LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

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EOM Overview and Testing

Volker Quetschke, David Feldbaum, Rodica Martin, Joseph Gleason, Guido Mueller

Distribution of this document:
LIGO Scientific Collaboration

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 – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 159
Richland WA 99352
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/

1 Introduction

The purpose of this document is to introduce the design for the aLIGO modulator and the performed tests and results.

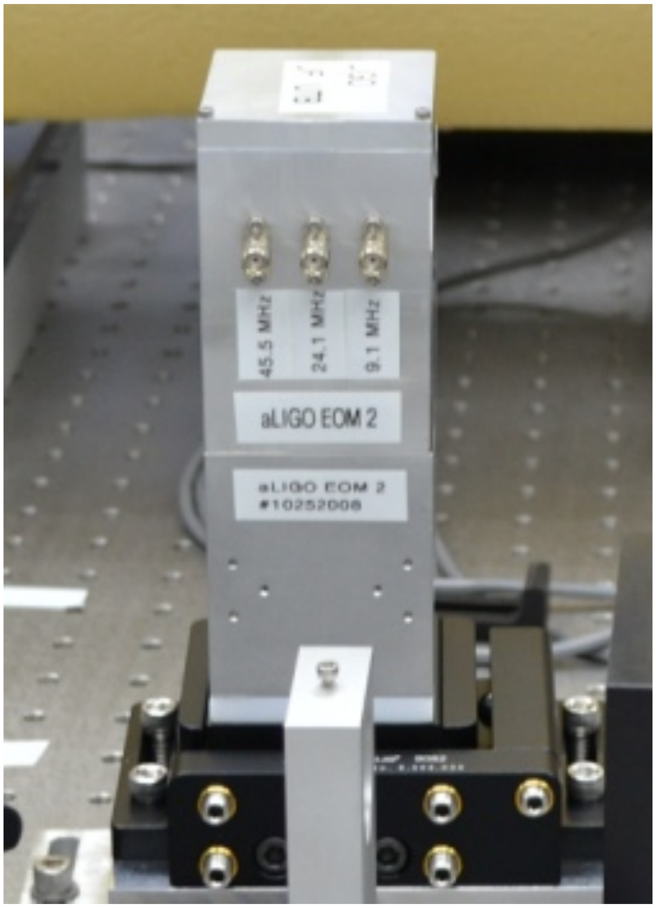


Fig. 1 EOM on PSL table

2 Design Requirements

The purpose of the modulators is to impose three sets of sidebands on the carrier light while being operated continuously at 165 W. The requirements on phase modulation efficiency, low residual amplitude modulation and thermal lensing will be addressed below. The EOM is the first optical element in the beam path after the PMC, except for steering optics.

3 Design

The EOM design use RTP (rubidium titanyl phosphate - $RbTiOPO4$). This material was found to be compatible with the requirements of a high power beam, while having a small thermal lensing effect and and good modulation characteristics. Additional information on the chosen RTP crystals can be found in the "Upgrading the Input Optics for High Power Operation" document (LIGO- T060267-00-D).

The design uses only one crystal but three separate pairs of electrodes to apply three different modulation frequencies. The following picture shows a schematic view of the electrode configuration and shows how the crystal is mounted.

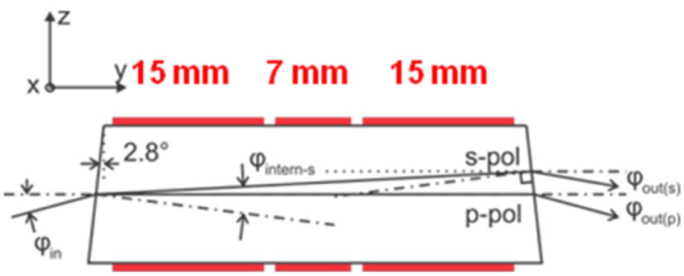


Fig. 2 (left) Electrode configuration and wedged crystal ends. (right) Inside view of the modulator.

The final assembled modulator with the separate electronics box that holds the resonant circuits is shown in figure 3.

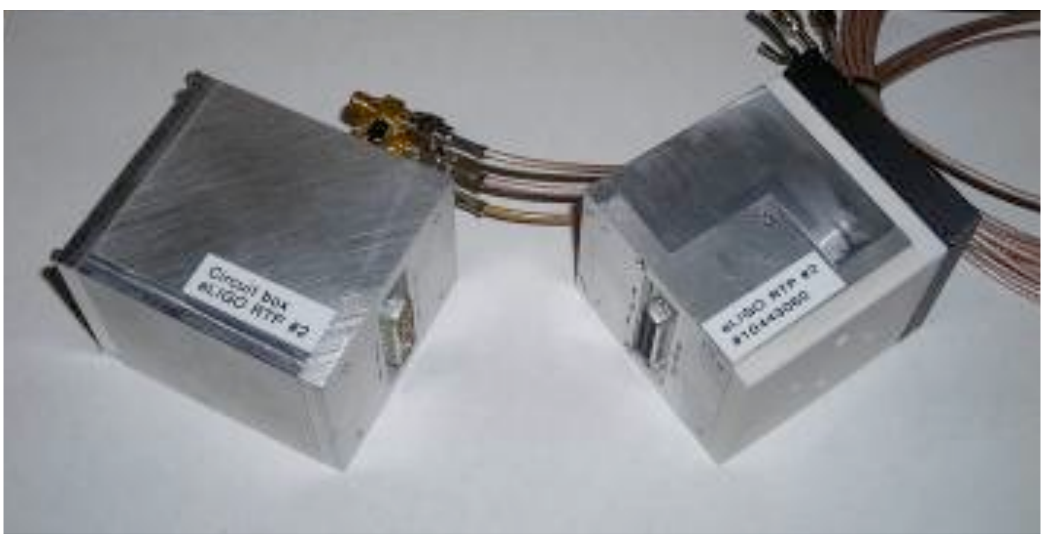


Fig. 3 Separate crystal and electronics box.

The electrodes are connected via D-Sub connectors, using two pins per electrode, to a separate box that holds the resonant circuit. The crystal box and the electronics box are separable for the following reasons:

- All required soldering during the tuning process can be performed without being inside the PSL enclosure to avoid possible contamination.
- A change of the electronics box can be performed without disturbing the optical layout – the crystal box stays in place while the electronics box is detached.

Reduced RFAM

To avoid cavity effects in the crystal and reduce RF-AM the RTP crystal was ordered with 2.85±0.1 degree wedges on the faces. The red rectangles in figure 3 represent the area where the electrodes are affixed. For p-polarized light the steering occurs in the plane of the table (the electrodes are perpendicular to the table):

The wedging leads to the following refraction angles, measured against the incident beam)

Polarization	**Angle [degree]**
P	4.7
S	4.2

Impedance matching

The modulation depth for each of the three modulation frequencies is enhanced by using resonant circuits. The impedance matching of the resonant circuit is realized using a Pi-network. Figure 4 shows a schematic overview of the used Pi network.

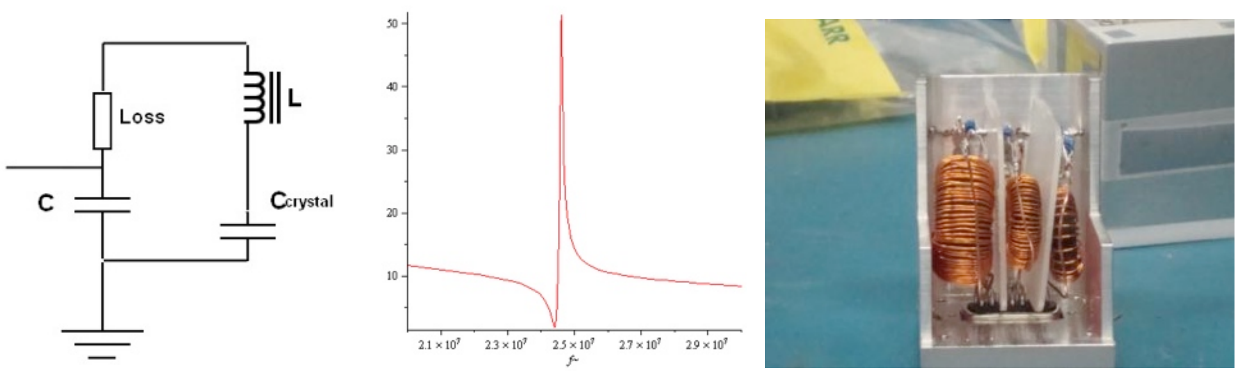


Fig. 4 (left) Schematic impedance matching circuit. (middle) Simulated impedance. (right) Three resonant circuits in aLIGO modulator electronics box.

4 Assembly and initial testing

The modulators were assembled and tested in clean room like environments using flow boxes and hepa filtered optical table enclosures. Assembly was performed at UTB, initial testing at UF

The table below shows the values for coils and shunt capacitors for the H1 and L1 modulators.

Frequency [MHz]	EOM-1: Number of turns per coil	EOM-1 pi network shunt capacitance	EOM-2: Number of turns per coil	EOM-2 pi network shunt capacitance
9.1	108	820 pF	102	680 pF
24.1	67	270 pF	68	270 pF
45.5	31	210 pF	30	190 pF

The modulation depth of each modulation was measured using an OSA and with three 24 dBm signals simultaneously driving all three electrodes.

After finalizing the modulators each modulator was tested with a 150 W laser and realistic PSL beam parameters to verify the high-power compatibility. The following picture shows the experimental setup:

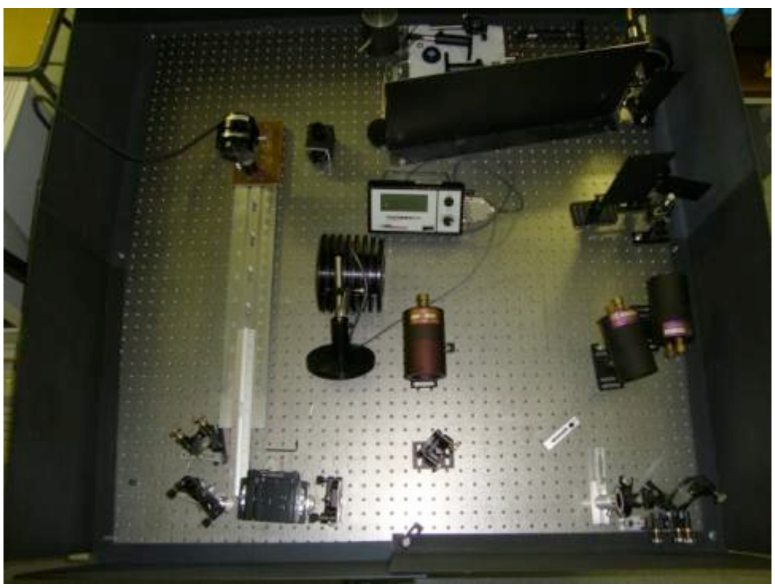


Fig. 5 Experimental setup at UF to measure the Gaussian beam parameters at power levels of up to 150W through the modulator crystal.

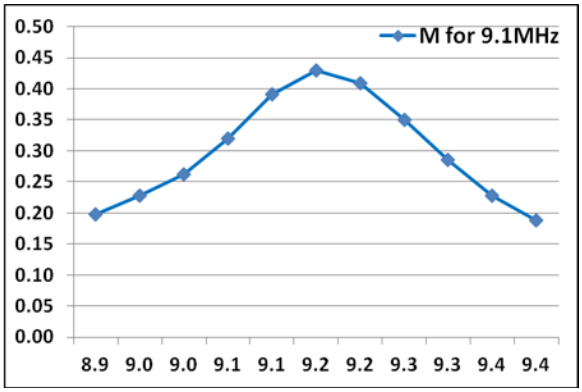
5 On site testing

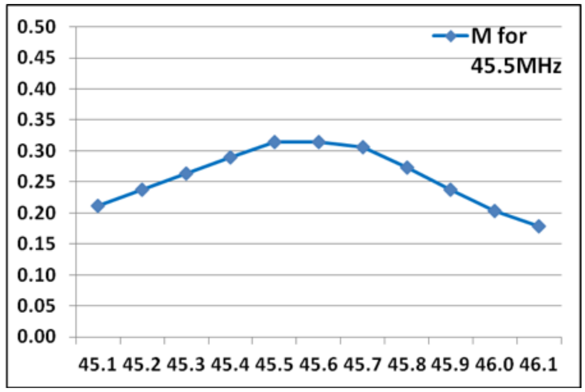
After installing the modulator at the site the frequency dependent modulation depth was measured. For the tests the modulators were driven with 24 dBm (10 Vpp) and the modulation depths were measured with the IO OSA on the PSL table.

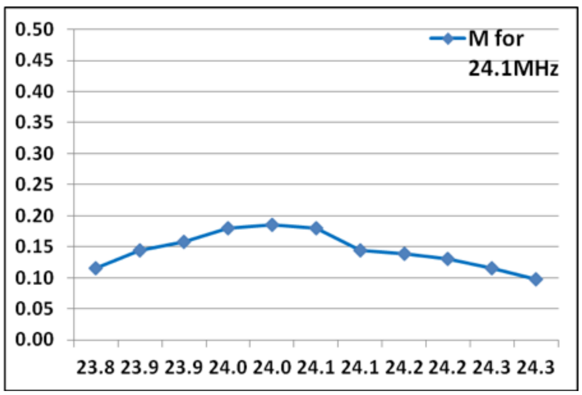
Also the residual amplitude modulation on the modulation frequencies was measured with an RF photodiode on the PSL table.

5.1 Modulation depth LHO

The following plots show the results for H1:







Measurements are referenced from here:
https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=3693

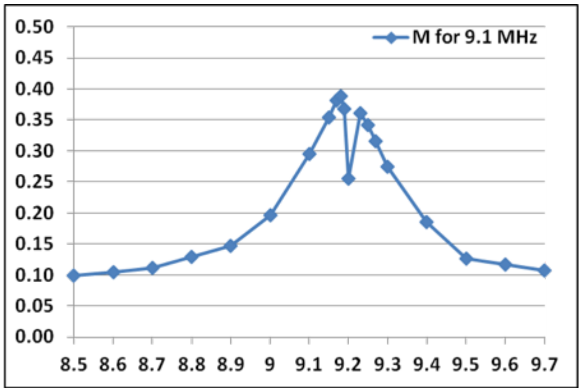
5.2 RFAM Modulation depth LHO

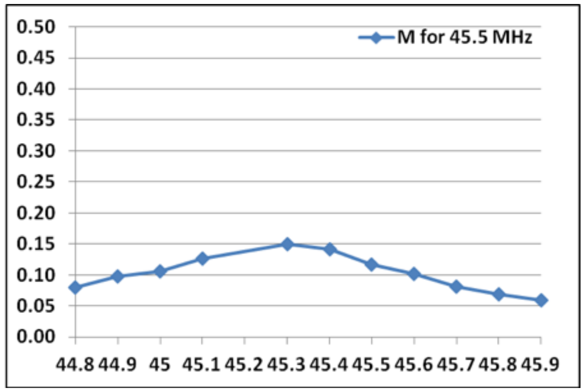
Freq.	PM	RFAM	RFAM/PM
45.5	0.31	5.5E-05	0.000177
9.1	0.39	9.13E-05	0.000234
24.1	0.14	3.17E-05	0.000226

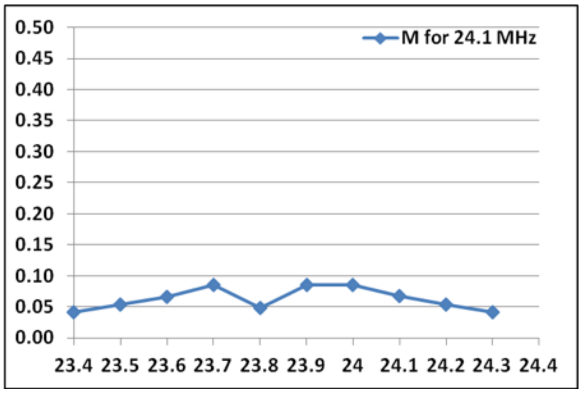
See: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=3695

5.3 Modulation depth LLO

The same set of measurements was performed at LLO:







Measurements are referenced from here:

https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=3027

5.4 RFAM Modulation depth LLO

Freq.	PM	RFAM	RFAM/PM
45.3	0.15	6.2E-06	0.000041
9.18	0.39	3.9E-05	0.000100
24.0	0.09	1.0E-06	0.000012

See: https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=3034

5.5 Thermal lensing

The (absence of) thermal lensing was measured and verified in:

PSL Mode Measurements – L1, see LIGO-T1300369 and
PSL Mode Measurements – H1, see LIGO-T1300379.