University of Victoria

ELEC 340

Applied Electromagnetics and Photonics

Lab 4 - Oblique Incidence and Waveguides

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A01 - B03

March 23, 2016

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1 Objective

This experiment will use a square structure divided diagonally to investigate reflection at oblique angles of incidence. Reflectionless cavities and waveguides will be examined to determine their resonant and cutoff frequencies.

2 Introduction

This experiment used MEFiSTo to explore the refraction of electromagnetic waves at oblique incidence. Waves at 45° incidence were explored with different permittivity transitions.

A Brewster angle interface was constructed so that an electromagnetic wave could strike at oblique incidence but not experience reflection. This occurs when the incidence is

$$\tan\theta_B = \sqrt{\frac{\epsilon_2}{\epsilon_1}}. \tag{1}$$

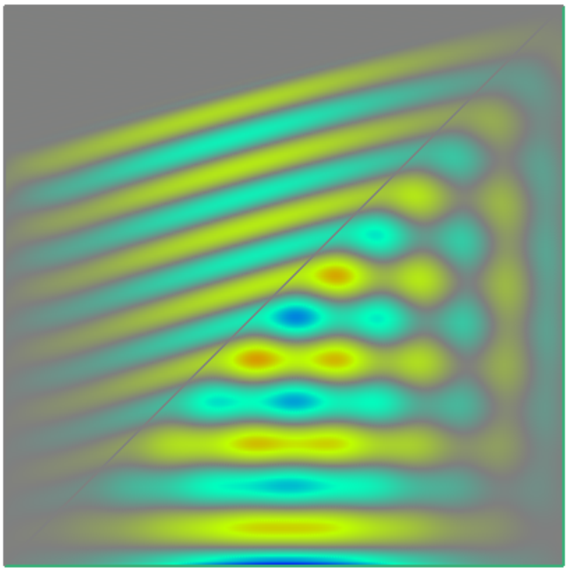
The behavior of electromagnetic waves in a cavity was examined next. An impulse function was used to determine the resonant frequencies of a cavity with $a = 30\,\mathrm{mm}$ and $b = 20\,\mathrm{mm}$. These resonant frequencies determine which transmission modes will be permitted.

Lastly, we downloaded a pre-built MEFiSTo waveguide and altered the mode and generating frequency to create new transmission modes for the same waveguide.

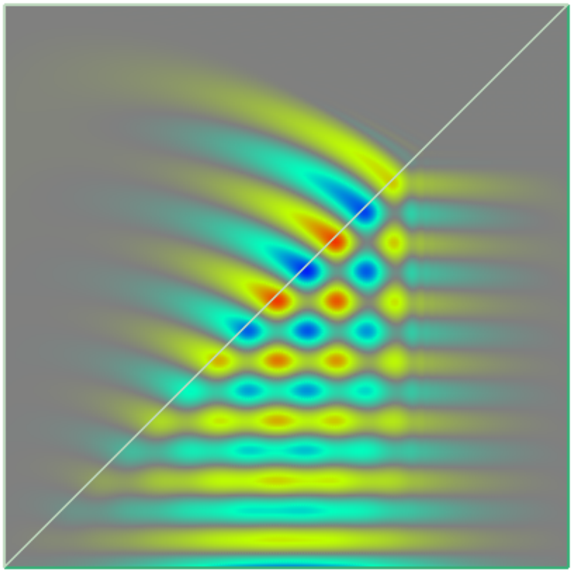
3 Discussion

3.1 Snell's Law

Task 4 *Compare the angles of incidence, reflection and transmission in an air* $\to \epsilon_r = 2$ *and* $\epsilon_r = 2 \to$*air interface.*



(a) $\epsilon_r = 1 \to 2$



(b) $\epsilon_r = 2 \to 1$

Figure 1: Behavior at 45° incidence

For Fig. 1(a), $\theta_i = 45°$, so:

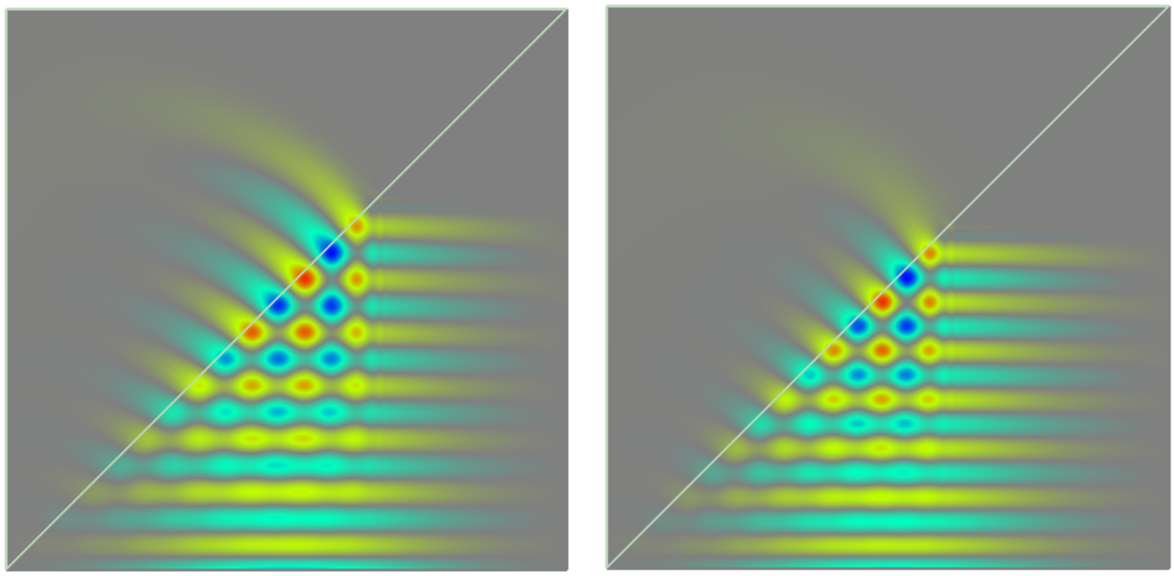
$$\sin\theta_t = \frac{1}{\sqrt{2}}\sin 45° \implies \theta_t = 30°$$
$$\theta_r = \theta_i = 45°$$

For Fig. 1(b), the interface has a critical angle of:

$$\theta_c = \sin^{-1}\sqrt{\frac{\epsilon_2}{\epsilon_1}} = \sin^{-1}\sqrt{\frac{1}{2}} = 45°.$$

Hence, $\theta_t = 90°$ and $\theta_r = 45°$.

Task 6 *Compare the images for $\epsilon_r = 2.0, 2.5, 3.0$ in the ABC-bounded region.*



(a) $\epsilon_r = 2.5 \to 1$ (b) $\epsilon_r = 3 \to 1$

Figure 2: Behavior at 45° incidence

Both waves in Fig. 2 experience total internal reflection. The critical angle, θ_c, for Fig. 2(a) is

$$\theta_c = \sin^{-1}\sqrt{\frac{1}{2.5}} = 39^\circ$$

and for Fig. 22(b)

$$\theta_c = \sin^{-1}\sqrt{\frac{1}{3}} = 35^\circ.$$

In both cases, the $\theta_i > \theta_c$ so total internal reflection occurs. Hence, $\theta_t = 90^\circ$ and $\theta_r = 45^\circ$ in both cases.

The "streaks" in are larger in Fig. 2(a) than in Fig. 2(b) (and even larger in Fig. 1(b)). (14) From the lab manual tells us that $\mathbf{E}_\perp^{trans}$ is scaled by $|T_\perp|$ and $|T_\perp| \propto^{-1} \eta_1$ [1]. Hence, $\mathbf{E}_\perp^{trans} \propto^{-1} \epsilon_1$. This is consistent with the streaks decreasing in size as ϵ_1 increases.

Task 8 *Capture an animation of* **H** *with pointer mode and comment on it.*

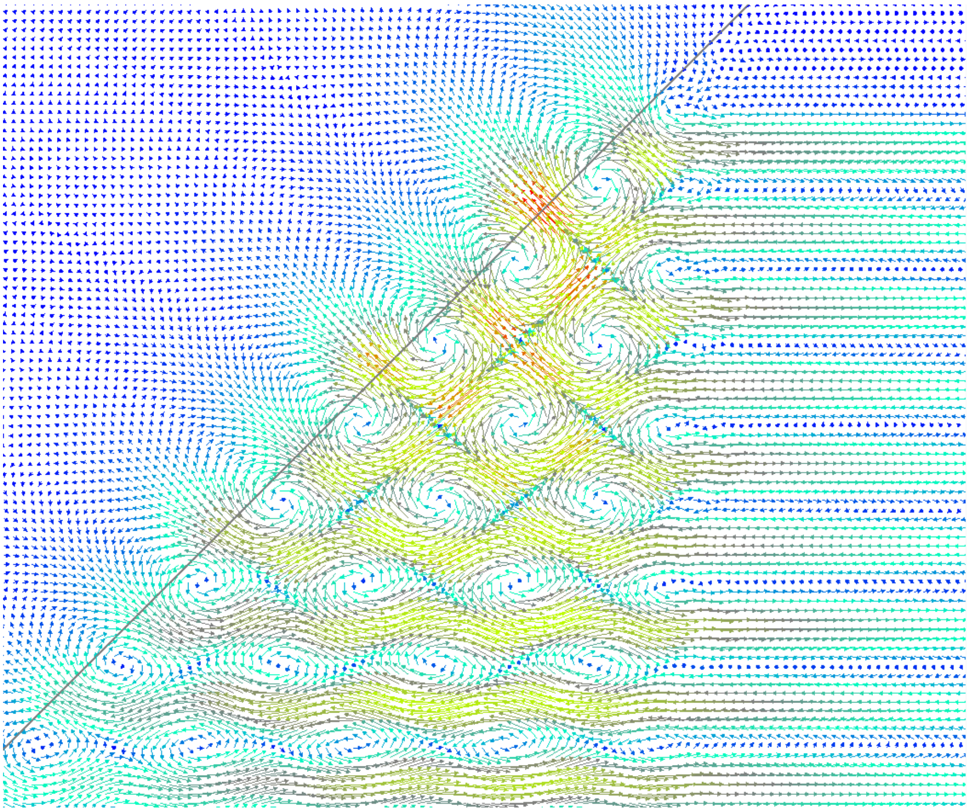


Figure 3: **H** for $\epsilon_r = 3 \to 1$

As **E** is reflected by the boundary it creates a standing wave, perpendicular to the plane of Fig. 3. As per Ampere's Law, **H** curls around the perpendicular **E** field, creating the "pools" in the image.

Fig. 4 shows that **H** is not altered by the boundary.

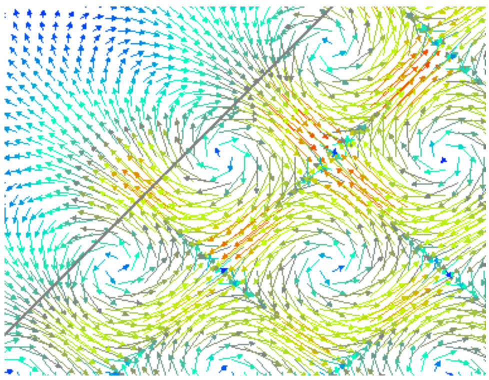


Figure 4: Inset view of Fig. 3

Since **E** was reflected by the boundary, **H** dissipates because it is not able to generate itself in isolation.

3.2 Brewster angle

Task 9 *Design a Brewster angle interface for zero reflection transmission of a plane wave from air to a dielectric with* $\epsilon_r = 4$*.*

Using (1), the Brewster angle for this interface is:

$$\theta_B = \tan^{-1}(2) = 63.435°$$

The second medium is designed with a base of 200 mm and height of 400 mm to ensure an incidence angle of θ_B. This is shown in Fig. 5.

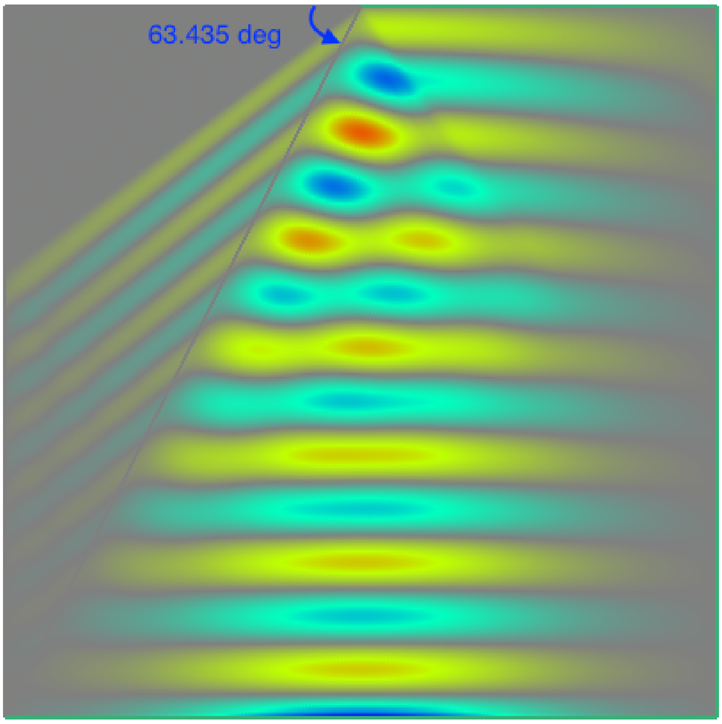


Figure 5: A Brewster angle interface

3.3 Rectangular waveguides and cavities

Task 16 *Obtain the resonant frequencies of the constructed waveguide and compare it to the calculated values.*

Fig. 6 shows the response generated by the impulse function.

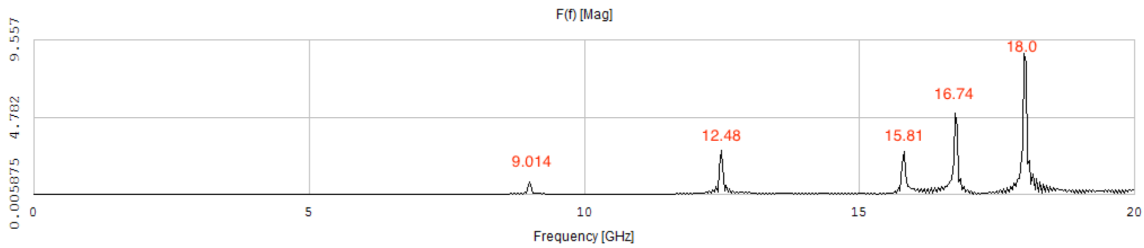


Figure 6: Frequency response of waveguide

For TE_{11}, the cutoff frequency is:

$$f_c = \frac{u_{p0}}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} = \frac{c_0}{2}\sqrt{\left(\frac{1}{30\,\mathrm{mm}}\right)^2 + \left(\frac{1}{20\,\mathrm{mm}}\right)^2} = 9.007\,\mathrm{GHz}$$

This corresponds with the first peak of Fig. 6.

3.4 Rectangular waveguide modes

Task 20 *Compare the propagation in a waveguide with TE_{10} and TE_{30}.*

TE_{30} has $f_c \approx 4.5\,\mathrm{GHz}$. Any frequency above this value with propagate through the waveguide, but significantly higher frequencies will generate the best graphics. Fig. 7 was generated with a source at 50 GHz

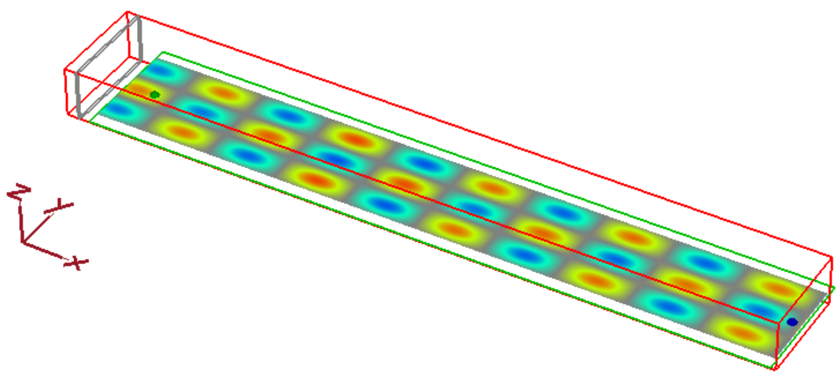


Figure 7: Transmission in a TE_{30} waveguide

4 Conclusion

This lab gave us a good understanding of the behavior of electromagnetic waves at boundaries as well as of how to simulate waves at oblique incidences. Snell's Law is insufficient in explaining electromagnetic reflection because it does not account for any transmission for angles beyond the critical angle. This is contrary to the simulation and is explained by the boundary conditions, which require perpendicular components to be equal (when scaled by the permittivity) at the boundary.

The Brewster angle structure showed how waves can be transmitted without causing reflection. Our work with the waveguides showed the relationship between the material dimensions of the structure and the allowable transmission frequencies.

References

[1] P. P. M. So, *Laboratory Manual for ELEC340 - Applied Electromagnetics and Photonics*, University of Victoria, 2016.