**LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY**

*LIGO Laboratory / LIGO Scientific Collaboration*

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# Input Optics Acceptance Documentation: EOM-Electro-optic Modulator

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# 1 Introduction

The top level DCC entry for the aLIGO Input Optics acceptance documentation is E1201013. The acceptance documentation for the Electro-Optic Modulators is linked to this entry under related documents, following this structure:

- LIGO-E1201013: aLIGO Input Optic
  - LIGO-T1300084: IO EOM
    - T020020: IO Requirements documents covers EOM requirements
    - T080075: IO procurement readiness review included the EOM
      - L080041 include the Q&A and L080069 the final report
    - T0900386: IO FDR covers EOM FD
    - LIGO-D1100392: EOM Assembly document includes links to all parts
    - LIGO-T0900475: AdvLIGO Phase Modulator Assembly procedure
    - E1300758 and G1200980 describes the testing and tuning of the aLIGO modulators.
    - T1000097 is the general IO installation plan which includes the EOM installation.

In sections 2 to 11 below we address the 10 items listed in section 1 of M1100282: Acceptance Deliverables and Criteria for Advanced LIGO, with information appropriate to the IO Faraday isolator.

# 2 Requirements documentation:

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 and a first power control unit (half wave plate and polarizer).

a. The final design document T0900386 of the IO also includes the final design of the EOMs. It was reviewed as part of the entire IO review.

b. The EOM was reviewed during the review of the IO procurement readiness T080075. The review report is available at L080069, questions and answers at L080041. The FDR report for the entire IO is available at L1000062. The questions of the committee are at L0900243. Answers from the IO at G1000002 and G1000007.

c. A first set of design requirements for the electro-optic modulator (EOMs) are part of the input optics requirements in T020020-04. More detailed requirements were formulated in T080075 as being '*according to the current ISC design*': The EOMs have to produce three pairs of sidebands at different RF frequencies between 9 and 45MHz with modulation indices of up to m = 0.4 for these core interferometer modulation frequencies. The assumed RF power driving the EOMs was

24dBm. The aLIGO ISC conceptual design T070247 mentioned m=0.2 for both frequencies but reduced the RF power to 10-20dBm; the third frequency for controlling the IMC is not specified.

d. The EOMs are part of the PSL layout and are shown in D0902114. We also maintain two as-build drawings of the PSL layouts which take into account minor adjustments required for example for mode matching into the as-built IMC.

Drawings for all parts for the EOM assembly can be found at LIGO-D1100392. Initial assembly instructions and prototype test results are available at LIGO-T0900475. Test results of the installed modulators are available at E1300758.

e. Bill of materials: No in-vacuum part.

f. The IO interfaces including the IO/PSL interfaces are described in section 2 in T0900386. The main interface for the EOM is with CDS which provides the electronic signals.

g. Software to control the EOM is not required.

h. Designs are available at LIGO-D1100392.

# 3 Design overview and detailed design documentation:

The EOM uses a ~40mm long, 4x4 mm cross-section, wedged RTP (rubidium titanyl phosphate - RbTiOPO4) crystal as the electro-optic material. 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).

Three pairs of electrodes are used to apply the three modulation frequencies to the crystal. Each pair of electrodes is part of a Pi-network which is resonant at the modulation frequency and 50Ω matched. The design, assembly and testing results are summarized in E1300758.

Documentation related to the design of the EOM can be found under LIGO-D1100392: aLIGO IO EOM Assembly. This DCC entry also contains links to all components comprising the EOM.

# 4 Materials and Fabrication specifications:

Any special materials, or treatment of materials including preparation for in-vacuum use; this may be integrated into the Design documentation.

The EOM is placed on the PSL table and is not subject to LIGOs strict vacuum rules. The materials used for the EOM can be found under the assembly document LIGO-D1100392. The crystal itself is made from RTP or Rubidium Titanyl Phosphate.

# 5 Parts and spares

*Parts and spares inventoried: All elements of aLIGO must be recorded in the ICS or in the DCC using the S-number scheme. As-built modifications for parts or assemblies should be found here.*

The EOM assembly drawings and ICS records are available at LIGO-D1100392. ICS records still indicate that EOMs are at UF. We are working on sorting out all serial numbers to update this.

# 6 Assembly procedures:

The assembly procedure for the EOM is described in LIGO-T0900475. This document also describes the tuning procedure of the EOM.

# 7 Installation procedures:

The installation procedure for the EOM is part of the Input Optics Installation Plan T1000097.

# 8 Test documents

The EOMs were tuned and tested on site. This is described in E1300758 and in G1200980 The final tuning will depend on the free spectral ranges measured in the as-built main interferometer. The spatial mode (thermal lensing) of the beam leaving the EOM is measured as part of the PSL table testing described in T1300369 for L1 and in T1300379 for H1.

# 9 User interface software

There is no IO-developed software to control the EOMs. The resonance frequencies and modulation indices will be determined and controlled by ISC.

# User's manual:

The assembly and test procedures are sufficient as user manuals.

# 10 Safety:

There are no specific safety concerns for the EOMs. They have been reviewed as part of the AdvLIGO IO Hazard Analysis L0900192.

## Acronyms

EOM: Electro-optic Modulator

IO: Input Optics

LLO: LIGO Livingston Observatory

LHO: LIGO Hanford Observatory

ICS: Inventory Control System

DCC: Document Control Center

ISC: Interferometer Sensing and Control

RTP: Rubidium Titanyl Phosphate - RbTiOPO4

FDR: Final Design Review