RSE Experiment

Kentaro Somiya,[1] Peter Beyersdorf,[2] and Seiji Kawamura[2]
(1) Dept. of Frontier Sciences, Univ. of Tokyo, Kashiwa, Chiba 277-8562, Japan
(2) National Astronomical Observatory, Mitaka, Tokyo 181-8588, Japan

Abstract

For the next-generation gravitational wave detectors like Advanced-LIGO and LCGT, quantum noise is the most limiting opponents against the gravitational waves. To detune the interferometer and to enhance the signal in a particular frequency band is a way to reduce quantum noise, which will be employed in next generation detectors. A detuned condition is realized with an additional mirror at the signal port, which forms a compound cavity with the arms. In this cavity, signals in a particular frequency band are extracted from the arms, circulating within the additional cavity. This system is called (detuned) Resonant Sideband Extraction (RSE). We have constructed a 4m prototype of the RSE system to prove the physics and to ensure the control scheme before large-scale interferometers.

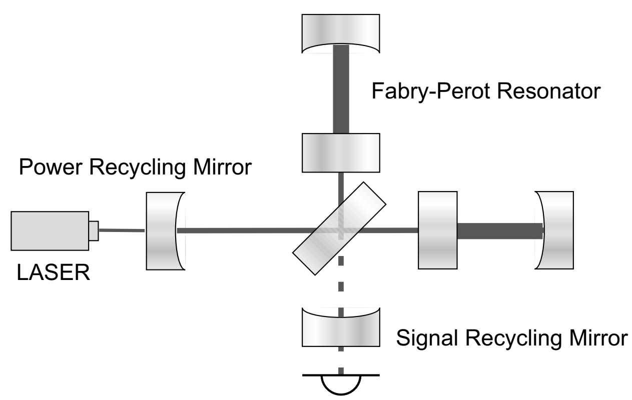

Fig. 1. Signal-enhancement techniques in a gravitational wave detector.

Gravitational waves can be detected by Michelson interferometer in which the differential motion of the two end mirrors appears as a signal to the anti-symmetric port that is kept dark fringe to reduce the influence of the shot noise (Fig.1.). There are three ways to increase the signal of the detectors: (i) to use high power laser or to use Power Recycling technique so that the incident light is increased, (ii) to employ Fabry-Perot resonator in both arms of the interferometer

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so that the power and the signal in the cavities are increased, (iii) to add a Signal Recycling Mirror (SRM) at the dark port to increase the signal. Current detectors have had (i) and (ii), and next-generation interferometers will install (iii) in addition to the other two techniques.

RSE is a combined technique of (ii) and (iii). While Signal Recycling (SR) is realized with the resonance of SR cavity, which consists of SRM and two front mirrors, and will enhance the signal for lower frequencies, RSE is done with the anti-resonance of SR cavity and will enhance the high frequency signal (Fig.2.). On the other hand, high-finesse Fabry-Perot cavities will enhance the low frequency and reduce the high frequency signal since the too much circulation will cancel the signal in the arms. Consequently, the combination of RSE and high-finesse cavities realizes the same frequency response against the signal that can be accomplished with a high power laser.

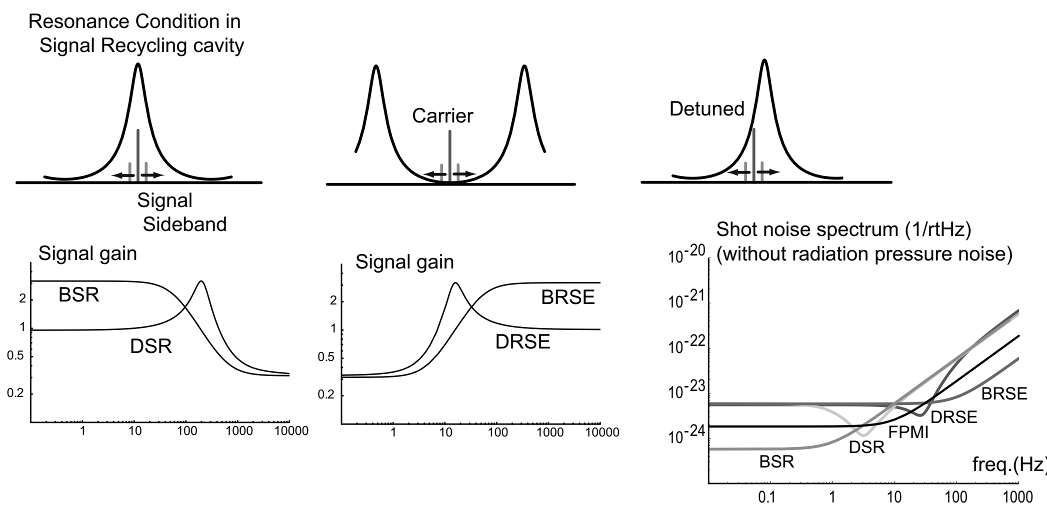

Fig. 2. Resonant condition and signal gain of SR/RSE and the detuned cases.

Moreover, if SRM is in a non-resonant position, which is called detuned case, the signal is enhanced in a narrow band, and then the sensitivity can be improved in particular frequencies [1]. This detuned-RSE gives the best signal-to-noise ratio to the gravitational waves from the neutron star binaries and should be installed in next-generation interferometers. We have built a 4m prototype detuned-RSE interferometer in National Astronomical Observatory in advance of larger scale interferometers.

In the SR/RSE interferometer, the signal coming out from the Michelson is reflected by SRM and reinjected to the interferometer. While the reflected light does not couple with the incident laser beam for the broadband case, it

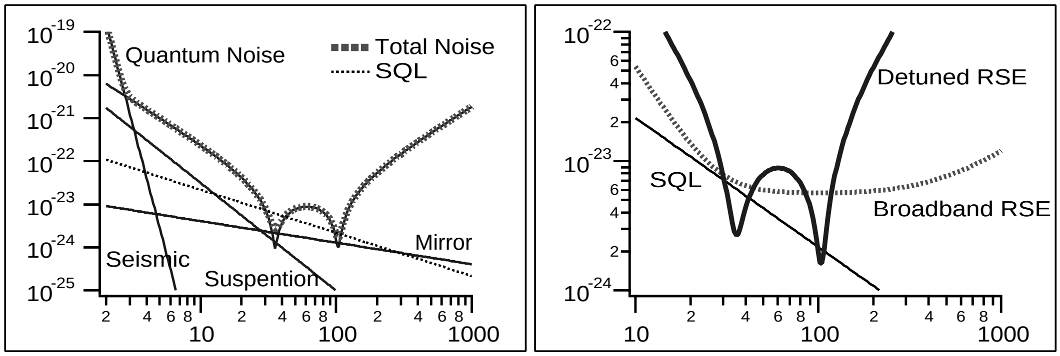

Fig. 3. Expected quantum noise for detuned RSE with LCGT parameters. Quantum noise limits the sensitivity and the optical spring can be seen as a total noise spectrum, which is partially beyond SQL.

does couple with the beam for detuned case and causes the radiation pressure effect. This effect, called optical spring [2], can enhance the signal at a different frequency from SR/RSE resonance as is shown in Fig.3..

While the broadband SR/RSE cannot circumvent the Standard Quantum Limit (SQL), which is defined by the sum of shot noise and radiation pressure noise [3], the detuned configuration can overcome SQL even with the conventional photodetection using Schnupp modulation-demodulation scheme [4]. This is because the high power laser light does not increase radiation pressure noise but also enhances the radiation pressure signal.

The experimental setup of our prototype is shown in Fig.4.. All the optical components are suspended by a single pendulum and are in a vacuum system. Arm length is 4m, finesse of the arm cavity is about 2000, SRM reflectivity is 80%, and the laser power is 500mW. There is no Power Recycling and total four degrees of freedom is controlled by one modulation and higher order demodulations; $L_\pm$ for the common and differential motion of the two arms, l_- for the differential motion of the central Michelson, and l_s for the SRM motion. From the bright port, $L+$ is obtained by demodulating by $2f_m$, where f_m is the modulation frequency (17.25MHz), ℓ_- is obtained by double demodulation of f_m and $2f_m$, and ℓ_s is obtained by demodulating by $3f_m$. From the dark port, $L-$ is obtained by demodulating by $2f_m$.

Since the optical spring is a classical effect, the two-peak signal enhancement can be seen by transfer function measurement, which is the goal of our experiment. The lower peak frequency of the optical spring is proportional to I/m, where I is the laser power and m is the mirror weight [5]. All of the optical components of out experiment weighs only 40 grams which is about 1000 times lighter than that in a large scale detector and the peak frequency of this setup

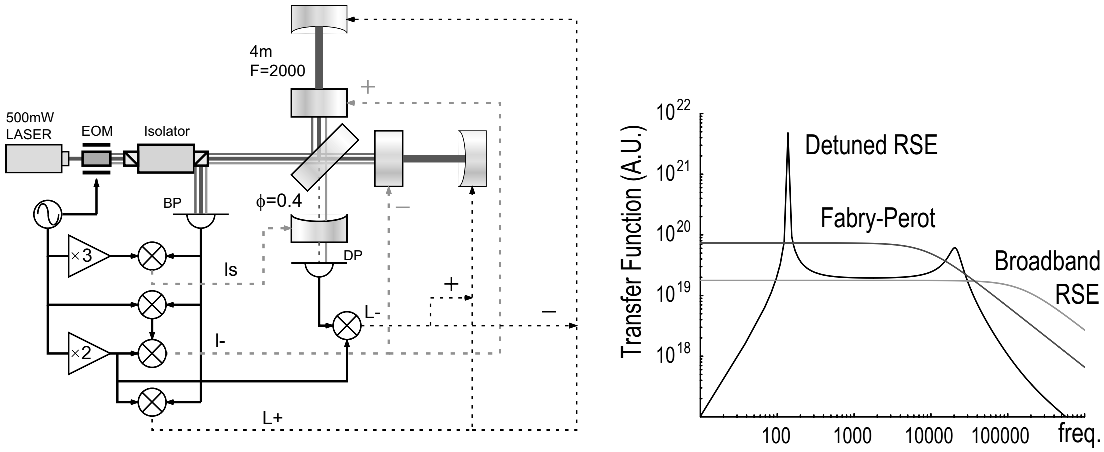

Fig. 4. The experimental setup and the control scheme of the 4m prototype RSE (Left). Transfer function of $L-$ (Right).

corresponds to that with a 1000 times higher power laser wand the same weight of mirrors. Finally the higher peak frequency is 30kHz and the lower is 100Hz with the detune phase of 0.4 rad from broadband RSE.

In conclusion, we have built the 4m prototype RSE interferometer and now conducting the experiment, and we have derived that the radiation pressure effect is measurable in our experiment due to its small masses.

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