Creating Dark Lines in Space with Linear Zone Plates

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Introduction

Zone Plates are optical elements that focus light by diffraction. It is composed of alternating rings of opaque and transparent regions which cause the light to constructively interfere at the focus. In this project we attempt to create a dark line at the focus. This is done through the introduction of a π-phase jump along the middle of a sinusoidal linear zone-plate. These type of zone plates have major implications in optical alignment.

Fig 1a

Fig 1b

Theory

Two wavefronts that are out of phase by π encounter complete destructive interference. For this to happen, half of the zone plate needs to be in an odd configuration and the other half need to be in an even configuration.

By analyzing the wave equation for two light waves out of phase by π it is possible to see why a phase jump causes destructive interference.

$$\Phi(d) = \frac{A}{d}e^{ikd} + \frac{A}{d}e^{i(kd+\pi)} \quad (1)$$

After using Euler's Formula to simplify:

$$\Phi(d) = \frac{A}{d}(\cos(kd) + i\sin(kd) + \cos(kd+\pi) + i\sin(kd+\pi)) = 0 \quad (2)$$

The transmittance for a sinusoidally varying zone plate can be expressed by this equation:

$$T = \frac{1}{2} + (\frac{1}{i\pi})\sum_{p=-\infty}^{\infty}\frac{1}{p}e^{\frac{-ip\pi r^2}{r_1^2}} \quad (3)$$

However, this equation can be approximated to:

$$T(x) = \frac{1 \pm \cos(\frac{\pi x^2}{f\lambda})}{2} \quad (4)$$

Fig 2a

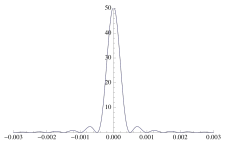


Fig 2b

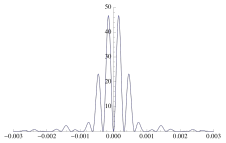


Fig 2a) The intensity profile along the focal plane of a zone plate without the π-phase jump. **Fig 2b)** The intensity profile along the focal plane of a zone plate with a π-phase jump.

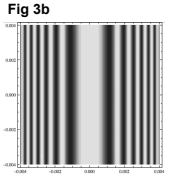
Creating zone plates

The zone plate designs were generated using Wolfram Mathematica. The equation shown for the transmittance as you move across the zone plate was used to genearte them. It was necessary to describe the transmittance of the zone plate as a piecewise function, in order to account for the π-phase jump.

The first image is a binary linear zone plate and the second is a sinusoidal linear zone plate:

Fig 3a

Fig 3b



The first image is a binary linear zone plate with the π-phase jump, and the second image is a sinusoidal linear zone plate with the π-phase jump.

Fig 4a

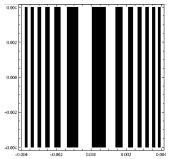
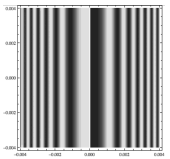


Fig 4b



The four designs were printed by photographer Gene Lewis (Darkroom Specialties LLC, Eugene, OR). Once generated, each of the zone plates were 8mm by 8mm.

The resulting zone plates looked like this,

Fig 5a

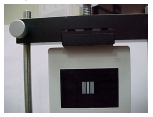


Fig 5b

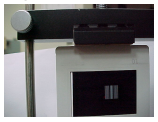


Fig 5c

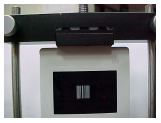


Fig 5d

To create these slides, the images were first downloaded and put into Adobe Photoshop. Then they were placed against a background and scaled to size. Then they were converted to a grayscale, RGB color space and placed on a .tiff file. Then each image was sent to a Raster Image Processor and the images was broken up into red, green, and blue imaging files. Then each of these different colored image file was sent to a Lasermaster 35mm film recorder that recorded each color channel's luminosity to ensure that the best quality image could be obtained. Then each film was exposed for 6.5 minutes, after which they were removed from the recorder and processed in an E-6 slide processor. After the films were dry, they were mounted onto plastic frames.

Illuminating the zone plates

When illuminated with a magnified beam of light, the resulting diffraction patterns for the four different zone plates were,

Fig 6a

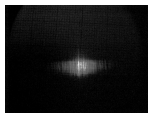


Fig 6b

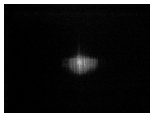


Fig 6c

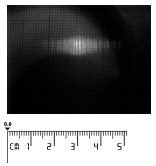


Fig 6d

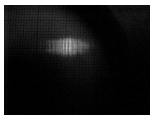


Fig 6a) The diffraction pattern created by an ordinary linear binary zone plate. **Fig 6b)** The diffraction pattern created by an ordinary linear sinusoidal zone plate. **Fig 6c)** The diffraction pattern created by a linear binary zone plate with a π-phase jump. **Fig 6d)** The diffraction pattern created by a linear sinusoidal zone plate with a π-phase jump.

Fig 7

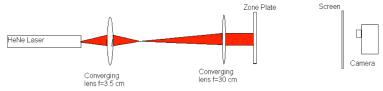


Fig 7) This is a diagram of the experiment setup used to take the images above.

We hope to in the future continue our study of these diffraction patterns, by traversing these patterns with a pinhole and using a photodetector to map the profile as the pinhole moves across the pattern, and possibly test the accuracy of zone plates as precision optical alignment devices.

References and Acknowledgements

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