DC Detection Experiment at the 40m Lab

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for the 40m Lab to the AIC group
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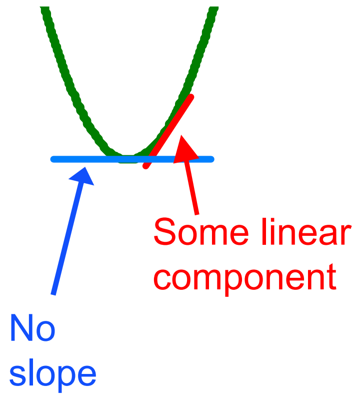
Heterodyne & homodyne readouts

❑ Heterodyne: traditional RF modulation/demodulation

- RF phase modulation of input beam
- Lengths chosen to transmit first-order RF sideband(s) to anti-symmetric output port with high efficiency
  - Initial LIGO: RF sidebands are in principal balanced at AS port
  - AdLIGO: with detuned RSE, one RF sideband is stronger than the other
- RF sideband(s) serve as local oscillator to beat with GW-produced field
  - Signal: amplitude modulation of RF photocurrent

❑ Homodyne: DC readout

- Main laser field (carrier) serves as local oscillator
  - Signal: amplitude modulation of GW-band photocurrent
- Two components of local oscillator, in DC readout:
  - Field arising from loss differences in the arms
  - Field from intentional offset from dark fringe



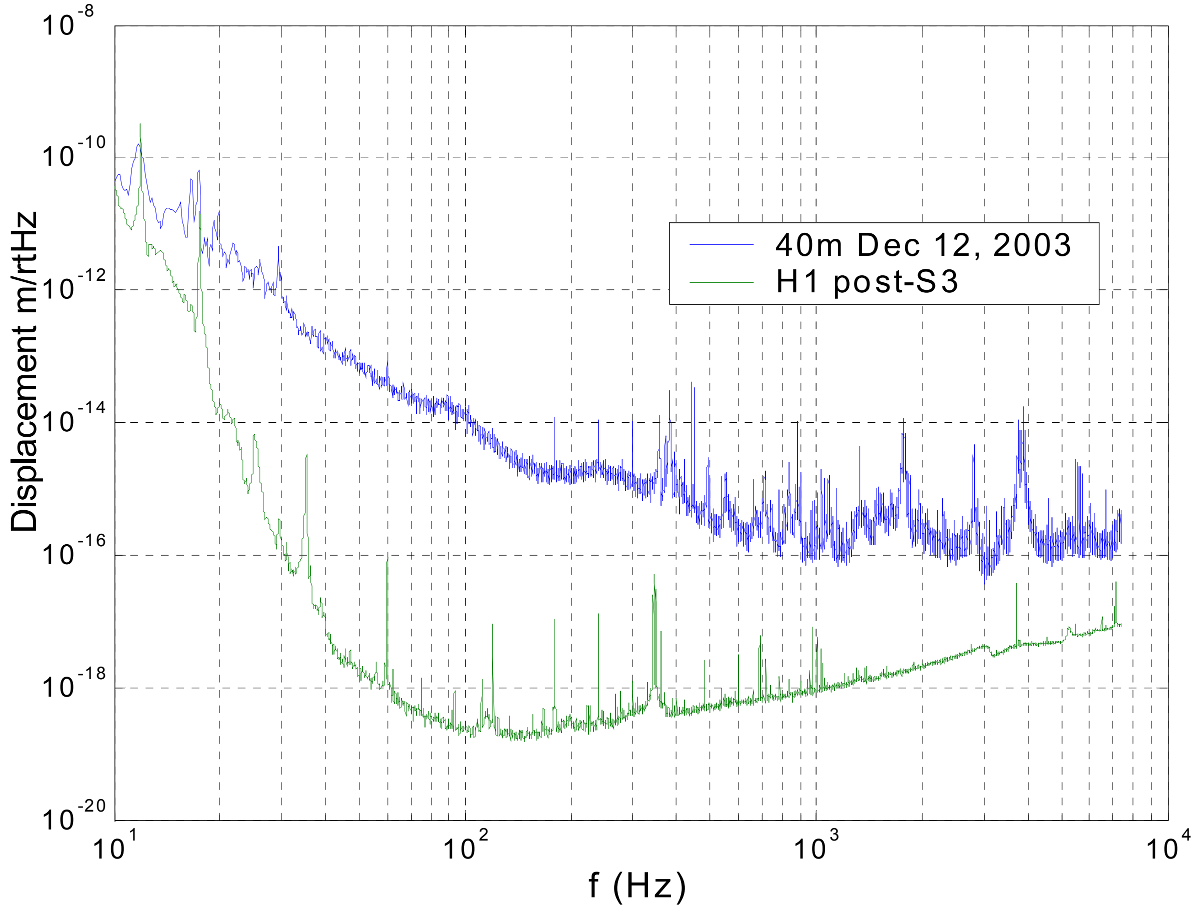
Why DC Readout at the 40m?

- Homodyne detection (via a DC readout scheme) has been chosen as the readout scheme for AdLIGO.
  - DC Readout eliminates several sources of technical noise (mainly due to the RF sidebands):
    - Oscillator phase noise
    - Effects of unstable recycling cavity.
    - The arm-filtered carrier light will serve as a heavily stabilized local oscillator.
    - Perfect spatial overlap of LO and GW signal at PD.
- It also avoids NEW noise couplings in detuned RSE due to unbalanced RF sidebands at the dark port.
- DC Readout has the potential for QND measurements, without major modifications to the IFO.
- The 40m is currently prototyping a suspended, power-recycled, detuned RSE optical configuration for AdLIGO. A complete prototyping of the AdLIGO optical configuration, in our view, includes the readout method.
- We can also prototype innovations for LIGO I (see Rana's talk).

What will we learn?

- We're not likely to see any quantum effects, given our noise environment. We may not even see any noise improvements.
- The most important thing we will learn is : How to do it
  - How to lock it?
  - How best to control the DARM offset?
  - What are the unforeseen noise sources associated with an in-vacuum OMC?
  - How do we make a good in-vac photodiode? What unforeseen noise sources are associated with it?
  - We hope to discover any unforeseen pitfalls.
- We will also perform as thorough an investigation as we can regarding noise couplings in detuned RSE, with both heterodyne and homodyne detection.
  - Parallel modeling and measurement studies.

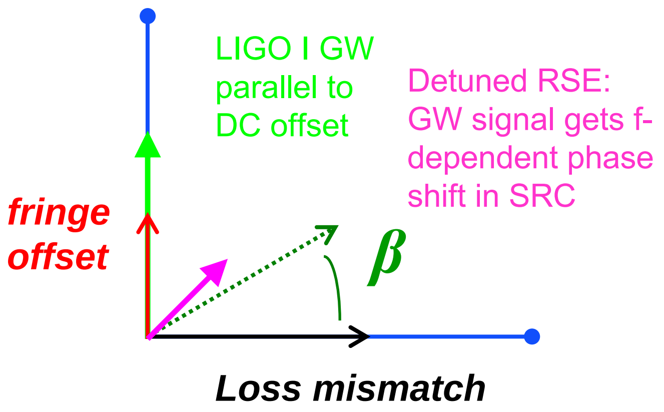
A little context



- The 40m Lab is currently not even close to being limited by fundamental noise sources.

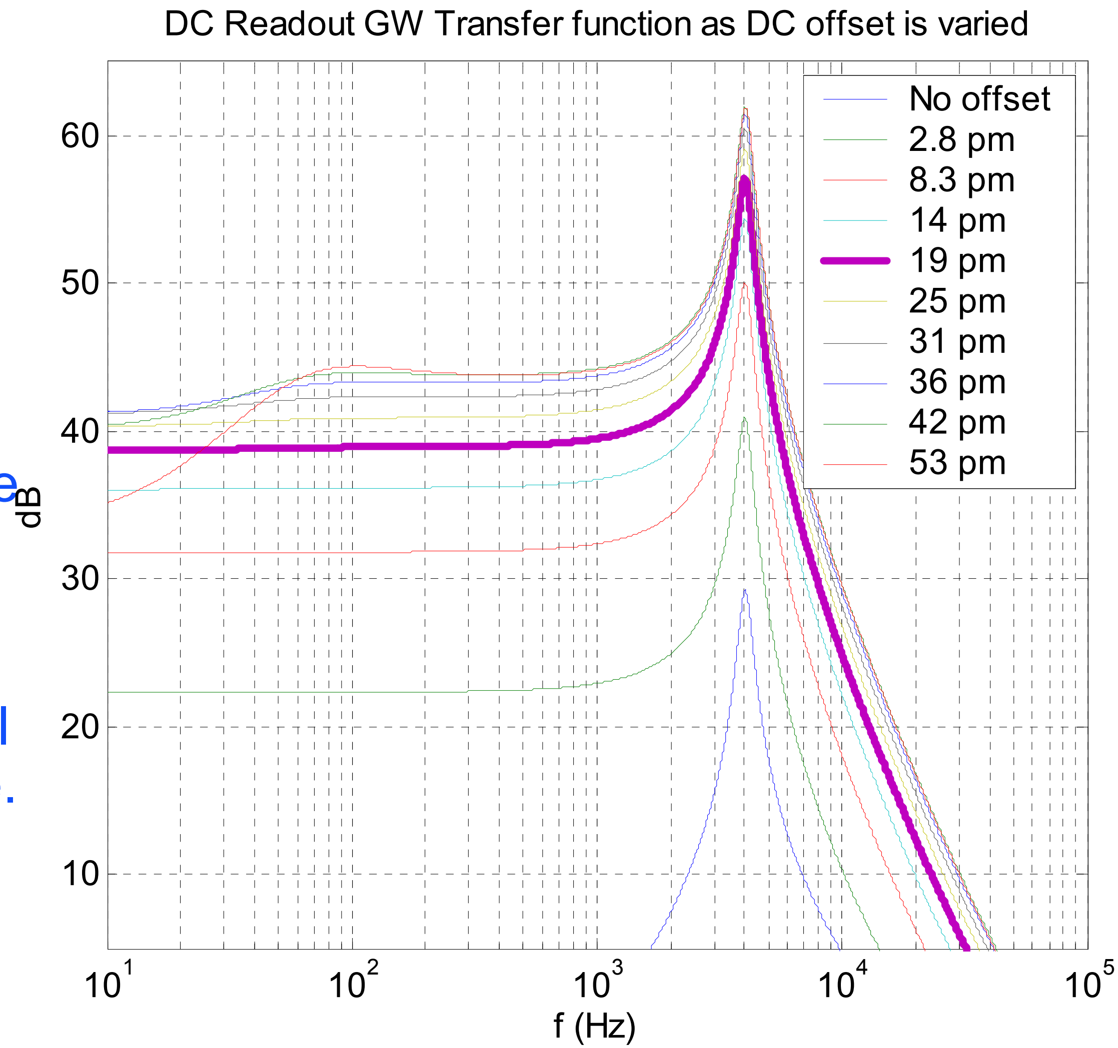
Making the DC local oscillator

- Two components
  - Carrier field due to loss differences (not controllable?)
  - Carrier field due to dark fringe offset (controllable)
  - An output mode cleaner should take care of the rest.
- Loss mismatch component
  - Average arm round trip loss: 75 ppm
  - Difference between arms: 40 ppm
  - Output power due to mismatch: 40 μW
- Detection angle, β
  - Tuned by adjusting fringe offset
  - Angle of GW is frequency dependent in detuned RSE
  - Homodyne angle of Buanonno & Chen?



DC Readout GW Transfer Functions

- DC Readout GW Transfer Functions, using different amounts of DC offset
- This changes the 'Detection Angle' as well as the amplitude of the LO.
- We'll look at a 19pm offset for reference. For AdLIGO, this will likely not be feasible.
- Modeling done in FINESSE.

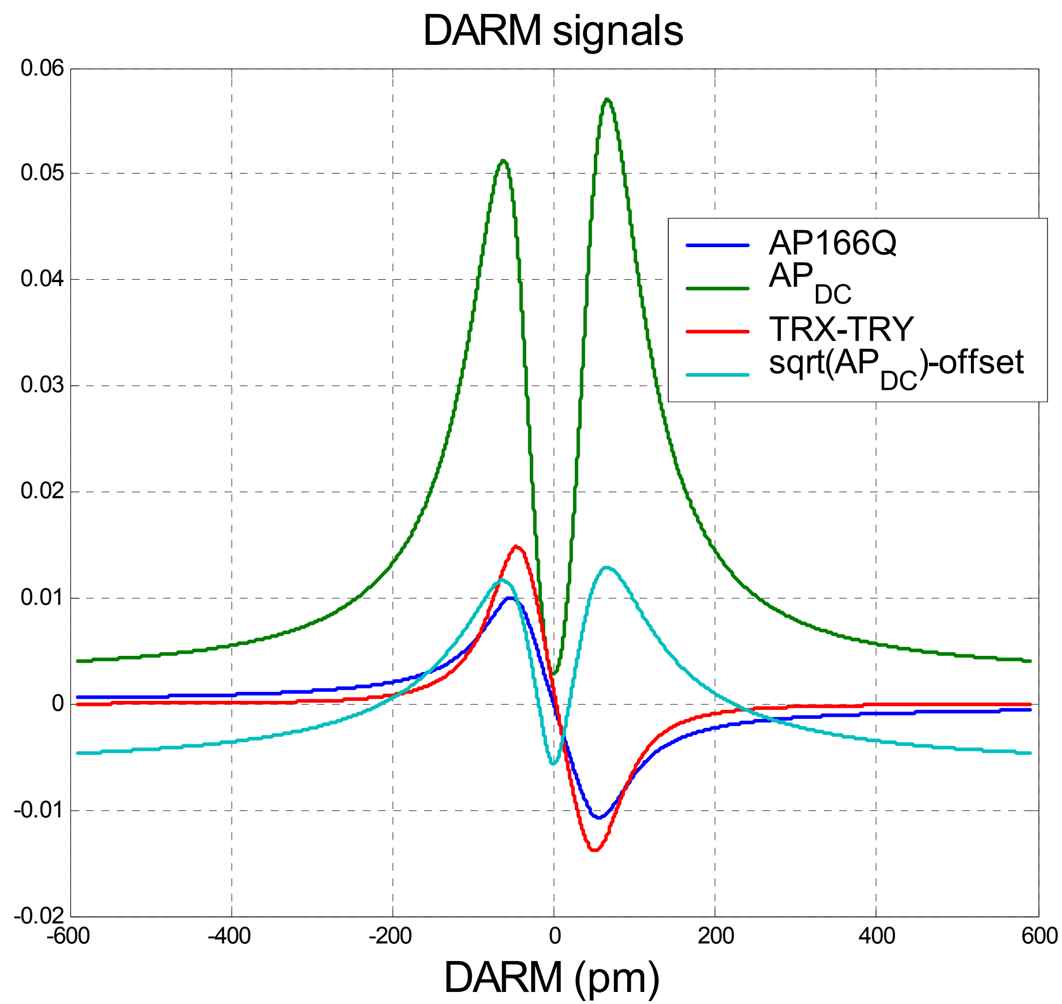


Controlling DARM

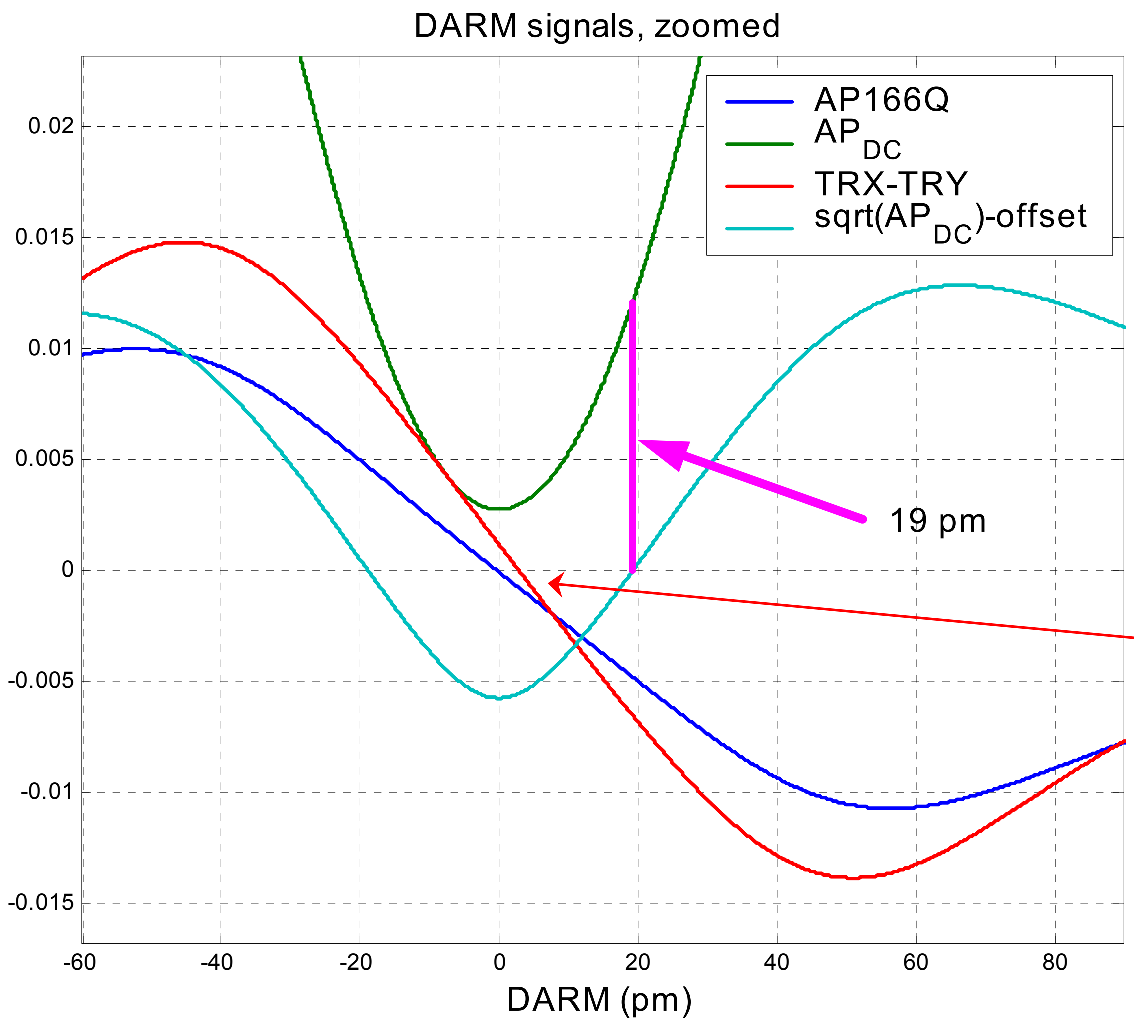
- I can think of 4 options to control an offset DARM:
    1. Standard RF (PDH) control, with a digital offset.
    2. A standard DC locking scheme, with an offset.
    3. A wacky DC locking scheme, like we do with the arms in our lock acquisition.
    4. A wackier scheme involving the difference of the Arm cavity powers.
- The linearity of 2-4 is …questionable.

DARM control signals

- The Difference between the ARM powers gives a DARM signal! This is an effect of the detuned signal cavity.
- Unsurprisingly, the square root of the dark port power also gives a nice DARM signal in a certain region.



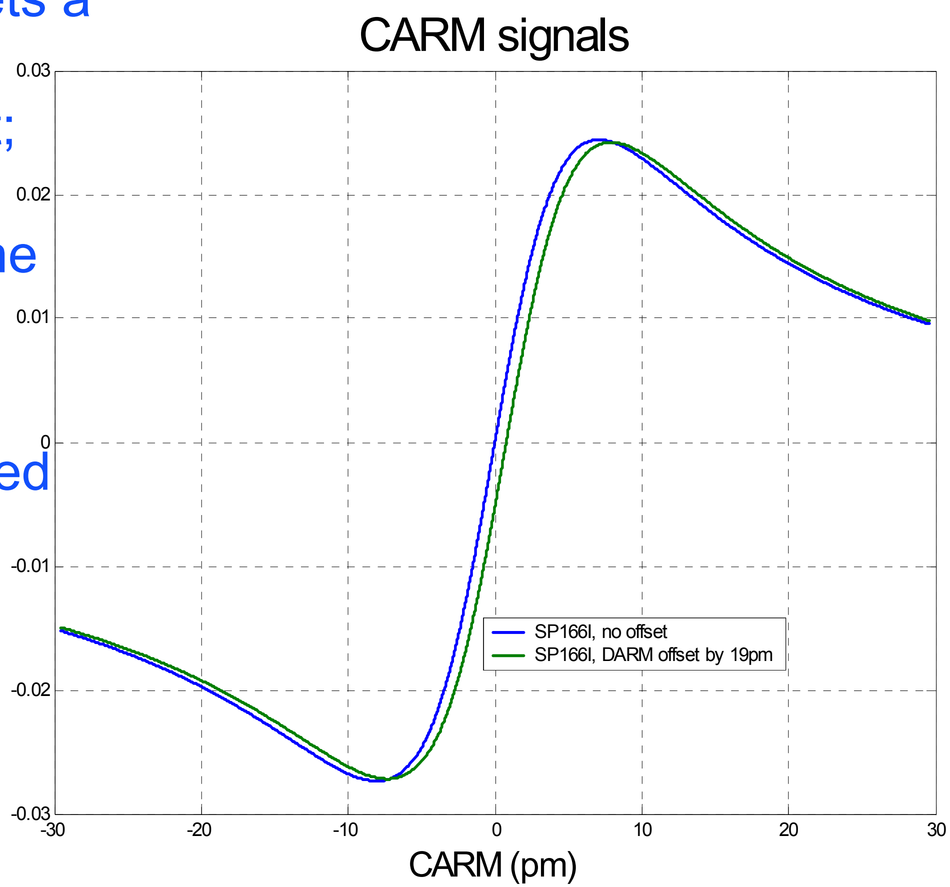
DARM control signals, zoomed



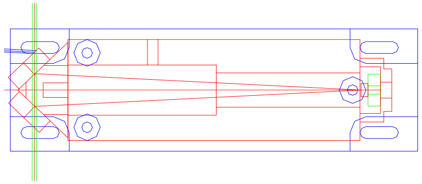
- A 19 picometer offset is well into the linear regime of the AP power signal. The LO power is about 9mW (for 1W after the MC).
- Note that the TRX-TRY signal has an offset due to the loss mismatch.

But what happens to *CARM*?

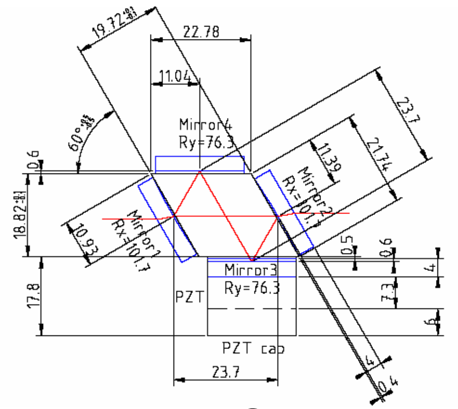
- Unsurprisingly, CARM gets a small offset too. Ideally, CARM will have no offset; this isn't realistic, as it depends exquisitely on the demodulation phase.
- Effect on the CM servo?
- Power at the BS is reduced by 3%



The Output Mode Cleaner



- We can use a 3 or 4-mirror OMC.
  - Off the shelf mirrors.
  - An easy spacer (Al?)
  - Cheap, quick, and easy to re-do.
- Finesse ~ 500
- In-vacuum, on a seismic stack.
- Considerations:
  - Astigmatism, counter propagating modes, accidental HOM resonances, RF sideband suppression.
  - Measurement of AP beam structure.

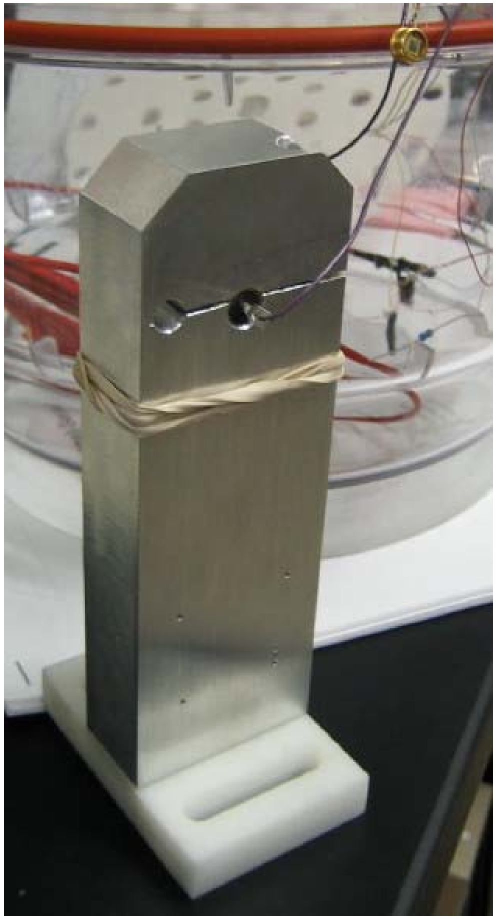


Controlling the OMC

- OMC length signal:
  - Dither-lock?
    - ✓ Should be simple; we'll try this first.
  - PDH reflection?
    - There's only one sideband, but it will still work.
- Servo:
  - Will proceed with a simple analog servo, using a signal generator and a lock-in amp.
  - Feedback filters can easily be analog or digital.
    - Can use a modified PMC servo board for analog.
    - Can use spare ADC/DAC channels in our front end IO processor for digital.
  - PZT actuation

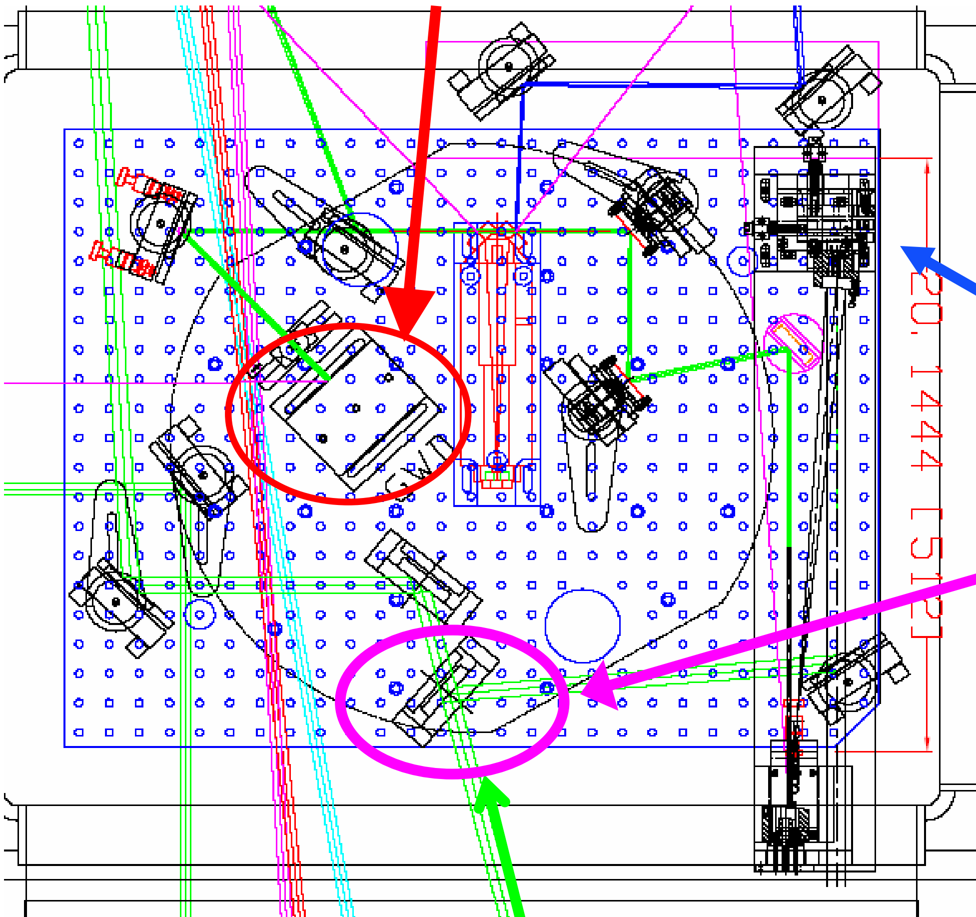
The **DC Detection** diode

- Ben Abbott has designed an aluminum stand to hold a bare photodiode, and verified that the block can radiate 100 mW safely.
- Electronic signal amplification will occur immediately outside the vacuum chamber. We will be susceptible to any magnetic fields inside the chamber.
- Another option is a diode in a can filled with an inert, RGA detectable gas; this will allow a similar electronic amplification stage to what we do now.



OMC Beam Steering : A preliminary layout is ready to go

The Diode



From SRM

Existing in-vac seismically isolated optical table

Mike Smith has designed a compact, monolithic MMT, similar to our input MMT. We'll be using spherical mirrors.

This will actually be the second PZT steering mirror. The first mirror after the SRM will also be a PZT steering mirror.

Further Plans

- Quantify:
  - ISS requirements.
    - Just how bad is having the ISS pickoff after the Mach-Zehnder?
    - In-vac sensing?
  - Study MZ phase noise effects
  - PRC/SRC/MICH/DARM loop couplings
  - OMC length couplings
- Ready for a review in mid/late April
- How much do fluctuations in the loss mismatch ‘quadrature’ couple into the GW signal?
- Sensing the OMC-input beam alignment?