Status of LIGO Simulation

Hiro Yamamoto / LIGO Lab

- Status
- Applications
  - » Sensitivity curve
  - » Lock acquisition - past and future
  - » Wave Front Sensor & Alignment Sensing and Control
- Issues
- Summary

Simulation group

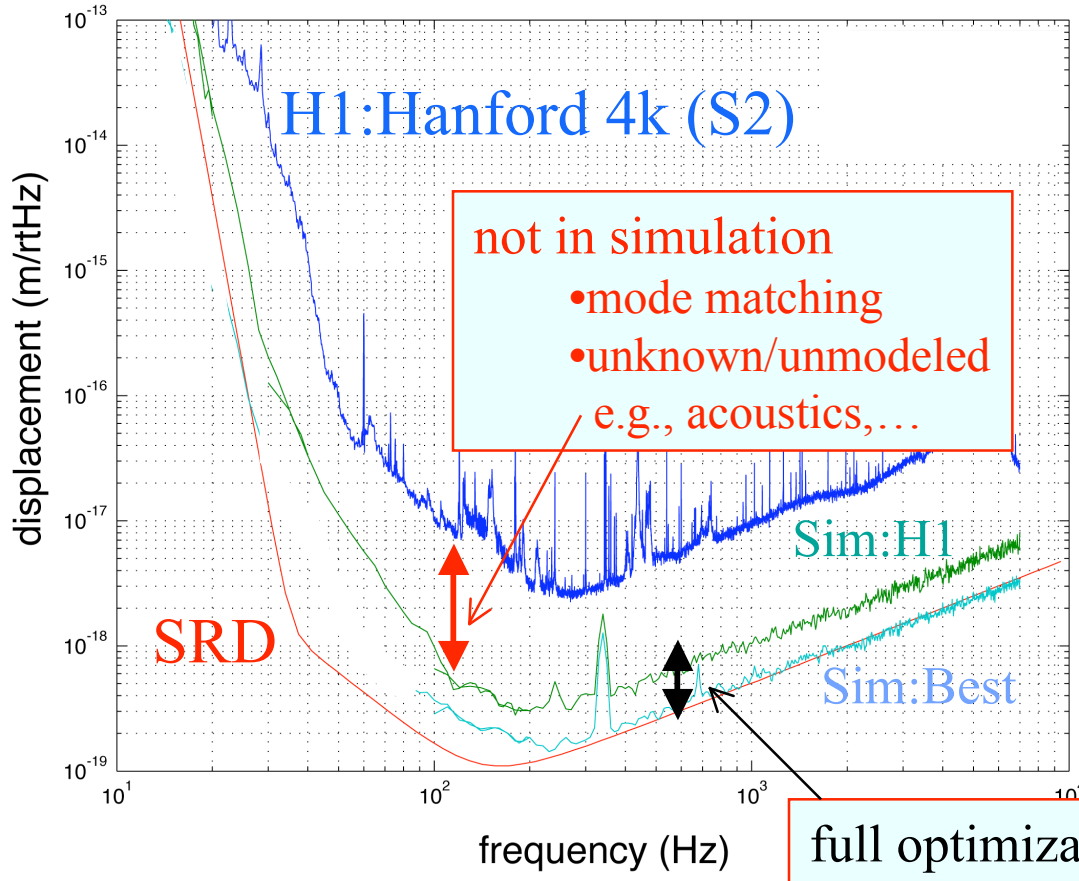
- H. Yamamoto (1 FTE) : Manager, Salesman, Science programmer
- M. Evans (1 FTE) : Lead Scientist for e2e application
- B. Bhawal (1 FTE), V. Sannibale (1/3 FTE) : Scientist
- B. Sears (1 FTE), M. Araya (1 FTE) : User Interface programmer

Status overview

- End to End simulation framework - pac13 talk G030261
  - » time domain simulation
  - » major physics for LIGO included
    - – fields&optics, mechanics, control systems
  - » generic development environment like matlab, dedicated for Interferometer
- LIGO simulation packages built using e2e
  - » Han2k - simplified LIGO simulation - T000094
    - – first lock acquisition design (<20 Hz)
    - – Minimum components needed for lock acquisition study
  - » SimLIGO - detailed LIGO model - T020138, T020139
    - – advanced lock acquisition, servo design, sensitivity simulation (< 16kHz)
    - – Major hardware and software components implemented
      - Digital length and alignment servo, digital suspension controller, etc

Application : sensitivity

"as built LIGO" will get there, almost



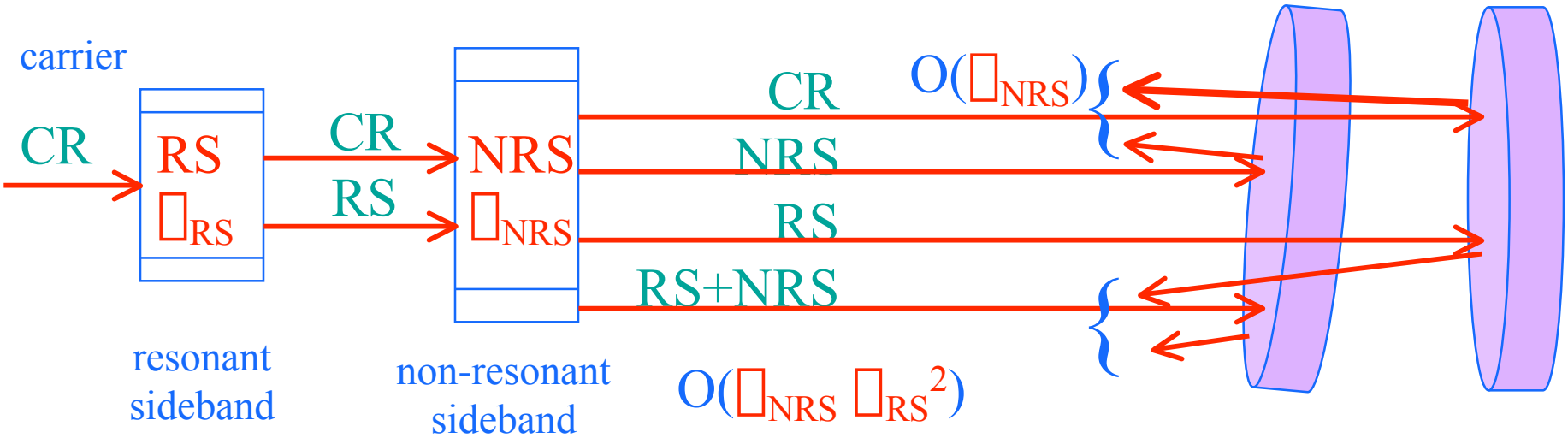
still work in progress
details in T030063

- Time domain simulation
- Interferometer with length and alignment controls
- realistic noise propagation
- signal extraction same as real experiment
- bilinear coupling automatically included

Application : demodulation
simple, but not so simple

P.Fritchel et al
"Alignment of an interferometric gravitational wave detector"
Appl. Opt. 37, 6734

The recycling mirror tilt can be detected solely by reflected field demodulated by NRS frequency. $O(\Phi_{NRS}) >> O(\Phi_{NRS}\,\Phi_{RS}^2)$

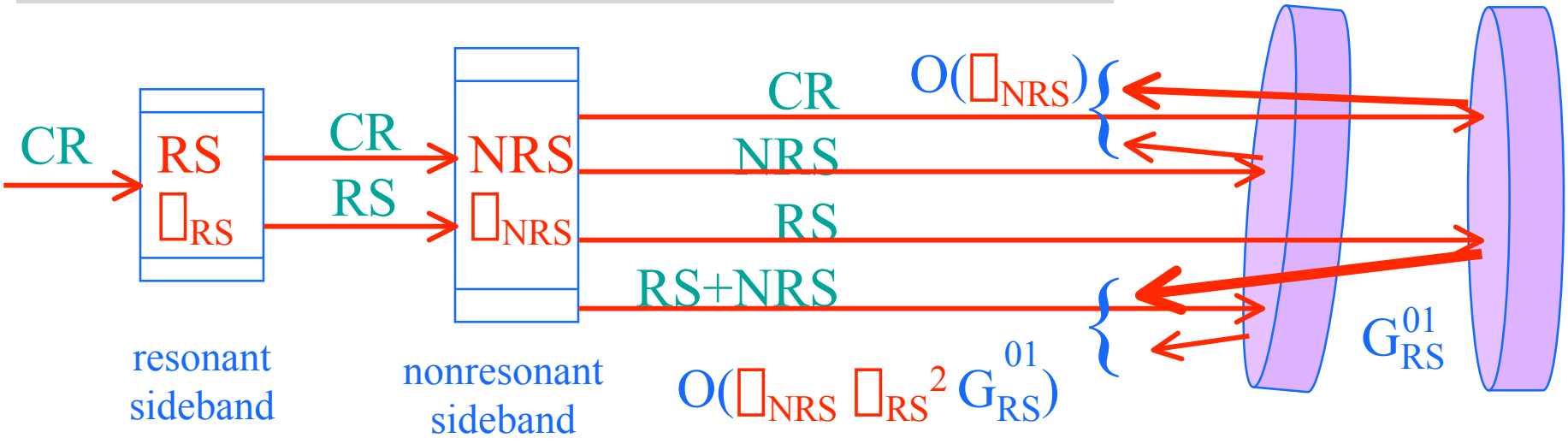


Application : demodulation

simple, but not so simple

From: Daniel Sigg <sigg_d@ligo.caltech.edu>
Subject: WFS3/4 mystery
Dear WFSer,
Biplab may have found the reason for the discrepancy between measurements and predication of WFS 3 and 4.
…
Dah! I guess it's obvious once you see it.

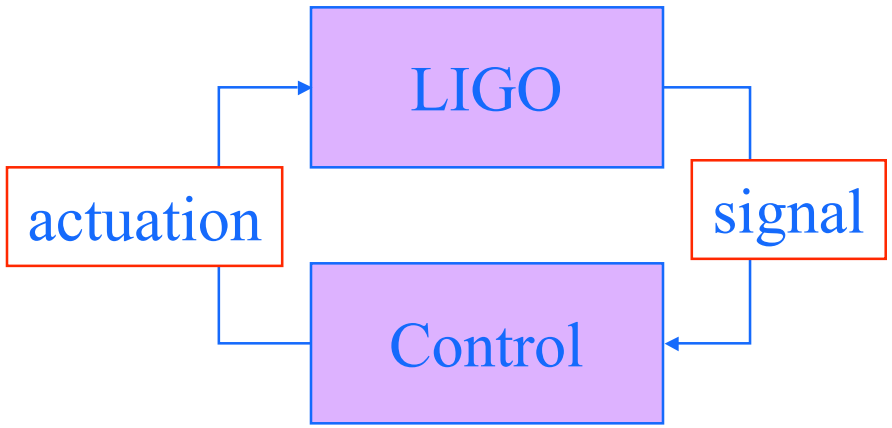
From: e2e
Sub: Re:WFS mystery
I am stupid, but I do all I am told to do honestly.



Application : ASC

linear system is simple - but hard to do it right

Weekly Report (May 22, 2003):
(Matt) … The trouble is that the ASC sensing matrix is not diagonal and not easily diagonalized (due to noise and gain variation). I have developed an algorithm for producing a robust control matrix. The resulting control matrix gives stable control in SimLIGO and will (hopefully) be tested at LHO next week.
Private communication:
Tests on H1 indicate that more work is necessary to account for extreme gain variation in WFS2 seen in H1 but not seen in SimLIGO, probably due to mode-overlap/thermal lens difference.



simple solution using matrix inversion

$a = G_1 * s_1 - G_2 * s_2 \sim O(s)$

When high gain is needed, G>>1

$\delta a \sim G * \delta s$

$\delta a(t) \sim G * \delta s(t)$

sophisticated solution by trial and error using simulation with reasonable noise and gain fluctuation may be needed

LIGO Application : lock acquisition revisited

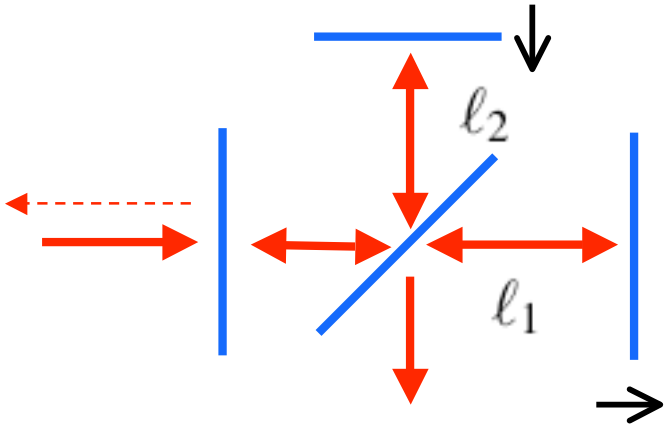
hot LIGO will be cool, woops, not (1)

Study when LIGO heating improves mode matching

G030176
(LSC, March)

- PRM nears optimally coupled for SBs
  - »e-mail in April from Daniel Sigg to Commissioning group

Here is another task for the commissioning list: Fix the asymmetry of the two 4K interferometers (by 55mm). (Matt et al. triggered me off.) …
Why didn't we notice this earlier?
D.Sigg, T030066 : Schnupp Asymmetry of the 4K Interferometers



$\ell_1 - \ell_2 = 300mm$ value for 2k IFO used also for 4k IFO

$\ell_1 - \ell_2 = 355mm$ should be for 4k IFO to be fixed

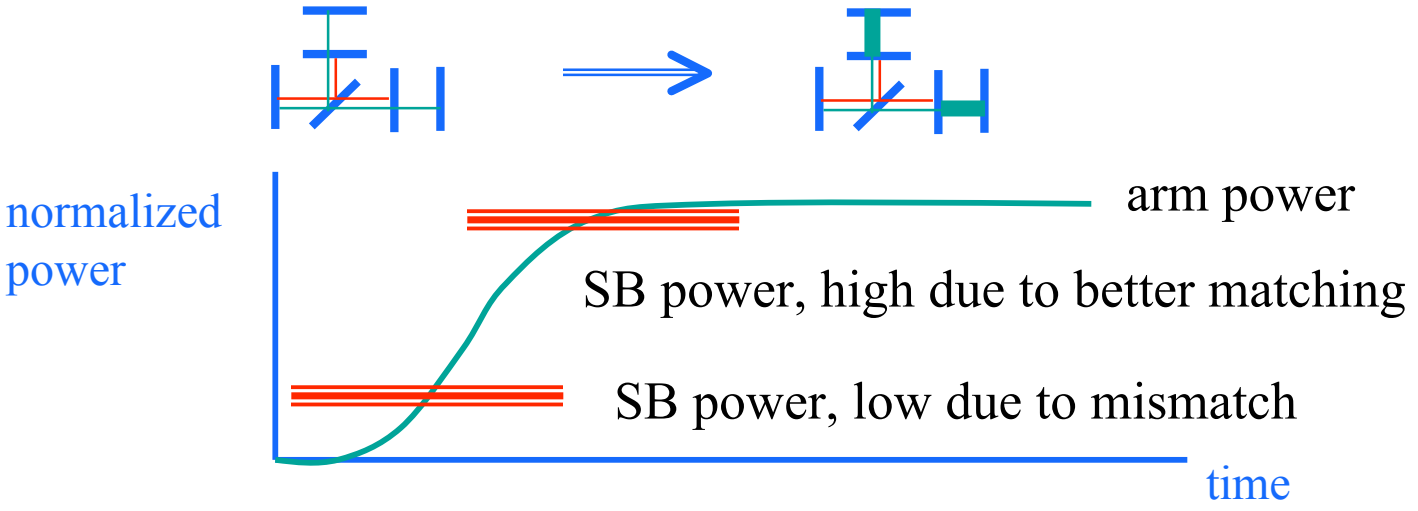
LIGO Application : lock acquisition revisited

hot LIGO will be cool, woops, not (2)

Study when LIGO heating improves mode matching

G030176
(LSC, March)

- State 4 singularity happens later and longer



- Use non-resonant SBs on reflection to avoid these issues?
  - »New control schemes using NRS being studied using simulation T030089

Issues
things to improve the simulation

- Needed realism
  - » mirror surface aberration using phase map measurement
  - » scattering light noise
  - » acoustic noise
  - » …
- Needed application
  - » systematic study of bilinear couplings and their effects on the sensitivity
  - » exploration of non-resonant sideband LSC control and acquisition continued investigation of ASC control, with series modulation and more sophisticated control matrix
  - » …

Issues

how to utilize simulation more efficiently

- past
  - » Lack of manpower to help build the tools
    - – resulted in delays of the delivery of fully functional product
    - – still no seismic model for Livingston
- present
  - » Lack of commissioning use of existing tools
    - – All simulation work outlined here was done by a few scientists in the simulation group
    - – application is very limited
    - – “Can e2e do this, do that ?” => “YES, YES, YES !!!” => sound of silence …
- future
  - » Developments are needed to make e2e useful for Adv.LIGO
    - – implementation of better optics and mechanics models
    - – improvement of software architecture driven by physics (64bit is not enough)
  - » Proper resources need to be allocated to use e2e in time (current resources are overwhelmed by current LIGO)

Summary

- Simulation engine and interface are ready
- LIGO simulation is ready
  - » lock, ASC design
  - » useful information for commissioning
- LIGO simulation needs improvements
  - » more reality
  - » more noises
- NEED MORE USERS
  - » Sany Yoshida & his undergrads (SLU) : LIGO
  - » Hideaki Hayakawa (ICRR) : TAMA/LCGT
  - » Michaela Malec (Institut fuer Atom- und Molekülphysik) : GEO