LIGO-T000080-00-D

Study of power recycling of a Fabry-Perot-Michelson interferometer

MASAKI ANDO, YING LI, KEITA KAWABE, and KIMIO TSUBONO
Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113, JAPAN

Abstract

In a power-recycled Fabry-Perot-Michelson interferometer, it is difficult to extract the four signals necessary for the longitudinal control independently. However, by the proper adjustment of the optical parameters, these signals are extracted in a good separation. In this article, we will describe this idea and the experiment to evaluate it.

1. Introduction

Laser interferometric gravitational wave detectors are under construction by LIGO, VIRGO, GEO and TAMA. All of them except GEO600 will be Michelson interferometers in which the mirrors are replaced by Fabry-Perot arm cavities to enhance the effective arm length. The power recycling technique will be applied to these interferometers in order to improve the sensitivity limited by the shot noise.

To operate a power-recycled Fabry-Perot-Michelson interferometer at the highest sensitivity, two arm cavities and the recycling cavity must be in resonance with the incident laser beam, and the interference fringe must be dark at the output port of the interferometer. Thus, in order to keep this operational point, it is necessary to control four degrees of freedom; the changes of the arm-cavity length (δL_1, δL_2) and the length between the recycling mirror and the front mirrors (δl_1, δl_2).

2. Signal extraction schemes for power-recycled Fabry-Perot-Michelson interferometer

Using the technique called frontal modulation (pre-modulation)[1–4] (Figure 1), the four signals which are necessary for the control of an interferometer are extracted as the difference and the sum of the motions of the arm cavities ($\delta L_- = \delta L_1 - \delta L_2$, $\delta L_+ = \delta L_1 + \delta L_2$), the differential motion of the front mirrors ($\delta l_- = \delta l_1 - \delta l_2$), and the change of the recycling cavity length ($\delta l_+ = \delta l_1 + \delta l_2$). In the general configuration, the reflectivity of the recycling mirror is chosen to be equal to, or a little less than, the reflectivity of the Fabry-Perot-Michelson part of the interferometer in order to obtain a large recycling gain. However, it is difficult to extract the δl_+ signal independently of the large δL_+ signal in this condition. With the mixing between signals, the design of the control system can be crucial in order to maintain the stability of the control loop and the sensitivity of the interferometer.[1,2] Therefore several methods to extract the δl_+ signal have been proposed or tested; such techniques as the frequency-shifted sub-carrier,[3,5] the mechanical modulations,[6] and the multiple phase modulations.[7] There is also the idea to obtain the well-separated signals using the linear combinations of the mixed signals.

On the other hand, these four signals are separated remarkably well when the reflectivity of the recycling mirror is set to maximize the gain of the sidebands, not

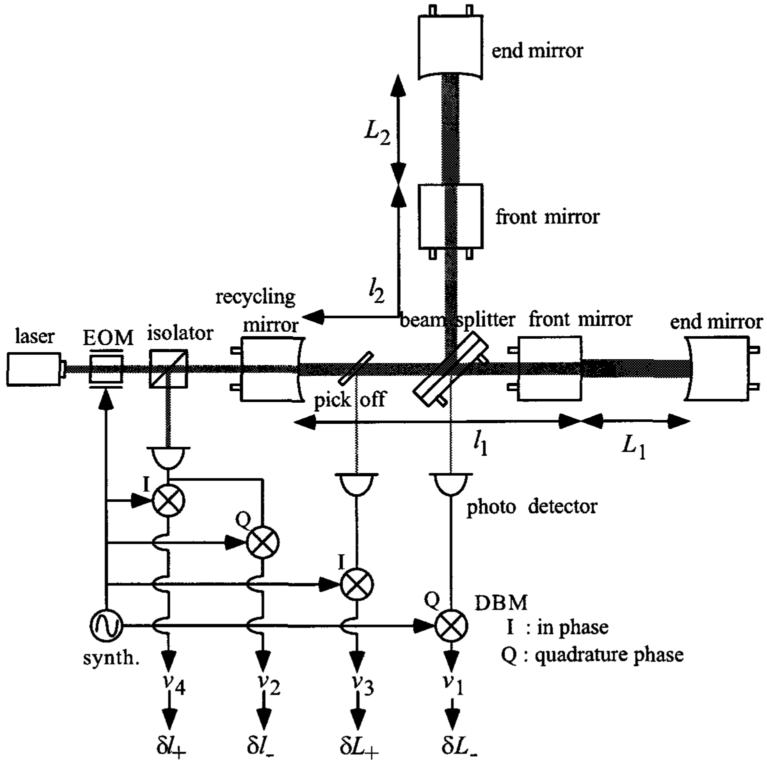

Figure 1: Signal extraction scheme for a power-recycled Fabry-Perot-Michelson interferometer.

the carrier. In other words, a good separation between signals can be obtained when the reflectivity of the whole interferometer is chosen to be zero for the sidebands, and non-zero for the carrier. Although the recycling factor decreases a little in this case, it can still be a reasonable value, 99% of the maximum value with the TAMA300 parameters. This method has the advantage of simplicity; it calls for no additional modulation, no signal-decoding system, and fewer constraints for the longitudinal control system.

3. Experiment on 3m Fabry-Perot-Michelson interferometer

We are researching this signal extraction method with 3m Fabry-Perot-Michelson interferometer in the University of Tokyo.[8] The mirrors and the beam splitter of this prototype interferometer are all suspended independently, and the main part of the interferometer is housed in a vacuum system. The length of the arm cavities is 3m, and the finesse of them are about 230. As a light source, a laser-diode-pumped Nd:YAG laser (LIGHTWAVE, 124-1064-050) is used. The reflectivity of the recycling mirror is 91%.

Table 1 shows the sensitivity of the signals to the motions in the four degrees of freedom calculated using the parameters of 3m Fabry-Perot-Michelson interfer-

	δL_-	δl_-	δL_+	δl_+
v_1	1	6.2×10^{-3}	0	0
v_2	3.6×10^{-5}	5.8×10^{-3}	0	0
v_3	0	0	0.51	2.6×10^{-2}
v_4	0	0	2.9×10^{-4}	4.5×10^{-2}

Table 1: Sensitivity of the signals to the motions in the four degrees of freedom.

ometer. These values are normalized so that the sensitivity of the v_1 signal to δL_- motion is equal to unity. The diagonal values are main signals needed for the control of the interferometer. The off-diagonal values represent the mixing of unnecessary signals, and they are less than 1% of the main control signals. According to a calculation, the recycling factor is 3.5, which is 78% of the value when the reflectivity of the recycling mirror is chosen to maximize the recycling gain; these values are sufficient because the main purpose of this experiment is to investigate the signal extraction method.

3m Fabry-Perot-Michelson interferometer has been already operated under the recombination configuration without the recycling mirror, and almost all of the noise sources has been identified. The recycling mirror has been installed and we are testing the lock acquisition of the power recycling with Fabry-Perot arm cavities.

Acknowledgments

A part of this research is supported by Research Fellowships of the Japan Society for the Promotion of Science for Young Scientists.

References

1. M.W.Regehr, *'Signal Extraction and Control for an Interferometric Gravitational Wave Detector'*, Ph.D thesis, California Institute of Technology (1994).
2. M.W.Regehr, F.J.Raab, and S.E.Whitcomb, *Optics Letters* **20** (1995) 1507.
3. R.Flaminio and H.Heitmann, *Physics Letters* **A214** (1996) 112.
4. , D.Babusci, H.Fang, G.Giordanp, G.Matone, L.Matone, V.Sannibale, *Physics Letters* **A226** (1997) 31.
5. J.Giaime, *'Studies of Laser Interferometer Design and a Vibration Isolation System for Interferometric Gravitational Wave Detectors'* , Ph.D thesis, Massachusetts Institute of Technology (1995).
6. M.Shiratsutsi, *'Control of the Coupled Cavity'* Master thesis, University of Tokyo (unpublished) (1994).
7. S. Akahane, *'Control of a Coupled Cavity Using a Multiple Phase Modulation'* Master thesis, University of Tokyo (unpublished) (1997).
8. K.Kawabe, S.Nagataki, M.Ando, K.Tochikubo, N.Mio, and K.Tsubono, *Applied Physics* **B62** (1996) 135.