University of Victoria

ELEC 340

Applied Electromagnetics and Photonics

Lab 2 - Uniform Plane Waves

Instructor:
Dr. Poman So

A.K. Blanken V00809798
T. Stephen V00812021
A01 - B03

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1 Objective

This experiment will use a MEFiSTo simulation to investigate the propagation of an electromagnetic wave through a waveguide. The results of the simulation will validate the Helmholtz equation and provide insight into the propagation properties of plane waves.

2 Introduction

Faraday's and Ampere's Laws can be applied [1, pp. 15-16] to a medium with constant permittivity and permeability to yeild the Helmholtz equation:

$$\nabla^2 \tilde{\mathbf{E}} = -\omega^2 \mu \epsilon \tilde{\mathbf{E}} = \gamma^2 \tilde{\mathbf{E}}. \tag{1}$$

This relation implies that *something...*

More about intrinsic impedance effect on propagation.

A little bit about polarization.

3 Procedure

3.1 Uniform plane waves in a parallel plate structure

A perfect parallel plate wave guide is created in MEFiSToby bounding a region of air with opposite, perfect electrical and magnetic boundaries. The ends of the waveguide are covered with an absorbing boundary. A wave source fills a vertical slice of the waveguide and will act on a transverse and parallel animation region. This arrangement is shown in Fig. 1, with the bottom electrical boundary, animation regions and source present.

The source emits a wave with $f = 15\,\mathrm{GHz}$ that travels through the medium, bounded by the walls of the waveguide. The solid red color of the yz-animation plane in Fig. 2 shows that the wave travels as a plane wave from its origin through the waveguide.

Does this agree with theory? What theory :(

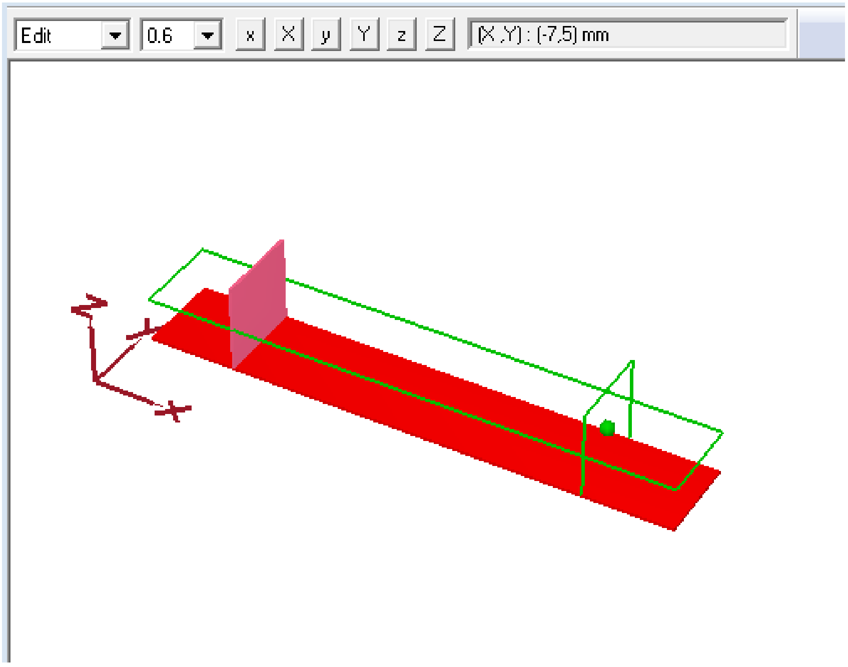


Figure 1: Perfect waveguide with dimensions 60 mm ×10 mm ×10 mm

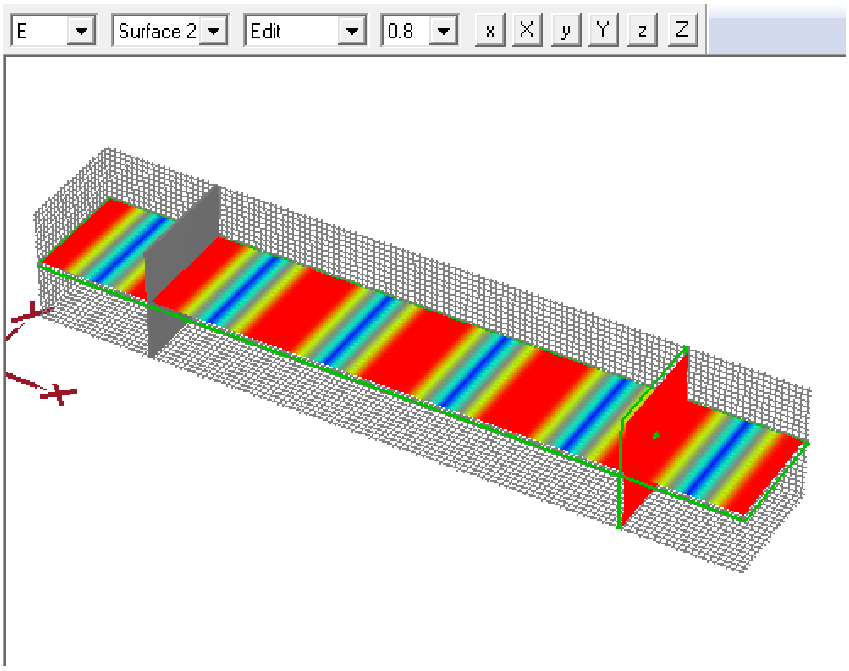


Figure 2: Wave propagation in air-filled waveguide

The physical properties of the propagation medium can be determined by examining the wave structure from Fig. 2

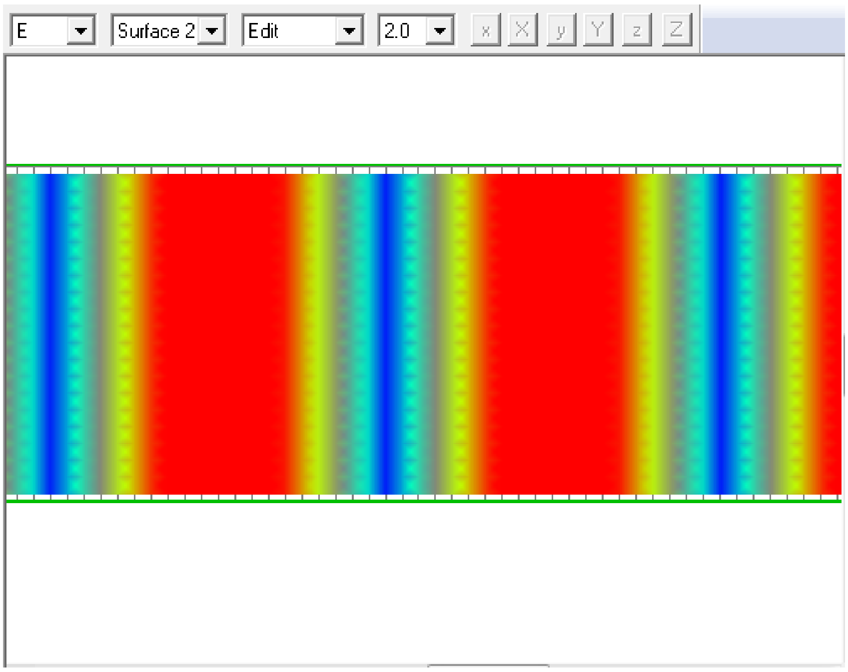


Figure 3: xy view of propagation in Fig. 2, with 0.5 mm mesh

There are 21 grid square between adjacent blue regions in Fig. 3. At 0.5 mm mesh resolution, this indicates that $\lambda = 10.5\,\text{mm}$

We're expecting around 20mm for 15 GHz in free space :(Maybe the mesh size is wrong?

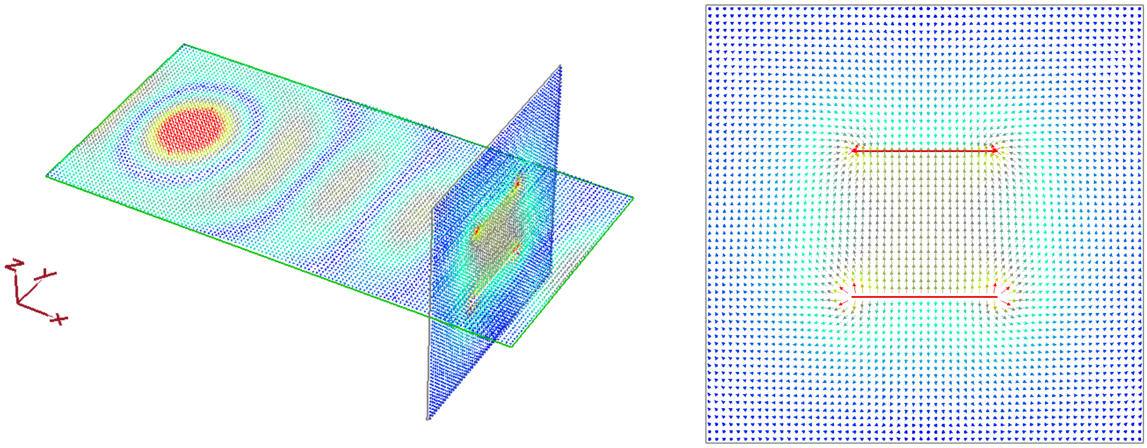
3.2 Waves in a non-ideal parallel plate structure

Removing the magnetic sidewalls from the waveguide allows the wave energy to escape the confines of the guide. When this change is made the wave propagation appears spherical near the source. As the energy moves away from the source, the propagation becomes more planar. This can be seen in Fig. 4(a). Fig. 4(b) shows that the orientation of all $\vec{E}_z$ are identical but their magnitude is not.

3.3 Dielectric and lossy media

The narrow-wide arrangement from Section 3.2 is changed to include a lossy dielectric between the top and bottom electric boundaries. The boundaries with dielectric are shown in Fig. 5.

Propagation in the dielectric is shown in Fig. 6.



(a) (b) yz-orientation

Figure 4: Propagation in a non-ideal parallel plate

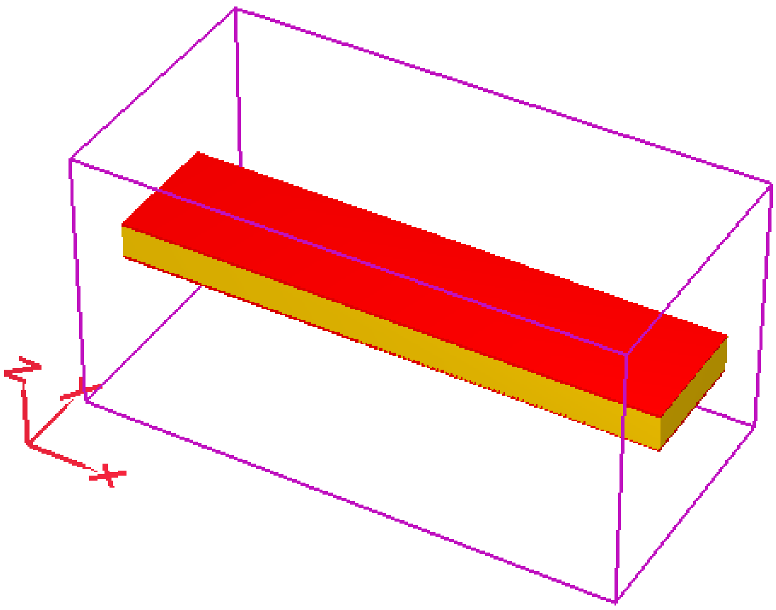


Figure 5: Waveguide containing a lossy dielectric material

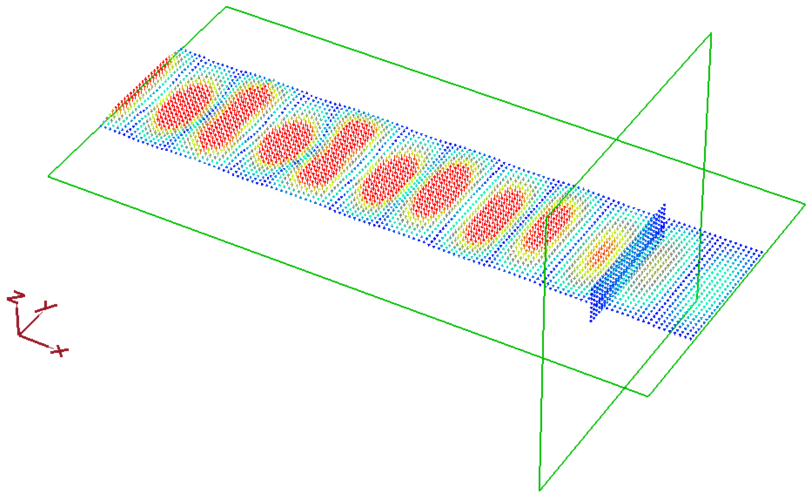


Figure 6: Propagation in a waveguide filled with a dielectric where $\epsilon_r = 4$ and $\sigma = 0.5$

The wave attenuates as it travels through the waveguide as a result of $\sigma > 0$.

4 Discussion

Task 4 Compare the phase velocity

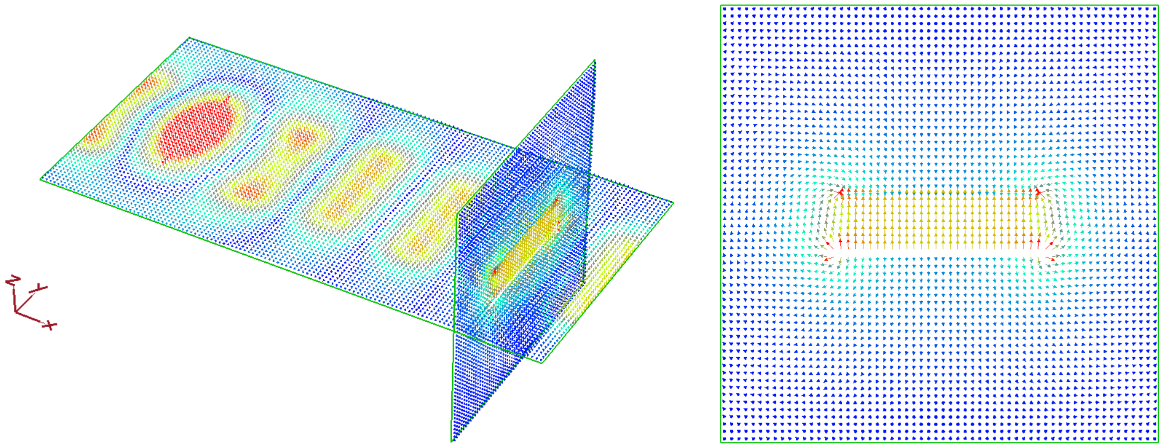
I suspect that we totally messed this up :(

Task 7 *Reduce the plate spacing to 4 mm and increase the width to 14 mm in the environment used for Section 3.2. Does the far field in the xy and yz planes behave like a uniform plane wave?*

Narrowing the gap between the electric field boundaries and widening them creates the propagation patterns shown in Fig. 7.

The magnitude of the waves in Fig. 7(a) is greater than those in Fig. 4(a) and the groups have a much shorter and wider region of similar magnitude. Fig. 7(b) confirms that both the direction and magnitude of the wave are similar far from the source. Changing the electric field arrangement to make the separation smaller and boundaries wider has restored the plane wave behavior for the region between the boundaries.

Task 8 *Determine α and β for the waveguide with dielectric from Section 3.3.*



(a)

(b) yz-orientation

Figure 7: Propagation in a non-ideal, narrow parallel plate

The lab manual suggests using Fig. 8 to determine the attenuation of the wave with equations (2) and (3).

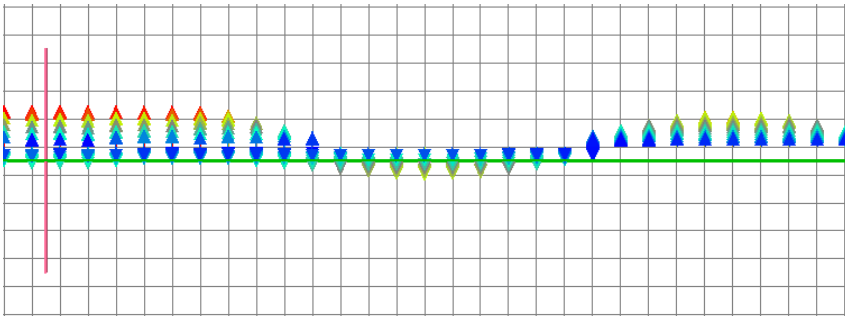


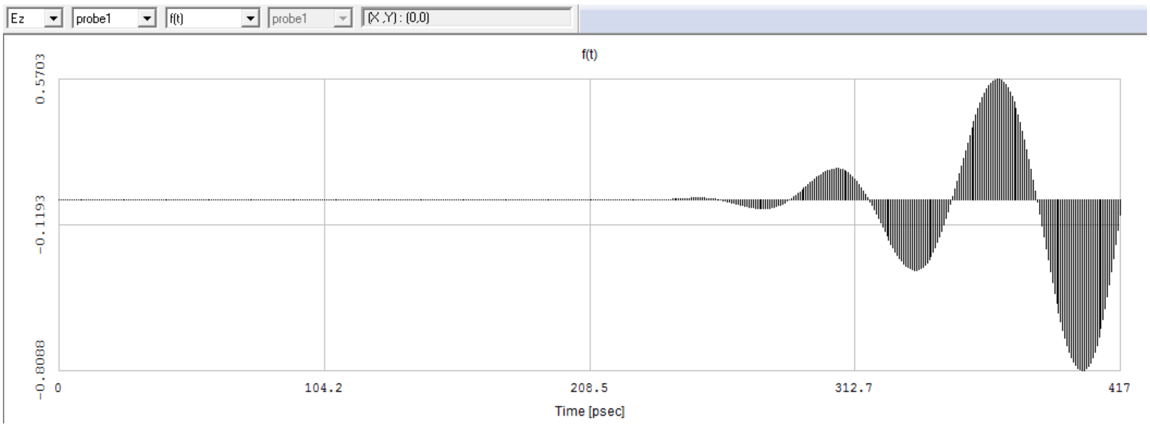
Figure 8: xz view of Fig. 6

$$\alpha = \frac{\ln\left(\frac{E_z(x_1)}{E_z(x_2)}\right)}{m\Delta x} \tag{2}$$

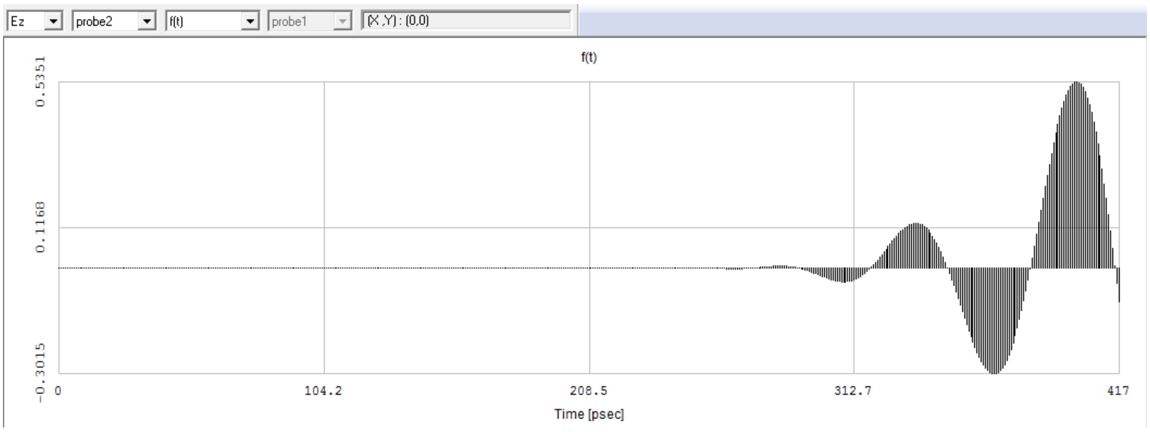
$$\beta = \frac{2\pi}{\lambda} \tag{3}$$

This method poses a problem since the magnitude of the electric field is not displayed on the graph. Determining the ratio of two points is extremely imprecise.

In order to obtain more accurate measurements of E_z, a second probe was added to the animation 5 mm closer to the source than the probe in Fig. 1. The E_z response at both probes is shown in Fig. 9.



(a) 35 mm



(b) 40 mm

Figure 9: E_z response at different distances from source

Using the peak positive value for both probes with (2) gives:

$$\alpha = \frac{\ln\left(\frac{0.5703\,\mathrm{V\,m^{-1}}}{0.5351\,\mathrm{V\,m^{-1}}}\right)}{5\,\mathrm{mm}} = 12.74\,\mathrm{Np\,m^{-1}}.$$

Using $\lambda = \frac{c_o}{f}$ and $f = 15\,\mathrm{GHz}$ in (3):

$$\beta = \frac{f \times 2\pi}{c_0} = 314.38\,\mathrm{rad\,m^{-1}}.$$

Task 9 *Compare the results of Task 8 to the theoretical values.*

The attenuation and phase constants are:

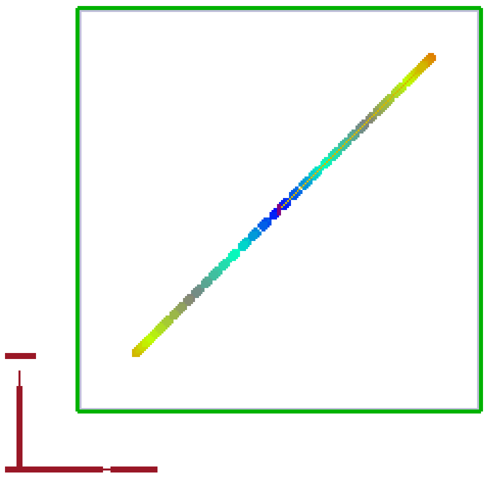
$$\begin{aligned}
\alpha &= \frac{\omega\sqrt{\mu\epsilon}}{\sqrt{2}}\sqrt{\sqrt{1+\left(\frac{\sigma}{\omega\epsilon}\right)^2}-1} \\
&= \frac{\omega\sqrt{\epsilon_r}}{c_0\sqrt{2}}\sqrt{\sqrt{1+\left(\frac{\sigma}{\omega\epsilon_0\epsilon_r}\right)^2}-1} \\
&= \frac{2\pi\cdot 15\,\mathrm{GHz}\cdot\sqrt{4}}{c_0\sqrt{2}}\sqrt{\sqrt{1+\left(\frac{0.5}{2\pi\cdot 15\,\mathrm{GHz}\cdot\epsilon_0\cdot 4}\right)^2}-1} \\
&= 46.96\,\mathrm{Np\,m^{-1}}
\end{aligned}$$

$$\begin{aligned}
\beta &= \frac{\omega\sqrt{\mu\epsilon}}{\sqrt{2}}\sqrt{\sqrt{1+\left(\frac{\sigma}{\omega\epsilon}\right)^2}+1} \\
&= 630.50\,\mathrm{rad\,m^{-1}}
\end{aligned}$$

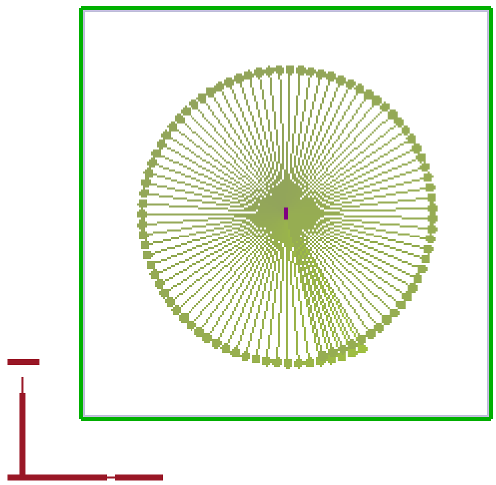
Oh no they don't agree :(

Task 10 *Modify the waves in* `Polarization_TE.mef` *to produce various kinds of polarizations*

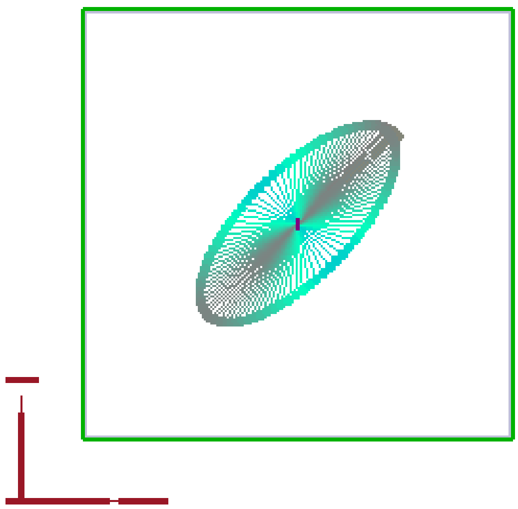
Fig. 10 shows the result of changing E_x and E_y.



(a) $A = 1,\ \phi_\Delta = 0^\circ$



(b) $A = 1,\ \phi_\Delta = -90^\circ$



(c) $A = 1,\ \phi_\Delta = 45^\circ$

Figure 10: Various polarizations of a propagating electric field

5 Conclusion

Summarize the entire report and note any unresolved issues. This section will usually repeat the abstract.

References

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