

*LIGO Laboratory / LIGO Scientific Collaboration*

LIGO-E1800050-v2

*Advanced LIGO*

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[Electric Field Meter Final Design Document](#)

Rich Abbott, Calum Torrie, Norna Robertson, Eddie Sanchez, Luiz Sanchez with input from Rai Weiss,  
Peter Fritschel and Dennis Coyne

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This is an internal working note of the LIGO Laboratory.

**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](mailto: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](mailto: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/>

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## 1. Scope & Introduction

The purpose of this document is to support the final design / design readiness review of the Electric Field Meter (EFM). An EFM has been proposed to measure stray (time varying) electric fields in the test mass chambers. The intent is to set limits on the displacement noise resulting from the electric fields interacting with a charged test mass.

Two prototype Electric Field Meters (EFMs) have been built and the documents presented here take into account lessons learned from these tests.

If successful, this review will authorize procurement of two full EFM's first articles and an engineering unit. The two EFM's to be ready for installation in an end station at both sites in the upcoming April (LHO) and May (LLO) vents.

All of the documentation related to the EFM is posted under:

- LIGO-E1800049: [Electric Field Meter \(Top Level\)](#)

This page contains (will eventually contain) links to the main documents and/or branches of the documentation tree: the final design document, the drawing package, assembly procedure, prototype QA inspection, and prototype test results.

## 1 Requirements

Some initial requirements were described in:

- LIGO-G1700239-v1: [Electric Field Meter for the Test Mass Chambers \(presentation @ commissioning F2F meeting at LLO, Feb 2017\)](#)

Reference should also be made to the 2 documents written associated with the 1<sup>st</sup> and 2<sup>nd</sup> prototypes, see links below on page 5.

## 2 Mechanical & Electrical Design & Interfaces (First Article)

The electronics are housed within a commercial vacuum cube (MDC part number #408003 <https://www.mdcvacuum.com/DisplayPart.aspx?d=MDC&wr=US&p=408003>) with conflat (CF) seals. Four faces of the cube are used for sensing, providing differential field measurement in X and Y. The z-axis was deliberately omitted due to packaging complexity. The sensing plate area is based on a calculation by Rai Weiss, the remaining dimensions of the sensor constrained by off the shelf components including feed-throughs and the vacuum cube flange.

Each of four opposing sides to the vacuum cube are outfitted with sensor plates. Each sensor plate feeds through to the inside of the cube via a standard Accu-Glass high-voltage feedthrough. Each sensor plate signal is applied to a  $10^{12}$  ohm resistor and the resulting voltages are buffered by four electrometer-grade operational amplifiers.

The signal across opposing faces of the cube is processed by a differential amplifier to yield X or Y axis field measurements. Remote controlled potentiometers are used to trim the common mode rejection of opposing plates. Calibration is achieved by driving detachable metal plates mounted in

parallel to the sensing plates. The calibration plates are also used to apply a common-mode signal during the common-mode trim calibration.

Voltage regulation is included on the differential amplifier circuit board internal to the electric field meter.

Electronic and Mechanical parts (including faces) will be identified with +X, -X, +Y and -Y labelling.

The EFM will be suspended from the BSC-ISI (stage 2) platform. The suspension is ~1m long (distance from BSC-ISI platform to the center of the EFM. Several designs are being evaluated, refer to relevant section below on page 5).

## 2.1 Summary of mass properties

In summary:

- the non-suspended mass is approximately 1 kg [including 3 new cable brackets with dog clamps, cable clamps for viton, new cable and housing for suspension rod]
- The suspended mass is approximately 15 kg (majority from “off the shelf” [cube flange](#) and associated CF flanges)
- 

## 2.2 Final Drawing package

The final assembly and part drawings are (and will be) posted under the following DCC links:

- LIGO-D1700365: [Electric Field Meter Assembly](#)
- LIGO-D1800024: [AdvLIGO SYS, XYZ Local CS for ELECTRIC FIELD METER](#)
- LIGO-D1800040: [Electric field meter Power and Drive Interface](#)
- LIGO-D1800037: [Electric field meter Sensing Board](#)
- LIGO-D1800050: [Electric field meter Field Sensor Block Diagram](#)

The 3D CAD model of the EFM is in the PDM vault, currently in the RnD folder. It will be integrated into the end stations models.

## 2.3 Parts List

A draft parts list has been posted to the DCC. A completed list is pending and will be added to the DCC following the review.

- LIGO-E1800051: [Electric Field Meter Parts List / Bill of Materials \[pending\]](#)

### 3 Design Analysis

Detailed design analysis is not yet complete. It is the intention to complete a Finite Element model of the completed EFM assembly.

## 4 Prototypes and Testing

### 4.1 Initial (1<sup>st</sup>) Prototype

Refer to the following document for a write up of this work

- LIGO-T1700103-v1: [Electric Field Meter for the Test Mass Chambers \(initial / 1st prototype\)](#)

### 4.2 Final (2<sup>nd</sup>) Prototype

Refer to the following document for a write up of this work

- LIGO-T1700569-v1: [Electric Field Meter for the Test Mass Chambers \(final / 2nd prototype\)](#)

### 4.3 In-Chamber Field Testing at LHO

Some in-chamber field meter measurements were performed at LHO in February 2018 at the Y end station. The LHO in-chamber field meter measurements, EY work is summarized in the following alog: -

- <https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=40656>

### 4.4 Suspension Testing at CIT

Investigations of a suspension system for the electric field meter, utilizing the 1-2 kg 2<sup>nd</sup> prototype version are in progress. Description of set-up and initial results from test on this prototype unit at Caltech can be found at: -

- LIGO-T1800063: [Investigations of a suspension system for the electric field meter.](#)

Further testing is planned with additional suspension configurations as well as tests with the final (15 kg) version.

## 5 Preparing for install

### 5.1 Assembly Procedure and Tooling

The assembly procedure will be created and posted to the DCC. We plan to write this during the next assembly of the components at Caltech.

Minimal tooling will be required and will be limited to Wiha allen keys and electrostatic (ESD) clean-room gloves.

## 5.2 Installation Procedure and Tooling

We also plan to write the installation procedure as we proceed with this next effort.

## 5.3 Connecting to existing Electronics

On the vacuum side the EFM will take advantage of available pins on an existing QPD cable, LIGO-D1000568, this will be done via the installation of a new splitter cable mounted at the cable brackets on the BSC-ISI. On the air side the EFM will connect to the existing QPD Amp Interface and in turn connect to the PEM chassis. Modifications required are included in the costs below.

## 5.4 Vacuum Prep

All components will be cleaned and baked as per LIGO procedures including the assembled circuit boards. Each cube flange assembly will need to have its final sealing in a [Neon](#) atmosphere glove bag.

## 5.5 Safety & Use

Three steps of the assembly / installation process that will require careful attention:

- It is the nature of electrometer amplifiers to be particularly sensitive to static electricity. Grounding straps are utilized during installation and assembly to mitigate ESD damage.
- All aspects of the sense plate inputs to the electric field meter board must be free of residue or surface moisture in order to preserve the  $10^{12}$  ohm input impedance. (Managed through normal LIGO clean and bake procedures.)
- Installation in the chamber is adjacent and near by the ETM suspension. Discussions will be held with the install teams on site and efforts will be made to utilize captive fasteners where possible and to cut down on the number of parts used.

## 6 Final Design Changes

The list below summarizes the issues that we are working on. Most are minor in nature but are listed for completeness.

- Board socket interference highlighted via 3D model. *[Have solution to solve this but will keep an eye on it.]*
- The MDC 6 way cube flange (#408003) is itself not vacuum compatible i.e. it has blind holes, as a result we will require to source vented fasteners with adequate torque levels. *[Have vendors lined up for this.]*

- Concerns about ceramic standoffs producing microphonic effects have led us to create (propose) a number of alternatives which we will test in parallel to fabrication. [Refer to options outlines in LIGO-D1800044: [ELECTRIC FIELD METER ASSY, STANDOFF](#)].

## 7 Deliverables

As part of this final design review, we deliver:

- This final design document
- The final drawing package and corresponding DCN
- The assembly procedure

[As mentioned above] if successful, this review will authorize procurement of two full EFM first articles and an engineering unit. The two EFM's to be ready for installation in an end station at both sites in the upcoming April (LHO) and May (LLO) vents.

## 8 Cost estimates

A fabricated equipment account has been setup, the account number is 8.63 as per

- LIGO-M1500001: [Estimated costs/schedule for aLIGO Interferometer Upgrades FY15-FY18](#)

It should be noted that version -v19 of the above document had a WAG of \$60k for this effort, version -v22 now has \$13k and a reduction of scope to "a single unit for LLO" in the notes field. This discrepancy will be discussed at the FDR and this section updated to match the decision.

An updated cost estimate of ~ **\$20,000 per EFM unit** was prepared on 27<sup>th</sup> Feb 2018 and is summarized at the link below.

- LIGO-E1800052: [Electric Field Meter Cost Estimate](#)

Costs for the proposed Engineering unit have now been added to version -v2.

## 9 Fabrication & Plans for acquisition of parts for fabrication

There are a mixture of electrical and mechanical components associated with this effort. As mentioned some are off the shelf (Accu-glass and MDC), some fabricated and machined and others include modifications to off the shelf parts (e.g. Accu-glass CF electrical flanges). Most items are from vendors that we have good relationships with. A risk associated with the availability of resistors was retired recently through the purchase of equivalent items (specialized resistors initially specified were replaced with an identical element that is not encapsulated in glass). The longest lead items are the custom electrical CF flanges from Accu-Glass. Initially they said 2-3 weeks but we are working on expediting this. The electric field meter sensing circuit boards are fabricated on Roger's 4350B ceramic hybrid substrates. This is not a standard process for us, although has already been verified to be in stock with the circuit board house.

## 10 Conclusion

In summary:

- The prototype experiences were successful
- Changes motivated by the prototype experience have been incorporated in the final design (first article)
- In chamber testing at both sites with these first article units will inform us greatly.
- While documentation is still in the works it is manageable and will be posted ahead of install.
- The installation and testing procedure are in progress and will be completed.
- We believe we are ready to start procuring the units (suspension tests will continue in parallel)
- (As mentioned above) the longest lead items are the custom electrical CF flanges from Accu-Glass. Initially they said 2-3 weeks but we are working on expediting this.