MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Laser Interferometer Gravitational Wave Observatory (LIGO) Project

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Subject: **Proposed initial detector MC and RC baseline lengths**

Pending a detailed optical layout of the three interferometers in the Integrated Layout System (which may reveal unforeseen constraints), we'd like to provisionally adopt the following baseline lengths for the Recycling Cavity and Mode Cleaner. This should provide an adequate basis for optical modeling and other design activities to proceed concurrently with the layout task.

Relations between MC length L_{MC} , RC length L_{RC} , RF phase modulation frequency f_m , and the geometry of our vacuum envelope are given in the Appendix. We have ruled out integer cavity length ratios from the acceptable options derived there,. This may not be necessary but seems prudent since, for integer ratios, odd-harmonic sidebands co-resonate in the recycling cavity. The effect may prove harmless, but at the moment we feel it's a concern.

With this exclusion we took those options affording minimum modulation frequencies to improve design margins in the electronics, particularly the photodetectors (we assume laser RF amplitude noise is not a concern). Finally, we chose specific lengths within the solution ranges with an view toward keeping the optics away from the extreme boundaries of the vacuum envelope. The proposed solutions for the Livingston 4 km and for the Hanford 4 km and 2 km are thus (see Appendix for definition of integers *n* and *k*):

IFO	n, k	L_{MC}/L_{RC}	L_{MC} (m)	L_{RC} (m)	f_m (MHz)
WA, LA 4 km	2, 1	1.33	12.50	9.38	24.0
WA 2 km	3, 2	1.20	14.00	11.67	32.1

Table 1: Proposed baseline lengths and modulation frequencies

Appendix:VE chamber separations and implied modulation frequency & length constraints

"Equipment Arrangement, Corner Station Washington" (PSI drawing #V049-5-001) gives the center-to-center distances between chambers nominally holding the mode cleaner end mirrors and the recycling mirrors and ITM's of each interferometer. We restrict the recycling mirror to positions within the HAM closest to the beam splitter, and the mode cleaner mirrors to positions within the other two HAM's in each input chain; this means the recycling cavity and mode cleaner cavity do not overlap axially, which is desirable in principle (due to scattering concerns) but may not be a necessary constraint.

For all chambers, we take a 1.5 meter zone centered on the chamber axis as the acceptable range of suspended optic mounting locations. This is likely to be overly conservative for HAM chambers, but may be close to the true limit for BSC's depending on SEI design details. Allowable mirror separations are therefore as follows:

Application	Chambers	C-C length (m)	Optic sep. range (m)
MC, typ.	WHAM-1 -- WHAM-2	13.72	12.22 -- 15.22
RC, WA 4 km (LA 4 km)	W(L)HAM-3 -- W(L)BSC-3	8.41	6.91 -- 9.91
RC, WA 2 km	WHAM-9 -- WBSC-8	13.05	11.55 -- 14.55

Table 2: VE chamber distances & viable optic separations per PSI V049-5-001

We may thus consider cavity length ratios **$1.23 < L_{MC}/L_{RC} < 2.20$** for the 4 km interferometers and **$0.84 < L_{MC}/L_{RC} < 1.32$** for the 2 km interferometer. Note that we have neglected effects of substrate thickness and the additional path due to folding mirrors on the 2 km interferometer; these are small compared to the overall range, but may be important for solutions lying near the separation boundaries.

For transmission of modulation sidebands by the mode cleaner, L_{MC} and f_m must satisfy

$$f_m = n \cdot \frac{c}{2L_{MC}}, \quad n = 1, 2, 3, \ldots$$

while for sideband coupling into the recycling cavity, L_{RC} and f_m must satisfy

$$f_m = (k + 1/2) \cdot \frac{c}{2L_{RC}}, \quad k = 0, 1, 2, \ldots \ .$$

The length ratio must therefore be

$$\frac{L_{MC}}{L_{RC}} = \frac{n}{k + 1/2}$$

with n and k positive integers ($n \neq 0$).

Combining this condition with the lengths shown in Table 2 gives several options for each interferometer, summarized below in Table 3. The range of admissible RF modulation frequencies is also given for each solution; in most cases one end of the frequency range (either upper or lower) is determined by an MC length limit, and the other by the applicable RC length limit. Preferred solutions are in bold type.

:

n, k	$\frac{L_{MC}}{L_{RC}} = \frac{n}{k + 1/2}$	4 km ?	2 km ?	f_m (MHz)
1, 0	2	✓		9.86 - 10.85
2, 1	**1.33**	✓		**22.70 - 24.55**
3, 1	2	✓		29.58 - 32.56
3, 2	**1.20**		✓	**29.58 - 32.47**
3, 3	0.86		✓	36.08 - 36.82
4, 2	1.60	✓		39.44 - 49.10
4, 3	1.14		✓	39.44 - 45.45
4, 4	0.89		✓	46.39 - 49.10

Table 3: Solutions for 4 km and 2 km interferometers up to $n = k = 4$

mez:mez

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