Laboratory assignment 10 (online) – Electromagnetic waves

Purpose: to study electromagnetic waves caused by oscillating charges.

Introduction

When an electric $\vec{E}$ and magnetic $\vec{B}$ field is changing with time t, the fields propagate through space. These interchanging fields propagate as waves away from their source. The equations necessary to describe the propagation of electromagnetic waves are called Maxwell's equations. The microscopic Maxwell's equations in differential form are

$$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{d\vec{B}}{dt}$$

$$\nabla \times \vec{B} = \mu_0 \left(\vec{J} + \epsilon_0 \frac{d\vec{E}}{dt} \right)$$

where ρ is the free charge density, ϵ_0 is the permittivity of free space, μ_0 is the permeability of free space, and $\vec{J}$ is the current density.

When electromagnetic waves propagate in free space (in a vacuum), then the current density and charge density is zero (no material means no charges). Maxwell's equations for free-space propagation of electromagnetic fields reduce to

$$\nabla \cdot \vec{E} = 0$$

$$\nabla \cdot \vec{B} = 0$$

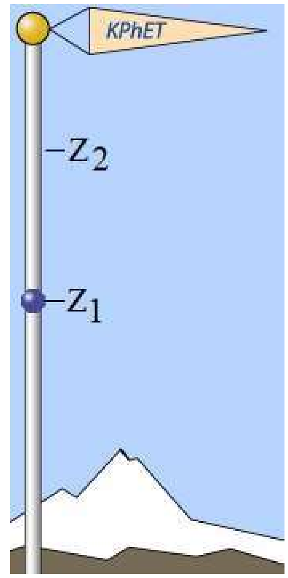
$$\nabla \times \vec{E} = -\frac{d\vec{B}}{dt}$$

$$\nabla \times \vec{B} = \mu_0 \epsilon_0 \frac{d\vec{E}}{dt}$$

where $\sqrt{\mu_0 \epsilon_0} = 1/c$ with c denotes the speed of light in vacuum. As shown in your lecture notes, these free-space equations can be manipulated rather quickly to deduce two coupled wave equations for the electric field and the magnetic field,

$$\nabla^2 \vec{E} = \frac{1}{c^2} \frac{d^2 \vec{E}}{dt^2}$$

$$\nabla^2 \vec{B} = \frac{1}{c^2} \frac{d^2 \vec{B}}{dt^2}$$



To cause an electromagnetic wave to begin to propagate, we must cause a time changing electromagnetic field. If we have a single charge that can move up or down and it is located at point z on the z-axis, then the electric field is strongest near z and weaker near z . If the object is moved to a position z , then the electric field becomes stronger near z and weaker near z . Thus, by moving the charge between two locations, adjacent locations experience a time changing electric field. Likewise, a magnetic field is created from the moving charge. Accelerating and decelerating the charge to move it from point z to point z causes a time changing magnetic field. Thus, moving a charge up and down in an oscillatory motion will create an oscillating wave. This idea of oscillating charges is the physics behind a radio transmission antenna, which are sources of electromagnetic radiation.

Just as oscillating charges create electromagnetic fields, electromagnetic fields can also cause charges to oscillate when the propagate by those charges. Charges being moved by electromagnetic fields is the physics behind a receiving antenna. The movement of the charges caused by the electromagnetic field induces a current, which can be used to sense the passing electromagnetic field (or play music in your car).

Laboratory assignment

1. Run the “Radio waves” PhET simulation.
2. When a net charge is present, there is an electric field. When a net charge is in motion a magnetic there is a resultant magnetic field. Set the field display type to full field and the transmitter movement to oscillate. Describe what happens.

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3. Change the frequency and amplitude sliders (play with the slider settings). Describe what happens to the fields.

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4. Set the transmitter movement to oscillate, field display type to curve with vectors, and radiated fields. Describe what happens in the transmitter and the receiver.

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5. Click on Electron Positions to activate the wave graphs. Describe what happens in the transmitter and the receiver.

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6. After playing around with the settings of frequency and amplitude. Describe what you see.

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7. Explain why you lose your FM radio signal as you travel farther away from the radio station's transmitter.

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8. Using the equation for the speed of a wave, $v = \lambda f$ where the velocity is equal to the speed of light in vacuum $c = 2.998 \times 10$ m/s, calculate the carrier wavelength of a signal from KPhET 98.7. Note that FM stations transmit in the Megahertz range, so KPhET 98.7 is transmitting a frequency of 9.87×10 Hz.

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9. National Public Radio (NPR) transmits a signal that has a wavelength of 3.38 m. What is the frequency of this signal?

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10. Write a brief conclusion to this laboratory.

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