LIGO-G050468-00-R

DESIGN AND CONSTRUCTION OF OPTICAL LEVER RECEIVER

ANALYZE, BUILD AND TEST A PROTOTYPE OPTICAL LEVER RECEIVER FOR LIGO

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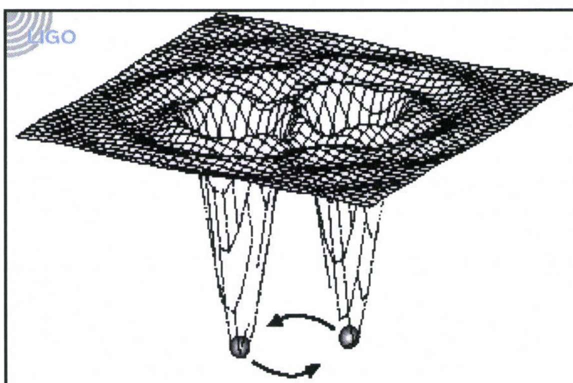
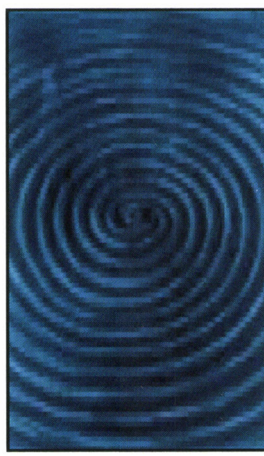
GRAVITATIONAL WAVES

Figure 1: *Gravitational Wave*

- Einstein posited that similar to accelerating charged particles produce electromagnetic waves, moving masses should also generate gravitational waves.
- Gravitational waves are ripples in the fabric of space and time produced by incidents such as collision of two black holes and supernova explosions in universe.



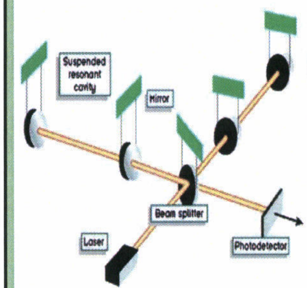
A binary system of compact massive objects rapidly orbiting each other produces ripples in spacetime.



- Gravitational waves travel at the speed of light and are neither scattered nor absorbed by dust.
- Reveals that it carries enormous new information about the universe.
- When gravitational waves passes through an object, it stretches that object's dimensions in one direction while shrinking it at right angle to the stretching.

LASER INTERFEROMETER GRAVITATIONAL OBSERVATORY

- LIGO is L-shaped architecture and by shooting lasers at each tunnel, LIGO can observe if the distance between the test masses in one arm is shortened while the other increases and shortly the opposite effect when it detects the gravitational wave.



- Mirrors in either end of the LIGO's 4-kilometer arms would move by only 10^-18 meters with respect to each other.
- There are different type of noise sources including seismic noise and thermal noise that can excite the system.

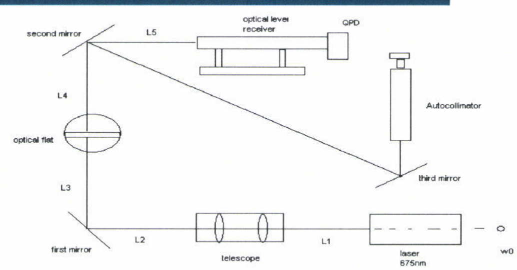
OPTICAL LEVER SYSTEM

- An optical lever system is used in LIGO for recording the angular positions of the main interferometer mirrors and for auxiliary damping.
- The current optical lever system uses reflection of collimated laser beam from the interferometer mirror onto a quad photodiode (QPD).

DRAWBACKS OF THE CURRENT OPTICAL LEVER SYSTEM

- The sensitivity of the current optical lever system depends on the length of the lever arms between the mirror and the QPD.
- Unable to differentiate the lateral and angular displacement of the mirrors .
- When the optical lever beam makes a large angle with respect to the normal of the mirror, the cross-coupling between the axial displacement of the mirror and the angular displacement can be problematically large.

EXPERIMENTAL OPTICAL LEVER SYSTEM



COMPUTER MODEL OF THE EXPERIMENTAL OPTICAL LEVER SYSTEM

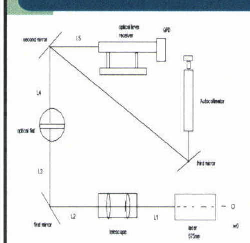
- The analysis uses the method of paraxial optics rays and ray matrices (ABCD) as applied to the Gaussian Beam.

$$M = \begin{bmatrix} 1 & 0 \\ \frac{n-n'}{Rn'} & \frac{n}{n'} \end{bmatrix}$$

Formula 1: *Refraction matrix for spherical surface where R is the radius of the surface and +R is for convex and –R for concave*

$$M = \begin{bmatrix} 1 & L \\ 0 & 1 \end{bmatrix}$$

Formula 2: *Translation Matrix where L is the distance*

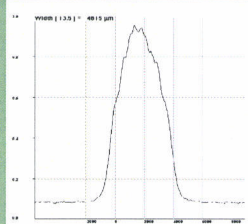


- The first step was to calculate the translation matrix from initial beam waist location to the first lens of the telescope.
- The ray matrix for the lenses was calculated using refraction matrix for spherical surfaces.
- ABCD matrix was calculated from the initial beam waist location to the QPD.

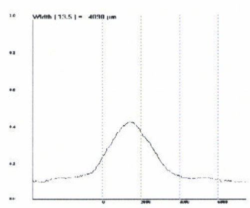
THE PURPOSE OF TELESCOPE

- A telescope of magnification factor 1.7 is used in between the laser and the first mirror to magnify the input optical beam size in the experimental optical system.
- The telescope was included in the computer model of the experimental optical system and the magnification factor by plotting magnification of the telescope as the function of the output beam spot size.
- The ideal output beam spot size for the experimental optical system is 4mm in diameter.

INPUT AND OUTPUT OPTICAL BEAM

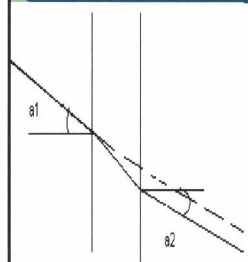


Input optical beam detected by the beam scanner



Output optical beam as detected by the beam scanner

OPTICAL FLAT

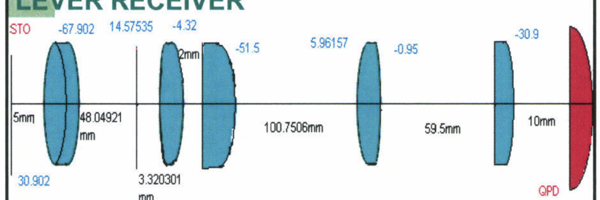


- When a beam passes through the optical flat, it changes only the height of the beam without affecting the angle.
- Once the prototype optical lever receiver is focused, the QPD should only measure the angular displacement of the beam and not the lateral displacement produced by the optical flat.

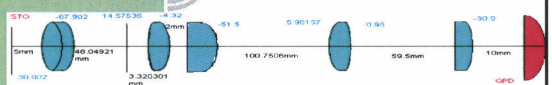
PROTOTYPE OPTICAL LEVER RECEIVER

- The optical lever receiver is a device that magnifies small displacement making possible to accurately measure the displacement.
- However, the prototype optical lever receiver is designed only to magnify small angular displacement without affecting the lateral displacement of the input optical beam.

DESIGNING THE PROTOTYPE OPTICAL LEVER RECEIVER

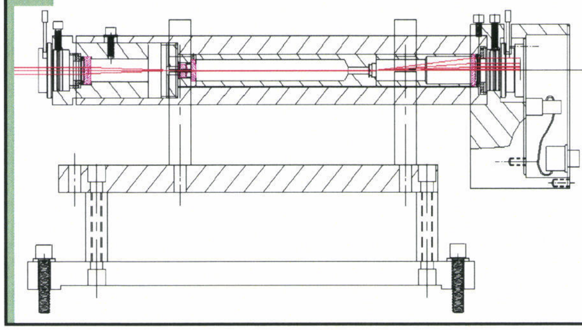


- The computer model of the prototype optical lever is designed from the surface data summary developed by Dr. Michael Smith using ZEMAX optical design program
- The Surface data summary provides description of the surfaces, its type, radius, thickness, material and diameter of the glass to be used.



- The system ray matrix for the first thick lens can be determined by multiplying the matrices in a reverse order i.e. by multiplying the refraction matrix for spherical surface 8 to translation matrix from surface 8 to surface 7 and then to refraction matrix of surface 7 and so on till surface 6.
- The focal length of the thick lens is inversely proportional to the value of C of system ray matrix of thick lens.
- Focal length= $\frac{-1}{C}$
- Using refraction matrix, translation matrix and ray matrix formulization from the surface 6 to QPD a computer model for the prototype optical lever receiver is designed in matlab.

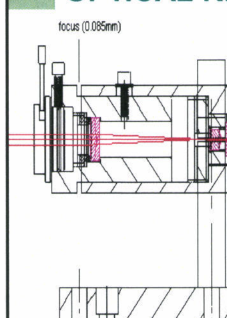
CONSTRUCTION OF THE PROTOTYPE OPTICAL LEVER RECEIVER



ALIGNMENT OF INPUT OPTICAL BEAM

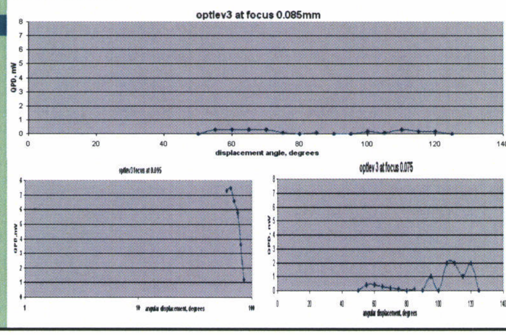
- With the help of the first mirror the input optical lever beam is made to hit the center of the prototype optical lever receiver.
- With the second mirror the beam is adjusted to travel parallel to the table by placing a screen at the far distance.
- The last three lenses of the prototype optical receiver is removed and the input beam is allowed to pass through the first two lenses.

FOCUSING THE PROTOTYPE OPTICAL RECEIVER



- The first method used was by measuring the output beam spot size with vernier calipers at a close distance and at far distance.
- The second method uses beam scanner which is connected to a computer.
- The final method is by laterally displacing the input optical beam using the optical flat.

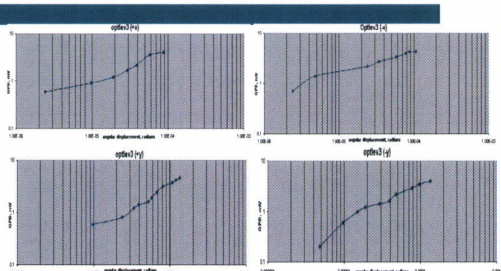
THE BEST FOCUS WAS FOUND TO BE AT 0.085mm



SENSITIVITY OF THE PROTOTYPE OPTICAL LEVER RECEIVER

- The angular deviation of the optical lever beam was measured using autocollimator.
- The oscilloscope and the voltmeter connected to the QPD measured the displacement voltage.
- The oscilloscope gives a voltage reading in a graphical format. The horizontal input angle gives a displacement in x axis and vertical input angle gives displacement in y axis.

SENSITIVITY OF THE PROTOTYPE OPTICAL LEVER RECEIVER



- The prototype optical lever receiver is sensitive up to the angular deviations of 1.8 arc seconds or 8.70E-05 radians.
- It can measure the displacement voltage accurately up to 4 milli - volts.

CONCLUSION

- The prototype optical lever receiver can be used to maintain the exact established angle of the suspended optics.
- It can be also used for rapid replacement and adjustment of the damaged or displaced core optics without its primary reference.
- It can also temporarily replace Wavefront sensor based alignment error signals if Wavefront system ceases to operate.

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