point source which the lens transforms into a plane wave. The wavevectors of these plane waves lie on a cone. As mentioned earlier, this is a defining characteristic of Bessel beams. Using standard scalar diffraction theory, it can be shown that the field close to the optic axis is given by Eq. (2).

III. EXPERIMENT AND RESULTS

A 1 mW He–Ne laser (Melles-Griot 05-LHP-211) is used to illuminate the annular slit. The He–Ne laser beam is expanded using a microscope objective and lens to a diameter of about 1 cm. An annular slit is placed in the back focal plane of a lens of focal length 150 mm.

Initially the student can hold a piece of paper in the beam at various distances from the lens. One can clearly observe by eye (for a He–Ne laser power of 1 mW or greater) a central maximum in the beam that appears (as one moves further away from the annular slit) to approximately retain its size. After some point this central maximum diminishes and dies away as the Bessel beam fades. This allows the student to determine the propagation distance of the beam. For a more detailed study a CCD camera (Pulnix 2015) and computer frame grabbing card/software were used to record the beam and its profile at various points. The beam was telescoped (magnification of around 2.5) to increase its size on the camera. A picture of a typical Bessel beam taken with our setup is shown in Fig. 2. The profile of the beam for three different positions is shown in Fig. 3. To eliminate slight asymmetries, the profiles were azimuthally averaged on a computer. As seen in Fig. 3, the central maximum of the beam retains its size as the beam propagates for more than 500 mm. Knowing the pixel size and magnification of our telescope system, the size of the central maximum was found to be approximately 20 microns.

IV. RECONSTRUCTION OF A BESSEL BEAM

A further simple experiment may also be undertaken by the student. This involves observing what happens to a Bessel beam when obstructed by an obstacle. As expected, diffraction dominates though, interestingly, after some distance beyond the obstacle, the outer lobes of the Bessel beam act to replenish the central maximum and thus the beam is reconstructed. This startling effect can be reproduced simply in the laboratory by placing a transparent slide with a very small dark spot in the Bessel beam path. Subsequent to this, the beam was observed at points beyond the obstacle. Figure 4 shows what may be observed. Just beyond the obstacle, the beam profile is shown to have deviated dramatically from the Bessel profile. However, as the camera was moved further away from the obstacle the beam was seen to regenerate itself and reform into a Bessel beam. The profile taken of the beam shows this to be the case. Figure 5 compares this reconstructed profile to that of the original Bessel beam. Notably, the power in the central maximum is only partially diminished. This reconstruction effect for Bessel beams was recently explained in terms of Babinet’s principle in optics.

V. DISCUSSION

Bessel beams are interesting as they have a central region that appears to overcome the effects of diffraction. When the central maximum of a zeroth-order Bessel beam is compared to a Gaussian beam of the same size, the central maximum of the Bessel beam does not exhibit diffractive spreading. The propagation length of a Bessel beam can be shown to be

$$Z_{\text{max}} = \frac{fD}{R},$$

with the terms defined on Fig. 1. For our beam, we have an annular slit whose total diameter was measured to be $R = 3.8$ mm and the clear aperture of our lens was measured to