Caltech 40m Lab Update

LSC meeting at LSU

Aug 16, 2006

Robert Ward, Caltech

and the 40m team:

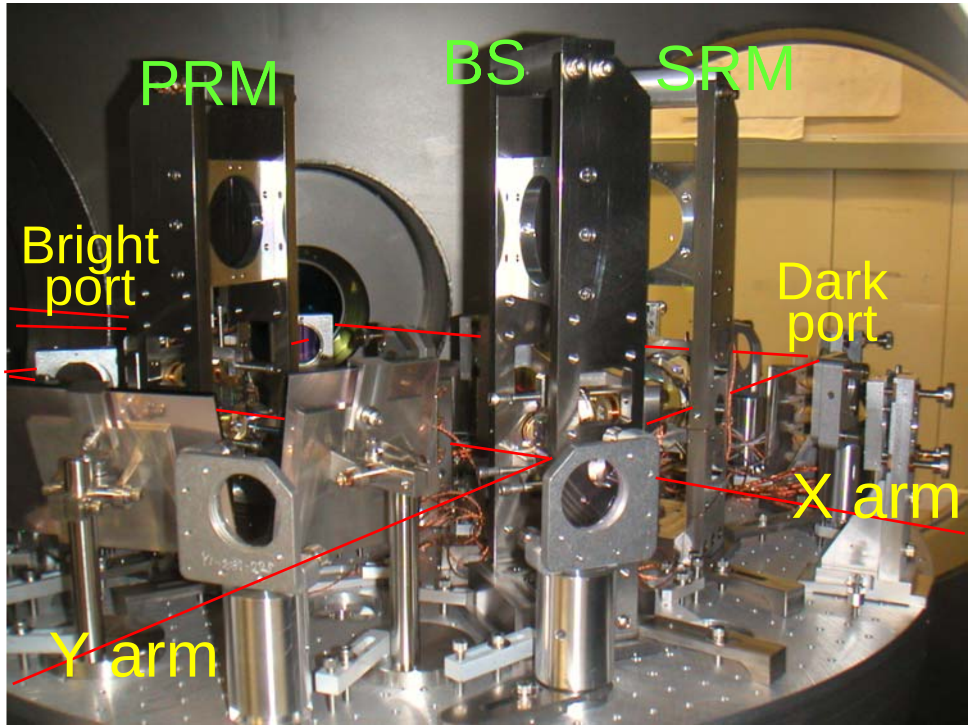
Rana Adhikari, Benjamin Abbott, Rolf Bork, Daniel Busby, Matthew Evans, Keisuke Goda, Jay Heefner, Alexander Ivanov, Seiji Kawamura, Osamu Miyakawa, Shally Saraf, Michael Smith, Robert Taylor, Monica Varvella, Stephen Vass, Sam Waldman,

and Alan Weinstein

Caltech 40 meter prototype interferometer

Objectives

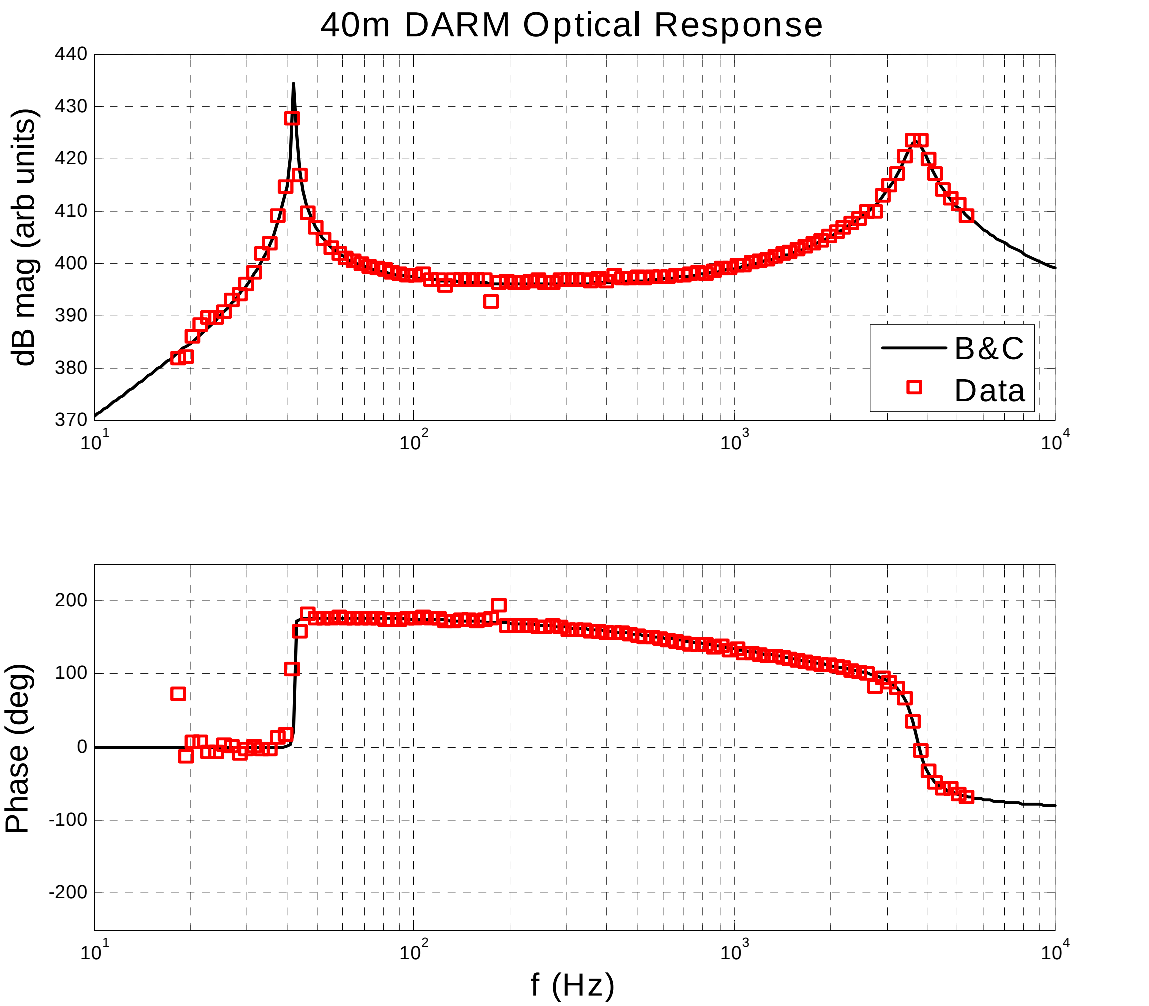
- Develop **lock acquisition procedure** of detuned Resonant Sideband Extraction (RSE) interferometer, as close as possible to AdLIGO optical design
- Test/Characterize LSC scheme
- Develop DC readout scheme
- Characterize noise mechanisms
- Test QND techniques
- Develop/Test ASC scheme
- Extrapolate to AdLIGO via simulation

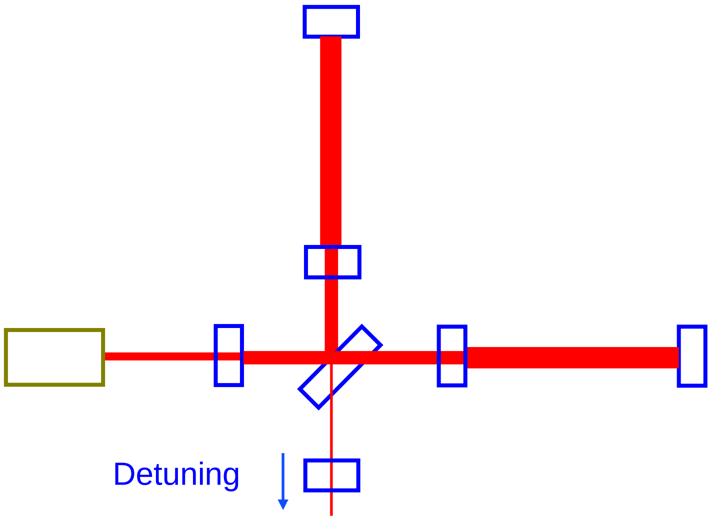


Prototyping will yield crucial information about how to build and run AdLIGO (and eLIGO).

DARM Optical response

Optical spring and optical resonance of detuned RSE were measured and fitted to theoretical prediction from A. Buonanno and Y. Chen, PRD64, 042006.





Optical Response paper

- “Measurement of Optical Response of a Detuned Resonant Sideband Extraction Interferometer” Miyakawa *et al*, Published in Phys. Rev. D74, 022001 (2006) LIGO-P060007-00-R

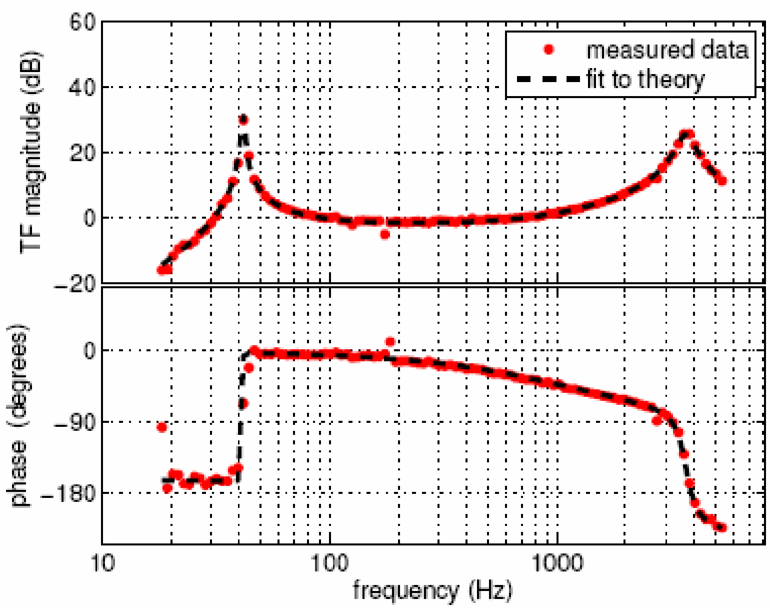


FIG. 3: The magnitude (top) and phase (bottom) response

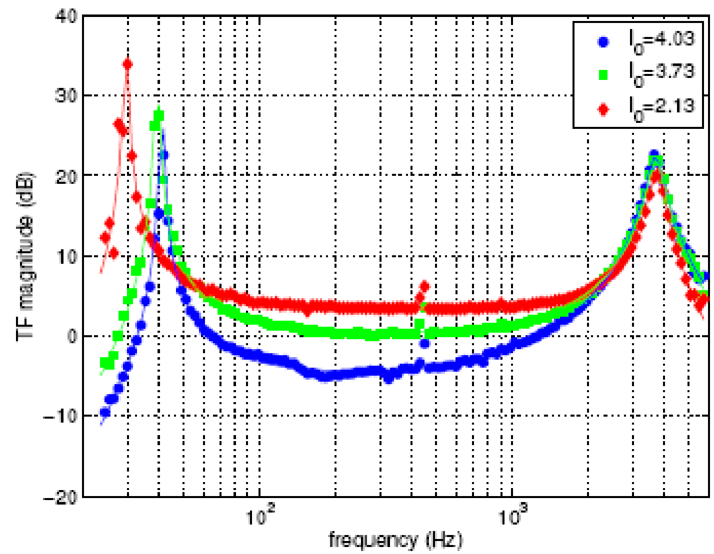
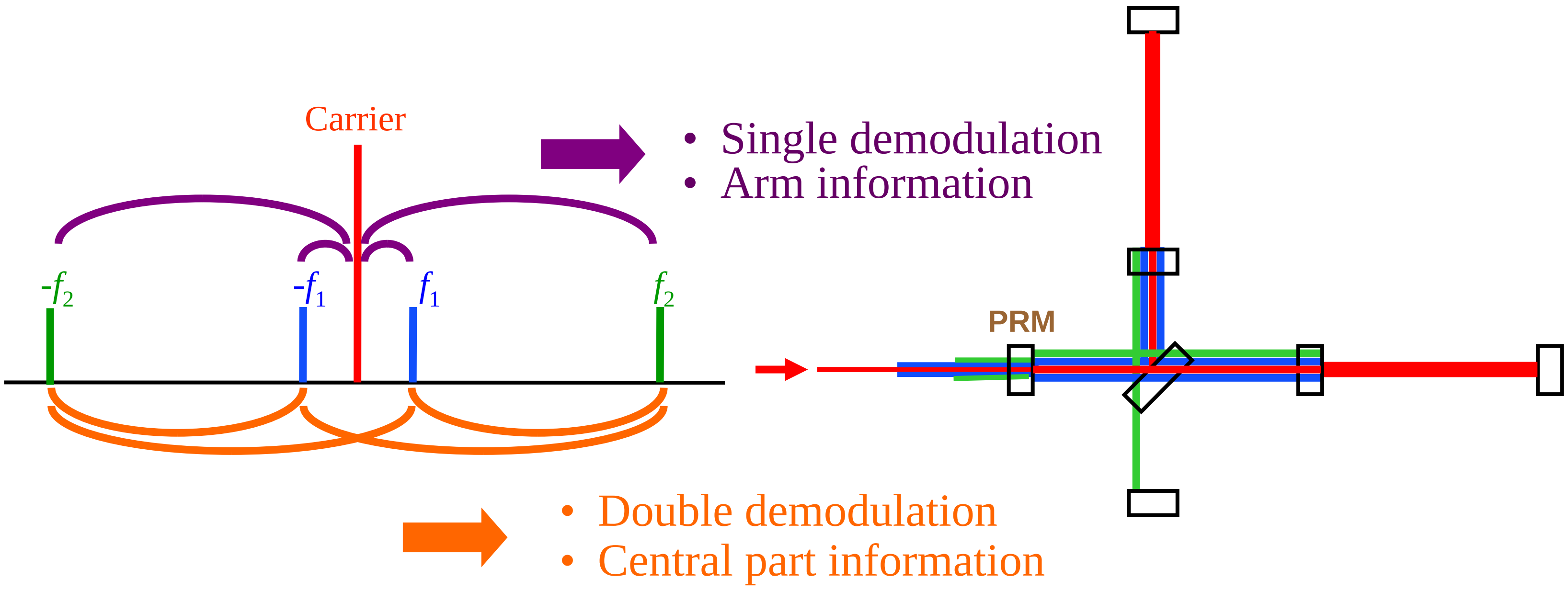


FIG. 4: The magnitude response of the 40m interferometer

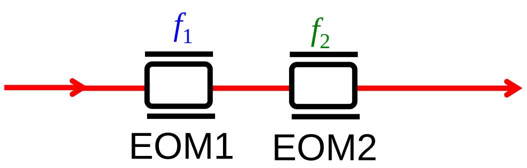
Signal Extraction Scheme



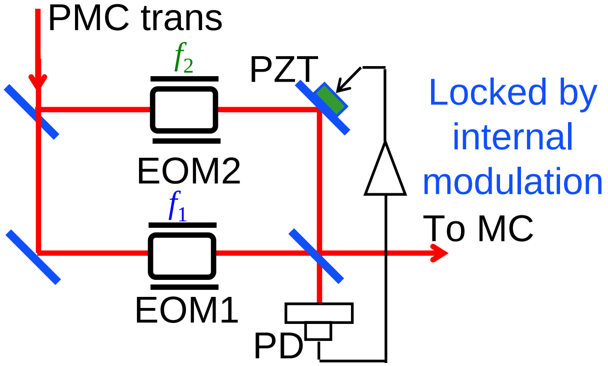
- Arm cavity signals are extracted from beat between carrier and f_1 or f_2.
- Central part (Michelson, PRC, SRC) signals are extracted from beat between f_1 and f_2, not including arm cavity information.
- Only +f_2 sideband resonates in combined PRC+SRC

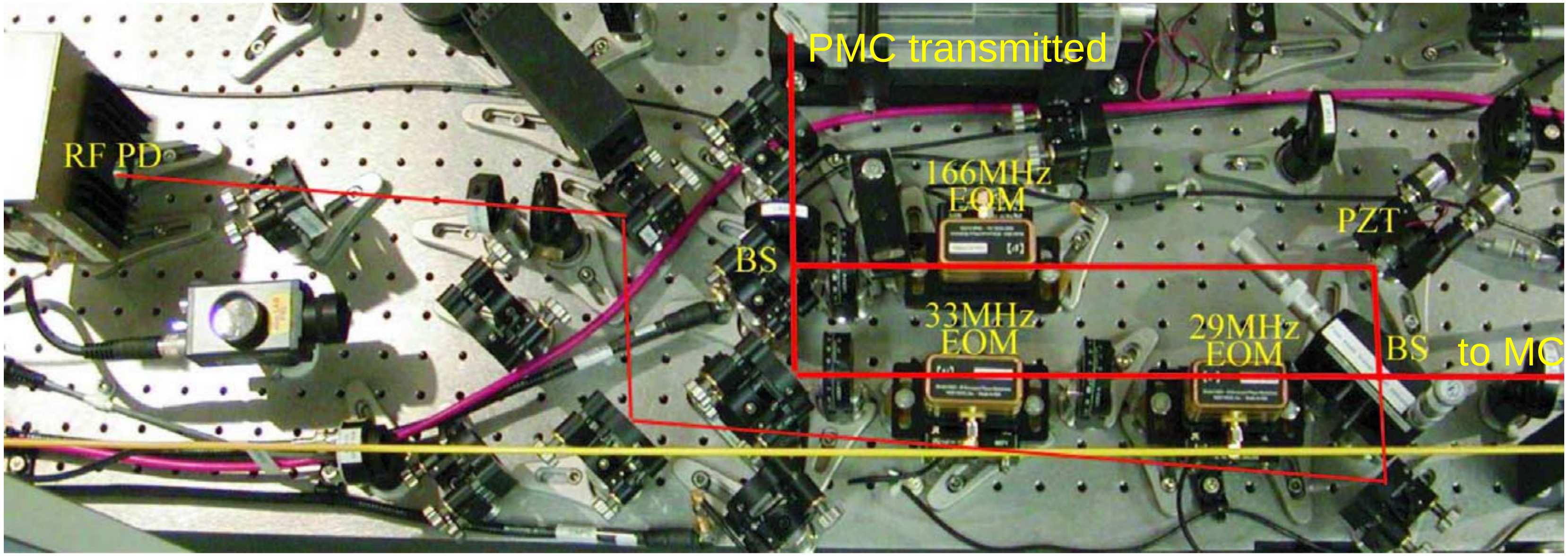
Mach-Zehnder interferometer on 40m PSL to eliminate sidebands of sidebands

Series EOMs
with sidebands of sidebands



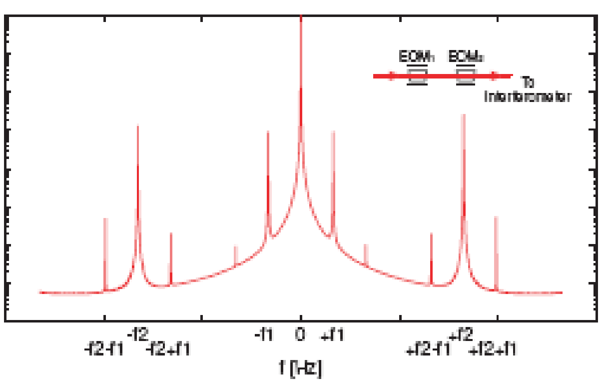
Mach-Zehnder interferometer
with no sidebands of sidebands

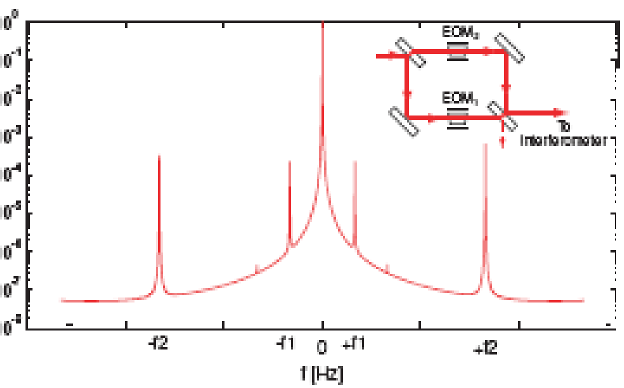


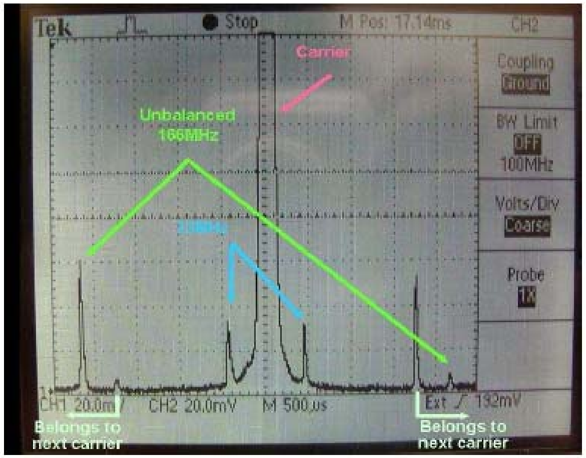


Control sidebands paper

- “Control Sideband Generation for Dual-Recycled Laser Interferometric Gravitational Wave Detectors”, accepted for publication in Classical and Quantum Gravity. http://www.ligo.caltech.edu/docs/P/P060022-00/
- Bryan Barr, Glasgow, lead author

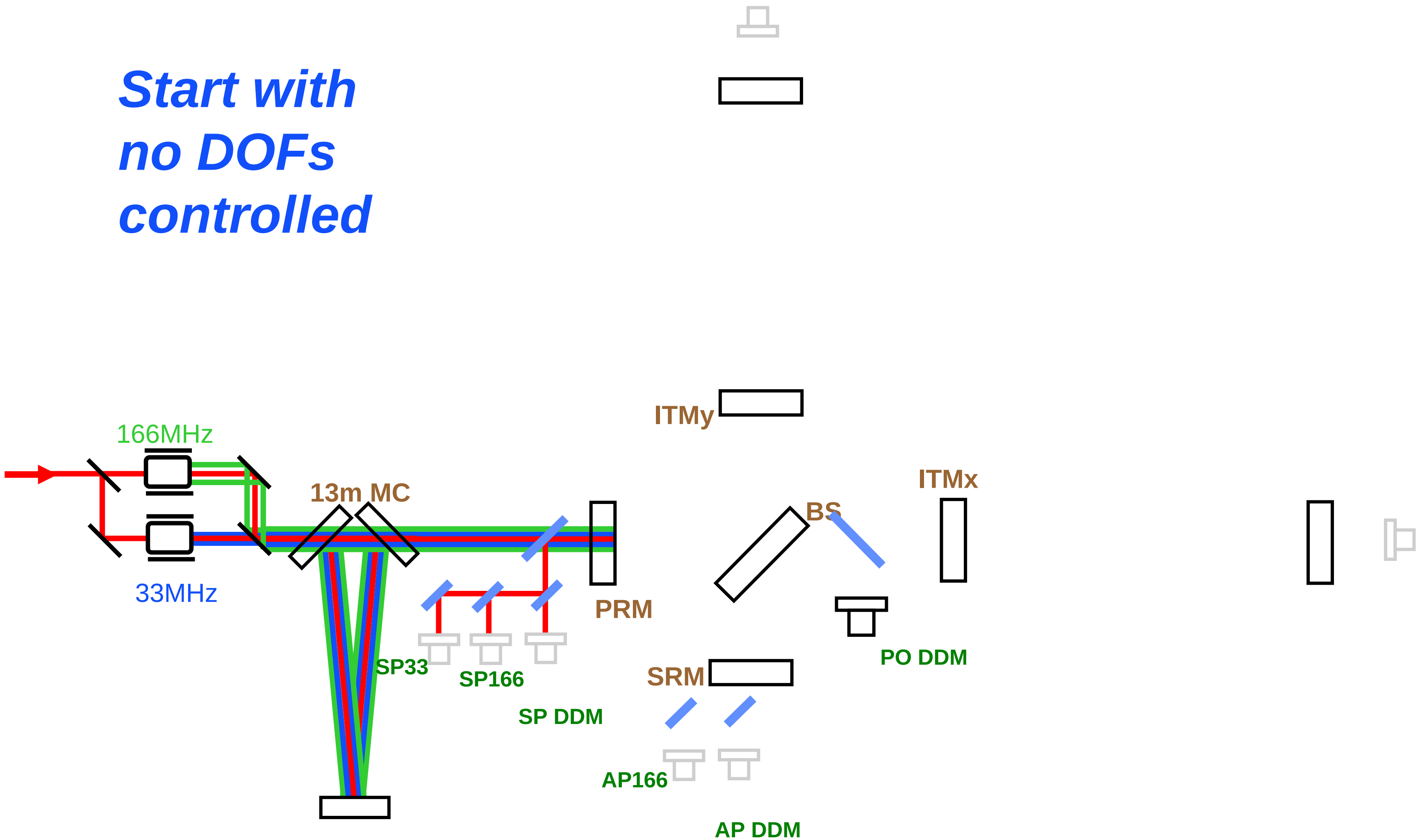






40m Lock acquisition procedure (v 1.0)

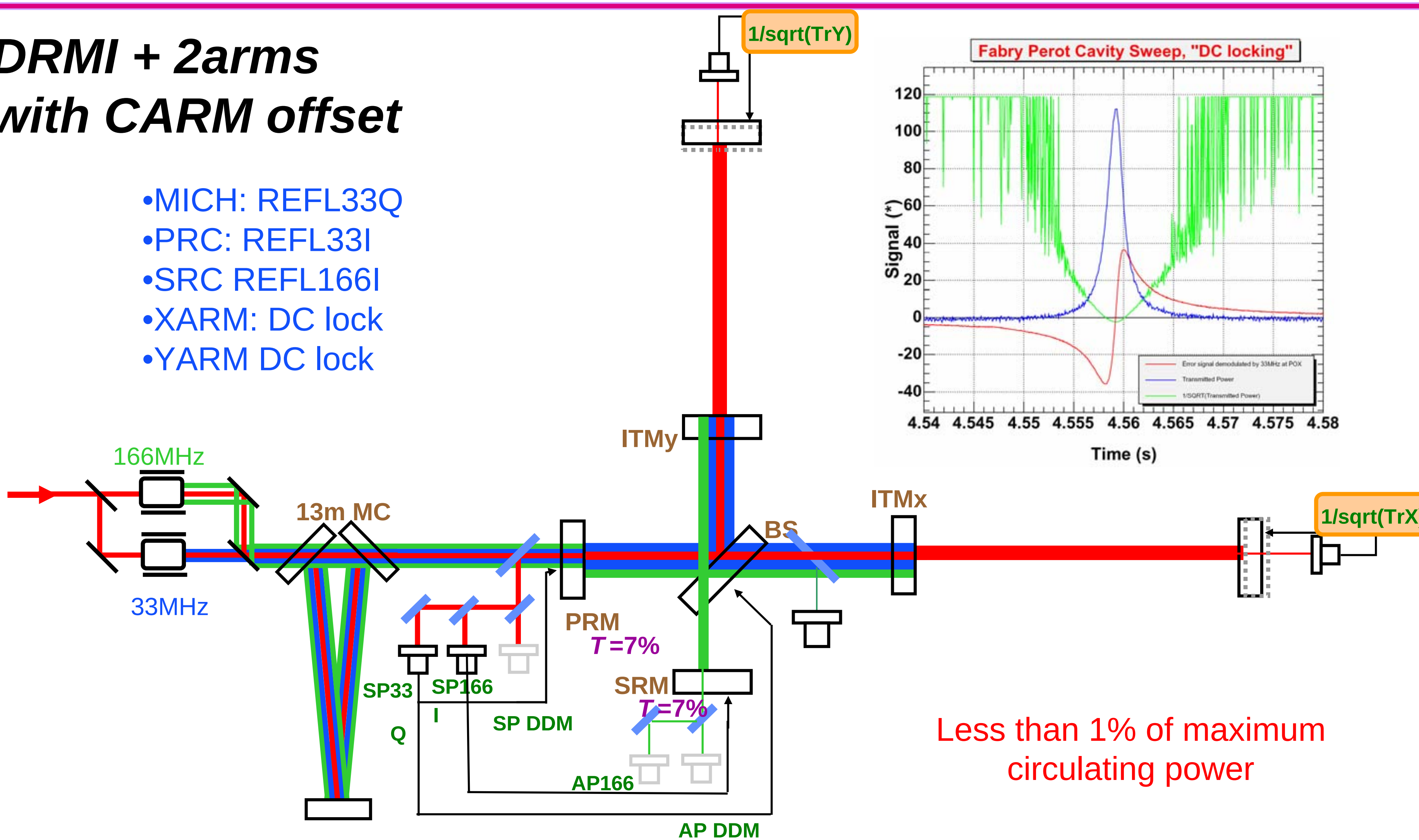
Start with no DOFs controlled



40m Lock acquisition procedure (v 1.0)

DRMI + 2arms
with CARM offset

- •MICH: REFL33Q
- •PRC: REFL33I
- •SRC REFL166I
- •XARM: DC lock
- •YARM DC lock

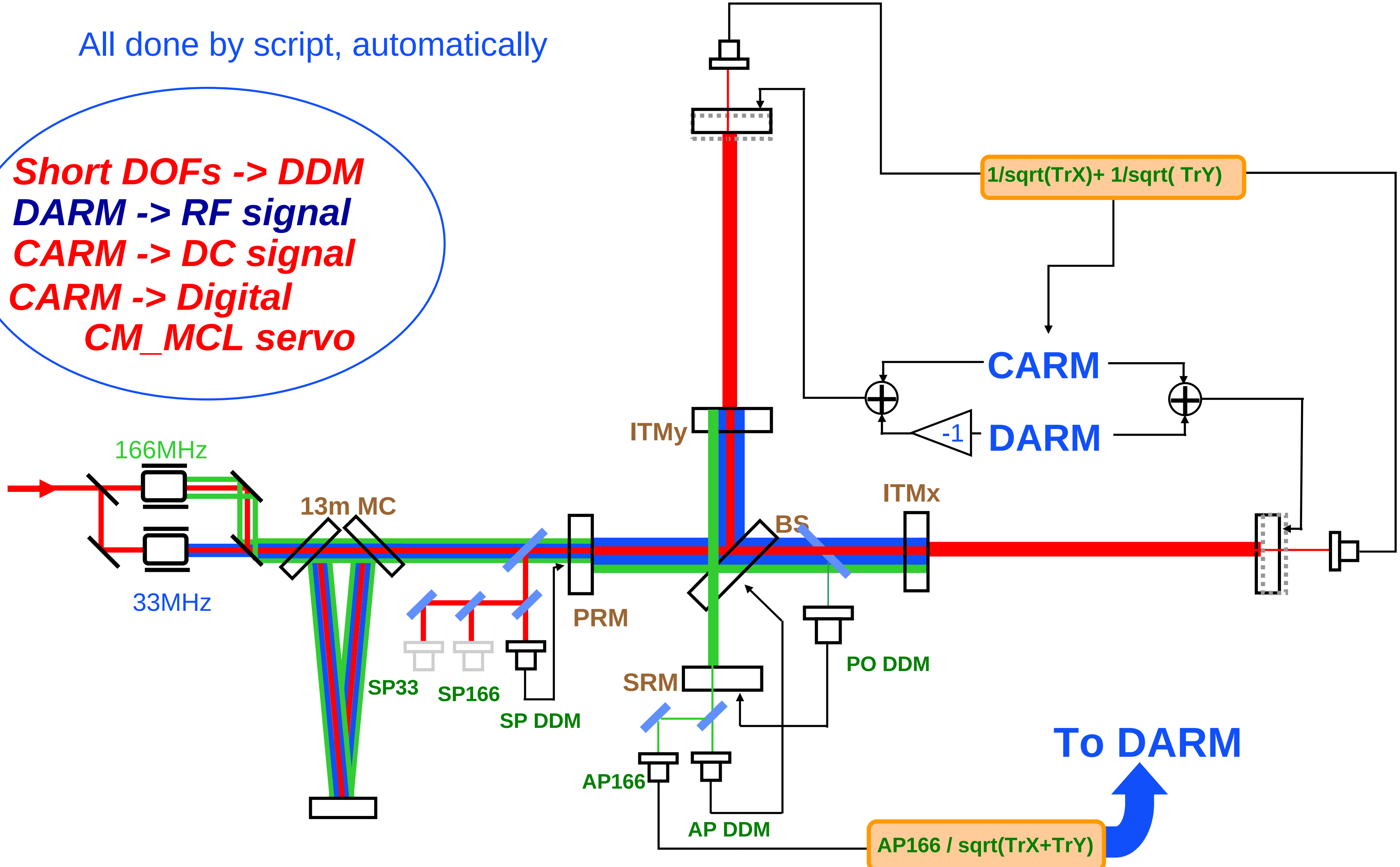


Less than 1% of maximum circulating power

40m Lock acquisition procedure (v 1.0)

All done by script, automatically

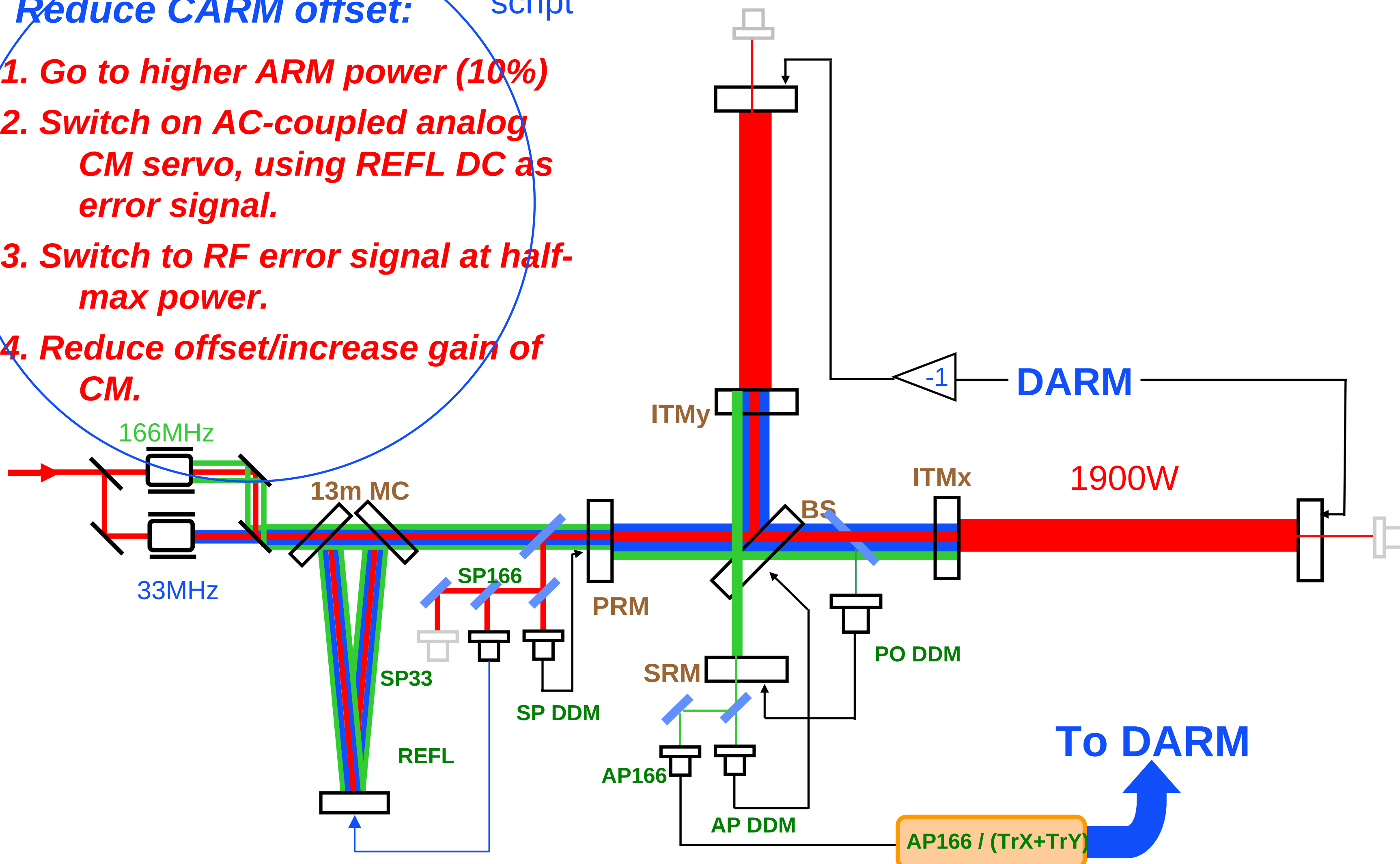
Short DOFs -> DDM
DARM -> RF signal
CARM -> DC signal
CARM -> Digital CM_MCL servo



40m Lock acquisition procedure (v 1.0)

Reduce CARM offset: script

1. ***Go to higher ARM power (10%)***
2. ***Switch on AC-coupled analog CM servo, using REFL DC as error signal.***
3. ***Switch to RF error signal at half-max power.***
4. ***Reduce offset/increase gain of CM.***



Lock acquisition development, automation

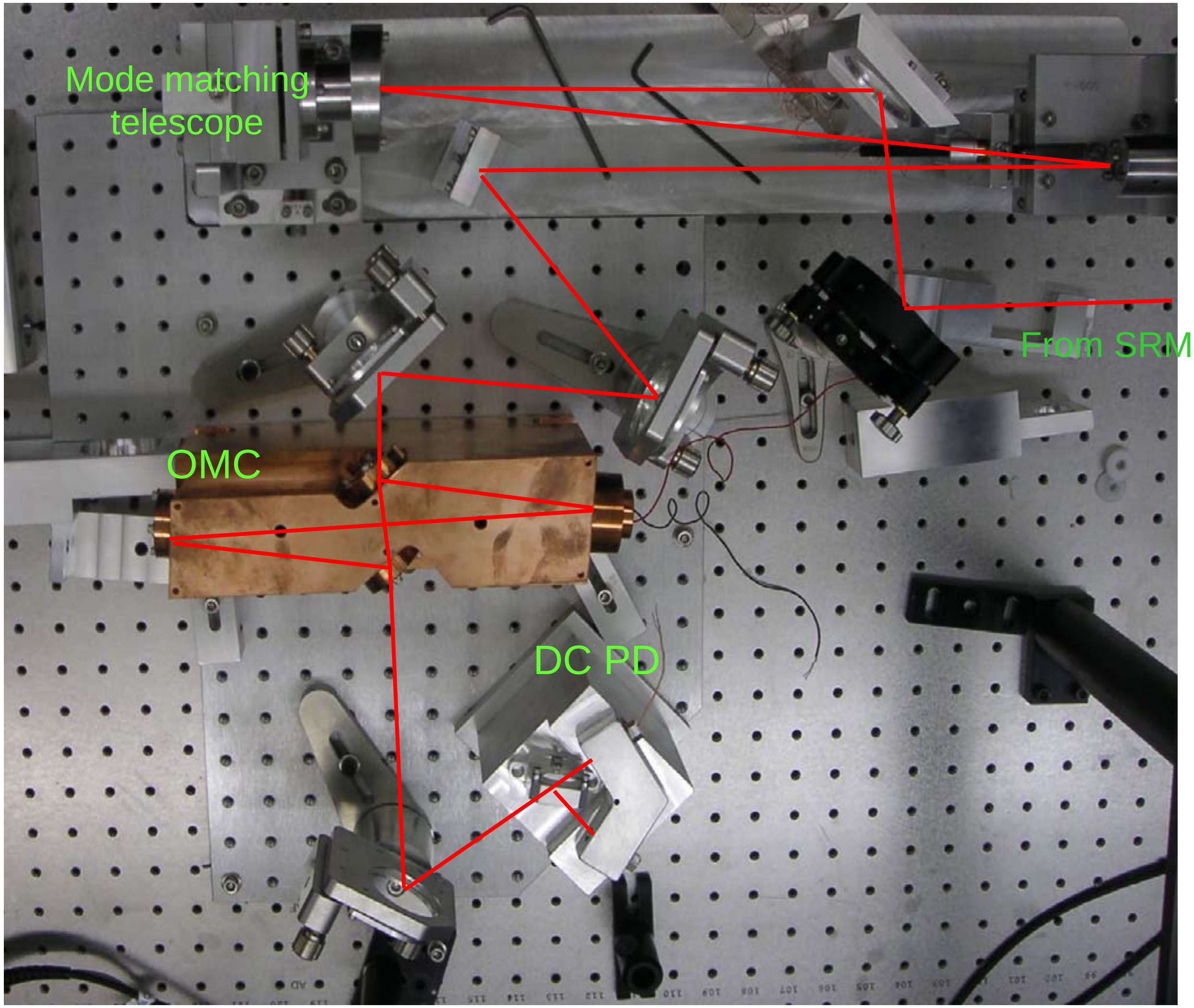
- Initial, scripted, auto-alignment works now for all DOFs
- All loops use single-demod signals (carrier+one sideband) for initial lock acquisition, to aid in tuning double-demod signals (offsets, demod phases).
- In initial stage, all loops now have useful power level triggers.
- Fast input matrix ramping: all signal handoffs are automated and smooth.
- With improved LO levels, now using real double-demod at 133 and 199 MHz.
- Work continues on **Deterministic Locking**.
  - » PRFPMI, DRMI, no DRFPMI
- E2E modeling of lock acquisition under development

DC Readout

Motivations

- DC Readout (AdvLIGO baseline) has technical noise benefits:
  - RF Oscillator phase noise (significant at ~few kHz)
  - Laser frequency noise (close to limiting)
  - Perfect spatial overlap of LO and GW signal at PD.
- Limited by photodetector saturations; Output Mode Cleaner removes most of the junk light
- Removing the junk light reduces shot noise.
- Homodyne detection has lower potential shot noise

DC readout beamline at the 40m



Output Mode Matching Telescope, Output Mode cleaner, and DC PDs all aligned on breadboard before installation.

Will be placed in vacuum on a seismic stack—no suspension.

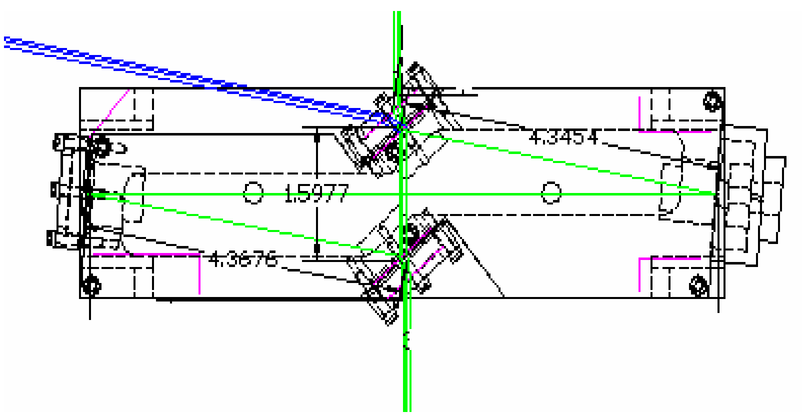
Two PZT tip/tilt mirrors for input steering

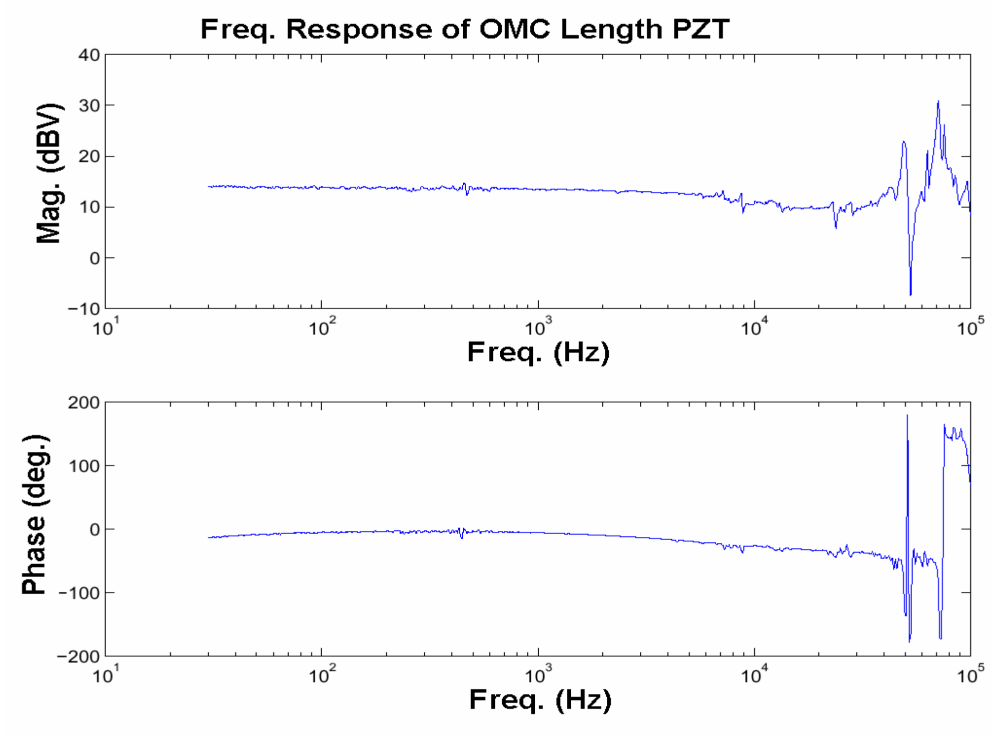
DC readout beamline status

- All components pre-aligned on breadboard(s) to be installed in-vac
- OMMT aligned and coarsely focused with picomotor
- OMC dither-locked at 20 kHz using length PZT and PD at reflected and transmitted port
- Dither-align to OMC using tip/tilt PZTs (one of 4 DOFs tested)
- In-vac alignment procedure developed, using fiber-fed beam from DC PD mount back through all components to SRM. Tested in air.
- All components disassembled, catalogued, and baked.
  - » Ready to be re-assembled in clean room (next week)

Output Mode Cleaner

- Finesse : 190
- Locked transmission : 95%
- Loss per round trip : 0.1%
- Voltage response of length PZT: 8 nm/V
- L = 48 cm





DC Readout

- PCIX system for digital control
  - digital lock-in software for controlling 5 DOFs
  - “oscillator” generated digitally (calibration lines?)
  - will interface to existing RFM network
  - 32 kHz real time control
- Development of In-Vacuum Photodetector
  - 2mm InGaAs diodes, with an amplifier/whitening circuit in a can.
  - input-referred noise of 6nV/rtHz
- No Fast Shutter (based on 40m need/complexity)
  - Will look for dedicated solution instead for eLIGO

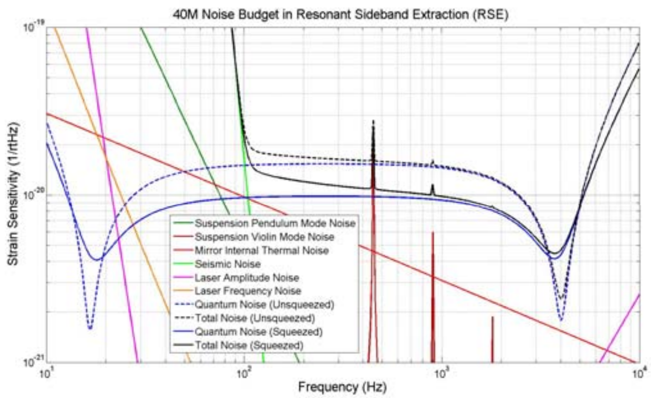
First post-installation steps

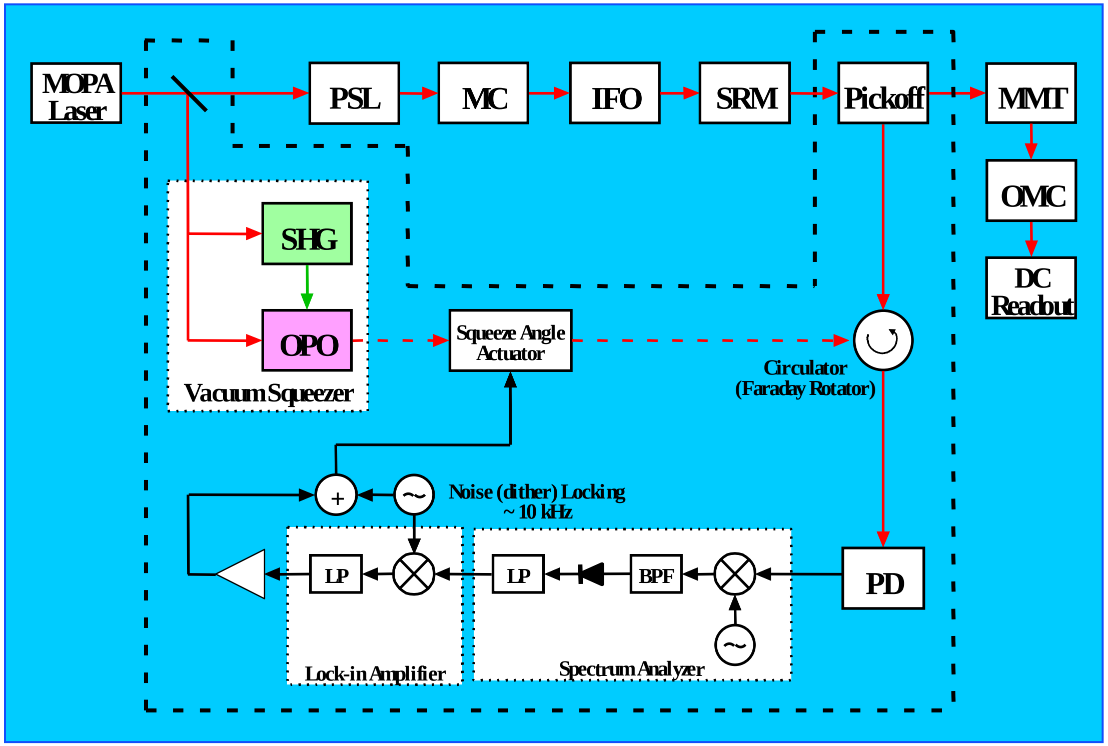
- Establish lock acquisition
  - » Control the IFO (with RF signals)
  - » Control the OMC length
  - » Control steering into OMC
  - » Determine optimal L- offset
  - » **Control DARM with DC signal**
- Characterize and verify noise mechanisms
- Explore parameter space of offsets, demod phases, SR detune
- Noise budget, calibration
- Some noise reduction

Squeezing Project @ 40m

Keisuke Goda, Osamu Miyakawa, Eugeniy Mikhailov,
Shailendhar Saraf, Steve Vass, Alan Weinstein, Nergis Mavalvala

Goal: First Experimental Demonstration of a Squeezing-Enhanced GW Interferometer in the Advanced LIGO Configuration (RSE)



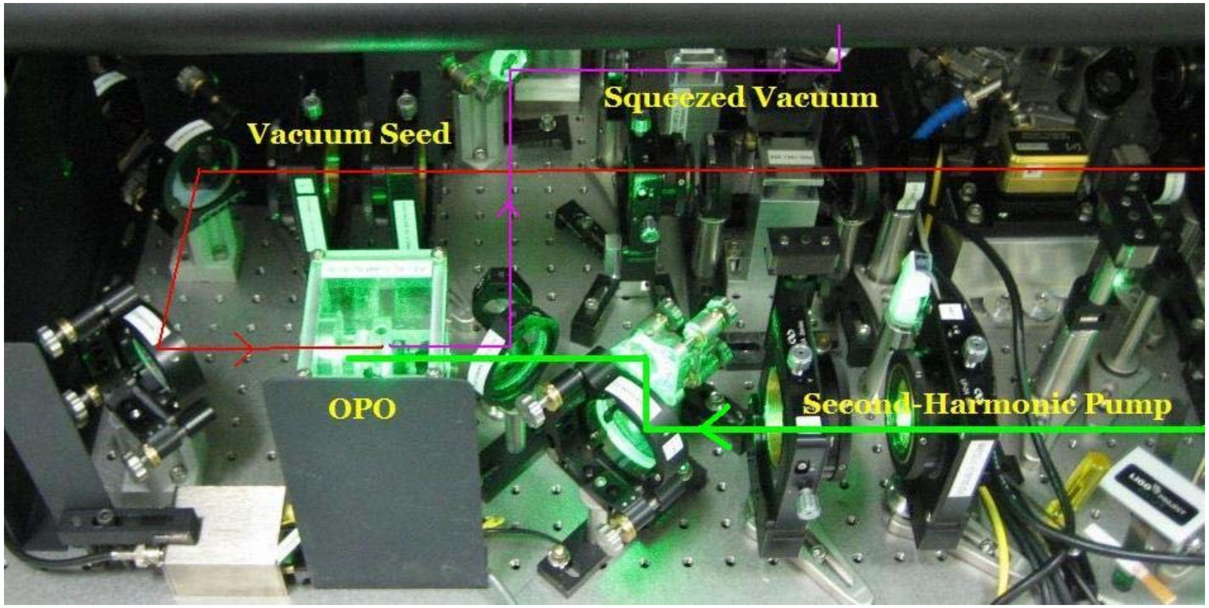


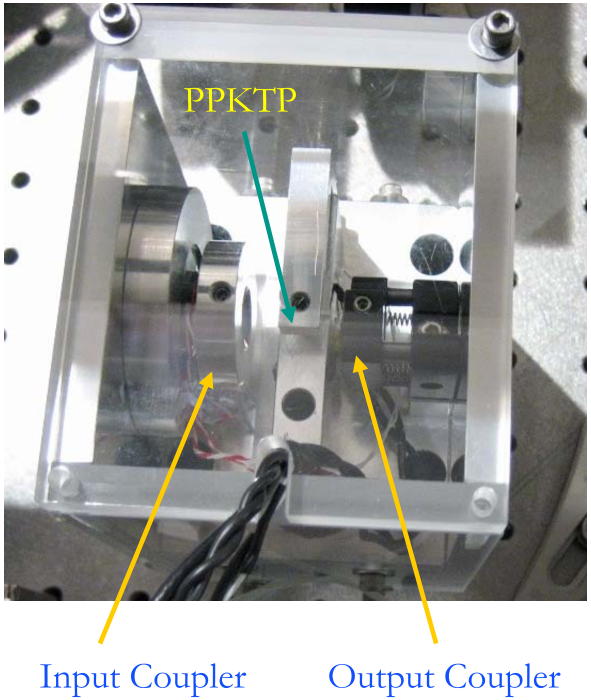
RSE

- Input Power to BS = 700mW
- Homodyne Angle = 0
- Squeeze Angle = $\pi/2$
- Initial Squeezing Level = 10dB
- Mode Mismatch Loss = 5%
- Faraday Rotator Round-Trip Loss = 10%
- OMC Loss = 10%
- PD Loss = 10% (90% Quantum Efficiency)
- Sum of Other Optical Losses (mirrors, lenses, etc..) = 5%
- SRC Offset = -0.3085*1064nm

- Squeezed vacuum is injected into the dark port via an optical circulator (Faraday)
- Noise-locking technique is used to lock the squeeze angle

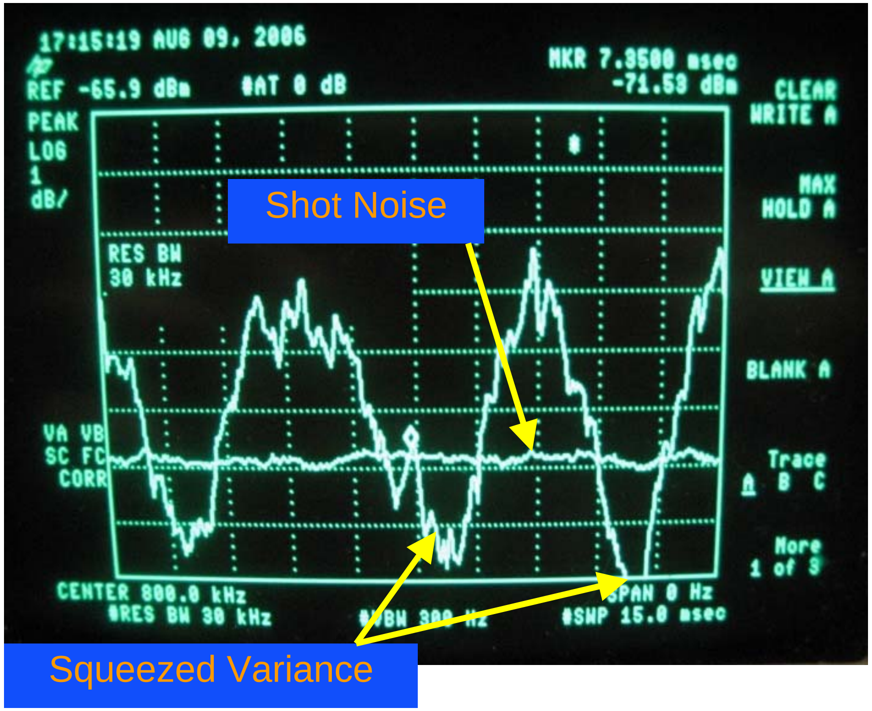
Generation of Squeezed Vacuum in Optical Parametric Oscillation with PPKTP





- The OPO is a 2.2cm long cavity composed of a periodically poled KTP crystal with flat/flat AR/AR surfaces and two coupling mirrors (R = 99.95% at 1064/532nm and R = 92%/4% at 1064/532nm).
- The OPO is pumped by 400mW of green light.
- PPKTP's nonlinearity : LiNbO3's nonlinearity = 4 : 1
- The crystal is maintained at 35 deg C for maximum 1064/532 parametric down-conversion.
- Quasi-phase matching is used and both the seed and pump are polarized in the same direction.
- No GRIIRA (green-induced infrared absorption)

Some Results & Future Work



About **2dB** of Vacuum Squeezing

(yet to be optimized)

- Center Frequency = 800 kHz
- RBW = 30 kHz
- VBW = 300 Hz

Things to Do

- Optimization
- Lock the squeeze angle
- Get more squeezing
- Install the picomotor mirrors in OOC
- Noise-hunting
- Lock the interferometer in RSE
- Mode-match the squeezed vacuum to the interferometer field
- Inject squeezed vacuum and see its effect on the sensitivity
- Test DC Readout-compatible squeezing

What's **NEXT**?

- We have a clear set of objectives for the next ~6 months or so.
  - » lock acquisition
  - » DC readout
  - » squeezing
- What should come next?
  - » new signal matrix (**lower RF sideband frequencies**)
  - » new modulation scheme (**non-Mach-Zehnder**)
  - » **ASC** system
  - » **Thermally actuated** Output Mode Cleaner
  - » **Suspension Point Interferometer**