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THE JPL PHASE B INTERFEROMETER TESTBED

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INTRODUCTION

Future NASA missions with large optical systems will require alignment stability at the nanometer level. However, design studies indicate that vibration resulting from on-board disturbances can cause jitter at levels three to four orders of magnitude greater than this. Feasibility studies have shown that a combination of three distinct control layers will be required for these missions, including disturbance isolation, active and passive structural vibration suppression, and active optical pathlength compensation. The CSI technology challenge is to develop these design and control approaches that can reduce vibrations in the optical train by a factor of 1000 to 10,000.

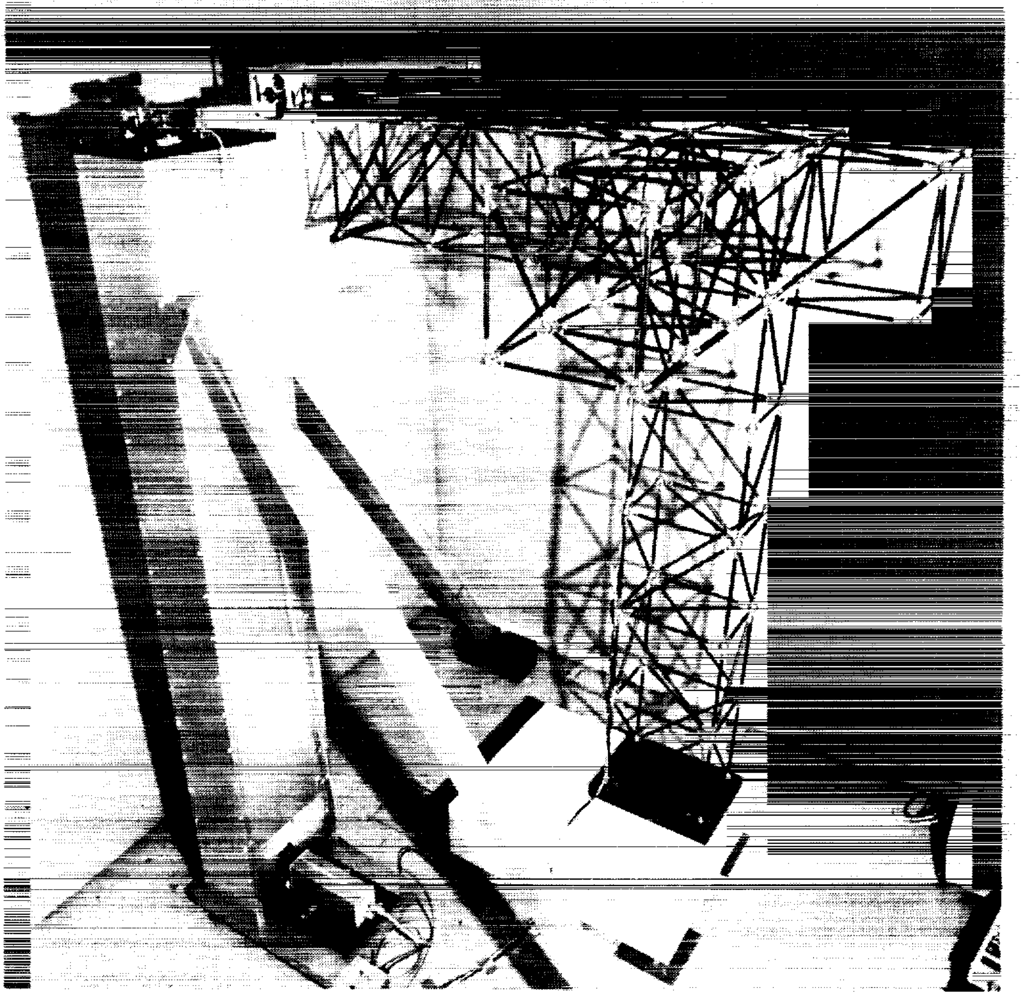
The JPL Phase B Testbed, part of an evolutionary chain of testbeds at JPL, has been developed to demonstrate and validate these control approaches. The Testbed structure was designed to resemble a portion of a concept design for an optical interferometer telescope, and is made with truss construction and includes multiple resonances within the control bandwidth. The Phase B Testbed also includes a full complement of sensors and actuators for isolating disturbances, suppressing structural vibrations, and compensating the optical pathlength, and fast real-time computers for implementation of the control algorithms and recording the results. In addition, the development environment has been designed to maximize turnaround time for new control designs. Thus far, the optical compensation and structural vibration suppression control layers have been demonstrated, and development of the disturbance isolation control layer is ongoing. Experimental work in the near future will focus on combining these three control layers in the expectation that the disturbance rejection of the combined system will achieve the required attenuation.

This paper was presented as a poster session at the Fifth NASA/DOD Controls-Structures Interaction Technology Conference, March 3-5, 1992 at Lake Tahoe, Nevada. The focus of the paper is on describing the Phase B Testbed structure and facility, as the experimental results are included in other papers presented at this same conference.

THE JPL PHASE B TESTBED STRUCTURE

The Phase B Testbed structure consists of a truss structure 2.5 m high with two horizontal arms which support optical components similar to those that would be required on a functioning optical interferometer. The optical pathlength compensation system is attached to the end of one of these arms, and can be seen in the photograph below. The structure is constructed from aluminum tubes which can be removed easily, allowing for inserting active and passive damping truss elements or for changing the experiment configuration without major disassembly. The truss elements attach to aluminum nodes which have threaded holes drilled at the proper angles. If required for modal testing or structural control, accelerometers can also be attached to these nodes. Input disturbances can be injected into the structure at any of the nodes using modal shakers. A NASTRAN model of the structure predicted 16 vibratory modes below 100 Hz, and this was verified experimentally.

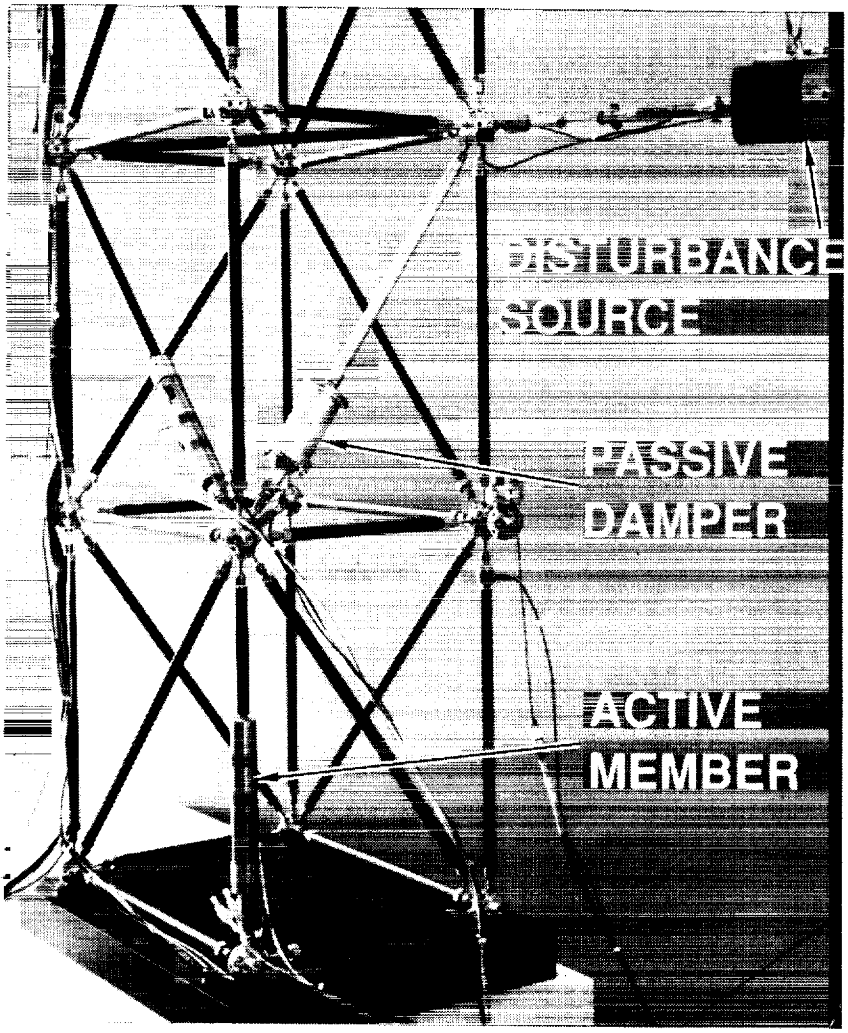
A second, rigid structure or "tower" was constructed for the purpose of supporting an optical bench on which the simulated star source is mounted. Due to its large surface area the tower design was potentially susceptible to acoustic noise, and accordingly it was constructed with damping material in all its joints. The Testbed structure, which is more affected by seismic disturbances, is mounted on a 1500 kg block of steel. Despite these precautions, the ambient disturbances in the laboratory cause motion in the optical pathlength of tens of microns--several orders of magnitude greater than the required stability--and thus increase the challenge of meeting the requirements. In fact, the ambient noise constitutes a convenient disturbance source for control experiments, and many of the initial experiments used no additional auxiliary disturbance source.



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

STRUCTURAL QUIETING LAYER

The structural quieting layer is designed to reduce the vibration level in the structure to provide disturbance attenuation before it acts directly on the optical elements. This is accomplished through a combination of passive damping and active control. Due to the design of the truss structure, passive or active members can be substituted easily for aluminum truss elements. Passive dampers, which employ a viscous fluid, have the advantages of being robust, simple in design, and requiring no power. Experiments using passive dampers have demonstrated the ability to attenuate disturbances in the structure by a factor of 40. Active members utilize a piezoelectric actuator embedded within the structure. Two schemes for controlling the active members have been demonstrated thus far: dial-a-strut, and state feedback structural control. The dial-a-strut controller can be made to emulate any passive member, though its greater value lies in its ability to electronically fine-tune the mechanical impedance of the active member to maximize energy dissipation. The other scheme consists of using full state feedback to generate control signals to the active members. This strategy is theoretically capable of achieving higher control performance, but is more sensitive to modeling errors in the system. In practice combined control and structure optimization will be used to determine the locations for and the optimal blend of passive and active members.



OPTICAL COMPENSATION LAYER

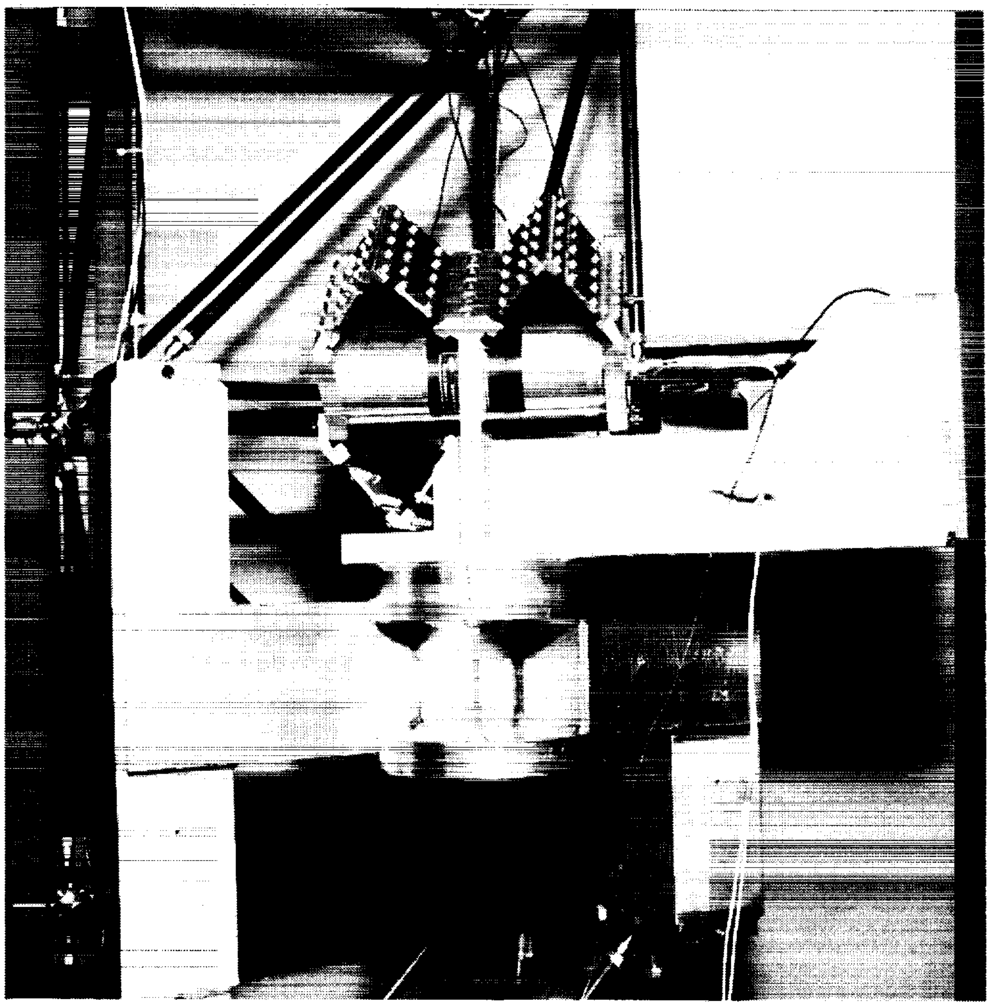
The object of the optical compensation control layer is to maintain a desired optical pathlenth through the optical train by moving optical elements with actuators. This system consists of a cat's eye retroreflector, which employs a primary and a secondary mirror and which has the property of returning a reflected laser beam parallel to the incoming light path. A heterodyne laser interferometer is used to measure pathlength through the optical train, with a resolution of 2.5 nanometers. Two actuators are used in this system. The first consists of a piezoelectric stack to which the secondary mirror is mounted. An identical actuator is used to force a counterweight in the opposite direction to that of the secondary mirror, rendering this system essentially reactionless.

The second actuator consists of a voice coil actuator which reacts between the retroreflector assembly and the aluminum frame mounted to the truss structure. The retroreflector assembly uses Invar in its construction for thermal stability, and is suspended from the aluminum frame using flexures in a parallelogram geometry. An eddy current sensor is used to sense the relative position of the retroreflector and the frame. The combination of the voice-coil and piezoelectric actuators provides the control system engineer with the capability to perform high-bandwidth optical pathlength compensation.

ISOLATION FIXTURE

The function of the isolation fixture is to demonstrate disturbance isolation on the Phase B structure. Disturbances such as those resulting from reaction wheel dynamics are simulated using a modal shaker with 10 N maximum force output. The shaker, which is configured as a proof-mass actuator, is mounted in a flexure mechanism which supports its weight yet allows straight-line motion. The body of the shaker motor and hardware holding it constitute the reaction mass. Reaction forces from the shaker are coupled to the structure through the horizontal "L" shaped bracket seen in the photograph below. This bracket is mounted on a turntable so that the direction of action can be altered. The isolation fixture can be attached to the Phase B structure in more than a dozen different locations.

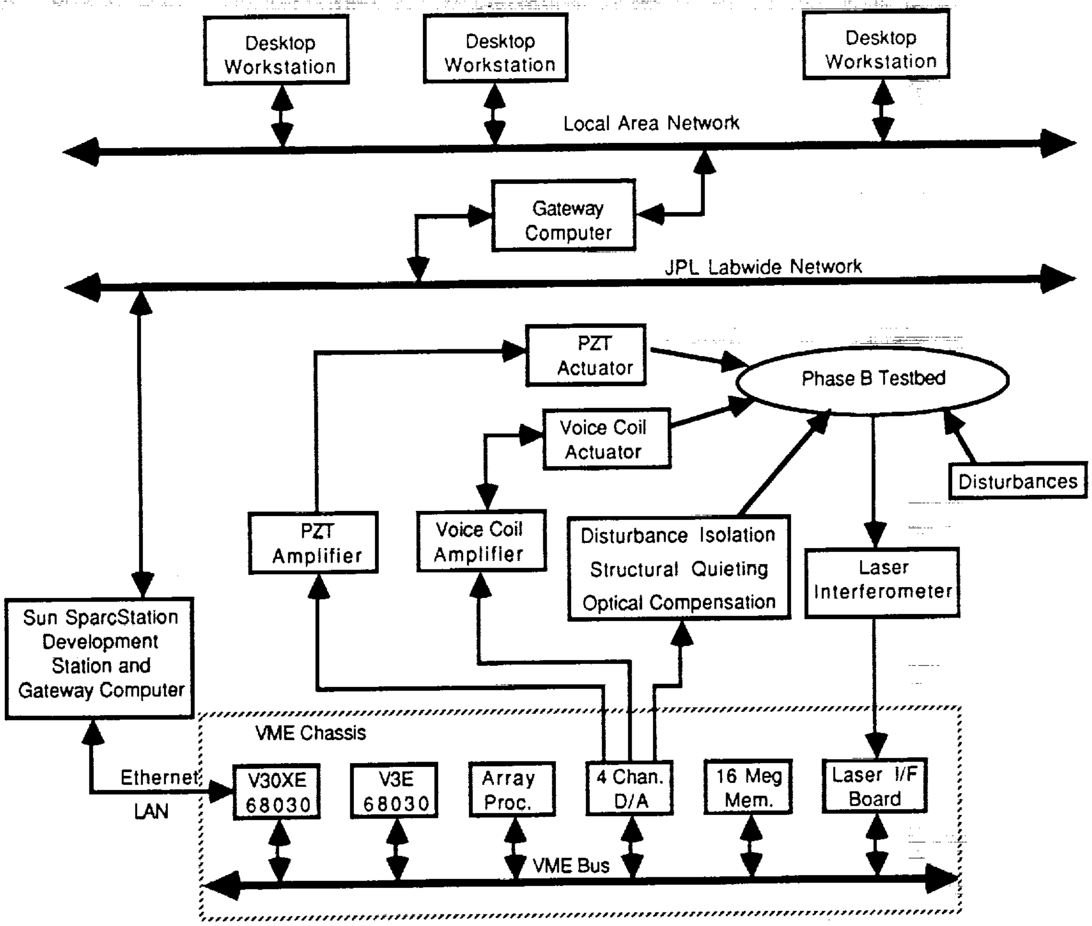
Disturbance isolation is achieved by mounting an isolator between the shaker and the "L" bracket. An active strut is shown in the photograph, though passive struts can also be substituted in the same location. By replacing the isolator with a rigid element, the isolation fixture becomes a controlled disturbance source. The isolation fixture is a recent addition to the Phase B Testbed, and experiments in disturbance isolation are in progress.



REAL-TIME COMPUTERS

Control of the Testbed structure and optical pathlengh is achieved using single board computers (SBC's) mounted in a VME chassis. Heurikon 68030-based SBC's are used in conjunction with a CSPI Supercard II array processor, which is used for the computationally intensive control loops. In addition, 16 bit analog to digital and digital to analog conversion is performed by Data Translation converters, and a custom board made in-house is used for interfacing the laser interferometer to the VME bus. The real-time computers are connected through ethernet to a Sun Sparc workstation, which is used to compile, load, and execute programs on the SBC's and also to archive and display experimental results. Compilation is performed using GNU's cross-compiler. The VxWorks operating system is used to arbitrate and synchronize among multiple tasks within the SBC's and to load and run software.

JPL's CSI laboratory was designed to facilitate the rapid development, implementation, and analysis of experiments. The workstation and the real-time computers are interconnected via ethernet to form a local area network (LAN) within the laboratory, which is also connected to JPL's main network using the SparcStation as a gateway. This connectivity makes it possible for anyone connected to the nationwide Internet network to remotely log into the real-time computers, and in fact, most development work for the experiments is performed from the analysts' offices using their workstations for network access.



SUMMARY AND CONCLUSIONS

Experiments to date have included demonstration of optical compensation and structural quieting resulting in stability of the optical pathlength of tens of nanometers. Details of the experimental results can be found in references 1–6 and in other papers presented at this conference. Control designs for disturbance isolation using the isolation fixture are currently being developed, which will be followed by the simultaneous application of all three layers of control. Disturbance rejection of four orders of magnitude or greater is anticipated.

ACKNOWLEDGEMENTS

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