CHARA TECHNICAL REPORT

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Beam Combining Optical Components

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1. INTRODUCTION AND GENERAL INFORMATION

The CHARA Array will employ five 1-m size, Alt/Az 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. More information about the CHARA Array can be found at our WWW home page listed below.

Three beam sizes will be used within the Array. The telescope aperture size is 40 in which is reduced to 5 in by the telescope primary and secondary acting as a beam compressor. This 5-inch beam travels through the light pipes and optical path length equalizer (OPLE) and is then further reduced in size to 1 in by the beam reducing telescopes (BRT) on the beam sampling tables (BST) at the end of the OPLEs. This report deals with the optics, mounts and interfaces required for the 1-inch beam size. This will include all the subsystems in the beam combining laboratory (BCL) and all subsystems downstream of the OPLEs.

I have attempted to break all the systems into smaller pieces and to identify 'standard' components where ever possible. Each of these pieces and components will be briefly described below and an example part or parts, where possible, identified and costed from available catalogs. Equivalent parts from other manufacturers will be accepted, but only if they are a direct one-for-one replacement for the part listed and meet the requirements set out in the accompanying text. Due to incompatibility problems we have experienced in the past, vendors that can supply complete sets of matching parts (baseplate, stem, mount and optic) will be preferred over vendors supplying only a subset of parts.

Along with the text below describing the standard components and the various subsystems within the BCL and BST, a spread sheet has been created for budgeting the parts and to aid in creating a purchasing list. The spread sheet and the text and figures in this technical report together make up the requirement specification of the small beam size parts.

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2. COATINGS AND WAVEBAND

The waveband for the optical system is to be 500-700 nm. All reflection and transmission optic coatings will be optimized for this band. Furthermore, since the S and P polarization states will be split and used in separate optical systems, some components will be required to work with both polarization states while others will be optimized for one state or the other. The polarization state for each optic will be set out in the sections below. In the spread sheet, the Newport BD.1 coating has been specified for the visible light mirrors while the ER.2 coating has been specified for the IR mirrors. However, equivalent coatings will be acceptable provided they meet or exceed the same specifications and documentary evidence of their performance can be supplied by the vendor.

3. STANDARD COMPONENTS

Many of the optical systems within the BCL and BST areas will use similar optics, for example beam folding mirrors, lenses and beam-splitters. Even many of the parts unique to each device will require a baseplate and stem for the mount. This section describes these standard components.

3.1. Baseplate, Post and Holder

The beam center height at the time of writing this report is 7.5 in above the table surface for the science beams and 12 in above the table surface for alignment beams. All optics in the BCL and BST will need to be held stably at these heights. There will therefore be two recommended systems, one for the science and one for the alignment optics.

The baseplate must have holes suitable for connecting to the 1-inch square grid of $\frac{1}{4} - 20$ mounting holes on the tables. The baseplate must also have a surface area that will allow us to use clamps in order to have the flexibility of placing these components in positions other than directly on the tables 1-inch hole grid.

The posts and holders must attach to the baseplate and hold the optic at the correct height. The holders will attach to the base-plates using a $\frac{1}{4} - 20$ hex-bolt. The stems must be made of stainless steel and of at least 1 inch diameter and must accommodate both a $\frac{1}{4} - 20$ and a $8 - 32$ thread connection to the optic mount.

The combined baseplate, holder and stem must allow an adjustment in height of the optic of 2 in or more. This adjustment may be achieved either by a continuously adjustable stem and post holder combination or by providing various sizes of interconnecting posts.

3.2. Translation Stages

Some components will require small translation stages for X or XY motions. Translation stages will have mounting holes suitable for the 1-inch hole grid pattern of the optical tables and accept standard $\frac{1}{4} - 20$ mounting hex-bolts. The stages will also be capable of attaching to the standard bases described in Section 3.1.

The actuators will either be manual or motorized. The stages will accept actuators using the standard shoulder diameter of $\frac{3}{8}$ inches so that normal commercial micrometers or motorized micrometers can be used. The micrometers may be purchased separately from the stages themselves.

The manual adjustment screws will have a resolution of 1 μm or smaller while the motorized actuators will have a step size of 30 nm or smaller. The actuators will hold position to this precision over time and must not require that the controller or power be connected in order to hold position. The motorized actuators must be computer controllable, either through an RS232 port or equivalent, or by simple TTL pulses. The controller will also have the option of using a hand paddle for working within the BCL area.

3.3. Folding Mirror

The folding mirrors consist of a 2.5-inch or larger mirror with a coating optimized for the band for which it is used. Reflection must be greater than 97% in the visible band. Higher reflectivity mirrors will receive priority, and a reflectivity of 99% is preferred. The mirror surface will be $\lambda/20$ peak to valley or better at 632 nm and have a scratch and dig of 10-2 or better.

The mount for the folding mirror must allow control in both tilt axes for mirror alignment and must attach to one of the standard bases set out in Section 3.1. The mounts will accept actuators using the standard shoulder diameter of $\frac{3}{8}$ inches so that normal commercial micrometers or motorized micrometers can be used. The micrometers may be purchased separately from the mounts themselves.

In *Technical Report No. 35*, it is shown that in order to achieve a visibility transfer factor of 0.99 or greater, the following relationship must apply:

$$\frac{\theta D}{2\lambda} \leq 0.25, \tag{1}$$

and so with a beam size of 25 mm and a wavelength of 500 nm this implies an angular positioning stability of 10 micro-radians ($2''$). Another constraint is beam positioning. A 10 micro-radian error in positioning over 25 m will shift the beam position by 1%. In order to facilitate easy alignment of these components, the manual mounts must be adjustable to half this precision, that is 5 micro-radians ($1''$) and the motorized mounts to 20 times this precision or better (0.5 micro-radians or $0\farcs1$).

The manually controlled mounts will use standard micrometers or adjustment screws with a locking mechanism. These are a standard mechanical component and need not be purchased from an optics supply company. The manual adjustment screws will have a resolution of better than 1 μm. Furthermore the manual adjustors will hold this position over time with the same precision.

The motorized mounts will use actuators that fit in the standard $\frac{3}{8}$-inch shoulder hole in the mounts and have a step size of 30 nm or smaller. The motorized micrometers will hold their position when the power or controller is removed and will also allow manual adjustment.

3.4. Flat Beam Splitters

Many beam splitters are required in the BCL area. They must accommodate the full size of the optical beam in reflection and transmission. Various reflected/transmitted light ratios are required ranging from 30% up to 50% reflection. In most cases the reflection surface will be optimized for the P polarization state, although in some cases they will be optimized for the S polarization state. The optical surfaces will be $\lambda/20$ peak to valley or better at 632 nm with a scratch and dig of 10-2 or better. They will be coated for maximum performance in the optical band of 500-700 nm.

The beam-splitters will be placed in gimbal mounts optimized for maximum clear aperture for the transmitted beam at 45° incident angle. The gimbal mounts will accept standard $\frac{3}{8}$-inch adjustable screws, micrometers or motorized actuators. The adjustable resolution of the mounts will be the same as that for the mirror mount described in Section 3.3.

The manually controlled mounts will use standard micrometers or adjustment screws with a locking mechanism. These are a standard mechanical competent and need not be purchased from an optics supply company. The manual adjustment screws will have a resolution of better than $1\,\mu$m. Furthermore, the manual adjustors will hold this position over time with the same precision.

The motorized mounts will use actuators that fit in the standard $\frac{3}{8}$-inch shoulder hole in the mounts and have a step size of 30 nm or smaller. The motorized micrometers will hold their position when the power or controller is removed and will also allow manual adjustment.

The optic and mount will require an elevator base which can connect to both the gimbal mount and a standard base plate as described above. The elevator base must also be able to attach to a standard translation stage as described in Section 3.2.

3.5. Shutter

The shutters will be required to block the full 1-inch beam width inside the BCL. They must be motorized with a computer interface but will only need to either be in or out of the beam. When out of the beam, the shutter must not block the adjacent beam. The clear area between beams on the optical tables is 2 in, and so, when out of the beam, the entire unit must not use more than 2 in of space. These shutters do not need to be high speed. A shutter that can open or close within a few seconds is acceptable.

3.6. Five-Axis Lens Positioner

Some lenses will require very fine adjustment in up to 5 axes. These mounts must be able to attach to the standard base and stems described in Section 3.1 and allow adjustment in five axes and focus, that is focus, tip, tilt, X, Y, and Z. They must accommodate up to a 2-inch optic and have adjustability in X/Y of $1\,\mu$m and in Z of $5\,\mu$m or better.

4. NOMENCLATURE

Each optical system has been broken up into numerous sub-assemblies, identified by a unique code and described in its own subsection below. The codes consist of three parts: a single letter showing which subsystem the optic belongs to; a second letter denoting the type of part; and a number, if there is more than one such part in the subsystem. Table 1 contains a complete listing of the single letters used in these codes.

An exception to these rules are some subsystems located on the Beam Sampling Table (BST) which already have identifying labels. These include the longitudinal dispersion correctors (LDC), the atmospheric refraction correctors (ARC), and the beam reducing telescopes (BRT). The laser metrology system (LMS) for the OPLE carts is also on the BST but will not be included in the beam sampler system.

TABLE 1. Letter Codes.

Subsystems		Sub-assemblies	
Letter	Subsystem	Letter	Subassembly
A	Alignment	B	Beam Splitter
B	Beam Sampler	C	Camera
F	Fringe Tracker	D	Detector
I	IR Imager	F	Fiber Coupler
T	Tip/Tilt	H	Spatial Filter
V	Visible Imager	L	Lens and mount
		M	Mirror
		P	Periscope
		R	Retro-reflector
		S	Light Source
		W	Aperture Wheel

5. ALIGNMENT SYSTEM (A)

The alignment system spans a number of the optical tables in the BCL and on the BST, although the majority of the parts are on the alignment and fringe tracking tables. The alignment method will consist of injecting either laser or filtered white light into the system using a periscope to move the light from the alignment beam height down to the science beam height. The light is then auto-collimated at one of several positions in the light chain and reflected back into the fringe tracking and imaging optics. This light then reaches both the fringe tracker and imaging detectors and can also be sampled by the periscope and sent to a CCD or reference detector. In this way, white light fringes can be created within the optical system and the optical alignment checked for each beam and optic.

Another part of the proposed alignment scheme is to have small (1-3 mm) holes drilled in the center of all the large beam mirrors (those upstream of the BRTs) so that small LEDs, or fibers, can be placed in the center of each. The reference detector discussed in Section 5.9 can then be used to image each of these small point sources in turn. Each mirror's light source can be used to roughly align the mirror directly downstream. The cost of these holes and point sources will not be part of the alignment system and needs to be included in the costing of the mirrors themselves.

Figure 1 contains a schematic of the alignment table. The alignment system has been broken into several sub-assemblies as labeled in the figures, and each sub-assembly will be briefly described below. Some of the alignment optics are mounted on the fringe tracking table (Figure 2), the tip/tilt and imaging table (Figure 3) and the beamsampler table (Figure 4).

5.1. AS1: White Light Source

The white light source must produce a collimated black body beam of approximately 1 inch in diameter at the alignment beam height. The source will also require a standard shutter and a set of filters. Apart from the shutter and the filters, the existing white light source used in Nils Turner's doctoral research effort should be sufficient for initial alignment. A more powerful light source is desirable, but its purchase can be delayed.

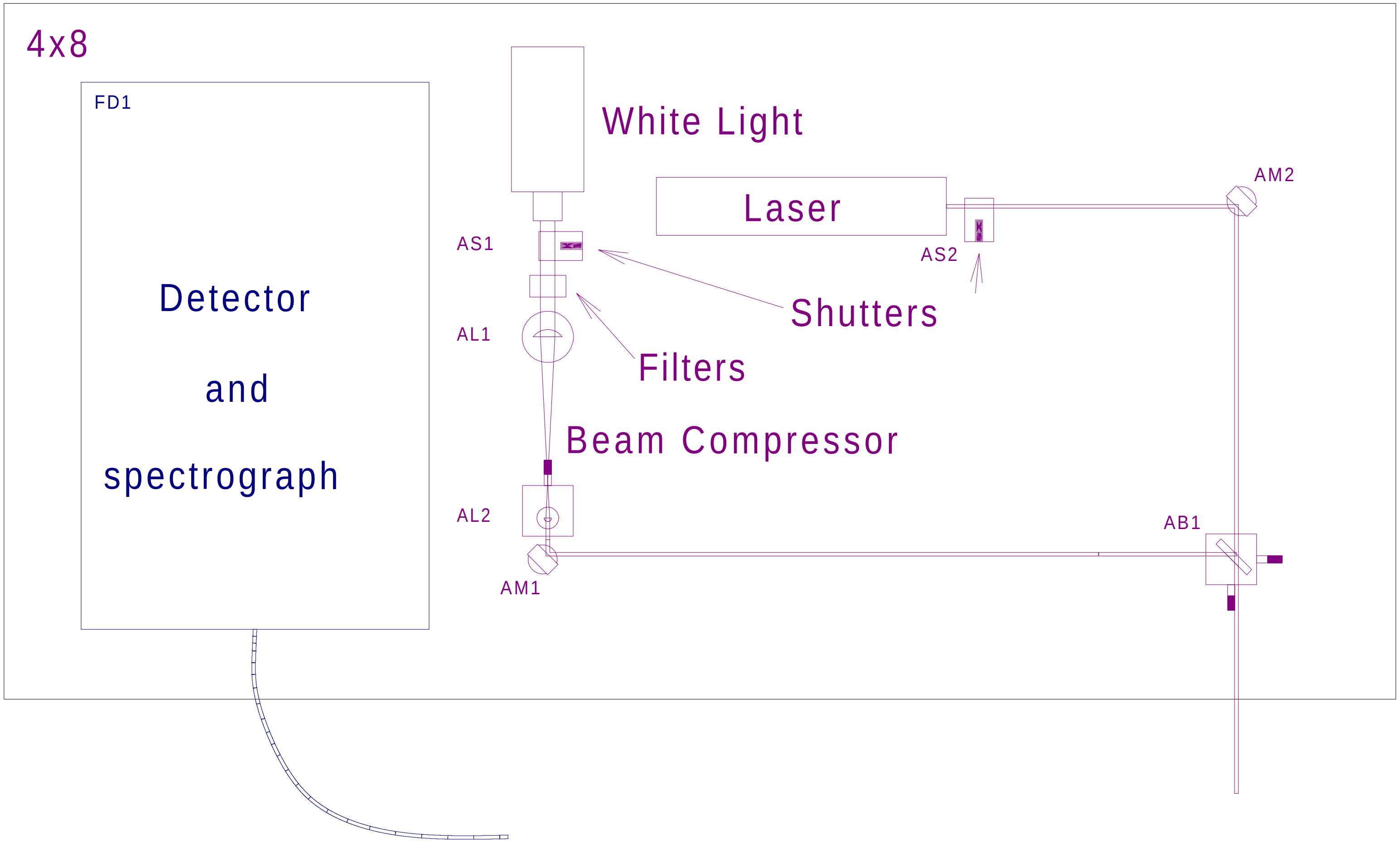

FIGURE 1. Schematic of the alignment optics table in the BCL.

5.2. AL1 & Al2: Beam Compressor

The large beam size of the white light source needs to be reduced to match that of the laser/collimator output so that it can pass through the same spatial filter. Two achromatic lenses are required with appropriate mounts with a focal length ratio of approximately 10:1. Complex lens mounts will not be required, although careful focusing of the elements is important. The first lens must be big enough to accommodate the beam size of the white light source. The mounts must attach to a standard alignment height base described in Section 3.1.

5.3. AM1 & AM2: Folding Mirrors

These mirrors are required in order to ensure that the laser and white light beams are at the correct height and orientation. They will be standard folding mirrors as described in Section 3.3.

5.4. AB1: Beam Splitter

This beam splitter is for combining the laser and white light beams. It requires motorized (or very fine manual) actuators and a standard XY stage. The beam splitter itself is a standard component described in Section 3.4.

This beam splitter should work for both the S and P polarizations, but will be optimized for P.

5.5. AH1: Spatial Filter

The spatial filter must be a combined objective lens and pinhole mount with three axes of adjustment: XY position of the pinhole and focus. These adjustments must have a resolution of less than $2\,\mu$m and a travel of over 10 mm.

5.6. AC1 & AC2: Alignment CCDs

The alignment CCD camera AC1 is to aid in adjusting the source beam alignment to the pin hole. No lens is required for this unit as it is only there to show what light is getting through the pin hole. A 'standard' inexpensive monochrome CCD that produces a video signal is adequate. It must be mounted such that it can be moved in and out of the beam, and while it would be useful to be able to control this from within the control room, the camera need not necessarily be remotely actuated.

The second alignment CCD camera AC2 is used for looking at the aperture plane of the science and alignment beams and is the same as AC1.

5.7. AL3: Collimation lens

A collimation achromatic lens is required after the spatial filter. This lens must have the correct focal length to ensure a 1-inch beam size after the pin hole. The lens must use an anti-reflection coating optimized for the optical band of 500-700 nm.

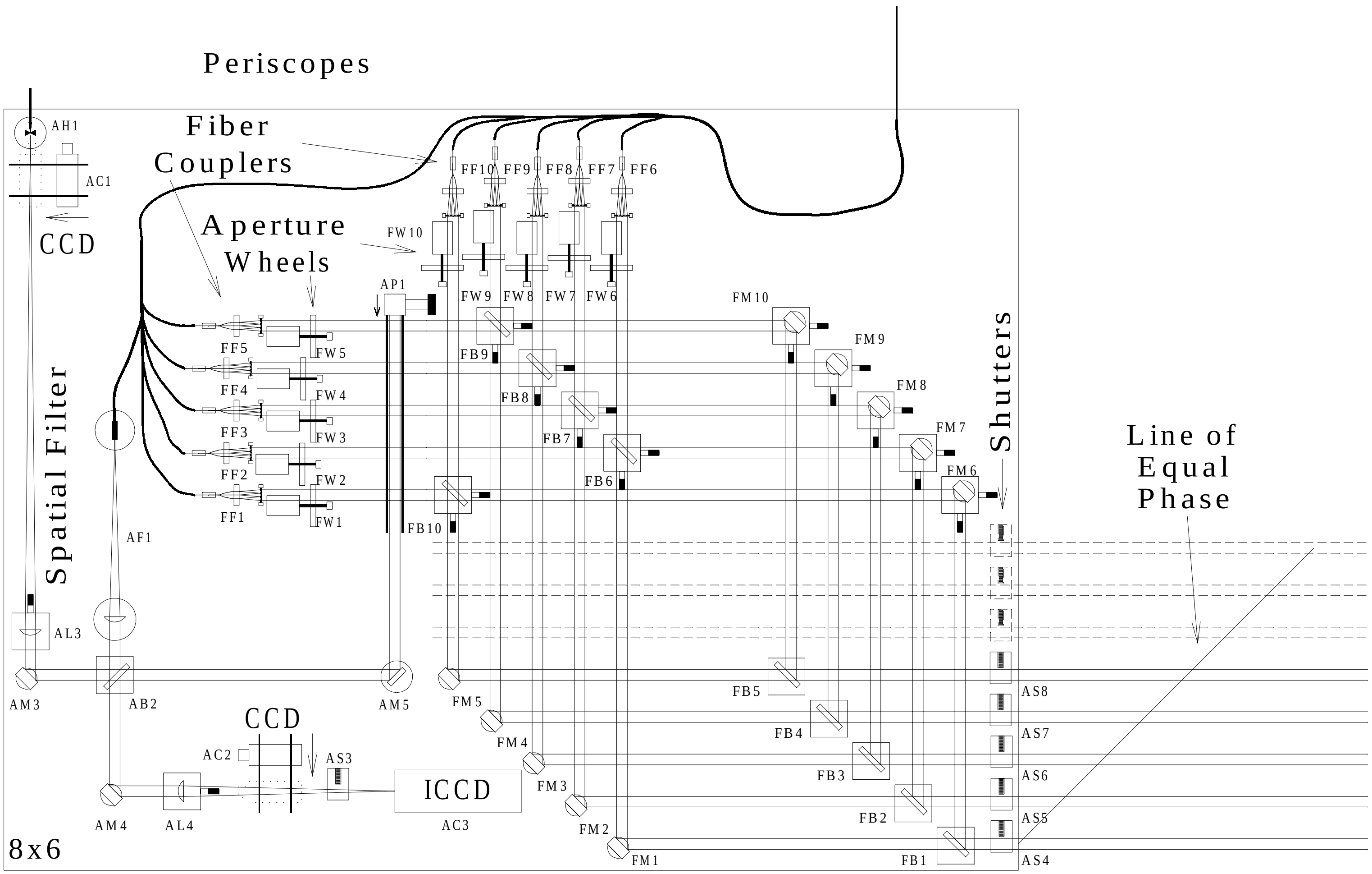

FIGURE 2. Schematic of the fringe tracking table in the BCL.

5.8. AM3-AM5 & AB2: Light Distribution

The light distribution system breaks the white light or laser light into two parts for insertion into the five telescope beams. One standard beam splitter is required with an R/T of 50/50. This beam splitter should work for both the S and P polarizations, but will be optimized for P. The folding mirrors are standard manual mirrors.

5.9. AL4, AS3 & AC3: Reference Detector

The reference detector is to be used to aid in ensuring that all beams are optically superimposed. The existing ISIT camera can probably be used, although a more linear device would be preferable. A shutter is required for this camera for high light level protection. The imaging lens is mounted on a motorized X mount so that the focus can be adjusted from the control room. This focus control will be enable the imaging of both the aperture and image planes, and allow the operator to image each of the small point sources on the larger beam mirrors discussed in Section 5.

5.10. AP1: Periscope

The periscope transports the beam between the alignment and the science beam heights in either direction. It will be mounted on a motorized slide so that it can be placed in any of the five science beams. This slide should be repeatable to within 1 arcsecond. It requires a standard mirror at the top and a cube beam-splitter at the bottom. In this way star light can pass through the cube to the fiber coupler and up into the alignment system simultaneously. The cube splitter must meet the same optical requirements as the standard splitters described in Section 3.4. The beam splitter should work for both the S and P polarizations, but will be optimized for P.

5.11. AS4-AS8: Shutters

A shutter will be required for each incoming science beam. Using these shutters it will be possible to select which beam reaches the fringe tracking optics. This will allow us to check to alignment of the tip/tilt detectors (TD1-TD5) for each beam against the reference detector (AC3).

5.12. AF1: Fiber Coupler

Money has also been allocated to 'fiber switching' within the spectrograph of the fringe tracking system (see Section 6.7). This subsystem will allow light injection into a fiber so that it can be sent through each fiber in the fringe tracking system and out into the fringe tracking optics on the table for alignment. This extra feature may not be necessary but will remain budgeted until we are sure that other alignment systems, like the periscope and slide, have enough precision to allow us to optically superimpose the fiber coupling lenslet arrays in the fringe tracking system and the tip/tilt detectors.

5.13. AR1-AR5: 1-inch Retro-Reflectors

The 1-inch retro-reflectors are used to auto-collimate the beams for checking optical alignment of the other elements in the system. They are standard mirrors as described in Section 3.3. Four of these mirrors will require a motorized X stage, and all five must be mounted on locking kinematic bases so that they can be removed and replaced to an accuracy of better than 1 arc-second.

5.14. AR6-AR10: 5-inch Retro-Reflectors

These mirrors serve the same purpose as the 1-inch retro-reflectors described above, except that they will be used for the 5-inch beam size upstream of the BRT. They must have the same optical tolerances as all other flat fold mirrors of this size, and be placed in a motorized gimbal mount capable of sub-arcsecond resolution. These mirrors will also require kinematic bases with better than an arcsecond repeatability. There will be two locations for each of these retro-reflectors: one on the beam sampling table after the beam reducing telescopes and another after the OPLE carts near the periscopes that bring the light from the POPs into the OPLE. It is for this reason that two kinematic mounts are budgeted for each mirror. Since these retro-reflectors will usually be placed upstream of the OPLEs, they need not be mounted on translation stages. The coatings for these mirrors must cover both the optical (500-700 nm) and IR (up to 2.5 μm). No coating type has been identified yet and so an estimate of the cost of coating has been used in the spread sheet.

5.15. AR11-AR15: Secondary Retro-Reflectors

The final position for retro-reflection is from the telescope secondaries themselves. This will either be a small mirror or a corner cube attached to the secondary mirror within the area that represents the secondary obscuration (nominally a $\frac{5}{8}$-inch area). While the decision between mirrors and corner cubes is yet to be made, corner cubes are listed in the spread sheet since they will be easier to use and will not require moving the secondary during the alignment procedures. Unfortunately, corner cubes with high quality optics are not standard catalogue items. We need to look into this a bit more.

6. FRINGE TRACKING SYSTEM (F)

The fringe tracking system is responsible for providing error signals for the OPLE carts and also for calculating correlation estimates in a subset of the available baselines. The optical system for the fringe tracker combines five sets of two beams in the aperture plane. The output of each of these combinations is broken up into seven sub-apertures and coupled to multi-mode fibers which take the light to a spectrograph. Note that not all beam combinations are present in the fringe tracker, although it should be possible to reconfigure for a different baseline subset using the beam sampler system described in Section 10. Figure 2 contains a schematic diagram of the fringe tracker optical system, while space for the spectrograph has been left on the alignment table illustrated in Figure 1.

6.1. FM1-FM5: Folding Mirrors

These mirrors are required to fold the beams inside the fringe tracker. They will be standard motorized folding mirrors as described in Section 3.3.

6.2. FB1-FB5: Beam Splitters

These beam splitters are for dividing the incoming light into two. They require motorized (or possibly very fine manual) actuators. These beam splitters are a standard component described in Section 3.4. and will be optimized for the P polarization state.

6.3. FM6-FM10: Folding Mirrors

These mirrors are required to fold the beams inside the fringe tracker. They will be standard motorized folding mirrors as described in Section 3.3 mount on motorized XY translation stages as described in Section 3.2.

6.4. FB6-FB10: Beam Combiners

These beam combiners are for combining the light from two telescopes and are the point at which the fringes are formed. They require motorized actuators and motorized XY translation stages. The beam splitters themselves are a standard component described in Section 3.4. These beam splitters will be optimized for the P polarization state.

6.5. FW1-FW10: Aperture Wheels

The aperture wheels will be capable of placing aperture stops of various sizes in front of the fiber coupling systems, including one stop that completely blocks the beam. It is likely that we will construct these wheels in-house as few commercial devices exist. Those that do exist are extremely expensive. A Klinger motor has been included in the budget, although virtually any computer-controlled motor would suffice. Each stop will consist of seven aperture holes, lined up with the fiber couplers of various sizes, ranging from the largest possible (completely open) to completely closed.

6.6. FF1-FF10: Fiber Coupling Lenslet Array

The fiber coupling lenslet arrays break the 1-inch beams exiting the beam combiners into seven sub-apertures and couple the light from each sub-aperture into a multi-mode fiber. No known commercial product of this type exists, however, the technology required to build these devices has been developed at the University of Hawaii for their curvature sensing adaptive optics detector. Buzz Graves from the group in Hawaii has supplied a ROM costing for building the lenslet arrays and potting these to the fibers.

The mount must allow adjustment in the X and Z directions so that the various lenslet arrays can be optically superimposed. It is for this reason that XY translation stages have been included in the cost of the mounts. Only estimates for the fiber bundles themselves and suitable clamps for holding them into position are available to date. The fibers will be multi-mode and optimized for the optical waveband of 500-700 nm.

6.7. FD1: Spectrograph

The spectrograph and related detectors are yet to be fully specified and designed, and so this report only includes cost estimates. The spectrograph will hold all 70 fibers (7 each from ten couplers) in a clamp in a slit-like configuration and use a dispersive element (probably a prism) to form a series of spectra across the detector (probably a fast CCD). The spectral resolution should be approximately 256 bins across the visible band of 500-700 nm. On-chip binning will be used to control the size and number of spectral channels and to ensure linearity of spectral channels in the wavenumber domain.

Fiber switching equipment has been included here for inserting the light from the fiber coupler in the alignment system (AF1) into the fibers entering the spectrograph.

7. TIP/TILT DETECTION SYSTEM (T)

The tip/tilt detection systems provides image position data for the tip/tilt servo loop and for telescope guidance. A layout of the tip/tilt detection optical system is given in Figure 3. Note that space on this table has been reserved for the imaging system, which remains unfunded at this time. Both the tip/tilt and the imaging systems share one polarization (the S polarization) of the science light. The other polarization state (P) goes into the fringe tracking system described in Section 6. The tip/tilt system will use all of the S polarization state until the imaging system is funded and built.

7.1. TB1-TB5: Polarizing Beam Splitter Cubes

These are 2-inch cube polarizing beam splitters, with the same optical specifications as the standard beam splitters set out in Section 3.4. The cubes will allow the P polarization state to pass and reflect the S polarization state. The optics will be optimized for the optical band of 500-700 nm and do better than 98% polarization split. Polarizing filters may be required in the fringe tracker and the imaging system to ensure a more complete polarized beam.

The cubes will be mounted on tilt/rotations stages that allow at least 7° tilt and rotation adjustment with a sensitivity of 1 arcsecond. The control screws will provide locks to avoid drift.

7.2. TW1-TW5: Aperture Wheels

These aperture wheels will be identical to those in the fringe tracking system set out in Section 6.5 except that the aperture stops will be single holes covering the entire telescope diameter down to completely blocked.

7.3. TL1-TL5: Imaging Lenses

The imaging lens must create an image of the star on the quadrant detector so that a 1-arcsecond image on the sky will cover an area some 5 mm in diameter on the quadrant detector. A 1-arcsecond image on the sky will be 40 arcseconds in the small beam, which is approximately 160 microradians. This implies an equivalent focal length of $\frac{0.005}{160\times10^{-6}} =$ 31 m, which can be achieved using a single achromat lens and a microscope objective.

7.4. TD1-TD5: Quadrant Detectors

Initially, quad-photomultiplier cells will be used for the image position detectors, at least that is how the budget is being calculated. Eventually we may decide to use a CCD or some other optical arrangement and APDs. To begin with, however, the quad cell

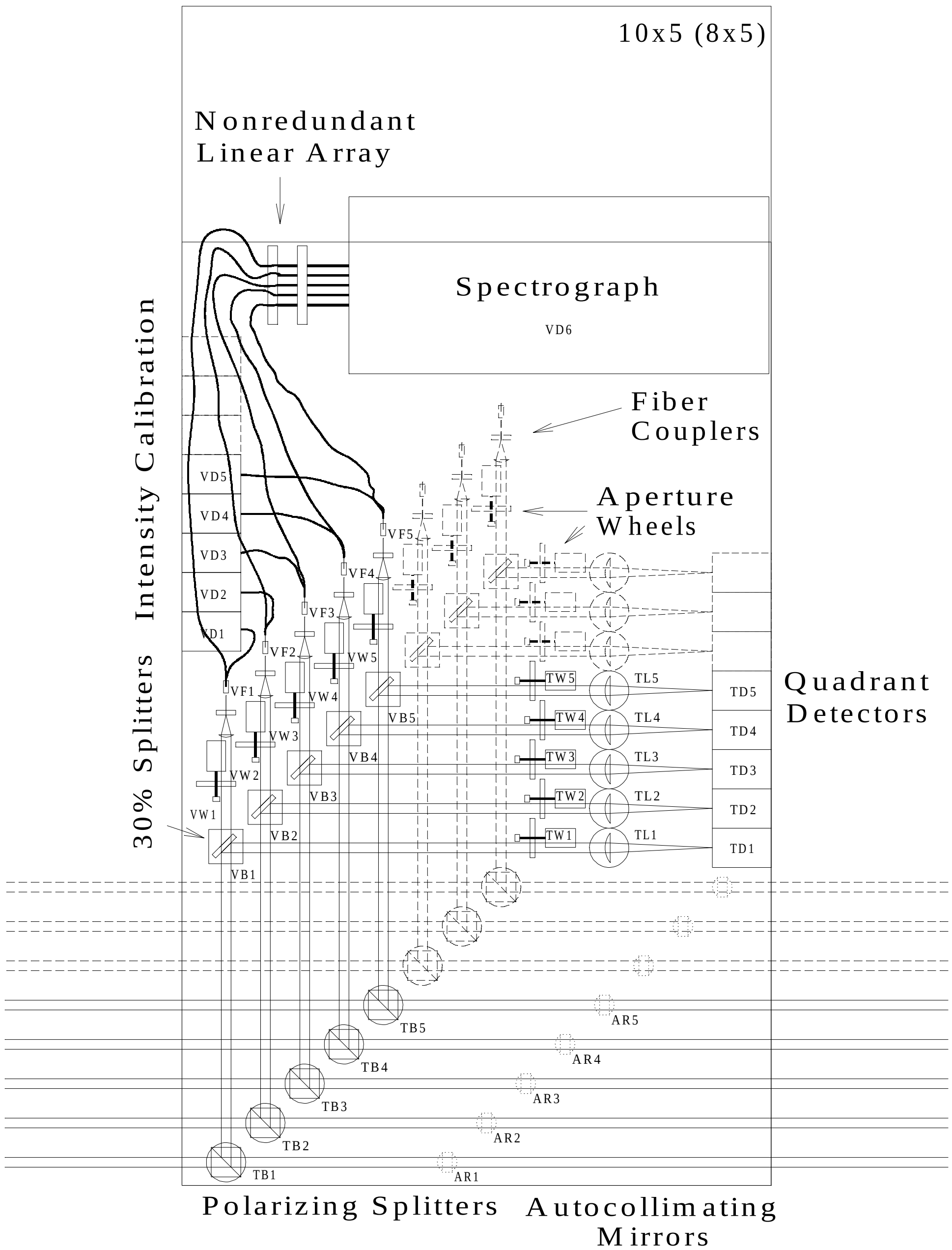

FIGURE 3. Schematic of the Tip/Tilt detector and imaging table in the BCL.

photomultipliers will be easily installed, and at 20% quantum efficiency should achieve a magnitude limit of 10 in the V band.

Each detector must be mounted on a motorized XY stage so that the center of the detectors can be optically superimposed on the fibers in both the fringe tracking and the imaging systems. The cost of the high voltage power supply, the discriminators and the counters required to connect these detectors to a control computer have been included in the costing of this subsystem. The cost of the control computer itself has not been included here and should be part of the general control system budget.

8. VISIBLE IMAGING SYSTEM (V)

The visible imaging system uses part of the S polarization and couples each beam into a single-mode fiber. These fibers are brought into a non-redundant, 1-dimensional pattern and fed into an imaging spectrograph. In this way, the detector has fringes in one dimension and a spectrum in the other, allowing us to measure all available baselines and closure phases in many optical bands at once. The imaging system is unfunded at this time, but remains a part of this specification so that a cost estimate can be made. The optical layout for the visible imaging systems is shown in Figure 3.

8.1. VB1-VB5: 70/30% Beam Splitters

These beam splitters are for dividing the incoming light into two. Some 70% of the light is reflected into the tip/tilt system while the remaining 30% is allocated to the imaging system. These beam splitters are a standard component described in Section 3.4 and will be optimized for the S polarization state.

8.2. VW1-VW5: Aperture Wheels

These aperture wheels will be identical to those in the tip/tilt detector system set out in Section 7.2.

8.3. VF1-VF5: Fiber Couplers

The fiber couplers in the imaging system use a single achromat lens to focus the light from each beam onto a single mode fiber. Each coupling system is mounted on a moving slide so that internal pathlengths within the imaging system can be adjusted. Note that we already have the hardware for three fiber coupling systems so only two more have been added to the spreadsheet.

8.4. VD1-VD5: Intensity Detectors

It will be necessary to measure the light intensity in each fiber for visibility calibration. The intensity detectors here include fiber couplers to extract 10% of the light to be brought to an avalanche photo diode (APD) and counting circuit.

8.5. VD6: Spectrograph

It is in the spectrograph that fringes are actually created and measured. The single-mode fibers are brought together to form a non-redundant 1D pattern and brought to a focus using a large achromat. Cylindrical elements are used to shorten the equivalent focal length of the optical system in the direction perpendicular to the non-redundant pattern of the fibers. A prism is also used to create spectra along this perpendicular axis. In this way, fringes are formed in one dimension across a blown-up Airy pattern while the second dimension is used for spectral resolution.

Money has been added to the spread sheet here for 'fiber switching' to cover possible extra costs for the fibers, for example, couplers required to connect the fibers to the alignment fiber system or connectors for the APDs discussed above (VD1-VD5).

No off-the-shelf components for the large achromat and prism required in the spectrograph are available, so an estimate of a custom item has been included in the spread sheet.

Five XYZ stages are required along with five XZ stages for the fiber mounts.

9. IR IMAGING SYSTEM (I)

No estimate for the IR imaging system is available yet.

10. BEAM SAMPLING TABLES (B)

The beam sampling tables are located on the western end of the OPLE area and apart from the dichroic split and beam folding mirrors contain the following subsystems:

- Longitudinal dispersion correctors (LDC)
- Atmospheric dispersion correctors (ARC)
- Beam reducing telescopes (BRT)
- 5-inch retro-reflectors (AR6-AR7)
- Laser metrology systems for the OPLE carts (LMS)

The retro-reflectors are part of the alignment system described in Section 5 and the LMS systems are part of the JPL contract and will not be included in this report.

Figure 4 contains a schematic of the optical layout of the beam sampling tables.

10.1. BB1-BB5: Dichroic Splitters

The dichroic splitters reflect the optical light ($\lambda \leq 1\,\mu$m) into the BCL while allowing the IR light ($\lambda \geq 1\,\mu$m) to pass through. It is assumed here that they will consist of a standard motorized beam splitter mount and substrate but will require a specialized coating.

The dichroics and their mounts, along with the beam folding mirrors described in Section 10.2, are placed on a sliding platform so that any of the telescope outputs beams can be sent to any of the fringe tracking and imaging optical beams. This means that the baseline subset used for fringe tracking and visibility measurement can be selected.

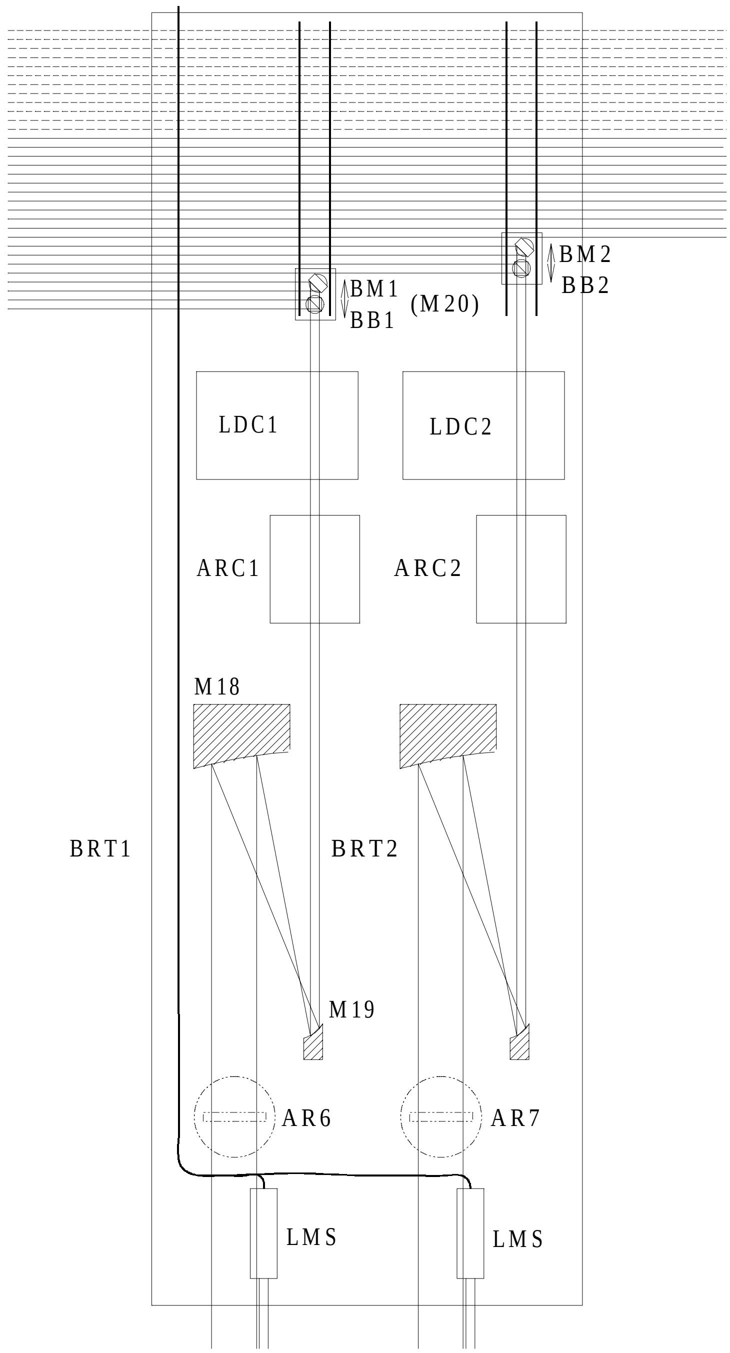

FIGURE 4. Schematic of the one of the beam sampling tables in the OPLE area. The metrology systems while shown here, are part of the OPLE cart contract with JPL.

10.2. BM1-BM5: Beam Folding Mirrors

The beam folding mirrors will be mounted along with the dichroic beam splitters on the moving platforms described in Section 10.1 and will be standard mirrors on motorized mounts, except that the coating will be one optimized for the IR band (ER.2).

10.3. LDC1-LDC5: Longitudinal Dispersion Correctors

The longitudinal dispersion correctors consist of two opposing wedges that can be moved with respect to one another so that a controlled amount of glass can be introduced into the science beams. This glass introduces a known amount of dispersion into each beam and will be used to compensate for differential air paths within the Array optical chains. For example, approximately 0.5 mm of BK7 glass will introduce the same dispersion as 1 m of air. The prisms are yet to be fully specified and so only a cost estimate has been placed in the spreadsheet. This cost estimate is based on the cost of the prisms used in SUSI.

The translator mounts required to move one prism along the other are based on the quote obtained for the sliding platforms described in Section 10.1.

10.4. ARC1-ARC5: Atmospheric Refraction Correctors

The atmospheric refraction system is similar to the LDC, except that it corrects for refraction in the atmosphere rather than within the instrument itself. The ARC systems consist for a set of Risley prisms that can be rotated under computer control.

As for the LDC, no specification or firm costing is available at this time for the ARCs and so an estimate has been placed in the spreadsheet.

10.5. BRT1-BRT5: Beam reducing telescopes

The beam reducing telescopes are a pair of paraboloids with an infinite equivalent focal length, in other words an afocal telescope. They reduce the beam size of 5 in coming out of the OPLE carts down to the 1-inch beam size used in the rest of the optical chain. The BRT design is based on the OPLE cart design, without the extra parts required for movement, and the cost estimate for these mounts has been based on the real costs of building the carts to date.