Interferometer Sensing & Control (ISC)

Technical Status
NSF Review of Advanced LIGO Project
April 26, 2011

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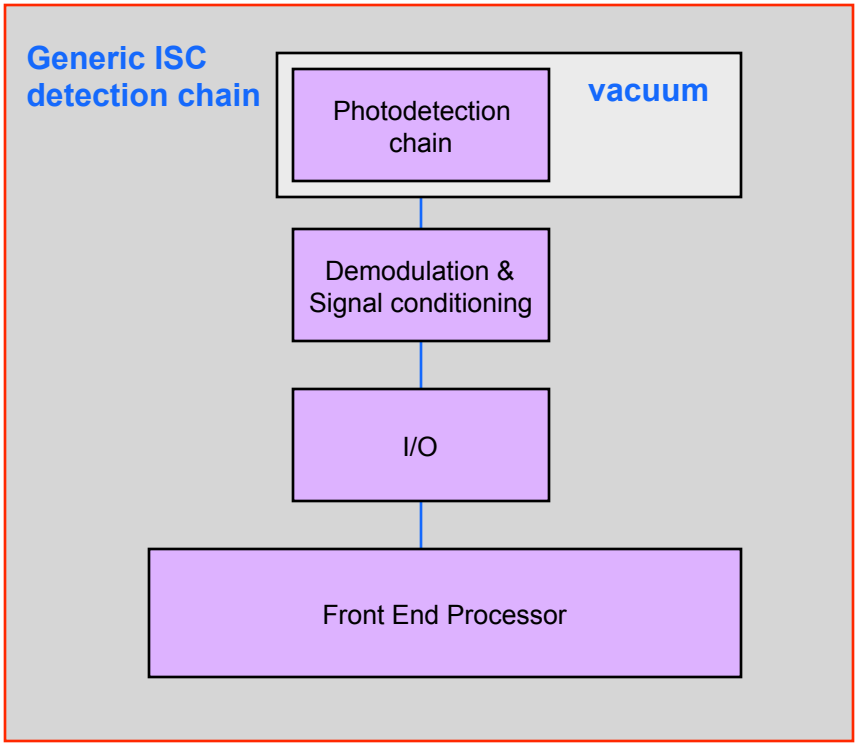
ISC Functions

- **Global sensing & control of the interferometer length degrees-of-freedom**
  - LSC: Length Sensing & Control
  - 4km arm lengths, recycling cavity lengths, Michelson
  - Final stage of frequency control
  - ***Readout of the gravitational wave channel***
- **Global sensing & control of the interferometer alignment**
  - ASC: Alignment Sensing & Control
  - 4 test masses + 1 beamsplitter + 2 recycling mirrors = 7
- **Lock acquisition of the interferometer**
- **Detection tables for all senses beams**
  - Opto-mechanical hardware; photodetectors
- **RF components: sources, distribution, demodulation**
- **Digital controls hardware and software for all length and alignment controls**

ISC Design Concept

- **Input beam phase modulation scheme**
  - » Designed to interferometrically sense all degrees-of-freedom with sufficient SNR
  - » Similar to initial LIGO, but different in detail due to additional cavity
- **Detection hardware**



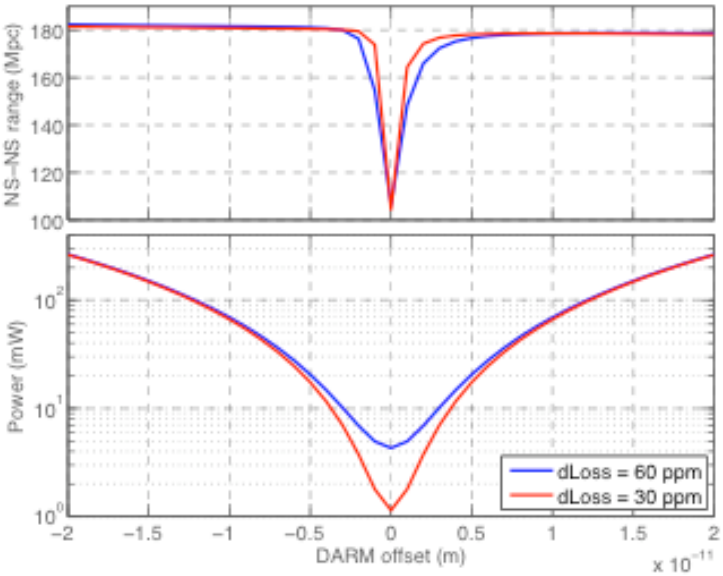
All beams involved in critical control loops will be detected in-vacuum, on vibrationally isolated tables

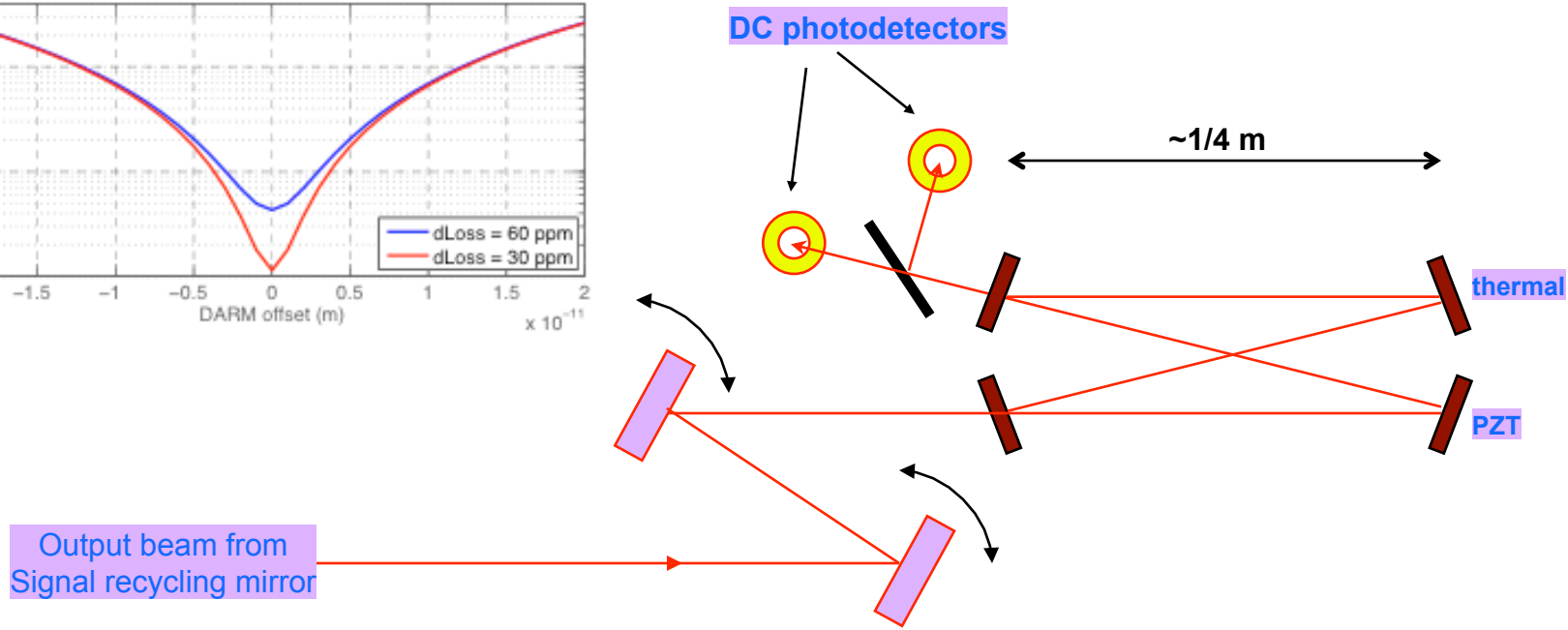
ISC Design Concept

- **Custom photodetectors**
  - Commercial InGaAs diodes, custom preamps
  - Single element diodes as used in iLIGO; quadrant diodes are new (used silicon in iLIGO)
  - Preamps designed to detect specific RF frequencies with high SNR
  - Vacuum packaging: electronics in a laser-welded custom box, w/ a feedthru for the photodiode (on vacuum side of box)
- **Signal conditioning electronics & controls**
  - RF sources, demodulation, signal conditioning filters: concepts similar to iLIGO with engineering updates based on lessons learned and new technologies
  - Digital controls
    - 16 kHz rate for LSC loops, 2 kHz for ASC
    - Infrastructure for data converters and real-time CPUs is defined by DAQ: commercial components used throughout

ISC Design Concept

- **GW channel: DC readout with output mode cleaner**

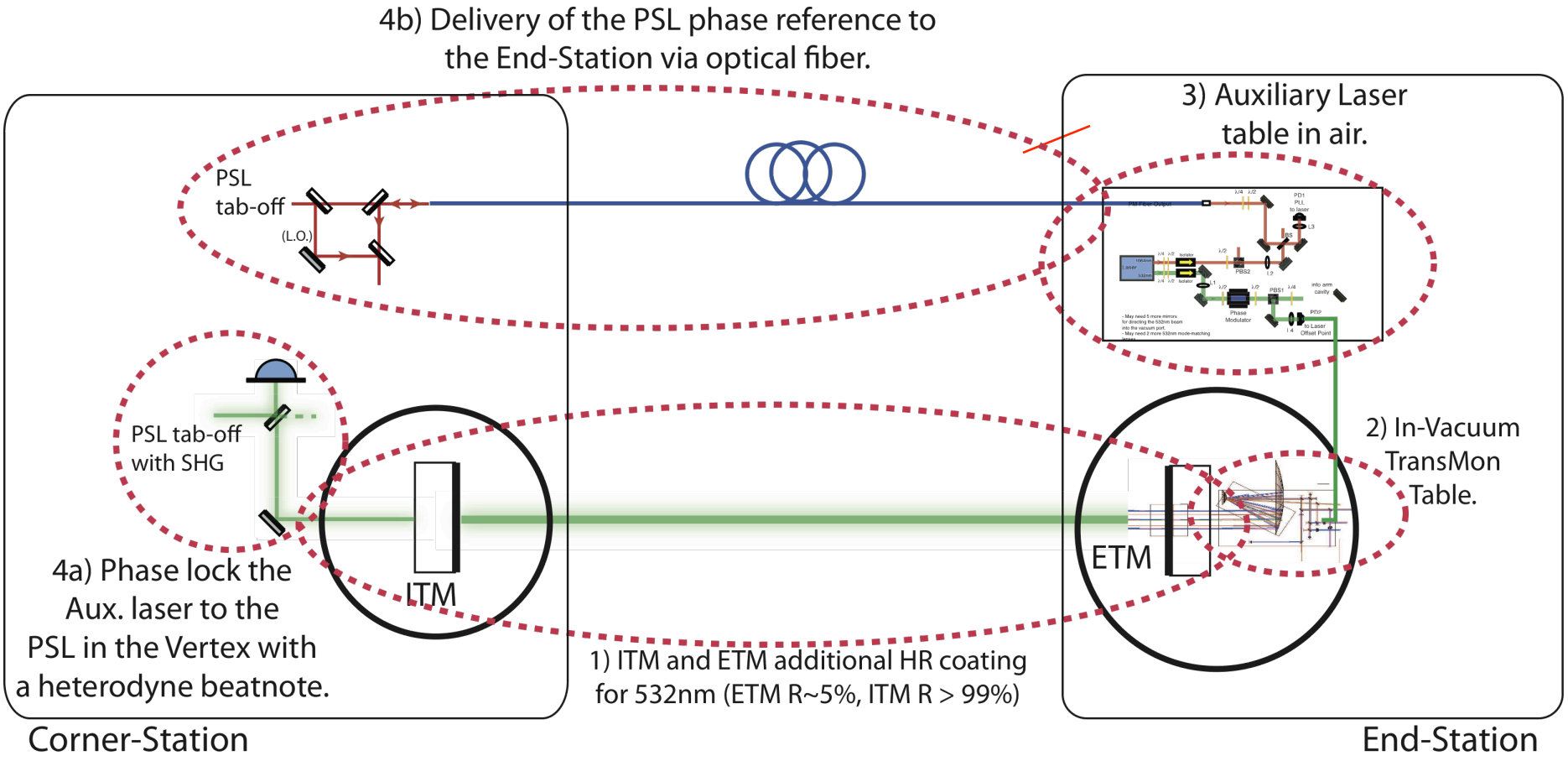




ISC Design Concept

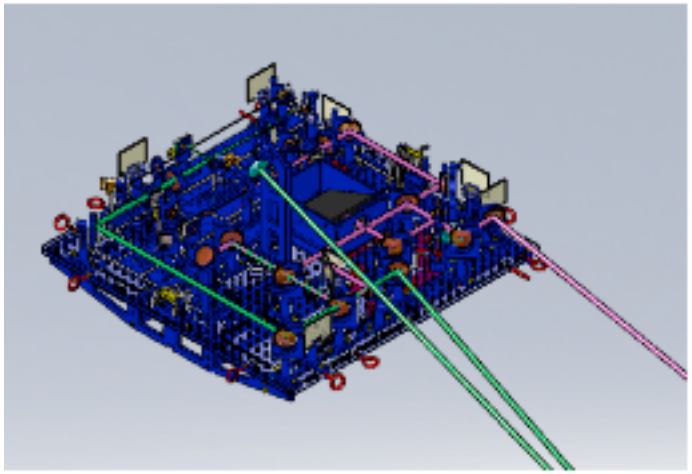
- **Lock Acquisition concept**
  - Start by controlling the long arms: put them at a known point off-resonance, and suppress fluctuations to ~1 nm
  - Lock up vertex degrees-of-freedom using RF signals that are more robust but have lower SNR than operation signals
  - Bring the arms into resonance in a controlled fashion
- **Arm Length Stabilization system achieves the first step**
  - Inject a 532 nm beam through the ETM and sense the arm cavity with Pound-Drever-Hall technique
  - TM coatings designed to give a moderate finesse arm cavity for the green beam & insensitive to the recycling cavity optics
  - Green beam is frequency locked to the main IR beam

Arm Length Stabilization design



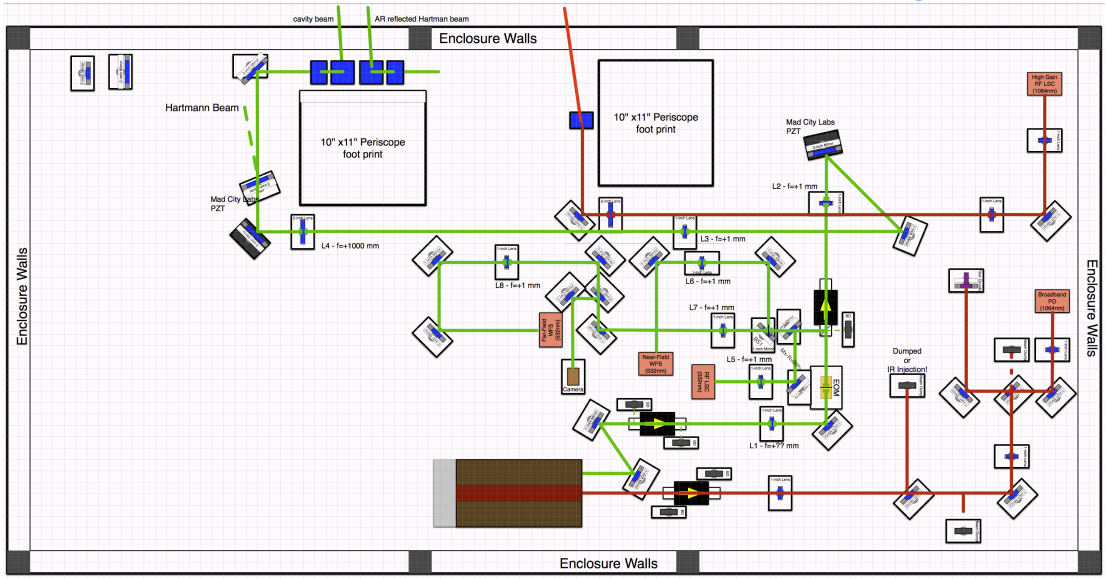
ALS design being carried out by ANU

ETM Transmission Monitor & ALS injection table



Suspended Transmission Monitor
Hung behind the ETM on a double suspension

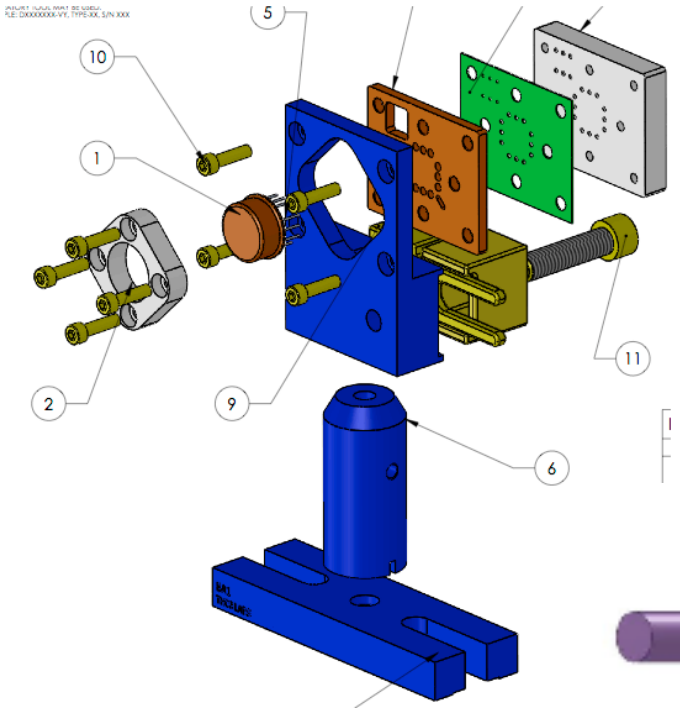
ALS laser and injection table

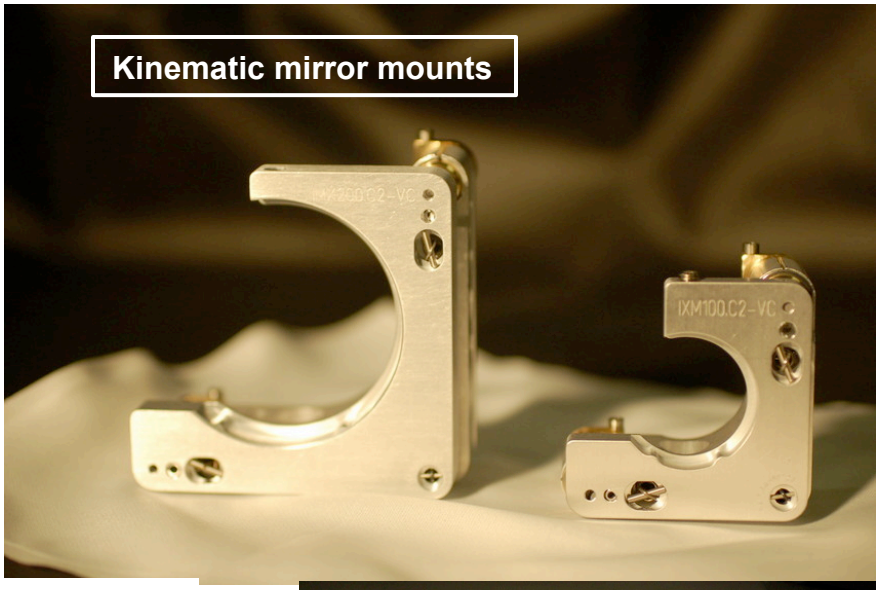


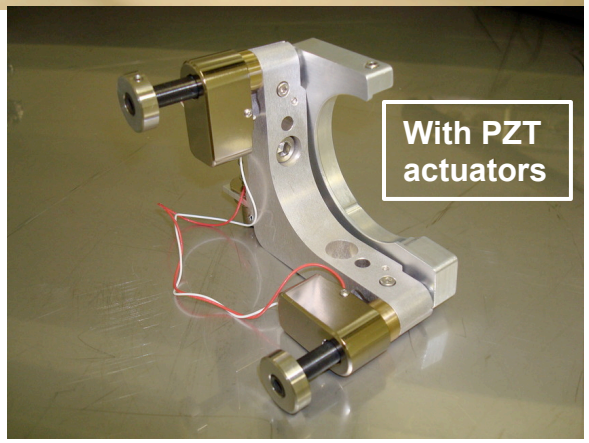
First unit currently being constructed at LHO

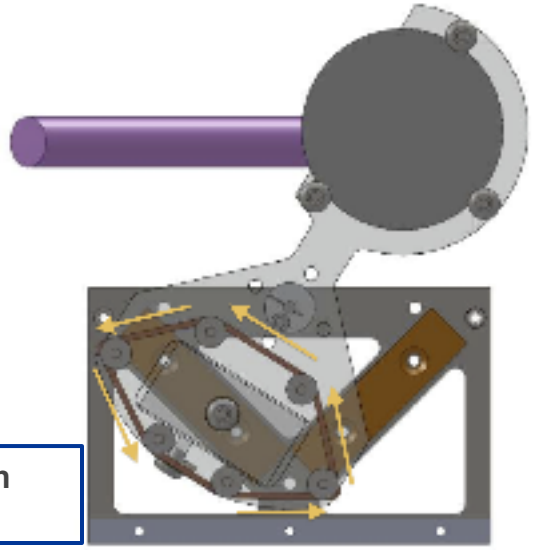
LIGO Components developed for TransMon & other In-Vac ISC detection

Quadrant Photodiode assembly



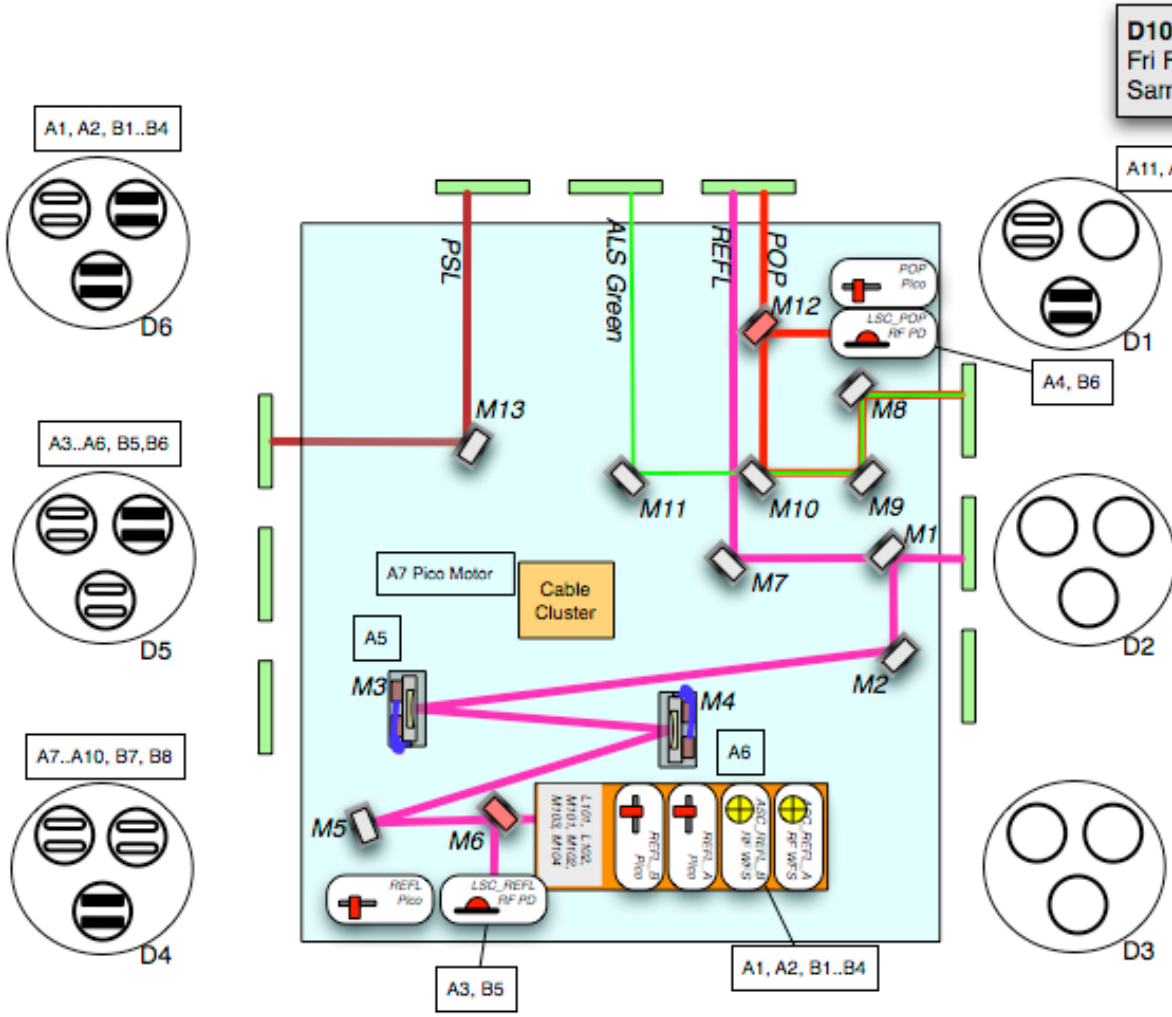






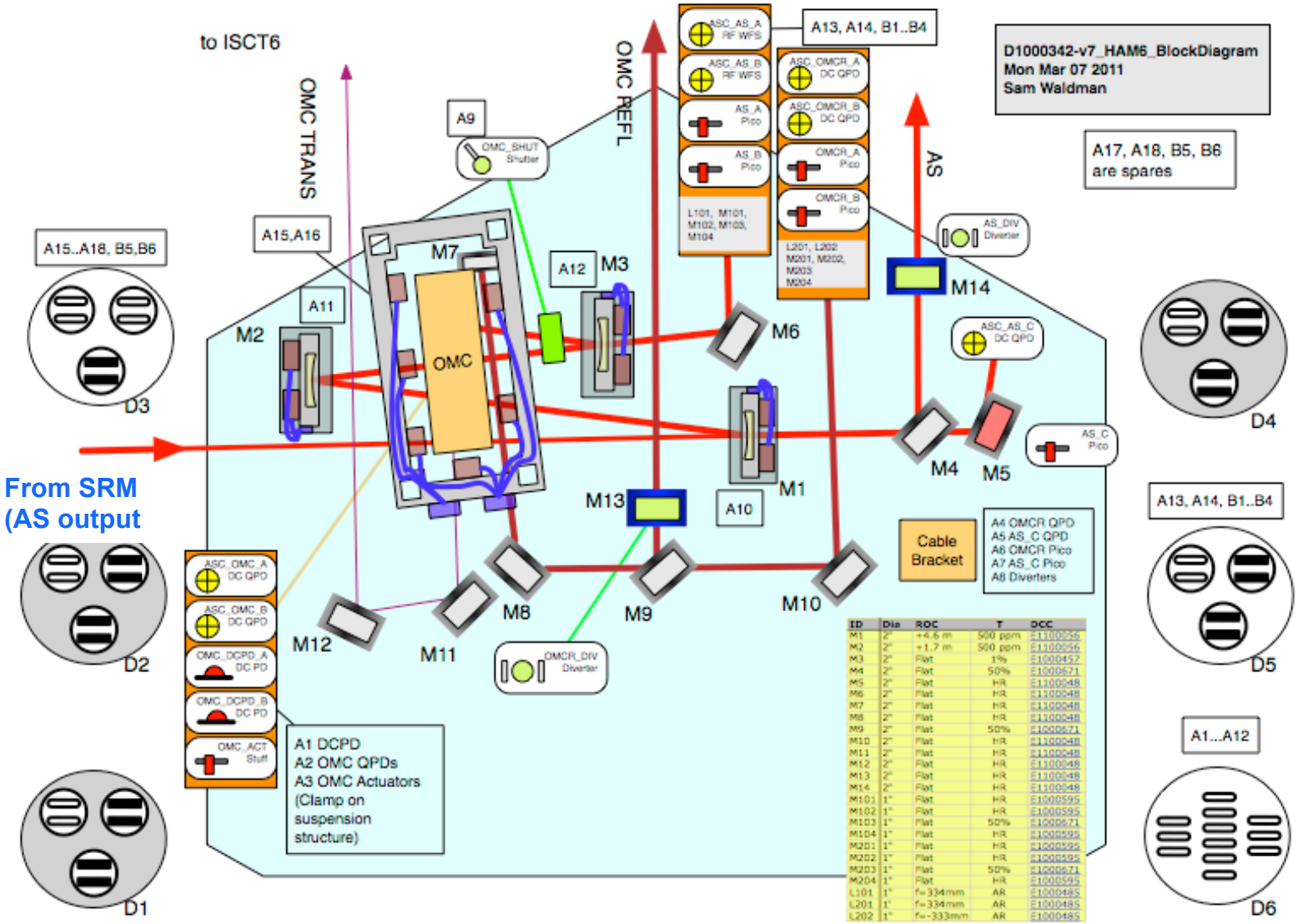
Beam diverter to dump high power beams in vacuum

In-Vacuum Detection of Reflection & PRC Pick-Off beams: HAM1



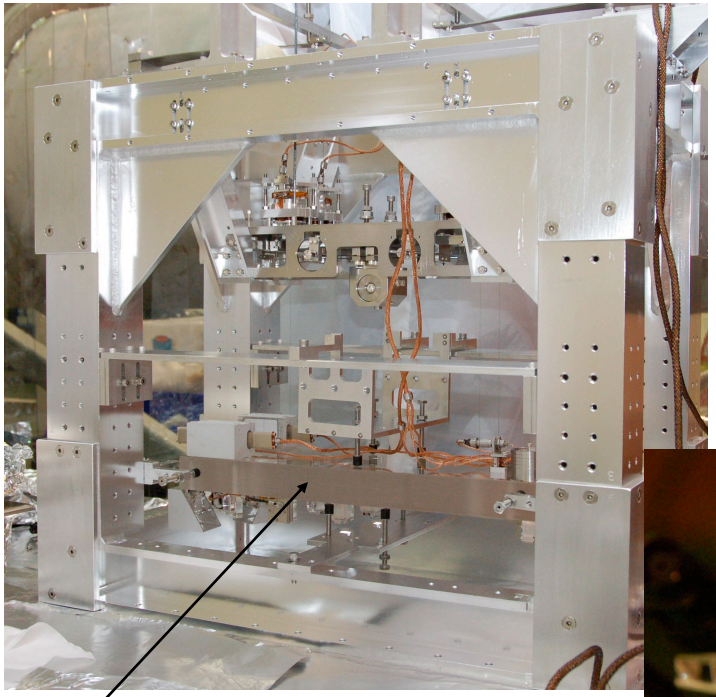
ID	Dia	ROC	T	DCC
M1	2"	Flat	50%	E1000671
M2	2"	Flat	HR	E1100048
M3	2"	+1.7 m	500 ppm	E1100056
M4	2"	-0.6 m	500 ppm	E1100056
M5	2"	+1.7 m	500 ppm	E1100056
M6	2"	Flat	50%	E1000671
M7	2"	Flat	HR	E1100048
M8	2"	Flat	IR/GRN HR	E1000425
M9	2"	Flat	IR/GRN HR	E1000425
M10	2"	Flat	Dichroic	E1000669
M11	2"	Flat	Green HR	E1000652
M12	2"	Flat	HR	E1100048
M13	2"	Flat	HR	E1100048
M101	1"	Flat	HR	E1000595
M102	1"	Flat	HR	E1000595
M103	1"	Flat	50%	E1000671
M104	1"	Flat	HR	E1000595
L101	2"	f= tbd	AR	E1000845
L102	1"	f= tbd	AR	E1000485

In-Vacuum Detection of Anti-symmetric port (main output) beam

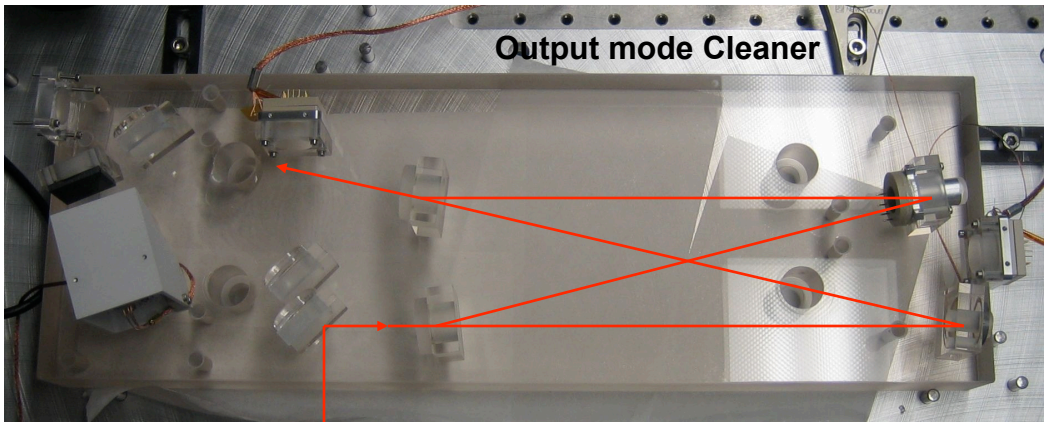


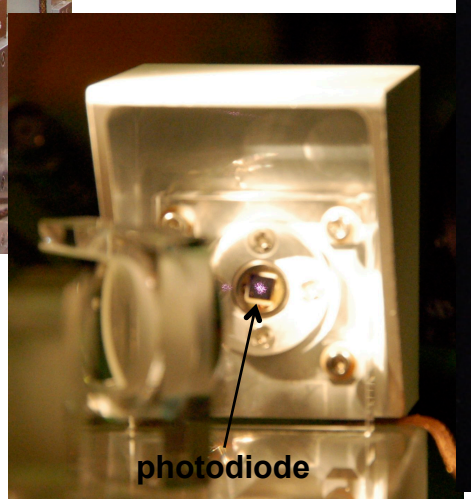
Output Mode Cleaner

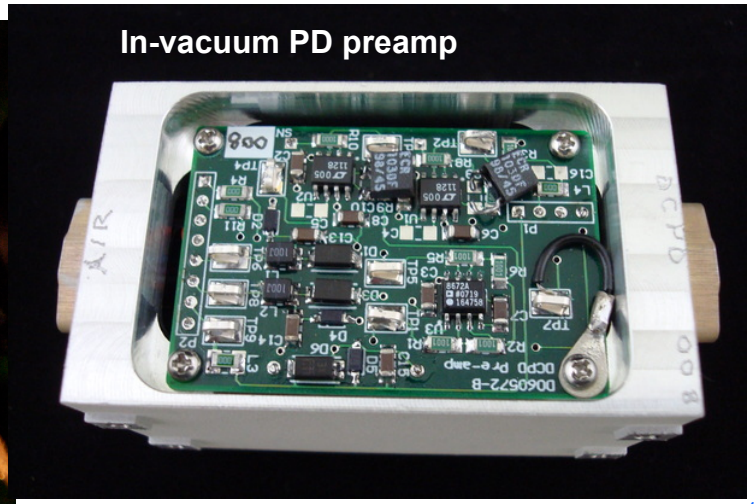
- **Enhanced LIGO implements the Advanced LIGO design of DC readout with Output Mode Cleaner**



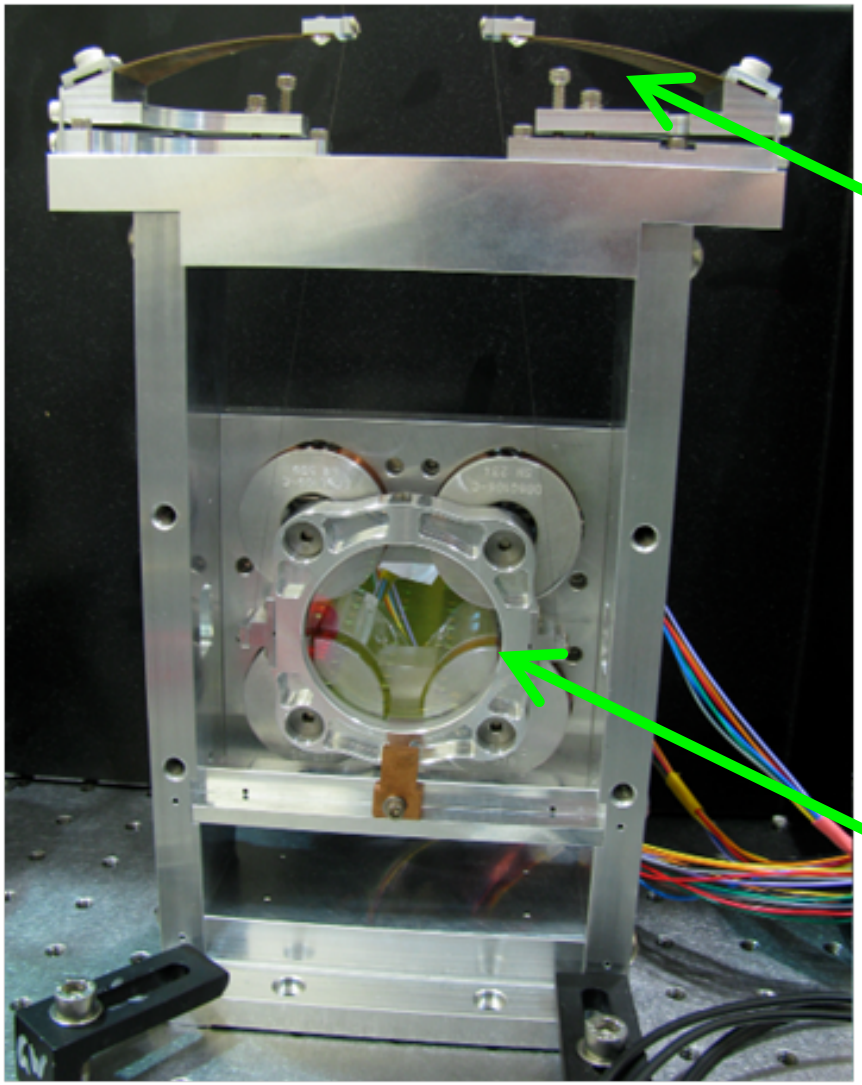
OMC in its double suspension





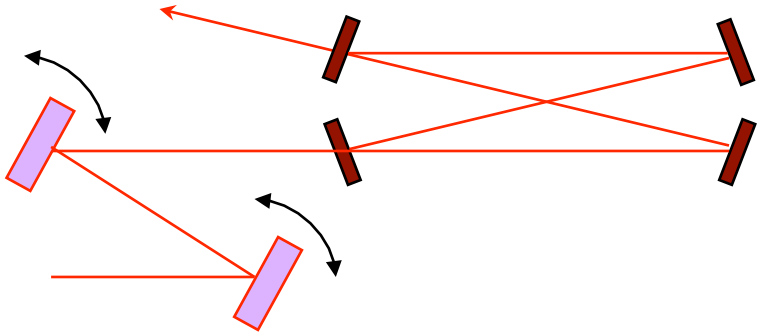


Steering the beam into the Output Mode Cleaner



Tip-tilt mirror mount

Vertical compliance with blade springs



Holds a 2” mirror

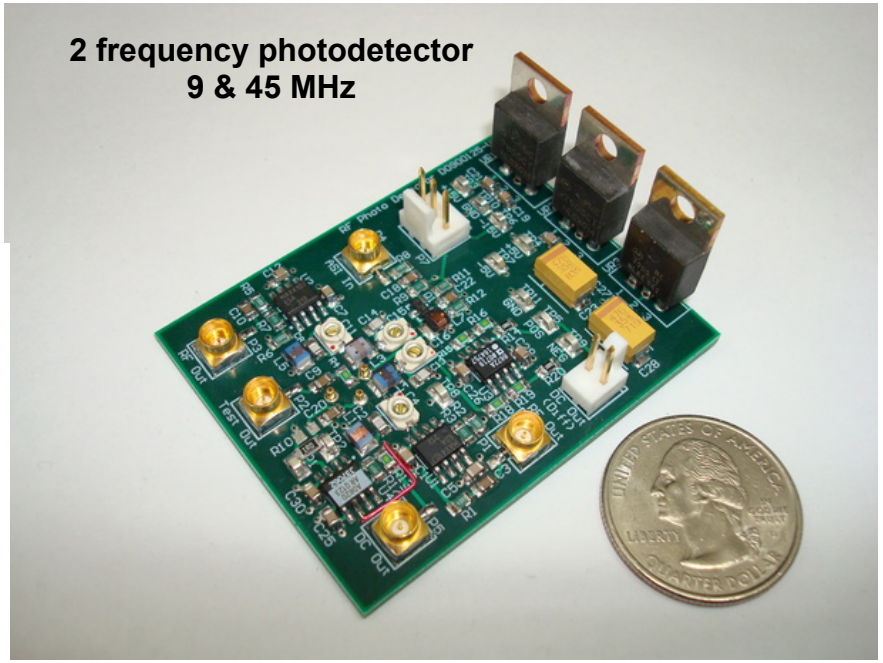
Developed by ANU

Custom RF photodetectors

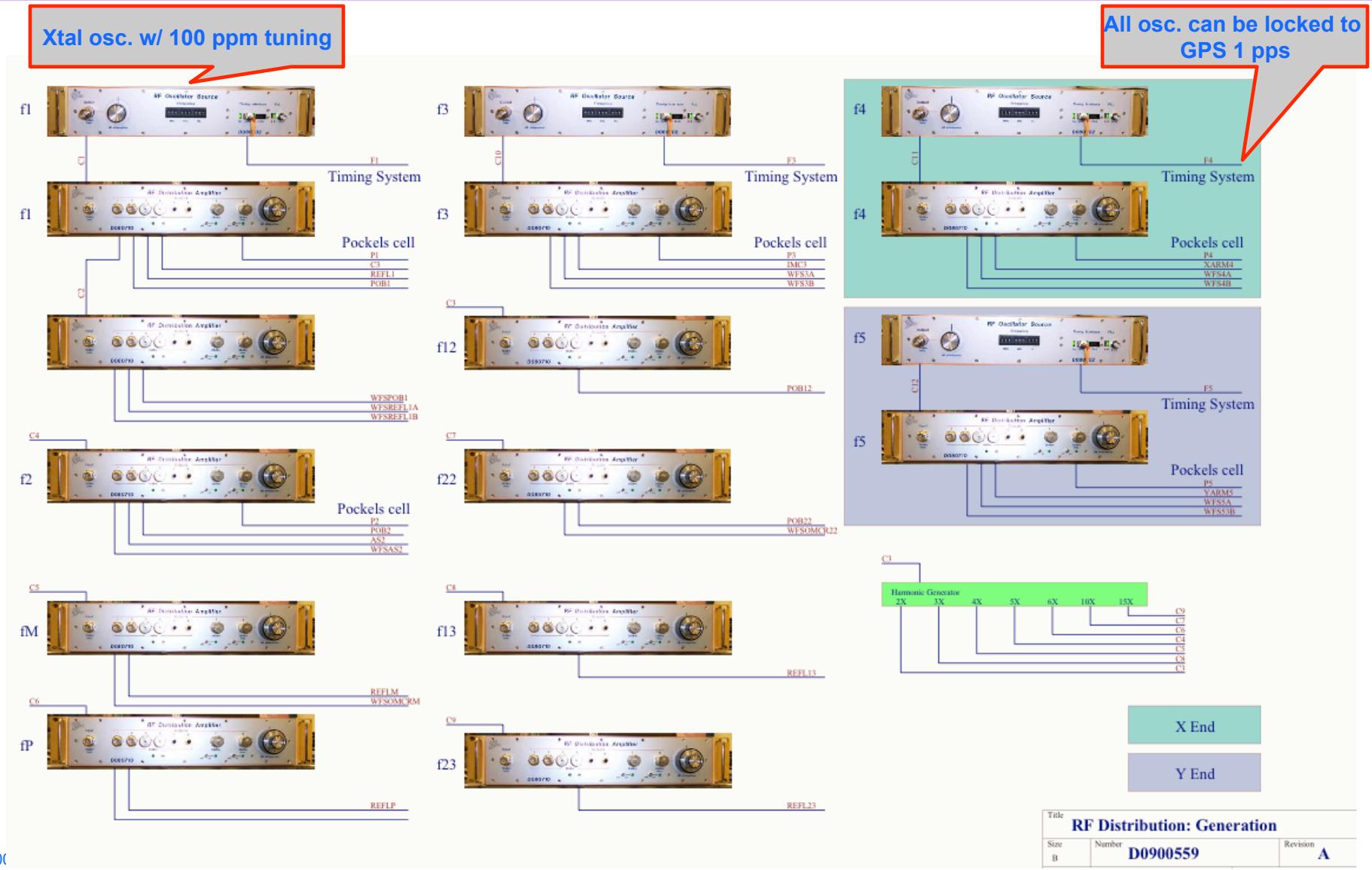
- **New transimpedance amplifier design tested in eLIGO**
- **aLIGO detectors are designed to read out multiple RF frequencies**
  - » Single InGaAs diode element versions for length readout
  - » Quadrant InGaAs diode versions for angular alignment readout

5-way Coaxial Vacuum Feedthrus

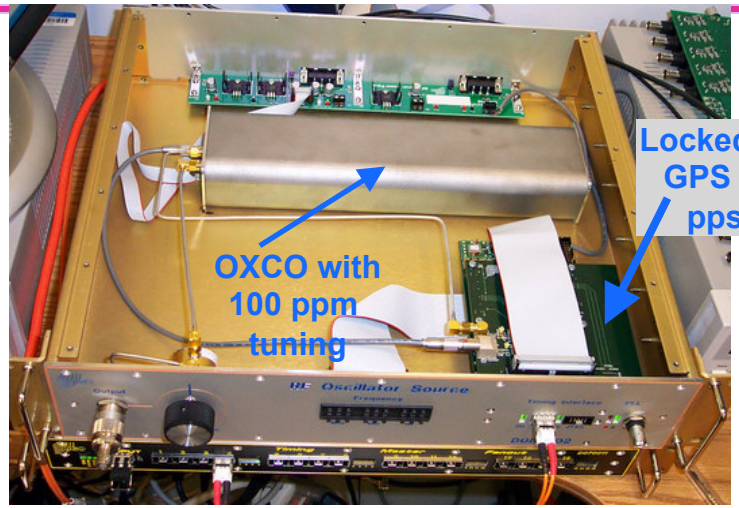
Vacuum Side

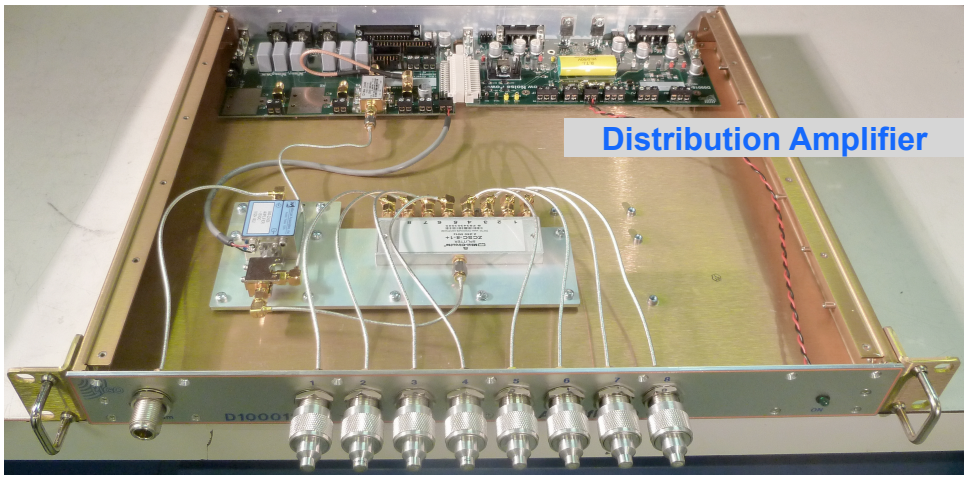


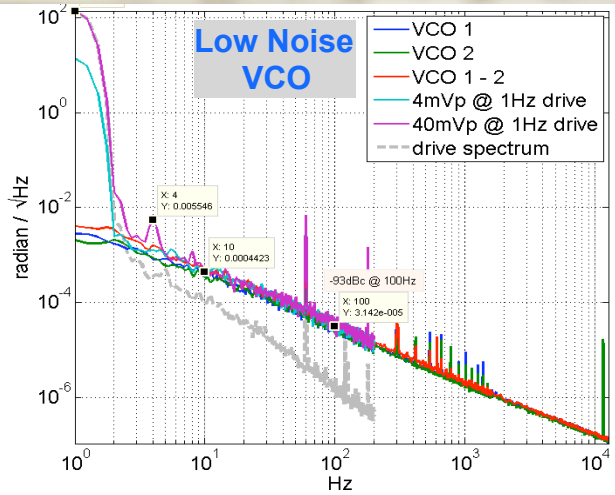
RF oscillators and distribution



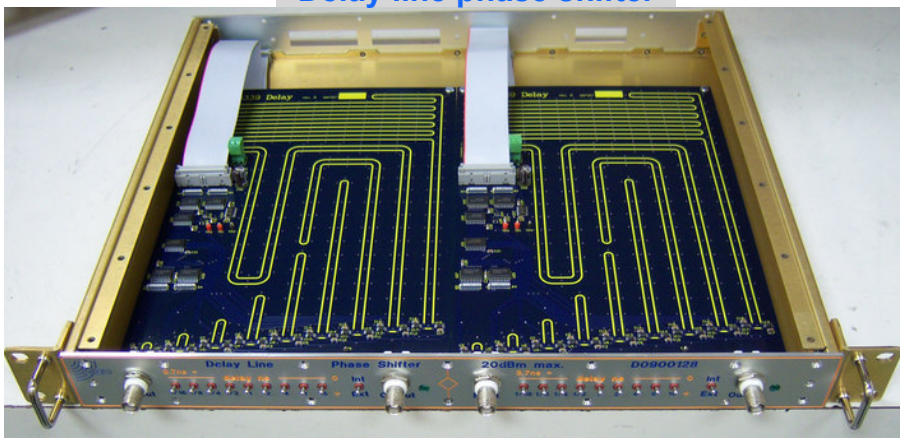
RF components





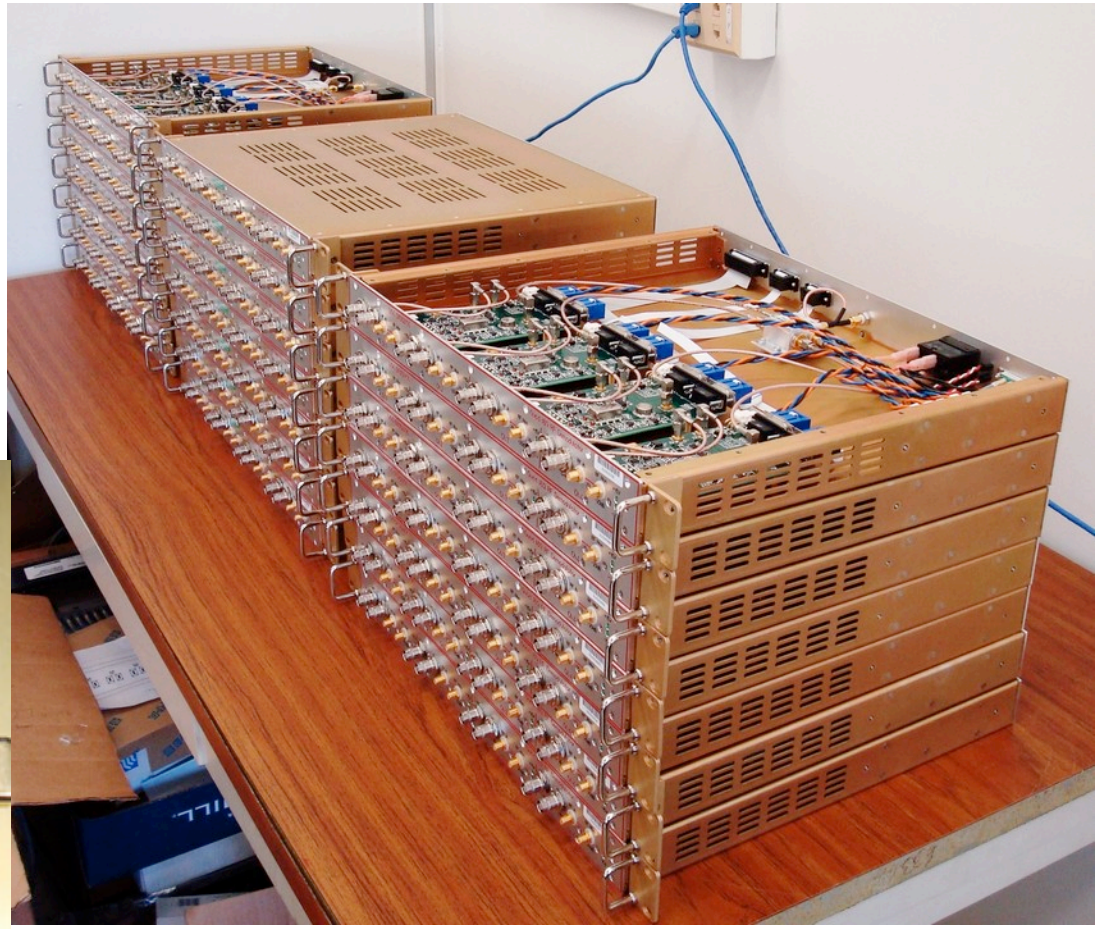


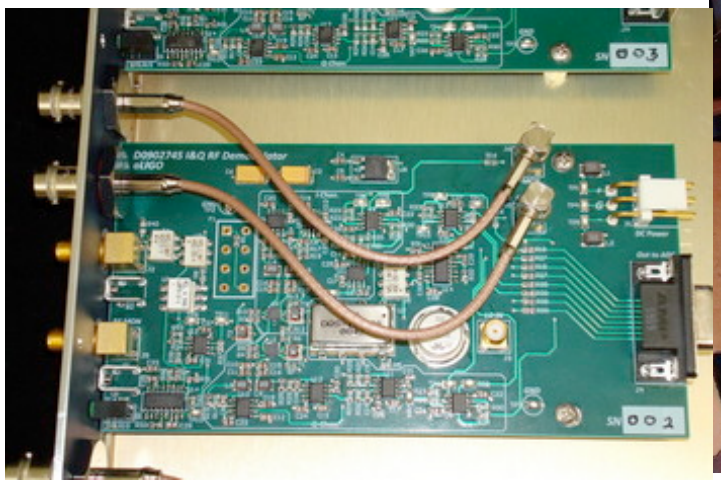
Delay line phase shifter



RF I & Q Demodulator, 9-100 MHz

- **New design based on FET switches**
  - » 4-channel chassis that can service both Length & Alignment (WFS) sensors





ISC Development Status

- **ISC completed its Final Design Review in June 2010**
  - Length Sensing & Control design
  - Alignment Sensing & Control design
  - ETM Transmission Monitor
  - Lock Acquisition & Arm Length Stabilization
  - Output Mode Cleaner
  - Tip-Tilt mirror mounts
  - Some components had already gone through final design: RF oscillators; distribution amplifiers; demodulator boards; quad detector trans-impedance amp
  - Some components were deferred for later FDR: custom RF photodetectors; in-vacuum fast shutter for PD protection

ISC Project Status

- **Production of opto-mechanical components**
  - All custom optics have been ordered, many received: 1” and 2” superpolished, IBS coated mirrors, splitters, lenses
  - Nearly all mechanical components designed and in production
  - In-vacuum fast shutter, for PD protection, still needs more development
- **Production of electronics**
  - Nearly all RF components have been built (remaining item is low-noise VCOs)
  - Signal conditioning electronics in production
  - Production of new version of RF detectors still pending

Subsystem Project organization

- **People**
  - Lead scientist: Peter Fritschel (MIT)
  - Lead engineer: Rich Abbott (Caltech)
  - Collection of scientists at MIT, Caltech and the Observatories
    - Mechanical engineer added to group at the beginning of 2010 (@MIT)
  - EE tech support at Caltech; assembly support from all sites
- **Breakdown of responsibilities**
  - Electronics: Caltech and LHO
  - Optical and opto-mechanical: MIT
  - Modeling from MIT and Caltech
- **Foreign contribution -- Australia National University is designing and providing:**
  - Arm Length Stabilization system
  - Tip-Tilt mirror stages

ISC Near term activities

- **Assembly at LHO of Transmission Monitor and Arm Length Stabilization table for the H2 One Arm Test**
  - Installation & alignment plan for the TransMon
- **Cabling design for RF coaxial distribution & multi-conductor cables**
- **In-situ testing of installed ISC equipment**
  - Photons-to-ADC counts type testing
- **Final design review of RF photodetectors & start of production**
- **Input Mode Cleaner controls for LLO**