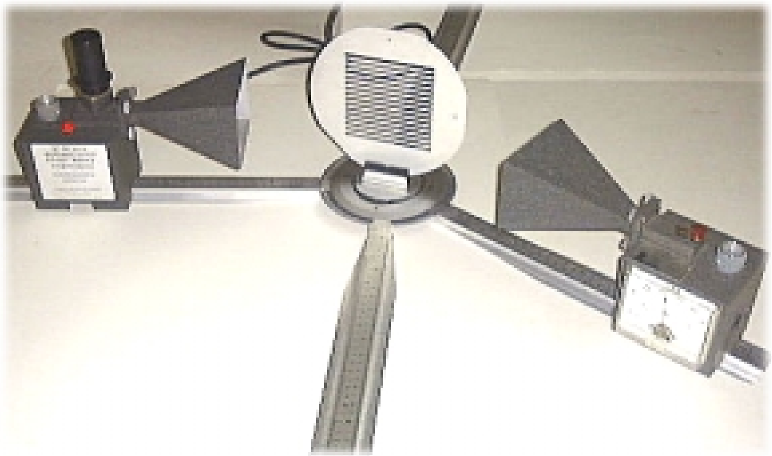
MICROWAVE OPTICS

REFERENCES

Halliday, D. and Resnick, A., Physics, 4th edition, New York: John Wiley & Sons, Inc, 1992, Volume II.

INTRODUCTION



The Microwave Optics set is essentially a sophisticated toy that can be employed to illustrate - in a qualitative and often quantitative fashion - many of the phenomena associated with wave propagation in general and electromagnetic wave propagation (including polarization) in particular.

In this experiment you should make qualitative observations to the best of your (or the apparatus') ability. The text below describes nine possible experiments you can do with the apparatus.

This experiment is worth only one weight. You should perform at least four of the following experiments with at least 2 from 5, 6, 7 and 8.

THE APPARATUS

Figure 1 shows the basic components of the set, the transmitter, with its klystron oscillator producing microwaves of approximately 3 cm wavelength, the receiver, the antenna horn, and various positioning devices and slides.

The apparatus is set up by placing the receiver and transmitter (with attached horns) facing each other on their slides, with the ends of the horns about 20 cm apart. Set the gain control on the receiver at about 3 divisions, let the klystron (transmitter) warm up for at least two minutes. *Very slowly* adjust the repeller tuning knob on the transmitter to obtain maximum power as read on the receiver meter. You will find various power peaks. For your experiment, use the peak that gives the highest reading. This tuning must be done very carefully. It should be checked for *minor* adjustment before each experiment.

Note that while taking readings it is important, in order to avoid affecting your data, that you avoid placing your hand or any other object within the region of the microwave field.

Also note that the meter on the receiver is very heavily damped in order to reduce the effects of extraneous electrical noise. We thus recommend that all measurements in which apparatus is moved or positioned be made by moving the components *very slowly*.

Be careful! The top of the transmitter gets very hot.

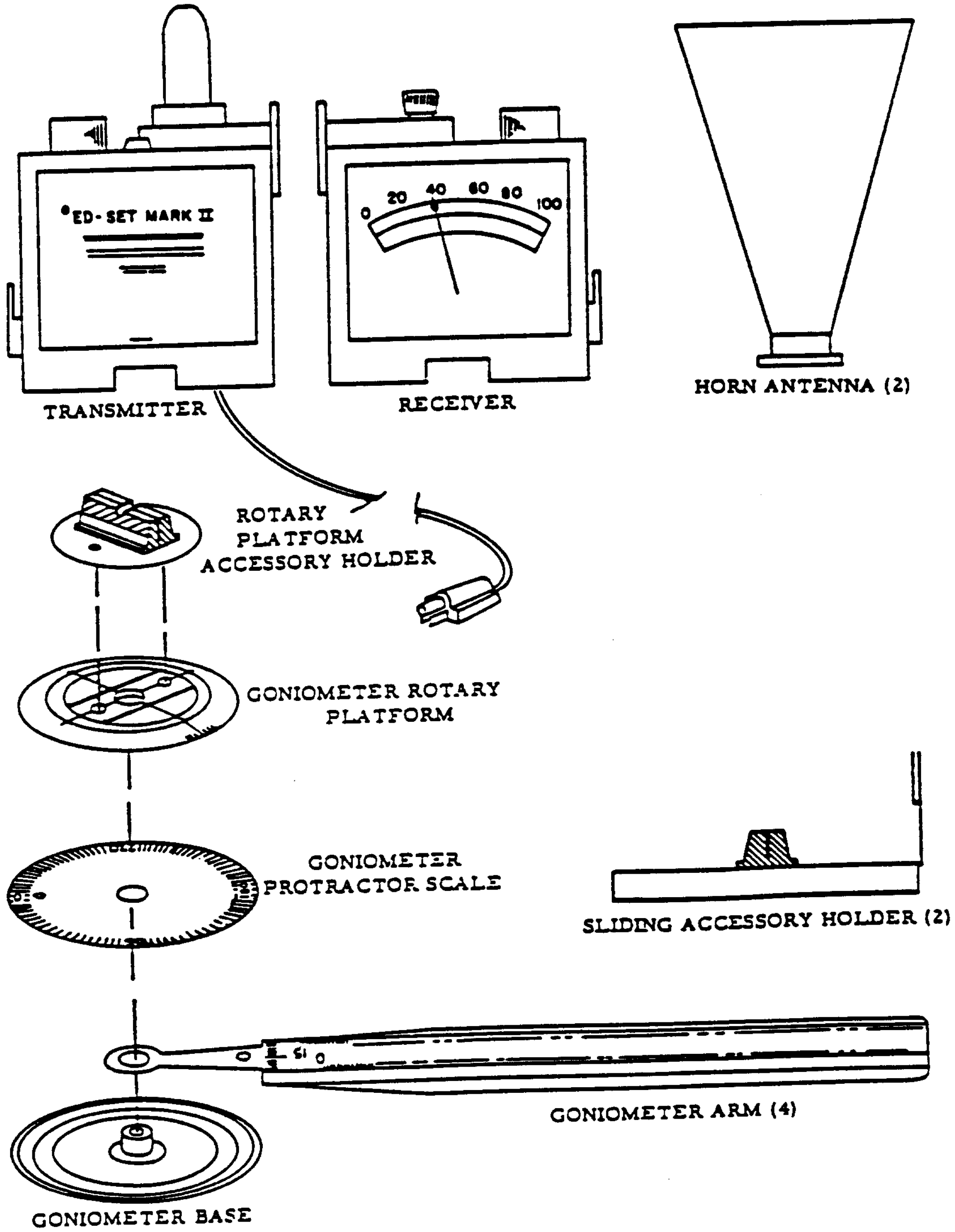


Figure 1.

Figure 2 shows the various masks, reflectors, refractors, slits and grids that you have available to mount in the accessory holder for your various experiments.

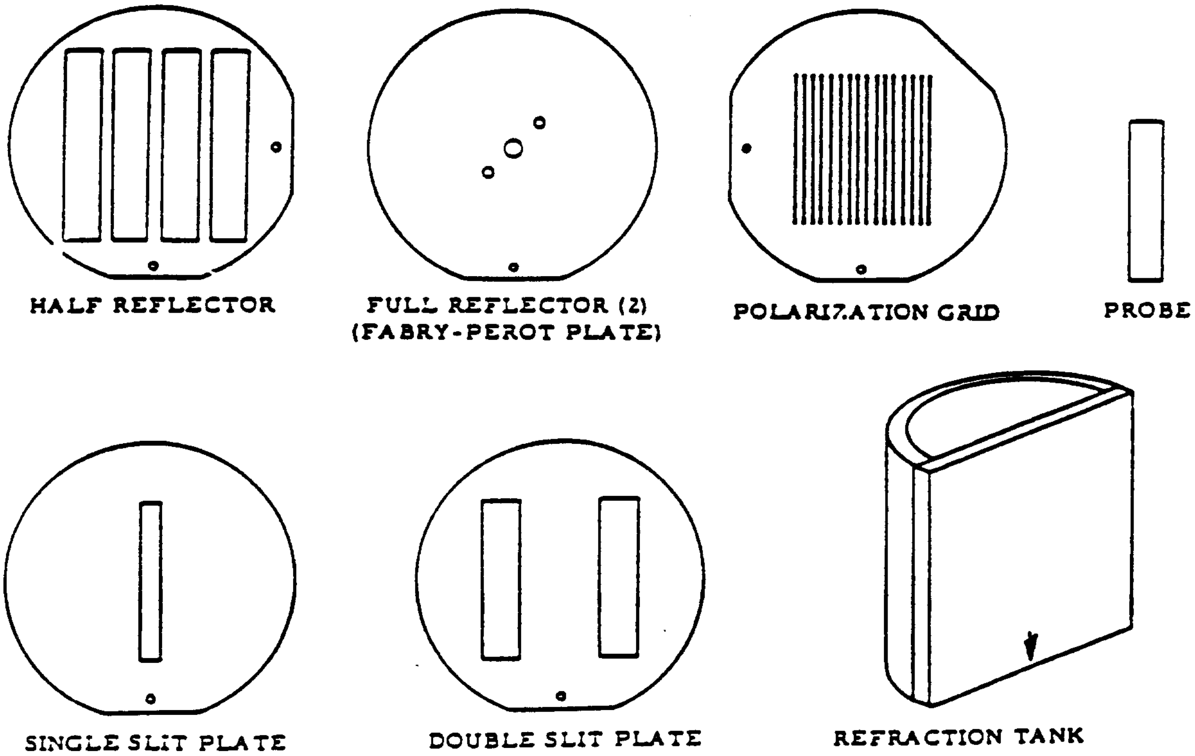


Figure 2.

THE EXPERIMENTS

1. Absorption

Placing the receiver and transmitter (with attached horns) on their slides, facing each other with the ends of the horns about 20 cm apart, set the gain control on the receiver to obtain a reading of 100 on the receiver meter. Place, on the rotary platform, an absorber such as a text book with the cover at an angle of 45 degrees to the line between the transmitter and receiver. Note the receiver reading, giving the transmitted power. Now move the receiver to the 90 degree position to maximize reflection off the book cover into the receiver and observe the reflected powers. The incident (original) power level minus the sum of the transmitted and reflected power is the absorbed power. The absorption is the ratio of the absorbed power to the incident power. You may also try other absorbers such as wood, dry-wall board, cellulose sponge, glass plates, plastics, etc. The measurements in this section can only be very qualitative.
Note: If the absorber is too small, bending of the waves around it can distort your readings.

2. Polarization

The klystron and horn produce electromagnetic waves with the electric vector polarized vertically. Arrange the apparatus as in the previous section, but with the polarization grid placed in a plane perpendicular to the beam in the rotary platform accessory holder. Rotate the grid about an axis perpendicular to its plane and observe the receiver readings. Can you explain how the polarization grid works? Interpret your observations in the light of what you know about polarization of light.

3. Law of Reflection

Arrange the apparatus as in Figure 3. Rotate the rotary platform and find the position for the peak reading. Repeat this procedure using different angles between receiver and transmitter. For one or two angles, use the polarizing grid in place of the full reflector, with the grid turned first with its slots horizontal, then with its slots vertical. Can you prove that the direction of polarization does not change when the microwave is reflected? Knowing that the direction of polarization of the electric vector for these microwaves is vertical, what do you conclude?

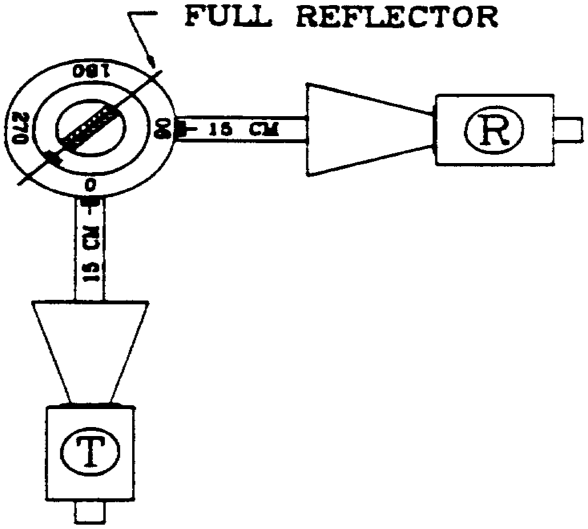


Figure 3.

4. Standing Waves

Standing Waves

Arrange the apparatus as in Figure 4. This arrangement will create a standing wave pattern between the transmitter and the full reflector. A portion of the wave pattern is picked up by the probe plate and reflected to the receiver. As you move the full reflector you can observe the variations of the signal being picked up by the receiver. Plot a graph of the standing wave intensity in terms of reflector position and find the positions of the maxima and minima that you can use to determine the wavelength, λ.

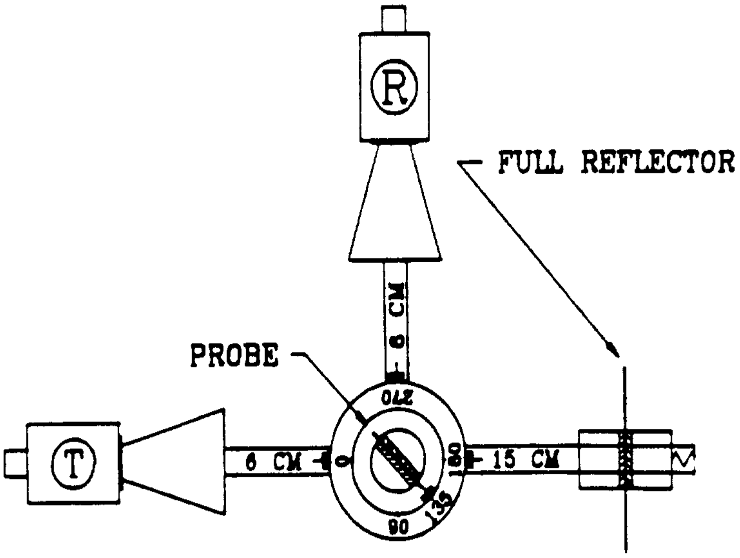


Figure 4.

5. Michelson Interferometer

An interfereometer is an apparatus that can be used to measure the wavelength of a wave by utilizing the interference between two waves (see Reference, Volume II, Chapter 45-6, pp.959-960**)**. Arrange the apparatus as in Figure 5.Optimize the setup for sharpest nulls by removing the full reflectors from the two sliding accessory holders and by slightly changing the positions of the transmitter and receiver from their 10 cm marks until a maximum reading is obtained. Place the two full reflectors on the two holders again and position the 270 degree full reflector for a minimum reading on the meter. Sharpen this null by adjusting the 180 degree full reflector. Adjusting the 270 degree full reflector will now give deep nulls. The free space wavelength can now be determined by measuring the distance travelled by the 270 degree full reflector between nulls. This distance is equal to ½ wavelength in free space.

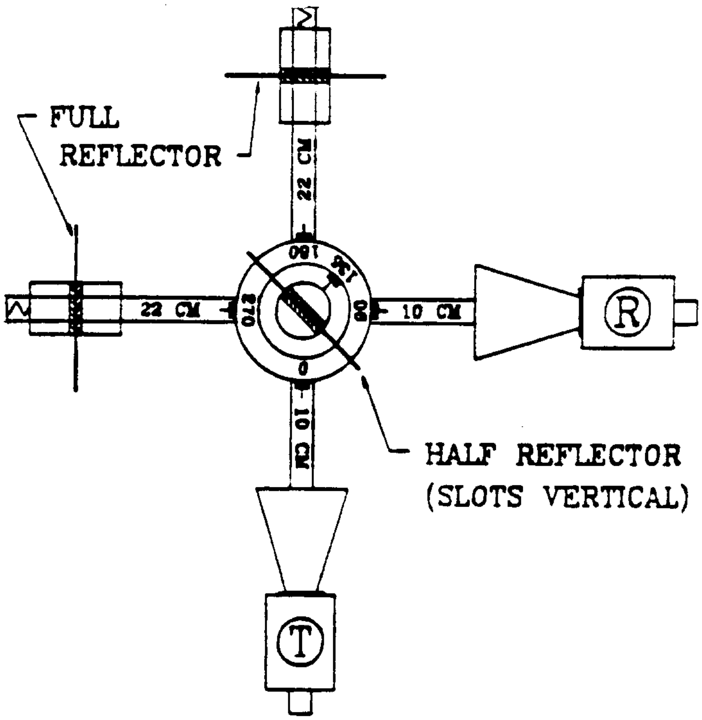


Figure 5.

In addition you may measure the index of refraction of low loss materials in this sheet form by placing the sheet in a vertical position between the 270 degree full reflector and the half reflector. Subject to minor error caused by multiple reflections within the sample, the index of refraction can be calculated using

$$\eta = 1 + \frac{\Delta}{d}$$

where η is the index of refraction, Δ is the full reflector movement required to restore the original null after insertion of the material, and d is the thickness of the sample (see the Appendix for the details).

6. Thickness of a Thin Film

Arrange the apparatus as in Figure 6. Using the positioning attachment, move the full reflector away from the half reflector to produce sharp nulls and peaks in the receiver readings. By noting the distance between the full reflector and the half reflector at null points, it will be observed that nulls occur when the distance between the full reflector and the half reflector are multiples of half wavelengths of the microwaves. This is analogous to optical thin-film interference effects which produce dark and light bands in the reflected light of a single colour (see Reference, Volume II, Chapter 45-4, pp.955-958). In this case the spacing between the half reflector and the full reflector plays the role of the thickness of the thin film.

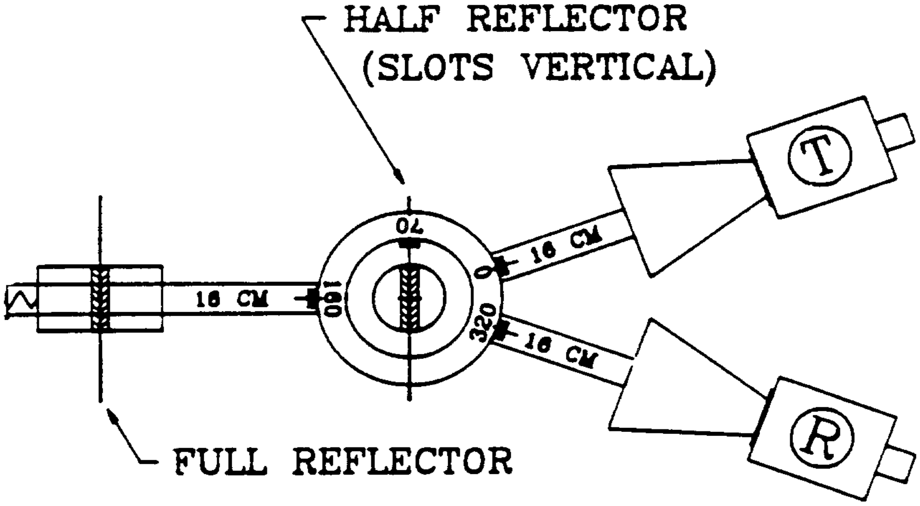


Figure 6.

7. Single Slit Diffraction

The simplest diffraction pattern to analyze is that produced by a long narrow slit.
Place the receiver and transmitter (with attached horns) on their slides, facing each other with the transmitter horn tight up against the single slit plate and the receiver horn as close to the slit as you can put it, but far enough away that you can swing the receiver arm through a considerable angle. Then measure the diffraction pattern of the single slit (*i.e.*, received intensity as a function of angle of receiver). How many minima and maxima can you observe? How does the angle of the first minimum or the second maximum compare to theory? You might consider plotting the intensity versus angle results on polar or linear graph paper. Try both narrow and wide single slits.

Repeat this measurement, but with the slit removed, so that the transmitter horn opening is essentially a single slit. In this case you will only be able to observe the central maximum and the first minimum. How does the position of the first minimum compare to theory? How does the angular width of the beam from the horn relate to the width of the horn?

The condition for the first minimum is $a \sin\theta = \lambda$. The general formula for the minima in the diffraction pattern produced by the slit of width a is given by $a \sin\theta = m\lambda$ (where *m*=1,2,...). There is a maximum approximately halfway between each adjacent pair of minima. (see Reference, Volume II, Chapter 46-2, pp. 970-972).

8. Double Slit Diffraction

Repeat the measurement of part 7, with the double slit plate substituted for the single slit plate. Compare the positions of the several maxima you obtain with the theoretical prediction for a double slit of slit spacing equal to the spacing between centres of the slots. Try making measurements with the receiver close-up as in part 7, and with the receiver placed near the end of its slide arm.

The two slits act as a coherent sources of waves that interfere constructively and destructively to produce the regions of varying intensity (see Reference, Volume II, Chapter 45-1, pp. 947-950**).** For a **maximum**, the two waves must arrive at a given point in phase resulting in the following relationship:

$d \sin\theta = m\lambda$ where m is an integer: *m*=0,1,2,...

where d is the separation between the centres of the two slits, θ is the angle at which the maximum is observed.

For a **minimum**, the two waves must differ in phase by an odd multiple of π (half-wavelength) resulting in:

$d \sin\theta = (m + \frac{1}{2})\lambda$ where m is an integer: m=0,1,2,...

9. Index of Refraction

Arrange the apparatus as shown in Figure 7. Fill the refraction tank with the material to be measured (polyethylene beads.) Set the tank to select the angle of incidence and then rotate the receiver arm to obtain maximum received signal and find the angle of refraction. Do this for several angles of incidence and deduce the refractive index. Use Snells law (see Reference, Volume II, Chapter 43-5, pp.912-913) to calculate the index of refraction for 3-cm microwaves propagating in the tank filled with polyethylene beads ($n_a \sin i = n_t \sin r$, where $n_a \approx 1$ and n_t are the refraction indexes of air and of the tank filled with polyethylene beads respectively).

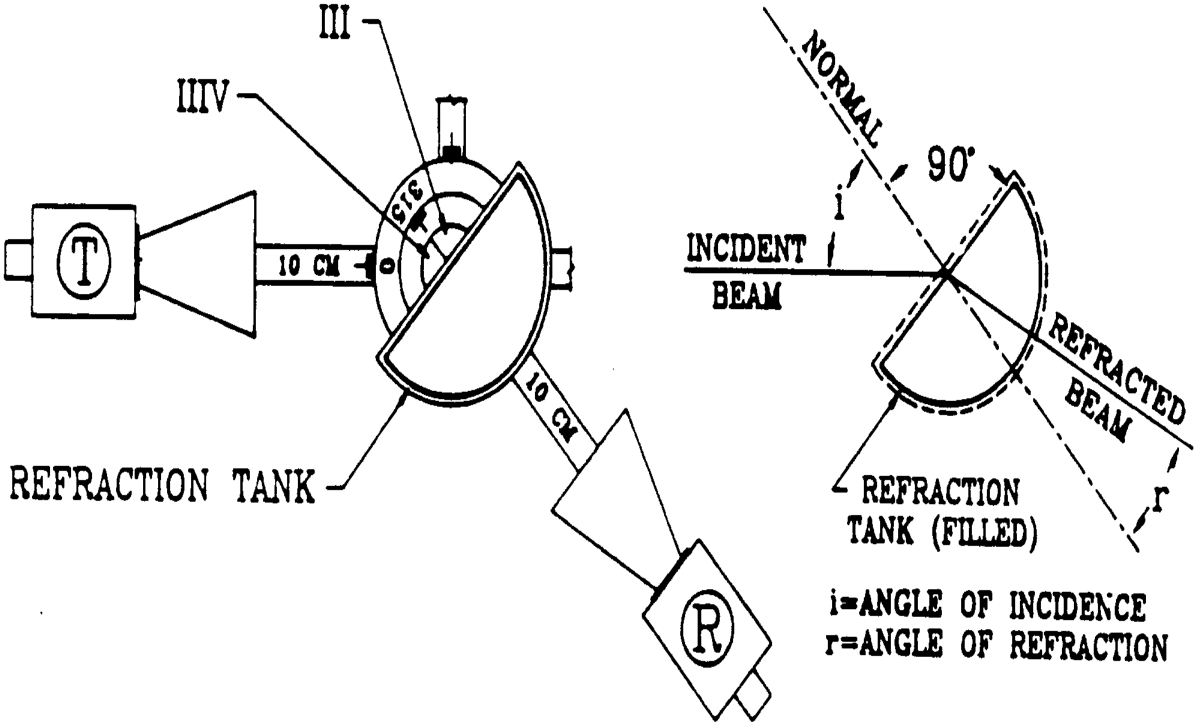


Figure 7.

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APPENDIX

For any light travelling through successive media, the optical path length is the sum of the products of the geometrical path length of each segment and the index of refraction of that medium (see Reference, Volume II, Chapter 43-5, pp.912-913). When the distance between the movable full reflector (I) and the half-reflector is *D*, the path length of the wave travelling forth and back is 2***D*** (the wave passes twice through the equivalent air film). When the slab of material of thickness d is inserted between the full reflector I and the half-reflector, the wave path length is changed. It becomes $2(D-d)+2d\eta$. The full reflector movement Δ is required to restore the original null resulting in the following relationship between the slab thickness *d*, the full reflector movement Δ and the refraction index η of the inserted slab: $2(D-d)+2d\eta-2\Delta=2D$, from which the refraction index of the slab can be determined: $\eta=1+\frac{\Delta}{d}$.