FUTURE PROSPECTS FOR GRAVITATIONAL WAVE EXPERIMENTS IN BRITAIN

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Abstract

A design for a laser interferometric gravitational wave detector of long baseline which is proposed to be built in Britain is discussed. Some aspects of experimental developments relevant to this are described.

Introduction

Development of a 10m arm length prototype laser interferometer for the detection of gravitational waves has been underway at Glasgow for approximately ten years. This work has led to a greater understanding of the techniques required to operate such detectors, and an amplitude sensitivity of $\sim 3 \times 10^{-18}$ in a kilohertz bandwidth has already been achieved. However theoretical considerations on sources of gravitational waves indicate that a much better sensitivity is required to be comparable with the predicted levels of radiation from various astrophysical sources. To consider possible ways of achieving the necessary sensitivity, we at Glasgow, in collaboration with B.F. Schutz at University College, Cardiff, and I. F. Corbett and colleagues at Rutherford Appleton Laboratory carried out a Design Study [1], completed in May 1986. The main conclusions of this study may be summarised as follows :

1) A strain sensitivity better than 10^{-22} for pulses of a few milliseconds duration is needed to give a reasonable probability of detecting gravitational waves.

2) A detector based on Fabry Perot interferometers with 1km arms or longer should be capable of attaining this sensitivity.

3) A suitable site for such a detector exists in Scotland.

In this talk we present some aspects of the design and discuss a possible site for such a detector, and refer to some of the recent work at Glasgow being carried out towards achieving the required design parameters.

Design Parameters of a Long Baseline Detector

The basic parameters of the proposed long baseline detector in Britain may be summarised as follows. We propose to build a vacuum system with two arms of 1km at right angles to each other, with the possibility of extending the arm length up to approximately 3km at a later date. The pipe diameter would be 36 inches and the vacuum 10^{-8} torr, probably provided by turbo-molecular pumps. Inside this vacuum system would be several interferometers - two full length and two half length making use of end-stations and mid-stations on each arm. Fabry Perot cavities formed between test masses of up to 1000kg would be used in the arms of each interferometer. The system would be illuminated by laser power of between 20 and 200W, either from a bank of argon lasers coherently locked together [2,3], or one or more Nd-YAG lasers, possibly frequency doubled. The mirrors forming the cavities would be of very high quality, with losses $<10^{-4}$. Recycling techniques[4,5] would be used to reduce the photon shot noise limited sensitivity. High Q suspensions ($Q \sim 10^8$) and high Q materials for the test masses ($Q \sim 10^6$) would be used to reduce thermal noise effects. Seismic isolation would be provided by a combination of pneumatic air mounts, isolation stacks and a double pendulum suspension for the test masses.

Detector Site

A suitable site for such a detector has been identified in Scotland. This site, at Tentsmuir Forest on the east coast with latitude and longitude 56.4° N and 3° W respectively, would allow a detector with arms oriented appoximately 4° west of north and 4° south of west of a length up to ~ 2.6km. This seems to be a reasonably quiet site for ground vibrations, the spectral density for ground displacement being approximately $10^{-7}/f^2$ m/$\sqrt{\text{Hz}}$ below 100Hz.

Recent Work on Some Aspects of the Design Parameters of a Long Baseline Detector

As well as work on the development of our 10m prototype detector, work on several aspects of the design of a long baseline detector has been, and is currently being, pursued at Glasgow. The areas of study include coherent addition of argon lasers, development of suitable suspensions for seismic isolation and the development of cavities of tunable finesse.

1) Coherent Addition of Argon Lasers

Research has been carried out during the last year on the phase locking of a high power argon laser (4W single line) to one of more modest power[3]. Both injection locking and homodyne phase locking techniques were developed and compared, and the advantages of injection locking in providing easier acquisition of lock were demonstrated. The light beams from the two lasers were added coherently and efficiencies of ~ 70% were obtained. Figure 1 shows a schematic diagram of the layout used for homodyne phase locking and the residual phase fluctuations between the two lasers after coherent addition using this technique.

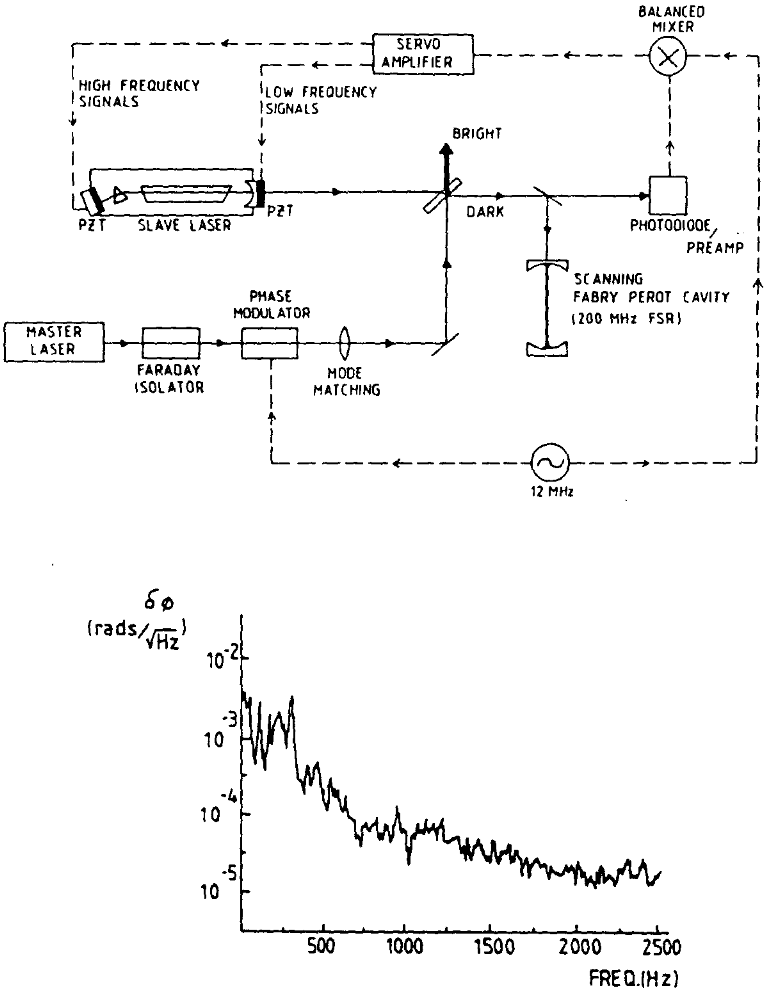

Fig. 1. ***Arrangement for phase locking and coherent addition, and a spectrum of residual phase fluctuations between the laser beams***

This work leads us to believe that the higher light powers which will be required to achieve the projected sensitivity of the proposed long baseline detector could be approached by addition of many argon lasers. However a considerable number of such lasers would be required, and they are expensive to run and maintain. With the advent of new laser and electro-optic technology the possibility of replacing such a laser system with a potentially more economical and reliable CW YAG system looks promising.

2) *Development of a Compound Suspension System*

We are currently investigating, both theoretically and experimentally, a balanced double pendulum system for seismic isolation.A schematic diagram of a prototype system is shown in figure 2. At present the distance between the test mass and a reference point is sensed by a Michelson interferometer arrangement and a feedback force is applied to the mass to keep its distance from the reference point constant. The feedback is applied between magnets mounted on the mass and coils mounted on another suspended mass as shown. By using this reaction mass, rather than attaching the coils directly to ground, one reduces direct coupling of ground vibrations into the feedback system. The reaction mass is however damped to the ground by another magnet and coil electronic feedback system of low bandwidth. Experimental results from this system are encouraging. The main feedback loop operates with a unity gain frequency of ~ 450Hz and a new upper normal mode resonance of ~ 200Hz, and both modes of the double pendulum are adequately damped. A more sophisticated feedback system, which incorporates control of orientation of the test mass and allows for feedback both to the test mass and to the upper suspended mass, is currently under development. The design of this system has been chosen to reduce the effects of unwanted electromagnetic damping and also of shot noise in the current through the feedback coils, both of which effects could potentially introduce excess motion of the test mass.

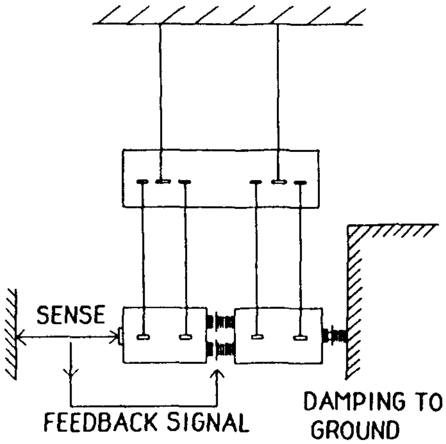

Fig. 2. Schematic diagram of a prototype balanced double pendulum system for seismic isolation

3) *Development of Cavities of Tunable Finesse*

It will become important for future interferometric gravitational wave detectors to be able to balance the responses of the two cavities to the phase fluctuations of the highly stabilised laser light. This requires that the finesse of one of the cavities should be tunable by changing the transmission of one of its mirrors. As a first step towards this, a cavity has been set up with its rear mirror consisting of a pair of mirrors whose separation can be controlled by means of a piezoelectric transducer (see figure 3). This rear combination acts as a mirror of variable transmission. In operation the illuminating laser is phase modulated at two frequencies, 12MHz and 100MHz. The laser is frequency locked to the cavity formed by the input mirror and the closer of the rear mirrors using an r.f.reflection locking scheme[6] based on the 12MHz modulation. The 100MHz modulation is used in another reflection locking loop to servo control the distance between the rear mirrors. This frequency is chosen to coincide with the free spectral range of the cavity to which the laser is locked, and thus the 100MHz modulated light is transmitted through to the rear cavity. By varying the locking point of the 100MHz control loop, and hence the transmission of the rear cavity, the finesse of the whole system can be varied by more than a factor of two. The decision to make the rear combination the "mirror" of tunable transmission was determined by the availability of suitable mirrors in the laboratory. In practice, in an interferometric detector it would be better if the input mirror was of variable transmission, and this will be addressed in future work.

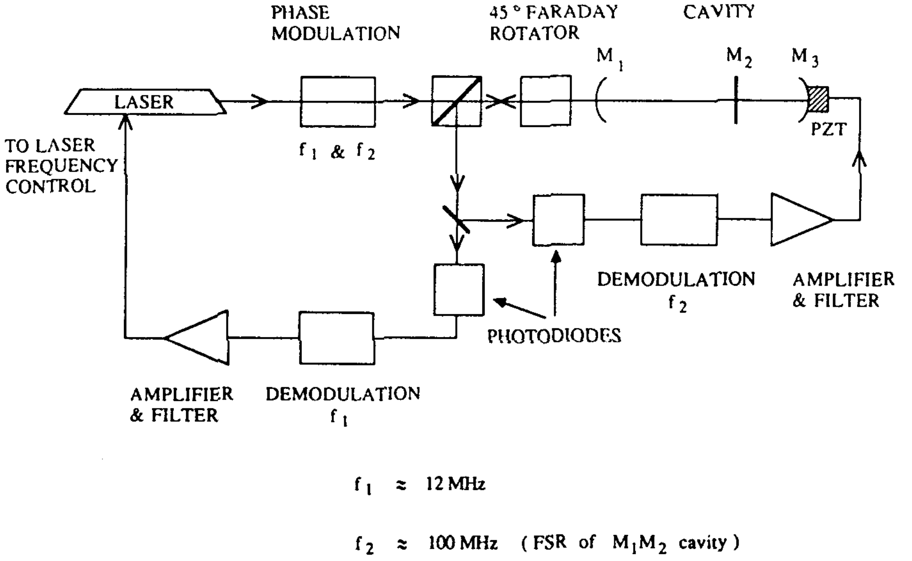

Fig. 3. Test arrangement for a cavity of tunable finesse

Conclusion

Laser interferometric detectors of kilometre scale have considerable promise for the detection of gravitational waves. Much development work is still to be carried out, but experimental progress with both the prototype detector, and in the areas described above is encouraging.

References

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