CHARA TECHNICAL REPORT

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Optical Mounts and Tables

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1. INTRODUCTION AND GENERAL INFORMATION

The CHARA Array will employ five (and possibly up to eight) 1-m size, alt-azimuth style telescopes at a site on Mount Wilson in southern California. The telescopes will be housed separately and operated remotely from a central laboratory. Light from each telescope will be directed by subsequent flat mirrors through vacuum pipes to additional optics and instrumentation at the central laboratory.

All of the optics in the Array will need to be supported on concrete piers, optical breadboards or optical tables. This technical report deals with what will be required of the optical mount points inside the optical path length equalizer (OPLE) building and beam combining laboratory (BCL). The effect of movements of the mirrors along the array arms will also be briefly considered.

2. OPTICAL COMPONENTS TO BE MOUNTED

The following subsections contain a complete list, as of the writing of this report, of the optical systems contained in the CHARA Array. These are broken into three sub-groups: those outside the central laboratory, those in the OPLE area, and those in the BCL.

2.1. Optics Outside the Central Laboratory

The following optics will need to be mounted along the array arms:

- The telescopes themselves, including the tip/tilt secondary, the acquisition system and possibly atmospheric refraction correction (ARC) optics;
- A mirror to relay the light along the light pipe; and
- Relay mirrors for maintaining optical symmetry in each arm.

The telescopes will be mounted on a large concrete pier, which in turn will be contained within the telescope housings. This will represent a large material and thermal mass and it

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is to be hoped that the small measure of protection offered by the telescope enclosures will help keep these optics stable during the night. Furthermore, since the telescope secondary will be the primary tip/tilt actuator, small movements of these optics will result only in beam shifts and very little residual wavefront tilt.

2.2. Optics inside the OPLE area

The following optics will need to be mounted inside the OPLE area:

- Relay optics from telescope light pipes to pipes of pan (POPs),
- POP optics,
- Relay periscope optics from POP to OPLE,
- OPLE optics,
- Laser metrology system (LMS) for the OPLEs,
- Beam reducing telescopes (BRT),
- Alternative location of ARC optics,
- Longitudinal dispersion corrector (LDC),
- Alignment auto-collimation mirrors, and
- Beam sampling and relay mirrors.

The first three items in this list will be mounted inside the vacuum system on as-yet unspecified mounts, probably made of a steel framework. Since these mounts are inside a vacuum which itself is inside a thermally controlled environment, they should contribute no more to beam displacement than do optics mounted on more standard optical mounts such as commercial optical tables.

2.3. Optics inside the Beam Combining Laboratory

The following equipment will need to be mounted inside the BCL area:

- Dichroic beam splitter for Visible/IR separation,
- Tip/Tilt detectors and optional high speed tip/tilt mirrors,
- IR imaging system,
- Fringe tracking system,
- Visible imaging system,
- Alignment optics, and
- Reference laser and white light source.

This part of the array optics is, at the time of writing this report, the least well known or specified. It is assumed that all the optical components in this area will be mounted on standard optical tables on solid steel (or concrete) legs. No estimate for the area of tables required for each system is available; however, a safe guess would be three $6' \times 12' \times 18''$ tables, one each for the IR imaging system and IR alignment optics, the fringe tracker and tip/tilt system, and the visible light imaging system and optical alignment optics. It may be possible to fit all of these components on smaller tables; however, with a cost differential of a few thousand dollars it would be best to have too much table area, rather than too little.

3. THE EFFECT OF VIBRATION AND CHOICE OF TABLES

Since a great deal of the optics will be mounted directly onto concrete piers in the ground, or on the OPLE tracks, it will not be possible to use vibration isolation systems, such as air flotation, on the optical tables used elsewhere in the array. It will be all but impossible to maintain relative alignment of floated tables and, in any case, if only one mirror in the optical chain has vibration problems the entire optical arm will be affected. So, even when an optical table is being used it will need to be mounted on plain steel or concrete legs. We will simply have to hope that there will only be small amounts of vibration caused by the local environment. Apart from the movement of the nearby 100-inch dome there are few sources of vibration nearby and the fact that the Mark III functioned so close by should give us hope that vibration will not be a show stopper. It would, however, be a good idea to have local measurements made of the power spectral density of vibration on the inertial slabs once the concrete has set.

With this in mind, and pending the analysis of these measurements, it should not be necessary to buy the 'best' (read most expensive) tables. Barring differential expansion problems, standard tables should be up to the task. It has also been suggested that simple breadboards grouted to concrete piers would be cheaper and achieve much the same performance. Indeed, this method has been used in other optical array projects. As will be shown below, however, this will cause major logistic problems as in the OPLE area the vacuum tubes must go below the optical tables. Furthermore, the table surfaces required in the BCL remain largely unspecified. If we are to use large amounts of concrete it should be poured while the rest of the major works are being completed and we are not in a position to specify the size or position of these piers. Finally, concrete piers will be difficult to move should it become necessary to change the optical arrangement.

4. THERMAL STABILITY

There are two parts of the array to consider for thermal stability. Outside of the central facility the optics will either be in a vacuum or fully exposed to the local environment. Even those optics in a vacuum will be placed on mounts which themselves will be subject to large temperature changes. It may be necessary to wrap these mounts in thick layers of insulation material in order to reduce the effects of expansion and contraction of the these mounts throughout the night. Fortunately, the design of the telescope itself takes into account temperature changes. A temperature shift of 25°C will be used as a worst case figure for the calculations that follow.

Inside the central facility the optics and mounts will be inside a thermally controlled environment. While the absolute temperature will be allowed to slowly shift as the seasons change, throughout a single observing night only very small changes in temperature should occur. A worst case figure of 1°C will be used to calculate the effects of expansion and contraction of optical mounts inside the building. Larger shifts than this over longer time periods may be possible, however, like many similar systems, it will be necessary to perform a regular, probably daily, alignment of the system. Thus, only changes that can occur during a single night are of the most importance here.

Table 1 shows the movement of mounts under these conditions, based on a linear expansion coefficient of $12\mu\mathrm{m\,m^{-1}\,{}^\circ C^{-1}}$.

TABLE 1. Maximum mount shift due to temperature changes.

Location	Temperature Shift	Expansion
Outside	25°C	$300\,\mu\mathrm{m\,m^{-1}}$
Inside	1°C	$12\,\mu\mathrm{m\,m^{-1}}$

5. EFFECTS OF MOUNT MOVEMENT

There will be two primary effects of a mount moving due to temperature change or vibration:

1. An introduction of wavefront tilt, and
2. Beam displacement.

Both of these will reduce the measured visibility.

Since the optical system includes a dynamic tip/tilt servo it is unlikely that vibration induced wavefront tilt will cause severe problems, unless the frequency of vibration is outside of the range of the tip/tilt servo. This is unlikely to be the case, although it does add to the argument that power spectral density measurements of local vibrations should be undertaken on the inertial slabs once they are complete. Thus, only slow changes in wavefront alignment need be considered, where 'slow' means long in comparison with the visibility measurement sample time. This will certainly include any effects due to thermal expansion.

We write the fringe intensity pattern across a one dimensional beam as

$$I(x) = 1 \pm V \cos\left(\Delta\phi - \frac{x\theta D}{\lambda}\right) \tag{1}$$

where V is the visibility, $\Delta\phi$ is the optical path length difference between the two beams, $-\frac{1}{2} \le x \le \frac{1}{2}$ is the normalized position within the beam, D is the beam diameter, θ is the wavefront tilt, and λ is the wavelength. The ± sign is included to show that this may be measured on either side of a beam splitter. When measuring the visibility this is integrated across the beam, yielding

$$\begin{aligned} I_{\mathrm{tot}} &= \int_{-1/2}^{1/2} 1 \pm V \cos\left(\Delta\phi - \frac{x\theta D}{\lambda}\right) dx && (2) \\ &= 1 \pm V \frac{2\lambda}{\theta D} \sin\left(\frac{\theta D}{2\lambda}\right) \cos\Delta\phi. && (3) \end{aligned}$$

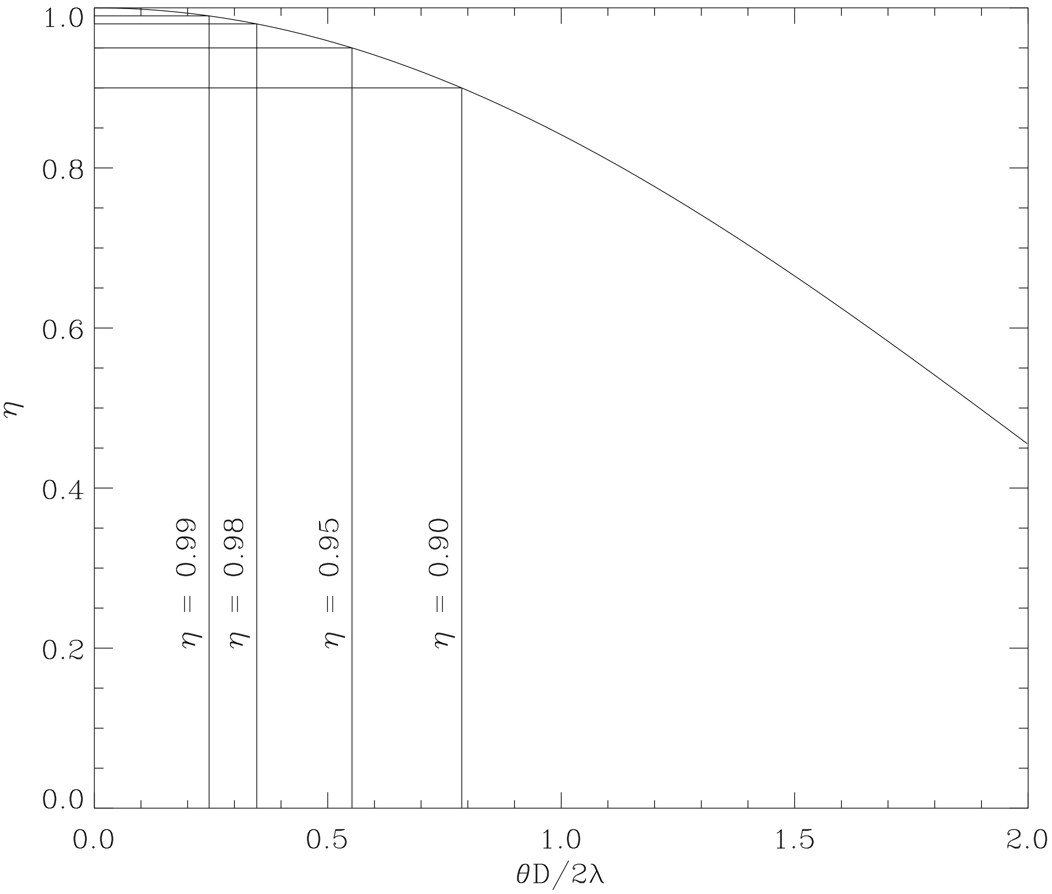


FIGURE 1. The visibility transfer factor (η) due to the addition of a constant tilt of one beam with respect to another. The horizontal axis is marked in the dimensionless units of $\theta D/2\lambda$, where D is the aperture diameter, θ is the tilt and λ is the wavelength.

The visibility transfer function due to a constant wavefront tilt is therefore

$$\begin{aligned} \eta &= \frac{2\lambda}{\theta D} \sin\left(\frac{\theta D}{2\lambda}\right) && (4) \\ &= \operatorname{sinc}\left(\frac{\theta D}{2\lambda}\right). && (5) \end{aligned}$$

This function is plotted in Figure 1 and some important points are tabulated in Table 2 assuming a 25-mm beam and a wavelength of 600 nm.

This visibility transfer factor is only of importance if the tip/tilt detector has been moved with respect to the beam splitter creating the fringes. Any other movement will be corrected by the tip/tilt servo. A comparison of Tables 1 and 2 makes it clear that the largest expected shift of an optical mount inside the BCL due to thermal changes during the night fall within the $\eta = 0.99$ criteria. For example, if the quadrant detector is 10 meters away from the beam splitter, the allowed differential movement of the components is 118 μm. If the tables

TABLE 2. Allowable wavefront tilt for a given visibility transfer factor.

η	$\frac{\theta D}{2\lambda}$	$\theta(\mu\mathrm{rad})$
0.99	0.246	11.8
0.98	0.348	16.7
0.95	0.552	26.5
0.90	0.787	37.8

in the BCL are the largest commercially available, that is some 2 feet thick, the maximum thermal expansion is expected to be less than $10\,\mu$m. Thus, we can conclude that within the thermally controlled environment of the OPLE and BCL areas it will not be necessary to obtain the most expensive optical tables and that movement of these surfaces due to differential thermal expansion should not be a major concern.

Apart from wavefront tilt, differential motion of optical mounts will result in a beam displacement. For example if a mount near a telescope, some 300 meters away from the BCL, moves it will introduce a tilt. This tilt will be removed by the tip/tilt servo but a beam displacement will still be introduced. Using the figure given in Table 1 and assuming that the mirror moving is some 20 m distant from the telescope secondary a beam shift of up to 6 mm could occur at the output of the OPLEs representing some 5% of the beam size. Beam displacement then is potentially a much larger problem than wavefront tilt, and while it may not result in severely reduced visibility measurements it will reduce the amount of light reaching the beam combiner and thereby affect the magnitude limit of the array. Ultimately it may stop any light reaching the beam combiner at all.

These problems should be investigated in more detail when the design of the mirror mounts along the light pipes and near the telescope are being finalized. In the mean time we can conclude that standard optical tables will be quite adequate for mounting components within the OPLE and BCL areas. Furthermore the proposed concrete and steel OPLE support system should also perform well within allowable limits.

6. TABLE LOGISTICS

A major concern, especially at the end of the OPLEs, is where and how an optical mount surface can be placed in the correct position without interfering with the other subsystems in the area. The POP vacuum pipes must be able to go beneath the mounting surface and the beams leaving the OPLEs must go above. This probably means that optical breadboards grouted to concrete piers will not be a workable method, despite the potential cost savings. Furthermore, shaping the concrete such that the POPs can go below and be accessible for future servicing will reduce any potential savings. Figures 2 and 3 show a first cut at determining the positioning of these optical systems and tables.

Figure 2 shows an elevation of one of the OPLE mounts looking from the west. Note that all dimensions are in inches and are well known, except the height of the optical rail which has been scaled up from that of the Sydney University Stellar Interferometer. A 12-inch thick table can fit between the output beams above and the POPs below resulting in a final beam height of $45\frac{1}{4}$ inches from the floor and $7\frac{1}{2}$ inches from the optical table surface. A thicker table is also possible, however, the POP mirror boxes (not shown in this diagram) will require enough room to move a mirror in and out of the beam path within the POPs.

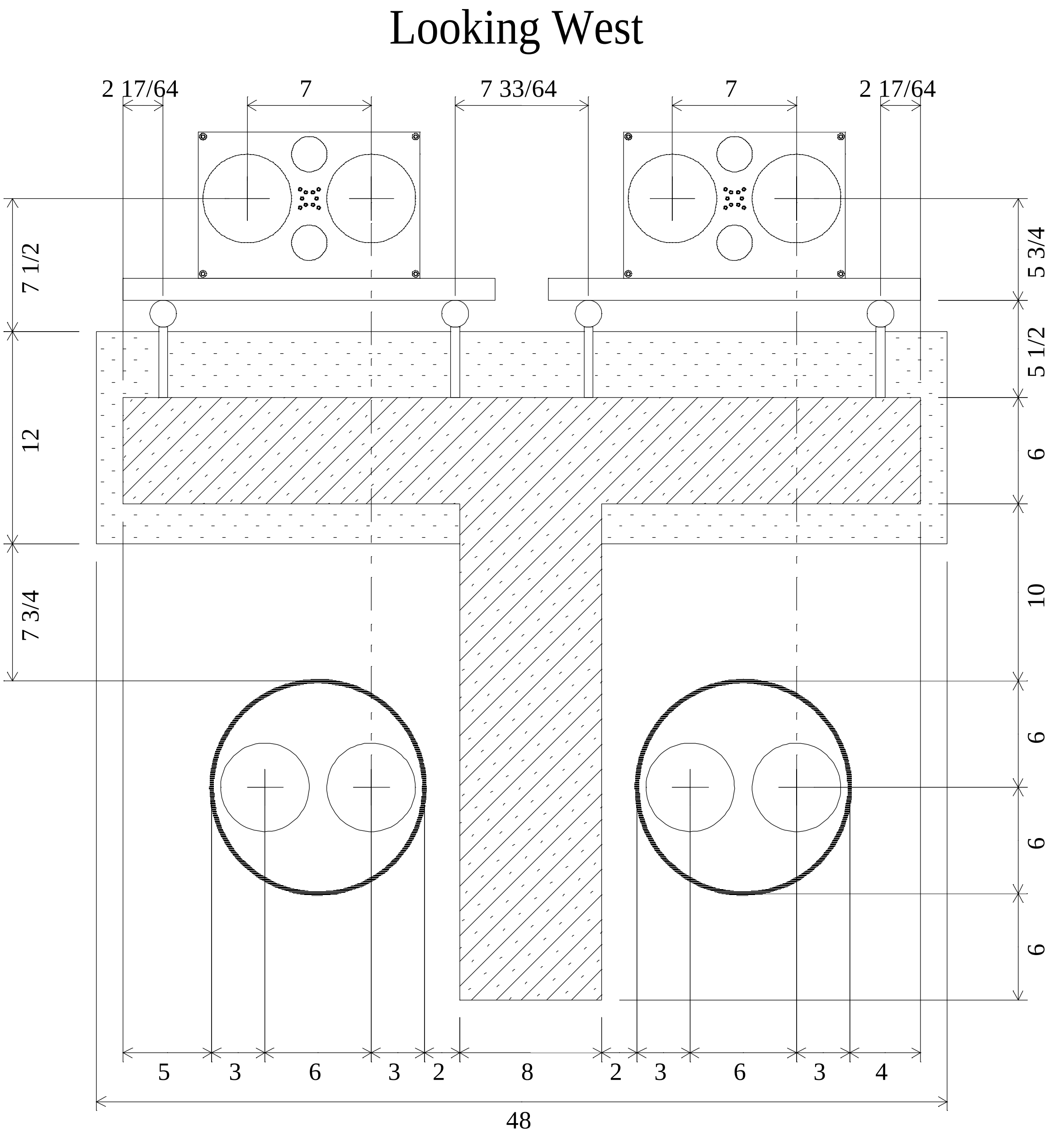
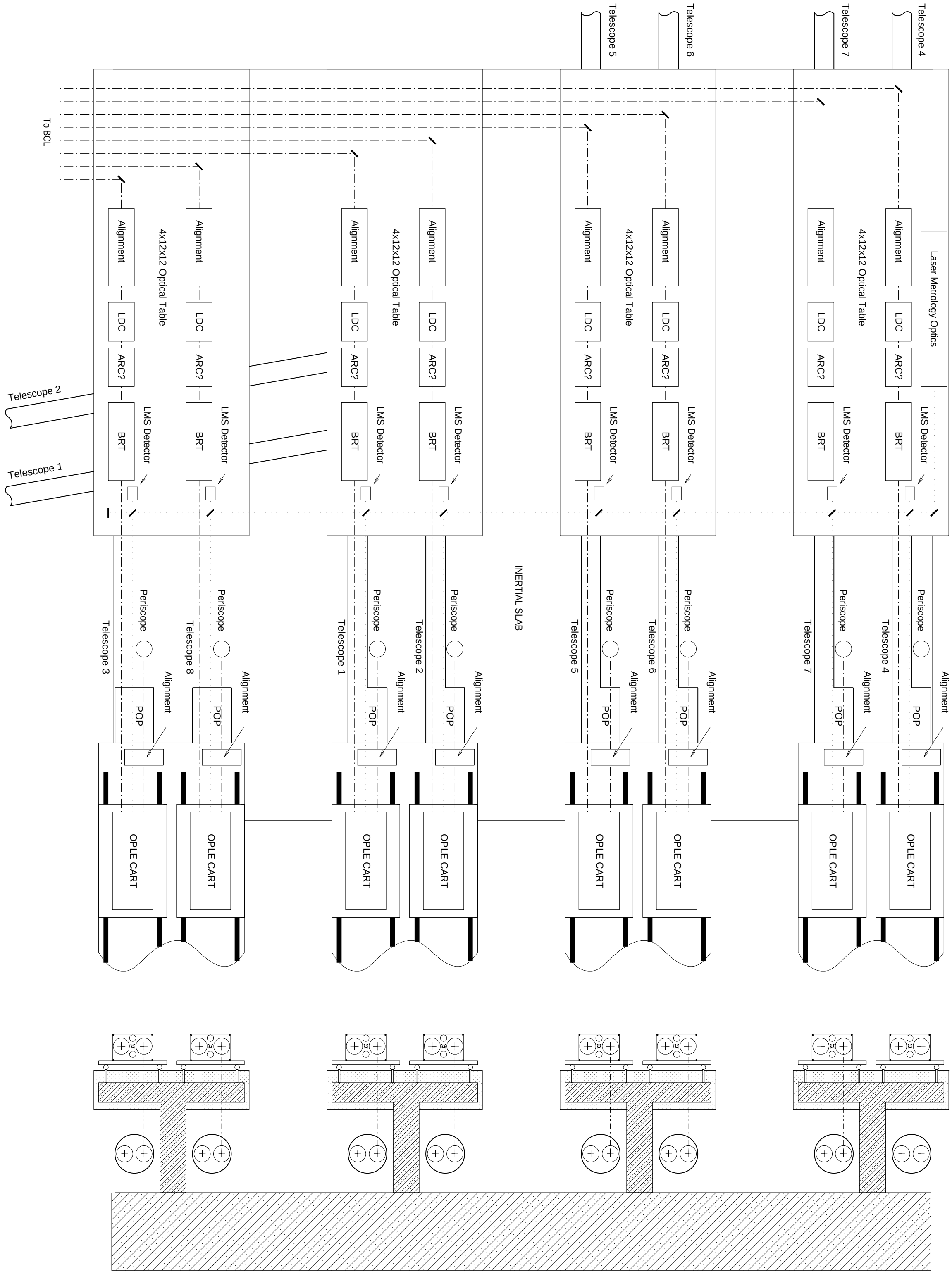


FIGURE 2. Elevation view looking west of one OPLE 'T' support showing two carts on top of the support and two POP pipes below. The dotted area behind the 'T' is the end of a $4' \times 12' \times 12''$ optical table.

FIGURE 3. OPLE termination optics. See text for discussion.



It is unlikely that a table thicker than 12 inches will allow enough room for these mirrors.

Figure 3 shows the plan and elevation of the end of the OPLEs, including all of the optical components and laser metrology system for the OPLE carriages. Fortunately, there is enough room on the inertial slab to support all of the required systems, including $4' \times 12' \times 12''$ optical tables for the BRT, ARC, LDC, LMS, alignment system and beam samplers. Note that with this layout it will not not be possible to simultaneously observe in the visible and IR bands. Unfortunately an alternate location for the LDC after the dichroic beam splitter has yet to be identified.

Most of the optical systems listed above remain largely unspecified, and they have yet to be designed. Therefore the size of these systems is unknown. The boxes shown in Figure 3 represent a 'best-guess' for these components. The ARC is labeled with a question mark as the preferred location for this subsystem is on the telescopes themselves. However, it may be necessary to place them here due to thermal stability and cost considerations. The dotted lines show the proposed beam paths for the LMS beams while the dot-dash lines show the science light beam paths. The optics for the beam sampling system are not shown in detail but will completely fill the last part of the optical tables.

It may be possible to use shorter tables in this location, and thereby save several thousand dollars. However, since we do not know the size of any of the optical systems to be mounted here, nor the space required for any support or alignment optics, I believe it is a false economy to reduce the table area here. It would be very expensive if we found we simply couldn't fit everything we needed to put in this location. It is likely that these tables will need to be purchased and put into place before the light pipes are constructed and the central enclosure is complete.

7. CONCLUSION

A great deal of the optical systems to be placed within the OPLE and BCL area remain unspecified. It is therefore difficult to reach strong conclusions concerning tables sizes and exact positioning. It would therefore seem appropriate to err on the size of having too much space rather than too little. The recommended table size for the end of the OPLEs is therefore $4' \times 12' \times 12''$ and that within the BCL is $6' \times 12' \times 18''$.

A preliminary analysis of beam tilt and movement and a layout of the OPLE area have been completed, showing that standard optical tables will be quite adequate and will also fit within the available space. The focus of this report has been the optical tables within the central beam synthesis facility. A more detailed analysis of the problems associated with the mirror mounts along the light pipes and on the telescopes themselves will also be required.

We should investigate the cost of having vibration spectral density measurements made on the inertial slabs once they are complete in order to confirm that standard tables are up to the job. This can be done commercially, or could possibly be done ourselves using the metrology system purchased for the construction of the OPLE carriage prototype.