

Abstract

Going to make LIGO the best possible ever.

Adaptive Mode Matching in Advanced LIGO

Thomas Vo

Spring 2017

Preface

The era of gravitational waves astronomy was ushered in by the LIGO (Laser Interferometer Gravitational-Wave Observatory) collaboration with the detection of a binary black hole collision (Detection paper). The event that shook the foundation of space-time allowed mankind to view the cosmos in a way that had never been done previously.

Contents

Preface	3
1 Introduction	7
1.1 Gravitational Waves	7
1.2 The LIGO Instrument	7
1.2.1 Dual-recycled Fabry-Perot Interferometer	7
1.2.2 Limitations	7
1.3 Squeezed States of Light	7
1.4 The Effects of Mode-Matching	7
2 Modeling Mode-Matching	9
2.1 How it works	9
2.2 Defining Mode-Matching	9
2.2.1 Misalignment	9
2.2.2 Waist Size and Location	9
2.3 Finesse Simulations	9
2.3.1 ALIGO Design with FC and Squeezer	9
2.3.2 Looking at just Modal Change	9
2.3.3 QM Limited Sensitivity	9
2.4 Results	9
3 Mode Matching Cavities at Syracuse	11
3.1 Adaptive Mode Matching	11
3.2 Actuators	11
3.2.1 Thermal Lenses	11
3.2.2 Translation Stages	11
3.3 Sensors	11
3.3.1 Mode Converters	11
3.3.2 Bullseye Photodiodes	11
4 Mode Matching Cavities at LIGO Hanford	13
4.1 Beam Jitter	13
5 High Power Commissioning	15
5.1 Effect on Mode-Matching	15
6 Solutions for Next Generation Detectors	17

Chapter 1

Introduction

1.1 Gravitational Waves

In 1915, Albert Einstein published his theory of general relativity.

The seminal equation in this theory is:

Soon after 1918, Einstein developed a linear theory of gravity that allowed the creation of gravitational waves. There was a lot of controversy about whether gravitational waves arise from a physical effect or due to an arbitrary gauge transformation. Felix Pirani was able to solve the puzzle by attacking the problem in a

Gravitational waves are the

Even with the theoretical formulation of gravitational waves resolved, the detection of gravitational waves by ground-based detectors was still a controversial topic among scientists in the field. This was due to the incredible amount of accuracy needed to actually measure strain.

Even with some of the most energetic events known to humanity such as the merger of neutron stars and black holes, the amount of strain expected is on the order of 10^{-24}

1.2 The LIGO Instrument

In the simplest form, the LIGO instrument is an incredibly large Michaelson interferometer. If we imagine the interferometer as a measure of the differential arm length, it becomes a natural way of detecting gravitational waves.

The LIGO instruments are considered dual-recycled Fabry-Perot interferometers

1.2.1 Dual-recycled Fabry-Perot Interferometer

A Fabry-Perot cavity is a Power Recycling If the interferometer is operating such that the 4 km arms are exactly different in arms a pi over two times the wavelength, then the intensity of the light at antisymmetric port will be close to null. This means the power from the arms will

Signal Recycling⁹

1.2.2 Limitations

Noise budget: - Quantum Noise - Seismic - Thermal Noise

1.3 Squeezed States of Light

The Quantum Noise is a fundamental source that can be helped by squeezing.
This is Squeezing (Caves, Dwyer, Kwee, Miao)

1.4 The Effects of Mode-Matching

Theory section of modematching.

An example of how mode-matching can affect the overall sensitivity.

Chapter 2

Modeling Mode-Matching

2.1 How it works

2.2 Defining Mode-Matching

2.2.1 Misalignment

Anderson, Kognelik and Li
Guido Paper

2.2.2 Waist Size and Location

Anderson, Kognelik and Li
In contrast to the misalignment orthogonality

2.3 Finesse Simulations

2.3.1 ALIGO Design with FC and Squeezer

2.3.2 Looking at just Modal Change

2.3.3 QM Limited Sensitivity

2.4 Results

- * Signal recycling cavity mismatches
 - * Mismatches before the OMC
 - * Mismatch contour graph: Comparing all of ALIGO cavities
 - * Optical Spring pops up at 7.4 Hz in the Signal-to-Darm TF, re-run with varying SRM Trans which should.

Chapter 3

Mode Matching Cavities at Syracuse

3.1 Adaptive Mode Matching

Real time digital system and model.

3.2 Actuators

3.2.1 Thermal Lenses

Fabian's work and UFL paper.

3.2.2 Translation Stages

3.3 Sensors

3.3.1 Mode Converters

3.3.2 Bullseye Photodiodes

Chapter 4

Mode Matching Cavities at LIGO Hanford

4.1 Beam Jitter

Current measurements of mode-matching.

Chapter 5

High Power Commissioning

5.1 Effect on Mode-Matching

What is the effect on mode-matching when you change the laser power?

Chapter 6

Solutions for Next Generation Detectors

- * SR3 Heater
 - * SRM Heater
 - * Operation: range (in terms of watts and
 - * Translation stages
 - * Mechanical description (Solidworks designs)
 - * Constraints (range, vacuum, alignment, integration)
 - * Electronics
 - * Software

List of Figures

List of Tables