DIFFERENTIAL DIFFRACTION IN MICHELSON STELLAR INTERFEROMETRY

M. HRYNEVYCH*
Chatterton Astronomy Dept
University of Sydney, NSW, 2006
Australia

Abstract. Diffraction in Michelson Stellar Interferometery, with particular reference to SUSI, is examined. A justification of the use of Fresnel diffraction is made, both theoretically and experimentally, and a calculation of fringe visibility loss for SUSI is given.

Key words: Diffraction – SUSI – Fringe visibility

1. Introduction

Diffraction effects in stellar interferometry become increasingly important as the baseline over which the interferometer operates is increased and has been the subject of a number of investiagtions Tango and Twiss (1974), Bagnuolo (1988), Mekarnia and Gay (1989). When two beams are brought to coherent interference; each beam will have propagated through different pathlengths within the instrument, and so will have diffracted by a different amount. Since the object of stellar interferometry is to measure quantitatively the fringe visibility (i.e. at coherent interference) it is essential to estimate the effects of diffraction so that they can be corrected. In a long baseline interferometer, diffraction has the greatest effect on fringe visibility after those due to pathlength compensation and atmospheric turbulence and is intrinsic to a stellar interferometer.

One effect of diffraction is to distort the propagating wavefront through the interferometer, to the extent that if the two arms are sufficiently different in length then the interference fringes produced will be significantly diminished in contrast due to the mis-matched wavefronts. The other occurs due to beam spread from diffraction; not all starlight reflected by the siderostats will be within the detection area at the interference plane.

These fringes occur in the direction of propagation and SUSI will detect them using a non-imaging detection system. Effectively, they will be integrated over the entire beam area. Using the Michelson definition of visibility the visiblity of the integrated fringe intensity is given by,

$$\mathcal{V} = 2\int_0^{\rho_0} \sqrt{I(z_1,\rho)I(z_2,\rho)}\cos(\phi(z_1,\rho)-\phi(z_2,\rho))\rho d\rho. \tag{1}$$

where the effects of diffractive beam-spread have been incorporated.

It is clear that if z_1 and z_2 are approximately equal then $I(z_1,\rho) \approx I(z_2,\rho)$ and $\phi(z_1,\rho) \approx \phi(z_2,\rho)$, so that the visibility becomes a direct measure of the modulus of the complex degree of coherence. However, with large differences between z_1 and z_2 the diffracted intensities are largely different, so the correction becomes significant.

* now at the School of Physics, University of Melbourne, Parkville, Victoria, 3052, Australia

J.G. Robertson and W.J. Tango (eds.), Very High Angular Resolution Imaging, 224–226.

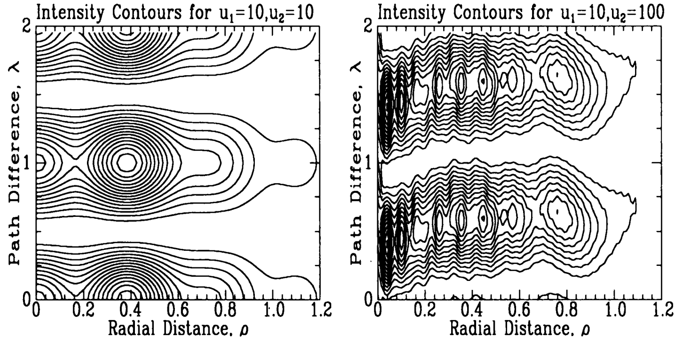

Fig. 1. Fringe distortion due to diffraction effects for two combinations of u_1 and u_2. Here, u_1 and u_2 are propagation variables with the form $u = ka^2/z$, where k is wave number, a is aperture radius, and z is the propagtion distance from the siderostat.

2. Diffraction Studies

In calculating diffraction intensity distribution $I(z, \rho)$ for SUSI there are a number of assumptions that can be made. As fringe visibility measurements will be made over very narrow bandwidths ($\approx$ 0.5nm), it can be assumed that the incident light is quasi-monochromatic. Also, SUSI is constructed with r_0 diameter siderostats, the major component of atmospheric distortion will be from tilt. For diffraction such tilts are quite small in magnitude and will be essentially removed, so it is possible to assume an incident plane wave.

The scalar theory of diffraction using the Kirchhoff diffraction integral with the Fresnel approximation was found to be the most suitable for calculating $I(z, \rho)$ (Hrynevych (1992)) and it has the potential for incorporating higher order atmostpheric distortions. It's validity (as a function of distance from the aperture) was tested experimentally and was shown to be in very good agreement throughout the entire operating range of SUSI.

3. Calculation of Visibility Loss

Using the Fresnel diffraction theory it is possible to calculate fringe visibilities and derive the explicit forms of the intensity distribution in the interference plane. By using estimates based on the loss of energy, the additional diffraction due to intermediate apertures has been found to be negligible. Hence, diffraction in SUSI can be regarded as occurring from the two entrance apertures.

The distortion of fringes is shown in figure (1) where the resulting fringes for two sets of internal pathlengths are shown; one where the paths are equal and the other where there is a great difference in path. It is clear that the different paths not only produce structure in fringes but also distort them so that they are no longer purely transverse to the direction of beam propagation.

The calculation of visibility loss is shown in the contour maps of figure (2) over a range of pathlengths in the two arms of the interferometer in terms of the optical coordinate $u = 2\pi a^2/\lambda z$. The calculation was performed for a detector area equal

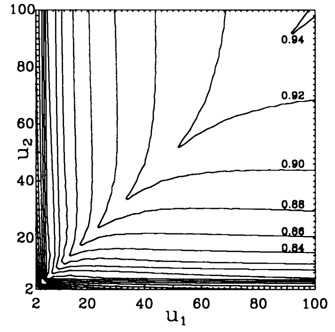

Fig. 2. Visibility Loss Contours of a range of optical cordinates, u_1 and u_2, in the two arms of a stellar interferometer. The contours represent visibility loss calculated for the geometrical beam.

to the aperture area. Of particular interest to SUSI are u values that lie between the longest effective internal path of 330m ($u = 17.309$) and the shortest effective path of 119m ($u = 47.83$).

4. Conclusions

This work has considered the diffraction effects present in SUSI and has found that for an r_0 aperture size with narrow bandwiths that a scalar theory using the Fresnel approximation sufficed for this calculation. It has also laid the ground for the study of diffraction of an incident starlight that has undergone distortion from atmospheric turbulence. By accurately being able to calculate the effects of the propagation of such a wavefront through the instrument it should be possible to study the effects of any spatial filtering due to diffraction.

Acknowledgements

I acknowledge the support of an Australian Postgraduate Research Award. The SUSI project is funded by the Australian Reasearch Council and the University of Sydney. The support of the Pollock Memorial Fund and the Science Foundation for Physics within the University of Sydney is also gratefully acknowledged.

References

Bagnuolo, W.G.: 1988, in Simulations for the CHARA/GSU Interferometer and Binary Star Speckle Photometry, ed(s)., *Frieden, B.R.*, NOAO-ESO Conference on High Resolution Imaging by Interferometry, Springer-Verlag:Munchen, 981-994

Hrynevych, M.: 1992, *Diffraction Effects in Michelson Stellar Interferometry*, Ph.D. Thesis,Chatterton Astronomy Department,University of Sydney:Sydney

Mekarnia, D. and Gay, J.: 1989, 'Alteration du Visibilite par Diffraction de Fresnel en Synthese D'Ouverture', *J.Optics* **20**, 131-140

Tango, W.J. and Twiss, R.Q.: 1974, 'Diffraction Effects in Long Path Interferometers', *Appl. Opt.* **13**, 1814-1819

https://doi.org/10.1017/S007418090010765X Published online by Cambridge University Press