EE 429/559 Photonics

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Interactive computer simulation homework I: Resonators

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For the computer simulation homeworks, we will be using the **LASER** program from the Modern Physics Simulations volume of the CUPS (Consortium for Upper-level Physics Software) project [Douglas Brandt, John R. Hiller, and Michael J. Moloney, *Modern Physics Simulations: The Consortium for Upper-level Physics Software*, Wiley, New York, 1995]. The program consists of two parts: a three-level laser simulation and a resonator (cavity) simulation which uses ray tracing. In the first homework, we will be concerned with resonators. In that part of the simulation, you may send rays back and forth in the cavity, visually outlining the shape of a Gaussian beam. Tools in the simulation allow a quantitative comparison between the "envelope" of the ray diagram and the properties of the Gaussian beams. This will permit you to demonstrate a connection between pure ray tracing and an electromagnetic resonant wave. It is interesting that the launching of paraxial rays produces a picture entirely consistent with that of electromagnetic theory for Gaussian beams.

1. **Cavity Stability and Cavity Shape**

   (a) Bring up the cavity simulation (by selecting **Cavity Stability via Ray Tracing**). Press **Insert** and observe that a single ray is injected into the cavity and bounces back and forth. The bouncing stops at 100 bounces, or when the ray angle to the axis gets too large. Adjust the **ray launch angle** until you observe a stable bouncing pattern (i.e., the rays do not go out of bounds).

   (b) There is a simple algebraic stability condition (also called the *Confinement Condition*) for the cavity:

   $$0 < g = \left(1 - \frac{d}{R_l}\right)\left(1 - \frac{d}{R_r}\right) < 1, \tag{1}$$

   where d is the distance between the mirror vertices, and R_l and R_r are the radii of curvature of the mirrors. R is taken positive if the mirror is concave as seen from the middle of the cavity, and negative if the mirror is convex (Note that this convention is the opposite of what your textbook employs). Read the values of d, R_l, and R_r from the screen and calculate g. Report these values and whether the cavity is stable or unstable.

(c) Repeat parts (a) and (b) using a *negative* value for R_l, the radius of the left-hand mirror. Find and report a negative value of R_l where the cavity is unstable, and one negative value of R_l where the cavity is stable.

2. **Determining the Rayleigh Range z_0** Use the default simulation (select **Restore Default Values** under the **Lasers** menu) to launch (insert) a ray in the cavity. Select a launch angle of about 0.03 radians, and set the y-magnification for $10\times$ by pressing **Magnify**. This scheme should permit a more precise determination of the beam waist location, since the curvature of the beam is more evident. Keep in mind that the screen value of beam transverse dimensions must be divided by 10 when the $\times 10$ magnification is selected. The mirrors are *not* replotted after magnification. After the rays have stopped bouncing, select the **BmWidth** mode. The axial location z' and length of the vertical bar that appears may be adjusted via mouse-dragging or keystrokes so that it may be used for measurements.

   (a) Measure the "raw" (z') value of the beam waist and the z'-value of each mirror, then subtract z'_{waist} to obtain z-values for each mirror.

   (b) Use the z- and R-values for the right-hand mirror (both > 0) to calculate z_0. Then use the z- and R-values of the left-hand mirror (both < 0) to determine z_0. These two values should agree very closely.

3. **Checking Beam Width Behavior** In this exercise, you will use the z_0 value you have just calculated, so keep the same ray diagram intact for making beam width measurements.

   (a) Measure the beam waist radius W_0 (it is half the length of the adjustable vertical bar).

   (b) Measure the beam width at the point where the beam strikes the right-hand mirror.

   (c) Use your value of z_0 and the measured waist radius W_0 to calculate the beam width at the right-hand mirror, and compare to your measured value.

   (d) Repeat parts (b) and (c) at the left-hand mirror.