EXPERIMENT 1
OPTICAL POWER MEASUREMENT

OBJECTIVES:

The objectives of this experiment are to understand the basic concepts of optical power measurements using optical power meters, the difference between calibrated and non-calibrated optical power meters, the proper use of the various optical power units and conversion between those units. In order to gain experience with optical power measurement, the optical power loss due to microscope glass slides will be determined experimentally using a non-calibrated optical power meter. The experimental results will be compared with theory.

EQUIPMENT:

1. Optical Power Meter: INFOS, Model # M100.
2. HeNe Laser: Coherent, Model # 31-2090-000.
3- One glass microscope slide, marked with 8 circles.
3. Five glass microscope slides, each marked with a single circle.
4. Glass slide holder.
5. Laboratory jack.
6. Short optical bench (about 1/4 meter long).
7. Horizontal and vertical translation stages assembled on a bench base.

PRELAB ASSIGNMENT:

Read appendices B and C thoroughly in order to prepare for this laboratory experiment. The information contained in appendices B and C provide basic background for optical power measurement, which is important for understanding this experiment and future experiments.

Before the experimental part of this experiment, the laboratory instructor will briefly explain appendix B and C, but it's your responsibility to fully understand their contents.

INTRODUCTION:

It is well-known that when an optical beam is incident *normally* from a medium with refractive index n_1 onto another medium with refractive index n_2, part of the beam is reflected and part of it is transmitted (see Figure 1). Note that the incident beam encounters a single interface only. The reflectivity R_1 and transmissivity T_1 in this case are given by:

$$R_1 = \frac{P_r}{P_i} = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2 \qquad\qquad (1)$$

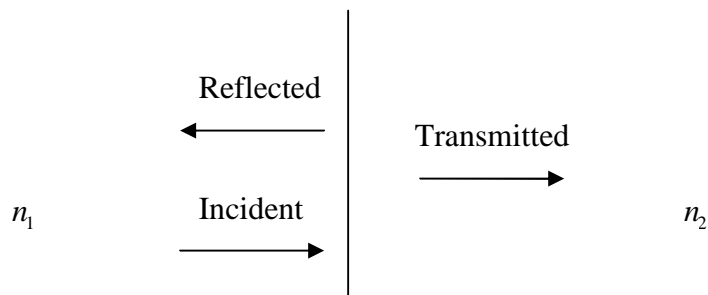$$T_1 = \frac{P_t}{P_i} = 1 - R_1 = \frac{4n_1 n_2}{(n_1 + n_2)^2} \qquad (2)$$

Figure 1: Reflection and Transmission of Light at a Single Interface.

Where P_i, P_r and P_t denote the incident, reflected and transmitted powers, respectively. The subscripts in R_1 and T_1 denote reflection and transmission through a single interface.

The situation becomes more involved when light passes through a slab of material with a non-zero thickness d, as shown in Figure 2. The refractive index of the slab is assumed to be n_2 and the refractive index of the surrounding material is assumed to be n_1. This type of problem is different from the single interface problem shown in Figure1, because in this particular case, the light beam encounters two parallel interfaces, leading to multiple reflections inside the slab.
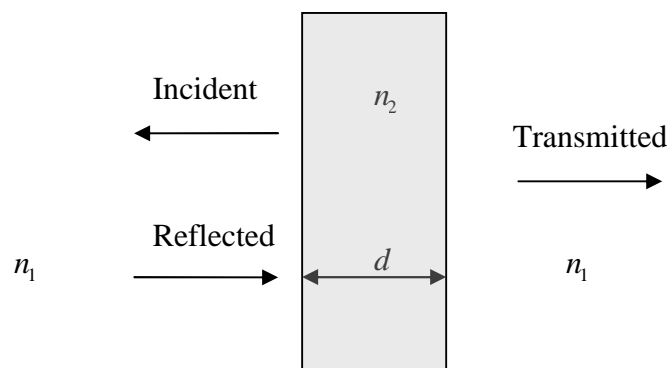

Figure 2: Reflection and Transmission of Light at Two Parallel Interfaces.

According to theory, the transmissivity T_2 of the slab shown in Figure 2 is given by:

$$T_2 = \frac{P_t}{P_i} = \frac{(1 - R_1)^2}{(1 - R_1)^2 + 4R_1 \sin^2 \delta} \qquad (3)$$

Where R_1 is the reflectivity of a single interface, which is given by equation (1), $\delta = k_o n_2 d = (2\pi/\lambda)n_2 d$ and λ is the free space wavelength. The subscript in T_2 indicates the presence of two parallel interfaces.

According to equation (3), when the parameter δ is a multiple of π (i.e. $\delta = k_o n_2 d = 0, \pi, 2\pi, 3\pi, \ldots$) the transmissivity reaches a *maximum* value of 1. However, when δ is an *odd* multiple of $\pi/2$ (i.e. $\delta = k_o n_2 d = \pi/2, 3\pi/2, 5\pi/2, \ldots$) the transmissivity reaches a *minimum* value of $(1-R_1)^2/(1+R_1)^2$. Thus the transmissivity T_2 of the slab *always* lies in the range:

$$(1-R_1)^2/(1+R_1)^2 \le T_2 \le 1 \qquad (4)$$

Let us assume that the slab is made of *glass* ($n_2 = 1.50$) and the surrounding medium is *air* ($n_1 = 1.00$). Using equation (1) results in $R_1 = 0.04$. Then using equation (4), it is easy to show that T_2 lies in the range:

$$0.852 \le T_2 \le 1.0 \qquad (5)$$

Using equation (5), we can calculate *range* of the power loss in dB that an optical beam encounters when passing through a slab of glass (see appendix B):

$$-10\log(0.852) \ge dB_{Loss} \ge -10\log(1.0)$$

$$0.696\ dB \ge dB_{Loss} \ge 0\ dB \qquad (6)$$

In this experiment, the power loss due to a glass slab in the form of a microscope slide will be measured in dB. Because the thickness d of the microscope slide is *not uniform* across the slide, the parameter δ changes value depending on the location where the light beam passes through the slide. This means that the power loss caused by the glass slide is also not uniform. However, according to theory this loss must always lie in the range given by equation (6). Also according to equation (6), the *mean* loss of the glass slide equals $(0 + 0.696)/2 = 0.348\ dB$.

The gain an insight into how the slide thickness effect the transmissivity, let us note that a $\pi/2$ *change* in the parameter δ can cause the transmissivity to change from maximum to minimum or vice versa. For $\Delta\delta = \pi/2 = k_o n_2 \Delta d$, we have $\Delta d = (\pi/2)/(k_o n_2) = \lambda/(4n_2) = 0.6328/(4 \times 1.5) \approx 0.11\mu m$. Thus a very small change in d can lead to large changes in the transmitted power.

This experiment consists of two main parts. In part A, the optical power loss experienced by a light beam as it passes through different locations of the same glass slide will be measured. In part B, the optical power loss due to a number of glass slides, separated by air gaps will be measured. Note that in part B, optical power readings will be repeated using different meter wavelength settings. One objective of part B is o find out if the meter setting has an effect on the optical loss measurements.

PROCEDURE:

PART A:

1- Turn on the optical power meter and the HeNe Laser. Wait for about 15 minutes in order for the HeNe laser output to stabilize.

2- In the optical power meter, select $\lambda = 0.85\,\mu m$ and the dBm scale. [*The optical power meter is clearly not calibrated, because the HeNe laser has a wavelength of* $0.633\,\mu m$].

3- Align the Laser and the power meter for maximum meter reading. This gives the value of P_i in dBm, record it in table 1. [*Take extra care not to move the laser source or the power meter after you take this reading*].

4- Insert the glass slide (the glass slide marked with 8 circles) between the laser source and the power meter (see Figure 3). The slide should be positioned so that the laser beam passes through circle number 1. [*The glass slide must be kept clean, by holding the slide on the sides only*].

5- Record the power meter reading in table 1 in the column marked P_o.
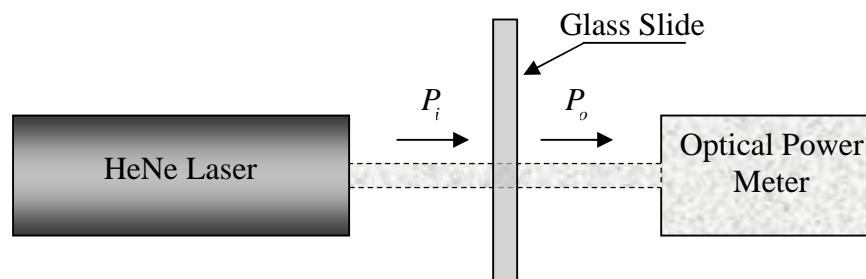

Figure 3: A Glass Slide Inserted between the Laser Source and the Optical Power Meter.

6- Repeat step 5, when the light passes through circles number 2 through 8.

7- Calculate and record the power loss in dB ($dB_{Loss} = P_i - P_o$) for each of the 8 cases.

8- Calculate the average *experimental* dB loss and record its value in table 1.

9- Plot the dB_{Loss} versus circle number.

10- Compare the experimental results obtained in table 1 with the theoretical *range* of the dB power loss [as predicted by equation (6)]. Are the results within the predicted range?

11- Compare the average theoretical and average experimental dB power losses.

12- Discuss the results, write comments and some conclusions.

Circle Number	P_o (dBm)	dB_{Loss}	$P_i =$	dBm
1				
2				
3				
4				
5				
6				
7				
8				
	Theoretical Average dB loss	Experimental Average dB loss		
	0.348 dB			

Table 1: Input and Output Powers in dBm when Light Passes through Different Locations of the Microscope Glass Slide.

PART B:

1- Leave the optical power meter setting at $\lambda = 0.85 \ \mu m$ and the dBm scale.

2- Remove the slide used in part A.

3- Align the Laser and the power meter for maximum meter reading. Record the meter reading in table 2.

4- Insert the glass slide # 1 between the laser source and the power meter. The slide should be positioned so that the laser beam passes through the circle.

5- Insure that the laser beam passes (as close as possible) through the *center* of the circle.

6- Record the power meter reading in table 2 in the column marked P_o.

7- Add slide # 2 (do not remove slide # 1). Record the meter reading in table 2.

8- Keep adding new slides, one at a time and record the meter reading in table 2, until you finish inserting all the five slides provided.

9- Calculate the dB loss in each case and record the values in table 2.

10- Plot the dB_{Loss} versus the total number of slides used.

11- Change the power meter setting to $\lambda = 1.310 \ \mu m$.

12- Remove all the slides.

13- Repeat steps 3 through 10 using the new meter setting. *Add the slides in the same previous order, slide 1 first, followed by slide 2 and so on.*

14- Discuss and compare the results obtained in tables 2 and 3. Does the dB loss measurement depend on the power meter setting? Write some conclusions.

Slide Number	P_o (dBm)	dB$_{\text{Loss}}$	$P_i =$ dBm
1			
2			
3			
4			
5			

Table 2: Input and Output Powers in dBm when Light Passes through a Number of Microscope Glass Slides. The Optical Power Meter is Set at $\lambda = 0.85\,\mu m$.

Slide Number	P_o (dBm)	dB$_{\text{Loss}}$	$P_i =$ dBm
1			
2			
3			
4			
5			

Table 3: Input and Output Powers in dBm when Light Passes through a Number of Microscope Glass Slides. The Optical Power Meter is Set at $\lambda = 1.310\,\mu m$.

QUESTIONS:

Make sure you read Appendix B, before you answer these questions.

1- Convert 0dBm to: a) mW   b) W   &   c) μW

2- Convert 0.1 mW to: a) dB   b) dBm   &   c) dBμ

3- Convert $0.3\,\mu$W to: a) dB   b) dBm   &   c) dBμ

4- A 2.5 mW optical beam passes through a lossy optical element. If the loss of the element is 10 dB, calculate the output power in mW and in dBm.

5- The input to a lossy element is $25dB\mu$ an the output power is $14dB\mu$. Calculate the dB element loss.