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Advanced LIGO UK

Production BOSEM Status and Interferometric OSEM Development

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LSC-Virgo Meeting

Amsterdam (Netherlands)
20th - 26th September 2008

G080466-00-K

LIGO GEO 600 IGR Science & Technology Facilities Council CARDIFF UNIVERSITY University of Strathclyde

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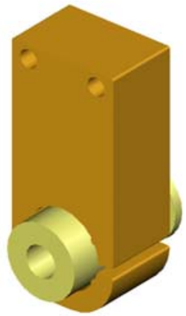
Presentation Overview

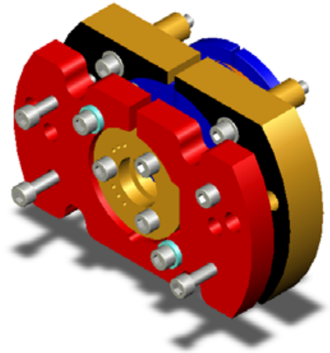
- **BOSEMs** *(S. Aston, R. Cutler, D. Lodhia, A. Vecchio)*
  - Configuration
  - Quantities
  - Characterization
  - Noise Prototype Status
  - Full Production Status

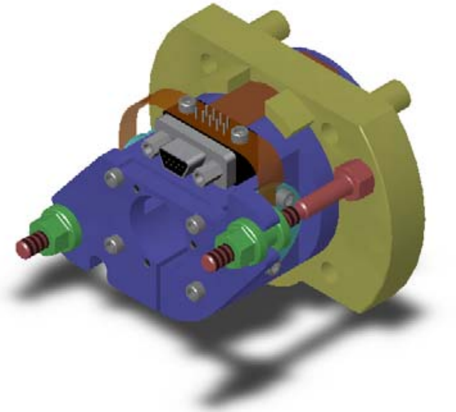
- **Interferometer** *(C. Speake, S. Aston, F. Peña Arellano, D. Hoyland)*
  - Design Motivation
  - Fringe Interpolation Method
  - Design Realisation
  - Prototype Fabrication
  - Optical Development
  - Electronics Development
  - Characterization

- **Summary**

BOSEM:- Evolution







Initial LIGO

(OSEM)

Advanced LIGO

Controls Prototype (Hybrid OSEM)

Advanced LIGO

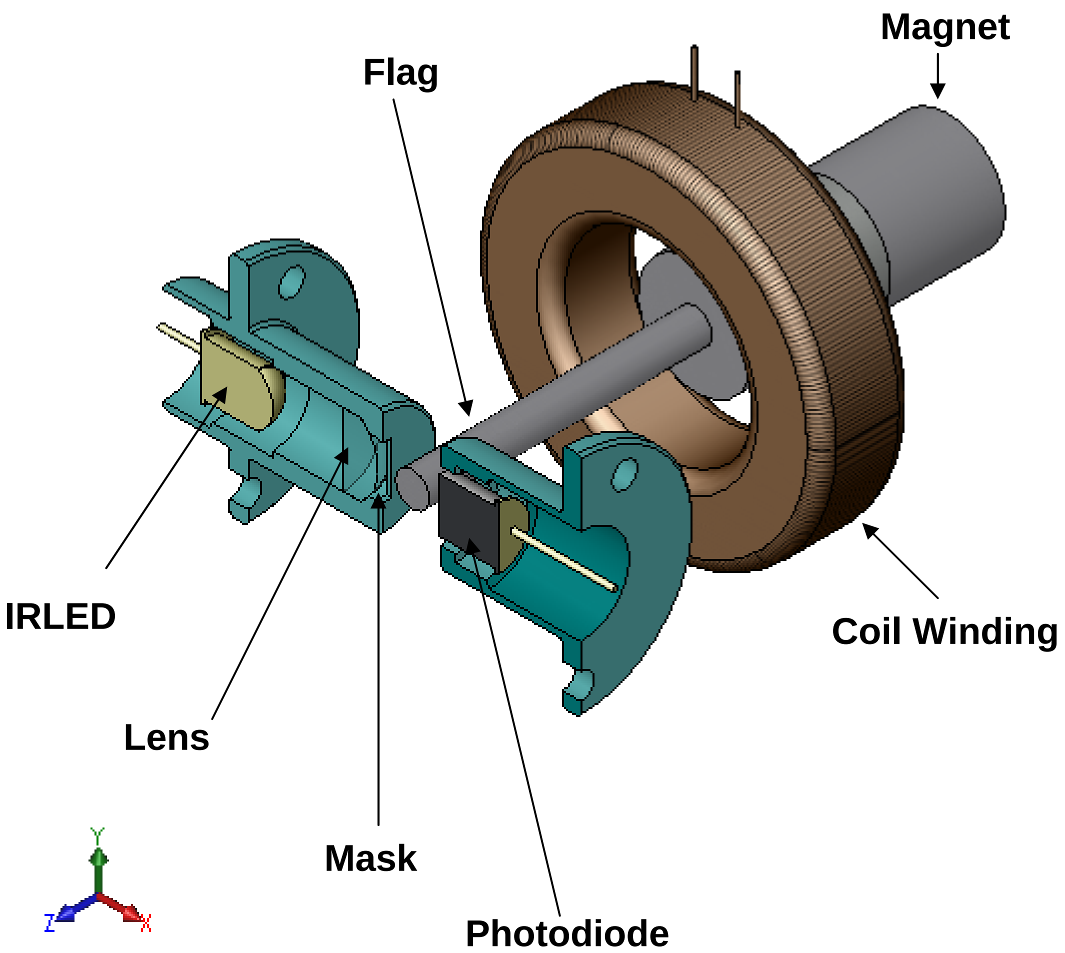
Noise Prototype & Final Production (BOSEM)

1st Generation

2nd Generation

BOSEM:- Configuration

- Key sensor and actuator components *(see right)*:-
- Significant changes from 1st generation Initial LIGO OSEM:-
  - Stronger actuator force 50mN -> 500mN
    - Higher coil current
    - More coil windings
    - Larger magnets
  - No Ceramabond used in fabrication process
  - Standard leaded device packages (i.e. not surface mount)
  - Commercial-of-the-shelf connectors (sub-D to μ-D)
  - Flexi-circuit for interconnections



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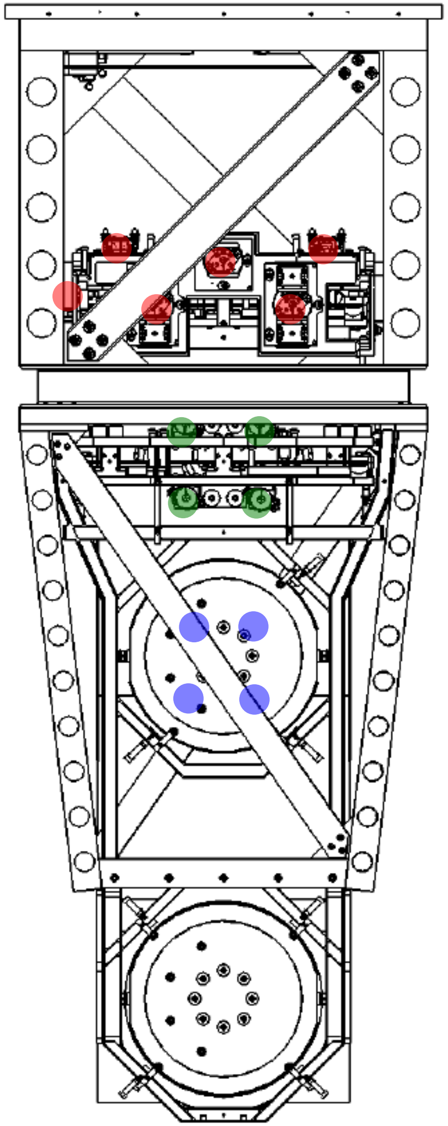
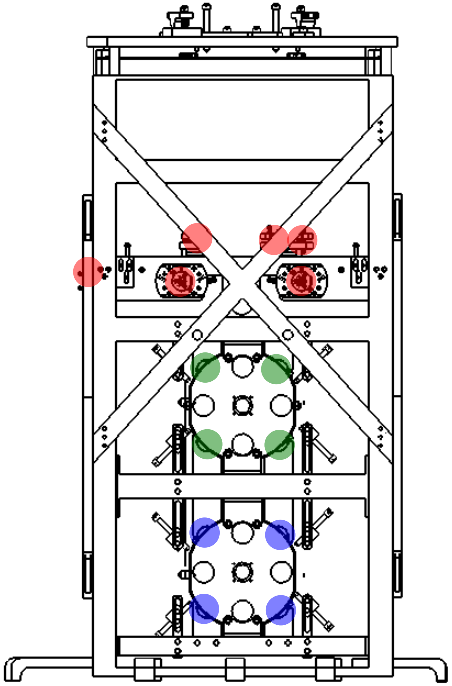
BOSEM:- Quantities

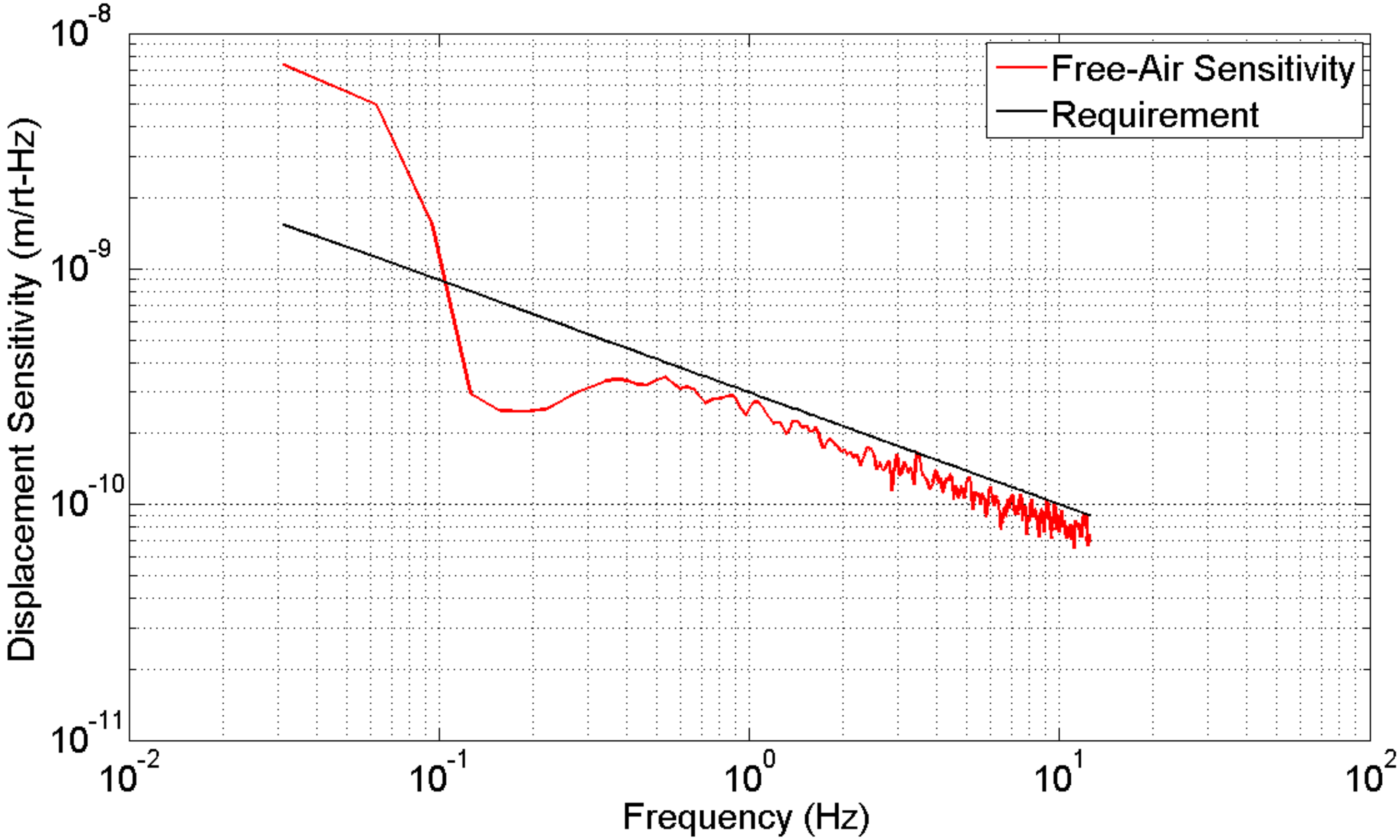
- BOSEM counts
  (not including spares):-
- Quad suspensions:-
  - End Test Mass (ETM) ~20
  - Input Test Mass (ITM) ~20
- Triple suspensions:-
  - Input Mode Cleaner (IMC) ~14
  - Recycling Mirror (RM) ~14
  - Folding Mirror (FM) ~10
  - Beam Splitter (BS) ~10
- Double suspensions:-
  - Output Mode Cleaner (OMC) ~6
- Single suspensions:-
  - Steering Mirror (Tip/Tilt) ~4
- <u>Delivery</u> Quantities:-
  - Noise Prototypes = 79 OSEMs
  - Advanced LIGO = 654 OSEMs





BOSEM:- Characterization I

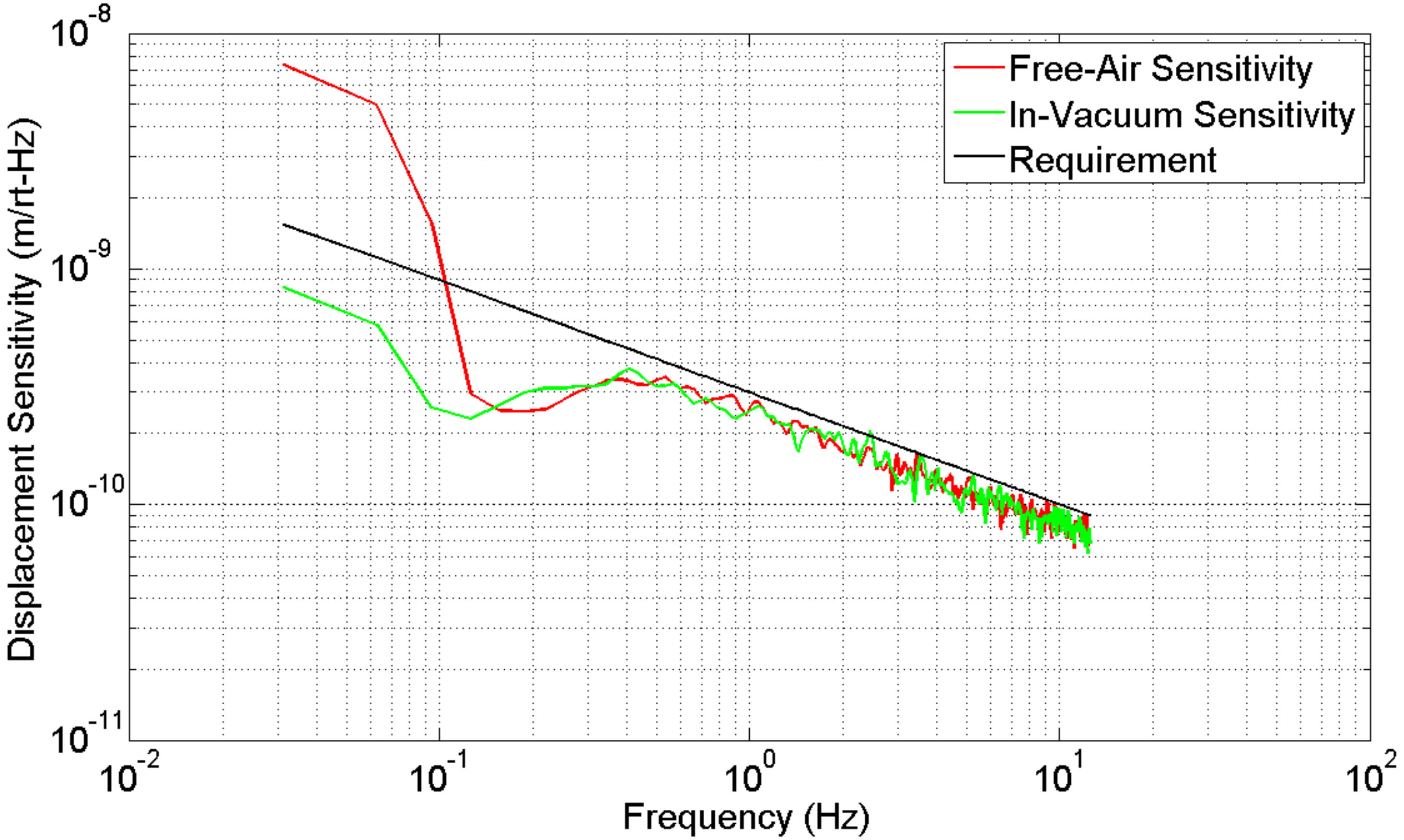
- Requirements[1]:-
  - Sensitivity @ 1Hz = 3×10^{-10}m/√Hz and @ 10Hz = 1×10^{-10}m/√Hz
  - Operating Range 0.35mm (peak-peak)



[1] K.A. Strain *"Input to the OSEM selection review decision".* LIGO-T040110-01-K

BOSEM:- Characterization II

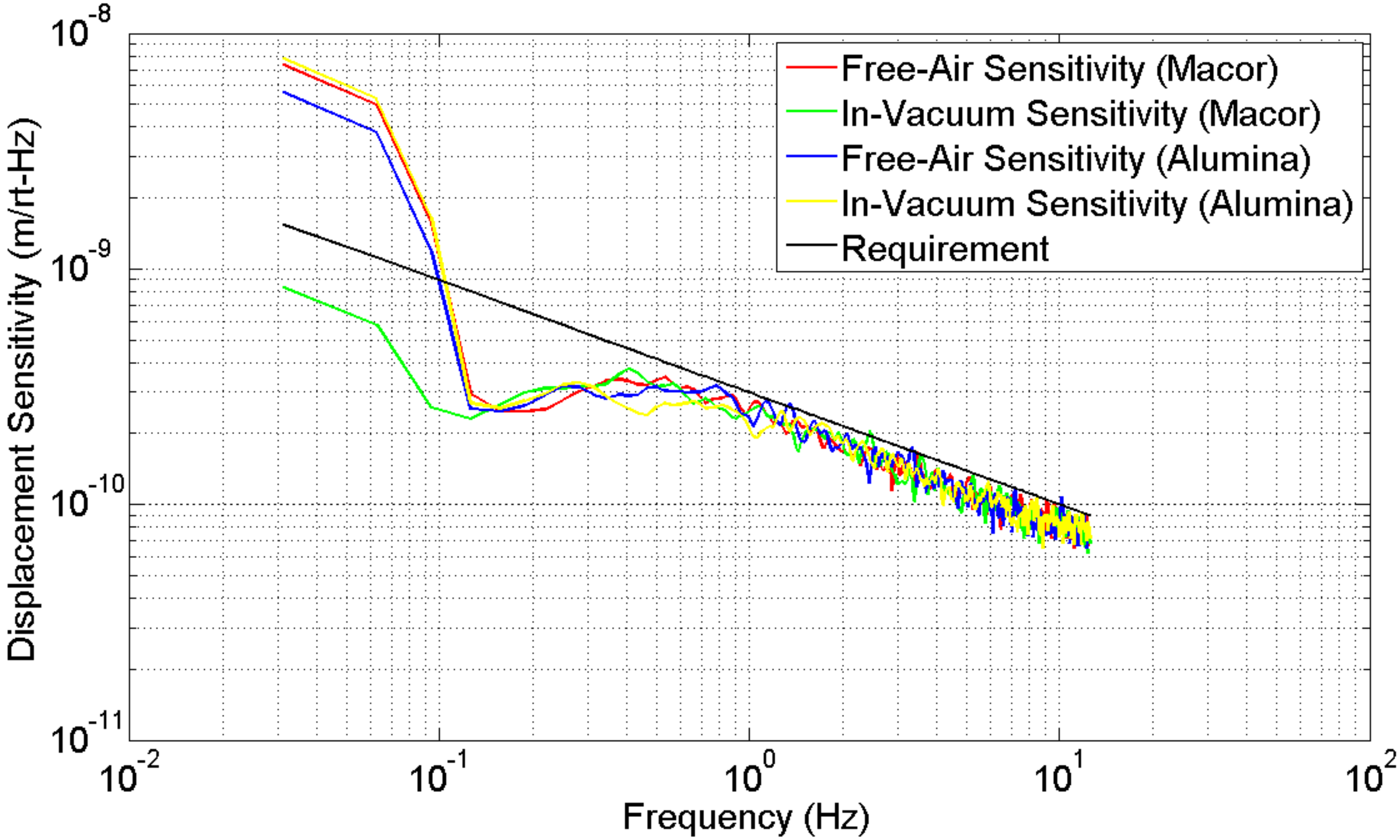
- Requirements[1]:-
  - Sensitivity @ 1Hz = 3×10^{-10}m/√Hz and @ 10Hz = 1×10^{-10}m/√Hz
  - Operating Range 0.35mm (peak-peak)



[1] K.A. Strain *"Input to the OSEM selection review decision".* LIGO-T040110-01-K

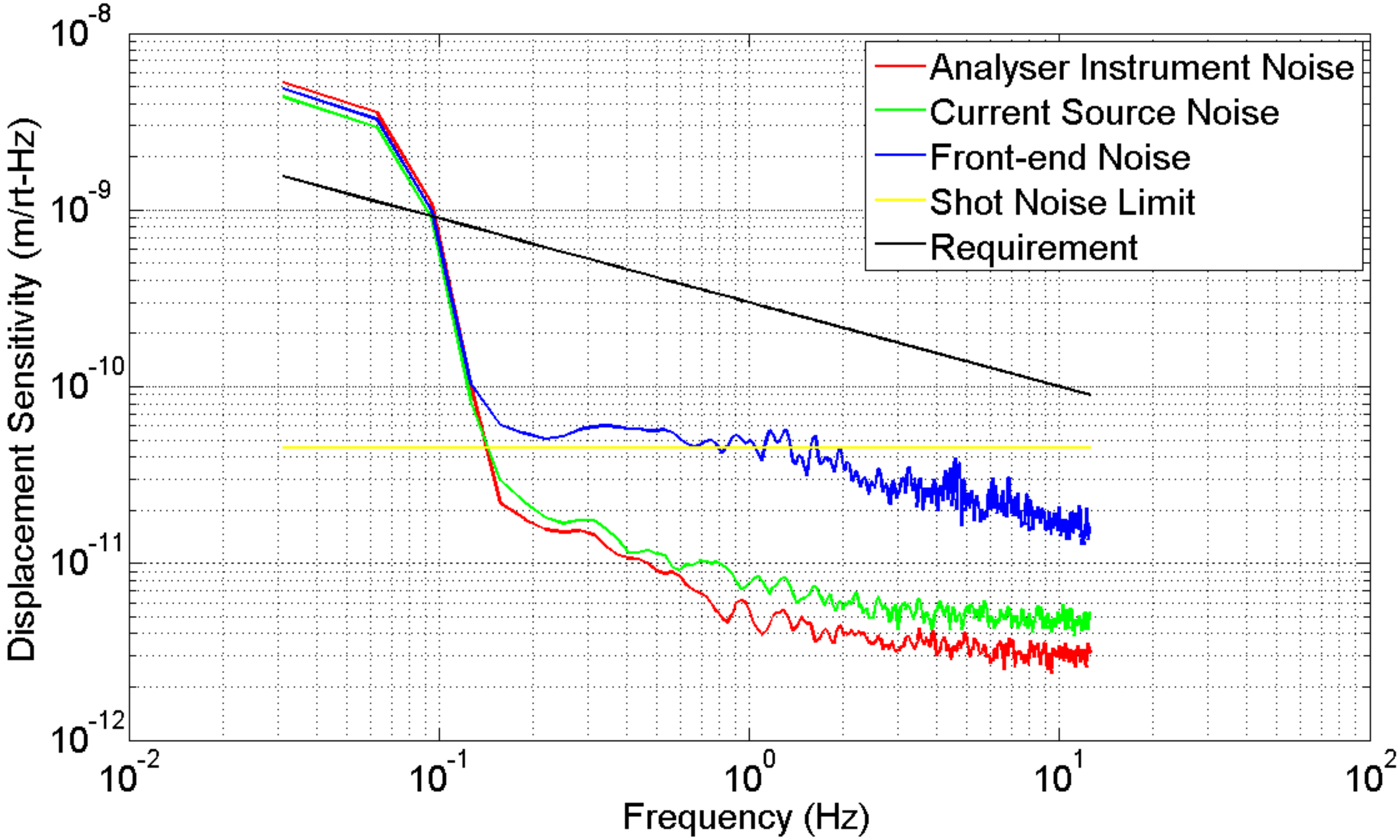
BOSEM:- Characterization III

- In search of a factor of 3 improvement @ 1Hz:-
  - Switched Macor Sleeve (1.46 W/mK) with Alumina Sleeve (35 W/mK)
  - Applied thermal compound at key interfaces (no observable improvement)



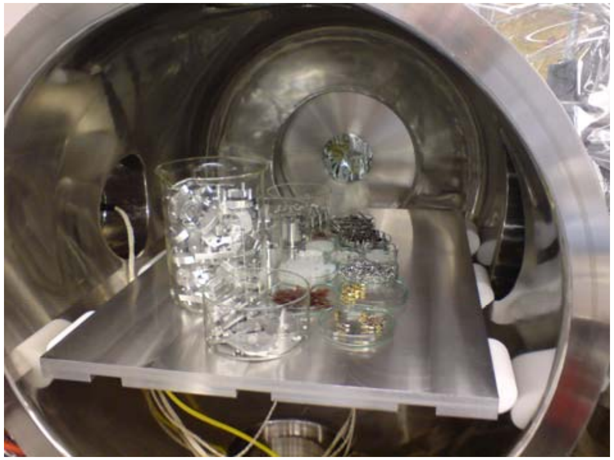
BOSEM:- Characterization IV

- Sanity check of electronics noise sources:-
  - Do not appear to be restricting us (n.b. these have been end-to-end measurements)
  - Further investigation of noise sources is ongoing (plus other stabs-in-the-dark)



BOSEM:- Noise Prototype Status

- Noise Prototype deliveries are complete! ☺ *(Spring 08)*
  - Comprised of:-
    - 79 units in total delivered to USA
    - Units were assembled, tested and shipped as LIGO UHV compliant parts
    - Cleaning and baking carried out in Birmingham facilities
    - LIGO UHV qualification (e.g. RGA scans) undertaken at Caltech
  - Current Status:-
    - Units employed in Quad at LASTI, OMC, and Tip/Tilt suspensions
    - Operational experience gained has been fed back into final production BOSEM



Pre-assembly bake out

Dedicated clean-room assembly suite

Assembled BOSEMS at testing station

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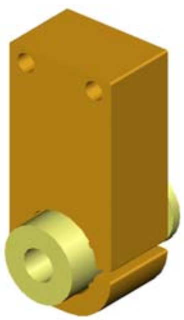
BOSEM:- Full Production Status

- Full production of 654 BOSEMs (inc spares and Noise Prototypes) underway:-
  - Rough Breakdown:-
    - ~6 months parts procurement and fabrication (March 08 – August 08)
    - ~6 months assembly and testing (September 08 – February 09)
  - Key Milestones:-
    - 1st delivery, 28th November 2008 (training exercise) ~24 Units
    - Final delivery, 1st June 2009


Received opto-electronic parts

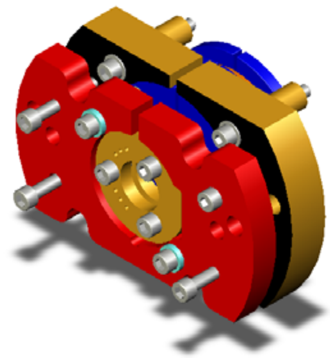

Mechanical parts awaiting inspection

BOSEM:- Evolution



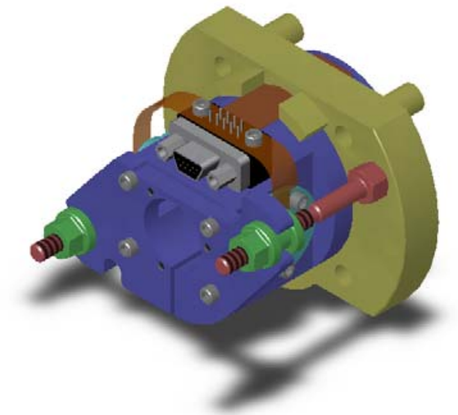
Initial LIGO

(OSEM)



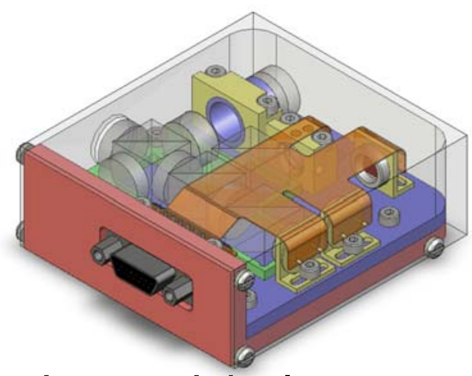
Advanced LIGO

Controls Prototype (Hybrid OSEM)



Advanced LIGO

Noise Prototype & Final Production (BOSEM)

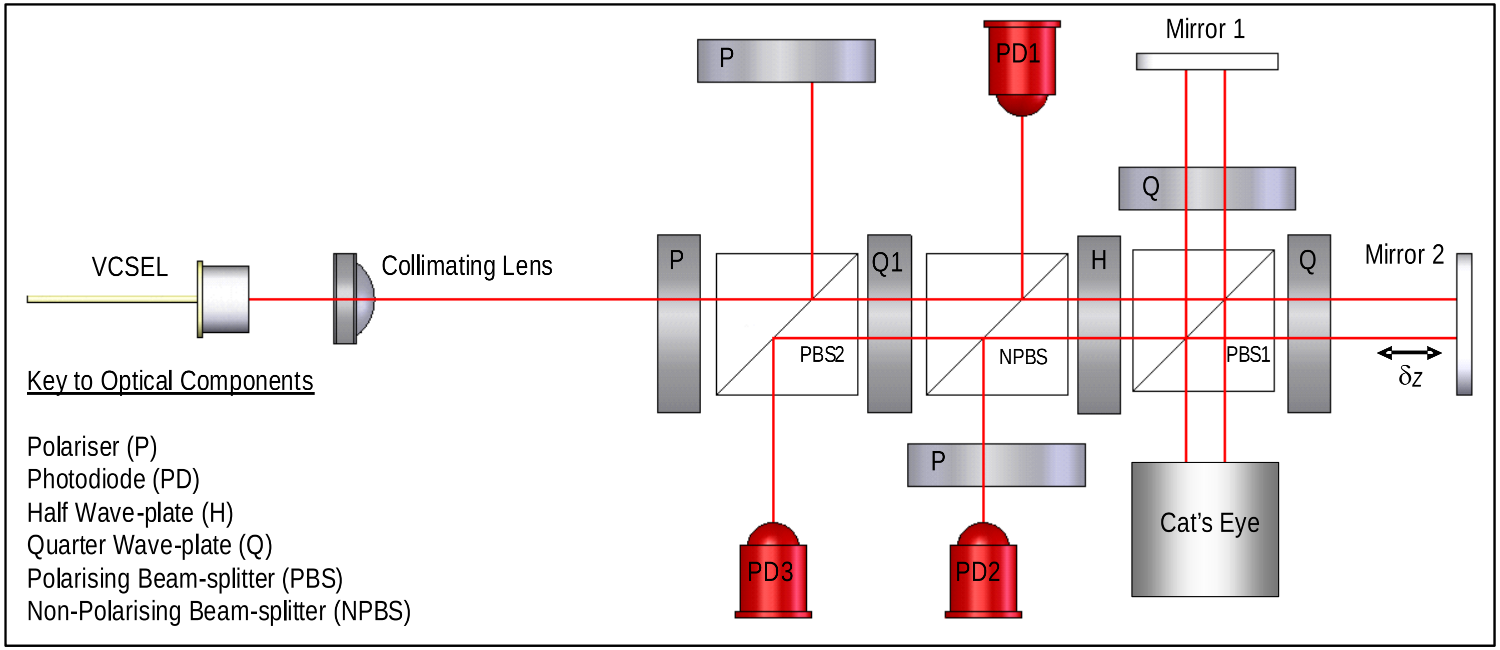


Advanced / Ultra LIGO

(Interferometric Sensor (EUCLID))

Interferometer:- Design Motivation

- OSEMs offer the best you can hope for with a shadow sensor configuration
- To ensure good <u>low frequency stability</u> we needed to avoid active parts that can age, thermally expand, generate heat, exhibit hysteresis, e.g. piezos, AOMs, EOMs etc. This naturally led to a Homodyne Interferometer
- Required to be, compact / portable, and robust against misalignment. This has led us to develop a compact interferometric sensor (EUCLID)

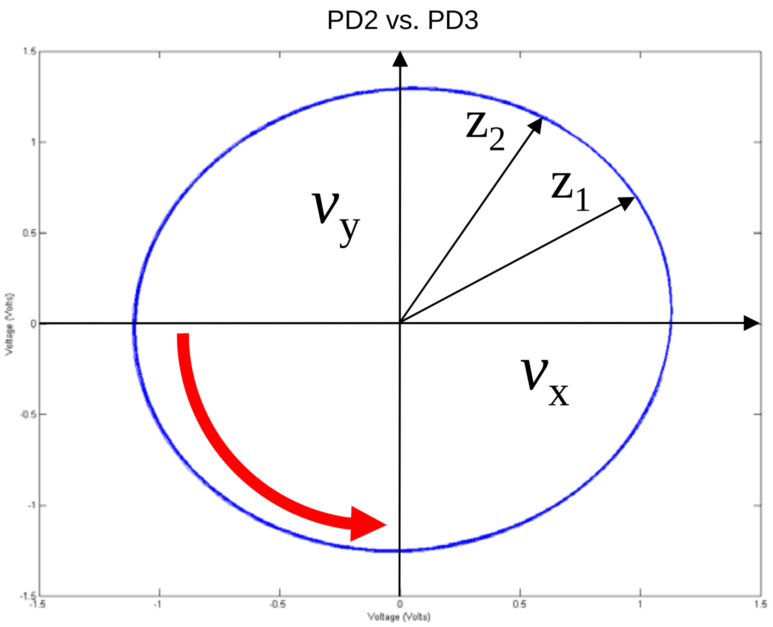


Optical Layout [2]

[2] C. C. Speake and S. M. Aston *"An interferometric sensor for satellite drag-free control".* IOP, Class. Quantum Grav. 22 (2005)

Interferometer:- Fringe Interpolation Method

- Two fringe intensities I_2, I_3 are 90° out of phase (PD2 and PD3)
- Target mirror motion (Mirror 2) generates a circular Lissajous figure with I_2, I_3 plotted as v_x, v_y



- Phase calculation:-

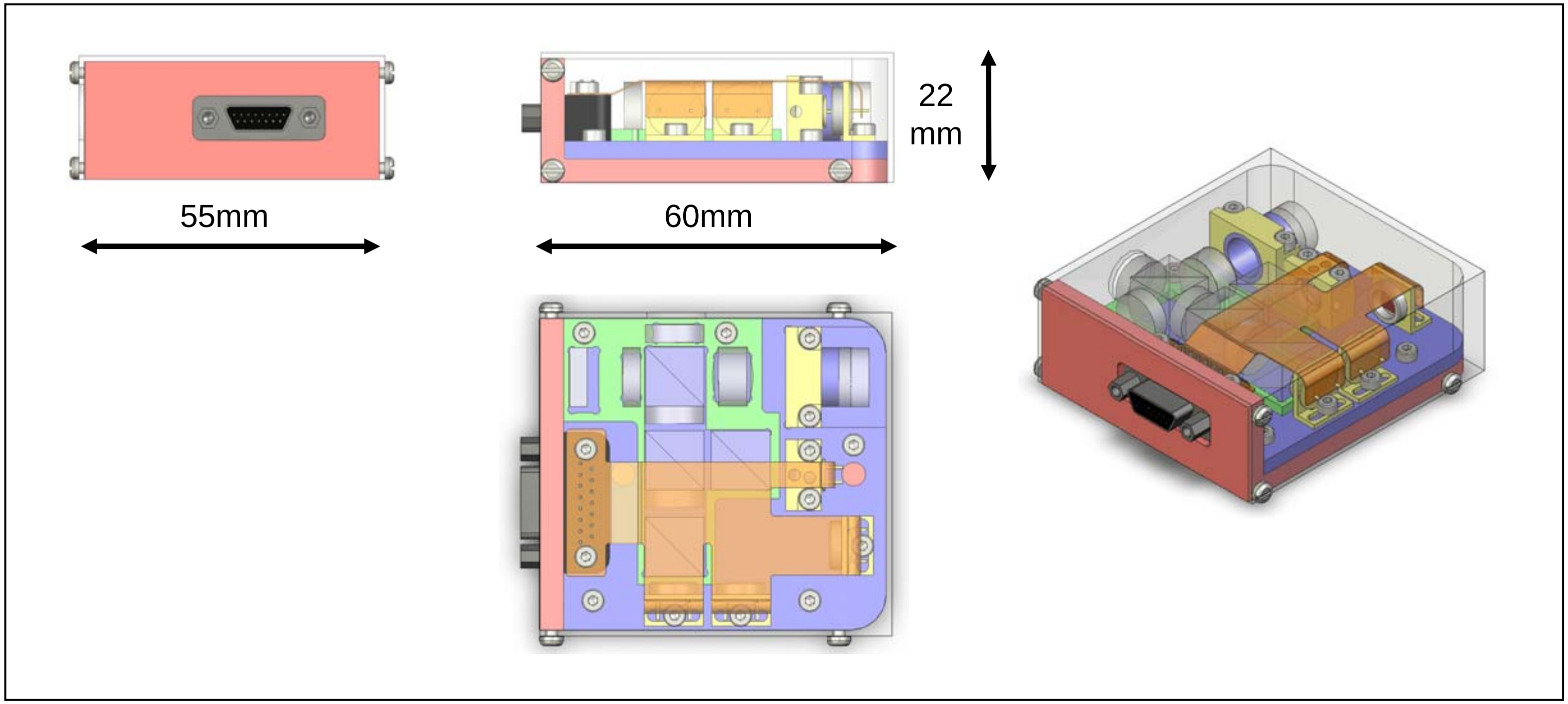
$$\Delta\phi = \arctan\left(\frac{\left(v_{y_2} - v_{y_0}\right)}{\left(v_{x_2} - v_{x_0}\right)}\right) - \arctan\left(\frac{\left(v_{y_1} - v_{y_0}\right)}{\left(v_{x_1} - v_{x_0}\right)}\right)$$

- Displacement calculation:-

$$\Delta z = \frac{\Delta\phi}{2\pi} \cdot \frac{\lambda}{4}$$

Interferometer:- Design Realisation

- Compact dimensions of 60mm x 55mm x 22mm
- Robust against misalignment +/- 1°
- Resolution of 1 pm/√Hz over a large working range > 2mm
- Can be constructed to be LIGO UHV compliant
- Incorporates VCSEL with known high MTBF



3D CAD Model

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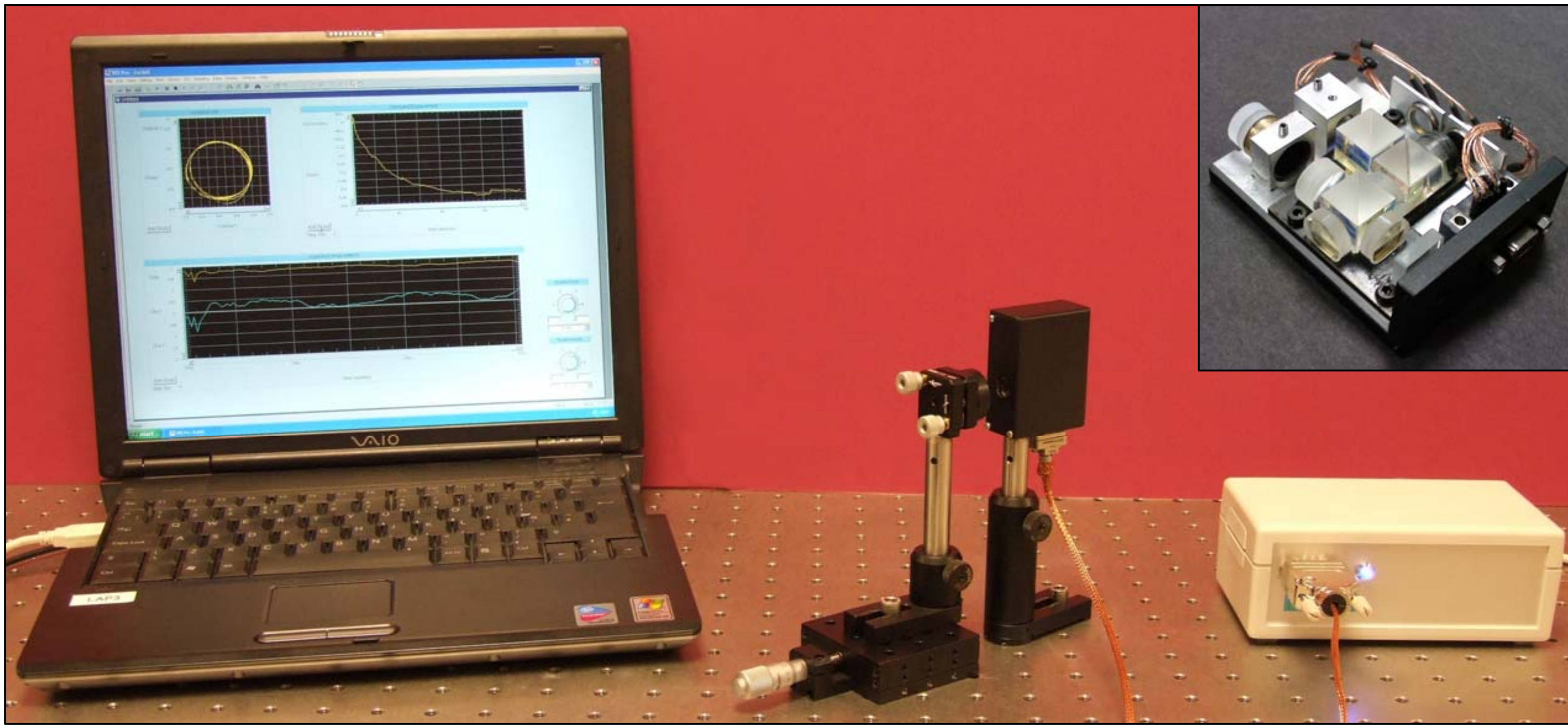
Interferometer:- Prototype Fabrication

- We have designed and fabricated a bench-top prototype for evaluation
  - Also Includes:-
    - Data processing software
    - Support electronics
- Characterization is ongoing



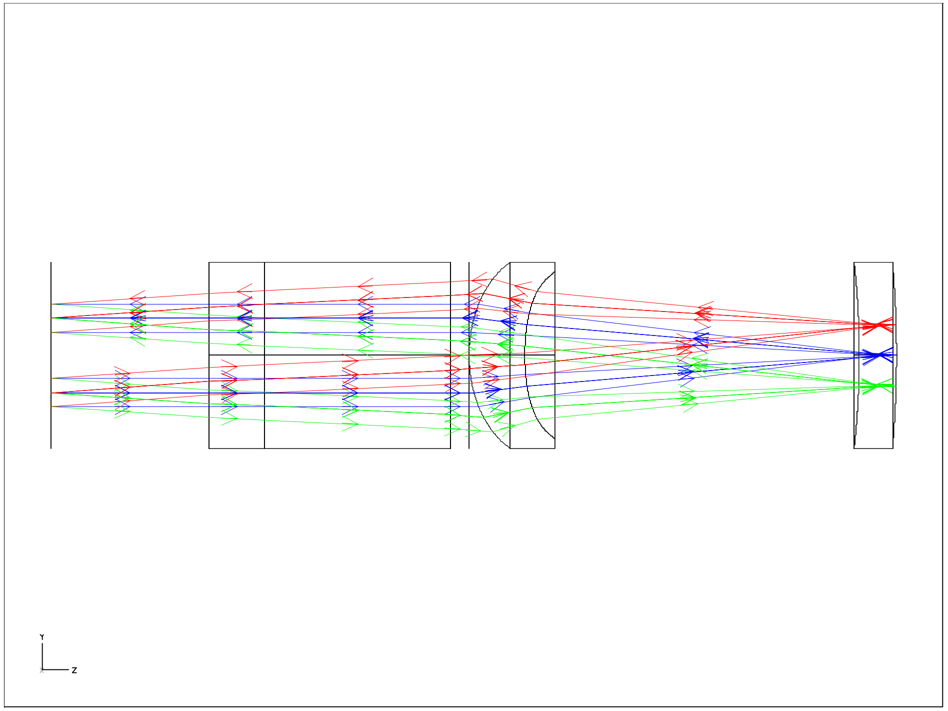
Prototype and support equipment. (Inset: with cover removed)

Interferometer:- Optical Development I

- Optimisation of the lens shape with Zemax
  - Fabián Peña Arellano

- The effect of aberrations on the wavefront is minimised

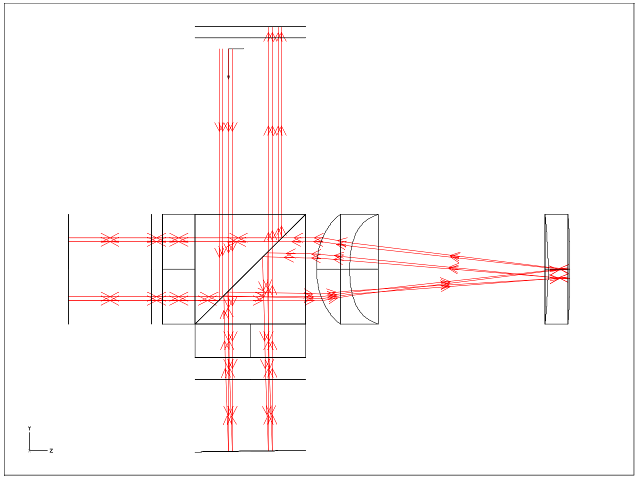
- The parameters are also adjusted using other configurations in order to achieve the best mirror tilt immunity possible



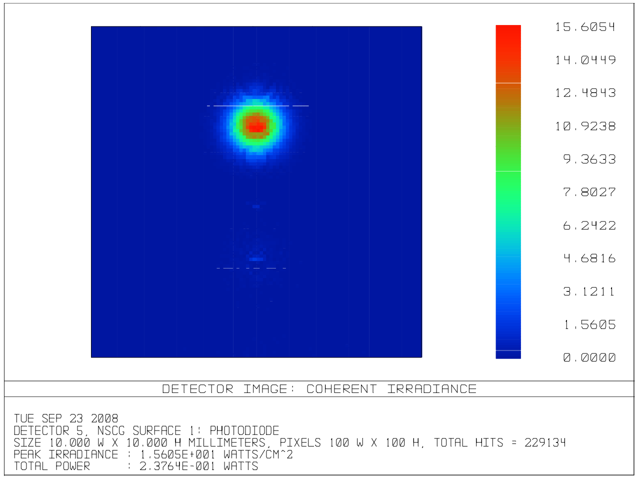
OPTO CAD Model

Interferometer:- Optical Development II

- Calculation of the fringe visibility
  - *Fabián Peña Arellano*
- Achromat. Preliminary quantitative agreement
  - For 1° mirror tilt:-
    - ± 1 mm displacement range
    - 50% change in visibility
- Aspheric. Preliminary prediction
  - For 1° mirror tilt:-
    - ± 5.7 mm displacement range
    - 50% change in visibility



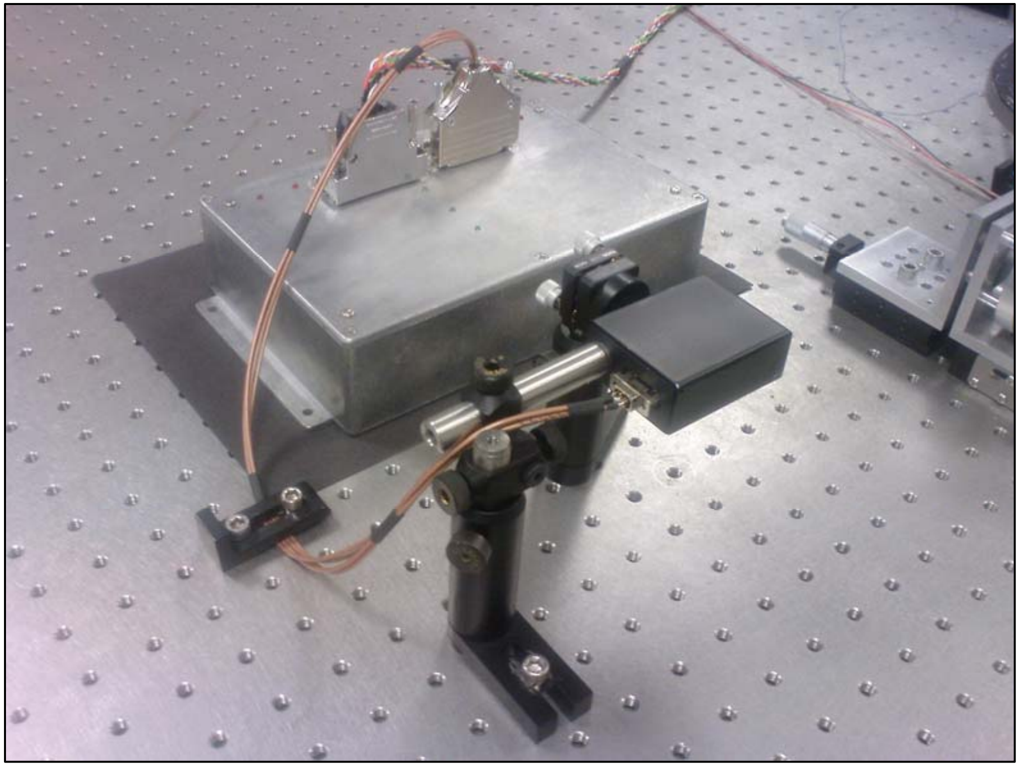
OPTO CAD Model



OPTO CAD PLOT

Interferometer:- Electronics Development

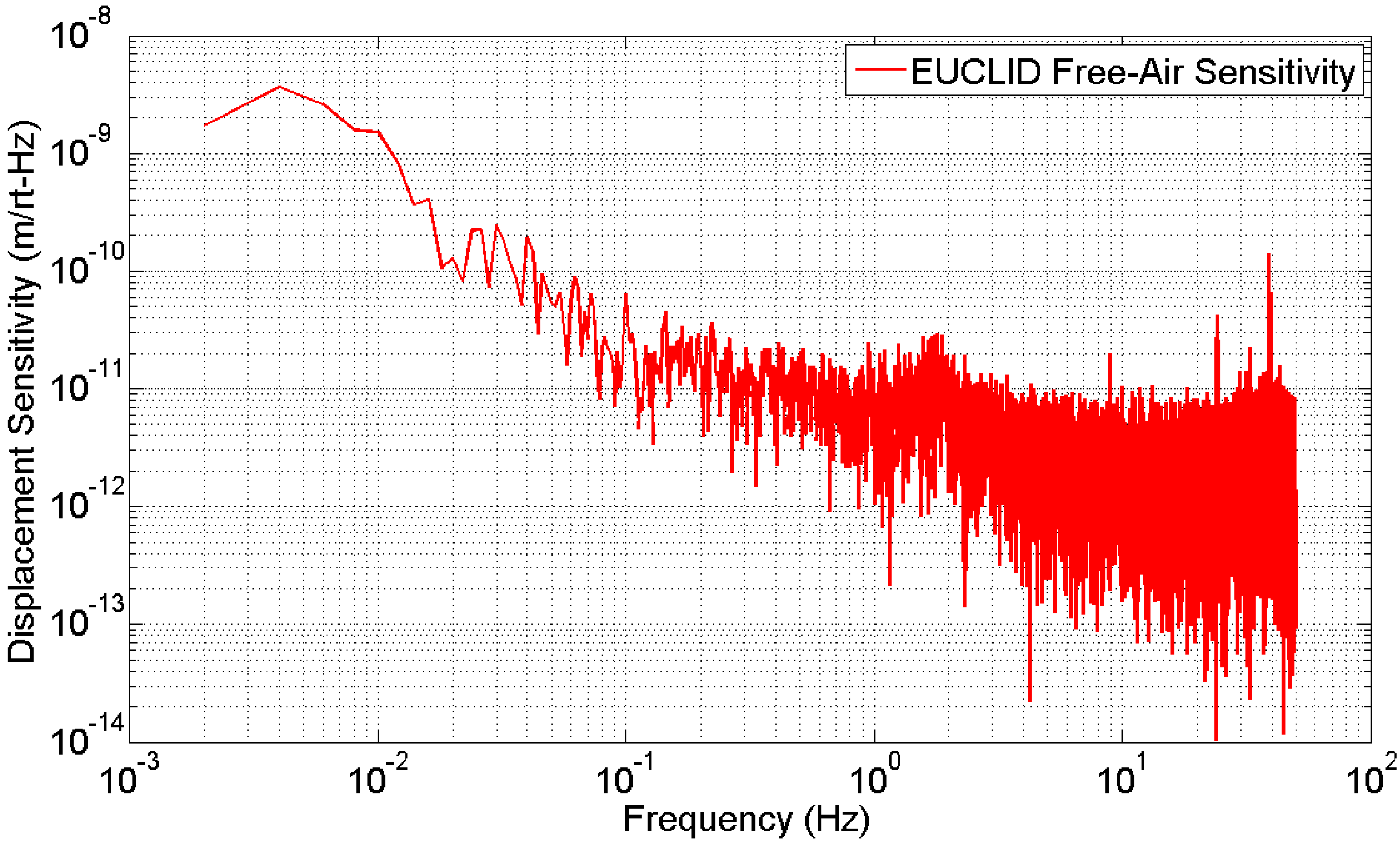
- Design and fabrication of support electronics:-
  - *David Hoyland*
- Modified BOSEM Satellite Box:-
  - Utilises single channel (of 4 available) current source
  - Utilises 3 channels (of 4 available) of trans-impedance amplifiers



Support Electronics and Interferometer Prototype

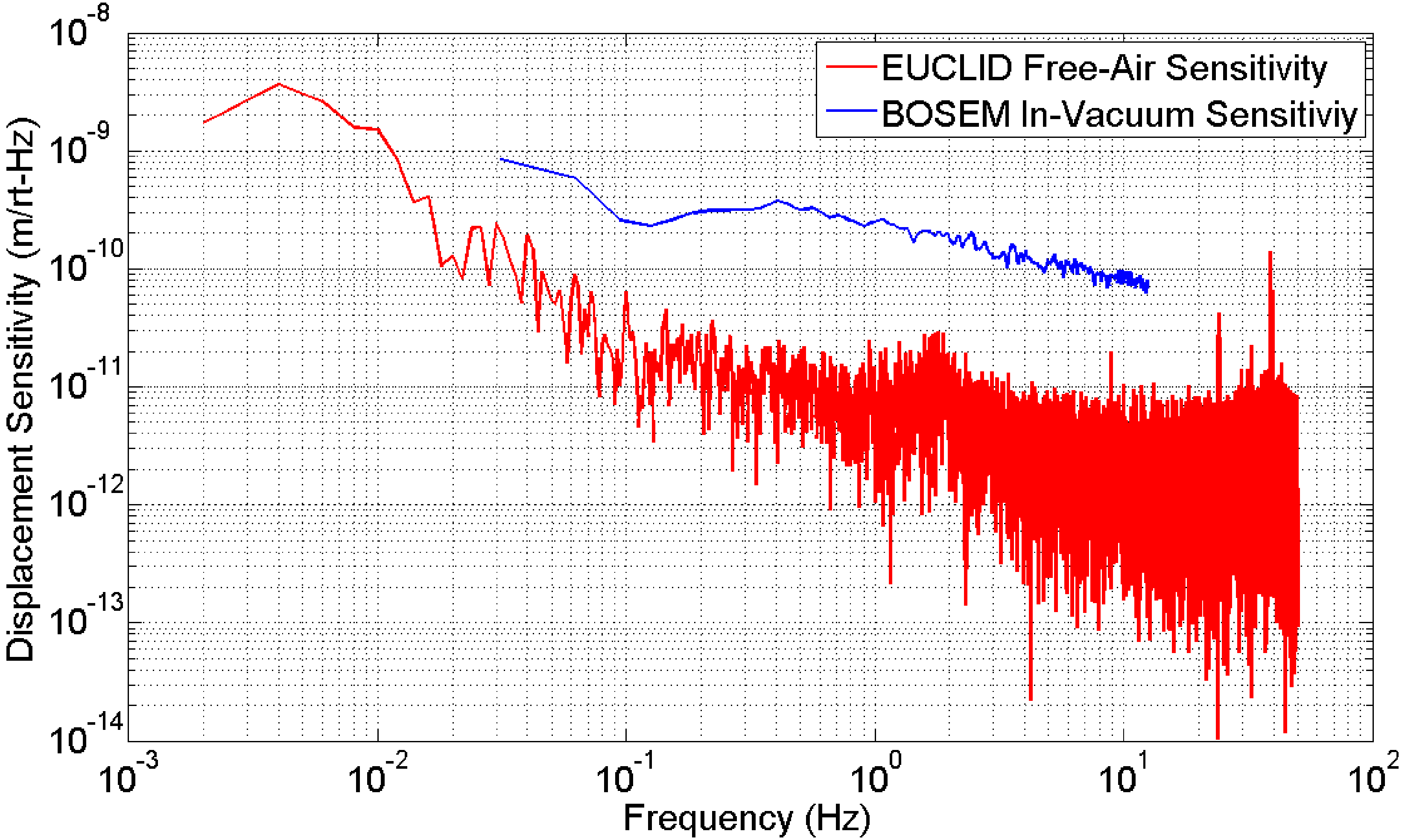
Interferometer:- Characterization I

- Results from end-to-end test driving EUCLID with Satellite Box



Interferometer:- Characterization II

- Comparison between Interferometric OSEM and BOSEM performance
  - n.b. we plan to go in-vacuum and try temperature controlled VCSEL diodes



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Summary

- Continue with our task to deliver and support in-vacuum BOSEMs and Harnesses for Advanced LIGO
- Deliver and support electronics coil drivers for Advanced LIGO
- Build upon the experience gained with BOSEMs and apply to interferometer development. For example:-
  - Transfer knowledge from manufacturing study and clean-assembly processes
- Continue to develop and characterise interferometric OSEM (EUCLID)
  - Produce additional prototypes
  - Hope to supply a quantity of non-UHV and UHV samples to LIGO for evaluation
- We seek feedback on interferometric OSEM specifications. For example:-
  - What features would be desirable for potential applications?
    - Sensitivity
    - Working range
    - Dimensions
    - Tilt-immunity
    - Cost

Thank you for your attention