MULTIPLE MIRROR TELESCOPE OBSERVATORY

Smithsonian Astrophysical Observatory *and* Steward Observatory, University of Arizona

MMTO Technical Memorandum 83-15

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Subject: Fringe Contrast Measurements for Telescope Phasing

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We demonstrate here the capability of measuring the contrast and position of interferometric fringes produced by two phased mirrors of the MMT. The goal of this experiment was to give a preliminary indication of whether or not an automatic mirror phasing system using one ot the MMT Point-4 computers would be feasible. We conclude that 10 seconds is sufficient time for phasing a given pair of mirrors (hence, about 1 minute to phase the entire telescope) using stars up to 6th magnitude given a modest hardware FFT device.

On June 29 (UT) 1983 we made interferometric observations of two point sources. We used the B-E mirrors (center to center seperation = 5 m), phased to produce fringes, to observe alpha OPH ($m = 2.1$) and epsilon HER ($m = 3.9$) at 7500 A with a 300 A bandpass at 25 x. Estimated seeing size was 1 to 1 3/4 arc sec.

The fringes ran parallel to the video raster of the speckle camera (horizontally). Ideally, the fringes should be centered relative to the seeing distribution, but to determine whether or not our algorithms could detect fringe position, we purposely positioned the fringes at both the top and bottom relative to the seeing distribution, as well as at the center. We did this by slightly moving the beam combiner (see MMT Technical Memorandum 83-4. The new prism system had not yet been installed). During the course of the observations, it was necessary to make small adjustments in the beam combiner position to account for elevation and temperature changes (hence demonstrating the need for a real time phasing system).

We sampled the data in a strip across 128 video lines. The strip sampled one video field only, it integrated to 8 bit accuracy, and was set to be approximately as wide as a speckle (see figure 1). The sample was moveable; we could position it at the top, center, or bottom of the raster. The experiment compared fringe contrast statistics for data sampled at the top and bottom 128 lines of the video raster (the center sample was not really needed). For each relative fringe position, we sampled at the three raster positions. We define a fringe-sample as one relative fringe position measurement sampled at one raster position.

The contrast statistics for each fringe-sample were ultimately based on 600 samples. Twenty samples were Fourier transformed, from which the Fourier modulus was computed. We then determined the fringe contrast (method described below) for the 20 samples. This was repeated 10 times. Statistics were calculated, and then this process was repeated two more times using different frames captured from the same video record. The contrast data is then extracted from the averages and statistics of the three sets of 200 samples.

The contrast-detecting algorithms used the Fourier modulus to look at the noise bias at frequencies immediately above and below the expected fringe frequency (See figure 2. The 5 m fringe spacing is 4.3 lines per fringe at 7500 A so that the 5 m baseline is at 128/4.3 = 30 in the 128 point transform). The algorithms then found the average intensity at those frequencies and determined a line based on those averages. The line is therefore a linear estimator of the noise bias. The algorithms then integrated between the line and the signal. A "fringe contrast" ratio was calculated (= integrated signal divided by the average value of the noise bias). Note that negative contrast ratios are possible because the line may actually be an overestimate of the noise bias; if a very small signal is present, our "contrast" may come out negative because the signal is sitting below this arbitrary line.

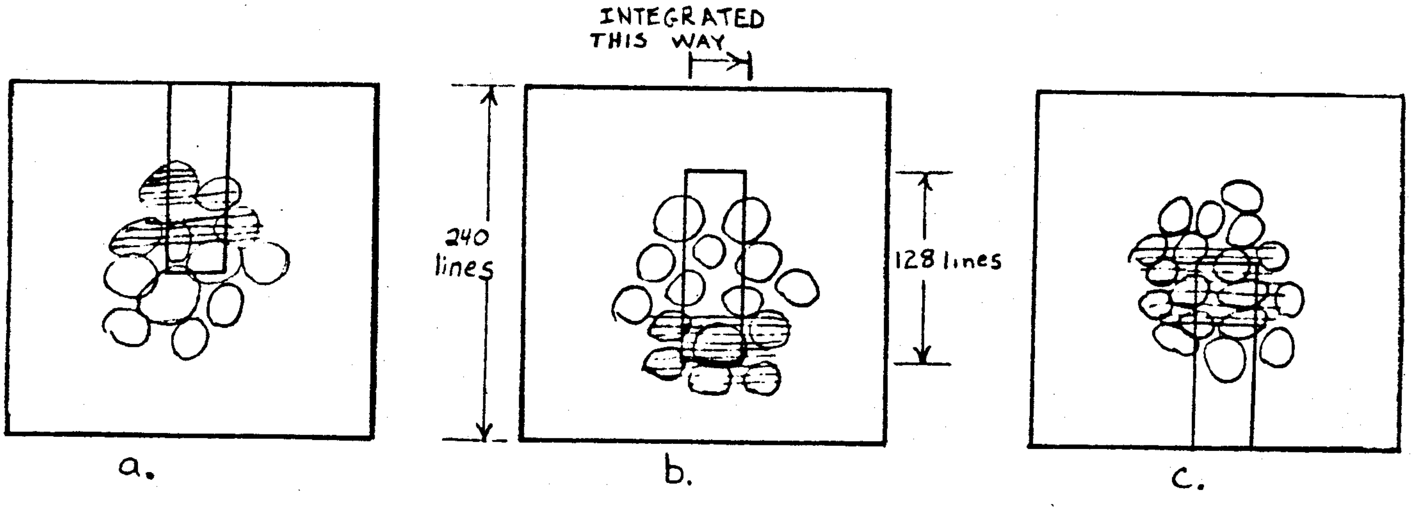

Figure 1. Each figure represents a fringe-sample. (a) has the fringes at the top of the seeing distribution and the sample at the top of the raster. (b) has fringes at bottom, sample at center. (c) is yet another fringe-sample. Note that there are nine possibilities in the scheme.

Letting F be the measured fringe contrast for a given fringe-sample, we define an error signal E as F(sample at Bottom) - F(sample at top) for a given fringe position. This gives us an estimate of how well centered the fringes were over the length of the observation (see Table 1). The "fringe error" column gives merely a visual estimate (+/- 5 fringes) of how far, on average, the fringes were off-center from the raster, i.e. the distance in number of fringes from the center of the image to the region of maximum fringe contrast. The "path error" column provides the calibration of fringe error in terms of beam commbiner pathlength difference. Thus, for observation A, in which the fringes were centered with respect to the seeing distribution, the "+10" in the "fringe error" column indicates that the fringes were estimated to be 10 fringe widths above the center of the sampling raster, either due to poor centering of the image or offset centering of the fringes on the seeing distribution (our program could not distinguish which).

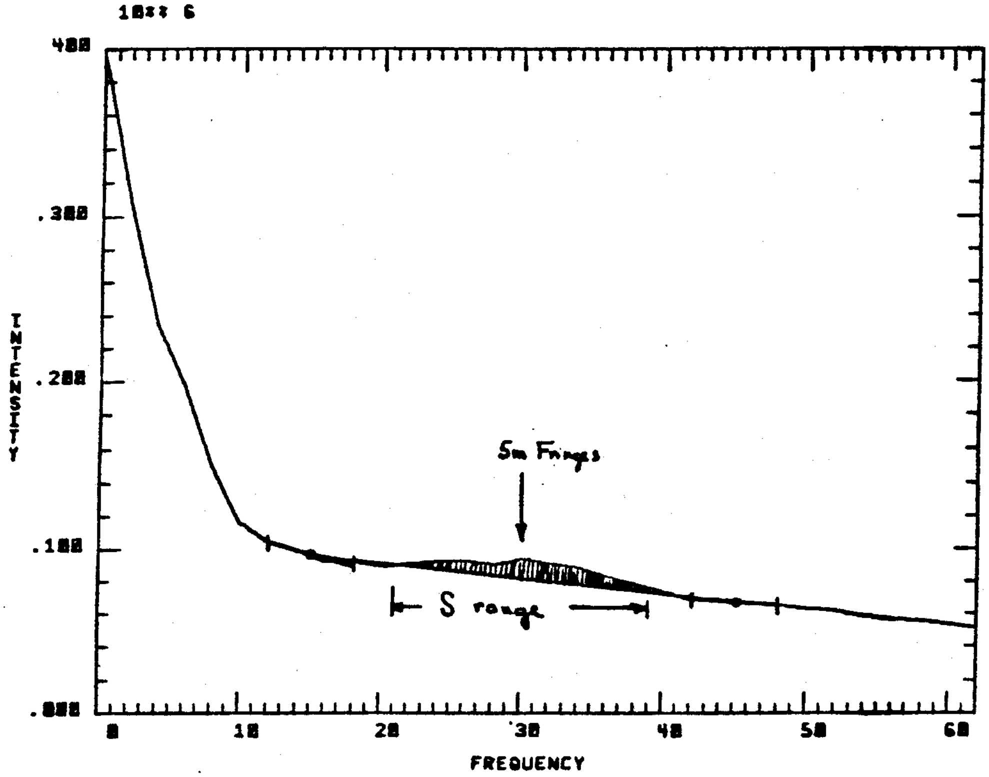

Figure 2. The squared Fourier Modulus for an unresolved star using an opposite MMT mirror pair. The line segment and the shaded area define the integrated signal calculated by our algorithm.

Table 1

OBS.	E=F(B)-F(T)	Std.error	S/N	Fringe error	path-error
A	-1.9	1.0	1.9	+10	7.5um
B	2.1	0.7	3.0	-20	15
C	-1.2	1.1	1.1	+10	7.5
D	-0.7	1.2	0.6	<5	<4

The data indicates that our algorithms could in fact detect when the fringes were off-center. For observation A, in which the fringe error appeared to us to be about 10 fringes high, the algorithms found E = -1.9, indicating a stronger signal at the top than at the bottom. The sign of E tells the sense in which to make the correction, (-) to correct down, (+) to correct up. For observation B, in which the fringe error was 20 fringes low, E = 2.1, indicating a stronger signal at the bottom. The C and D observations showed similar results. We point out that statistics for the D observation (the dimmer star) are similar to those for the brighter star. Although at first surprising, this indicates that the statistics are dominated by atmospheric effects (seeing) and image motion (largely induced by telescope motion in this experiment) and not by photon statistics. It is our experience with other analogue (as contrasted to photon-limited) measurements that this is true for objects to about m=6 (If seeing is about 1 arc second). For fainter objects, the photon statistics begin to dominate. In these measurements the quantity (F) is a measure of the mean number of correlated photons detected per scan at fringe frequencies, and our ratio is normalized by an arbitrary (but constant) factor. Looking at item D in the Summary of Measurements Table shows that, in fact, the individual F measures show higher fringe contrast for the fainter star. This corresponds to improved seeing for that object. Note also that we do not have three measurements for the dimmer star. The improved seeing and tight observing schedule called for other experiments (science) instead.

All of the data analysis was carried out on a Z-80 with a Forth Floating-point FFT. Contrast data for each fringe-sample (a single pair of mirrors - 600 samples) took a whopping 15 minutes to compute. But the important point is that only 10 seconds (=600 fields/60 fields per sec) of data were used for each pair. For full phasing of all six mirrors, 5 baselines x 2 sample-pairs (at top and bottom) x 600 FFT's per sample pair = 6000 FFT's that will have to be executed for 10 second phasing of the telescopes. One must note here that these numbers are only good to m=6. After that, phasing time increases with magnitude, requiring 100 sec for m=8 (which is .1 times as bright as 6th magnitude). These figures show that we require a modest ($15k ?) array processor (MC68000 based devices) which can reduce FFT times to less than 1ms.

One other point of interest (assuming data capture in instrument computer Grinnell) is that of data transmission bandwidth from digital video field in Instrument Point Four to FFT capability on the Cophasing Point Four (assuming use of the "spare" Point Four for this purpose). We require 6000 128 point FFT's in 10 seconds, which is 13 us/pixel. This is just within the Point 4 data transmission bandwidth. However, if bandwidth is a problem, a 64 point transform would suffice. A better solution presumes high-speed digitization capabilities in the FFT signal processor itself. Such devices are increasingly becoming available (and cheaper!).

Summary of Measurements Table

A. alpha OPH m = 2.1 Fringes "centered"

sample @	<F>	std. error	E=bottom - top
top	9.34	0.79	
center	9.45	0.65	-1.92±1.0
bottom	7.42	0.82	
B. alpha OPH		Fringes "low"	
top	-1.75	0.51	
center	-1.19	0.48	+2.1±0.7
bottom	0.35	0.55	
C. alpha OPH		Fringes "high"	
top	5.27	0.71	
center	7.75	0.85	-1.24±1.1
bottom	4.03	0.76	
D. epsilon HER m = 3.9		Fringes "centered"	
top	4.34	0.72	
center	8.43	0.71	-0.68±1.2
bottom	-1.68	0.94	