

Designing Optical Layouts for AEI's 10 meter Prototype

Stephanie Wiele
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This summer I worked at the Albert Einstein Institute for Gravitational Physics as a member of the 10 meter prototype research group. My job was to help design the optical layouts needed for the prototype detector; specifically I designed the layout of the table outside the vacuum system for the suspension platform interferometer (SPI) and the layout of the mirrors within the vacuum system for the Michelson interferometer.

Introduction

Near end of this year, construction is anticipated to begin on a 10 meter prototype gravitational wave detector designed by a research group at the Albert Einstein Institute (AEI) in Hanover, Germany. The purpose of this prototype will be to test new technologies, like high power lasers and digital control systems, to update current gravitational wave detectors and to be used as a training device for people who will work on the next phase of GEO 600, GEO-HF (high frequency). It will also provide a low-noise environment for future experiments that require such an environment. [1]

One of the difficulties with ground-based detectors is distinguishing interferometer arm length changes due to gravitational waves from arm length changes due to seismic activity. To minimize this noise as much as possible, each of the three tables within the prototype vacuum system will be suspended from springs attached to four vertical posts. Within each table, seismometers will track table movement due to ground movement. Using information from the seismometers and position sensors

outside the tables, each table will be actuated using voice-coil style actuators so that they will be “quiet” with respect to their own area of the ground. Since ground conditions will not be necessarily exactly the same for each table, a second sensor, the suspension platform interferometer (SPI), will also be used to actuate the tables. The SPI will be used to monitor the distance between each table, so as to keep the distance between the tables fixed and to suppress interferometer arm length changes due to seismic activity. [1]

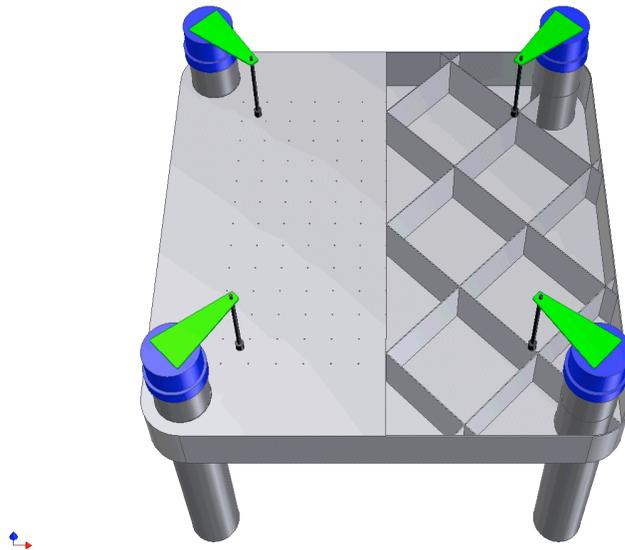


Figure 1. *Diagram of the prototype tables.* [1]

The idea for using the SPI came from a research group at the University of Tokyo in Japan, who developed a suspension point interferometer. Unlike the Japanese device, which is part of a suspended mirror system, the prototype SPI will be mounted on the tables on Zerodur plates; however, the main purpose remains the same. When the SPI is locked, it acts as a “rigid bar”, keeping the arm length constant so that any length changes would only be due to a gravitational wave. [3] The SPI at the AEI is based on the interferometer design for the LISA Pathfinder mission, a heterodyne Mach-Zehnder interferometer. In this type of interferometer, after the laser beam is split, the two parts

are both frequency shifted using acousto-optic modulators (AOM) so that they differ by a constant amount called the heterodyne frequency (which is much less than the frequency of the laser). The two parts travel different paths, interfere at another beamsplitter, and are detected at a photodiode. Any change in pathlength will result in a change in phase of the heterodyne frequency, which will be registered by the photodiode. The benefit of this set-up will be that all phase-shifts (or pathlength changes) that occur when producing the beams, can be eliminated when the heterodyne frequency signal is measured with reference to phase-shifts from another interferometer (using the same beams) that does not experience a length change. [3]

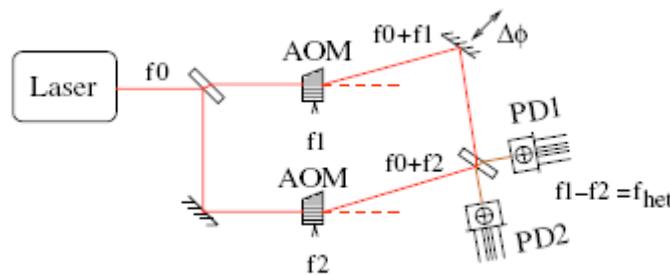


Figure 2. Heterodyne Mach-Zehnder Interferometer schematic. [3]

The diagram of the SPI to be used in the prototype, which was designed by Katrin Dahl, is shown in the figure 3. It contains three different interferometers: one as a reference to monitor any path length changes occurring on the table outside the vacuum system, one to monitor the length of the west arm, and one to monitor the length of the south arm. Each interferometer is detected by two photodiodes after the beams are recombined at another beamsplitter. Although only one photodiode is necessary to monitor the interference, two are used to ensure an accurate reading (the phases detected at each photodiode should cancel) and to help identify sources of electronic noise.

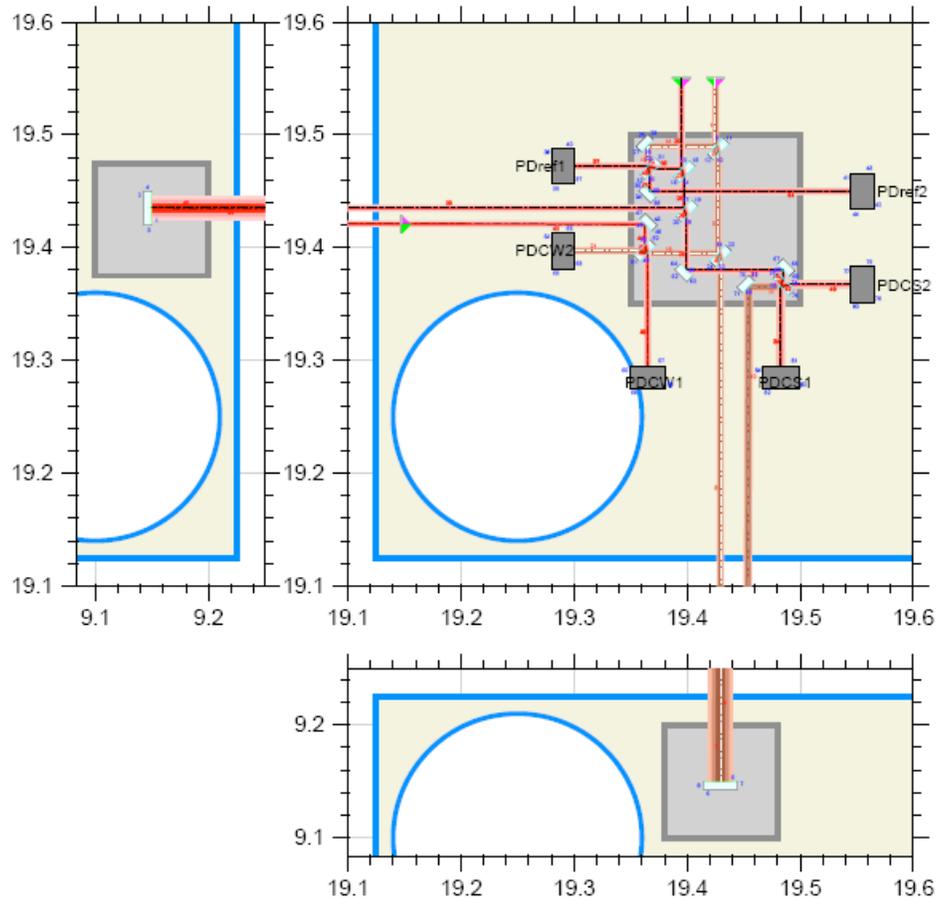


Figure 3. *Diagram of the SPI (units in meters).*

My Project

My initial project was to help design the layout of the optical components required to generate the two beams for the SPI, which can be seen in figure 4 below. All units in this diagram and those following are in meters. When the laser light is emitted from the laser box, the beam is elliptically polarized. The beam first passes through a quarter-wave plate so as to become linearly polarized, and then through a half-wave plate to choose the orientation of the polarization. The polarization of the beam is rotated as it passes through a Faraday isolator, which is used to protect the laser box from being

overloaded by back reflections. Light reflected back from the beamsplitter will have its polarization rotated even further as it passes through the Faraday isolator again and will be blocked by the half-wave plate. After the Faraday isolator, a polarizer is used to select S-polarized light. The beam is then split into two parts, each of which passed through an AOM. One side will be frequency shifted up by about 11 kHz and the other side will be frequency shifted down by about 11 kHz, creating a heterodyne frequency of 22 kHz. After passing through the AOMs, each path is directed into an optical fiber which

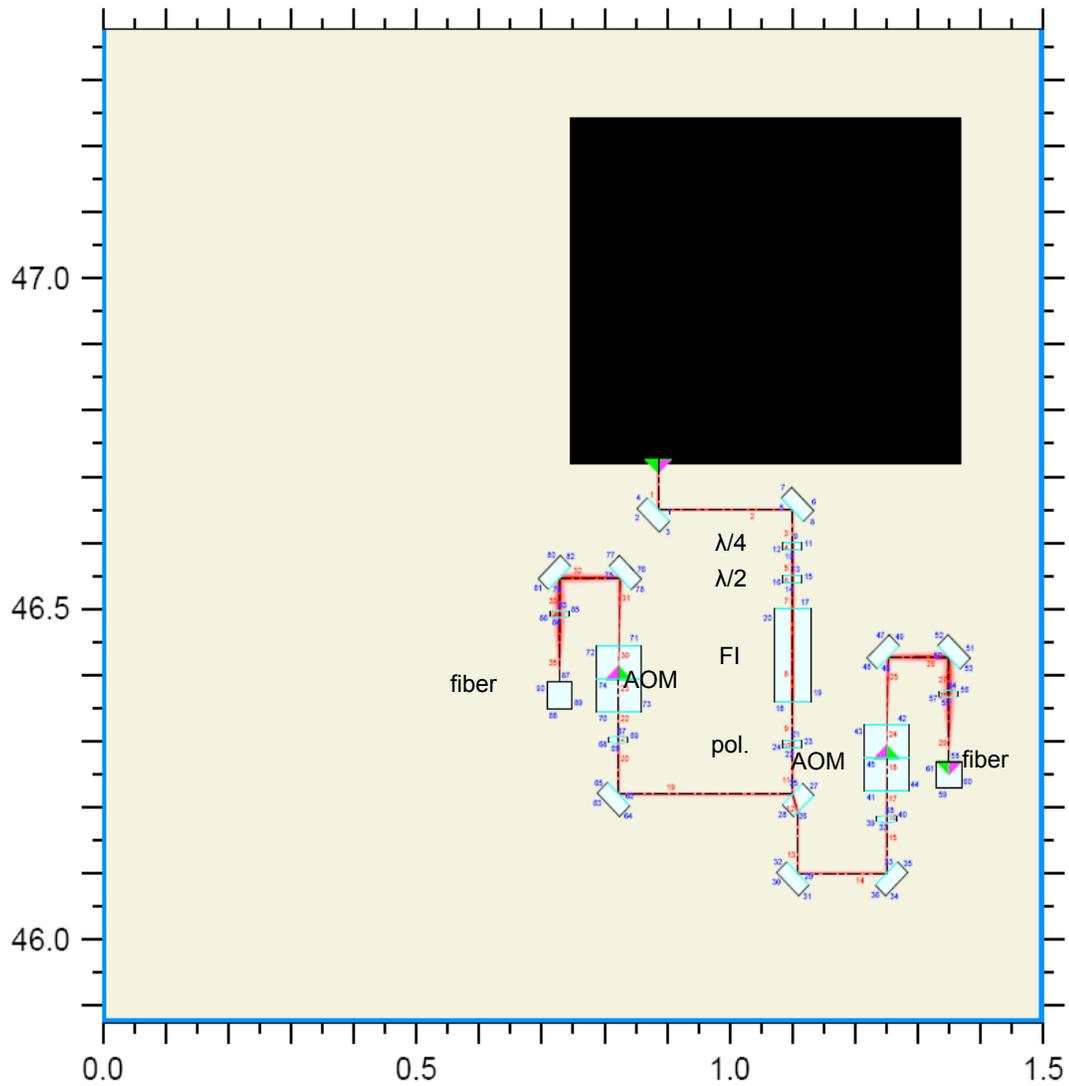


Figure 4. SPI components outside the vacuum system.

components in a compact way, so as to leave space for future experiments, and to ensure that the optical path lengths traveled by the laser beam after the beam splitter were equal. The main challenge was figuring out how to model the AOMs using the commands available in OptoCad; I ended up modeling it as a block of fused silica with a diffraction grating in the center, as was suggested in examples in the OptoCad manual.

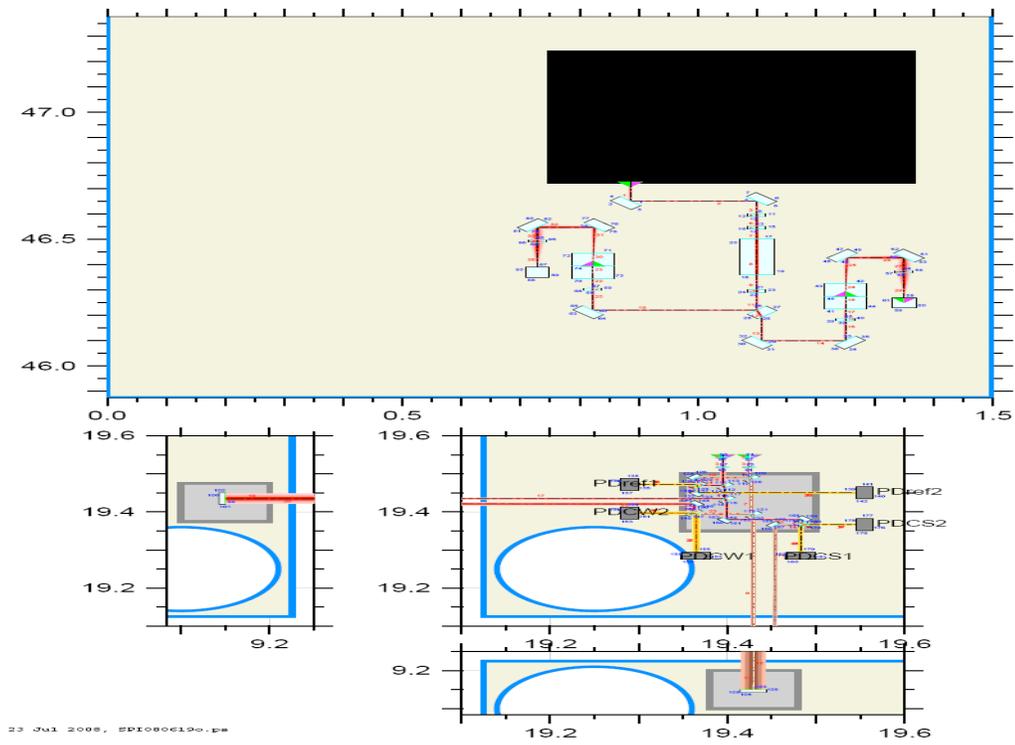
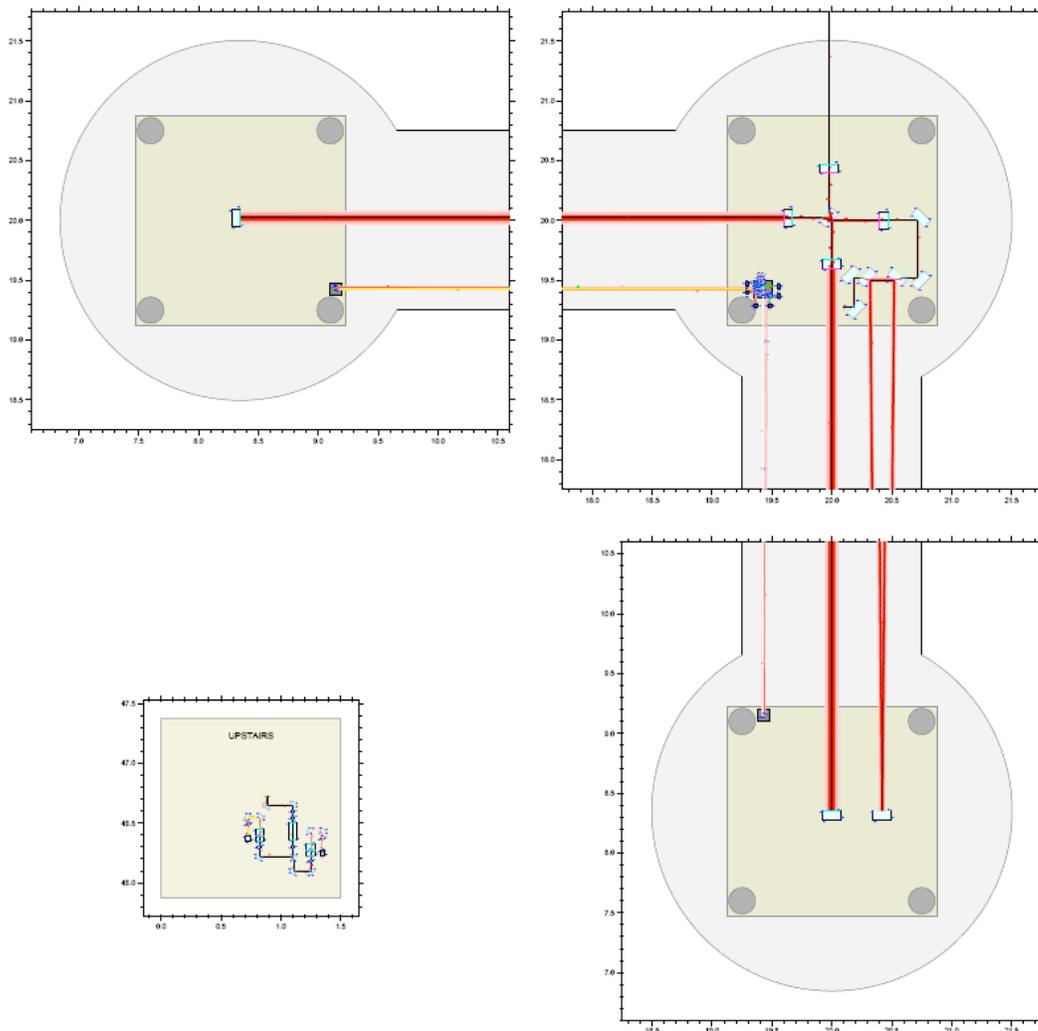


Figure 5. SPI diagram produced using “save” and “restart” commands.

The next challenge was to figure out how to model the optical fibers in order to connect my diagram with the SPI diagram designed by my mentor, Katrin Dahl. According to the designer of OptoCad, Roland Schilling, there was no way to directly model optical fibers; however, he suggested using the “save” and “restart” commands. OptoCad can save beam information at a given surface, and then restart it where directed within the program code. This worked well, at least for picture purposes, but created

difficulties for modeling purposes, as I will discuss later. Once I learned how to implement the “save” and “restart” commands, the next challenge was to get the beams to look as they would when exiting an optical fiber, and as they did in Dahl’s original diagram. I ended up using a combination of lenses which telescoped the beam down to almost the exact beam width assumed in Dahl’s diagram, as can be seen in figure 5 above. I also edited the diagram so that the yellow beam color would indicate that the two beams are interfering with each other.



My next project was to create the first optical diagram of the prototype

Figure 6. Diagram of the 10 meter prototype.

Michelson interferometer. My main task was to ensure that all the mirrors they wanted on the center table would fit so that the beamsplitter mirror was located in the center. With the estimated mirror diameter of 14 cm and depth of about 6 cm, there was enough space on the table for all the mirrors required before the beam encountered the beam splitter, a larger image of which can be seen in figure 7. The hardest part of this diagram was figuring out which commands to use to correctly depict the mode cleaner since they are both transmitting and reflecting and at an angle to the incoming laser beam.

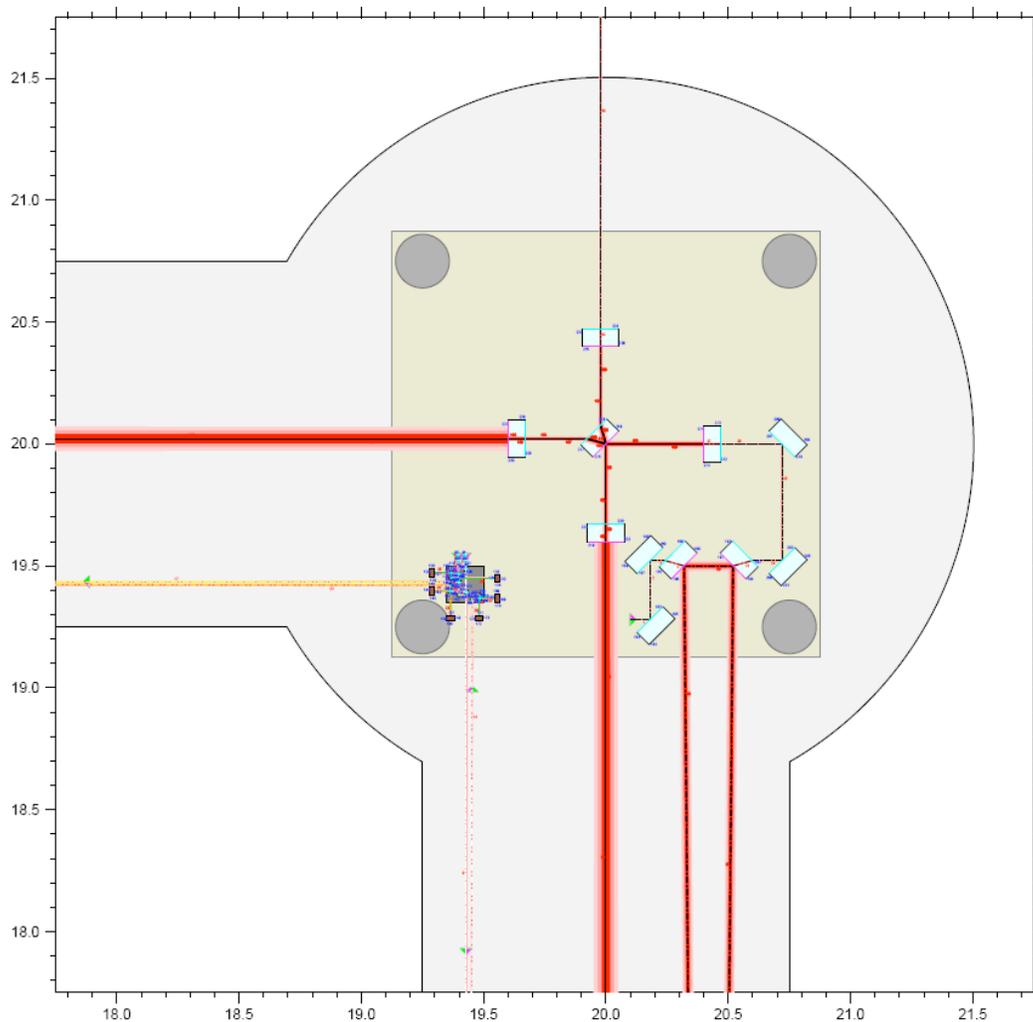


Figure 7. *Prototype center table.*

Conclusions and Future Work

It was really interesting to be part of a research group that is still in the fairly early stages of designing its experiment. I learned how much planning and work is required before an experiment can even begin, and how many values remain undefined as the planning progresses. With the prototype diagram that I worked on, for example, I only worked with estimated values for the mirror sizes and locations, since they had not been defined yet. After working on this diagram, I realized how important it is not only to consider the requirements for the present set-up, but also the requirements that future set-ups may have. One of my initial ideas was to place the mirrors before the beamsplitter on the northern half of the table, rather than the southern half, until Katrin Dahl pointed out that it is important to keep the table as open as possible for future experiments. After I finished the diagram, it was decided that the SPI will be moved to the center of the tables rather than at the far edge. This will require making two diagram pictures, one showing the main interferometer mirrors, which will be suspended, and one showing just the SPI.

I also learned that computers are from perfect at being able to model exactly what you want them to. With my first diagram, it was difficult to figure out how to get the program to save the SPI beam information to a file when using the “save” and “restart” commands. For purely modeling purposes, the new design is to let the beams continue as if the fibers were not there and to use mirrors and lenses to direct the beams so they are the same distance apart as they would be when exiting the fiber in the vacuum chamber and to focus the beams down to the proper width.

There is a lot of work that will still be done on this project, and some of what I did this summer will most likely be changed, but it was a great experience working on an experiment that is still in the development stages.

Sources

- [1] Goßler, Stefan. “The Hannover 10 m prototype interferometer”. AEI seminar, May 2008.
- [2] Y. Aso, et al. *Active vibration isolation using a Suspension Point Interferometer*. Journal of Physics: Conference Series **32** (2006) 451-456.
- [3] G. Heinzel, et al. *Interferometry for the LISA technology package (LTP) aboard SMART-2*. Class. Quantum Grav. **20** (2003) 153-161