Unit-08 Microwave Experiment I

Objective：

Study the characteristics of microwaves, such as wavelength, energy decay, reflection and refraction. Use Michelson-Interferometer to calculate the wavelength of the microwave and the refractive index of the plastic plate.

Apparatus：

Transmitter, receiver, goniometer, L-type meter, prism model, rotating holder, based holder, rotating table, metal reflector, partial reflector, plastic panel, Vernier caliper

Principle：

Microwave is a kind of wave which can deliver electrical energy and magnetic energy and it can convey in vacuum. The electric field $\vec{E}$ and magnetic field $\vec{B}$ of a microwave are perpendicular to each other and the propagation direction is determined by $\vec{E}\times\vec{B}$. The characteristics of microwaves can be determined by Maxwell's Equation.

As shown in Figure 1, $\vec{E}$ oscillates in *y*-direction and $\vec{B}$ in *z*-direction. Therefore, the wave propagates in *x*-direction. The speed of the electromagnetic wave in vacuum is quite equal to velocity of light $c = f\lambda$, here *f* representing frequency, λ representing wavelength. And the speed of an electromagnetic wave becomes c/n in a medium that refractive index *n*.
[Note] $c = 3\times10^{8}\ m/s$ 。

As shown in Fig.2, microwave is a kind of electromagnetic waves whose wavelength is among 1 m ~1 mm (about 300 MHz~300 GHz of the frequency).
[Note] The wavelength of the microwave we use in this experiment is 2.85 cm.

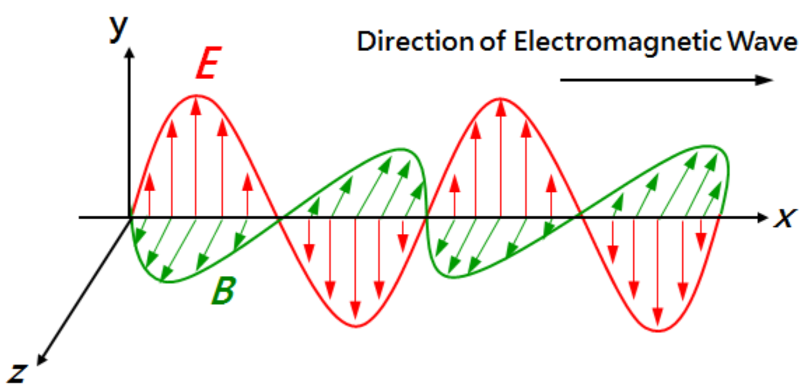

Figure 1. Propagation direction of an electromagnetic wave

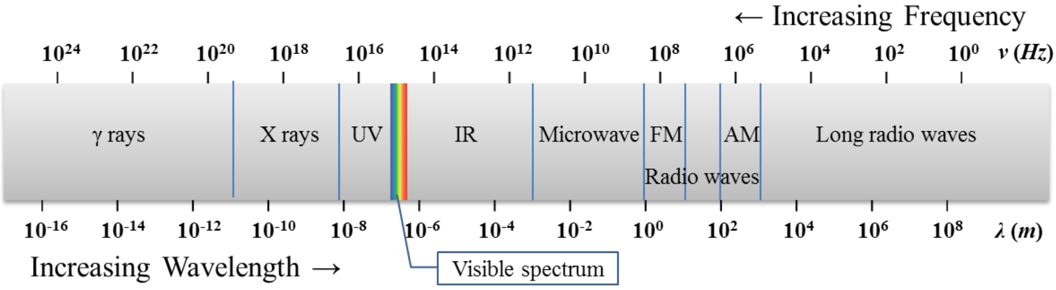

Figure 2. Spectrum of the electromagnetic wave

The element is a diode principally in the microwave transmitter and a crystal detector in the microwave receiver. The receiver can convert the received electromagnetic energy into current and display the value of the current corresponding to the strength of the incident electromagnetic wave power.

A. Standing wave

The trumpet of the microwave receiver is not a perfect receiver. Nevertheless, it can be used as part of the reflector. Utilizing the trumpet of the receiver and transmitter, it will be able to produce standing waves due to microwave reflecting back and forth.

The adjacent section points (belly) of the microwave represent half wavelength. We can calculate the wavelength and frequency ($f = c/\lambda$) through measuring the spacing of the standing waves nodes or antinode of the pitch.

B. Refraction

As shown in figure 3, when the electromagnetic wave propagates through two different media, its traveling direction occur deflection, called refraction. In here refractive index of the two mediums are n_1 and n_2. The relationship of the refractive index in the vacuum and the medium can be described as the ratio of the speeds in the two different media.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\Rightarrow \theta_2 = sin^{-1}\left(\frac{n_1 \sin \theta_1}{n_2}\right)$$

From Snell's Law, we get (θ_1 is the incident angle ; θ_2 is the refraction angle)

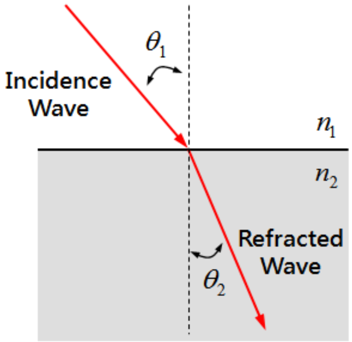

Figure 4. Relationship of the refraction

C. Michelson Interference

(a) Wavelength of microwave λ

Show in figure 4, the transmitter emits the microwaves through the plastic reflector which divided the waves into two waves. One of the waves penetrates through the plastic reflector to the reflector A which reflects the wave back to the receiver. Another wave is reflected by the plastic reflector toward the reflector B and reflected back to the receiver.

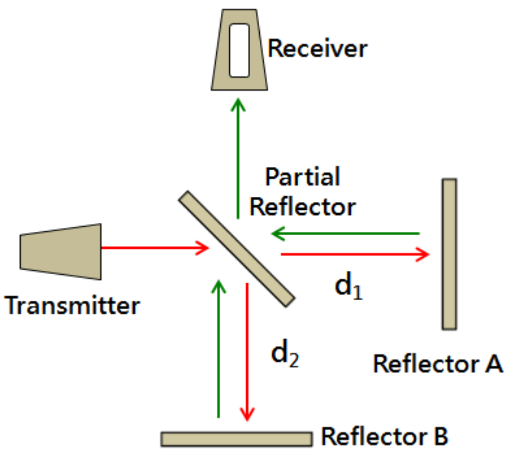

Figure 4. Michelson Interference set-up I

If the path difference between the signals of two reflected waves in the receiver is $2(d_1 - d_2) = m\lambda$, the two waves will build constructive interference and the signal strength of the receiver is also the largest.

$$2(d_1 - d_2) = m\lambda \qquad m = 1,2,3\ldots \qquad (1)$$

Show in figure 5, the path difference when shift again the reflector A to next position Δd in which the signal strength of the receiver is the largest is

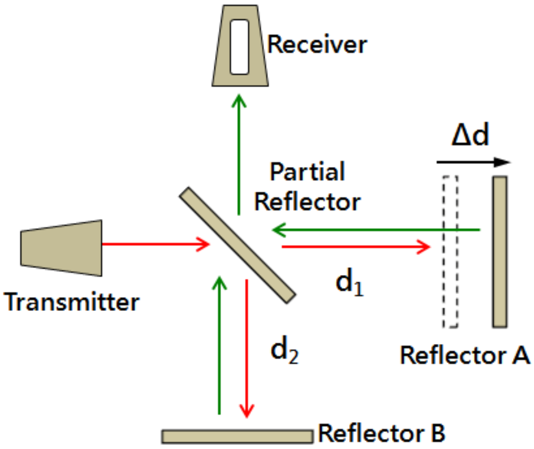

Figure 5. Michelson Interference set-up II

$$2(d_1 + \Delta d - d_2) = (m+1)\lambda \qquad m = 1,2,3\ldots \tag{2}$$

Substitute equation (2) into equation (1), we can find the wavelength of the microwave

$$\lambda = 2\Delta d$$

(b) Refractive index of the medium *n*

Also, we can measure the refractive index of the medium through the Michelson interference. Shift the reflector A to make sure the path difference between d_1 and d_2 satisfy $2(d_1 - d_2) = m\lambda$ and enter a medium between the partial reflector and the reflector A. If the thickness of the medium is *t*, refractive index is *n*, and the path difference became $2[(d_1 + nt - t) - d_2] \neq m\lambda$. Then shift reflector A forward for a distance Δd. It turns out to be that

$$2[(d_1 + nt - t - \Delta d) - d_2] = m\lambda \tag{3}$$

Substitute equation (3) into equation (1), we can find the refractive index of the medium

$$(n-1)t - \Delta d = 0$$

$$\Rightarrow n = \frac{t + \Delta d}{t}$$

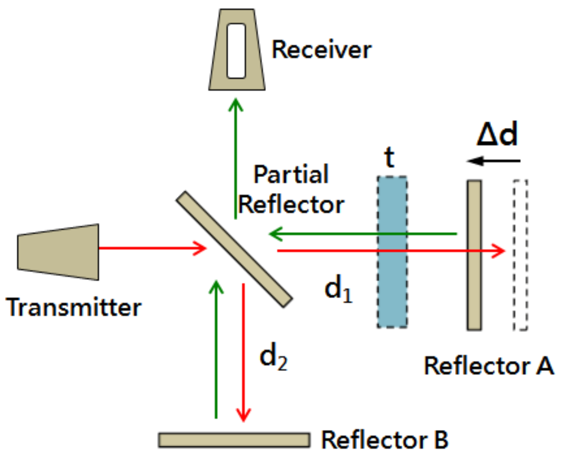

Figure 6. Michelson Interference set-up III

Remarks：

1. Do not look directly into the transmitter! Do not point the transmitter toward your classmates.
2. Do not stand in front of the devices because your body may give rise to the reflection of microwave. You had better stand in back of the transmitter or receiver, and do not place any extra objects, especially metal items, on the table in case of reflection of microwave.
3. Switch the variable sensitivity anticlockwise to the left-end before you turn on the transmitter. And make sure the value on the meter is smaller than 1.00 in order to prevent damage to the device. Shut off the transmitter and notify assistants if the value is larger than 1.00.
4. Turn off the apparatus immediately after finished the measurement.

Procedure：

- **Prepare**
  1. Adjust the angle of transmitter and receiver both the same angle (ex: 0.0°).
  2. Place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.

A. Wavelength measurement of the microwave λ

1. Switch off the intensity multiplier on the receiver. The variable sensitivity turns counterclockwise to the minimum at this moment.
2. Set up the device as figure 7 and place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.

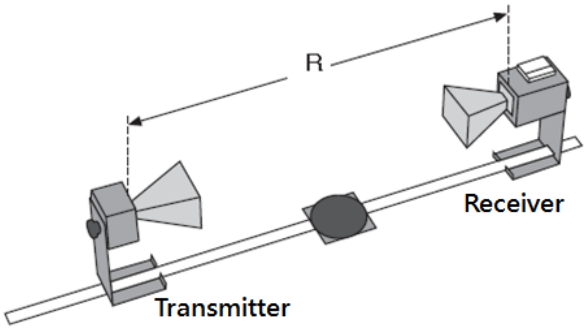

Figure 7. Experiment set-up I

3. Adjust the distance R between transmitter and receiver at about 50.00 cm.
4. Plug in the transmitter, and then switch the multiplier of the receiver to 30X.
5. Adjust the position of the receiver to find a local maximum of the intensity meter, and record the position of receiver.
6. Tune the variable sensitivity switch to amplify the value of the intensity meter to 1.00 mA equivalently.
7. Move the receiver **backward** smoothly. When you find a minimum value of intensity, record the position of receiver and the value of the meter (Intensity).
8. Then, move the receiver **backward** again until you find another maximum value. Record the position of receiver and the value of the meter (Intensity) again.
9. Repeat above steps.
10. Calculate the wavelength and the frequency of microwave.
11. Plot $I-R^{-1}$ and $I-R^{-2}$ diagrams.

B. Refraction measurement of the microwave

1. Switch off the intensity multiplier on the receiver. The variable sensitivity turns counterclockwise to the minimum at this moment.
2. Set up the device as figure 8 and place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.

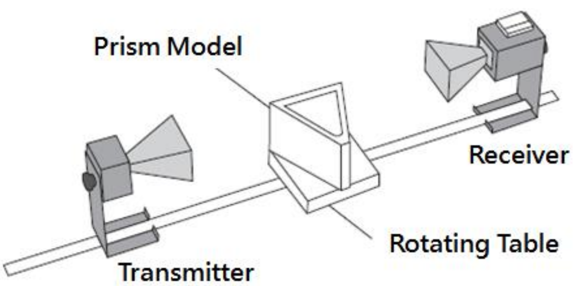

Figure 8. Experiment set-up II

3. Adjust the distance *R* between transmitter and receiver at about 50.00 cm.
4. Put the prismatic model that with pellets of styrene on the rotating table.
5. To make the incident wave vertically incidents in particular surface of prism model. (as figure 9)
6. Plug in the transmitter, and then switch the multiplier of the receiver to 30X.

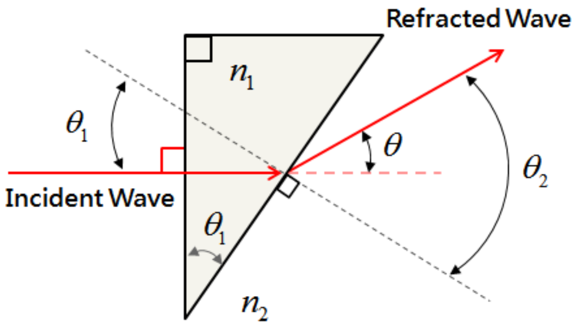

Figure 9. Diagram of the microwave incidence into the prismatic model

7. Rotate the movable arm of the goniometer until the signals of the receiver reach the maximum values. Record this angle as θ.

8. Calculate the refraction angle θ_2 through the prism $\theta_1 = 22^\circ$.

$$\theta_2 = \theta_1 + \theta$$

9. Used the refractive index n_1 of the pellets of styrene with Snell's Law.

$$n_1 = \frac{n_2 \sin \theta_2}{\sin \theta_1} = \frac{n_2 \sin(\theta_1 + \theta)}{\sin \theta_1}$$

C. **Michelson-Interference**

(a) Wavelength measurement of the microwave λ

1. Switch off the intensity multiplier on the receiver. The variable sensitivity turns counterclockwise to the minimum at this moment.
2. Experiment set up as figure 10. Put L-type meter on the goniometer.
3. Place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.
4. Set the angle between the plastic reflector and the transmitter is 45° and make sure the brown surface of the plastic reflector is the incident surface of the microwave.
5. Plug in the transmitter, and then switch the multiplier of the receiver to 30X.

6. Fix the reflector B and record the position d_2. After adjust the position of the reflector A to find a maximum signal of the receiver and record the position d_1 of reflector A.
7. Tune the variable sensitivity switch to amplify the value of the intensity meter to 1.00 mA equivalently.

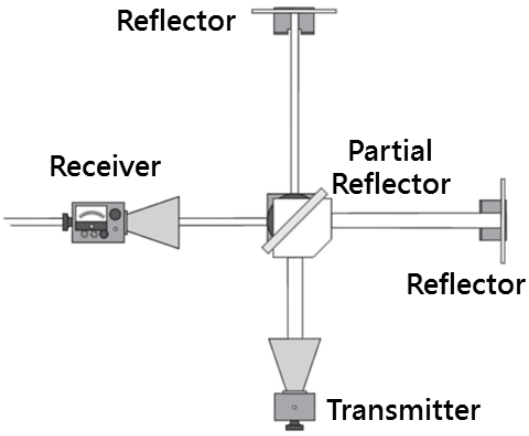

Figure 10. Experiment set-up III

8. Move the reflector A **backward** to another position where there is another maximum signal of the receiver and record the position of the reflector A again. Repeat upper steps to get five maximum signal position d_1'.
9. Subtract the adjacent positions d_1 to find $\Delta d = d_1' - d_1$.
10. Calculate the wavelength λ of the microwave.

$$\Delta d = d_1' - d_1$$
$$\Rightarrow \lambda = 2\Delta d$$

(b) Refraction measurement *n*

1. Switch off the intensity multiplier on the receiver. The variable sensitivity turns counterclockwise to the minimum at this moment.
2. Measure and record the thickness *t* of the polyethylene panel by Vernier caliper.
3. Fix the reflector B and record the position d_2. After adjust the position of the reflector A to find a maximum signal of the receiver and record the position d_1 of reflector A.
4. Place the polyethylene panel between the reflector A and the plastic reflector.
5. Move the reflector A **forward** to another position where there is another maximum signal of the receiver and record the position as d_1' of the reflector A.
6. Calculate the position difference $\Delta d = d_1' - d_1$.

7. Find the refractive index n with equation.

$$n = \frac{t + \Delta d}{t}$$

<u>Questions</u>：

1. What is the relationship between the ideal plane wave and the intensity and distance of the spherical wave? Is it possible to speculate that microwave is a plane wave or a spherical wave? Please explain.
2. In this experiment me measure the index with refraction with Ethafoam prism model filled with Styrene pellet. Will the result different, if we measure with whole Styrene? Please explain.
3. When the refractive index n of the plastic plate is measured by the Michelson Interference method, the reflector plate A is moved forward to obtain the experimental result according to the experimental procedure. Is the same experimental result if the reflector A is moved backwards? Please explain.
4. If we can use microwave to do slit-experiment? Please explain.