End to End simulation for LIGO

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PAC meeting at Caltech

May 2, 2000

- Current status
- Major activities
- W2K one arm run
  - » fringes, freq.noise, ringdown, tidal,...
- Ongoing activities
  - » lock acquisition, ...
- Future plan
  - » schedule
  - » human and computer resources

Current status

- Simulation engine
  - » Almost all fundamental pieces are almost completed.
  - » Simple 3D mirror
    - – LSC and ASC can be simulated
  - » MSE 0.3, ...
- Modular design is showing its value
  - » e2e is used for the simulation of parts of LIGO
- e2e has caught up the hardware development, in some areas at least
  - » e2e is used to assist commissioning at LHO
  - » e2e is used for the lock acquisition design
- But still many things to be done
  - » PSL, IOO not completed
  - » Thermal lensing to be implemented
  - » Speed improvements
  - » Closed loop time step,...

Major activities - 1

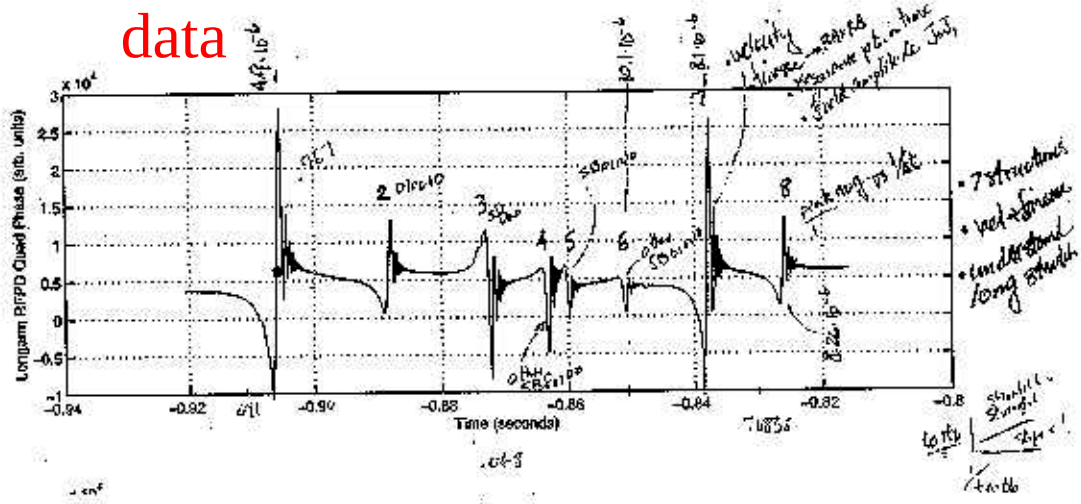
- Simulation engine
  - » speed improvements
    - – for the multi mode simulation
  - » needed features
    - – macros, function parsing, save&load,...
- Optics
  - » revision of optics/field implementation
    - – multi mode, summation cavity, polarization from the ground up
    - – clean implementation for speed, easy update and maintenance
  - » thermal lensing
- Mechanics
  - » 3D mirror (simple and MSE-based)
  - » parametrization of seismic motion and BSC/HAM stacks
  - » thermal noise

Major activities - 2

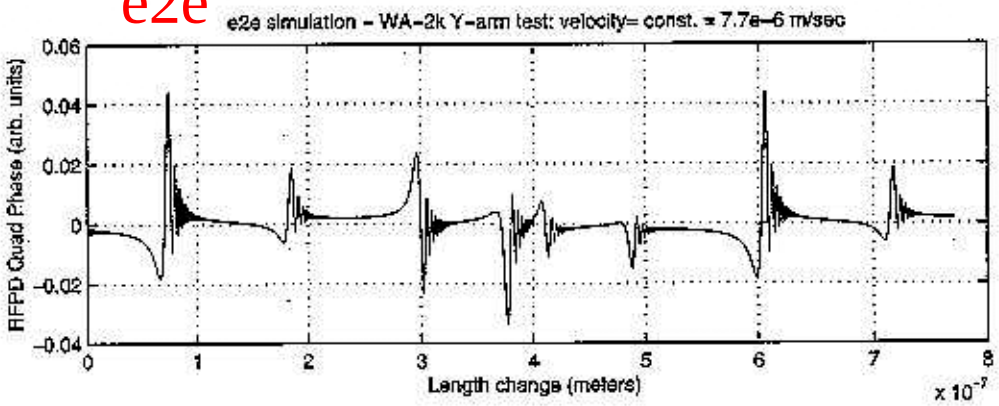
- Lock Acquisition design
- Assist commissioning
- Evangelize
  - » let people understand what e2e can do
- Alfi - e2e GUI
  - » support of folder structures
    - – logical organization of codes
    - – group-wise libraries of subsystems and utilities
  - » improvement to handle more complex structures by tree views

W2K one arm run:
Fringe structure revealed

data

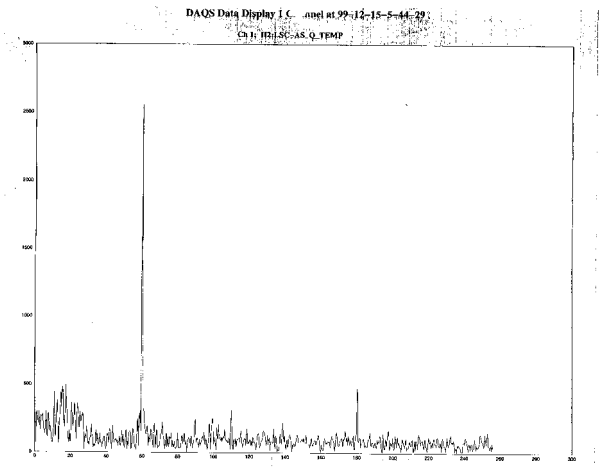


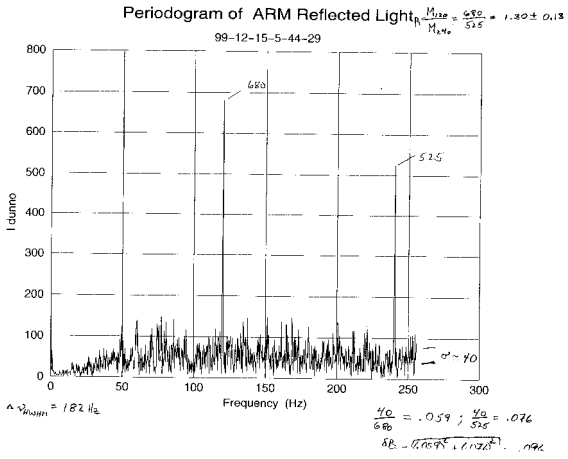
e2e



W2K one arm run:
60Hz laser noise quantified

During a discussion on 12/15/99 Daniel Sigg proposed that the data may be explai
ned by frequency modulation at only 60 Hz.

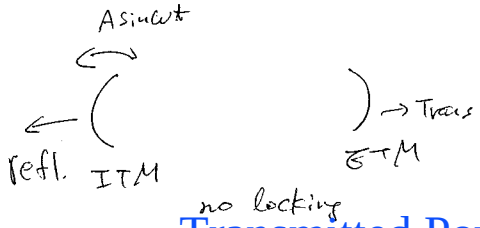




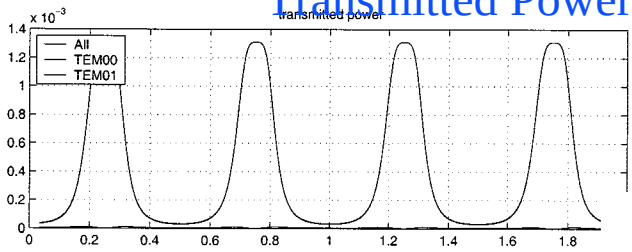
Conclusion: Modulation amplitude of 2.55*HWHM gives the observed ratio of 60Hz
to 180 Hz in the RFPD In Phase signal and the observed ratio of 120Hz to 240Hz i
n the Reflected Light signal. 2.55*HWHM corresponds to 464 Hz peak. This will
be compared to observed signals such as control signals from the mode cleaner in
an effort to locate and eliminate the source of the 60 Hz modulation.

$$df(t) = 454\sin(2\pi \cdot 60 \cdot t)$$

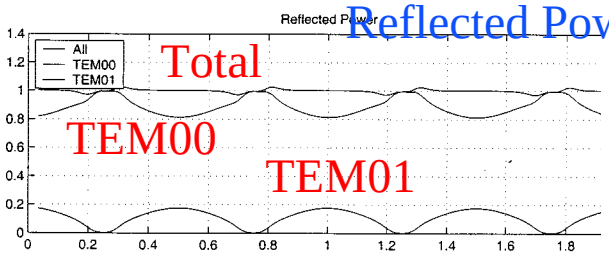
W2K one arm run:
Effects of mirror tilt

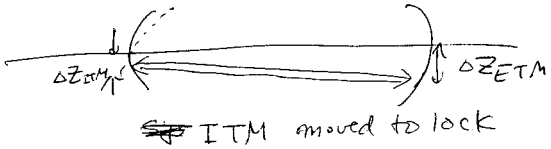


Transmitted Power

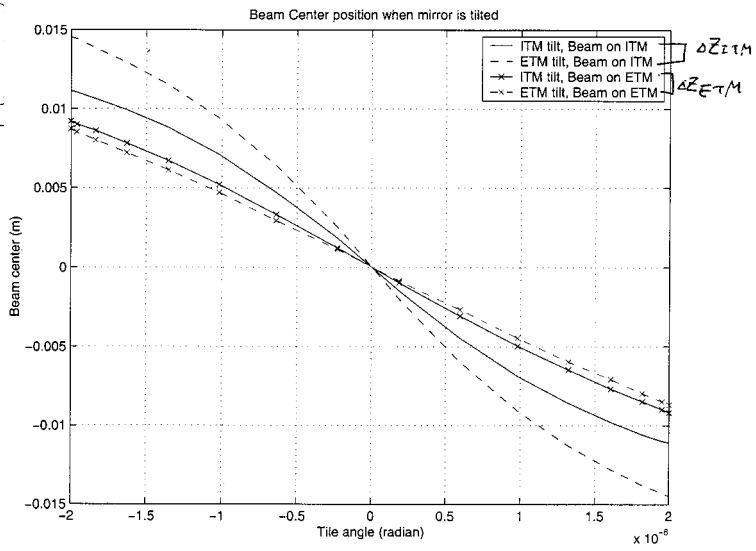


Reflected Power



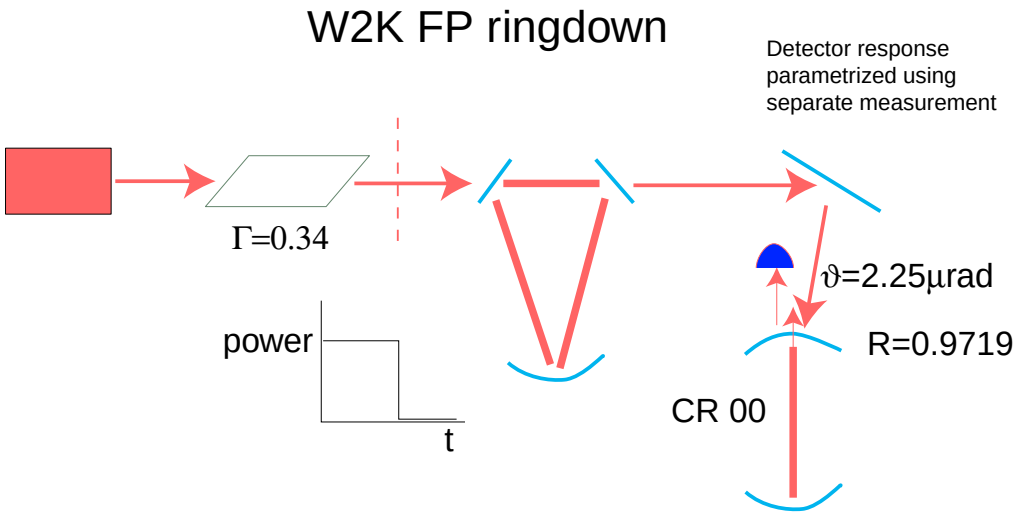


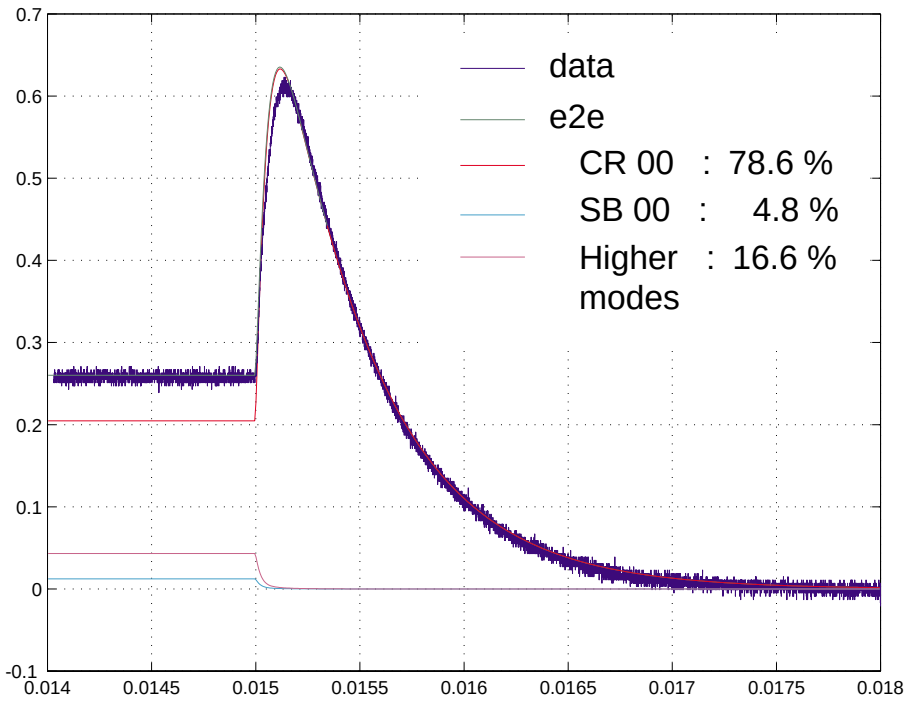
Beam center



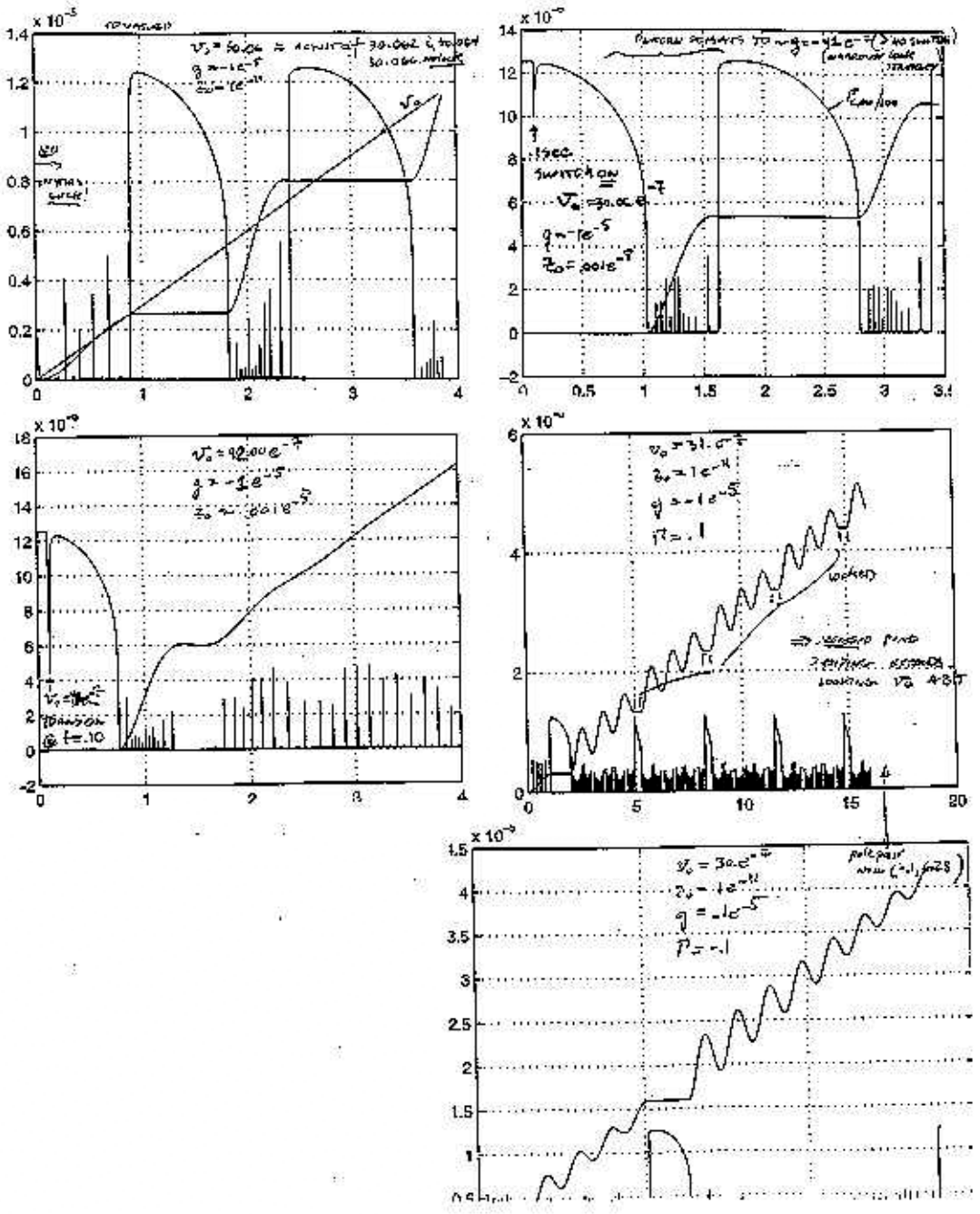
Tile angle

W2K one arm run: Mode matching from ring down measurement



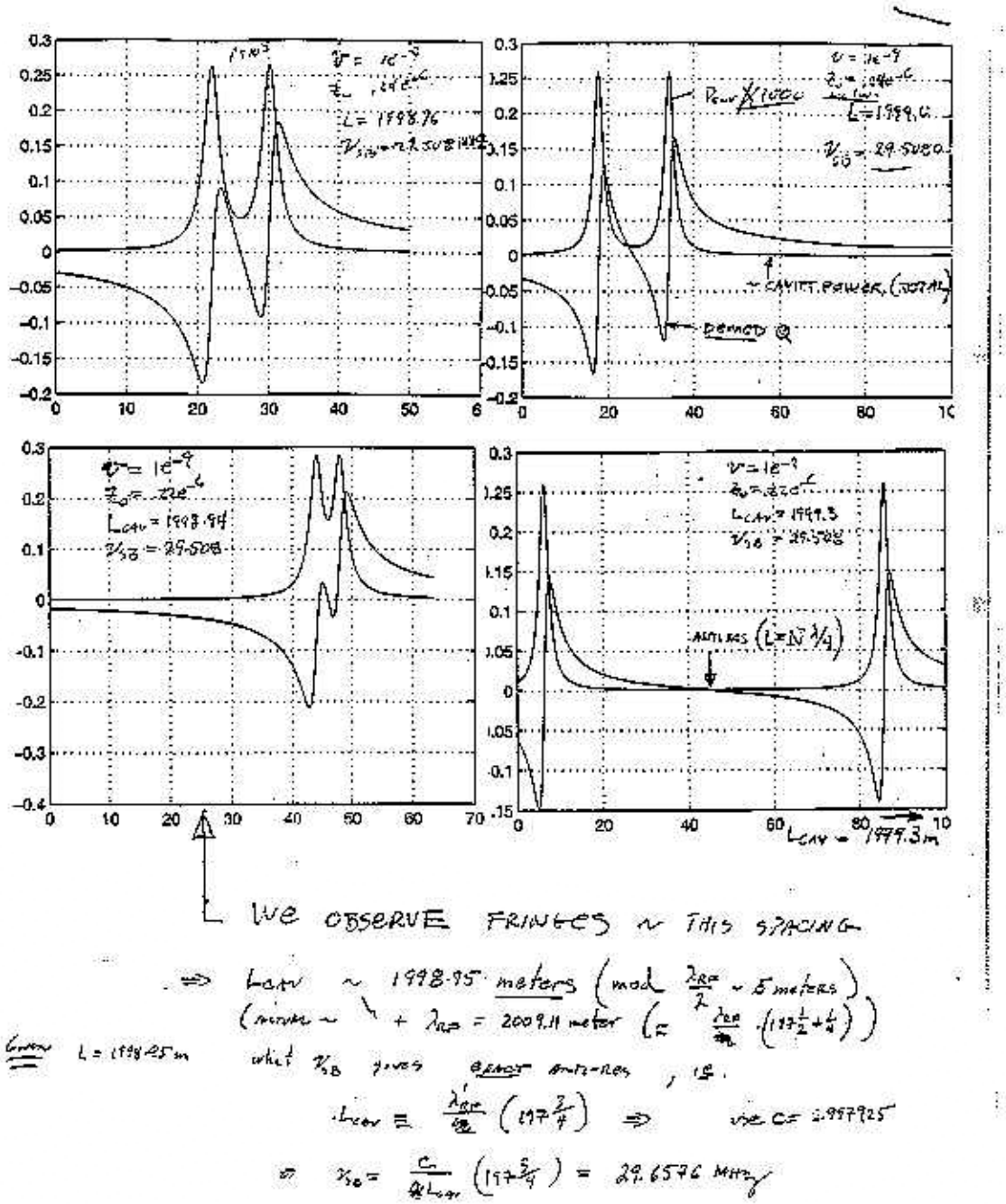


W2K one arm run:
Tidal effect studied



LIGO W2K one arm run:

Arm length “measured” with sub cm accuracy

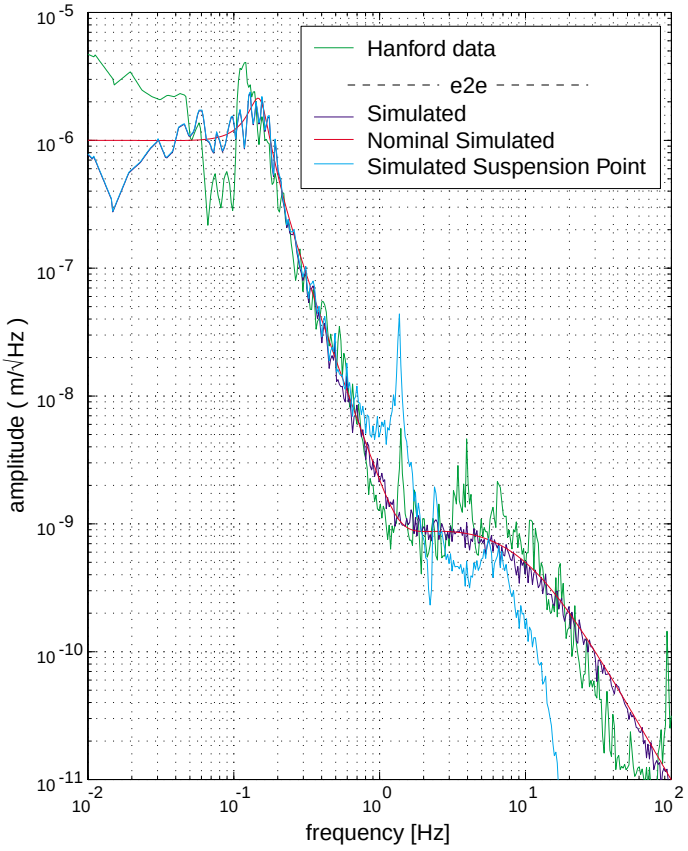


Ongoing : Lock Acquisition

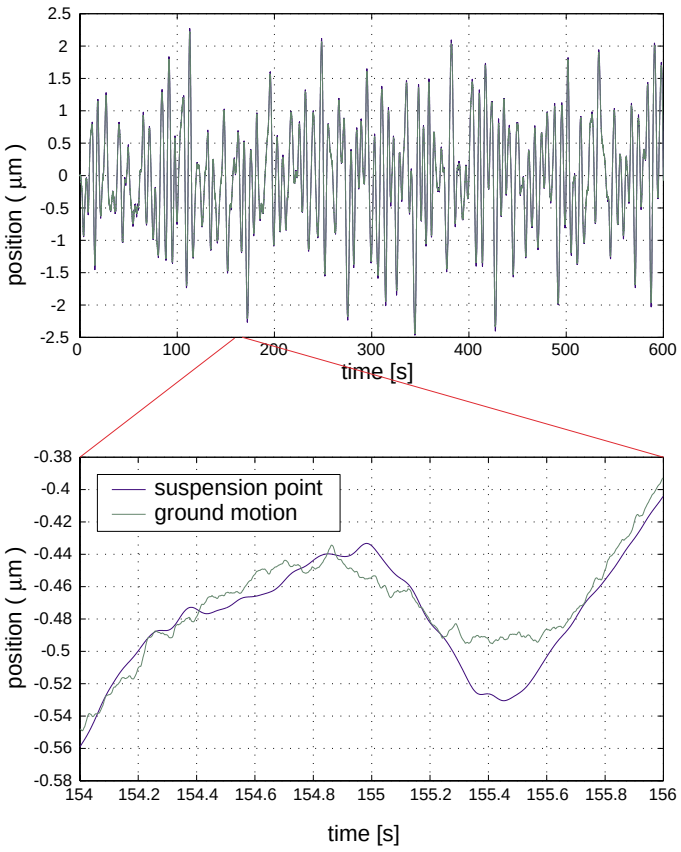
- Old design reviewed and decided that it needs to be revised.
- Take same steps to lock
  - » michelson lock -> one arm -> two arms -> full
  - » use new lock design by M.Evans
- e2e based
  - » spatiotemporal and temporal simulation
  - » flexible
  - » better subsystem integration
  - » realistic noises
- Status
  - » design based on scalar mode is completed
    - – seismic noise and laser frequency noise
  - » code provided to CDS for Michelson lock
  - » analysis including higher order modes is going to start
    - – at least 10 times slower -> CPU problem

Ongoing :
Lock Acquisition - seismic

Measured vs. Simulated Seismic Spectra



Simulated Seismic and Suspension Point Motion

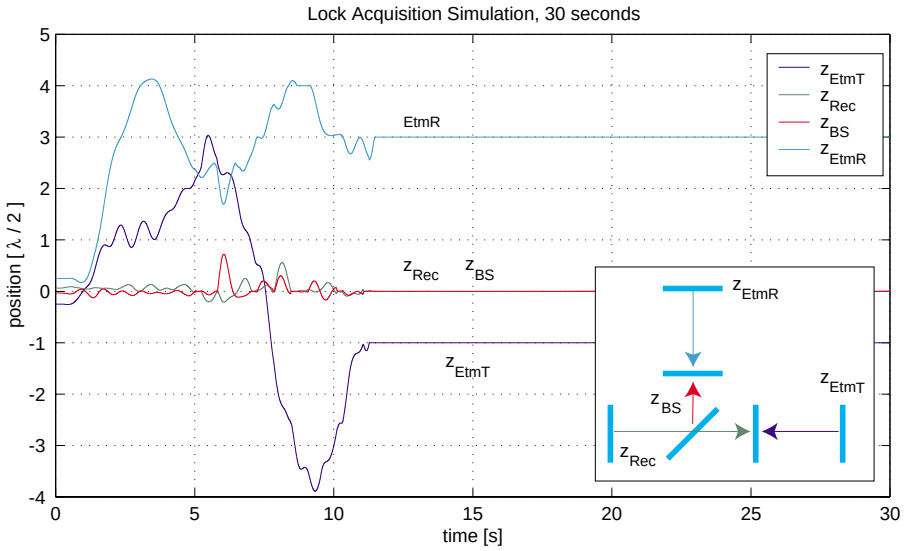


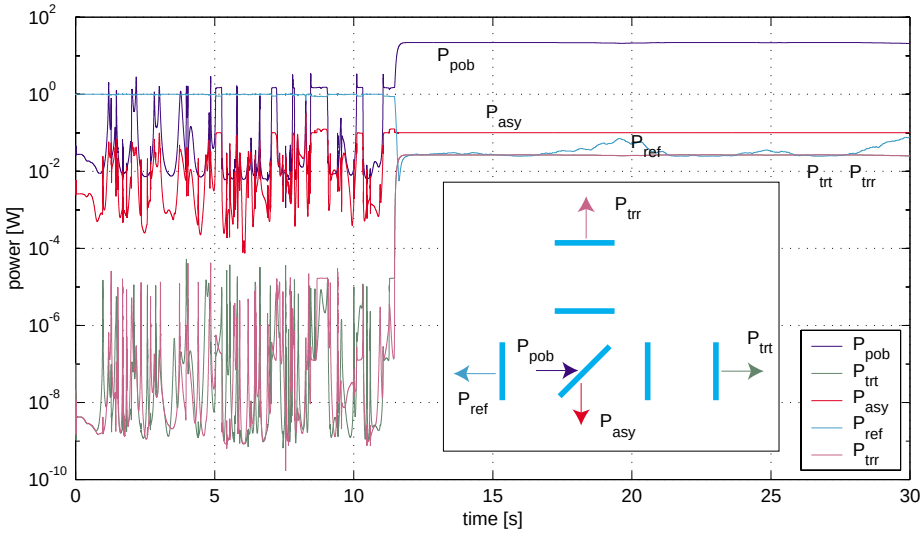
Correlation of mirror motions

mirrors in corner station = $\delta x_{\text{very low f}} + \delta x_{\text{low f}} + \delta x\,(i)$

mirrors in end stations = $\delta x_{\text{very low f}} + \delta x\,(i)$

Ongoing :
Lock Acquisition - process





Matt Evans on March 14, 2000

Ongoing : details of PSL - Rick's mail

I have been troubled for a long time by the fact that we have so much light on the reference cavity RFPD that comes from the fact that the laser output mode quality is not very good. We are only able to match about 60% of the light to the reference cavity (even without sidebands). Thus we have 30-40% of the input light always on the RFPD.

I wonder what the implications of this are. For instance, I guess that the shot-noise-limited sensitivity is compromised. Also, RFAM on the input light would cause a large DC offset due to all of the light on the RFPD.

Right now, David Ottaway, Michael Landry, and I are trying to track down the source of the PSL table vibrations coupling into the frequency spectrum of the mode cleaner and long arm cavity error signals. You and Giancarlo are looking for the role of reference cavity motions, but it appears that motion of the RFPD is playing a big role. If we tap on the RFPD while listening to the MC length control signal on a pair of headphones, we hear a very strange (and loud) sound that we do not hear when we tap on any other optic.

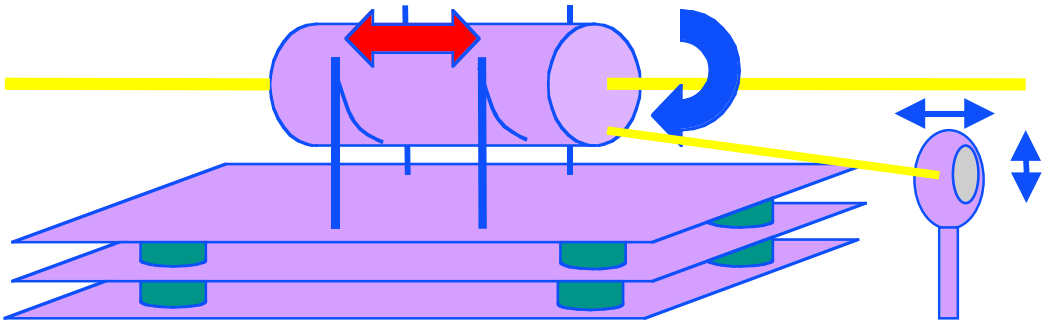
Several people have proposed that the effect is due to light scattering from the surface of the photodetector back to the reference cavity forming spurious interferometers. We have tried inserting a quarter-wave plate to reduce the backscatter, but have not been successful in reducing the effect.

If you or Biplab were here, I would ask you if we could use the e2e to model what might be causing this effect (I think that this is much more important right now than the reference cavity motions, although I'm sure that they will be dominating our signals before we are finished). I think that the e2e model would have to include motion of the RFPD, spatial non-uniformity of response of the RFPD, RFAM on the input light, a spurious cavity set up between the RFPD and the reference cavity, and of course the reference cavity. Also, we have a lens in front of the RFPD with a short focal length and we were discussing possible subtle effects like the motion of the RFPD near the focus of the lens causing the Guoy phase between the TEM00 sidebands and the higher order mode (garbage) light to vary resulting (perhaps via non-uniformities of the RFPD response) in the frequency noise we see.

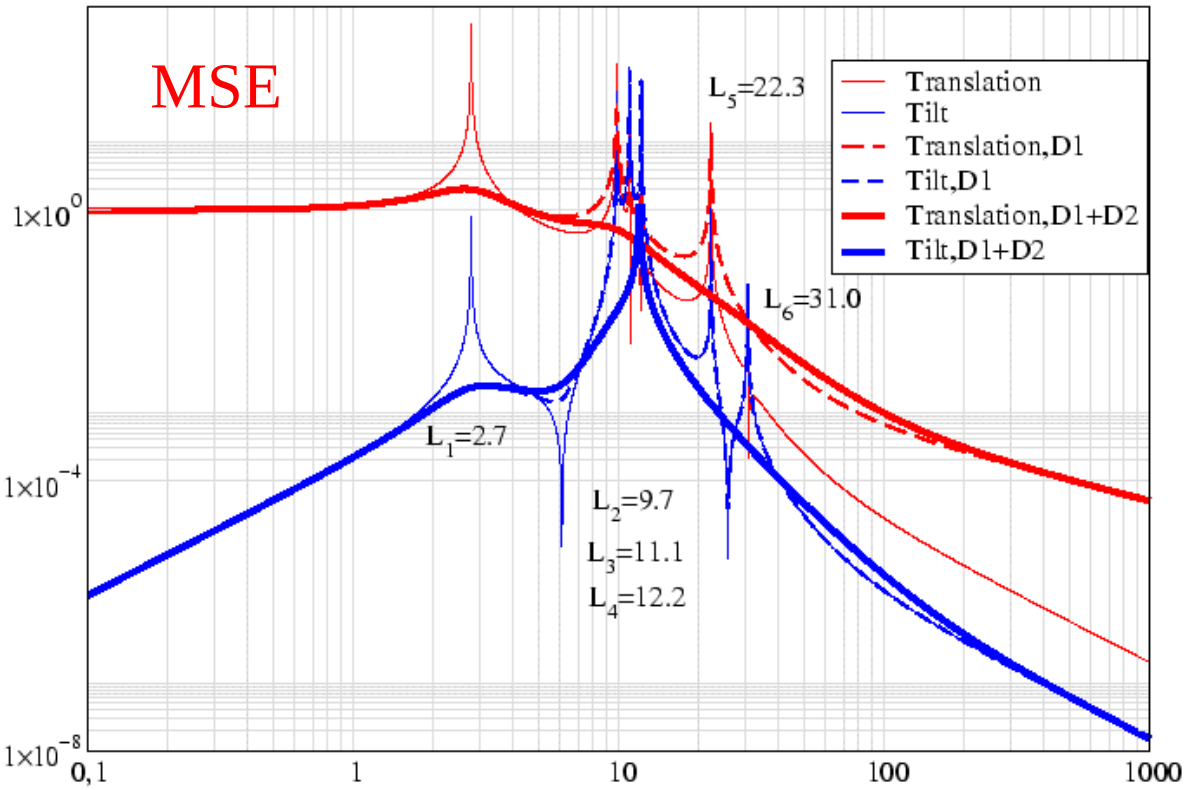
Do you think that this is something that the e2e could help with?

YES!!!

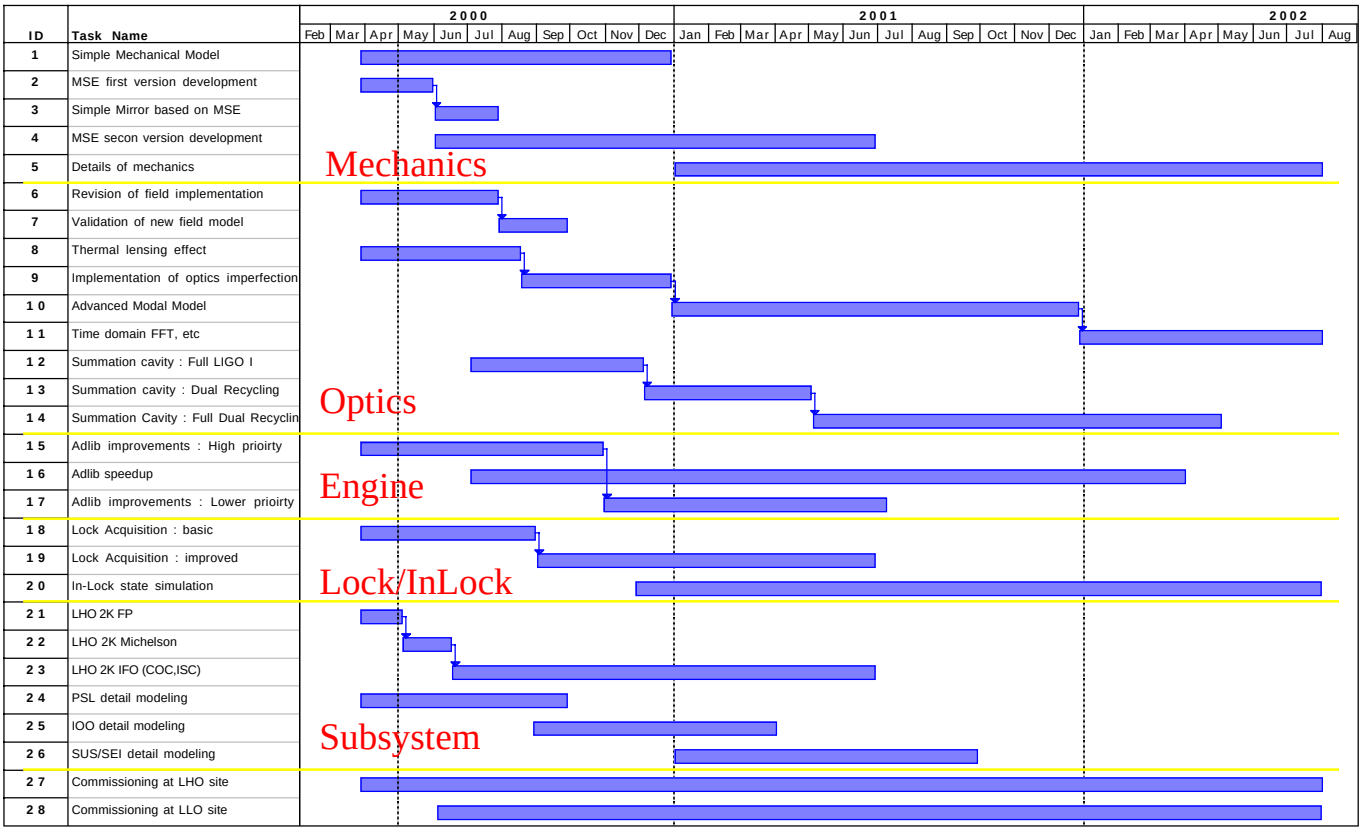
Ongoing : details of PSL - ref. cavity



X motion



Future plan : outline



assist commissioning

Future plan : Human Resources

- 1 graduate student
  - » M.Evans (CIT)
    - – Lock Acquisition (thesis topic)
- 2.8 FTE scientists
  - » H.Yamamoto,B.Bhawal (CIT) 2 FTE
    - – Optics, Mechanics, Engine, assisting commissioning, many programmer's work
  - » L.Matone (CIT) 0.3 FTE
    - – COC model, optics modeling, assisting commissioning
  - » G.Cella (Italy) 0.5 FTE
    - – Mechanical Simulation Engine development
- 1FTE programmer
  - » E.Maros (CIT) 0.2FTE, B.Sears (CIT) 0.8FTE
    - – Developing GUI
- We need more scientist(s) to do all of the following:
  - » implement physics in e2e
  - » subsystem modeling
  - » assist commissioning

Future plan : Computing resources

- Lock Acquisition working using scalar field
  - » 5 minutes - just to test an idea
  - » 5 hours - randomly swinging mirrors to fully locked state
- Multi mode will make it at least 10 times slower
- We need a programmer
  - » to speed up the software
    - – Improvement logic
    - – multi threads
  - » We have ideas, but don't have time
- We need a higher performance CPU
  - » Simulation is sequential
  - » Several CPUs for multi-threaded simulation run
  - » Many quick short runs and very long runs
  - » Run GUI and simulation on the same machine