Space Interferometry Mission (SIM) thermal design[1] [4852-49]

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ABSTRACT

The Space Interferometry Mission (SIM) has some very tight stability requirements that drive the thermal control approach well beyond the traditional spacecraft thermal control regime. The precision support structure will be constructed of composite materials with a quite low coefficient of thermal expansion (CTE) on the order of 10^{-7}/K. Even then, the temperature variations of the structure cannot exceed about 0.2°C. For the main optical elements, which will be fabricated of ultra-low expansion (ULE, 10^{-8}/K CTE) glass, the temperature stability must be such that the temperature gradient through the glass cannot vary by more than a couple of millikelvin through the 5 cm thickness over a one hour period. The laser metrology system, which measures motions on the order of a few tens of picometers (10^{-12}m), contains some sensitive optical elements whose temperature variations cannot exceed a few tens of microkelvin (10^{-6}K). This paper will describe how the SIM thermal control designers have addressed some of these very challenging requirements.

1. INTRODUCTION

SIM, slated for launch in 2009, will measure the positions of stars to the unprecedented accuracy of 4 μas (about one billionth of a degree of arc). Not surprisingly, such a requirement presents many challenges to the designers of SIM. There are several other papers[1,2,3] in the same conference that describe SIM in some detail, so only a very brief overview will be given here. This paper will focus on the thermal control design challenges.

Although SIM is still in the conceptual design phase, and has been for several years, thermal control was perceived (correctly) to be a major challenge. A thermal design working group was formed and it performed some detailed modeling of the areas thought to be most challenging. Initially, it was a challenge simply to operate the software so the results were believable at the millikelvin level. It should be emphasized that we do not believe the predictions of absolute temperature at the mK level, but we are confident that we are predicting changes in temperatures at the mK level. SIM is much more sensitive to changes than it is to absolute temperatures, so this is acceptable. Furthermore, we have performed some tests on representative test articles and achieved remarkable agreement between modeling and experimental measurements at the millikelvin level.[4] These results will not be discussed here. The purpose of this paper is to describe the current thermal control design for SIM.

About a year ago, the configuration of SIM changed drastically. At that point, we had done quite a lot of thermal modeling on the previous configuration (SIM Classic) and had convinced ourselves that we understood the major thermal challenges and had approaches in which we were confident. Since the state of the configuration was in great upheaval, it did not make sense to continue developing the thermal models in more detail, so we temporarily disbanded the thermal working group. In the sections that describe the various thermal areas, it will become apparent that in several areas we do not have current thermal models. We believe that we have approaches that will work for each of these areas, but detailed modeling has been on hold. The configuration seems to have settled down, and so we will be resurrecting the SIM Thermal Working Group in the near future to develop thermal models in the areas that now have better mechanical definition.

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2. OVERVIEW OF SIM

One of SIM's primary objectives is to characterize the orbits of planets around nearby stars for planets almost as small as the earth. SIM accomplishes this by measuring the lateral reflex motion of the parent star in response to the gravitational tug of the planet as it orbits the star. Previous ground-based observations have only been able to measure the radial component of velocity (towards and away from the earth). This leaves an ambiguity about the inclination of the orbit, and therefore, about the mass of the planet. By measuring the lateral motion, SIM will eliminate this ambiguity and extend the observations to planets with longer orbits and smaller masses. SIM will measure the positions of a few thousand stars about fifty times each over the course of its five-year mission. From these data, the trajectory of the star can be determined, allowing us to infer the orbital period, eccentricity, and inclination of the planet. The planet's mass can then be determined unambiguously as a proportion of the known star mass.

SIM is a space-based interferometer that simultaneously uses three optical interferometers to perform astrometry. A fourth interferometer is carried as a spare. Two of the interferometers are designated Guide Interferometers, and basically serve the function of a very accurate star tracker to determine the orientation of the main science interferometer with respect to the sky. There are two science interferometers, but it is planned to operate only one at a time. The science interferometers have an astrometric baseline of 10 m and a circular field of regard (FOR) of 15° diameter. The science interferometers measure the locations of stars. An infrared laser metrology system measures the orientation of the science interferometer with respect to the guide interferometers so the measurements can be related to a coordinate system tied to the sky. The laser metrology system forms a truss of linear measurements betweens pairs of corner cube retro-reflectors. Basically, the system uses 3-D triangulation to determine the positions of the corner cubes, which, in turn, define the astrometric baseline vectors.

Currently, it is planned to use the space shuttle to launch SIM plus an integral propulsion module to inject SIM into its earth-trailing solar orbit, although an option would use an Evolved Expendable Launch Vehicle (EELV) instead. After six months of in-orbit checkout and calibration, SIM will starts five years of science measurements.

Because of the challenges inherent in SIM, its architecture is a little atypical. Unlike many spacecraft dedicated to scientific investigations, SIM has only one science instrument. This single optical instrument is very large (on the order of 11m x 3m x 3m and it has some very stringent stability requirements. The optical elements are mounted within a large precision support structure (PSS) with a small coefficient of thermal expansion (CTE). This PSS is effectively a giant optical bench although it surrounds all the optics.

Most of the traditional engineering subsystems are mounted in a separate enclosure that is isolated physically and thermally from the PSS. The traditional spacecraft engineering subsystems include power, attitude control, command and data handling (C&DH), structures, communications, etc. This is not a comprehensive list. The separate enclosure corresponds to the spacecraft bus of a more typical spacecraft. On SIM, this spacecraft bus is quite a bit smaller than the instrument, and it is mounted on the bottom of the PSS. We refer to this enclosure as the "backpack." The backpack also houses a major portion of the substantial instrument electronics.

2.1. A Note about units

SIM makes some very precise measurements. Some readers may not be familiar with all of the units used frequently by people working on SIM, so a brief summary is given here.

The angular positions of stars are often stated in micro arc seconds, abbreviated μas (or sometime uas, in which "u" is used in place of the Greek mu). A micro arc second is one millionth of an arc second, which is a measure of angle. There are 60 arc seconds in an arc minute and 60 arc minutes in a degree. Therefore $1° = 3.6 \times 10^9$ μas. SIM's goal is to measure star positions with an accuracy of 4 μas, so this is very close to a billionth of a degree.

Another measure of angle often used in descriptions of optical systems is milli arc second (mas). This is one thousandth of an arc second. 1 mas = 1000 μas.

When converted to radians, the following relations hold:

$1\ \text{as} = 4.848\ \mu\text{radian} = 4.848 \times 10^{-6}$ radian
$1\ \text{mas} = 4.848 \times 10^{-9}$ radian
$1\ \mu\text{as} = 4.848 \times 10^{-12}$ radian

Linear distances in SIM are often expressed in micrometers (μm), nanometers (nm), and picometers (pm). These are respectively a millionth, a billionth, and a trillionth of a meter (US definitions of "billionth" and "trillionth"). Thus,

$1\ \mu\text{m} = 10^{-6}$ m
$1\ \text{nm} = 10^{-9}$ m
$1\ \text{pm} = 10^{-12}$ m

The total error budget for the optical path length difference between the two arms of the science interferometer for SIM is a few hundred picometers, and some items in the error budget are allocated less than 20 pm. To put this in perspective the diameter of a hydrogen atom is about 100 pm.

Temperatures in SIM are mostly near room temperature. When operating temperatures are quoted, they will usually be in degrees Celsius (°C). When talking about cold regions dominated by radiative heat transfer, for which absolute temperature must be used, typically kelvin (K) will be used. However, the emphasis for SIM is temperature changes. For SIM, these will typically be quoted in millikelvin (mK) and sometime in microkelvin (μK).

$1\ \text{mK} = 10^{-3}\ \text{K} = 10^{-3}\ ^{\circ}\text{C}$
$1\mu\text{K} = 10^{-6}\ \text{K} = 10^{-6}\ ^{\circ}\text{C}$

Correct usage of the kelvin unit does NOT have a degree symbol (°). Similarly, one does not say "degree kelvin." A kelvin is a degree Celsius. Another quirk of SI units is that when spelled out, kelvin is not capitalized even though the unit (K) is capitalized in recognition that it is named after a person. Similarly for watt and W, newton and N, gauss and G, henry and H, etc. I find that I have to override my spell checker, which insists on capitalizing these names of famous people. Units not named after people, such as the meter, are not capitalized in either case. The following website discusses correct and incorrect usage of SI symbols: http://lamar.colostate.edu/~hillger/correct.htm. A printed book is also available from the US Metric Association.[5]

3. THERMAL ENVIRONMENT

The SIM Flight System will be launched into an earth-trailing solar orbit (ETSO), similar to the orbit for the Space Infrared Telescope Facility (SIRTF). This orbit has a period of about one year plus a week, so its semi-major axis is just a few percent greater than 1 AU (Astronomical Unit). Throughout the five-year mission, SIM drifts away from the earth at an average rate of about 0.1 AU per year or less. One of the reasons for selecting this orbit is to reduce thermal fluctuations in the environment. Several years ago, the mission design had SIM in a low earth orbit. The varying thermal input from the earth, and to a lesser extent, the moon, caused tremendous challenges to the thermal design, as well as causing difficulties for other subsystems. The use of ETSO basically makes it feasible to operate SIM at all. The main thermal disturbance now is due to the frequent changes of orientation of the SIM Flight System as it points to targets all over the sky.

4. THERMAL DESIGN

There are five regions of SIM that use different thermal control approaches: 1) traditional spacecraft engineering subsystems, 2) Precision Support Structure, 3) Optical elements exposed to space, 4) Optical elements inside the PSS, and 5) External metrology beam launchers. Each of these will be discussed separately, although, of course, there are some interactions among them.

4.1. Traditional Spacecraft Engineering Subsystems

The standard spacecraft elements plus instrument electronics are housed in the backpack, as described above. The backpack structure is a simple rectangular box of aluminum honeycomb and the temperature control approach is fairly standard. Heat pipes connect the panels on which the various components are mounted. The enclosure is covered with multi-layer insulation (MLI) expect for open areas sufficient to radiate enough power to maintain the temperature below the maximum allowed operating temperature. The radiator areas are painted white to reduce solar input, while keep the cost low. Heaters ensure that temperatures do not fall below the minimum operating point.

The solar array and high gain antenna (HGA) are mounted on booms attached to the backpack. The HGA is painted white, but there are no additional temperature controls. The solar panel is always perpendicular to the sun and never shadowed. The rear is painted black to radiate heat. The front surface also radiates heat. The panel simply comes to an equilibrium temperature based on the balance of heat in (minus electrical power taken out of the cells) and heat radiated out. This is a standard approach for paddle type solar panels.

To date, very little emphasis has been placed on the spacecraft subsystems, including thermal control, because they are perceived to be relatively straightforward in comparison with the instrument.

4.2. Precision Support Structure (PSS)

The PSS is the main structure to which all the major optical elements are mounted. In some sense, it is a very large optical bench. Two main aspects drive the PSS thermal control system: preventing the structure itself from deforming more than a few micrometers and maintaining the optical elements at a stable temperature close to room temperature. The challenge of designing the PSS temperature control approach is really one of controlling changes, rather than absolute temperatures. SIM, inherently measures differences between points on the sky. In order to meet absolute accuracy requirements, SIM frequently recalibrates itself. In between calibrations, things cannot drift more than some small acceptable amount. But for much longer times, there are very few absolute requirements. Most requirements have a time component. For instance, the PSS is required not to deform more than 10 microns per hour.

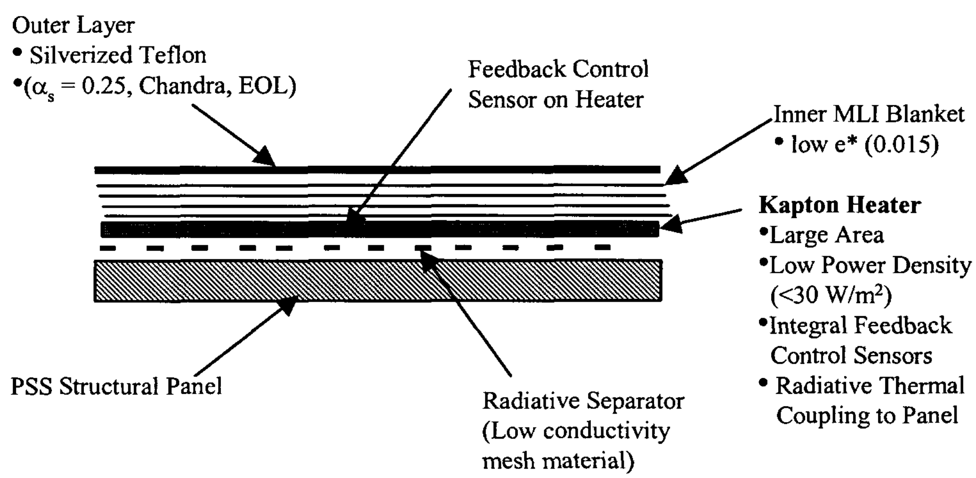

Figure 1 PSS Thermal Control Approach

Because the PSS is essentially an optical bench, it is fabricated of materials with very low coefficient of thermal expansion (CTE) of around 10^{-7}/°C. If heaters where mounted directly to the PSS, then the materials of the heaters would change the effective CTE of the structure. Instead, the heaters are mounted on radiator panels stood off a small distance from the main PSS using thermally insulating stand-offs. This approach, illustrated in Figure 1, is still conceptual, so details have not been developed, but the stand-offs will have to be designed so that deformations of the radiator panels are not transmitted to the PSS. Possibly, a simple mesh material could be used similar to that used between layers of the multi-layer insulation (MLI) that covers the radiator panel on the outside of the PSS. The outer surface of the MLI is silverized Teflon, which acts as an optical solar radiator (OSR) so the MLI is cold-biased even with full normal solar illumination. The heater panels are controlled to operate at a nominal room temperature (around

20°C) with a dead band of 0.2°C. The various heater panels tend to turn on and off independently of one another, so the temperature swings average to a lower value than 0.2°C. Also, because the heater panels are coupled only by thermal radiation to the PSS, the PSS temperature swings are much lower than for the heater panels.

4.3. Optical elements exposed to space

The front end of the optical train contains several large mirrors (Siderostats and primary mirrors) whose deformations must not exceed 15 pm during an observing tile, which last nominally one hour. These optical elements collect the incoming starlight and therefore have a view to cold space. As for the PSS, deformation over time is more important than absolute deformation. An internal metrology system uses infrared lasers to measure the pathlength followed by the starlight as it travels through the instrument from the front end all the way to the Astrometric Beam Combiner (ABC). This laser metrology system only measures the center of the optics, whereas the starlight bounces off the annular portion surrounding the metrology. Any general cupping of the optic changes the pathlength followed by starlight, but not the distance measured by metrology. This results in a direct error in the SIM measurement. The error allocated to this contribution is 15 pm (1 σ) over a one hour period for each of the large optics. The concern here is not wavefront quality. The surfaces of these large optics are required to be around $\lambda/70$ rms. With a wavelength of say 700 nm, the surface "roughness" is on the order of 10 nm or 10,000 pm. SIM basically averages the wavefront over the peaks and valleys and calibrates the offset between this average and the measurement made by the internal metrology beam. The concern here is that this offset not change by more than 15 pm (RMS) over an hour. Assuming a CTE of 10^{-8}/K for ultra low expansion (ULE) glass, a change in the temperature difference between the front and the back surface of the mirror of 2.7 mK will produce an average deflection of 15 pm. Thus, the thermal control scheme for the optics must ensure that the variations over one hour shall be less than 2.7 mK.

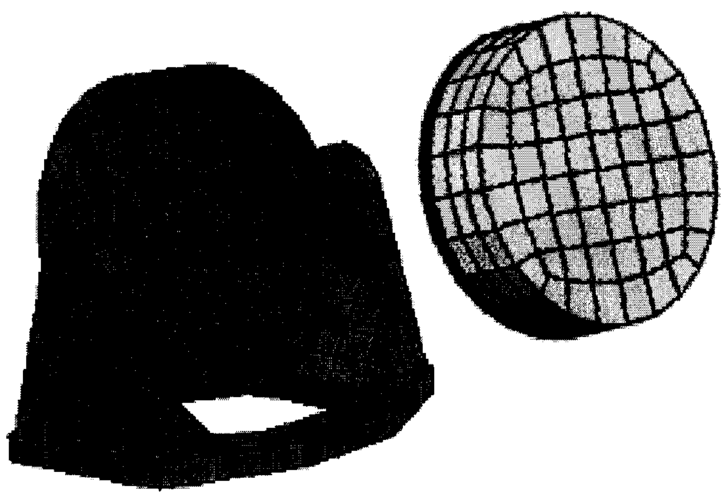

Figure 2 Siderostat Mirror and Gimbals

Figure 2 shows an exploded view illustrating the concept for controlling the temperature of the Siderostat mirror. The mirror is mounted inside the cavity supported by the gimbals. The front surface of the mirror is coated with protected silver, so its emissivity is very low (1-2%). Behind the mirror, a heater plate is stood off about 1 cm. This plate is heated uniformly over the area by a thin film heater. The mirror is physically decoupled from the radiator as much as possible to reduce distortions. The sides and back are then surrounded by MLI. The plan is simply to operate the heater at a constant low power level (1-2 W range) by maintaining a constant voltage or current. The power level is selected to produce an operating temperature of nominally 20°C, although the actual temperature is not very important. If needed, the power level can be changed, but there is no plan to include active control. Changes in the bulk temperature do not introduce errors into SIM's measurements because the corner cube for internal metrology is mounted directly to the front face of the Siderostat with the vertex accurately aligned in the plane of the front surface. This corner cube is not shown in the figure. Because the heat is applied to the rear of the optic and the front surface is exposed to cold space, the mirror comes to an equilibrium condition with a gradient through the thickness. The rear is about 0.2 K warmer than the front. The static deformation due to this constant temperature gradient is acceptable. Changes in this situation are what must be kept to an extreme minimum. Although the bulk thermal time constant for the mirror is on the order of hours, modeling has shown that the gradient (temperature drop through the glass) stabilizes in about 20 minutes. Basically, the temperature difference from back to front of the mirror must not change more than 2.7 mK over one hour.

Thermal modeling has shown that the main perturbation is due to the motion of the mirror itself. In order to point the line of sight of the science interferometers to different stars, the mirror is rotated about two orthogonal axes of the gimbals ±3.75°. In the original scheme, the walls enclosing the optics were maintained at a constant temperature of 20°C. However, as the mirror moved over a few degrees, the geometric view factors to the walls and to space changed enough that the temperature difference through the thickness of the mirror exceeded the required 2.7 mK. We have now developed a modified approach. The walls of the enclosure for the front-end optics are now covered with MLI. The underlying structure is still maintained at constant 20°C, but the outer layer of MLI, which has a partial view to space through the opening that allows starlight to enter, is allowed to come to a much lower equilibrium temperature in the range of 150 – 200K. In fact, to encourage even lower temperatures, the opening has been enlarge significantly to several square meters and the outer layer of the MLI inside this open area is black (both visible and IR). The advantage is that the contrast between the cold walls and cold space is much less than the same situation with warm walls. Now, as the mirror moves around, there is much less change in its thermal equilibrium condition. With this approach, it appears possible to meet the stringent thermal requirements on these optical elements. This has been confirmed by modeling, but eventually, it will be necessary to demonstrate this experimentally. This approach has imposed an operational constraint on SIM that sunlight never be allowed to enter even the lip of the open cavity as this would raise the temperature of the illuminated wall, which would then reradiate to the optics and exceed the required temperature stability. A sun exclusion plane has been defined, as shown in Figure 3.

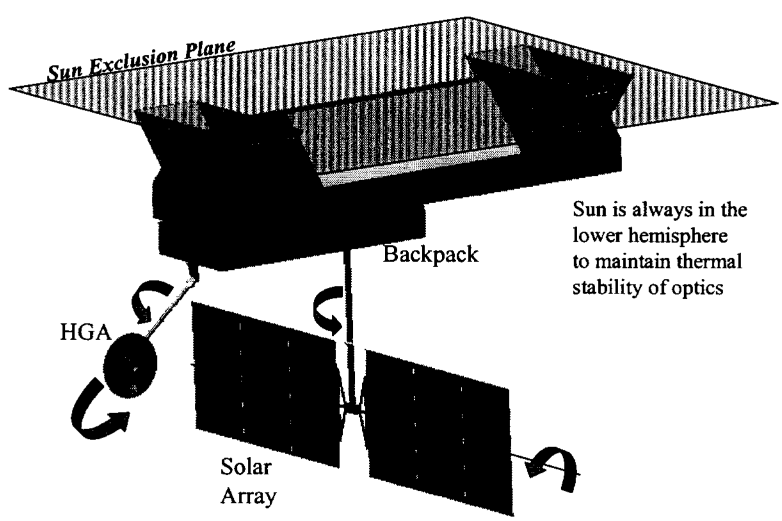

Figure 3 Sun Exclusion Plane

4.4. Optical elements inside the PSS

The PSS is the large prismatic structure in Figure 3. It encompasses the open Siderostat Bays (one at each end) and all the optical elements mounted in the middle portion. Inside this central portion, there are several optical elements whose deformations (and therefore temperatures) must be controlled within precise limits. Figure 4 gives a sense for the locations of some of these elements. The starlight paths are also shown as well as the infrared beams forming the external metrology truss. Each of the optical elements housing inside the PSS will be discussed in the following subsections.

4.4.1. Small transfer flats

Most of the optical elements within the PSS are small flat mirrors. With these mirrors, the front to back temperature difference can be considerably larger, on the order of 40 mK, before the deformation reaches the 15 pm level. Most of the mirrors are fixed, so articulation does not cause changes to the thermal environment. The walls of the surrounding PSS operate at a controlled stable temperature of nominally 20°C. The temperature variations are easily controlled by enclosing the backs and sides with MLI to increase the thermal time constant so the mirrors respond slowly to changes in the environment. No heaters are necessary. These mirrors are mounted using thermally insulating kinematic mount flexures to minimize conductive heat transfer to the optics.

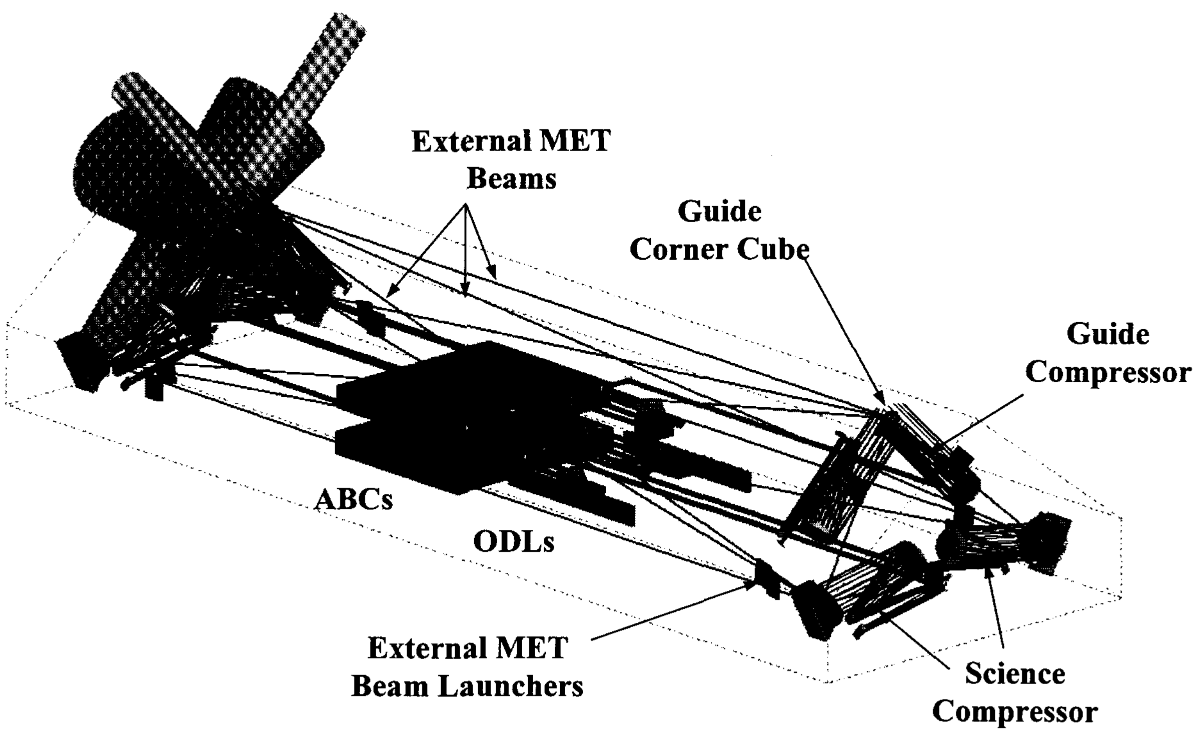

Figure 4 Optical Layout

4.4.2. Optical Delay Lines (ODLs)

The Optical Delay Lines (ODLs) are basically carriages running along rails carrying a corner cube rertroreflector. Their function is to vary the distance the starlight travels from the Siderostat Mirror to the ABC. The compresses starlight beam is directed onto one mirror of the corner cube. From there, it bounces to a second mirror and then to a third mirror. Following this, it exits the corner cube parallel to the incoming beam, but offset a few centimeters. When the corner cube is translated along the direction of the incoming light, pathlength is added without changing the aim point of the outgoing beam, which then enters the Astrometric Beam Combiner (ABC).

For each interferometer, there are two delay lines, a long stroke low bandwidth ODL and a short stroke high bandwidth ODL. One ODL is mounted in each arm of the each interferometer. The long stroke ODL makes large changes in the pathlength as the Siderostats are aimed to one side or the other to interrogate different stars. For the science interferometers, the ODLs physically move as much as 1.3m. The short stroke delay lines are controlled at a closed-loop bandwidth of about 100 Hz and are used to suppress vibrations in the structure at the nanometer amplitude level. The motion is imparted to the short stroke ODLs by voicecoils with a stroke of about a millimeter.

The temperature stability requirement for the three faces of the corner cube in the each ODL are similar to those for the small transfer flats discussed above. However, at least for the long stroke ODLs, the mirrors forming the corner cubes may experience a changing environment as they can travel the full length of their rails several times during a nominal one-hour observing window for each tile. If there were a spatial temperature gradient of the PSS along the direction of travel, or if there were any heat sources nearby, then the mirrors would be exposed to a changing thermal environment and maintaining the required stability may be challenging. We have not yet modeled this particular aspect. We expect to find that the temperature distribution of the PSS will be sufficiently stable that the same thermal control scheme applied to the small transfer flats will work here too. This is the current baseline approach. If we find that this approach is inadequate, then we plan to enclose the long ODLs inside a separate tent, perhaps with its own dedicated heaters and controllers.

4.4.3. Astrometric Beam Combiners (ABCs)

There are four Astrometric Beam Combiners (ABCs), one for each interferometer. The ABC is the heart of an interferometer. It is where the beams from the two arms of the interferometer are combined into a single beam and directed onto detectors. Before the beam combination point, part of the light is stripped off and focused onto a pointing camera CCD. This portion is used as the sensor to feed back to the pointing system (controlling the pointing of the Siderostat Mirror and Fast Steering Mirror). The rest of the light is directed onto another CCD detector to measure the fringe position. Also, a prism separates the incoming light into spectral components to aid in identifying the fringe position as well as to provide spectral information about the target star.

Within the ABC is the only place that starlight destined for the fringe camera actually passes through glass. Everywhere else in the system, reflections are used. There are a couple of reasons that refractive optics are avoided. The starlight detector is selected to sense visible light, thus the system must pass visible light through the system. The internal metrology system operates in the infrared (1.3 μm wavelength). This wavelength must also pass through the system. For glass, the index of refraction is different for different wavelengths. Refractive elements would cause some chromatic aberration, and this is undesirable, whereas reflective optics reflect all wavelengths at equal angles. But this is not the main reason. The internal metrology is supposed to be measuring the pathlength traversed by the visible starlight. Actually, it is the difference between the two that is detected. But any change in the glass, and there is a change in the measurement even though there has been no change in the anywhere else. This measurement must be stable to a precision of a few tens of picometers. Not only does the index of refraction of glass depend on wavelength, it also depends on temperature. Glasses also typically have a non-zero coefficient of thermal expansion. Although, in principle, it is possible to make a glass for which the change in index of refraction is compensated by the CTE, in practice this cannot be achieved for a glass that transmits both visible and infrared radiation. Anywhere that transmissive optics are used, very tight thermal control is required. This is the case in the ABC. The partially silvered surface that transmits half the incident light, and reflects the other half, is applied to a glass substrate. Pellicles (very thin tightly stretched membranes) were considered, but rejected on account of their predicted response to vibration. In addition to the glass substrate for the combining beam splitter, there are three compensating flats of the same glass to compensate for the different pathlength and different angle traversed by white light and by the internal metrology. All four pieces of glass must be temperature controlled to very precise levels. This is another area that has not yet been modeled. A detailed optical layout of the ABC has been developed only relatively recently, and thermal modeling has not yet begun in this area. However, based on some earlier modeling of beam launchers, we believe that we will be able to control the temperature to maintain sufficient stability by a combination of MLI tents to reduce the coupling of these elements to the surroundings, coupled with tight thermal control of the ABC housing, which, itself sits within the fairly stable PSS. With several layers of radiative decoupling, we believe that the disturbances will be attenuated to an acceptable level.

Within each ABC is a beam launcher for the internal metrology beam. Within the beam launcher, there are also some transmissive elements, but these only have to pass infrared, not visible light. Still, the temperature control requirements are about the same as for the combining beam splitter and compensating plates. The same temperature control approach is expected to work here as well.

Another thermal control challenge within the ABC is to cool the CCD detectors to around –100°C. This is to keep the detector background noise acceptably low. The difficulty is that the CCD is on the order of 2 to 3 meters from a suitable area for radiating from this temperature. Mechanical coolers are not an option because of the very stringent vibration requirements. The current baseline approach is to use low temperature heat pipes to transfer the heat directly from the CCD to a radiator on the top surface of the PSS (which the sun never illuminates), insulate the relatively long run to keep parasitic heat leaks to a minimum, and provide a very large radiating area so the equilibrium temperature can be lower than –100°C. Again, this is an area that needs to be modeled now that we have an ABC layout. If our modeling shows that this approach is not practical, then we would use thermoelectric coolers (several stages) and reject the heat at room temperature radiators, using normal heat pipes to carry the much greater thermal load.

4.4.4. External metrology beam launchers

There are currently nineteen external metrology beam launchers in the SIM configuration. This number has varied significantly over the years as SIM's configuration has changed in response to new challenges identified as we increase our understanding of performing astrometry at this level. The beam launcher design has also evolved, partially in response to thermal sensitivities identified by early modeling efforts. For the beam launcher that was investigated in detail the thermal stability requirement for the most sensitive component was on the order of 50 μK over an hour. While it might have been possible to meet this requirement using some exotic coatings and inventive thermal control approaches, it was easier to modify the design of the beam launcher. The newer versions are predicted to have much lower thermal sensitivities (by about two orders of magnitude) based on simple calculations. Detailed thermal models still need to be developed for the newer designs.

Some of the external beam launchers are inside the 20°C portion of the PSS, but others are in the cold (150-200K) open Siderostat Bays. For the beam launchers within the room temperature region of the PSS, the same approach is planned as for the internal metrology beam launchers inside the ABC discussed in the previous section. That is, the beam launcher will be surrounded by a local tent of MLI (of course providing openings for the infrared beams to enter and exit the device).

For the beam launchers mounted in the cold region, a steady state precision heater will be required for each beam launcher. The entire assembly will be surrounded by MLI, but it is possible that an additional blanket will be required between the heater and the beam launcher to increase the thermal time constant in order to attenuate any fluctuations in the heater, as well as the help reject any small changes in the Siderostat Bay wall temperatures as the Siderostats change their aim points. This area will be investigated in more detail in the near future.

5. SUMMARY

The Space Interferometry Mission is a very challenging undertaking, which in turn drives the thermal control subsystem design to use some innovative approaches. Although SIM is still in the conceptual design phase, a significant amount of thermal modeling and experimentation has already occurred to address the known difficult areas. We have developed methods that we feel will be capable of meeting the stringent requirements imposed by SIM. These approaches were developed for a previous version of SIM, but the principles still apply. During the recent reconfiguration of SIM, the thermal work was temporarily halted. Now that the configuration seems stable again, this work will resume and carry the modeling to a greater depth consistent with the more detailed optical layout now available.

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