Phase camera noise hunting and characterization of AOM

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1 Introduction

1.1 Gravitational waves

Gravitational waves are quadrupolar waves, that can be characterized as the ripples in the curvature of space-time. The waves could be generated in multitude of ways by changing the position of the mass, but the most notable sources of the wave remain to be binary neutron stars, black holes, and supernovas. The gravitational waves have not yet been detected due to extreme sensitivity needed for their detection.Current gravitational wave detectors use Michelson Interferometer set-up, and have arm lengths ranging from 600 m to 4 km. These interferometers in order to detect gravitational waves must be sensitive to the spacial distortions of less than 10^{-18} m, which is about 1/1000 of the diameter of a proton. In order to achieve such high sensitivity, the system must be well insulated from outside noise and the internal noise must be minimal.

1.2 Thermal Compensation System

Advanced Virgo is one of the next generation gravitational detectors. Advanced Virgo will be a more sensitive version of Virgo gravitational detector. The new detector will include a more powerful laser, heavier mirrors, higher quality optics, and a power recycling cavity. A new addition will also include a thermal compensation system. The thermal compensation system will be involved in compensating for mirror aberrations. Mirror aberrations are caused by inhomogeneities in the substrate of the mirrors, and thermal lensing due to gradual heating of mirrors by the laser. These aberrations impair sensitivity of the detector by contributing to the higher order modes, and causing decrease in power recycling and sideband signal. The thermal compensation system will correct for the aberrations by heating a compensation plate with a CO2 laser, and adjusting optical properties such that a beam will have a nice gaussian shape. To obtain wavefront images and aberration maps, a phase camera along with a Hartmann sensor will be used.

1.3 Phase Camera

A phase camera will be used in advanced Virgo for generating a frequency selective wave front image. The phase camera is being developed at NIKHEF, and will involve a heterodyne detection along with a pinhole scanning technique.

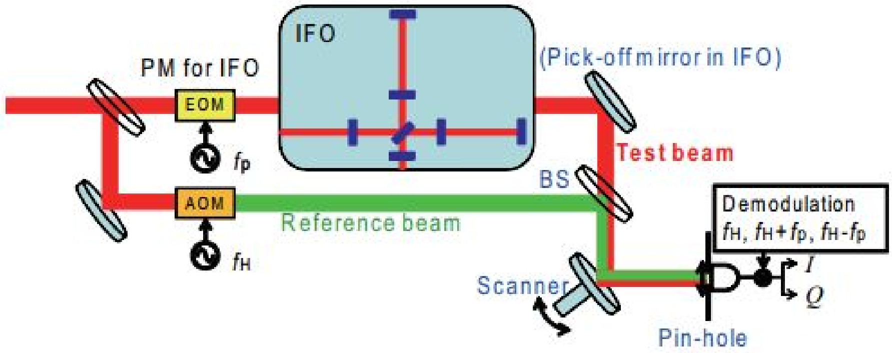

Figure 1: Phase camera set-up.

The phase camera will be implemented at the input port, the power recycling cavity, and the output port of the interferometer.

A 500 mW , 1064 nm laser is first split into two beams of equal power. The first beam, test beam, passes through the electro-optic modulator (EOM) which phase modulates and adds a sideband signal at 7 MHz. The NIKHEF system only uses 1 sideband, but in Advanced Virgo there will be 5 sidebands that will provide information of the beam on the 3 sites that it will be implemented. The second beam, reference beam, is passed through acousto-optic modulator (AOM) which adds 80 MHz to the frequency of the beam. The test beam is then traveled through the interferometer where it would acquire the aberration signal. The two beams are recombined to form a beat signal, and are scanned across a pinhole in a spiral pattern into photodetector (PD). The simple setup is shown in figure 1. The signal is then demodulated at the reference frequency, and the two beat frequencies(f(ref)+f(test), f(ref)-f(test)).

1.4 Acousto-Optic Modulator

An acousto-optic modulator (AOM) was one of the optical components that have been studied in this experiment. The purpose of AOM was to provide a frequency shift for a reference beam to generate a beat signal when the reference beam is coupled with the test beam. In the AOM a transducer is used to generate a sound wave on the MHz scale, which interacts with a transparent crystal. The acoustic wave generates a traveling periodic refractive index gradient in the crystal, which in turn induces a Bragg diffraction of the beam resulting in a frequency shift. Polarization Maintaining Optical Fibers

The two AOMs that were studied used optical maintaining fibers for input and output of the beam. Polarization maintaining optical fibers differ from regular optical fibers in that they maintain a true form of the input wave with its linearity and polarization. In a regular optical fiber inhomogeneities in the material, temperature change or mechanical stress within the fiber would cause aberration of the original beam. A polarization maintaining fiber reduce the effect of these factors by having a strong built in birefringence in one axis, and a lower birefringence at the other. The high birefringence of the fiber is introduced by two stress rods(figure 2). This makes fiber act much like a full

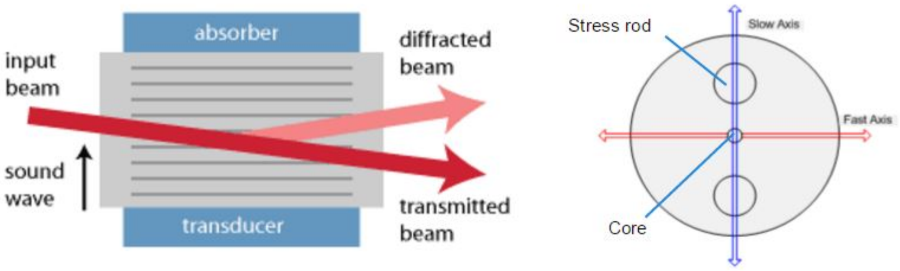

Figure 2: AOM operation mechanism and polarization maintaining fiber.

wave plate, having both fast and slow axis of transmission. With a linearly polarized beam oriented in the direction of the fast axis, the polarization and overall coherence of the light would be preserved.

2 Goals

The goal of the project was to reduce the power fluctuation at 80 Mhz demodulation frequency which was predicted to be caused by AOM. In addition there was a problem in the polarization stability of the beam, which was thought to be caused by an optical fiber. The polarization would fluctuate in orientation and ellipticity when a slight stress was introduced to the fiber.

3 Experimental Set-Up

The initial condition of the setup was measured using a half-wave plate, polarizing beam splitter (PBS), and a power meter (PM100USB). The setup is shown in fig. 3. The initial measurement provided us with information on polarization and power fluctuations, as well as information on the direction and ellipticity of the beam. The measurement was performed on the beam right before it enters collimator of the AOM, and the reference beam as it exits the second collimator of the AOM. Each measurement was performed with and without polarizing beam splitter, as a way to distinguish polarization fluctuation from non-polarized power fluctuation. A reference beam with a stable linear polarization once coupled with a test beam will help us achieve a strong stable signal. Initially the power meter was used on the reflected and the transmitted sides of the beam splitter, but once it was observed that there is no significant differences in measurements between the two (besides 99 % and 96% efficiencies of transmitted and reflected respectively) only the reflect side was used for measurement. The half wave plate enabled measurement of polarization at different beam orientations by changing angle between beam and the polarizer.

Once it was identified that entering beam had some ellipticity, a quarter-wave plate along with half-wave plate was added to the setup. The PBS was placed at output collimator, and the angles of the two plates were varied to insure a stable linear beam output (figure 3).

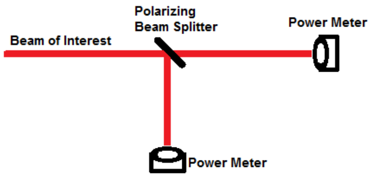

Figure 3: First set-up of the experiment.

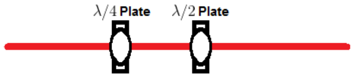

Figure 4: Addition of wave plates .

The fibers were tested with system being at initial condition, and using a fiber polarization controller (FPC560). The controller provided two levels of tensions to the fiber. At each level the ellipticity and the direction of the beam at the output collimator was measured using a half-wave plate, PBS and a power meter.

The amplifier was tested by connecting output to an oscilloscope . With built in fourier transform function in the oscilloscope we searched for strong frequencies that would may interfere with the desired frequency of 80 Mhz. The input gain was varied between 1 dBm and 10 dBm, and the input frequency was switched between 7 MHz and 80 MHz to segregate frequency dependent and independent noise.

The two AOMs were analyzed by observing a frequency response of each modulator. The input frequency was varied between 1MHz and 107 MHz, and the output power of the beam traveling through AOM was measured using the PBS and the power meter.

4 Results

Frequence response characterization of AOMs showed that the two AOMs had different optimal operating frequencies. Manufacturer labeled optima operating frequency was specified to be 80 +/- 1 Mhz. NIKHEF AOM at 79.3 Mhz showed to be well within that range; VIRGO AOM at 84.2 Mhz had an offset of close to 4 Mhz from the expected value. This discrepancy explains the reduced power transmittance of VIRGO AOM at 80 Mhz. The two AOMs otherwise behave similarly. (Fig 5)

By correcting the input beam with addition of waveguides and eliminating clipping of the signal we were able to half the power fluctuation. (Fig 6)

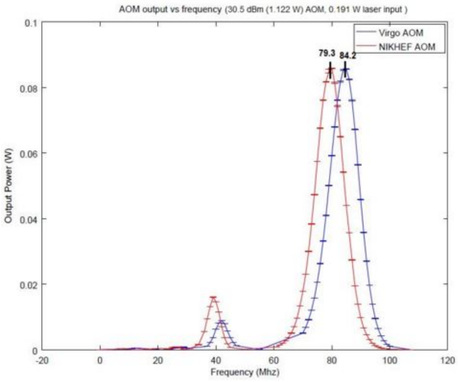

Figure 5: First set-up of the experiment.

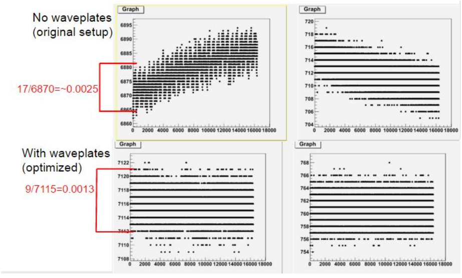

Figure 6: First set-up of the experiment.

5 Acknowledgments

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