CALIFORNIA INSTITUTE OF TECHNOLOGY

Laser Interferometer Gravitational Wave Observatory (LIGO) Project

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Refer to: LIGO-T970068-00-D

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Subject: Recycling Cavity and Mode Cleaner Cavity Baseline Dimensions

The limits of acceptable recycling cavity (RC) and Mode Cleaner (MC) cavity dimensions, and the associated modulation frequency, f_m, was explored in previous memorandum.[1] The purpose of this memorandum is to finalize the cavity dimensions based upon a more precise layout of the position of the optics as constrained by the suspension structures and the seismically isolated optics tables.

<u>Baseline MC and RC Optical Path Lengths</u>

The realizable cavity length ratios (derived in the Appendix with reference to the attached drawing LIGO-D970002-00-D) are:

- $0.84 < L_{MC}/L_{RC} < 1.21$ for the 2 km IFO
  $12725 \text{ mm} < L_{RC} < 14358 \text{ mm}$
- $1.31 < L_{MC}/L_{RC} < 2.09$ for the 4 km IFO
  $7326 < L_{RC} < 9191$
- For either IFO, $12054 \text{ mm} < L_{MC} < 15343 \text{ mm}$

Although these values are somewhat different than the estimates in LIGO-T960122-00-D, they permit the same preferred solutions for the cavity length ratios, which are given in the Table 1.

Table 1: Baseline RC and MC Optical Path Lengths

IFO	n, k [a]	L_{MC}/L_{RC}	L_{MC} (mm)	L_{RC} (mm)	f_m (MHz)
WA, LA 4 km	2, 1	1.33	12255	9191	24.463
WA 2 km	3, 2	1.20	15270	12725	29.449

a. see LIGO-T960122-00-D for definitions of n, k and formula for the modulation frequency, f_m.

It should be noted that the preferred[2] solutions result in RC lengths and MC lengths near their realizable limits. The next alternatives to the cavity length ratios (Table 2) result in higher modu-

1. M. Zucker, P. Fritschel, Proposed Initial Detector MC and RC Baseline Lengths, LIGO-T960122-00-D.
2. “Preferred” (as defined in T960122) because (i) they are not integer multiples of cavity lengths, which support odd harmonic sidebands and (ii) they result in the lowest modulation frequencies within the acceptable solutions.

lation frequencies, but permit more clearance of the optics from the tables and potentially allow for baffling at the HAM optics table perimeter (as opposed to within the bellows between HAM chambers). The values of the MC and RC lengths in Table 2 are examples only, to illustrate length margins and approximate modulation frequencies.

Table 2: Alternative RC and MC Optical Path Lengths

IFO	n, k [a]	L_{MC}/L_{RC}	example L_{MC} (mm)	example L_{RC} (mm)	f_m (MHz)
WA, LA 4 km	4, 2	1.60000	~13700	8563	~43.8
WA 2 km	4, 3	1.14286	14857	~13000	~40.4

a. see LIGO-T960122-00-D for definitions of n, k and formula for the modulation frequency, f_m.

In the balance of this memo, the baseline cavity dimensions are used.

RC Asymmetry

The realizable Schnupp asymmetry[1], δ, for the baseline RCs are given in Table 3. Note that the asymmetry defined here is not ± δ, but the total asymmetry instead. The first column gives the nominal, baseline asymmetry used to set the positions of the optics. The second column gives the asymmetry range which can be realized by re-locating the two Input Test Masses (ITM) equal and opposite amounts. The third column gives the asymmetry range which can be realized if in addition to re-locating the two ITMs, one ITM is moved further and the Recycling Mirror (RM) is moved to maintain a constant average RC length.

Table 3: Baseline RC Asymmetry

IFO	Schnupp Asymmetry[a], δ (mm)		
	baseline	Range: both ITMs re-located	Range: both ITMs and the RM re-located
WA, LA 4 km	300	0 to 868	0 to 1100
WA 2 km	300	0 to 376	0 to 465

a. The asymmetry defined here is the total asymmetry, not ± δ.

RC Core Optics Positions

The resulting positions of the ITMs, RMs, and BSs for the 4 km and 2 km IFOs are shown in the attached drawing, LIGO-D970003-00-D. This drawing also shows nominal positions for the MC mirrors, though these positions will change as the University of Florida proceeds with the design.

1. The desired asymmetry range of 0 to 500 mm (as stipulated in the Detector Subsystem Requirements document (LIGO-E960112-05-D) cannot be achieved for the 2 km IFO without increasing the chamber optics table dimensions, or overhanging the suspension. The achievable asymmetry range of 465 mm was deemed adequate by D. Shoemaker and the Detector Subsystem Requirements document will be changed accordingly.

The coordinate locations of the optical components are more readily conveyed in a table than via dimensioning in a layout drawing. The locations of the optics relative to the vertex (i.e., relative to the origin of the LIGO global coordinate system) are given in Table 4.

Table 4: RC Core Optics Positions

Optic	Surface[a]	Center Coordinate		
		X (mm)	Y (mm)	Z[b] (mm)
RM_{4k}	HR	-4596	212	TBD
BS_{4k}	BS	-200	212	TBD
$ITM_{x,4k}$	HR	4677	200	TBD
$ITM_{y,4k}$	HR	-200	4811	TBD
RM_{2k}	HR	12184	9060	TBD
BS_{2k}	BS	9163	9060	TBD
FM_x	HR	9163	-200	TBD
$ITM_{x,2k}$	HR	9713	-200	TBD
FM_y	HR	200	9072	TBD
$ITM_{y,2k}$	HR	200	9598	TBD

a. HR = High Reflectance, BS = beamsplitting, AR = Anti-Reflectance
b. The Z coordinate will be finalized with the COC wedge angles.

Appendix: Realizable Cavity Lengths

Assumptions and Dependencies

The basic dimensions for the placement of the chambers within the LVEA space at the corner station are all in PSI's drawing V049-5-001 (also known as LIGO-D960032). The basic dimensions of the BSC are in drawing V049-4-001 (5 sheets; also known as LIGO-D961093); the basic dimensions of the HAM are in drawing V049-4-002 (5 sheets; also known as LIGO-D961094).

The dimensions of the seismically isolated optics tables are defined in Hytec drawings recently submitted for the SEI PDR (incorporated as part of the SEI Preliminary Design Review Document, LIGO-C970257-00-D). The BSC optics table is 49.5 in. (1257 mm) in diameter per drawing LIGO-C97pending (Hytec-LIG-12001). The HAM optics table is 67.0 in (1702 mm) transverse to the laser beam direction by 75.0 in (1905 mm) parallel to the laser beam direction according to drawing LIGO-C97pending (Hytec-LIG-24011).

The dimensions of the Large Optics Suspension (LOS) and the Small Optics Suspension (SOS), are taken from the PDR level drawings of the SUS subsystem. The top level assembly drawings are LIGO-D960132-00 for the LOS1 and LIGO-D960001-00 for the SOS. The dimensions of the LOS2 assembly (used for the beamsplitter COC) were taken to be identical to the LOS1 with the assumption that the optic is centered in the structure.

The desired Schnupp optical length asymmetry range for the 4km interferometer (IFO) is defined to be 50 cm OPD[1] (+ 25 cm along one arm and -25 cm on the other arm) in the Detector Systems Requirements document (LIGO-E960112-05-D), but is unspecified for the 2km IFO. The nominal value of the asymmetry is 30 cm (i.e. +15 cm along one arm and -15 cm along the other)[2].

The baseline positions for the centers of the two IFO beams[3] within the beam tube aperture are 10 cm below the horizontal centerline and 20 cm on either side of the vertical centerline.

It was assumed that the suspension structures can be placed at the very edge of the optics tables. If slight adjustments later require a slight (~10 mm) overhang, this is considered acceptable.

The configuration for the Mode Cleaner (MC) was taken form the Input/Output Optics (IOO) Conceptual Design document (LIGO-T960170-00-D), with the following differences:

- the laser light is injected into the MC along a long arm of the cavity[4], as indicated in LIGO-D970002-00-D.
- it was assumed that implementation of the IOO mode matching telescope does not restrict the MC length

The coordinate system used is the LIGO global coordinate system defined in LIGO-L950128.

1. Optical Path Length (OPD), not physical path length.
2. B. Kells, e-mail communication, 2/17/97.
3. The two beams are a reference to the initial installation at the Hanford site. It is further assumed that the 4 km IFO at the Livingston site will be located at the same position within the BT aperture as at the Hanford site.
4. Injection into the long arm of the MC cavity is suggested as a potentially better configuration for jitter suppression in Action Item # 21 of the IOO DRR Review Report, LIGO-M960131-00-D.

The index of refraction for the fused silica COC is n = 1.44963 at λ = 1.064 µm. The speed of light in vacuum, c = 2.9979 x 10^8 m/s.

N.B.: The layout was done in two-dimensions (planform) and will be revised, as a refinement, to include out of plane length changes which result from the vertically wedged optics. This may alter the lengths/positions by ~ 5 mm.

Achievable Schnupp Asymmetry

Before selecting nominal cavity dimensions and COC positions, the physically realizable recycling cavity range was determined. In order to obtain an asymmetry close to the desired 50 cm in the 2 km interferometer, it was necessary to switch the positions of the 4km IFO and 2km IFO laser beams along the X-arm as compared to along the Y-arm. For the 2km IFO, this asymmetry coupled with the nominal 45 degree orientation of the LOS1 for the Folding Mirror (FM) results in an asymmetry in the limits of the range of Input Test Mass (ITM) placement in the two chambers relative to the FM. (This is apparent by viewing the two 2km IFO ITM chambers in LIGO-D970002-00-D, attached).

The 2km beamsplitter (BS) was placed along the x-direction so that at the maximum separation of the ITM & FM pair with the least inherent separation range (on the Y-arm[1]), there was no cavity asymmetry when the other ITM & FM pair (on the X-arm) is placed as close as possible[2]. The Schnupp asymmetry is then accomplished by moving (via reconfiguration) the ITM_y closer to FM_y and the ITM_x farther from FM_x, by the same amounts until the available range is exhausted. This results in a maximum asymmetry of 376 mm (± 188 mm). More asymmetry can be achieved by moving continuing to move the ITM_y closer to FM_y (another 89 mm) while also moving the Recycling Mirror (RM) further from the BS (up to 44.5 mm, at a rate of half the displacement of the ITM_y) to maintain the average cavity length. The resulting maximum asymmetry for the 2km IFO recycling cavity is 465 mm.

The 4km IFO has ample asymmetry range. The maximum achievable asymmetry is 1100 mm. The first 868 mm (± 434 mm) can be achieved by moving the two ITMs. Further increase in the asymmetry requires moving the ITM_y and the RM.

Achievable Recycling Cavity Range

Having established the basic topology for maximizing the Schnupp asymmetry, it is then possible to define the achievable range in the recycling cavity by placing the RM at the edges of the HAM optics tables closest and furthest from the BS. The resulting ranges in achievable recycling cavity lengths are:

- 12725 to 14358 mm for the 2 km IFO
- 7326 to 9191 mm for the 4 km IFO

1. Due to the BSC round optics table geometry and the nominal 45 degree orientation of the FM, the ITM/FM pair with the least initial or inherent range is the one which is placed in the positive x and y quadrant; this was arbitrarily selected to be on the Y-arm.
2. This placement of the BS results in the ITM/FM pair on the X-arm having the minimum range of separation.

The range in the 2 km IFO RC length, 1633 mm, is the range in placement of the RM LOS1 on the HAM optics table (as shown in D970002). The 4km IFO RC length range also includes 232 mm of additional range available in placing the ITMs on the BSC optics tables.

Achievable Mode Cleaner Length

The MC cavity was defined using the SOS and based upon the IOO conceptual design (with the modifications noted above). The Mode Cleaner (MC) cavity length can vary from 12054 mm to 15343 mm (the longer cavity length is shown in LIGO-D970002). This length range includes a minimum separation of the two adjacent mirrors of the 3-mirror MC of 182 mm, based upon the dimensions of the SOS, and an “nominal maximum” of 254 mm.

Achievable Cavity Length Ratios

Consequently, the cavity length ratios which can be realized are:

- $0.84 < L_{MC}/L_{RC} < 1.21$ for the 2 km IFO
- $1.31 < L_{MC}/L_{RC} < 2.09$ for the 4 km IFO

DCC:dcc

Attachments:
1) “Recycling Cavity Dimensional Range”, D970002-00-D.
2) “Recycling Cavity Layout”, D970003-00-D.

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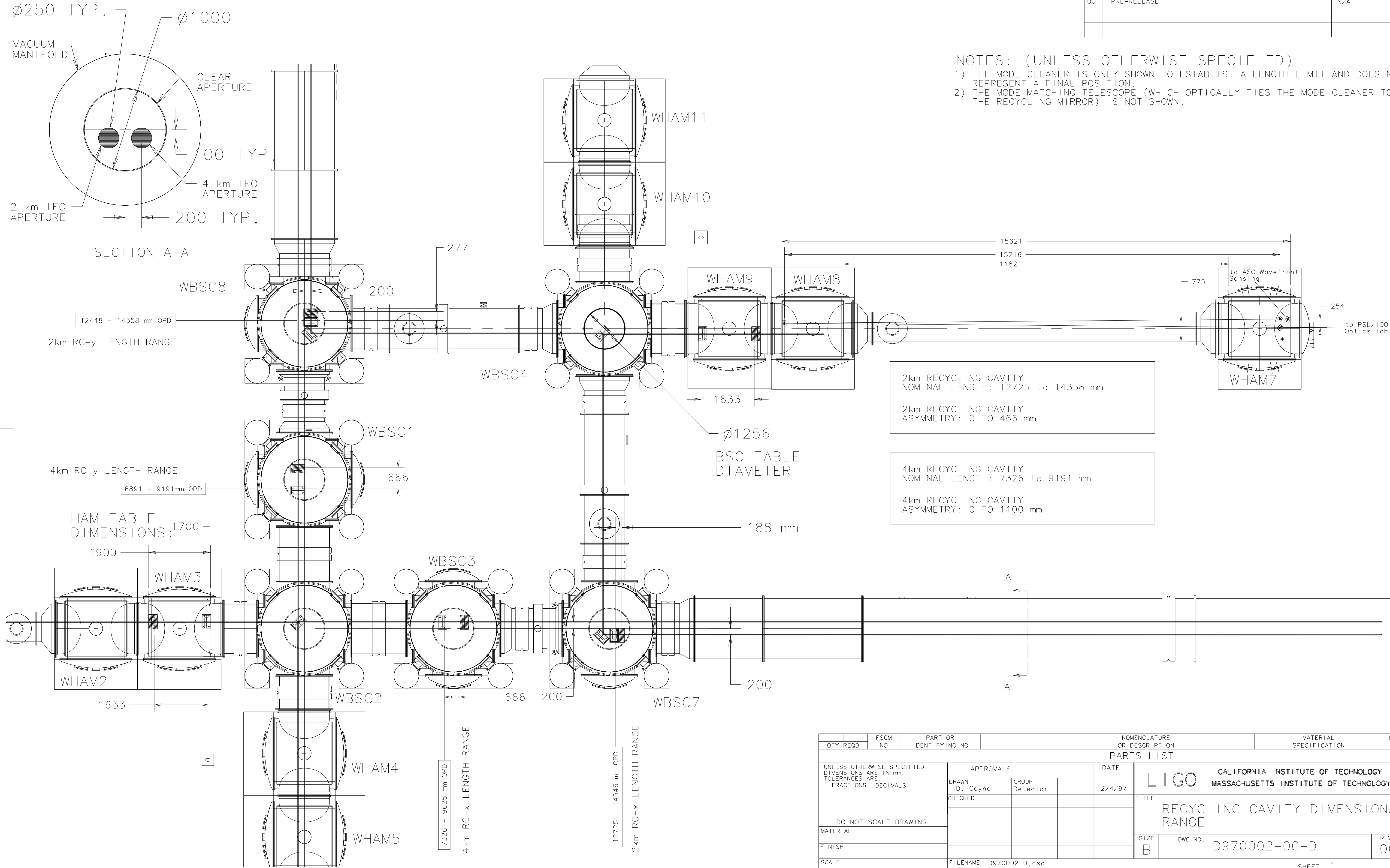
Document Control Center

REV	DESCRIPTION OF CHANGE	APPROVAL	DATE
00	PRE-RELEASE	N/A	

NOTES: (UNLESS OTHERWISE SPECIFIED)

1) THE MODE CLEANER IS ONLY SHOWN TO ESTABLISH A LENGTH LIMIT AND DOES NOT REPRESENT A FINAL POSITION.
2) THE MODE MATCHING TELESCOPE (WHICH OPTICALLY TIES THE MODE CLEANER TO THE RECYCLING MIRROR) IS NOT SHOWN.



QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO

PARTS LIST

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DRAWN D. Coyne	GROUP Detector		2/4/97
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TITLE RECYCLING CAVITY DIMENSIONAL RANGE

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SHEET 1

REV	DESCRIPTION OF CHANGE	APPROVAL	DATE
00	PRE-RELEASE	N/A	

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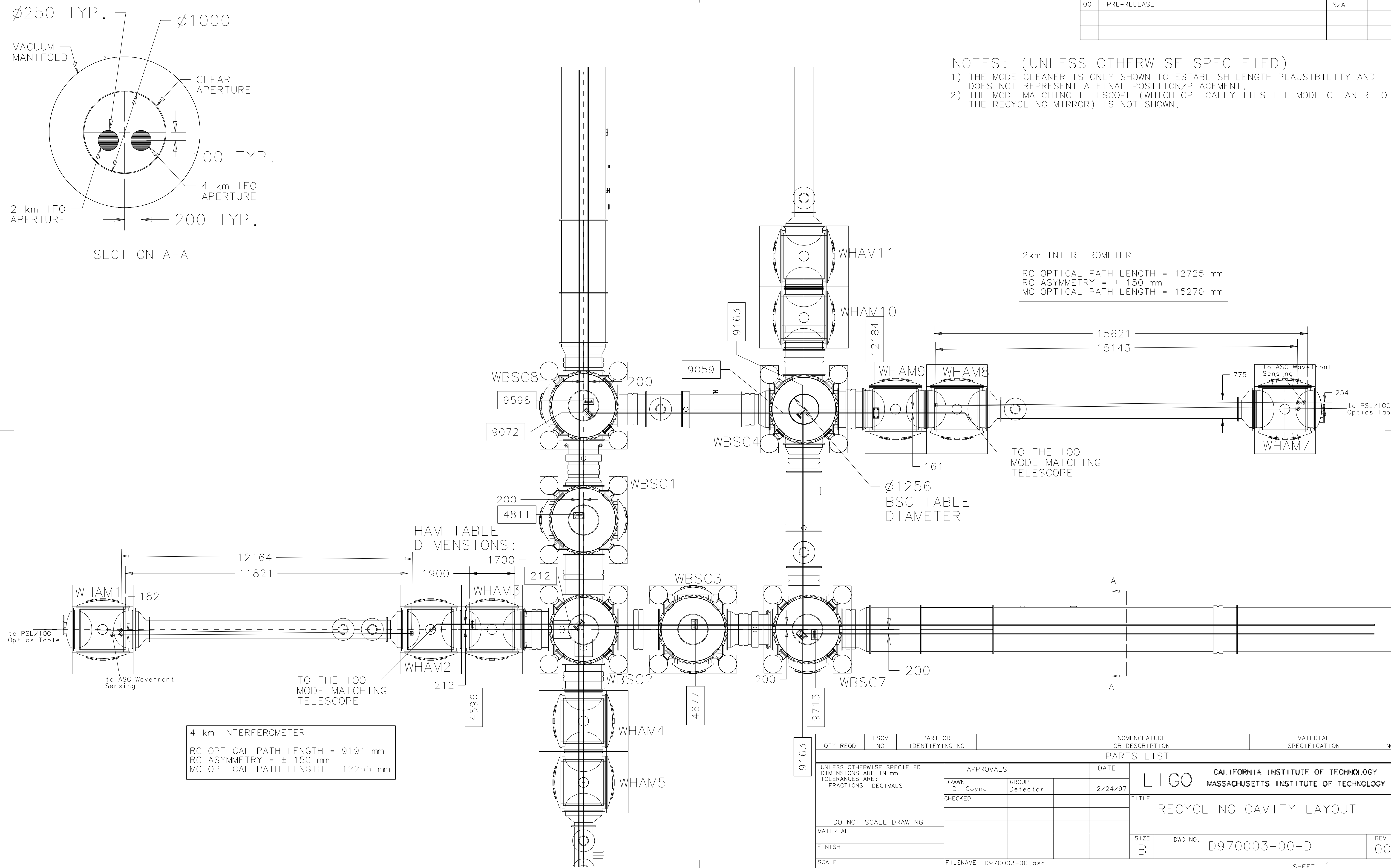
2) THE MODE MATCHING TELESCOPE (WHICH OPTICALLY TIES THE MODE CLEANER TO THE RECYCLING MIRROR) IS NOT SHOWN.



2km INTERFEROMETER

RC OPTICAL PATH LENGTH = 12725 mm
RC ASYMMETRY = ± 150 mm
MC OPTICAL PATH LENGTH = 15270 mm

4 km INTERFEROMETER

RC OPTICAL PATH LENGTH = 9191 mm
RC ASYMMETRY = ± 150 mm
MC OPTICAL PATH LENGTH = 12255 mm

QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION	ITEM NO

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TITLE: RECYCLING CAVITY LAYOUT

SIZE B — DWG NO. D970003-00-D — REV 00

SHEET 1