OSEM Development
UK Advanced LIGO project

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Overview

- Requirements:
  - Generic OSEM Requirements
  - OSEM Noise Performance Requirements
- OSEM Development Concepts:
  - Geometric based OSEMs
  - Interferometer based OSEM
  - Performance Summary
- Conclusions:
  - OSEM Recommendations

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Generic OSEM Requirements

- Range:
  - 3mm (peak-peak) working range (1.06mm *rms*), incorporating:
    - ± 1mm operating range
    - ± ½mm tolerance for relative positioning of OSEM and sensed mass
- Fit: (sensors must fit actuator)
  - Sense motion of mass through bore hole of coil former
  - Constraints (for the case of the TM quad) restrict layout envelope to 40mm (diameter) x 70mm (length), including connectors and mounts
- Vacuum Compatibility:
  - Sensor components must meet the vacuum compatibility requirements appropriate to an Advanced LIGO vacuum chamber
- Electrical Compatibility:
  - Sensor drive and output must be compatible with the specification of cables passing through the SEI system (ideally using LIGO cables)

OSEM Noise Performance Requirements

- Sensitivity Requirements for Local Control OSEMs:
  - Assume Eddy current damping and ISC feedback, most stringent requirement is MC longitudinal = $1.72 \times 10^{-11} m/\sqrt{Hz}$ *
  - For more detail, see E040108-00-K

- Sensitivity Requirements for Global Control OSEMs:
  - Science mode noise requirement about 10Hz: $\approx 1 \times 10^{-10} m/\sqrt{Hz}$ *
  - This figure also encompasses:
    - Transverse horizontal sensors on all suspensions
    - Other, less critical, degrees of freedom on RM and MC
  - Note that almost half the OSEMs fit one or other of these categories

* Figures extracted from “Recommendation of a design for the OSEM sensors” document LIGO-E040108-00-K

OSEM Concept Development

- Geometric Sensors:
  - Prototype developed by C.C. Speake and S.M. Aston at the University of Birmingham
  - Parallel independent development undertaken by our collaborator N.A. Lockerbie at the University of Strathclyde

- Basic Operation:
  - Use a reasonably collimated and strongly modulated light source
  - High power IRLED (880nm) emitter (OP-50L)
  - Beam passes through optical system which is partly mounted on an extension of the sensed mass
  - Beam is incident on a split photodiode detector
  - Detected photocurrents are demodulated to produce sum and difference signals:
    - Difference output provides useful displacement measurement read-out
    - Sum signal enables active intensity stabilisation of emitter output

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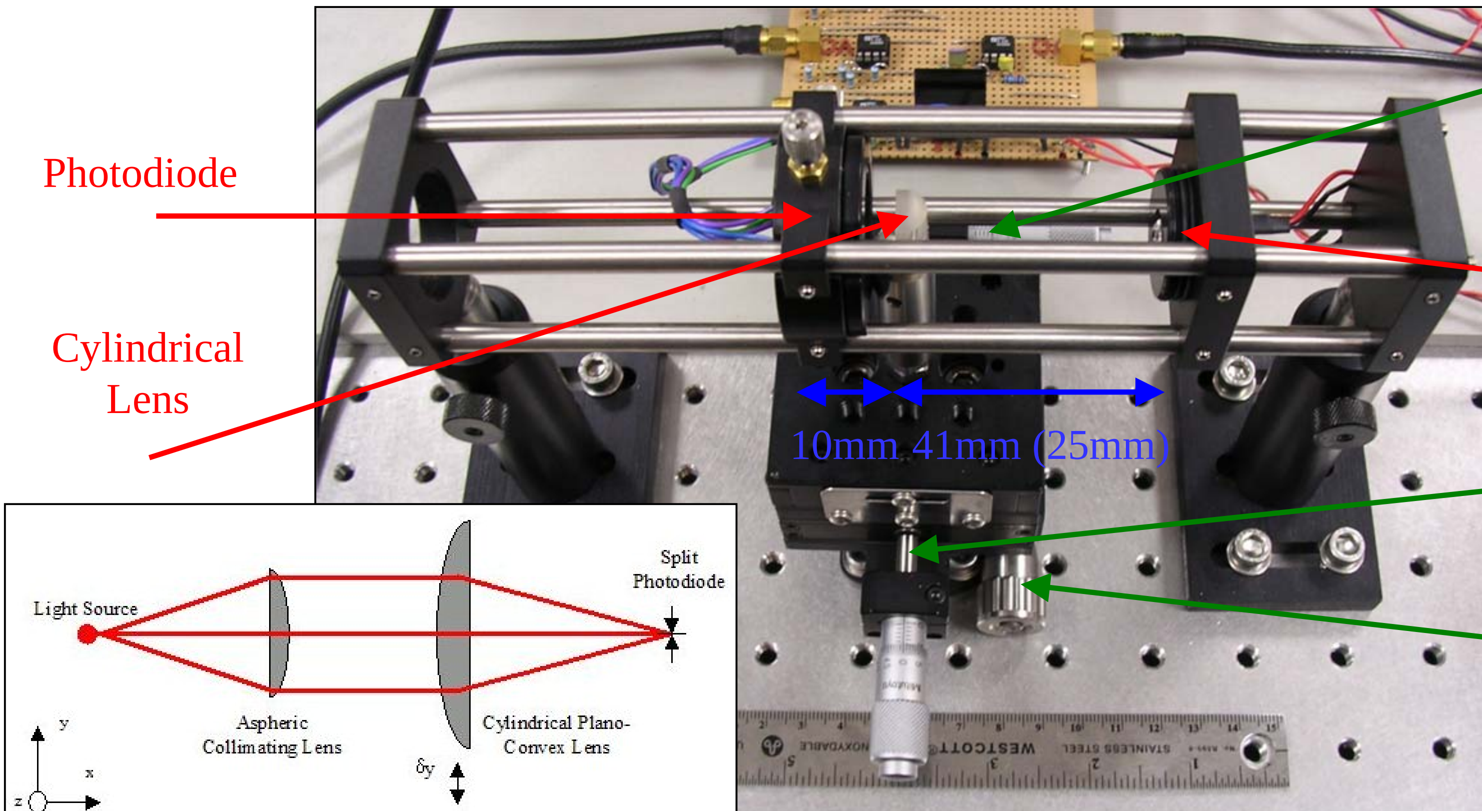
OSEM Concept Development

- Geometric Sensor Prototype (University of Birmingham):



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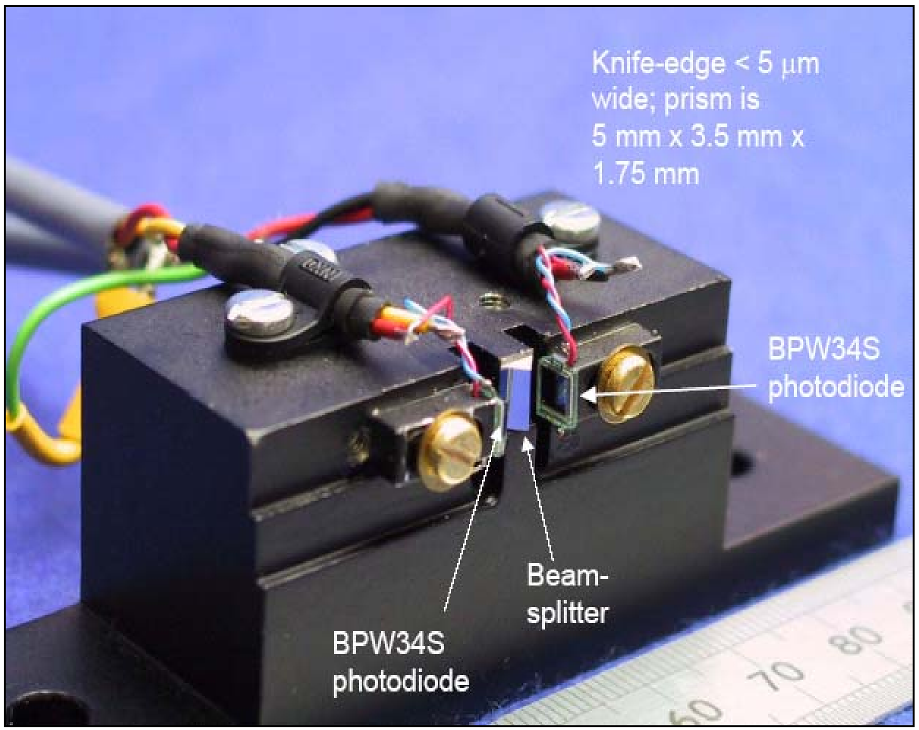
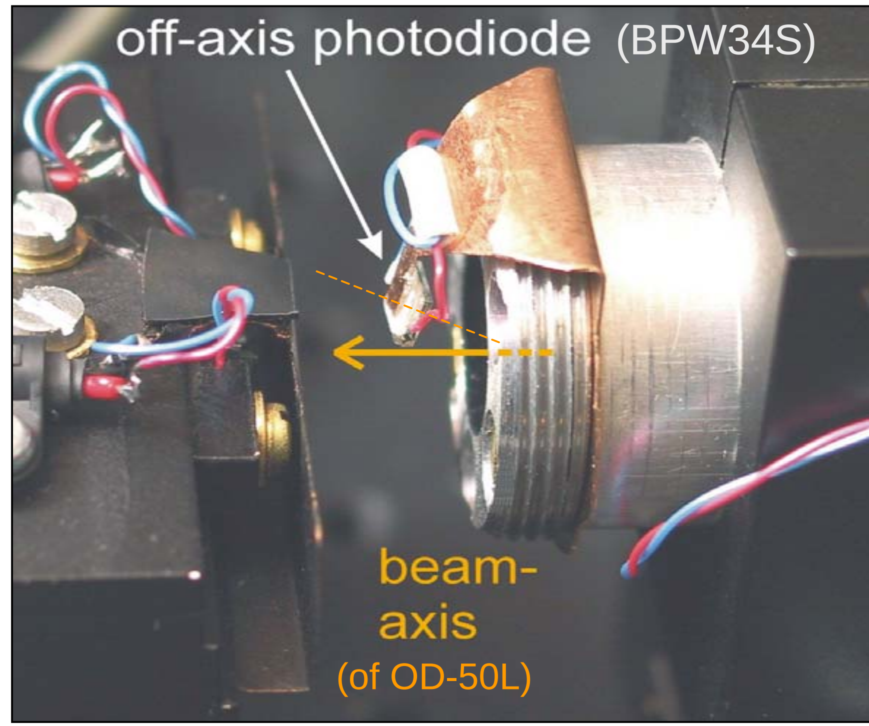
OSEM Concept Development

- Geometric Sensor Prototype (University of Strathclyde):





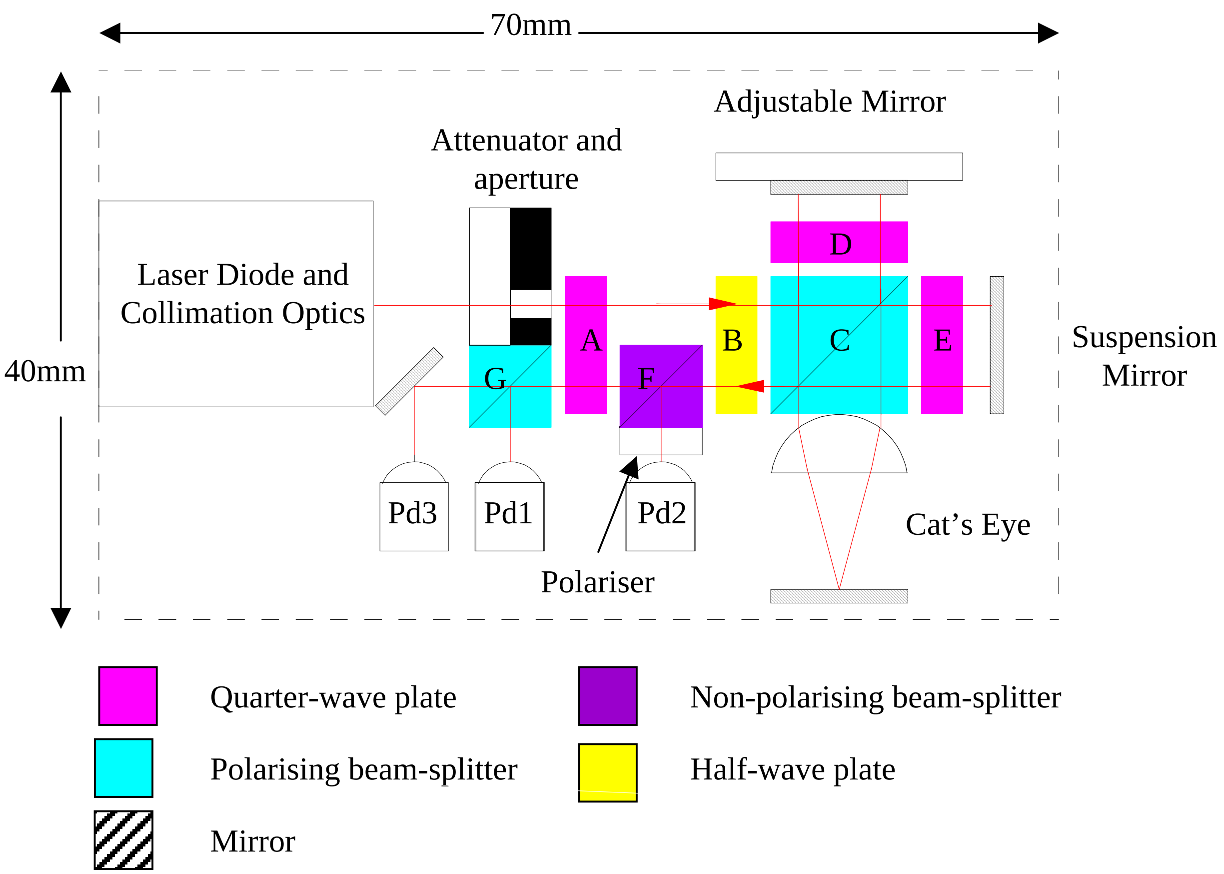
OSEM Concept Development

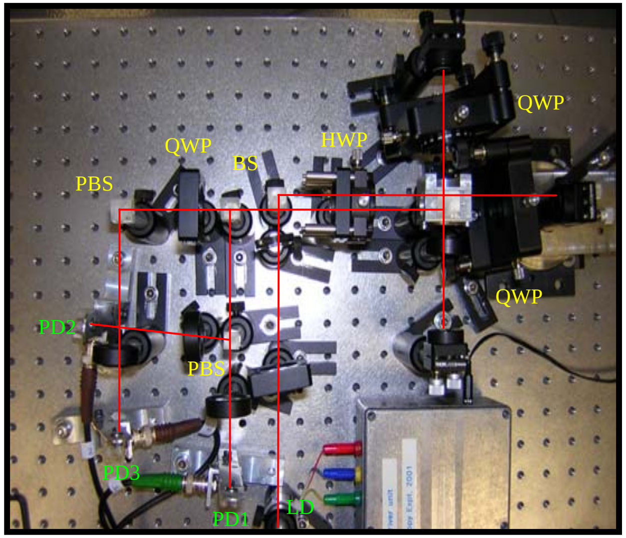
- Interferometric Sensor:
  - Development by C. Speake and S. Aston at the University of Birmingham

- Basic Operation:
  - Use a collimated laser diode light source
  - Low power (3mW) emitter (HL6314MG) at 635nm
  - 3 output interferometer has single element “bug-eye” pd’s at each output
  - Polarising beam-splitter gives quadrature outputs for 2 ports
  - 3rd port output is 180^{0} out of phase (allows subtraction of dc offsets)
  - 3 outputs are subtracted in pairs (via 2 difference amplifiers) resulting in 2 dc corrected channels to be read-out
  - Signal processing allows the fringes to be counted as well as fractional fringe measurements to be made
  - Dynamic range limited by the coherence length of the laser diode

OSEM Concept Development

- Interferometric Sensor Prototype (University of Birmingham):





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OSEM Development Performance

- Geometric Sensors:
  - Shot noise limited performance of $\leq 1.5 \times 10^{-11}$ m/√Hz about 10Hz and essentially flat down to 1Hz.
  - But this result was not achievable over the whole working range!
  - Common suspect component of excess noise is the IRLED emitter
  - Significant risk that there are no other alternative high power, low noise and good beam quality devices available

- Interferometric Sensor:
  - Performance of $\leq 5 \times 10^{-13}$ m/√Hz about 10Hz is achievable without a high power source or any modulation scheme
  - Perceived risk in complexity of construction and laser diode noise performance and MTBF (device screening maybe required)

Conclusions

- OSEM Recommendations:
  - We recommend the use of the interferometric design wherever high sensitivity is required together with basic (modified) initial LIGO OSEMs for global control and certain other locations

- Summary of Rationale:
  - Interferometric concept is the most secure approach to reaching the sensitivity requirement
  - Higher component cost partly offset by possible elimination of eddy current dampers