MICROWAVE OPTICS EXPERIMENTS

INTRODUCTION:

There are a large number of optics experiments which can be more readily performed in the centimeter wavelength regime than in the visible. One of these is the two-slit diffraction experiment, where the long wavelength makes the separation of interference fringes easily measurable with a ruler. Other diffraction experiments abound, and such devices as zone plates are easily fabricated for these wavelengths. It is also possible to study Bragg scattering from crystal models constructed with "Tinker Toys" or similar materials; Tinker Toy crystal models have unit cell dimensions which approximate a wavelength for a 3 cm klystron, and the first and second Bragg peaks can usually be measured for principal directions.

One experiment which exploits the long wavelength of the klystron radiation is that of total reflection from a paraffin prism. Apparatuses suitable for this experiment have been assembled by Mr. J. D. Leigh of our department. They consist of two large
paraffin prisms and the peripheral microwave emission and detection equipment.

It is assumed that students performing the total reflection experiment have already familiarized themselves with the operation of the klystron, wave guides, magic tees, attenuators, and detectors by means of previous experiments.

The reference for this experiment is Concepts of Classical Optics, John Strong, W.H. Freeman and Company, Inc., San Francisco, 1958, Appendix J, by G.F. Hull, pp. 507-524.

EXPERIMENTAL SET-UP:

In the first part of this experiment a single prism is employed. A klystron operating at wavelength of 2.7, 3.1, of 3.3 cm is connected to a horn which is positioned against one face of a 90° paraffin prism. The other two angles of the prism are about
35 and 55°. If the horn is placed against the face between the 90 and 55° corners, the radiation incident upon the opposite face will be totally reflected. The term "totally reflected" is a slightly misleading one, however. What it means is that there is no sinusoidal wave propagating from that face of the prism, i.e. no wave which can be described by an exponential of form e^{ikz}. There is, however, a non-propagating wave describable by an imaginary wave vector K=ik, i.e. an exponentially decaying wave
with amplitude $e^{iKz} = e^{-kz}$. We can measure the amplitude of this wave as a function of z, the distance from the face of the prism. The detector consists of a small diode with copper clips attached to it, which act as an antenna. The detector is mounted upon a
piece of optical bench stock, which is scribed with millimeter markers. Thus the distance from the prism face to the detector may be measured directly.

The pertinent equation for the "forbidden" transmitted amplitude is given by G.F. Hull in Am. J. Phys. 15, 111 (1947):

$$E_y = E_{0y} \, \exp 2\pi i [ft - \frac{x \sin r}{\lambda}] \exp[\frac{-2\pi z}{\lambda} \sqrt{N^2 \sin^2 (\alpha - 1)}]$$

Where E_y is the amplitude of the electric field for incident field E_0 polarized in the y-direction; f is the klystron frequency; t, time; z, the distance between the prism face and the detector; N, the index of refraction; r, the angle of refraction; x, the direction along the prism face orthogonal to y; and α, the angle of, incidence. $i = \sqrt{-1}$.

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Note the way in which the klystron wavelength enters into the formula above. For short wavelengths, say those in the visible, the effect we are looking for would be almost impossible to detect with laboratory equipment available to us.

Question #1: Assuming a wavelength-independent index of refraction of 1.5, calculate the distance z required to produce a 10 db drop in transmitted amplitude from the prism face for:
      a.) a 3.0 cm klystron, b.) a 10.6 micron CO_2 laser, c.) a 3250 angstrom Cd laser

EXPERIMENTAL PROCEDURE:
1. Determine the operating wavelength of the klystron via any method of your choice.
2. Measure the prism angles.
3. With the horn along the short side of the prism adjacent to the 90° angle, and with the SWR meter as detector, measure the z-dependence of E_y and compare your results with Eq. (1) above.
4. Place the horn along the long side of the prism and again determine the z-dependence of E_y. Why is the result no longer monotonic? Can you determine the klystron wavelength in this way?

For this part of the experiment you should take at least ten data points from zero to 10 cm along z, or until a 30 db drop is measured.

Question #2: Discuss the systematic errors involved in not being able to make z exactly zero.
Note: It may be necessary to stand away from the apparatus and keep your hands back while making the attenuation measurements; the SWR meter will be sensitive to reflections from your body impinging upon the detector.

PART II.
Repeat the experiments in Part I for which you obtained monotonic, exponentially decaying transmission, but now switch the klystron wavelength. Try to make measurements for all three available klystron wavelengths. Can you verify the wavelength dependence predicted in Eq. (I)? What are the error sources in these measurements?
If you wish, you may try to verify the x-dependence in Eq. (1). Why is this harder than the z or λ dependence verification?

PART III.
In this part of the experiment, two prisms are used. Now the detector should be placed squarely against the face of the second prism, as sketched below. z is now the separation of the prisms. Measure E_y versus z for this configuration. How do your results compare with those in Part I?
This part of the experiment is directly analogous to quantum mechanical tunneling through a potential barrier. The tunneling problem describes many physical phenomena in nature, for example, radioactive decay via alpha-particle emission. As part of your write-up for Part III, you should do the one-dimensional tunneling problem quantum mechanically, and compare your measured dependence of E_y upon z with the results of your calculation. (This problem may be found, with discussion, in any elementary text on quantum mechanics.)