# EXPERIMENTAL INVESTIGATION OF A CONTROL SCHEME FOR A TUNED RESONANT SIDEBAND EXTRACTION INTERFEROMETER FOR NEXT-GENERATION GRAVITATIONAL-WAVE DETECTORS


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**Our main goal is to detect gravitational waves**

Currently several gravitational wave detectors are being operated in the world.

In order to increase the chance of detecting the gravitational waves, their sensitivities need to be increased.

**Detectors need to be as sensitive as possible**

Resonant Sideband Extraction (RSE) technique will be used in some next-generation interferometers, such as Adv.LIGO and LCGT, to enhance their sensitivities.

**We have a plan to build the LCGT interferometer**

LCGT will use tuned RSE configuration, and Adv. LIGO will use detuned RSE configuration.

## MOTIVATION OF THIS PROJECT

A control scheme for a tuned RSE needs to be developed for the LCGT. Moreover, it could serve as a backup design for Adv.LIGO which will use tuned RSE configuration.

Testing the control scheme with a prototype interferometer to demonstrate the control of the tuned RSE for LCGT is necessary.

## Progress: We have…

### 2005

**Developed a control scheme**

- Single modulation and demodulation for Fabry-Perot arms
- Double modulation and demodulation for the central part

### 2006

**Designed and built the prototype RSE interferometer.**

**Started the 4m RSE interferometer experiment.**

- Fabry-Perot Arm length is 4m
- Main optics are suspended from a double pendulum system
- Built inside NAOJ's campus, Tokyo.

### 2007

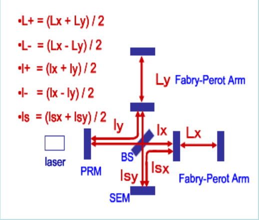
**Locked the central part in March**

**Locked the suspended Broadband RSE interferometer in July!**

## Control Scheme

### What to control ?

There are 5 degrees of freedom (DOFs) to be controlled




### …And How ?

Fabry-Perot arms: Single modulation and demodulation

Relatively easy to obtain clear control signals bcause the Fabry-Perot arms have high finesse

Central part: Double modulation and demodulation to avoid using carrier which contains mainly the arm signals. Two pairs of sidebands are pruduced by phase modulation (PM), and amplitude modulation (AM) .

Control signals for the 3 DOFs mix each other and it complicates the control. In order to make it as simple as possible, our control scheme uses the two sidebands as follows.

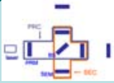
Michelson Asymmetry: **dl = ly - lx**

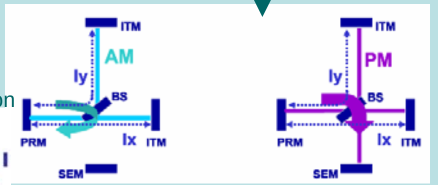
For fPM (17.25MHz), $dl/\lambda_{PM} = 1/2$

For fAM (103.5MHz), $dl/\lambda_{AM} = 3$ (f2 = 6×f1)

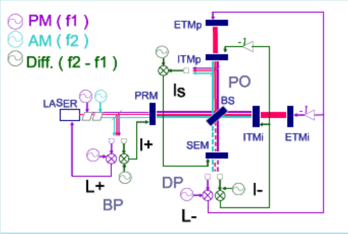
→PM Completely transmit through Michelson
PM resonant inside PRC + SEC

→AM Conpletely reflect from Michelson
AM resonant inside PRC




The control signals for the 5 DOFs are obtained from each detection port as shown below.




The signal matrix: A linearly independent signals can be obtained, with which the control is possible.

| | $L_+$ | $L_-$ | $l_+$ | $l_-$ | $l_s$ |
|---|---|---|---|---|---|
| BP | 1 | $7.6\ e^{-6}$ | $-2.6\ e^{-2}$ | $5.9\ e^{-4}$ | $1.3\ e^{-2}$ |
| DP | $-4.9\ e^{-8}$ | 1 | $3.2\ e^{-8}$ | $1.3\ e^{-2}$ | $4.6\ e^{-8}$ |
| BP | $-4.9\ e^{-2}$ | $-1.1\ e^{-4}$ | 1 | $-8.8\ e^{-3}$ | $-5.3\ e^{-1}$ |
| DP | $-1.0\ e^{-4}$ | $7.6\ e^{-2}$ | $1.4\ e^{-3}$ | 1 | $1.4\ e^{-5}$ |
| PO | $-1.5\ e^{-1}$ | $-1.2\ e^{-2}$ | 1.1 | $-2.2\ e^{-2}$ | 1 |

**In addition, we have developed a scheme to Optically Diagnolized Signal Matrix**

Possible Advantages:

Better S/N, Simpler lock acquisition, More robust control…

**The Delocation Scheme**


The operation will introduce a phase shift in the f 2 demodulation phase

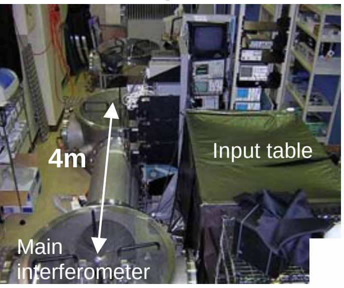
The diagnolized signal matrix:

| | $l_+$ | $l_-$ | $l_s$ |
|---|---|---|---|
| PO | 1 | $-4.3\ e^{-3}$ | $-7.7\ e^{-8}$ |
| DP | $2.2\ e^{-3}$ | 1 | $-1.9\ e^{-6}$ |
| PO | $-5.7\ e^{-6}$ | $4.9\ e^{-7}$ | 1 |

The sensing matrix for the 3 DOFs can be diagnolized.

**The delocation technique is currently not adapted, and will be tested in the future**

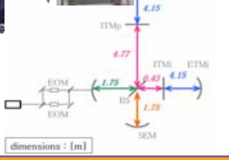
## Experimental Setup





Double suspension system

Uses Eddy current damping.




Optical Layout: Mach - Zehnder interferometer to avoid creating sidebands of sidebands

## BROADBAND RSE LOCKED!

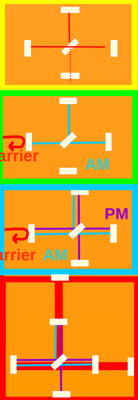
LOCK state

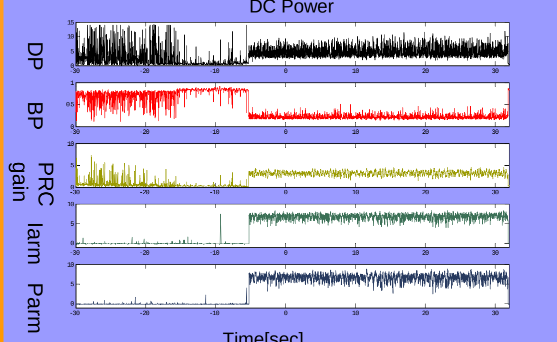
1: l- locked

2: l-, l+ locked

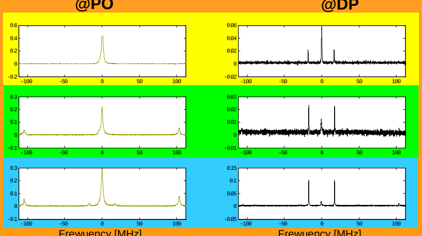
3: l-, l+, ls locked

4: RSE locked




Optical Spectrum Analyzer Output




CCD image when RSE is locked


Next step is to lock the arms with L+ and L- signal, which are currently controlled individually.

## RESULTS

- The Broadband RSE has been locked successfully with suspended optics
- The LCGT control scheme was demonstrated successfully.