Detection of Gravitational Waves with High Frequency Square Waves from Crystal Oscillator

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Abstract

We propose novel technique for detecting gravitational waves using setup like LIGO and a robust square wave generator as source of waves generating stable square waves with high frequency using an appropriate crystal oscillator. This change in source will prove very effective for the process of detecting gravitational waves because even if with extremely small change in phase of two interfering waves reaching the beam splitter there will be detectable change in the amplitude due to the suddenly rising sharp edge of these almost but not exactly destructively interfering waves upon the passing of gravitational waves. This idea of achieving detectable amplitude of a portion of signal reaching the detector will make it possible to record extremely small phase difference generated due to passing of some gravitational waves through apparatus in the two interfering square wave beams. The change suggested in the gravitational wave detection experiment using high frequency well regulated square wave source will produce the following effects. When no gravitational waves will reach the apparatus the square waves from crystal oscillator will move towards beam splitter and will split into two square waves heading towards reflectors kept orthogonally to each other at equal distance from beam splitter at the ends of two interferometer arms and these waves will reflect back to interfere destructively so that no signal will reach the detector. But when some gravitational waves will be reaching the apparatus and further suppose there is squeezing along arm A and stretching along arm B of the interferometer as an effect these gravitational waves will be producing the (very small) phase difference in the interfering square waves reaching back to beam splitter. Now, however small may be this phase difference its undetectably small amount still will remain detectable because of sharp rise and fall of amplitude at edges of square wave because of its typical shape and so some detectable part of these interfering waves will pass towards detector to offer a conclusive proof for the existence of gravitational waves!

1. **Introduction:** Experimental detection of gravitational waves is a big challenge of this time and enormous efforts are on world over by people working in highly sophisticated gravitational wave detection laboratories. Gravitational wave laboratories will be leading laboratories in the coming future to offer new important insights in our study of large scale phenomena. Detection and study of gravitational waves of different types and of different intensity and frequency will make revolutionary contributions to our knowledge about galactic dynamics. It will add greatly to our knowledge about astrophysical sources and about processes driven by strong gravitational fields. Objects of fundamental importance, such as astrophysical black holes, merge and radiate with luminosity larger than the entire electromagnetic universe, and these events will become clearly detectable only through a tool for detection of gravitational waves that are mainly associated with detectable amplitude with such unimaginably huge events [1]. When observed with gravitational waves these intrinsically interesting astronomical sources such as massive black holes and their merger, extremely compact stellar binaries and their collisions, supernovae events etc will surely yield many new surprises. Thus, the discovery potential associated with detection of gravitational waves is immense.

   Gravitational radiation was detected indirectly in 1974 by J. Taylor and R. Hulse, who observed its effects on the orbital period of a binary system containing two neutron stars, one of them a pulsar (PSR 1913 + 16). Efforts to detect gravitational waves directly have been severely challenged by the extreme weakness of the waves impinging on the Earth. However, as the 21st century begins, observations of the gravitational waves from astrophysical sources such as black holes, neutron stars, and stellar collapse are expected to open a new window on the universe [2].

   There are two major gravitational wave detection concepts: acoustic and interferometric detection [3]. The acoustic method deals with a resonance response of massive elastic bodies on gravitational wave excitations. Historically the acoustic method was proposed first by J. Weber [4] where he suggested to use long and narrow elastic cylinders as Gravitational Wave Antennas. Although a significant progress has been achieved in fabrication and increasing sensitivity of such type of detectors [4, 5, 6] the interpretation of obtained data is still far to claim undoubtedly the detection of gravitational waves. On the other hand a considerable attention has been shifted recently to more promising interferometric detection methods. The interferometric gravitational wave detector like Laser Interferometer Gravitational Wave Observatory (LIGO) and VIRGO [7, 8] represents a Michelson interferometer with a laser beam split between two perpendicular arms of interferometer. The principles of operation of such type of detectors are reviewed in Refs [9, 10, 11, 12, 13]. The action of gravitational waves on an interferometer can be presented as relative deformation of both interferometer arms. A gravitational wave with dimensionless amplitude h induces the opposite length changes $\frac{\delta l}{l} = \frac{1}{2} h \cos(\Omega t)$ in each arm of the Michelson interferometer, where l stands for the length of each of the arm, Ω for the gravitational wave frequency. These length changes produce opposite phase shifts between two light beams in interferometer arms, when interference occurs at the beam splitter of Michelson interferometer. The resulting phase shift of a single beam of light spending time τ in the interferometer can be written as [13]

$$\delta\phi = h\frac{\omega}{\Omega}\sin\left(\frac{\Omega\tau}{2}\right), \qquad (1)$$

where, ω is the light frequency. This phase shift results an intensity signal change of the light from interferometer beam splitter hitting the photo detector.

The main problem of the acoustic and interferometric methods that they both deal with gravitational waves with extremely small amplitudes of the order $h \sim 10^{-21}$ [14] reached the Earth from deep space. One can see from equation (1) that for gravitational wave frequencies in the 1 kHz range, $\Omega \sim 10^3$ Hz, and for the light in visual frequency range, $\omega \sim 10^{14}$ Hz, one has the maximum phase shift of the order $\delta\phi \sim 10^{-10}$ for interferometer arms length of the order 150 kilometers. Such extraordinarily weak effect requires exceedingly high detector sensitivity for both acoustic as well as interferometric detectors.

2. **The Novel Technique:** As seen above one requires extraordinarily high sensitivity of detectors to conclusively capture signal called gravitational wave and this may be one of the important reasons that we have not yet succeeded in this task even though many gravitational waves would have passed through our apparatus installed at different locations.

In this paper we suggest a new idea of using as source a square wave generator generating stable high frequency square waves from a crystal oscillator. This change in the source will cause passing of detectable value of the part of interfering square waves due to the typical steep rise and fall in the amplitude of waves at the locations of completion of distance equal to wavelength. Due to this typical shape of waves the undetectably small phase difference created in the interfering waves reaching the beam splitter due to passing of gravitational waves in the beams reflected back from two perfect reflectors, fixed at ends of two orthogonal interferometer arms, due to which these beams come back to interfere almost destructively at beam splitter will produce detectable portion of amplitude reaching the detector. We take high energy well regulated square wave generator as new source and perform usual experiment. Now, suppose when the beams of square waves were running through two mutually orthogonal arms and were coming back to beam splitter there was squeezing in the arm, A say, of the interferometer and reciprocally suppose there was stretching in the interferometer arm, B say, of the interferometer. As an effect of this specially chosen source generating square waves the phase difference, however small it may be, will produce detectable overlap in the interfering square waves because of their typical shape having a sharp rise, equal to full amplitude of the waves. It will cause reaching of sufficient amplitude towards detector which essentially will lead to reaching of detectable amplitude at the detector. This will give us a confirmation that though the phase difference is extremely small still our new choice of the shape of the waves makes it detectable to our instrument and thus will give a confirmation that beams are in fact not interfering destructively as they are sending in effect sizable amplitude towards detector.

The main idea in brief behind the suggestion in this paper is to capture the undetectably small phase difference that should result due to passing of gravitational waves by making it sizable by choosing the square shape for the waves from the source. Thus, we are suggesting a way out to achieve sizable value of the amplitude of waves reaching the detector by choosing typical square shape for the signal from the source to make the undetectably small phase difference detectable.

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