CHARA TECHNICAL REPORT

NO. 4 22 JUN 1994

Pipes of Pan - Switchable Optical Delay

S. T. RIDGWAY, T. TEN BRUMMELAAR, & W.G. BAGNUOLO

ABSTRACT: The use of switchable optical delays offers a cost-effective alternative to full-length OPLE's. The advantages and disadvantages and the cost tradeoffs are reviewed. The optimum compromise is for OPLE lengths of 40-55 meters, with switchable POP segments. Several reflections can be eliminated relative to the double-pass OPLE at the price of some additional cost in the POP's.

1. GENERAL CONSIDERATIONS

The baseline design employs 90m OPLE's used in double pass to achieve the required 340m optical delays. This entails several disadvantages.

The OPLE cost is quite high, approximately $22K/meter (seven beams) for building and rails. The use of the OPLE in double pass requires additional reflections to send the beam through the OPLE a second time. The double pass use of the OPLE's will require a modified OPLE cart and larger optics compared to the currently standard JPL design. The double pass also adds a pair of skew reflections to move the beams from the horizontal to the vertical plane, implying possible polarization problems. The 90m physical length is much longer than other installations, and the cable dragging problem and cable length is correspondingly greater. At large OPLE delay, the differential path in air is large (as large as the full 340m) requiring large dispersion compensation.

The use of switchable delays can potentially alleviate all of these disadvantages to some degree. The reduction in dispersion may permit deletion of the IR differential delay lines and at least reduces the size of the dispersion correction optics for the visible.

The double pass OPLE does have one significant advantage. The double pass is self-compensating for tilt error introduced by modulation of the catseye primary-secondary spacing.

2. COST TRADEOFF

Assign costs as follows: OPLE cost (for seven beams) $a per meter; POP cost (one beam) $b per meter (here assumed to be used in double pass); optics and mirror mechanisms (per

[1]Center for High Angular Resolution Astronomy, Georgia State University, Atlanta GA 30303-3083
Tel: (404) 651-2932, FAX: (404) 651-1389, Anonymous ftp: chara.gsu.edu, WWW: http://chara.gsu.edu

switchable delay segment) \$c per mechanism. Assume that the total required optical delay is L meters, and the OPLE physical length is B meters (optical delay $2B$ meters).

Then the total cost of the optical delay system will be

$$C = aB + 7b\frac{L-2B}{2} + 7c(\frac{L-2B}{2B}) \tag{1}$$

The minimum for the cost with respect to the OPLE length B will be at

$$B = \sqrt{\frac{3.5cL}{a-7b}} \tag{2}$$

For the best guess case, $a = 22000$, $b = 200$ and $c = 20000$. This leads to $B = 34$ meters. The corresponding total cost is \$1480K. For comparison, the baseline design of double-pass OPLE with no POP was budgeted at approximately \$2000K. This shows the cost savings potential of the POP delay.

3. OTHER TRADEOFF CONSIDERATIONS

In addition to cost, we want to consider operational convenience, simplicity and reliability.

For operational convenience we wish to have long observing periods without switching POP segments. With seven beams, this means that the OPLE length should be greater than the strict minimum to allow operational overlap between POP configurations. Ideally, it should be possible to stage the POP reconfigurations so that they are carried out for all beams simultaneously, rather than at irregular intervals.

In addition, we need to alternate between a star and reference at some distance in the sky without switching POP segments. This also requires additional OPLE capacity.

We would like to have the cleanest and simplest configuration for the initial debugging and for the most common and important observing conditions. Therefore, we would like to be able to observe with several of the inner telescopes with no POP delay segments and minimum OPLE delay for a star near zenith. We would also like to have a minimal POP and OPLE delay for a star near transit in the declination range 0 to +30 degrees.

An excessive number of POP segments will result in a large number of mechanisms, the failure of any one of which could render a beam useless for most observations. The total number of mechanisms should be limited.

4. OPLE LENGTH RECOMMENDATION

The recommended OPLE length is 50 meters. The availability of 100 meters of OPLE delay ensures long observing sessions near transit (of order several hours). It ensures a maximum uncompensated air path of about 100 meters, which is more than 3 times less than in the baseline design.

5. POP LENGTHS

In order to provide overlap between POP configurations, the recommended POP segment lengths are 35 meters instead of the nominal minimum 50 meters. This ensures some overlap of delay configurations to put some flexibility in observing.

However, not all delay lengths are equally important for all telescopes. Also, some can be dispensed with in connection with some restriction on observing, such as giving up the northern horizon. Some further numerical modeling of the array configuration will be needed to optimize the POP options.

6. IMPLEMENTATION

A part of the motivation for using the POP's is to reduce the number of optical surfaces in the array. An approach which reduces the number of reflections by 5, relative to the baseline design, is shown, not to scale, in figure 1. Note that, for drawing clarity, the POP's have been draw next to the OPLE carts. In the real layout, the POP's are parallel to and under (or over) the OPLE's, extending through the OPLE building and beyond by approximately 100 meters. Thus the OPLE build size has the same width and approximately half the length as the baseline design. The dotted lines indicate the extent of the vacuum system. Note also that the Beam Reducing Telescopes and Beam Sampling mirrors have also been included as part of the OPLE system.

This configuration requires a direct transmission of the beam from the extreme end of the southwest arm to the extreme end of the POP array, a distance of about 300 meters. Considering the slope of the terrain at the site, the optimum layout may be to locate the POP for this telescope, at least, above the OPLE, at an elevation similar to the south west telescope.

The use of the POP's also offers a strategy for deferment of costs in case of budget difficulties. The POP's can be installed initially with only a few mirror switching options, for the most common observing configurations. Additional options can be installed as needed at low incremental cost.

It should be noted that the POP's are required primarily for operation of the A configuration. With a 50 meter OPLE, a single POP configuration (with very short delays) will allow full operation of the four innermost telescopes and a single additional POP position

TABLE 1. Sky coverage above 40 degrees altitude.

Telescope	Max. Delay	Min Delay	Total Delay	POP-segments/Length
North inner	345	186	148	1/40
North middle	314	136	179	2/30
North outer	265	0	265	3/30
SW inner	303	112	199	1/32
SW outer	265	0	265	3/33
SE inner	296	89	206	2/34
SE outer	265	0	265	3/33

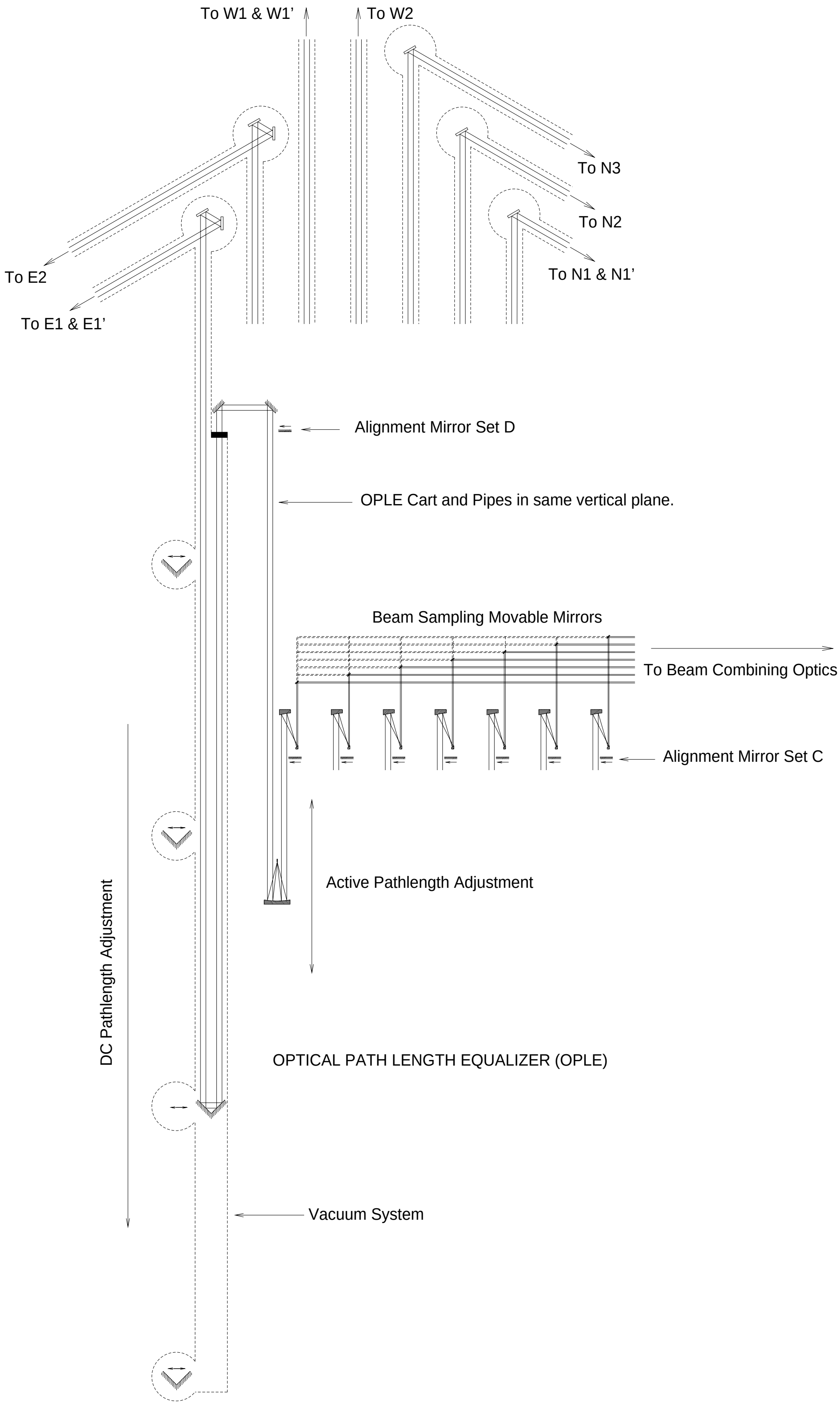

FIGURE 1. Optical layout of POP-OPLE scheme.

for each telescope will allow the full B array to operate over the whole sky. Operation of the A configuration on sources high in the sky will require large additional delay for the inner telescopes. Large delay for the outer telescopes is required only to operate the A array low in the sky.

7. MINIMUM POP REQUIREMENT

The POP requirement has been determined for the A array for sky coverage above elevation 40 degrees. This coverage includes declinations in the range -15 to +85 degrees at transit. The following table shows the the range of optical delays required. In this table, the overlap between delay segments would be twice the difference between the OPLE and POP's lengths, that is in the range 20-34 meters.

The approach requires 16 movable mirrors at intervals along the POP's, in addition to a fixed mirror set at the end of the longest segment. Costing this, conservatively, as 24 mirror mechanisms, the total cost for 50 meter OPLE's plus the required 480 meters of POP's would be approximately $1700K. This is sufficiently less than the baseline cost to allow a contingency for additional POP's as needed for operating convenience.

An alternate sky coverage option would be tilted to the south, including declinations in the range -25 to +75 degrees, and extending to 40 degrees elevation on the east and west horizons. This coverage could be obtained with 4 fewer mirror mechanisms, though with slightly less delay overlap, typically 20-26 meters of delay.