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LIGO Laboratory / LIGO Scientific Collaboration

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Optical Layout and Parameters for the POP/ALS Beams

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Table of Contents

1 Introduction

1.1 Purpose and Scope

This document describes the optical parameters of the pick-off power recycling (POP) beams and arm length stabilization (ALS) beams as they are extracted for power recycling cavity (PRC) and delivered to ISC. The ALS beams consist of two 532 nm (called green beams) from the two arm cavities injected from the ETMs and combined at the beam splitter (BS). The POP beam provides a sample of the forward going as well as backward going beam traveling in PRC extracted through PR2. This document provides details about the optical parameters and location coordinates of these beams.

1.2 Definitions

Sagitta or Sag: For a beam with 1/e^2 beam size of w incident on a mirror of ROC R, the sag is given by $\frac{w^2}{2R}$ between the center of the beam and the beam radius.

Beam size: Mentioned and plotted as 1/e^2 beam radius unless otherwise mentioned

1.3 Acronyms

ROC: Radius of Curvature

PRC: Power Recycling Cavity

SRC: Signal recycling Cavity

QPD: Quadratnt photodetectors

POP: Power Pick-off

POP_A: POP beam used for ISC QPDs in HAM3/HAM9 forward going transmission through PR2

POP_B: POP beam traveling from PR3 to PR2 transmitted though PR2and used for length sensing

BS: Beam splitter

ETM: End test mass

ITM: Input test mass

1.3.1 LIGO Documents

1. Muzammil A. Arain and Guido Mueller, "Optical Layout and Parameters for the Advanced LIGO Cavities," LIGO Technical Note, LIGO-T090043, available at https://dcc.ligo.org/cgi-bin/DocDB/ShowDocument?docid=566
2. Rodica Martin, "Coated Substrate, ALIGO Power Recycling Mirror 2," LIGO Engineering Document, LIGO-E0900247, https://dcc.ligo.org/cgi-bin/DocDB/ShowDocument?docid=4664.

3. R. Abbott et al., "Advanced LIGO Interferometer Sensing and Control Conceptual Design," LIGO Technical Note, LIGO-T070247.
4. Luke …… Building co-ordinate system reference

2 Optical Configuration

The optical configuration of the Advanced LIGO cavities is given in Fig. 1 where we include both recycling cavities and the arm cavities.

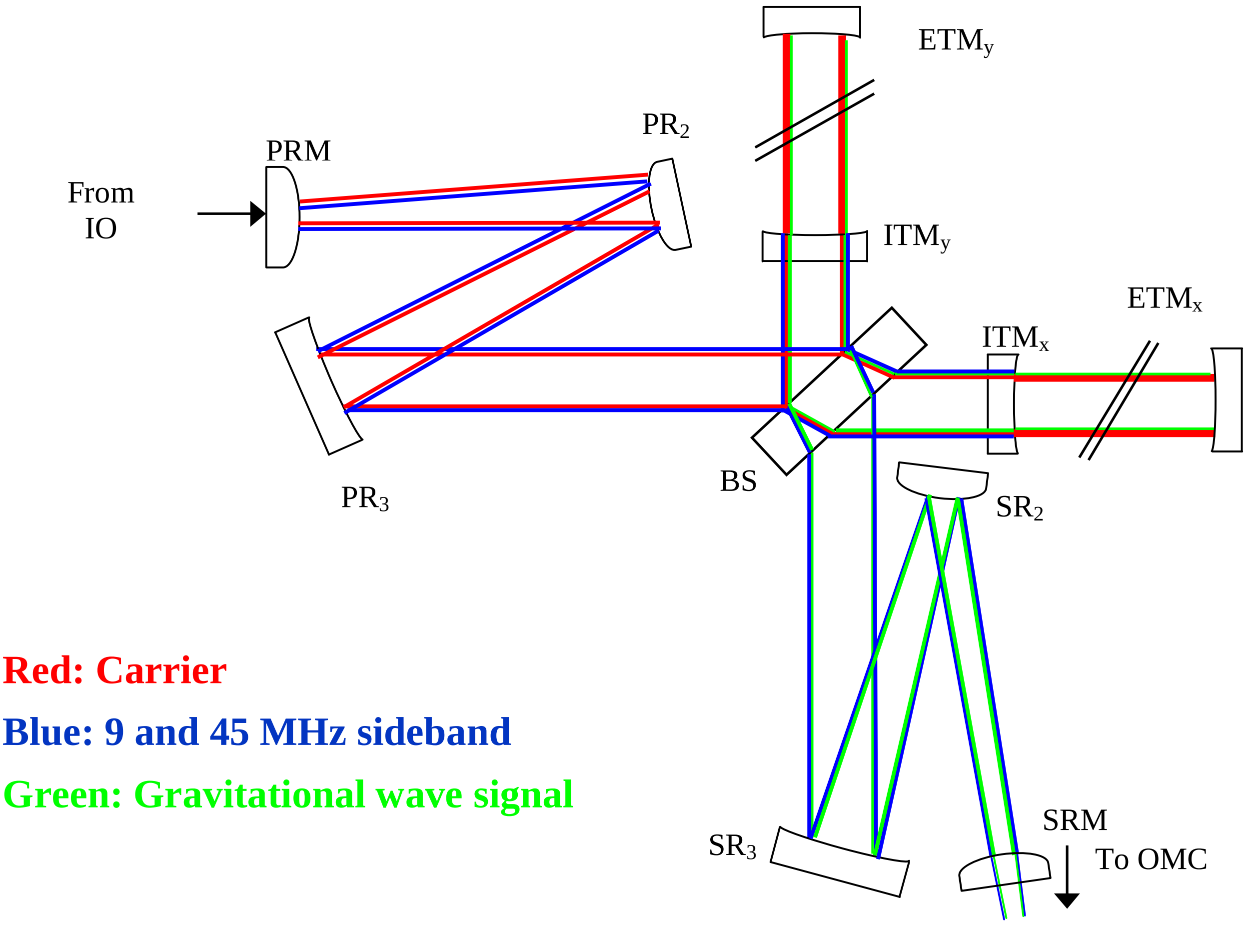

Fig. 1: Optical layout of Advanced LIGO cavities.

2.1 POP beams

There are two POP beams that are generated and separated in HAM3/HAM9. These two beams are termed as:

1. POP_A Beam

This beam is the forward going beam (1064 nm) traveling in PRC, i.e., the beam traveling from PRM to PR2. The transmission through PR2 (225 ppm transmission[2]) generates the POP_A beam. This beam is always present even if the cavity is not locked (as long as PRM sees a beam) and thus ISC plans to use it an alignment reference in HAM3/HAM9.[3] This reference is established using two QPDs placed 90 degree Gouy phase apart on HAM3/HAM9.

2. POP_B Beam

This beam is the backward going beam (1064 nm) traveling from PR3 towards PR2. The transmission through PR2 generates this POP_B beam. This beam is used for length sensing and control purposes and is delivered to HAM1/HAM7 to ISC.

2.2 ALS beams

ISC uses 532 nm beam for length sensing in the arm cavities. To do that, 532 nm (ALS or green beams) are injected from the AR side of ETMs in both X and Y arms. These beams then travel to PR2 and get transmitted through this mirror. Because of the BS, ITM, and CO wedge, ALS beams from the two arms deviate from the main IFO beam slightly and are thus spatially separated from POP_B beam. These beams are then delivered to HAM1/HAM7 by IO.

3 Interface between ISC and IO

3.1 Interface for POP_A Beam

In the case of POP_A beam, IO has the following responsibilities.

1. Collecting of light from PR2 beam using ROM1
2. Directing the light from ROM1 to ROM3
3. Placing the ROM3
4. Providing information about the co-ordinates and beam size
5. IO does not provide QPDs
6. IO co-ordinates with ISC for finalizing the QPDs location and ensuring that they do not interfere with the main or auxiliary beams in HAM3/HAM9.

3.2 Interface for POP_B Beam

In the case of POP_B beam, IO has the following responsibilities.

1. Collecting of light from PR2 beam using ROM1 mirror
2. Directing the light from HAM3 to HAM2 using ROM4
3. Handing the beam off to ISC at the HAM1/2 Septum window

4. IO provides a reasonably 'collimated' beam at the septum window
5. IO provides location and beam parameter information

3.3 Interface for ALS Beam

In the case of POP_A beam, IO has the following responsibilities.

1. Collecting of light from PR2 beam using ROM1
2. Directing the light from HAM3 to HAM2
3. Handing the beam off to ISC at the HAM1/2 Septum window
4. IO provides a reasonably 'collimated' beam at the septum window
5. IO provides location and beam parameter information
6. IO does not provide separation of ALS beams from the POP_B beam other than the existing separation due to wedges in the system

4 Nomenclature of the Optics

Figure 2-5 provide the nomenclature of the optics involved in POP/ALS beams other than the main cavity optics. The co-ordinate of the optics are shown in Table 2.

(Pictures from Luke/Rodica)

Table from Luke

Optics	ROC (m)	Alignment	Size of the Optics Diameter (inch)	Sag (µm) Straight/Folded	BCS Co-ordinates			Distance from PR2 HR	
					x (mm)	y (mm)	z (mm)	Straight (m)	Folded (m)
ROM1	Flat	Provision for actuation	3	POP_A+POP_B+ALS					
ROM2	Flat	Fixed	2	POP_B+ALS					
ROM3	Flat	Fixed	2	POP_A					
ROM4	1.5+/-0.015	Actuated	2	POP_B+ALS				2.5	2.44

5 Beam parameters at Hand-off to ISC

As explained in section 3, the beam parameters and locations for the various beams are listed in Table 2. Note that beam/waist size is listed as 1/e^2 radius. The co-ordinates are in BCS as explained in Ref. 4. The separations/co-ordinates are dependent upon the latest wedge angle information available.

Parameter/beam	POP_A		POP_B		ALS_x		ALS_y	
	Straight	Folded	Straight	Folded	Straight	Folded	Straight	Folded
Beam hand-off optics	ROM1	ROM1	Septum	Septum	Septum	Septum	Septum	Septum
Hand-off beam radius (mm)	5.5		2.39		1.69		1.69	
BCS co-ordinate (x)								
BCS co-ordinate (x)								
BCS co-ordinate (x)								
BCS direction cosine (α) (rad)								
BCS direction cosine (β) (rad)								
BCS direction cosine (γ) (rad)								
Waist location (m)	42.8	42.7	-6.775					
Waist radius (mm)	2.9	2.7	2.132					

6 Beam propagation

The POP_A and POP_B beams have vastly different profiles. The POP_A beam is only slightly converging while the POP_B beam is highly converging beam. The beam propagation as a function of distance from the HR side of PR2 is shown in Fig. 3.

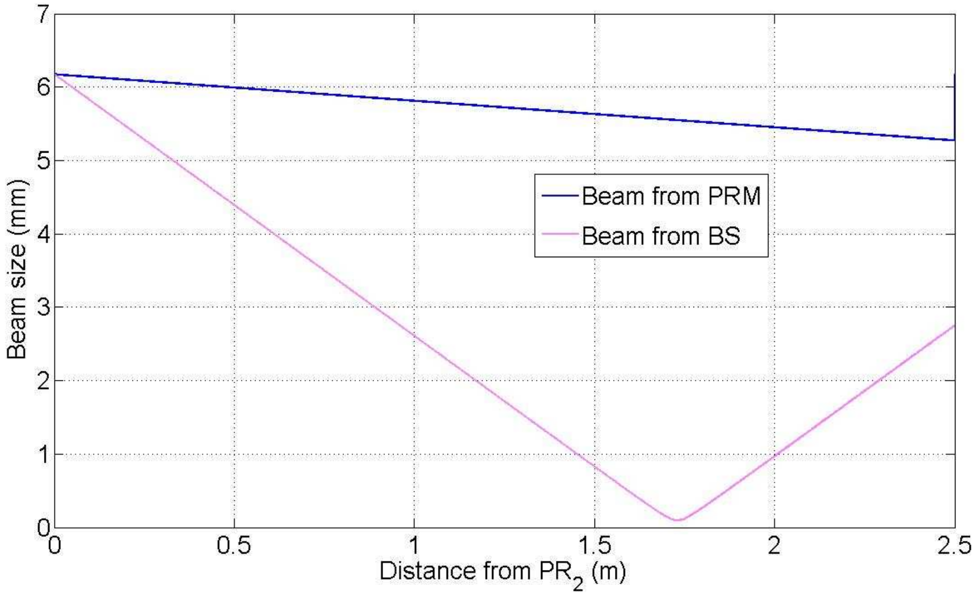

Fig. 3: Beam propagation for POP_A (Beam from PRM) and POP_B (beam from BS) as a function of distance downstream of PR2 mirror. Beam size is 1/e^2 radius.

As POP_B beam propagates to HAM1/HAM7 septum window, the beam propagation over a larger distance for POP_B beam is shown in Fig. 4 along with various sources of errors.

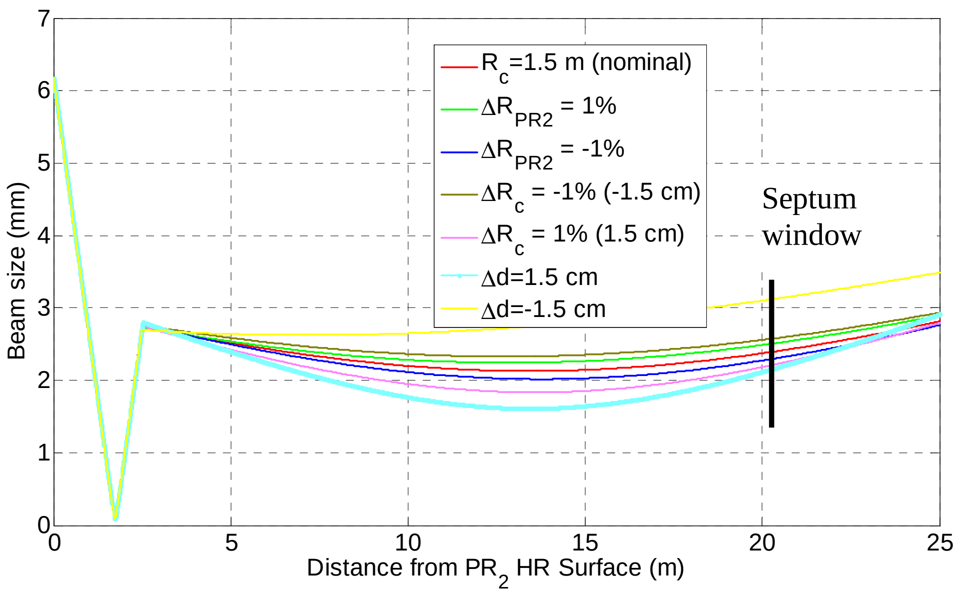

Fig. 4: Beam propagation for POP_B from HR side of PR2 mirror. Note that the mirror Rc (ROM4) is a collimating mirror placed at 2.5 (2.44 m for folded) from HR side of PR2. The septum window is located 17.706 m from Rc for straight.

7 Alignment and Control

To control the alignment of the beam, we have two picometer actuated mirrors. ROM1 will have a provision for picomotor actuated mirror but will not be placed at first. CDS has been informed to reserve channels. ROM4 will be an actuated mirror using picomotors. However, they do not operate in a feedback loop.

8 Effect of Wedge Angle Tolerance

Rodica/Luke

9 Summary

We have presented the optical parameters for the ALS and POP beams. Specifically, we hand over POP_A beam in HAM3/HAM9. POP_B and ALS beams are handed over on the septum window between HAM1 and HAM2. Beam sizes and divergence is described for various beams.