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course, as a second way to locate the real images formed by converging lenses if the lens is placed between the object and the position-finder.

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# Microwave Interferometer

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We present here the construction and performance of a small x-band (3-cm wavelength) interferometer quite suitable for the high-school or college physics laboratory. The apparatus (Fig. 1) can be built fairly easily from items available from the local hardware store. Dubbed "the Plumber's Delight" in the Bellarmine lab, this particular version was designed to work with 10.5-GHz (2.9-cm) microwaves.

As a preliminary venture, your class may want to try a no-funnel version; the system will work sufficiently well enough with no funnels at the two interferometer inputs, since the microwaves will enter the elbows directly.

To provide for several values of D, you will need several pairs of straight copper pipe to fit in the arms of the interferometer. Each pair should be equal in length. Since the copper tubing pieces fit snugly together, it is not necessary to solder anything except the funnels to the elbows; simply make sure that the arm lengths are symmetrical to within a couple of millimeters.

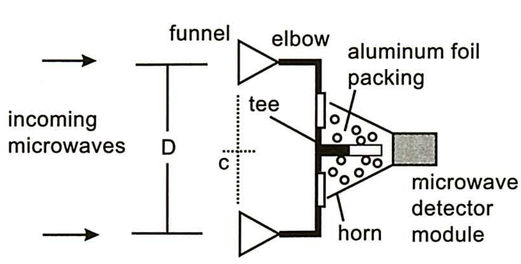


***Fig. 1. Top view of interferometer. Thick lines represent elbows and tees (more curved than shown) connected by straight sections of copper tubing. c = center of rotation.***

The combined output of the interferometer appears at the central branch and is butted up against the waveguide input of the typical microwave detector. To prevent any appreciable microwave radiation from reaching the detector horn before going through the interferometer, we simply packed some aluminum foil around the central section as indicated. Presumably, steel wool or other reflecting or absorbing material would be quite satisfactory. The interferometer is attached to the receiving horn with masking tape.

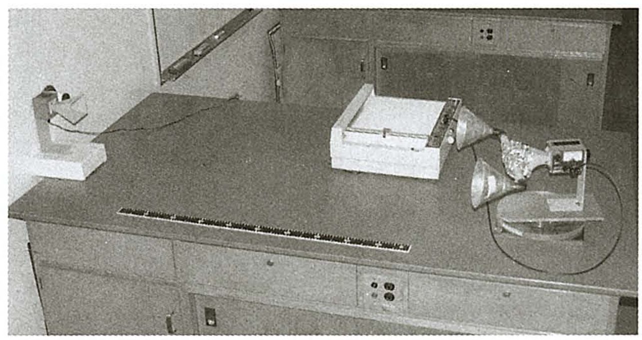

***Fig. 2. Experimental configuration. Left to right: microwave source, strip-chart recorder (if used), receiver assembly on rotating base. Note metric tape on edge of rotator and aluminum foil wrapped around receiver horn. Recorder must be placed well outside space between microwave source and interferometer.***

Mount the assembly (see Fig. 2) on a rotating base (such as a Lazy Susan); the rotation axis is vertical. It is rather important to have the rotation axis coincide with the intersection of the interferometer's symmetry axis and a line representing its "front,"—point "c" in Fig. 1. We attached a short piece (about 25 cm) of metric tape along the periphery of the rotating table to enable measurement of $\Delta\theta$, using the expression $\Delta\theta = (\Delta s/R) \times 57.3°$, where $R$ is the radius (in cm) of the rotating table and $\Delta s$ is the distance (in cm) along the periphery associated with rotation between two adjacent maxima or minima indications on the receiver module. Experimental uncertainty could be reduced by measuring $\Delta s$ for several consecutive maxima or minima. The distance between the microwave source and the interferometer should be much larger than *D*: our distance was approximately three meters.

We chose three values for *D*: 36.5, 25, and 20 cm, for which the expected fringe spacings were 4.4, 6.7, and 8.6 degrees respectively. Obviously, D is arbitrary, but if made too large, the resulting decrease in fringe-spacing becomes rather difficult to measure with any accuracy in a typical school lab.

In actual operation, the expected value for the angular separation $\Delta\theta$ between minima or maxima is calculated from the relation $(\lambda/D)57.3°$, where $\lambda$ is the wavelength of the microwaves and *D* is the baseline length. Caution: this relationship assumes that the microwave source and interferometer are in the same plane. Observed values will be within a few percent of the expected values (see Table I).

If a recording system (such as a strip-chart recorder) is available, your students could obtain an interferogram such as shown in Fig. 3. The pattern will not be symmetrical, mainly because it is very difficult to maintain uniform motion while the output of the receiver is being fed to the recorder. Another source of nonsymmetry could be spurious reflections of microwaves in the room entering the interferometer.

The first-time user of microwave apparatus should keep in mind that the microwave source and microwave detector should have the same polarization. Typical classroom apparatus is vertically polarized. This means that the broad dimension of the rectangular waveguide is along the horizontal. Or, if you look inside the waveguide of the source, there will be a little quarter-wave antenna (like a small nail), which should be vertical. If you look inside the waveguide of the detector module, there should be a somewhat similar structure (but it will usually be the crystal detector) and it too should be aligned vertically.

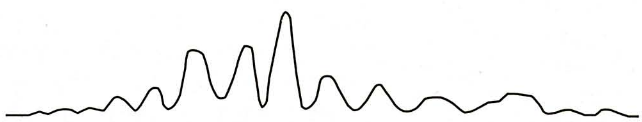

***Fig. 3. Typical interferogram obtained by manually rotating the interferometer.***

In addition, readings should be taken when the interferometer is facing more or less directly at the microwave source. Otherwise, the effective value of *D* is no longer the measured value. For example, if the angle between the interferometer axis and the line from the source to the center of the interferometer is 15°, then the effective value of *D* is $D\cos(15) = 0.97D$. introducing an error of about 3% in the calculation of $\Delta\theta$.

In a typical laboratory session, the class could be divided into several teams, each team being responsible for cutting two equal lengths of pipe. Each team would announce to the class what the expected value of $\Delta\theta$ should be for their value of *D* and the experiment run to see what happens. The innate spirit of good-natured rivalry should provide for a relatively dynamic lab session.

**Table I.**

| D (cm) | Expected Δθ (deg) | Observed Δθ (deg) |
|---|---|---|
| 20 | 8.3 | 8.6 |
| 25 | 6.4 | 6.5 |
| 36.5 | 4.4 | 4.4 |

***Note: The microwave source and detector are part of the Basic Microwave Optics System, model WA-9314B, from PASCO scientific. The transmitter and receiver may be purchased separately, part numbers are 003-04319 ($300) and 003-04313 ($225) respectively.***

## Reference

Additional discussions of basic radio astronomy concepts and projects suitable for senior high-school and college undergraduate students will be found in the book ($20 + $3 shipping) *Radio Astronomy Projects*, (by W. Lonc) available from Radio-Sky Publishing, P.O. Box 3552, Louisville, KY, 40201; e-mail radiosky@radiosky.win.net; also available from Radar, Inc., 168 Western Ave., Seattle, WA 98119, and its branches, as well as from the University Bookstore, Saint Mary's University, Halifax, NS, Canada B3H 3C3.