

## Measuring the Speed of Light with a Broadcast Television Receiver

Measuring the speed of light is one of the cornerstone physics experiments, encountered by essentially all physics students, either in high school or in college. We have developed an approach that takes advantage of the fast (several megahertz) electronics of the scanning section of an ordinary receiver for broadcast television, thus avoiding the need for special-purpose equipment. Students moreover learn about television transmission, antennas, and the principles of picture-tube scanning. Our approach requires an unambiguous reflector for the TV signal.

The experiment takes advantage of "ghost" images on the television screen. Knowing the scanning speed, the displacement of a ghost image from the principal image is proportional to the time lag induced by the reflector, whose distance from the antenna can be measured directly. To fix some numbers, the scanning speed for a line in the US broadcast standard (NTSC) is  $1/15,735$  second. If the reflector is 300 meters away, the ghost image is delayed by 0.0315 of a scan length, an amount that can be measured with fair accuracy.

We have conducted this experiment on two occasions with groups of high-school students in a program under the auspices of the Center for Astrophysical Research in Antarctica, an NSF-funded Center for Science and Technology. The site was Yerkes Observatory (Figure 1) in southeast Wisconsin. The observatory building with its large metal dome is the reflector: there are no other plausible sources for reflection since the main building is isolated in a flat open area. There is another smaller building on the grounds that houses other telescopes; this building has convenient electrical power and space to hold the laboratory classes.

We used a small amplified UHF antenna mounted on a proverbial ten-foot pole. This assembly with its cables was moved outdoors and hand-held by a student. The student pointed the antenna at the main Yerkes building, slowly rotated the antenna parallel to the horizon, while watching for the appearance of a ghost image on the TV. (For sake of visibility, the TV was left inside the doorway.) The immediate feedback afforded an appreciation of the directionality and other properties of the antenna. Other students then measured the displacement of the ghost image directly on the screen.

The geography was such that transmitting stations in Rockford, IL are almost directly on the line connecting the small building and the main building at Yerkes Observatory. Thus, in our case it was necessary only to measure the distance between the antenna and the

main building (about 100 meters), without needing to deal with a more complicated geometry for the path difference.

The same measurement could be made with an oscilloscope by adjusting it to trigger on the blanking pulse in both the main and reflected signals. We tried that: in practice the TV gives a substantially cleaner result. More to the point, the TV is a less intimidating piece of equipment from the perspective of many students.

Errors result from a number of sources, one of which is that the full dimension of the video field is typically not displayed, so the measurement of the displacement on the screen relative to the apparent screen width does not give a precise value for the time delay. Discussing this point, and arguing ways to work around it, help explain how TV displays work.

The lab classes we conducted consisted of eight students, one student assistant, and one instructor. The students were 10th-graders with no special expertise in mathematics and science, and no lab experience other than what they had seen in our program. The crucial concept of the project is to relate a length displacement on the TV screen to a time displacement, and to quantify this properly by constructing the appropriate ratio.

Given this experience, changes or additions to the procedure that have occurred to us include the following:

- 1) The assertion that the main building is indeed the reflector can be tested by using a directional antenna and trying different locations around the grounds.
- 2) Making a careful measurement of a moving image can be frustrating; the obvious solution is to tape the broadcast and then measure a still frame.
- 3) It would be good to derive the scan speed, rather than have to assume it. If it is sufficient merely to obtain an estimate, one can argue that ultimately the engineering design for television accommodates human visual perception, specifically the flicker rate, and resolution in the context of a moving image. By working backwards from these specifications, one can derive the technical requirements. An estimate of the scan speed comes from assuming that the system is not over-engineered. Speaking in these terms allows physiology to be related to the hardware.