AdVirgo, First Draft of an Optical Layout

A. Freise, M. Mantovani

02.10.2006

Introduction

Optical Layout for Advanced VIRGO:

- How is the design of an optical layout related to the R+D process:
  - Interface between different R+D tasks
  - Allows a system analysis of the entire interferometer
  - Provides specification for new mirrors (and other long lead time items)
- First draft of a possible optical layout
  - Notation
  - Beam waist position and beam sizes
  - Mirror positions and optical losses

Optical Layout and Advanced VIRGO R+D

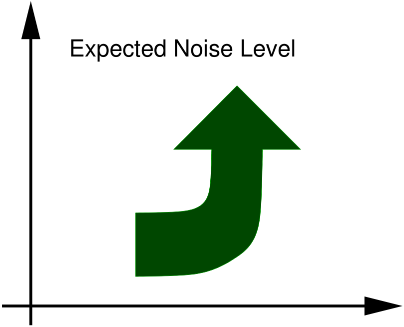
Development process from idea to realisation:

1. Analytical computation
2. Numerical simulation
3. Experiment

Optical Layout and Advanced VIRGO R+D

Development process from idea to realisation:

1. Analytical computation
2. Numerical simulation
3. Experiment



Optical Layout and Advanced VIRGO R+D

What role has a design of a detailed optical layout?

It allows to perform a system design of the entire interferometer.

- Systems design: a method to analyse and specify the effects of the integration of subsystems into the global system
  - standard in space projects
  - often neglected in ground-based projects due to the ability to 'fix it later'
  - interferometric GW detectors rely on being held on an exactly defined operating point and are thus affected by cross coupling between subsystems

Optical Layout and Advanced VIRGO R+D

What role has a design of a detailed optical layout?

It allows to perform a system design of the entire interferometer.

- Interface between apparently independent R+D projects
  - translate information between subsystems, for example, between input and output optics, or between the suspension design and LSC sensor noise
  - provides data to compute the sensitivity with a realistic parameter set (for example including locking accuracies, mode mismatches, etc
  - collect and provide a reference parameter list (book keeping)

Optical Layout and Advanced VIRGO R+D

Tasks directly related to the optical layout:

- Produce a multitude of optical layouts
- Do a parameter search around a proposed operating point
- Do a tolerancing simulation
- Perform noise propagation simulations

These tasks have merit within themselves but also generate experience with the new layout.

First Draft of an Optical Layout for Advanced VIRGO

The constraints:

- Take the VIRGO design and change it as little as possible
- Move the beam waist into the center of the arm cavities
- Widen the beam as much as possible (on the cavity mirrors)
- Add a Signal Recycling mirror

Our position with respect to Signal Recycling

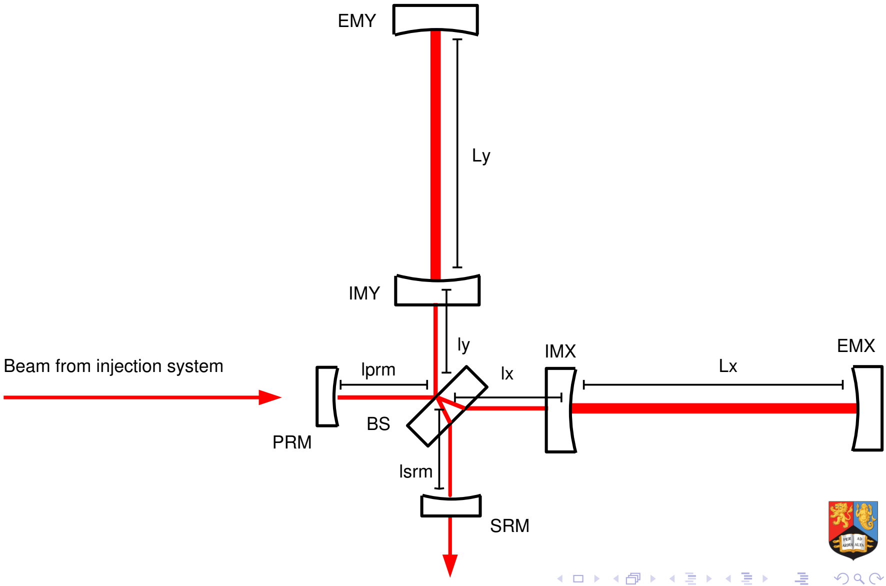
It has not yet been decided whether Signal Recycling will be part of the Advanced VIRGO design. However, it seems advisable to design the optical layout such that Signal Recycling can be added easily, maybe during a later upgrade.

Nomenclature

New names?

We propose to use a new set of names during the design of an optical layout, especially when employing numerical simulations. An extension of the historic name system to include additional output ports would probably be confusing. A new, clear set of names will avoid confusion between the current layout and the various layouts proposed for Advanced VIRGO. At the same time, it will make it easier for new or external members of the VIRGO working groups to become familiar with the subject.

Nomenclature



Optical Path Lengths

Name	Description
lx	distance from the BS to IMX
ly	distance from the BS to IMY
lprm	distance from the BS to the power recycling mirror (PRM)
lsrm	distance from the BS to the signal recycling mirror (SRM)
Lx	length of the X arm cavity (North)
Ly	length of the Y arm cavity (West)

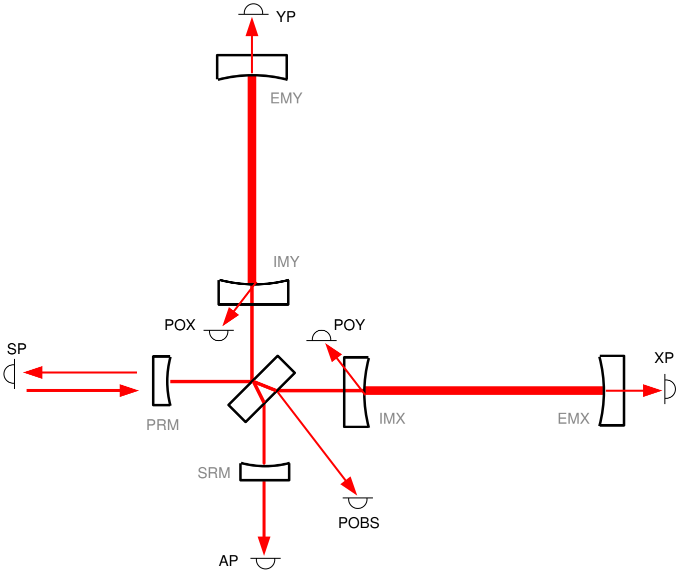
Table: Names of optical path lengths between primary optical surfaces in the main interferometer layout

Mirrors and Beamsplitter

New Name	Old Name	Description
BS	BS	main beam splitter
IMX	NI	input mirror of North (X) arm cavity
EMX	NE	end mirror of North (X) arm cavity
IMY	WI	input mirror of West (Y) arm cavity
EMY	WE	end mirror of West (Y) arm cavity
PRM	PR	power recycling mirror
SRM		signal recycling mirror

Table: New names for optical components and lengths of interferometer arms

Readout Ports



Readout Ports

New Name	Old Name	Description
AP	B1 (or B1p)	main dark fringe output port
SP	B2	light reflected by the power recycling mirror
XP	B7	light transmitted by the North arm (X arm) cavity
YP	B8	light transmitted by the West arm (Y arm) cavity
POBS	B5	light reflected at the AR coating of the beam splitter
POX		light refl. at the AR coating of the IMX (North input) mirror
POY		light refl. at the AR coating of the IMY (West input) mirror

Beam Widths

- The beam width should be maximised inside the arm cavities in order to minimise the influence of thermal noise
- Current limit to the coating size (homogeneous area): 30 cm
- Based on experience the beam radius should be generally no larger than one third of the mirror radius. This gives a limit of $w_{\mathrm{mirror}} = 5\,\mathrm{cm}$ for all the mirrors and $w_{\mathrm{BS}} = 3.5\,\mathrm{cm}$ for a beam splitter at 45 deg.
- This is only a starting point of an optimisation process

Radii of Curvature (ROC)

Mirror	Beam size w [cm]
cavity input mirror	3.52
cavity end mirror	3.52
beam splitter	3.54 (projected)
recycling mirror	3.53

Mirror	Radius of curvature R_C [m]
cavity input mirror	1910
cavity end mirror	1910
beam splitter	300k
recycling mirror	1320

Table: Beam radius at the main optical components and the corresponding radii of curvature. Please note that this table shows only absolute values for the radii of curvature as the sign convention is usually different for different simulations.

Optical Losses

The following list represents a simple 'working' set of reflectivities and transmission of the main mirrors:

Mirror	Transmission	Losses
IMX	$5\ 10^{-3}$	$5\ 10^{-5}$
EMX	$1\ 10^{-7}$	$5\ 10^{-5}$
IMY	$5\ 10^{-3}$	$5\ 10^{-5}$
EMY	$1\ 10^{-7}$	$5\ 10^{-5}$
BS	0.5	$5\ 10^{-5}$
PRM	0.07	$5\ 10^{-5}$
SRM	0.07	$5\ 10^{-5}$

The values quoted here correspond roughly to 0.5 MW of power in the arm cavities and 1300 W of power at the beam splitter for 100 W of light impinging on the power recycling mirror.

To Do List

- Go into more detail:
  - quantify the optical losses for realistic scenarios (including mirror maps, offsets in centering, etc)
  - check for free apertures in the vacuum tubes
  - perform a trade-off analysis of high recycling gain versus high arm cavity gain
  - ...
- Continue this design:
  - we need a parametrised signal recycling model that quantifies the effect of local optical losses on the detector sensitivity
  - develop possible LSC and ASC schemes
  - ...
- Create other possible layouts