LASER INTERFEROMETER GRAVITATIONAL WAVE DETECTOR

- LIGO -

LIGO Laboratory - LIGO Scientific Collaboration

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H2 One Arm Test Beam Geometry
Keita Kawabe

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California Institute of Technology
LIGO Project - MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project - NW17-161
175 Albany St.
Cambridge, MA 01239
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 159
Richland, WA, 99352-0159
Phone (509) 372-8106
FAX (509) 372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone (225) 686-3100
FAX (225) 686-7189

http://www.ligo.caltech.edu

Configuration	ROC[m]	Z_{R}[m]	w_0[mm]	w_{ITM} [mm]	w_{ETM}[mm]	z_w[m]
OAT	ITM 2307 ETM 2312	786.76	16.3 red 11.5 green	44.5 red 31.5 green	44.7 red 31.6 green	2003.0
Nominal	ITM 1934 ETM 2245	421.68	12.0 red 8.45 green	53.4 red 37.8 green	63.5 red 44.2 green	2162.8

Table 1: Beam parameters of the arm mode: Rayleigh range Z_{R}, waist radius w_0, beam radius on the ITM w_{ITM}, on the ETM w_{ETM}, and the waist position z_w measured as the distance from the ETM, assuming the cavity length of 4000 m.

1 References

1. aLIGO optics inventory, https://nebula.ligo.caltech.edu/optics/
2. S. Waldman, "The advanced LIGO ETM transmission monitor", LIGO-T0900385
3. K. Kawabe, "Requirement for Adjustment Procedure of Advanced LIGO Transmission Monitor Telescope", LIGO-T1100600
4. B. Slagmolen, M. Evans, and K. Kawabe, "TMSY Telescope focal tuning results", LIGO-G1101254

2 Mirror ROC, the Arm Mode, Telescope and ALS Table

Nominally, aLIGO ETMs have 2245(-5+15) m ROC, and ITMs 1934 (-5+15) m. Let's call this the Nominal configuration.

In H2 One Arm Test (OAT), due to various reasons we're using ETM04 substrate (2312 m ROC) as the ETM, and ETM02 (2307 m) as the ITM [1]. This makes a large difference in the Rayleigh range of the mode inside the arm.

Figure 1 shows the mode profile of two configurations with red ($\lambda = 1064$ nm) and green (532 nm) light. Table 1 shows the important parameters inside the arm.

Figure 2 shows the propagation of the mode past the ETM. The detailed parameters are given in the next few sections.

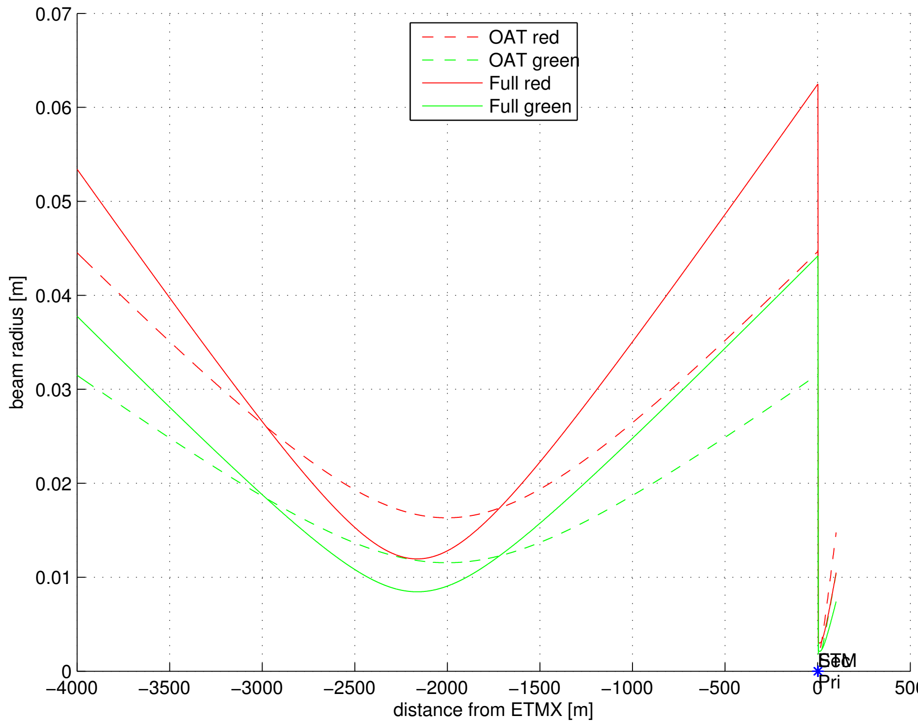

Figure 1: Mode profile in the arm. See Table 1 for the beam parameters.

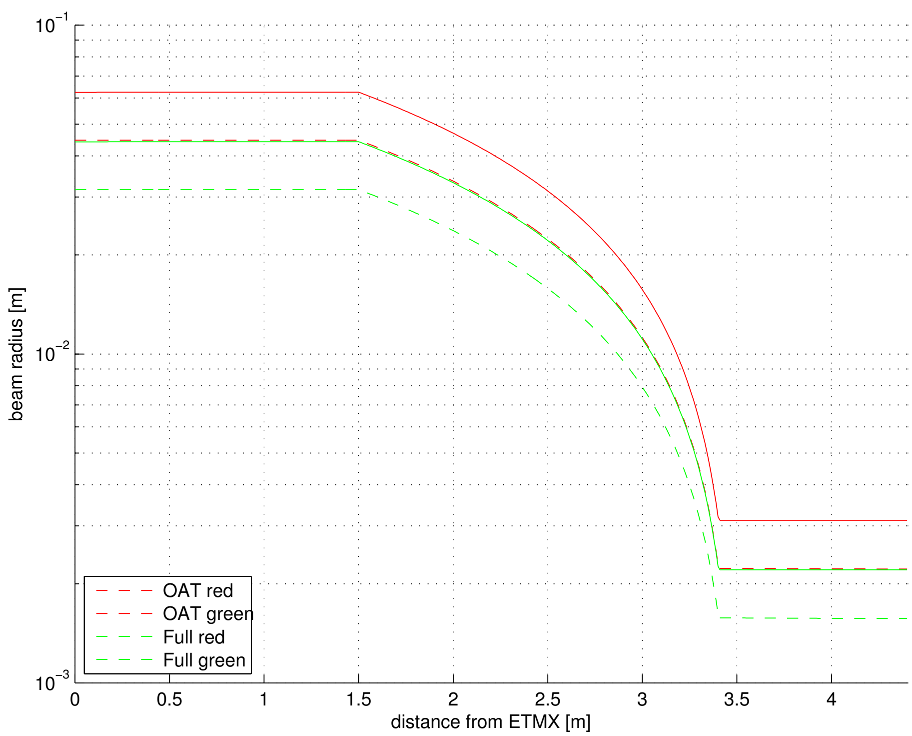

Figure 2: Propagation of the mode past the ETM. Note the log scaling in y axis. See Tables 2, 3 and 4 for the beam parameters.

Configuration	Z_R[m]	w_0[mm]	z_w[m]
OAT	402.6	11.7 red 8.3 green	1485.8
Nominal	204.6	8.3 red 5.9 green	1521.2

Table 2: Beam parameters seen from outside of ETM due to the lens effect of ETM. Positive z_w means that the waist is inside the arm. Refractive index of $n = 1.44963$ was used for calculating the lens effect.

Configuration	Z_R[m]	w_0[mm]	z_w[m]
OAT	6.80×10^{-4}	1.52×10^{-2} red 1.07×10^{-2} green	-0.2
Nominal	3.48×10^{-4}	1.09×10^{-2} red 7.67×10^{-3} green	-0.2

Table 3: Beam parameters inside the TMS telescope. The waist position z_w is measured from the secondary mirror. Negative number means that if the beam profile is continued from inside of the telescope to the outside as if the secondary is just a flat mirror, the waist would be between the secondary and the ALS table.

2.1 Between the Arm and the Telescope

Seen from outside ETM, due to the lensing effect of the ETM, the mode has a smaller waist radius parameter than in Table 1 and the waist location becomes closer to the ETM (Table 2).

2.2 Inside the TransMon Telescope

Transmission Monitor (TransMon) Telescope expands the green beam injected from the ALS table into the arm, and reduces the size of the red beam coming out of the arm. The telescope itself comprises two mirrors colloquially called the primary and the secondary. The primary has a radius of curvature of 4 m and the secondary -0.2 m, and the spacing between these mirrors is tuned within a tight tolerance of 1902.6+0.2-0.5 mm [2,3,4]. (Note that the true optimal tuning is not exactly 1902.6 mm but this number is close enough for all practical purposes.)

Inside the TransMon telescope, the beam diameter changes roughly by a factor of 20 over a distance of about 1.9 m. This fast reduction/expansion means that the Rayleigh range of the beam inside the TMS telescope is extremely small, and so is the waist radius parameter even though the beam never forms its waist inside the telescope (Table 3). This is the reason why the tuning tolerance is so tight.

Configuration	Z_R[m]	w_0[mm]	w_{sec}[mm]	z_w[m]
OAT	14.5	2.2 red 1.6 green	2.2 red 1.6 green	-1.56
Nominal	28.8	3.1 red 2.2 green	3.1 red 2.2 green	-0.12

Table 4: ALS table side beam parameters. Waist location z_w is measured from the secondary mirror here, negative number meaning that the waist is between the secondary mirror and the ALS table. Small z_w combined with large Z_R means that you can consider the waist to be on the secondary, and the beam radius on the secondary, w_{sec}, is besically the same as the waist radius w_0. This should be exactly the case with the Nominal configuration, but it looks as if it's not the case on this table because the telescope length was rounded to the first decimal point in mm.

2.3 Between the Telescope and the ALS table

Beam parameters between the telescope and the ALS table are listed in Table 4.

In the Nominal configuration, the waist location should be exactly on the secondary mirror, but on the table there is a very small error of $z_w = -0.12$ m (which is still less than 0.5% of the Rayleigh range). This is because of the rounding of the telescope path length between the secondary and the primary to the first decimal place in mm, i.e. 1902.6 mm. (The error in the distance between the ETM and the telescope primary, which was set to 1.5 m in the calculation, also has some effect on this waist location, but not as much as the telescope tuning.)