LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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Revised PSL Table Mode Matching for eLigo

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1 Introduction

The purpose of this document is to present the methods by which the proposal for the eLigo PSL table layout was reached. Also, it will be useful as a reference for the mode matching parameters.

2 Changes from Current PSL Table Setup

The major changes which have affected the table layout are:

- New 35W laser; box required to be in the closest corner of the table, 75cm X 75cm, with the output beam emerging 18-25cm from left side, with a waist of 0.21 mm located 7.0cm outside the box;
- A diagnostic breadboard for the laser, 60cm X 49 cm;
- The EOM outside the laser is no longer necessary, the EOM will be mounted inside the laser between the oscillator and the amplifier heads;
- The three EOMs after the PMC on the main beam path have been combined into one EOM in which the modulating field will be parallel to the surface of the table, eliminating the need to rotate the polarization of the laser beam before this EOM;
- The transmission optics in the main beam path will receive a special AR coating to reduce the power levels in the ghost beams;

2.1 Changes from Version 00

- Mode cleaner waist position determined to be 44’’ farther than previous version states; as a consequence, the beam profile, some cell 3 distances and one of the lenses had to be recalculated and are correctly different;
- ATF will do the AR coatings, and not REO (fit more optics in a coating batch, cheaper); we might put some of the ISS and Reference Cavity lenses to be coated along with the main path ones (lenses which would see a higher power were the only ones to be coated in the previous plan, when only 20 optics would fit in a batch);
- ISS path updated;
- SL 11, SL 12, SL 13 updated to values actually on the PSL table;
- Due to redesigning of MC mode matching, the M14 pick offs have less interference with SL7 (SL7 has moved farther from M14);
- PMC camera shown on drawing;

3 Mode Matching

There are three major “cells” on the main beam path which require a new mode matching setup. The first is from the laser to the PMC, the second is from the PMC to the EOM and the third is from the EOM to the MC (see figure below). This figure can be found on the mLigo wiki.

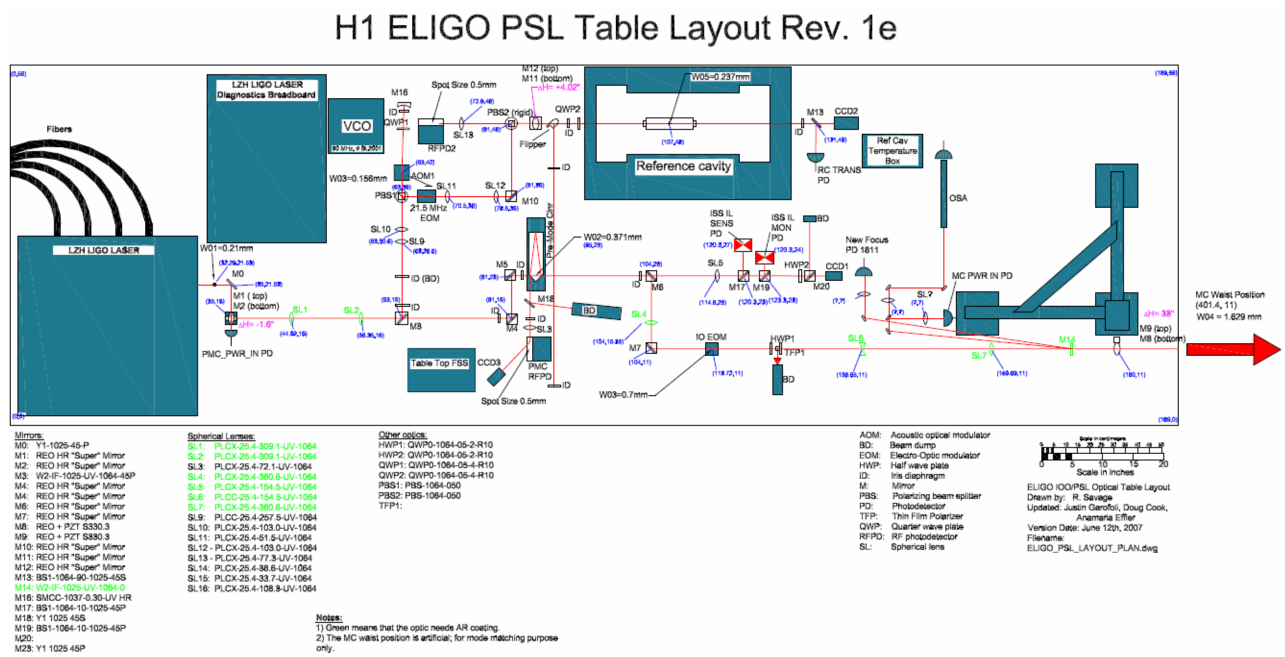

Fig. 1 Proposed PSL Table Layout

3.1 Requirements

The two mode matching lenses for the first "cell" are constrained to be between the turning periscope and the M3 steering mirror. The mode matching from the PMC to the EOM can be done with only one lens, so it can sit anywhere between the two optical elements. The third cell, into the MC, requires the lenses to be placed before the periscope.

The program used for the two-lens mode matching is an old FORTRAN code called mode10. Unfortunately, some of the source code has been lost, so due to lack of time to recreate a newer version, perhaps in MatLab, a compiled version of the code has been used. The advantage is that it uses the CVI list of lenses to look for possibilities and lists all of them. The program asks for a minimum distance from the input waist to the first lens (s1) and from the output waist to the second lens (s2), as well as for the waists themselves. These are important parameters to keep track of, since varying them will yield completely different results.

3.2 Main Path Optics and Locations

The following table shows the main path optics, including the table edge. The distances are shown both in cm and inches; the FORTRAN program requires distances in cm, while the table has mounting holes every inch, so it is easier to mark the elements in inches. This will probably also be useful during installation.

Optic	Size	Position on drawing(in)	Distance from laser w01(cm/in)	Distance from prev. optic(cm/in)
Laser w01	0.21mm	32.29, 21.53	0	0
SL1	68.75cm	44.92, 16	46.13 / 18.16	46.13 / 18.16
SL2	68.75cm	56.35, 16	75.16 / 29.59	29.03 / 11.43
PMC w02	0.371mm	85, 23	165.71 / 65.24	90.55 / 35.65
SL4	80.2cm	104, 15.35	233.4 / 91.89	67.69 / 26.65
EOM w03	0.7mm	113.72, 11	269.14 / 105.96	35.74 / 14.07
SL6	-34.36cm	138.65, 11	429.97 / 130.89	63.32 / 24.93
SL7	80.2cm	159.69, 11	484.97 / 151.93	53.44 / 21.04
M8	-	180, 11	535.76/ 172.24	51.59 / 20.31
M9	-	180, 11, 33	619.58 /205.24	83.82 / 33
MC w04	1.629mm	-	1000.1 / 393.74	478.79 / 188.5

Table 1. Main Path Components (w means waist, SL means lens)

The next table shows the mode matching parameters used in the program and the results obtained for each of the three cells. *D total* is the distance between the two waists, *d restricted* is the length where the lenses can use for mode matching, and *d12* is the distance between the two lenses. Since the second cell has only one lens, some of the parameters are missing. The restricted distance was calculated by taking the nearest optic (see 3.1) and claiming that the lens should be at least 4 inches away from it.

Distances	Cell 1:Laser to PMC	Cell 2: PMC to EOM	Cell 3: EOM to MC
Input waist	0.21mm	0.371mm	0.7mm
Output waist	0.371mm	0.7mm	1.629mm
s1 min	31.09cm / 12.24in	10.16cm / 4in	10.16cm / 4in
s1	46.13cm / 18.16in	67.69cm /26.65in	63.31cm /24.93in
s2 min	83.82cm / 33in	10.16cm / 4in	572.52cm / 225.40in
s2	90.55cm / 35.65in	-	614.20cm / 241.81in
d total	165.71cm / 65.24in	103.43cm / 40.72in	730.96cm / 287.78in
d restricted	50.8cm / 20in	83.11cm / 32.72in	148.28cm/58.38in
d12	29.03cm / 11.43in	-	53.45cm / 21.04in

Table 2. Mode matching cells with their parameters

The next figure shows the beam size as it propagates from the laser to the mode cleaner, as well as the locations of the waists in the scenario described above.

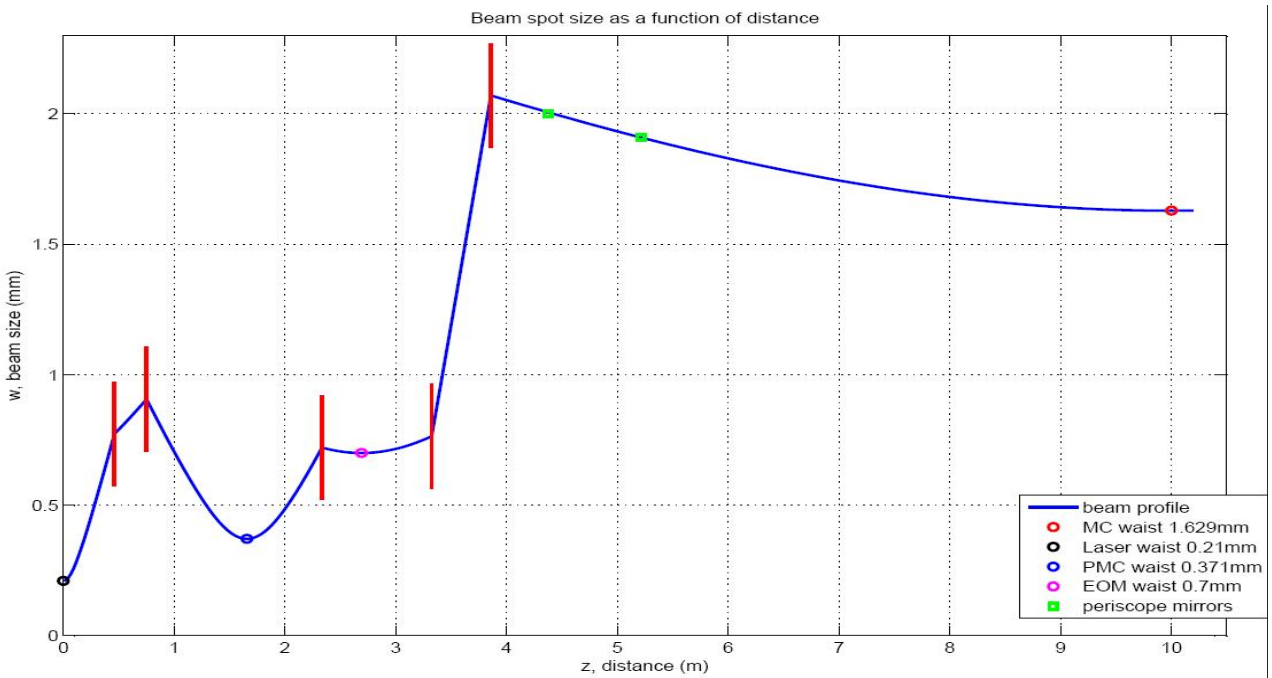

Fig.2 Beam size as it propagates from laser to MC

Notice in the picture above that there are no intermediate undesired waists. This is important since any waist presents the danger of introducing large noise into the interferometer; a randomly floating dust particle would occlude a significant fraction of the beam at such a waist, while if it traversed a wider beam, this noise would be greatly reduced.

3.3 Flexibility of the cells

Since some of the parameters of the laser or of the components may vary from design to implementation, it is important for the mode matching to adjust just by moving the current lenses, and not by having to replace them. That would cost time and money, especially because some of the main path optics require a special coating and cannot simply be bought off the shelf.

By varying some of the distances and waists involved, the lenses chosen were the ones which remained within the space required while also providing the desired mode matching.

3.3.1 Dithering Cell 1

The following figure shows where the two lenses have to move in order to maintain the proper mode matching into the PMC. The designed laser waist is 0.21mm, so two of the graphs show where the lenses would be if the laser waist was slightly wider or thinner. The other two modify the distance from the laser to the PMC by 20cm. The black limits shown are 4 inches away from the optic that constitutes that limit, so even if the lens is close to the limit, it would be a viable configuration.

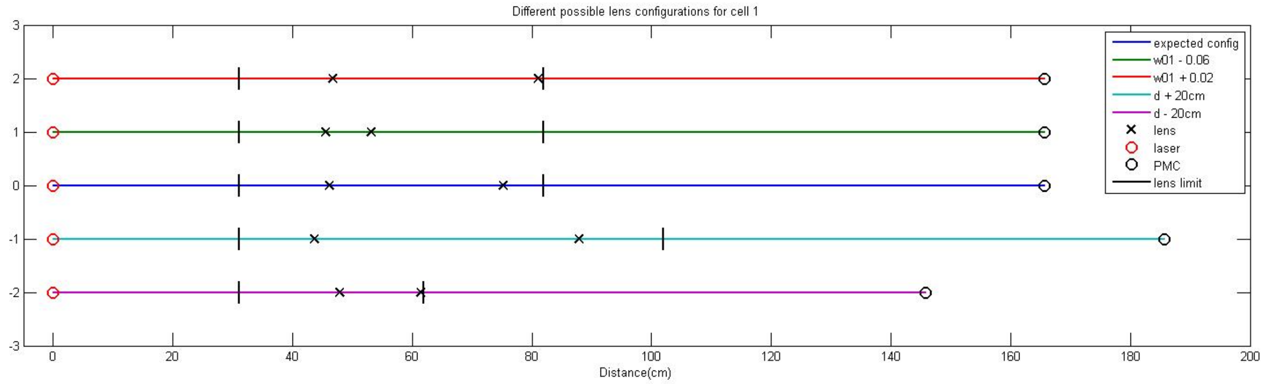

Fig.3 Positions of lenses for cell 1 for different configurations

3.3.2 Dithering Cell 2

Cell 2 is different since it has only one lens. The desired waist in the EOM is between 0.68mm and 0.7mm, so here are the possible results with same lens. The varying parameter is the position of the lens (1 cm increments). Notice that the EOM has to move in order to "catch" the waist. However, since there is only one lens, practically the mode matching should be easier than in the case of a two-lens system. The first configuration in the table is the nominal.

Waist(mm)	Distance from PMC to lens(cm)	Distance from PMC to EOM (cm)
0.700	67.7	103.43
0.695	66.7	99.55
0.690	65.7	95.81
0.684	64.7	92.20
0.678	63.7	88.74

Table 3. Varying the position of SL4 and results on mode matching

3.3.3 Dithering Cell 3

Just like cell 1, cell 3 has two lenses. A few calculations for their flexibility are shown below, including varying the mode cleaner waist (w04), the EOM waist (w03) and the total distance. The lenses stay well between the limits. The first limit is set by the EOM and the second is set by the periscope which takes the beam off the table.

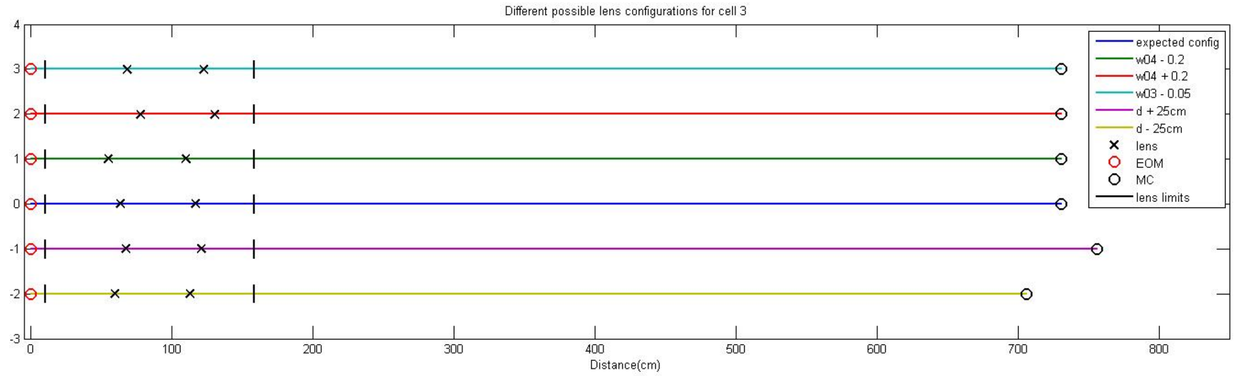

Fig. 4 Position of lenses for different cell 3 configurations

4. Pricing

The lenses necessary for this mode matching proposal can be procured (and are in stock) from CVI. The prices and number of items needed are shown in the table below. The first four items are on the main beam path and the rest are either on lower power pick offs or they are mode matching alternatives (marked with an *) in case some of the laser parameters change from design values (waist size, waist location, etc).

Part number	Drawing #	# reqd.	# spares	Surface figure	Scratch/dig	Price ea.
IF-1025-UV	M14	2	2	λ/10	10/5	$92.00
PLCX-25.4-309.1-UV	SL1, SL2	4	4	λ/10	10/5	$104.40
PLCX-25.4-360.6-UV	SL4, SL7	4	4	λ/10	10/5	$104.40
PLCC-25.4-180.3-UV	SL6	2	2	λ/10	10/5	$110.40
PLCX-25.0-72.1-UV	SL3	2	-	λ/10	10/5	$104.40
PLCX-25.4-154.5-UV	SL5	2	-	λ/10	10/5	$104.40
PLCC-25.4-257.5-UV	SL9	2	-	λ/10	10/5	$110.40
PLCX-25.4-103.0-UV	SL10, SL12	4	-	λ/10	10/5	$104.40
PLCX-25.4-51.5-UV	SL11	2	-	λ/10	10/5	$104.40
PLCX-25.4-77.3-UV	SL13	2	-	λ/10	10/5	$104.40
PLCX-25.4-257.5-UV	SL2*	2	-	λ/10	10/5	$104.40

Total: $4162.40

These optics are to receive special ATF (Advanced Thin Films) AR coatings with reflectivity <0.1% for 1064 nm light at normal incidence. One coating batch (both sides) costs somewhere around $4,500 and can coat up to 40 optics. Since the cost of the coating does not change with how many optics we choose to put in, we have decided to order some uncoated substrates even of lenses we currently have (cost of ~$100 each) and place them in the coating run.

Grand total: ~$9000.00