (< 3.0%). This shows that the results are good approximations to the speed of light.

3.2(a) Amplitude reflection coefficients measured with the slotted line.

The shifts in minima positions were:

Frequency/ GHz ±0.0005GHz	P_2/mm ±0.5 mm	$(P_2 - P_1)$/mm ±1.0 mm	Q_2/mm ±0.5 mm	$(Q_2 - Q_1)$/ mm ±1.0 mm	Average Shift Δmm	Δ/λ
3.0	68	25	475	27	26	0.256

Table 2: Values for phase shift for open circuited boundary respect to short circuited boundary

The shift of $\frac{\Delta}{\lambda}$ for the above section equals 0.256, which is approximately equal to the expected value of 0.25. This represents a phase shift difference of a quarter of the wavelength.

This is expected because with an open end, the L must be (2m+1) λ/4 and the perfect reflected wave is in antiphase with the incident wave, which the $\frac{\Delta}{\lambda}$ = 0.5 (L= 7λ/2). This gives a nearest value of 0.25 when m=7.

Error Calculations:

We need to work out the errors in Δ and **λ**. From the previous section, we know that the errors in P_1 and P_2 = 2.5mm and errors in Q_1 and Q_2 = 0.5mm.

Thus, $\Delta = \frac{P_2 - P_1}{2} + \frac{Q_2 - Q_1}{2}$. Therefore $\delta\Delta = \frac{1}{2}(\delta P_1 + \delta P_2 + \delta Q_1 + \delta Q_2) = 3mm$

Thus the total error is given by:

$$\frac{\delta\Delta}{\Delta} + \frac{\delta\lambda}{\lambda} = 13.0\%$$

The calculated value of 0.256 is well within the error range of 13.0% of expected value of 0.25.

3.2(b) Zero Reflection Coefficient

Previously, we considered the first part of this section without the offset. Thus, the maximum and minimum amplitudes are 7.8mV and 1.72mV respectively. This gives:

$$S\text{^}2 = \frac{A_{max}}{A_{min}} = \frac{7.8}{1.72} = 4.53$$

$$\rho = \frac{S\text{^}2 - 1}{S\text{^}2 + 1} = 0.2866$$

S^2 S^{}

\rho ρ \Rho P

\gamma γ \Gamma Γ

We, however, know that the detector output and a built-in offset and that the ratio of the maximum to minimum amplitudes is proportional to the square of the standing wave ratio S. This gives us a better result, where the offset was found to be 1.5mV. Therefore,

$$S = \sqrt{\frac{A_{max} - offset}{A_{min} - offset}} = \sqrt{\frac{4.5 - 0.63}{1.82 - 0.63}} = 1.803$$

$$\rho = \frac{S-1}{S+1} = 0.2865$$

We can tell from the value of ρ that the wave is badly reflected. WHY?

4. Velocity of microwaves in different material

In this section, different dielectric materials were placed in between the strip line and ground plane, thus affecting the velocity of propagation of the microwaves and influencing the wavelength.

Material	M/mm	d/mm	R/mm	(R-M)/mm	$\frac{R-M}{d}$	n= $\frac{R-M}{d}+1$
Glass	28	30	50	22	0.73	1.73
Glass	28	60	66	38	0.63	1.63
Glass	28	90	91	63	0.70	1.70
Glass	28	120	105	77	0.64	1.64
Perspex	28	30	40	12	0.40	1.40
Perspex	28	60	54	26	0.43	1.43
Perspex	28	90	61	33	0.367	1.367
Perspex	28	120	69	41	0.342	1.342
Teflon	28	30	85	57	1.9	2.9
Teflon	28	60	96	68	1.13	2.13
Teflon	28	90	145	117	1.3	2.3
Teflon	28	120	150	122	1.017	2.017

Table 3: Measured values for each material and calculated reflective index n

We calculated the average refractive index of Glass, Perspex and Teflon to be 1.66, 1.383 and 2.337 respectively. Comparing with to the actual refractive index of respective materials, which is 1.6 (Glass), 1.49 (Perspex), 2.3 (Teflon), shows that we are relatively close in values.

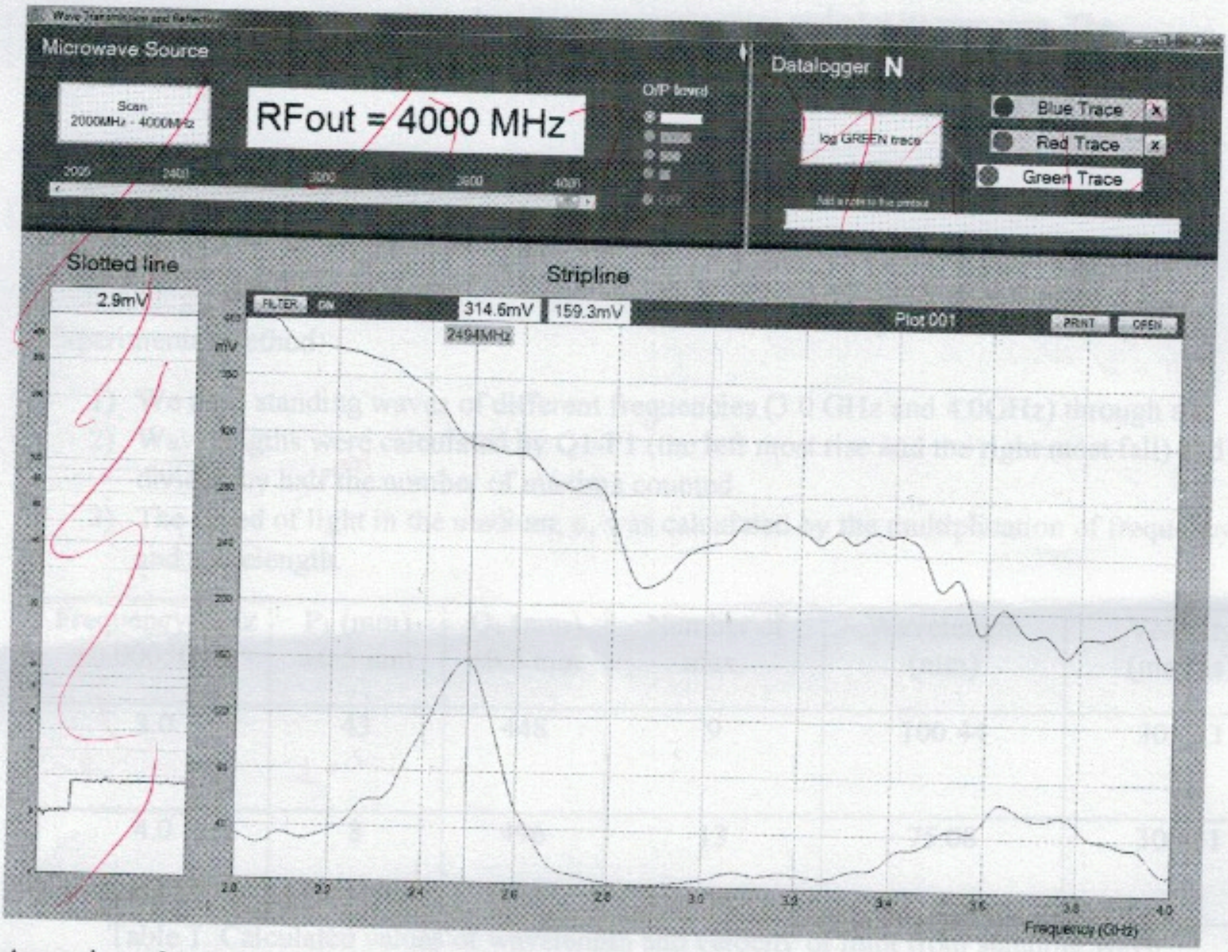
Error Calculations:

We set error values of R, d, and M to be ±0.5mm to obtain the relative uncertainty for the refractive index. Teflon material d=30mm

$$\frac{\delta R + \delta M}{R - M} + \frac{\delta d}{d} \approx 10\%$$

All calculated reflective index for the materials above fall within this range, thus aligning with what we would expect in theory.

5. Transmission through a Resonator



A spacing of 120mm between the 2 screwed yielded a primary resonance peak at 2494 MHz, which corresponds to a wavelength of 119.9mm, which is very close to the expected value which is 120mm. This shows that the wave was reflected almost perfectly with extremely small uncertainty with a phase shift of 180 degrees.

<u>Conclusion</u>

Through this experiment, we have studied the waveform properties of various microwaves across different media and frequency values. We also managed to get the velocity of light with high accuracy for the reflector setups. We also tested the open circuit to measure the shift ratio. We also calculated the refractive indices for various materials which agrees with the theoretical values within our uncertainty range. Finally, we deduced that the (essentially) perfect wave reflection did take place with the screws at 2494MHz.