Lab 4: Introduction to Electromagnetic Radiation

Goal

Generation of EM waves using Half-wave Antenna and propagation of microwaves as Gaussian beams.

Objectives

1. Determine the dependence of the wave intensity on the distance it travelled
2. Observe Gaussian beam properties

Expectations

1. You are expected to take detailed notes during each step outlined in the procedure that can be used during the lab report write-up.
2. You are expected to provide a neat table of the data that you measured where you clearly label what each data set is and include units for all measured quantities.
3. You are expected to clearly record the measured values of any components that you use.
4. You are expected to clearly record the detail related to images captured by the oscilloscope.
5. You are expected to make your final plots in a program such as Excel. Make sure that your data points appear clearly on the plots, that all axes are clearly labeled and have units.
6. If it is possible to compare your measurements with an expectation or a prediction, you are expected to do so in your lab report
7. You are expected to answer the questions encountered in this manual as well as discuss exercises given during the lectures in your lab write up.

Introduction to Concepts

Electromagnetic waves can generated by using alternating potential difference across a conductor as shown in Figure 1. An incident electromagnet wave can generate a potential difference across a conductor as shown in Figure 2 allowing detection of electromagnetic waves.

Antennas act as converters between conducted waves and electromagnetic waves propagating freely in space (see Figure 3). A dipole antenna can be thought of as a parallel circuit which consists of an inductor and a capacitor where the plates of the capacitor are bent open, and the inductance of the wire itself. The transition of the LC parallel circuit in to an dipole antenna is shown in Figure 4

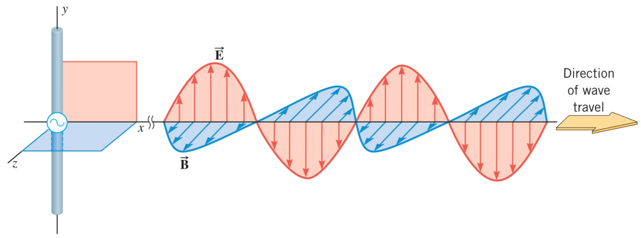

Figure 1: Far-field radiation (Electromagnetic wave) generated by oscillating potential/current in a dipole antenna

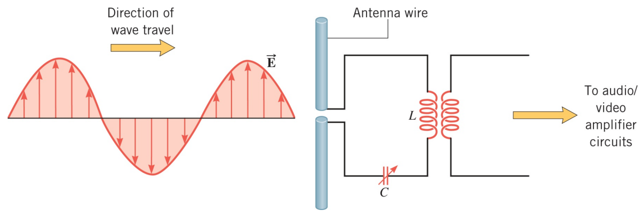

Figure 2: Far-field radiation can be detected with a receiving antenna wire that is parallel to the electric field.

Half-wave Antenna

Typically a dipole antenna is formed by two quarter wavelength conductors or elements placed back to back for a total length of $L = \lambda/2$. A standing wave on the conductor filaments yields the greatest voltage differential, as one end of the element is at a node while the other is at an antinode of the wave. The larger the differential voltage, the greater the current that flows between the elements. The far-field radiation generate by the dipole antenna can be given by,

$$\vec{E}(\vec{r}, t) = \vec{E}_o e^{(i\vec{k}\cdot\vec{r} - \omega t)} \tag{1}$$

and magnetic field component,

$$\vec{B}(\vec{r}, t) = \frac{1}{c}\vec{E}_o e^{(i\vec{k}\cdot\vec{r} - \omega t)} \cdot (\hat{k} \times \hat{n}) \tag{2}$$

Where $\omega = 2\pi f$ is the frequency of the EM wave, c is the speed of light in the medium, $\vec{k} = k\hat{k}$ is the wave vector propagating in $\hat{k}$ direction with $k = 2\pi/\lambda$, and $\hat{n}$ is the polarization unit vector.

A Gaussian EM Wave with Half-wave Antenna

The electromagnetic source (dipole antenna) is confined within a cavity to improve the directionality of the waves. Particular examples include the laser beam or the microwave signal generated by a horn antenna. The power radiated from such sources is described by a Gaussian beam profile. To specify and discuss the propagation characteristics of a Gaussian beam, we must define its diameter at a given location along propagation. There are two commonly accepted definitions as shown in Figure 5. The definition that we will use is the diameter at which the beam intensity (irradiance) has fallen to $1/e^2$ (13.5 percent) of its peak. The

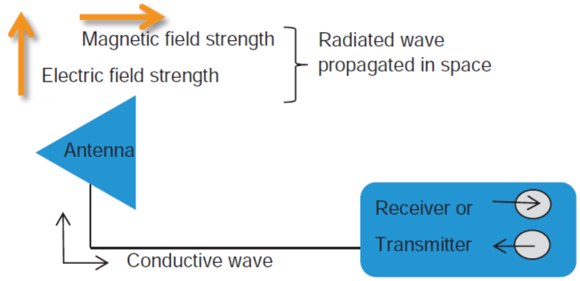

Figure 3: Basic functionality of an antenna is to act as converter between conducted waves and electromagnetic waves

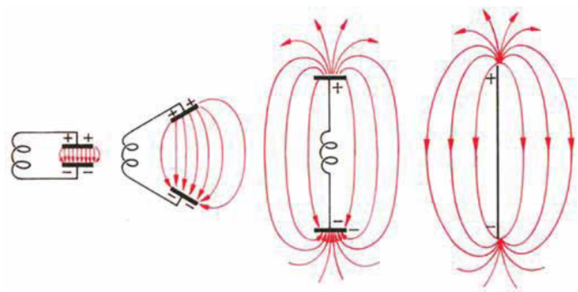

Figure 4: Simplified antenna model to explain generation of electromagnetic waves.

Growth in $1/e^2$ radius with distance the beam has propagated away from the origin is shown in Figure 6. The Gaussian waist is defined as the beam diameter at the origin of the beam.

A Gaussian beam is a monochromatic electromagnetic radiation where its magnetic and electric field amplitude profiles are given by the Gaussian function. This also implies the beam will have a Gaussian intensity profile. The intensity, $I(r,z)$ on a beam centered on an aperture passing through a transverse plane at position z with a beam diameter of $w(z)$ is given by equation 3. The Figure 7 shows the variation of beam diameter ,$w(z)$ as a function of propagation distance, z. The $I(r,z)$ gives the intensity at arbitrary radius r on the transverse plane at position z.

$$I(r,z) = I_o(w_0^2/w^2(z)) \left[e^{-2r^2/w^2(z)}\right] \tag{3}$$

Where I_o is the intensity at the beam origin, z is the axial distance from the beam's origin, $w(z) = w_o\sqrt{(1 + z/z_R)}$ is the beam diameter at z, w_0 is the beam waist radius as shown in Figure 7, r is the arbitrary radius on the transverse plane at position z, $z_R = \frac{\pi w_0^2}{\lambda}$ is called the Reyleigh range as shown in Figure 7, λ is the wavelength of the microwave signal. As an approximation only for large propagation distance, z such that $z >> z_R$, the beam diameter, $w(z)$ asymptotically approaches the value,

$$w(z) = \frac{\lambda z}{\pi w_o} \tag{4}$$

where z is presumed to be much larger than z_R so that the $1/e^2$ beam diameter contours asymptotically approach a cone of angular radius $\Theta/2$. Note that the angular radius is one

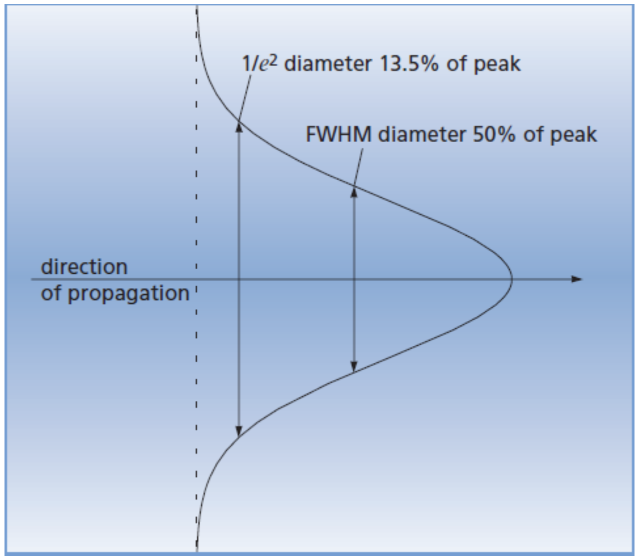

Figure 5: The intensity $I(r, z)$ at an arbitrary radius, r at a propagation distance from the source (antenna), z. Diameter of a Gaussian beam propagating from left to right defined using $1/e^2$ and FWHM. The diameter is a function of distance the beam propagated.

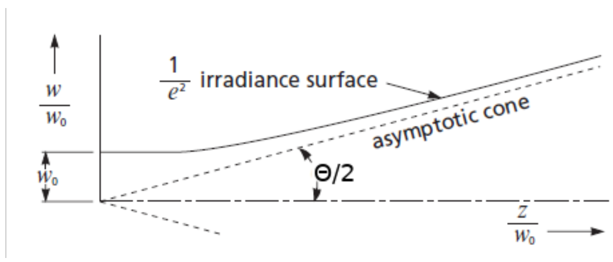

Figure 6: Growth in $1/e^2$ radius with distance propagated away from Gaussian waist

half of the total angular spread as shown in Figure 6. The Θ is also shown in Figure 7.

$$tan(\Theta/2) = \frac{w(z)}{z} = \frac{\lambda}{\pi w_o} \tag{5}$$

Preliminary Lab Questions

1. Using the equation 3 show that beam intensity has dropped to 13.5% of the peak intensity, I is at the beam waist, $w(z)$ and I_o is at the beam waist, w_o.

2. Derive the equations 4 and 5

3. The angle from the z axis to the arbitrary radius on the transverse plane where intensity is measured is given by the trigonometric relation $tan(\theta) = \frac{r}{z}$. Starting with equation 3 and for large z, ($z >> z_R$), equation 5 show that

$$I(\theta) = I_0(w_0^2/w^2(z)) \left[e^{-2(\frac{\pi w_o}{\lambda})^2 tan^2(\theta)} \right] \tag{6}$$

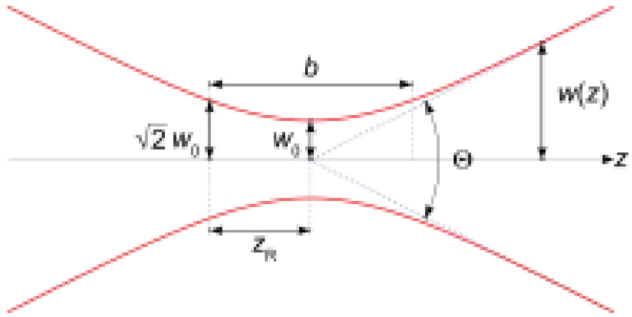

Figure 7: Gaussian beam diameter (width) $w(z)$ as a function of the distance z along the beam. the variation of beam diameter ,$w(z)$ as a function of propagation distance, z is plotted in Red. The w_0 is knows as the beam waist; b: depth of focus; z_R: Rayleigh range; Θ : total angular spread

Equipment and Parts

1. PASCO microwave optics system : Transmitter, Receiver, and Goniometer

Procedure

IMPORTANT: Reflections from nearby objects, including the table top, can affect the results of your microwave experiments. To reduce the effects of extraneous reflections, keep your experiment table clear of all objects, especially metal objects, other than those components required for the current experiment.

Introduction to the Microwave Optics System : Intensity of the Radiation

1. Note down the frequency of the microwave signal shown in the transmitter. ★
2. Use the correct stand to attach Transmitter and Receiver. The stands for the Transmitter and Receiver are labeled "T" and "R", respectively on its base.
3. Arrange the Transmitter and Receiver on the Goniometer as shown in Figure 8 with the Transmitter attached to the fixed arm.
4. Adjust both Transmitter and Receiver to the same polarity — the horns should have the same orientation, as shown in Figure 8.
5. Plug in the Transmitter and the Receiver. Turn the INTENSITY selection switch on the Receiver from OFF to 30X. (The LEDs should light up on both units.)
6. Adjust the Transmitter and Receiver so the distance between the source diode in the Transmitter and the detector diode in the Receiver (the distance labeled R in Figure 8) is 40 cm
7. The diodes are at the locations directly above the points marked "T" and "R" on the stands (shown in Figure 8).

8. Adjust the "INTENSITY" and "VARIABLE SENSITIVITY" knobs on the Receiver so that the meter reads 1.0 (full scale)

9. Set the distance R to each of the values shown in Table 1. Record the meter reading for each value of R. (Do not adjust the Receiver controls between measurements.)

10. After making the measurements, perform the calculations shown in the Table 9. ★

11. The electric field of an electromagnetic wave is inversely proportional to the distance from the wave source, ($E \propto 1/R$). Use the data from step 10 to determine if the meter reading of the Receiver is directly proportional to the electric field of the wave. ★

12. The intensity of an electromagnetic wave is inversely proportional to the square of the distance from the wave source ($I \propto 1/R^2$). Use the data from step 10 to determine if the meter reading of the Receiver is directly proportional to the intensity of the wave. ★

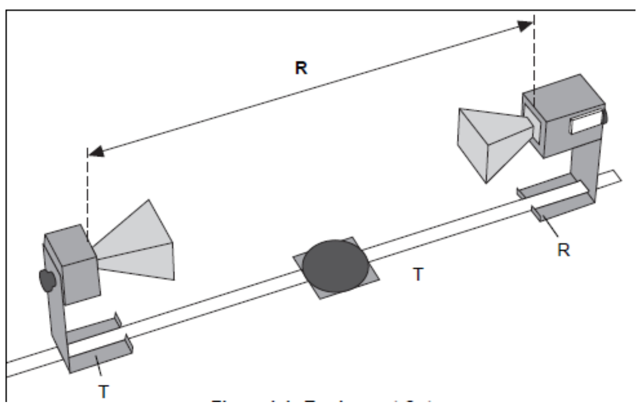

Figure 8: Equipment setup

R (cm)	Meter Reading (M)	M X R (cm)	M X R^2 (cm^2)
40			
50			
60			
70			
80			
90			
100			

Figure 9: Sample table for intensity and distance measurements

Radiation Pattern of a Gaussian Beam

1. Position the Transmitter so the output surface of the horn is centered directly over the center of the Degree Plate of the Goniometer arm (see Figure 10).

2. With the Receiver directly facing the Transmitter and as far back on the Goniometer arm as possible, adjust the Receiver controls for a meter reading of 1.0. Then rotate the rotatable arm of the Goniometer as shown in the figure 10. Set the angle of rotation (measured relative to the 180-degree point on the degree scale) to each of the values shown in Table 11

3. Record the meter reading at each setting

4. Repeat the measurements 3 times and take the statistical average of the results and the associated errors at each angle. State what is the error of final measurements.★

5. Plot the intensity vs. angle θ ★

6. Find the beam waist, $w(z)$ from the plot ★

7. Apply a Gaussian fit and obtain the Gaussian beam waist w_o using equation 6 ★

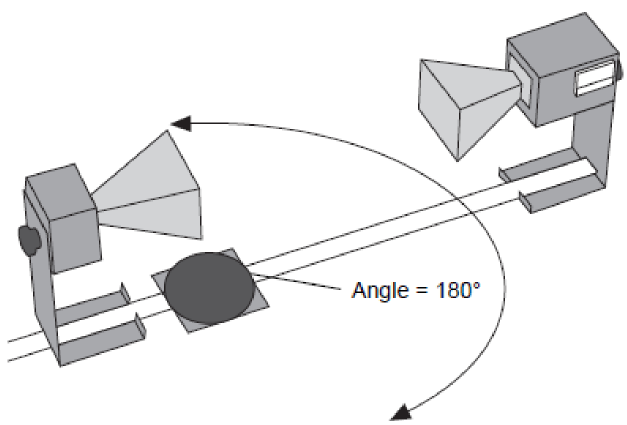

Figure 10: Setup for signal distribution measurement

Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading	Angle of Receiver	Meter Reading
90°		160		230	
100		170		240	
110		180		250	
120		190		260	
130		200		270	
140		210			
150		220			

Figure 11: Sample table for radiation profile measurements