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Initial Results of a White Light Nulled Fringe

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Abstract. Some proposed configurations for TPF nulling require precise, achromatic phase shifts of half of a wave while other configurations require fractional phase shifts (Angel and Wood 1997; Woolf and Angel 1997). Phase shifts can be created using simple delay lines, but the resulting phase shift is highly chromatic. Dielectric plates can balance this chromaticity utilizing the dispersive property of the dielectric material, in a manner analogous to an achromatic lens (Angel, Burge & Woolf 1996). In combination with the delay line, a dielectric plate can shift the coherence envelope any fraction of a fringe to obtain an achromatic phase shift of variable phase. Dielectric material pairs have been found to provide the appropriate highly achromatic phase shift to achieve a 10^{-6} null over the entire 7-17 μm bandwidth for TPF and a null to the 10^{-4} level in the visible region for SIM. In the laboratory, the technique is currently implemented in the visible region with a Twyman-Green interferometer and a single dielectric plate. An achromatic null in the 400 nm to 700 nm region has been achieved to the fourteen percent level in contrast, a two fold improvement over delay line alone.

1. Dielectric Plate Phase Delay Technique

To create an adequate null, the phase difference between the two beams must be half of a wave at all wavelengths. Merely adding a half wave of path length to one beam results in a highly chromatic null since the phase difference is inversely proportional to wavelength as shown in Figure 1.

This wavelength dependence is matched by adding optical path length through a dielectric medium, such as a glass plate. The resulting phase difference, seen in Figure 2, has a balanced linear component and a second order curvature due to the wavelength dependent index of refraction of the dielectric material.

An even deeper and broader null is created by using a second dielectric material to balance the second order curvature as illustrated by Figure 3. In the final solution, the air path and the thicknesses of the two plates balance to generate a half wave phase difference which is achromatic. The residual phase

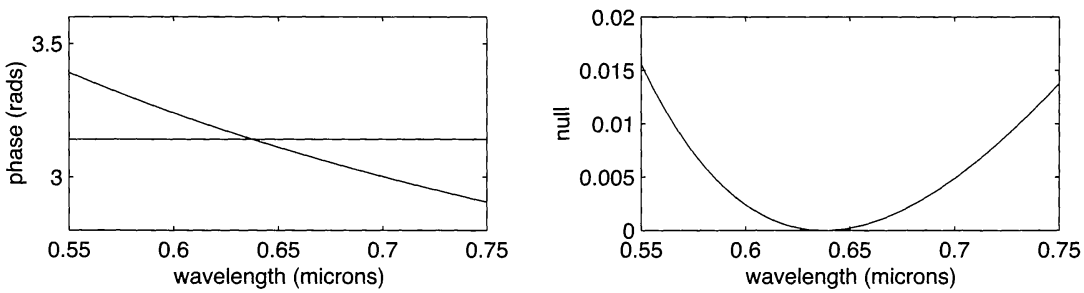

Figure 1. The phase and null variation with wavelength for a 30% bandwidth in the visible region. A phase shift via air path alone produces a phase variation inversely proportional to wavelength.

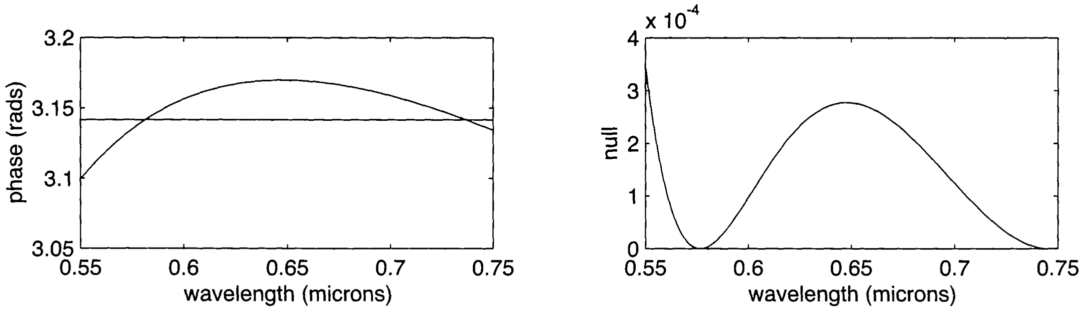

Figure 2. A single plate of BK7 and air path creates a less chromatic phase shift. The residual phase error is due to the wavelength dependent index of refraction of BK7.

error has a third order curvature. The phase error could be further reduced by adding additional plates, but two dielectric plates have been sufficient to yield solutions for both SIM and TPF which are shown in Figures 3 and 4.

2. Experiment

Presented here is the first step in demonstrating the achromatic phase plate technique and involves only a single dielectric material in the visible spectrum. A Twyman-Green interferometer was setup in the laboratory using a Tungsten Halogen source with a 1 mm iris in front of the source. The beam splitter and matching compensator plate were made of BK7 glass and adjusted to provide the traditional form of compensation for white light fringes. To achieve the achromatic null fringe, the BK7 compensator plate was tilted 3 degrees to add approximately 5 microns of optical path while a mirror was translated a corresponding 6.5 microns. Visual inspection of the fringe pattern and hand adjustment led to a black central fringe.

The fringe patterns are only described here, since publishing constraints prohibited color pictures. In the null configuration, the null fringe appears

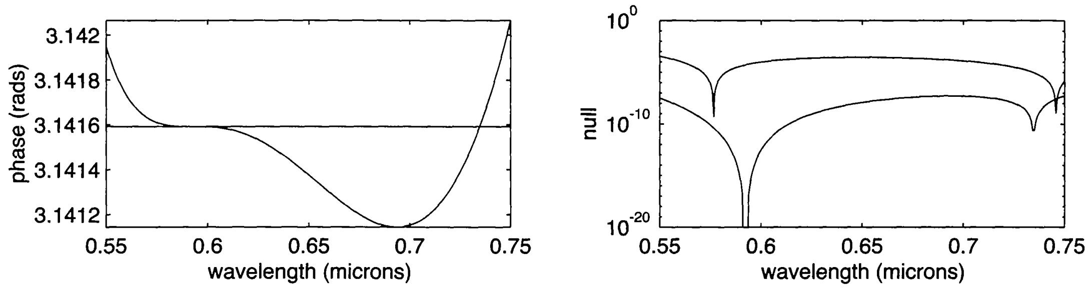

Figure 3. The left plot shows the phase compensation using both BK7 and fused silica plates. The right plot is comparison of the null achievable with a single BK7 plate to plates of BK7 and silica. This solution meets the SIM requirements for a null of 10-4 over a 30% bandwidth.

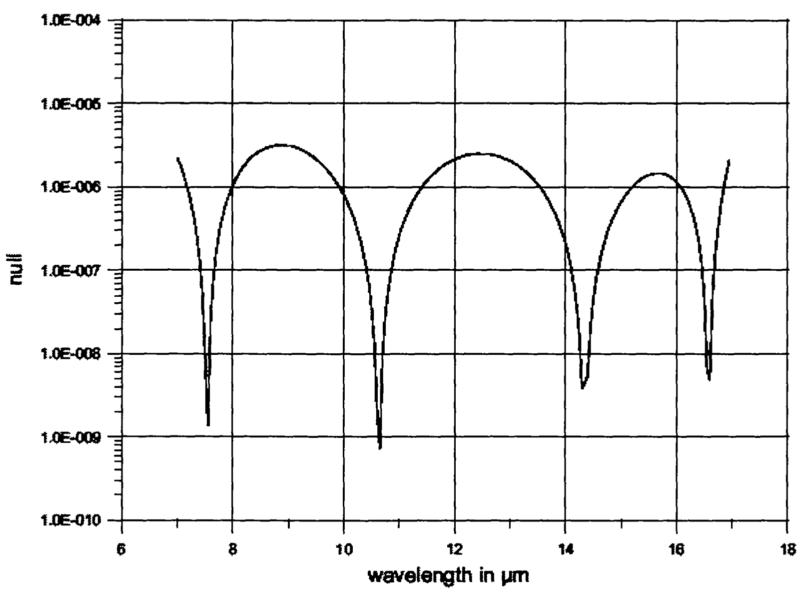

Figure 4. The technique provides a solution for TPF which covers more than an octave of bandwidth in the infrared. Even deeper nulls can be achieved for narrower bandwidths.

obviously black and colorless. The symmetric smear of the colors in the fringes away from the central fringe indicates that the coherence envelope is centered on the null fringe, and the central null fringe is indeed achromatic.

The BK7 plate was adjusted for traditional compensation of a constructive central fringe. Again the colors in the fringes smear out symmetrically from the central constructive fringe. The first dark fringe on either side of the central fringe is not as black as the nulled fringe, but appears brown with some smear of yellow.

3. Digital Image Results

A digital camera was used to acquire preliminary quantitative visibility results. The data in the red, green, and blue filters of the digital image show to a small extent how the fringes at different wavelengths are shifted to align achromatically. The digital irradiance values in these three bands adds incoherently to give the fringe contrasts. For the constructive mode, the contrast of the first dark fringe with respect to the central peak fringe is 27%. For the nulling mode, the contrast of the central null fringe with respect to the first bright fringe is 14%, a two fold improvement. The model shows that for a single piece of glass in the visible region, an order of magnitude improvement should be possible.

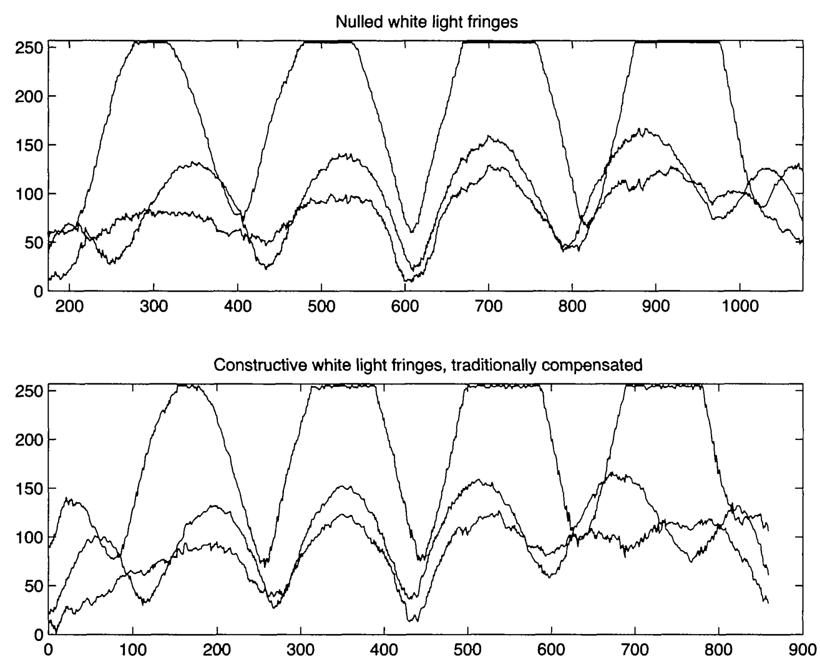

Figure 5. Shown is a slice of the jpg image captured by the color CCD camera in each of the red, green, and blue channels. The fringes of different colors are well phased in the top plot to create the null fringe and in the lower plot to create a constructive central fringe.

4. Future Work

The work presented here is work in progress. The future efforts of this project will strive to achieve the null predicted by the model, then to add a second dielectric material to produce an even deeper and broader null. It is our goal to demonstrate an achromatic null of 10^{-4} over a 30% bandwidth.

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