Space Interferometer Mission Testbed III (STB-3)

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Abstract— The Space Interferometer Mission Testbed III (STB-3) is part of the Space Interferometer Mission (SIM) project that is being developed at the Jet Propulsion Laboratory (JPL). SIM has various testbeds that will be used to demonstrate the feasibility of various technologies that should be demonstrated to mitigate risk to the SIM project and future Space Interferometer projects. Two major challenges are making precision measurements to picometer levels for the metrology system and controlling optical elements to nanometer levels. The STB-3 will be used to validate some of the nanometer technology that will be used by the SIM project. Specifically, STB-3 is designed to demonstrate pathlength feed-forward (PFF), white light fringe acquisition and tracking under nanometer level pathlength control on a flexible structure. STB-3 will demonstrate pathlength feed-forward with a three-baseline interferometer on a flexible structure using a SIM like architecture. Pathlength feed-forward uses fringe position information from the two guide interferometers to properly adjust the delay line position of the science interferometer delay line. In addition, STB-3 will demonstrate disturbance rejection and attenuation, at the levels required by SIM. STB-3 will evolve into the SIM instrument testbed in four phases. Phase 1 will demonstrate PFF on optical tables, phase 2 will demonstrate PFF on a flexible structure, phase 3 will demonstrate "full interferometer" functionality on a flexible structure, and in phase 4 it will be upgraded to meet the flight interferometer integration and test, and operations needs. This paper will focus on phase one of STB-3, phase 1 goals, phase 1 description, the facility, and the phase 1 and 2 development strategy.

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1. INTRODUCTION

The Space Interferometry Mission (SIM) will be the first space mission to use optical interferometry. It will determine the positions and distances of stars several hundred times more accurately than any previous program. This accuracy will allow SIM to determine the distances to stars throughout the Galaxy and to probe nearby stars for Earth-sized planets. SIM will also pioneer a technique to block out (null) the light of bright stars to take images of the interesting areas close to the star. SIM is scheduled for launch in 2005 and will operate in an Earth-trailing solar orbit. SIM is also an essential stepping stone within NASA's Origins program. The technology of optical interferometry, pioneered by SIM, together with light collectors on separated spacecrafts as demonstrated by DeepSpace 3 (DS-3) and the capability of building large optical collecting areas as required by the Next Generation Space Telescope (NGST) will enable a new generation of spaceborne instruments. The Terrestrial Planet Finder (TPF) will take family portraits of planetary systems and characterize their atmospheres. Later, Terrestrial Planet Imager will take pictures of these planets to determine their geographic layout. All these missions are currently planned for the early part of the next century.

Successful development of SIM requires that three "grand technological challenges" be met and overcome: (1) nanometer level control and stabilization of optical element positions on a lightweight flexible structure; (2) sub-nanometer level sensing of optical element relative positions over meters of separation distance; (3) overall instrument complexity and the implications for interferometer integration and test and autonomous on-orbit operation.

The Interferometry Technology Program (ITP) at NASA's Jet Propulsion Laboratory is addressing these challenges with a development program that plans to establish technology readiness for the Space Interferometry Mission by early in the year 2001. Some of these technological challenges have already been demonstrated on the Micro-Precision Interferometer (MPI) [1], Realtime Control System Testbed (RICST) [2] and the Palomar Testbed Interferometer (PTI) [3]. STB-3 will be the ultimate proving ground since it will be the only testbed with a SIM like architecture. The following describes the STB-3 design goals, development strategy and current status.

The Space Interferometer Mission Testbed III (STB-3) is one of various testbeds that are part of Space Interferometer Mission (SIM) project. Each individual testbed has specific objectives and technologies that it will demonstrate to mitigate the risk to the SIM project. The main objective for STB-3 is to demonstrate pathlength feedforward from two guide interferometers to a science interferometer on a flexible structure. STB-3 will evolve in four major phases. Phase 1 will demonstrate pathlength feedforward on optical tables,

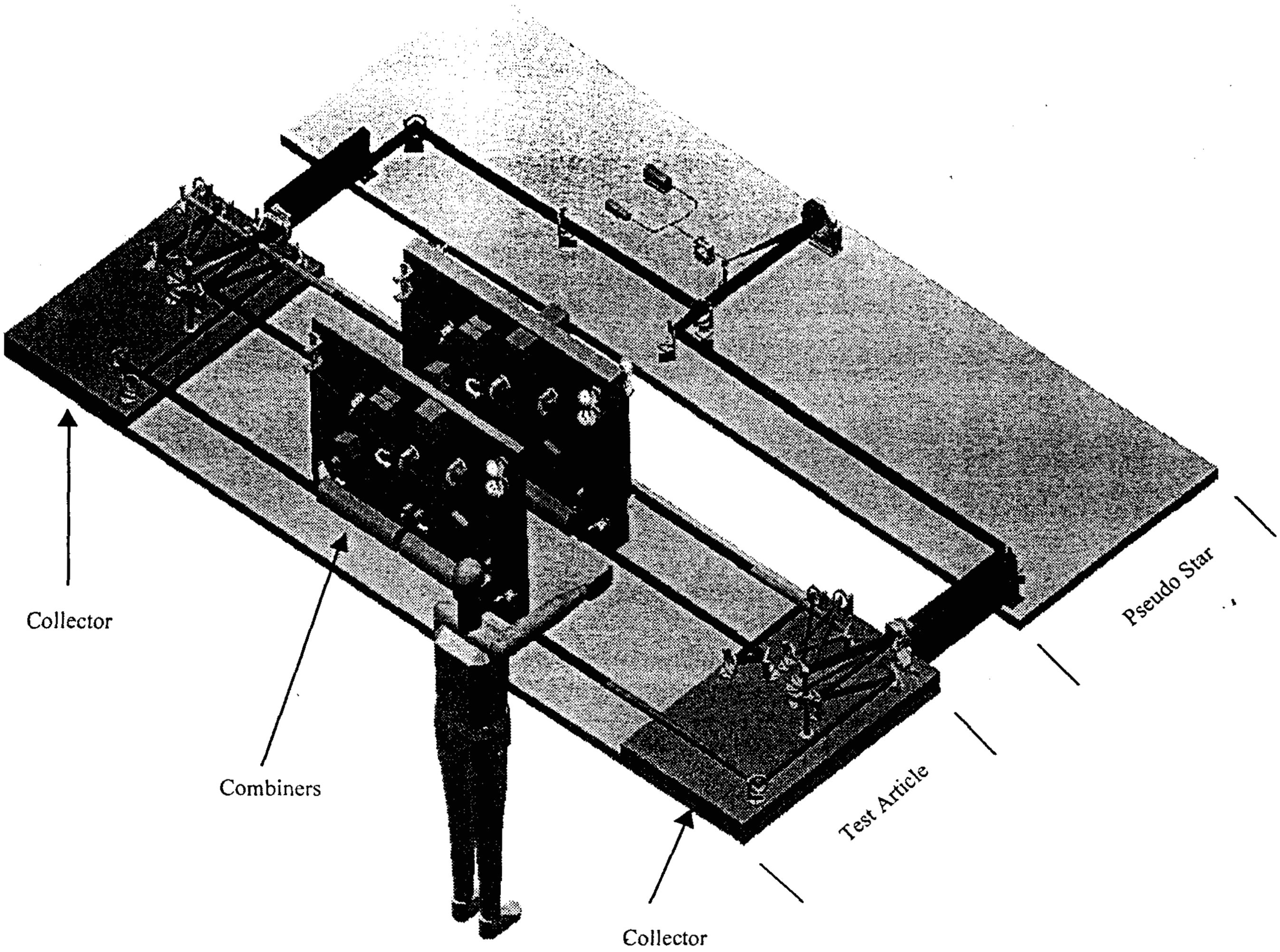

Figure 1 STB-3 Test Article and Pseudo Star

will demonstrate pathlength feedforwardon optical tables, Phase 2 will demonstrate pathlength feedforward on a flexible structure, Phase 3 will implement full SIM real-time complexity and in phase 4 it will be upgraded to meet the needs for the flight instrument integration and testing. Currently phase 1 is the only phase that has been defined well enough to proceed with implementation. At this point Phases 3 and 4 have not been completely defined and thereforewill not be covered in this paper. The rest of the paper will focus on phase 1 and briefly describe at a high level what is planned for phase 2.

2. Phase One Goals

There are three main goals for phase one. The first is to develop and assemble three interferometers(two guides and one science) and a pseudo star to feed the three interferometers on optical tables. The second is to demonstrate the functional operation of the three interferometersindependently. The third is to demonstrate that the three interferometers can operate as a system and to demonstrate PFF control. This will involve developing and implementing all necessary hardware and software required to demonstrate the three-baseline operation. The STB-3 hardware during phase 1 will consist of non-flight-like electronics, optics, collectors, combiners and optical tables. The non-flight-hardwarewill be functionally the same as SIM, although it will be different in form fit and size.

3. Phase One Description

The two main components of STB-3 (see figure 1) consist of the pseudo star and the test article, three interferometers, which can be broken down further into subcomponents.

The main function of the pseudo star is to generate three pairs of coherent collimated beams to feed the three interferometers.The pseudo star consists of a light source, parabola mirror, flat mirrors, gratings and mounts. The light from a laser and from a visible broad-band source are mixed

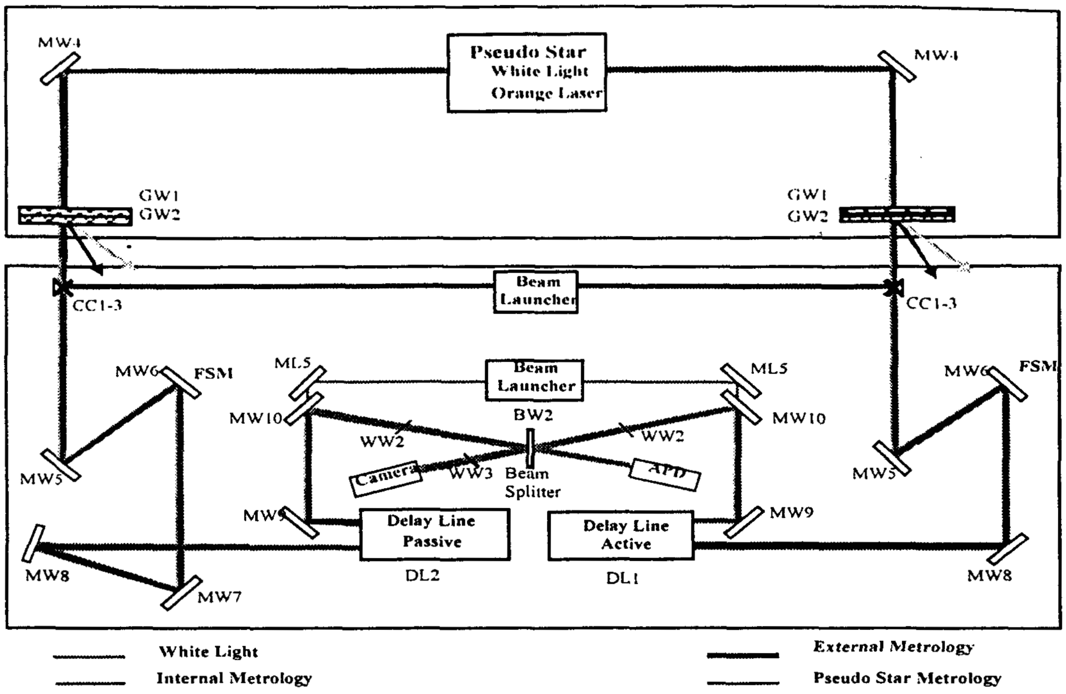

Figure 2 STB-3 Light Path Trace for One Baseline

into a fiber coupler. This output is the star simulator (pseudo star). The pseudo star laser source is used to simulate bright stars for the guide interferometers and the broadband source is used to simulate a dim science star. The parabolic mirror is used to collimate the beam, which then gets separated for the two arms of the interferometervia a beam splitter. Each beam will travel to a grating where it will get split into three beams, at 15 degrees relative to each other, for each of the three interferometers. The starlight will then trace a path through the test article as shown in figure 2. Note that this is shown for only one of the three baselines (interferometers).

The test article consists of two collectors, three combiners, external metrology, internal metrology, and the electronics associated with these items.

The main functions of the collectors are to direct the light from the pseudo star to each of the three individual combiners. The corner cubes for the internal and external metrology are also mounted on the collector.

The main function of the combiner is to combine the light from the two arms and adjust the pathlength to stabilize and detect fringes. It consist of an active and passive delay line, a camera, avalanche photo detector (APD) beam splitter, beam launcher for the internal metrology, mirrors, wedges and prisms.

The external metrology is used to measure the path difference between the two arms of the baseline. The expected baseline for the STB-3 is about 5 meters. The internal metrology is used to measure changes in the pathlength differencebetween the two arms that make up a single baseline. In order to get fringes the light path from the source to the beam splitter must be equal for each of the two arms of the interferometer. The metrology beams measure changes in the pathlength difference between the two arms that make up a single baseline (i.e. the pathlength from any given beam combiner to the metrology corner cube). Inside the beam combiner, an optical delay line equalizes the pathlength, from the stellar source to the main beam splitter, by performing feedback control using photons from the star as input to a sensor which reports the stellar fringe phase. This is done on the two baselines of the guide interferometers. The science baseline is nominally looking at a source that is too dim to allow the system to perform this kind of active fringe tracking. The fringe position information from the two guide baselines is used to adjust the delay line position of the science interferometer.

4. FACILITY

The facility for STB-3 will be located at the Jet Propulsion Laboratory in Pasadena for phases one through three. The building in which STB-3 will be located was not designed specifically to limit seismic, acoustic or thermal effects. STB-3 will rely on building temperature and humidity control, active suspension systems, and an acoustic enclosure if necessary to reduce environmental effects. There are insufficient funds available to improve the seismic, acoustic or thermal effects within the facility that would allow us to meet absolute on orbit performance. Minor modifications will be made to try and improve the facility environment as much as possible with the limited resources available. Because of this, STB-3 will not demonstrate absolute on orbit performance. Instead STB-3 will demonstrate 50nm RMS fringe tracking in a 50mm RMS disturbance environment. STB-3 will be collocated with the RICST testbed. STB-3 will occupy the right half of the facility and RICST will occupy the left half of the facility. A preliminary layout of the facility can be seen in figure 3.

Most of the facility work that is needed to support the STB-3 development has been completed. The necessary power, cable trays, air compressors, regulators, and environmental controls for temperature and humidity have been installed. The strategy for reducing the effects of acoustics is still being reviewed. It has not been decided if the whole room should be modified or if an acoustic enclosure for just the test article and pseudo star would be sufficient. The two 5' X 18' optical tables have also been moved into the facility.

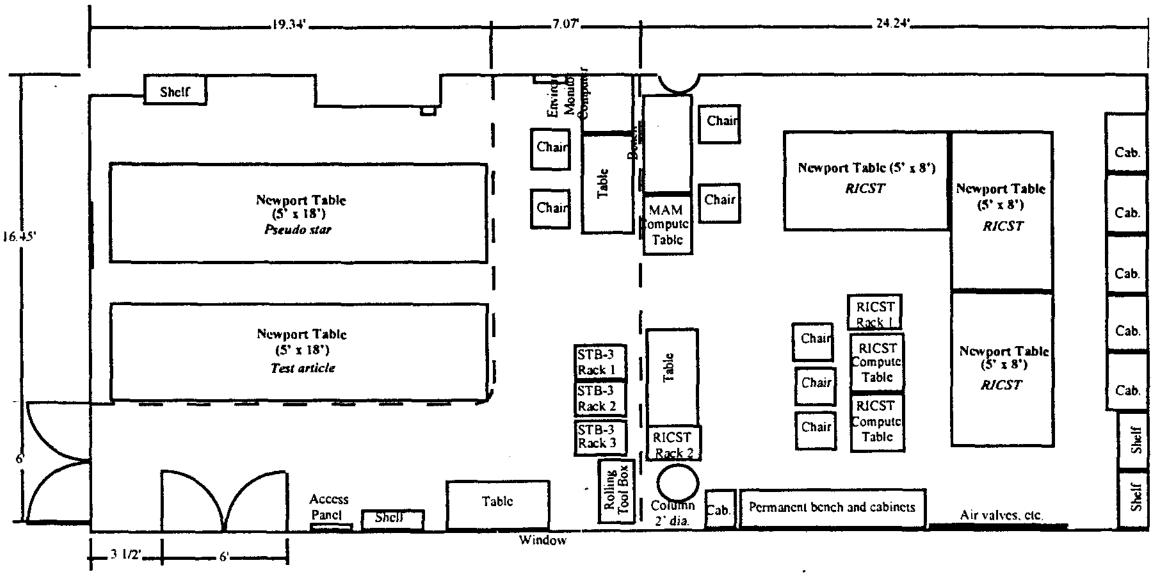

Figure 3 Preliminary STB-3 Layout

5. Phase One and Two Development Strategy

The architecture for STB-3 phase one has been defined and the implementation of phase one is underway. Phase two has also been defined at a high level but the detailed design still needs to be done. The following is a description of the phase one and phase two activities, as we know them today.

Phase one will demonstrate pathlength feed forward on a ridged structure (i.e. optical tables). During phase one all the software, electronics, optics and fixtures will be integrated and tested on two 5' X 18' optical tables. One of the two tables will support the pseudo star and the other the test article. The collectors and combiners will be assembled and aligned on smaller optical tables (breadboards) which will then be mounted on the 5' X 18' table. Isolation legs will be used on the optical tables to reduce any environmental vibrations that may propagate from the floor to the test article or the pseudo star. The development strategy is to build STB-3 up and characterize it incrementally. This will be done by first performing standalone tests. There are two main objectives for the standalone tests. The first objective is to characterize the facility environment in more detail. The second is to checkout as much as the STB-3 hardware as early as possible to verify hardware interfaces, basic functionality, of components, and flush out any gross problems early. Once the standalone tests are completed the first interferometer will be assembled, checked out and verified to be working prior to building up the second and third interferometers. Once the first interferometer is working, then the second and third will be assembled and individually checked out standalone. After all three interferometers have been tested standalone they will be integrated and tested to verify that they work together as a system with PFF disabled. Finally, PFF will be enabled and phase two will start after pathlength feedforward is demonstrated on the optical tables with the three interferometers.

In phase two the three interferometers will be moved from the optical table to a flexible structure. The pseudo star will remain on the 5' X 18' optical table. The main objective on the flexible structure is to demonstrate rejection of pathlength disturbances. The current strategy is to demonstrate 50 nm RMS fringe tracking in a 50 mm RMS disturbance environment. The first step in phase two will be to break down the test article into its three major components; the two collector breadboards and the combiner

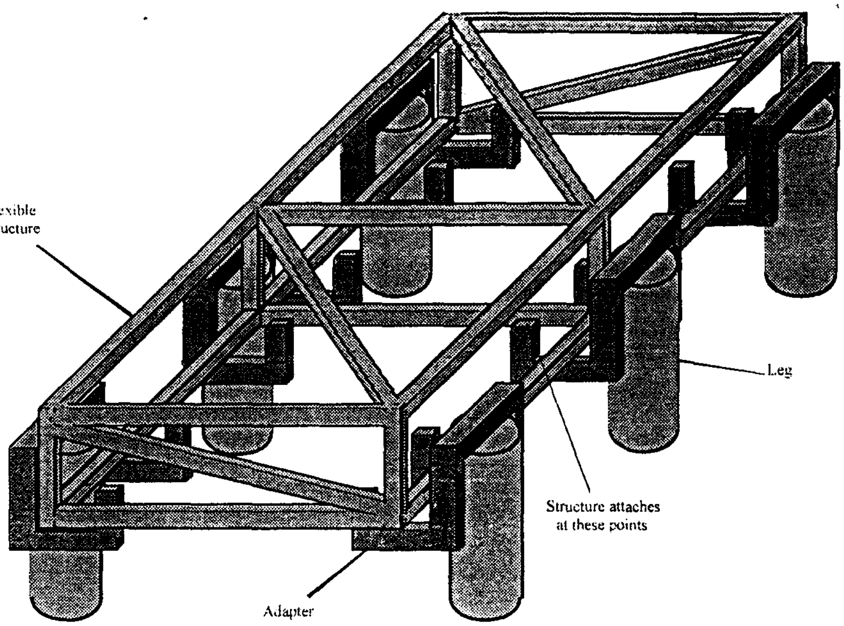

Figure 4 STB-3 Flexible Structure Concept

unit. The test article optical table will then be removed from the facility and the upgraded suspension system will be installed along with the flexible structure and mounts (see figure 4). Note that the setup shown in figure 4 is to illustrate the basic concept. The details of the type of structure and suspension mounts are still being designed. The upgraded suspension system would provide 6 DOF limited-range control of baseline orientation for interferometer control system testing. The same approach of incrementally building and testing will be used in phase two. Standalone tests will first be performed on the structure and suspension system to characterize them prior to installing the test article. The five breadboards (2 collectors & 3 combiners) will then be attached to the flexible structure using kinematic mounts so that they will not interfere with the natural modes of the structure. The same set of tests that were performed on the optical tables in phase one will be repeated, once the hardware has been mounted and aligned on the flexible structure. The demonstration of pathlength feedforwardon a flexible structure will mark the end of phase two and the successful completion of the STB-3 main objectives for the first two phases.

6. STATUS

Most of the facility work that is needed to support STB-3 has been completed. The architecture for STB-3 phase one has been defined and the review was held in December 1998. A go for phase one was given and the implementation of STB-3 is currently in process. All STB-3 procurements are underway and some of the STB-3 build up has started. Currently the STB-3 standalone tests are under way and are expected to be completed by May 1999. The first baseline is expected to be operational by early October 1999 and the other two baselines operational by the end of October 1999. The pathlength feedforwardon optical tables is expected to be completed by mid January of 2000. Reviews for phases two through four will be held when the phases have been firmed up and defined. Currently phase two and three are expected to be completed by April of 2001 and October 2001 respectively. Phase four would start shortly thereafter.

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The Space InterferometerMission Testbed III (STB-3) is one of various testbeds that will be used to demonstrate new technologies for the Space Interferometer Mission. The main technology objective for STB-3 is to demonstrate pathlength feedforwardon a flexible structure. Pathlength feedforward involves passing fringe position information from the two guide interferometers to the science interferometer which is nominally looking at a source that is too dim to allow active fringe tracking. This also requires controlling delay line position to nanometer levels. Pathlength feedforward will be demonstrated on optical tables first around January of 2000 and then on a flexible structure around April of 2001. The architecture for STB-3 phase one has been generated and reviewed. The implementation of STB-3 phase one is currently underway and expected to be completed by January of 2000.

ACKNOWLEDGEMENT

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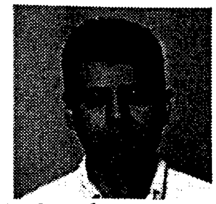
BIOGRAPHY



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