Unit-09　Microwave Experiment II

Objective：

Explore the phenomenon of polarization through the microwave. Verify the Malas's law and identify the Brewster angle.

Apparatus：

Transmitter, receiver, goniometer, metal grating, rotating holder, rotating table, plastic panel, Vernier caliper

Principle：

A. Polarization

Polarization (or called polarized) is a phenomenon which only exists in transverse wave. For an arbitrary electromagnetic wave, the vibration direction of the electric field at any point in all directions is possible, and is also known as random polarization or non-polarization. Common lights, including sun light and any light emitted from fluorescent lamps or light bulbs, are all non-polarization. In other words, if the oscillation direction of the electric field exists only in a particular direction, this aspect is the direction of polarization of the wave and so called the polarization wave, such as the electromagnetic wave at a TV station or a broadcast station.

1. Linear polarization: the vibration direction of the electric field is independent of time.
   (a) Trans Electric (TE) modes: the vibration direction of the electric field is parallel to the incident plane.
   (b) Trans Magnetic (TM) modes: the vibration direction of the electric field is perpendicular to the incident plane.

2. Circular polarization: the vibration direction of the electric field is dependent upon time. Therefore, the vibration direction of the electric field can be divided into two quadrature components with different phases but the same amplitude.

3. Elliptical polarization: the vibration direction of the electric field is dependent upon time. Therefore, the vibration direction of the electric field can be divided into two quadrature components with different phases and amplitudes.

B. Polarizer

A common polarizer is a directional thin film material, made by Polyvinyl Alcohol (PVA). As shown in figure 1. , the polarizer can select the vibration direction of the electric field. Only particular direction of the incident electromagnetic wave can be passed through. The vibration direction is in the polarizer transmission axis.
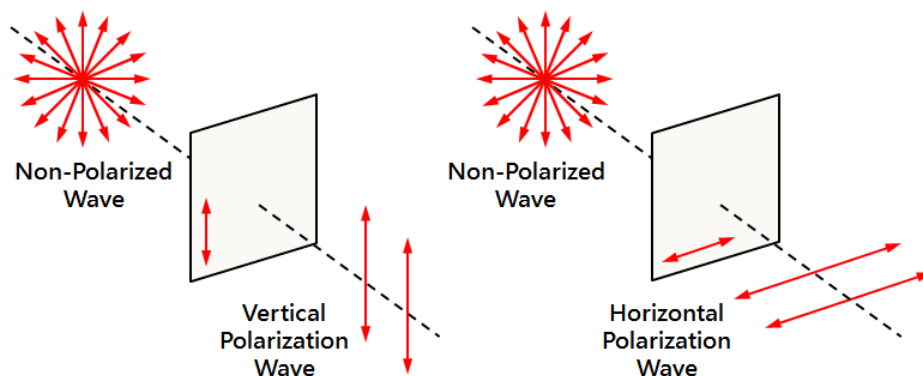

Figure 1. The electric field which is parallel to the transmission axis

C. Malus's Law

As shown in figure 2, assume the amplitude of the electric field for a polarized wave E_0 is and its intensity I_0 is proportional to the square of the amplitude E_0, it means $I_0 \propto E_0^2$.

$$I_0 \propto E_0^2$$

When a polarization wave pass through a polarizer, and the penetration component of the electric field which can pass is E_1. If the angle between the vibration direction of electric field and transmission axis of the polarizer is θ, so

$$E_1 = E_0 \cos\theta$$

And the intensity of the electric field which pass through the polarizer I_1 is proportional to the square of the amplitude E_1, it means

$$I_1 \propto E_1 = \left(E_0 \cos\theta\right)^2 = E_0^2 \cos^2\theta$$
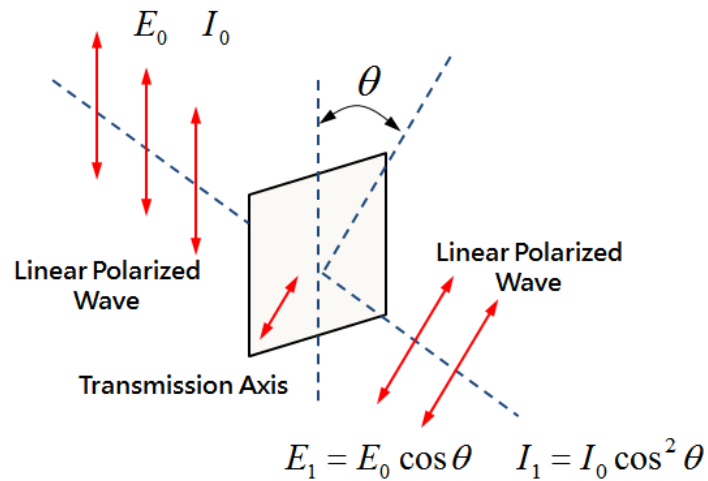$$\Rightarrow I_1 = I_0 \cos^2\theta$$

Figure 2. The variation of the intensity of a polarized wave incident into a polarizer

D. Microwave incident into metal grating

The best polarizer devices are metal fences for the electromagnetic waves in the spectrum between the infrared band and the microwave band. The reason it can polarize a plane wave is that the distribution medium is anisotropy.

As shown in figure 3 and figure 4. Generally, the vibration direction of the electric field for an incident electromagnetic wave can be divided into two parts. One is parallel to the metal lines and the other is perpendicular to the metal lines. The former is almost total reflection and the latter is almost fully penetration. Therefore, the penetration waves can be polarized.
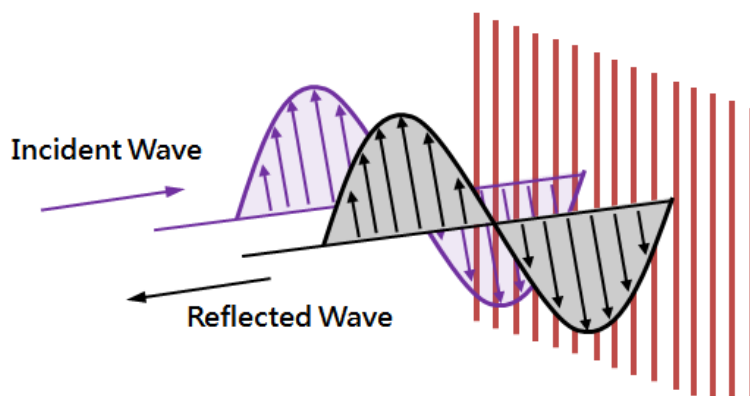

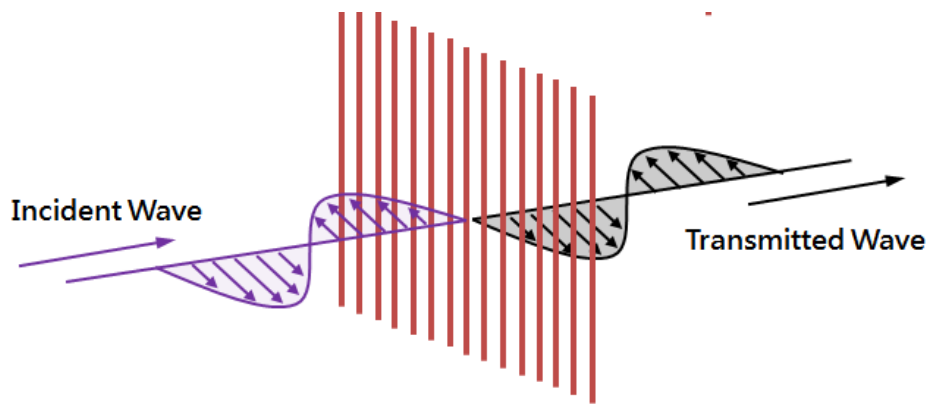Figure 3. Microwave incident into metal grating (parallel)

Figure 4. Microwave incident into metal grating (vertical)

E. Brewster's Law

As shown in figure 5(a), the non-polarized wave electric field vibration direction into vertical and horizontal polarization components incident on the two media, the reflected wave and the electric field vibration directions are refracted wave comprising vertical and horizontal polarization.

As shown in figure 5(b). When non-polarized wave incidence angle changes, that the reflected wave intensity of the vertically and horizontally polarized will vary the angle of incidence varies.
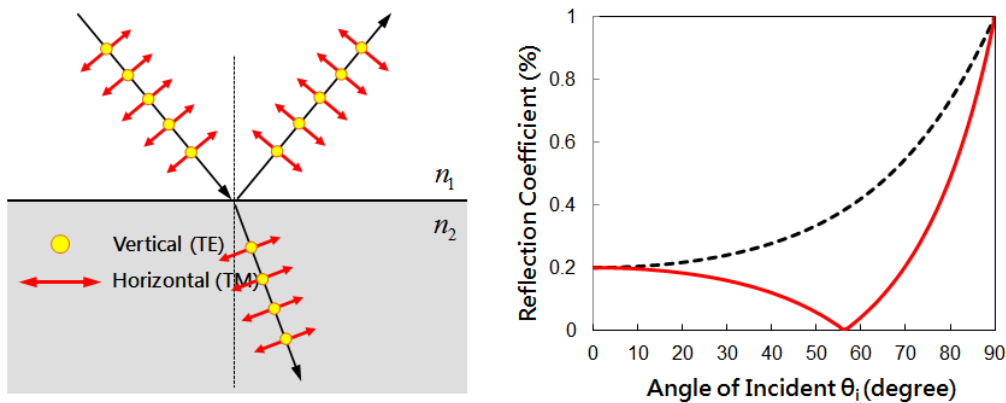
(a) Vibration direction of the electric field   (b) Reflection coefficient versus angle of incident

Figure 5. Non-polarized wave incident into a medium

After a non-polarized wave incident into a medium (divided into vertical polarized and horizontal polarized), when the angle between the reflective wave and refractive wave is 90°, only vertical polarized component is reflected for the reflective wave. Therefore, the reflective wave completely becomes a polarized wave, and the refractive wave keeps still in a partial horizontal polarized wave.

This particular incident angle is known as Brewster angle θ_B, as shown in Fig 5. We can find the Brewster angle θ_B from Snell's Law.

$$n_1 \sin \theta_B = n_2 \sin \theta_r$$
$$n_1 \sin \theta_B = n_2 \sin(90° - \theta_B)$$
$$n_1 \sin \theta_B = n_2 \cos \theta_B$$
$$\Rightarrow \tan \theta_B = \frac{\sin \theta_B}{\cos \theta_B} = \frac{n_2}{n_1}$$

that

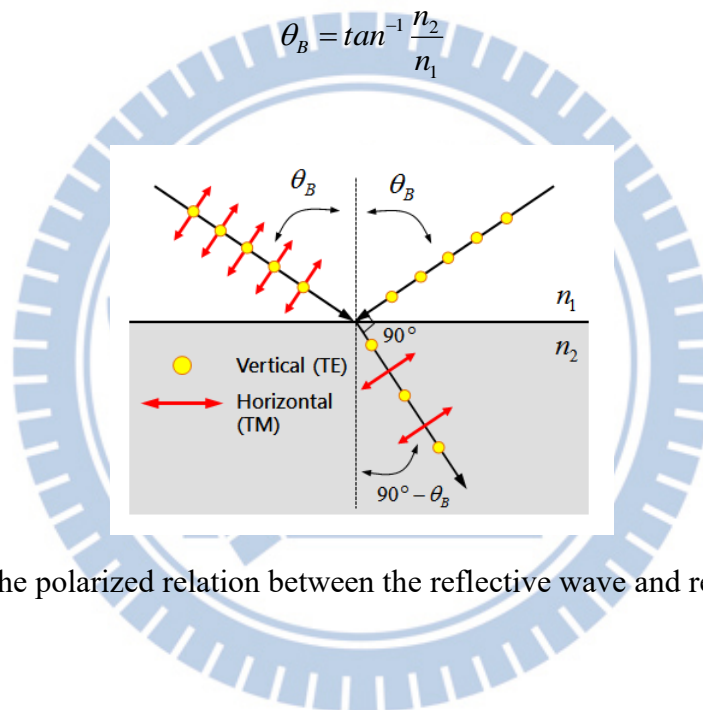$$\theta_B = \tan^{-1} \frac{n_2}{n_1}$$

Figure 6. The polarized relation between the reflective wave and refractive wave

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：

> **Preparation**
> 1. Place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.

A. The observation of the polarization phenomenon for the microwave
1. Switch off the intensity multiplier on the receiver. The variable sensitivity turns counterclockwise to the minimum at this moment.
2. Adjust the angle of transmitter and receiver both 0.0°.
3. Set up the device as figure 7 and place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.
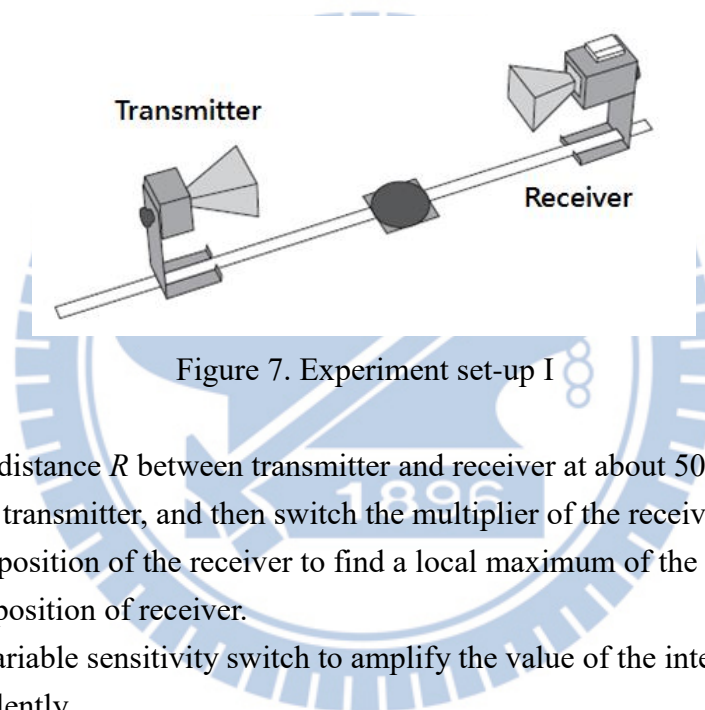

Figure 7. Experiment set-up I

4. Adjust the distance R between transmitter and receiver at about 50.00 cm.
5. Plug in the transmitter, and then switch the multiplier of the receiver to 30X.
6. Adjust the position of the receiver to find a local maximum of the intensity meter, and record the position of receiver.
7. Tune the variable sensitivity switch to amplify the value of the intensity meter to 1.00 mA equivalently.
8. Unfasten the screw in the back of the receiver and adjust the angles. Record the values I of measurement on the receiver.
9. Plot $I - \cos^n \theta$ diagram.
   [Note] You should determine the value of n firstly. $n = 1 \cdot 2 \cdot 4$

B. The observation of the incidence into a polarizer for the microwave
(a) Change the angles of the transmitter and receiver simultaneously
1. Switch off the intensity multiplier on the receiver. The variable sensitivity turns counterclockwise to the minimum at this moment.
2. Adjust the angle of transmitter and receiver both 0.0°.
3. Set up the device as figure 7 and place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.

4. Adjust the distance R between transmitter and receiver at about 50.00 cm.
5. Experiment set up shown in figure 8. Make sure the metal grating is attracted to the base holder in the horizontal direction and then fix it on the goniometer.
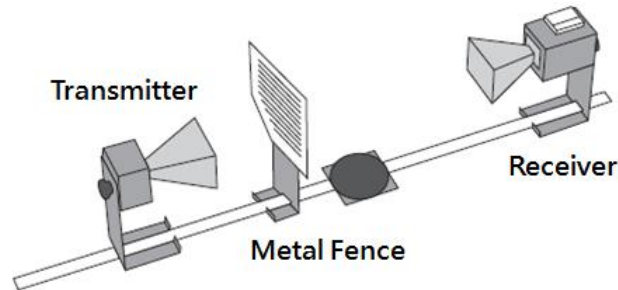

Figure 8. Experiment set-up II

6. Plug in the transmitter, and then switch the multiplier of the receiver to 30X.
7. Adjust the position of the receiver to find a local maximum of the intensity meter, and record the position of receiver.
8. Tune the variable sensitivity switch to amplify the value of the intensity meter to 1.00 mA equivalently.
9. Unfasten the screw in the back of the transmitter and receiver and adjust the angles. Record the values I of measurement on the receiver.
10. Plot $I - \cos^n \theta$ diagram.
    [Note] You should determine the value of n firstly. $n = 1 \cdot 2 \cdot 4$

(b) Fix the angle of the transmitter to 0°, the angle of the receiver to 90° and change the angle of the polarizer
1. Switch off the intensity multiplier on the receiver. The variable sensitivity turns counterclockwise to the minimum at this moment.
2. Adjust the angle of the transmitter back to 0° and the angle of the receiver to 90°.
3. Set up the device as figure 7 and place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.
4. As shown in Figure 8, place the rotating base on the goniometer and then attach the metal grating to the base in the horizontal (0.0°) direction.
5. Plug in the transmitter, and then switch the multiplier of the receiver to 30X.
6. Adjust the direction of the stripes in the metal grating to horizontal (0.0°), 45.0°, verticality (90.0°) and record the values I of measurement on the receiver.

C. Measure the Brewster angle

1. Switch off the intensity multiplier on the receiver. The variable sensitivity turns counterclockwise to the minimum at this moment.
2. Adjust the angle of transmitter and receiver both 90.0°.
3. Set up the device as figure 9 and place the transmitter and receiver respectively in the fixed arm and movable arm of the goniometer.
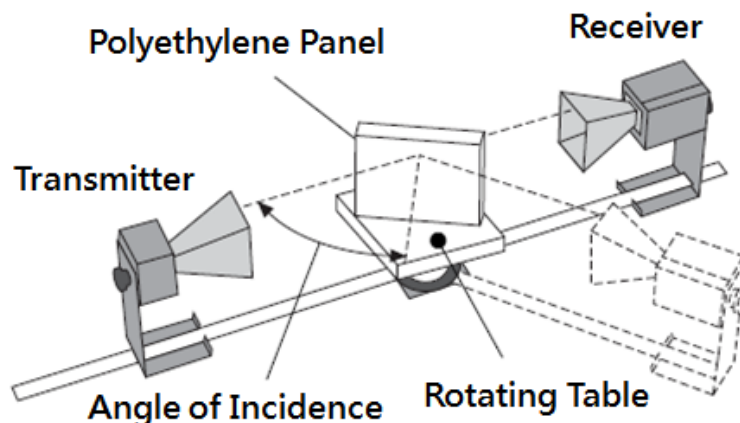

Figure 9. Experiment set-up III

4. Fix the rotating table on the protractor and put the polyethylene panel on it.
5. Plug in the transmitter, and then switch the multiplier of the receiver to 30X.
6. Adjust the distance between the rotating table and polyethylene panel so that the microwave can incident to the polyethylene panel at 70.0°.
7. Rotate the movable arm so the receiver is located at the reflection direction, that is, the reflection angle is 70.0°
8. Move the receiver back and forth to get the maximum value on the meter.
9. Record the values on the intensity multiplier and I of measurement on the receiver.
10. Calculate the intensity of the microwave I'.
    [Note] I' =value of the intensity multiplier $\times I$
11. Do the same as above while setting the angle behind the transmitter and receiver to 0°. Record the values on the intensity multiplier and I of measurement on the receiver.
12. Change the angle of the microwave incidence and Record the values on the receiver per 5.0° when angles of the transmitter and receiver are both 90.0° and 0.0° simultaneously.
13. Plot $I' - \theta_i$ diagram.

    [Note] Both the vertical polarization (**the angles of the transmitter and receiver are both 0.0° simultaneously**) and horizontal polarization (**the angles of the transmitter and receiver are both 90.0° simultaneously**) should on the same diagram.

14. Find the possible range of the Brewster angle θ_B from this diagram.

15. Measure the values I on the receiver per 1.0° in the range when angles of the transmitter and receiver are both 0.0° and 90.0°. 。

16. Plot $I' - \theta_i$ diagram.

   [Note] Both the vertical polarization (**the angles of the transmitter and receiver are both 0.0° simultaneously**) and horizontal polarization (**the angles of the transmitter and receiver are both 90.0° simultaneously**) should on the same diagram.

17. Find the Brewster angle θ_B.

18. Calculate the refractive index n.

Questions：

1. In the instruction, A and B-(a), what is the value of n inferred from your experimental results? Please explain.

2. Compare the limitation of stripe width and the gap from the polarizer with the wavelength of microwave. Do they influence the experiment? Please explain.

3. Can the Brewster angle and the total reflection of the critical angle be exist at the same time? Please explain.