DCC

Control System Modeling and Design for Acquisition of a LIGO Interferometer

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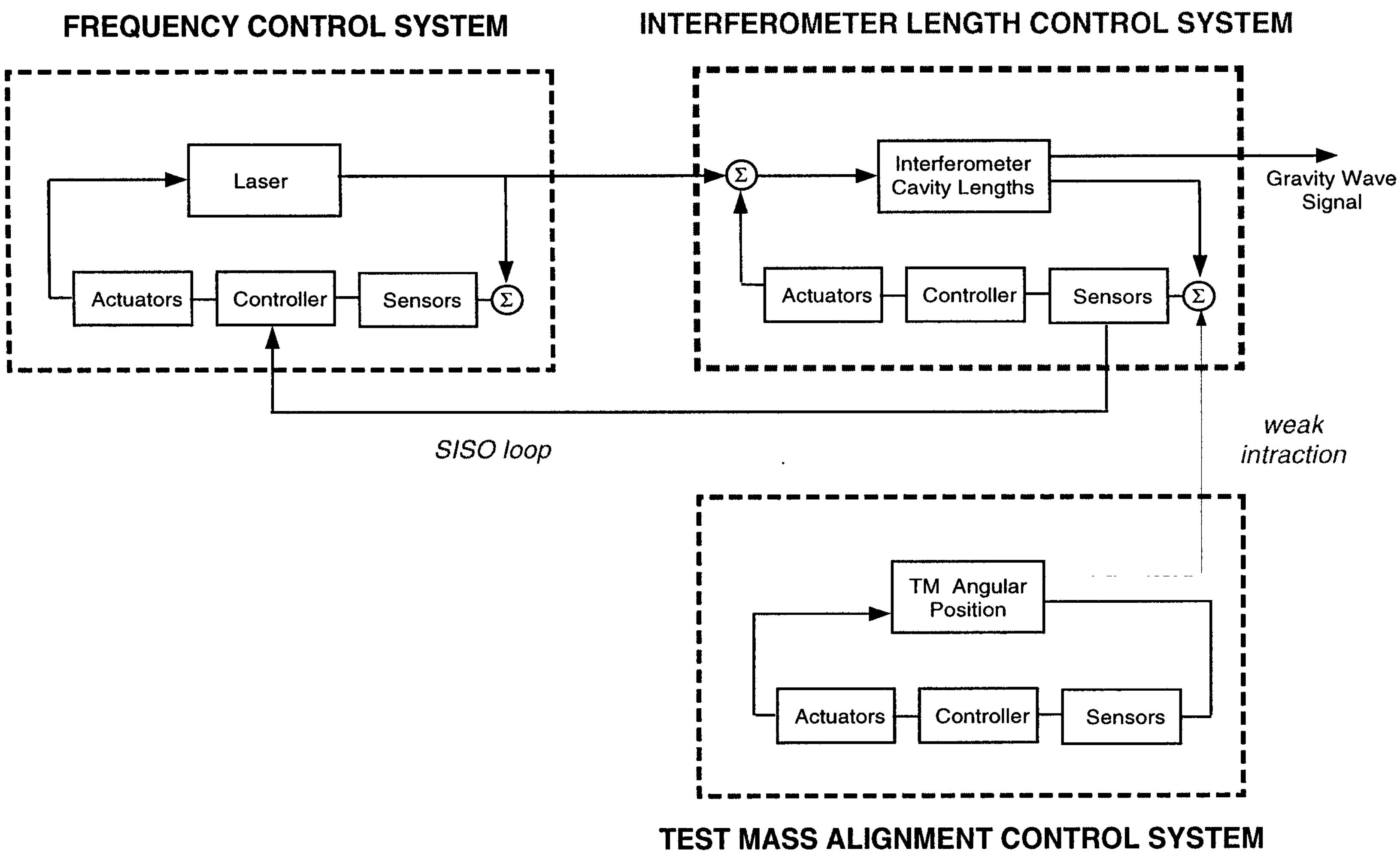
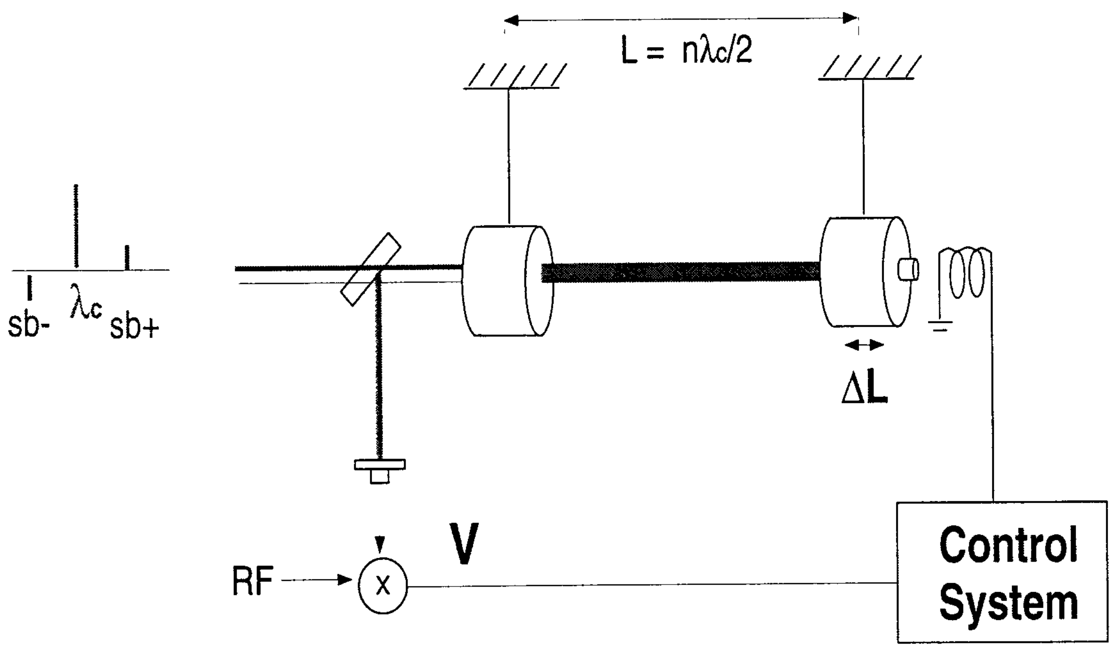
Outline of Presentation

- Description of an IFO Length Control System and its modes of operation
  - ›› Operations Mode
  - ›› Acquisition Mode
- Motivation of need for a model of Acquisition
- Building Block Modeling Approach
  - ›› Lessons for LIGO from Coupled Cavity Model
  - ›› Lessons for LIGO from Recombined Ifo Model
  - ›› Recycled IFO Model
- Major challenges in locking LIGO
- Conclusions (i.e. importance of acquisition modeling to LIGO)

BLOCK DIAGRAM OF INTERFEROMETER SERVO CONTROL SYSTEMS



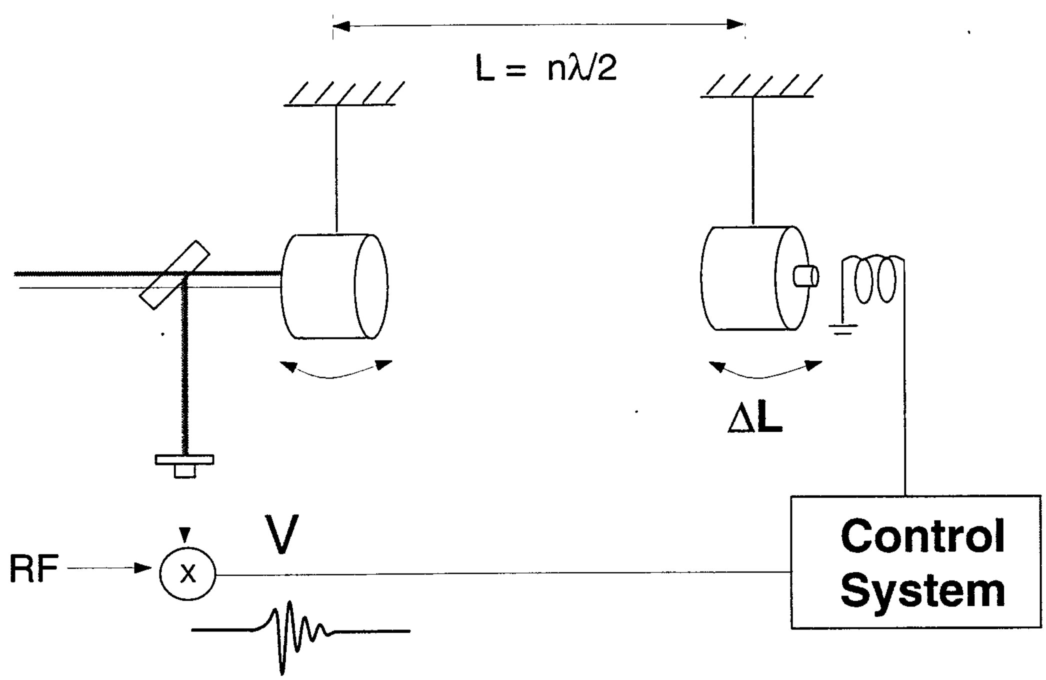
Interferometer Length Control System



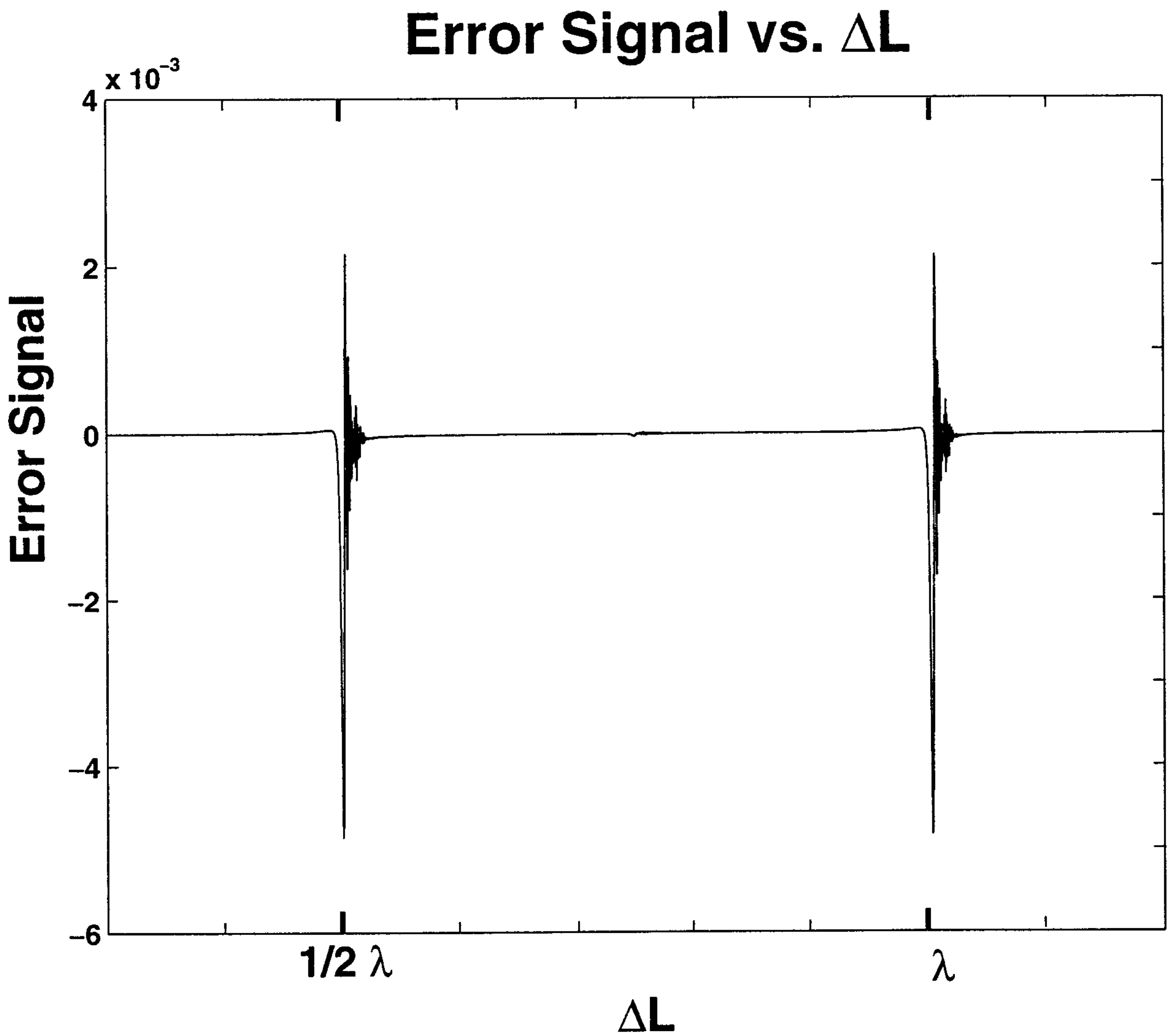
- Operations Mode
  - IFO on resonance ==> ΔL <1 nm
  - Can model as a simple linear system

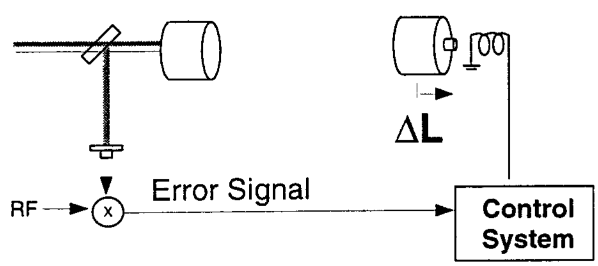
$$V(\omega) = \left(\frac{G}{2\pi j\omega + p_c}\right) \cdot \Delta L$$

Interferometer Length Control System (contd. 2)



- Acquisition Mode
  - ›› ΔL goes through many fringes
  - ›› Control signal is usable for only μsecs at a time
  - ›› Can **NOT** model as simple linear system; is a system with memory

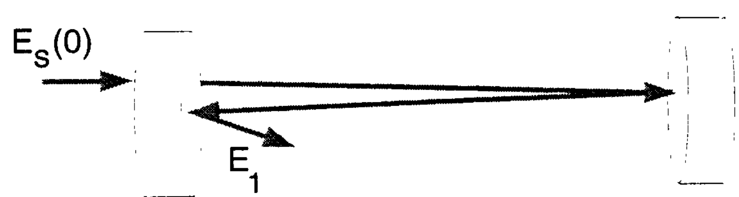

Error Signal vs. ΔL
x 10^-3
4
2
0
−2
−4
−6
Error Signal
1/2 λ
λ
ΔL


ΔL
RF
x
Error Signal
Control System

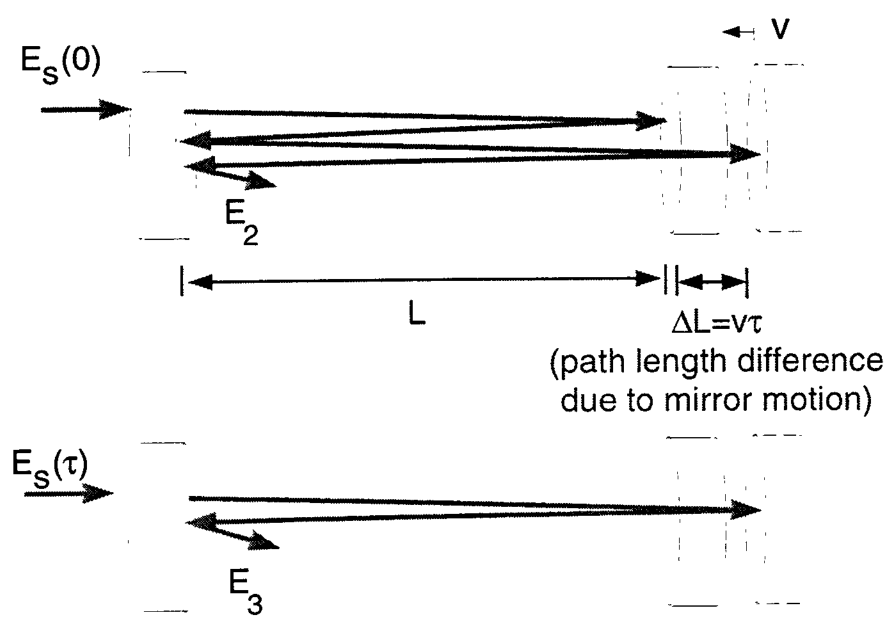
Optical Dynamics During Acquisition (memory!)

- E field in cavity at time "t" equals Σ of fields due to light entering cavity at discrete times, t, t-τ,...

E field in cavity at τ: $E(\tau) = E_1 + tE_s$



E field in cavity at 2τ: $E(2\tau) = E_2 + E_3 + tE_s$

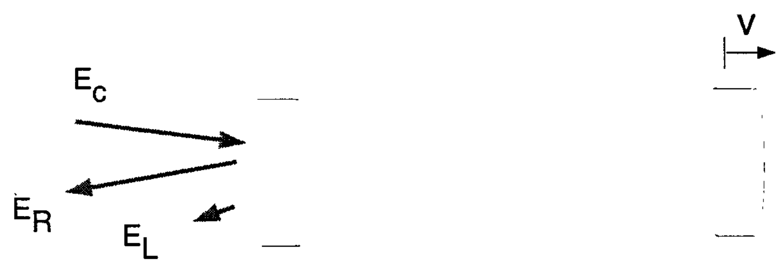


LIGO-G970025-00-D

Optical Dynamics During Acquisition (contd. 2)

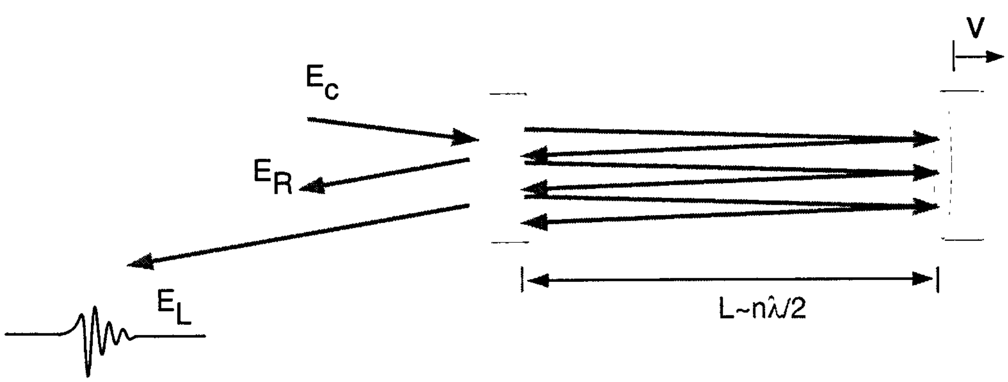
- Why do you see a fringe?

FIELDS WHEN IFO OFF RESONANCE:



Field propogating to left is dominated by prompt reflection E_R

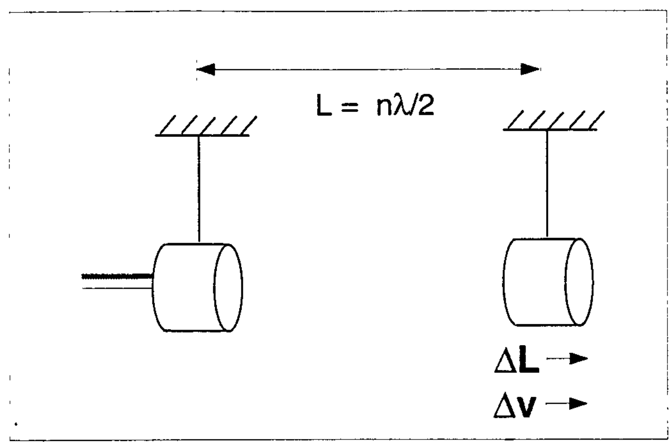
FIELDS WHEN IFO CLOSE TO RESONANCE:



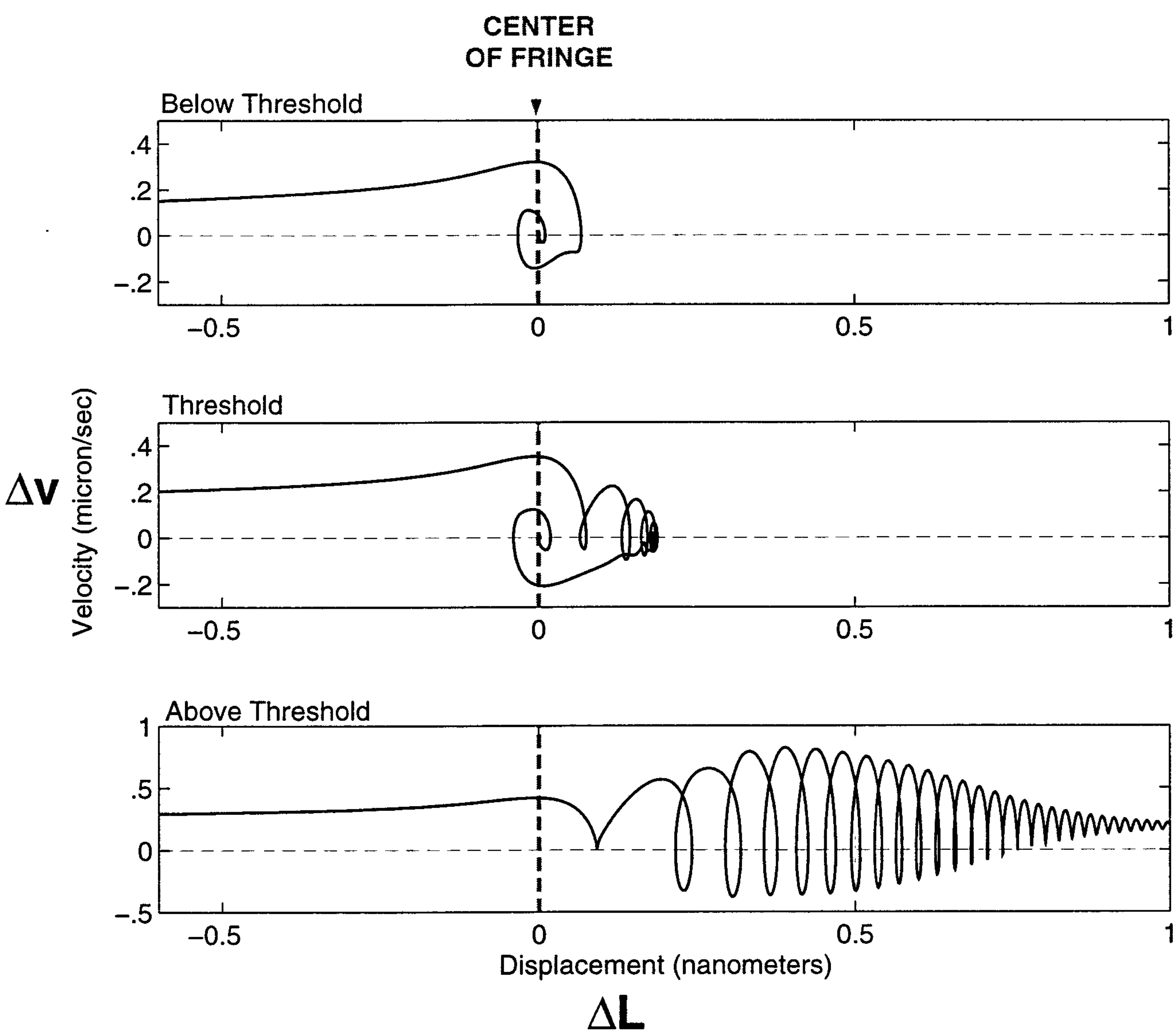
Field propogating to left has large component of leakage field (contructive and destructive interference creates fringe structure)

Motivation of Need for a Model of Acquisition

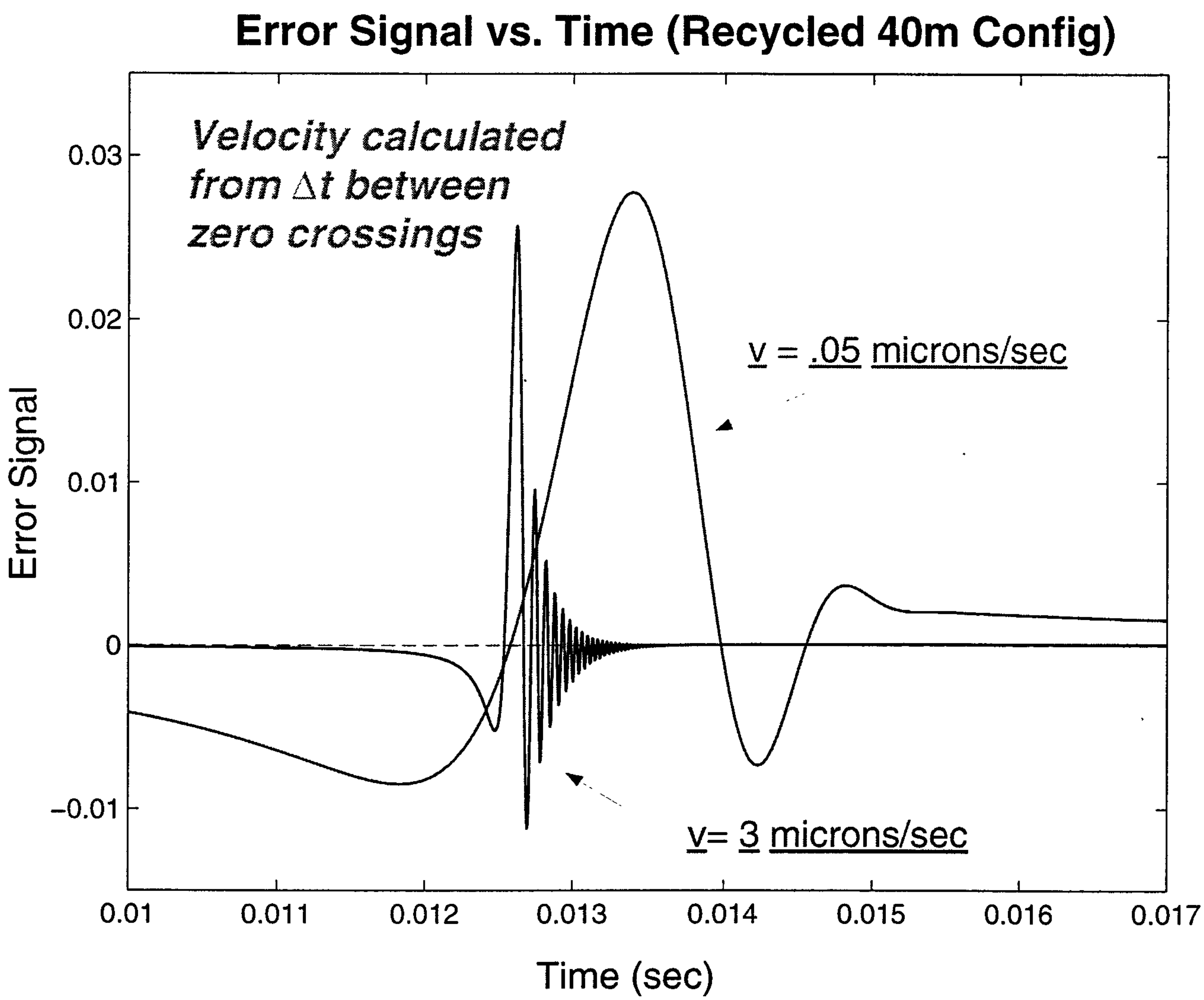
- Provides fundamental understanding of locking process
  - The single Fabry-Perot model introduced us to concept of "Threshold Velocity"
- Diagnostic Tool
  - Fringe gives information on relative velocity of test masses (no other direct measurement of this has been done)
  - Other possibilities not yet explored???
- Opens up realm of possibilities for doing computer control
  - We were able to use real-time fringe information to slow up test mass in order to aid locking capability of analog servo for Single Fabry-Perot

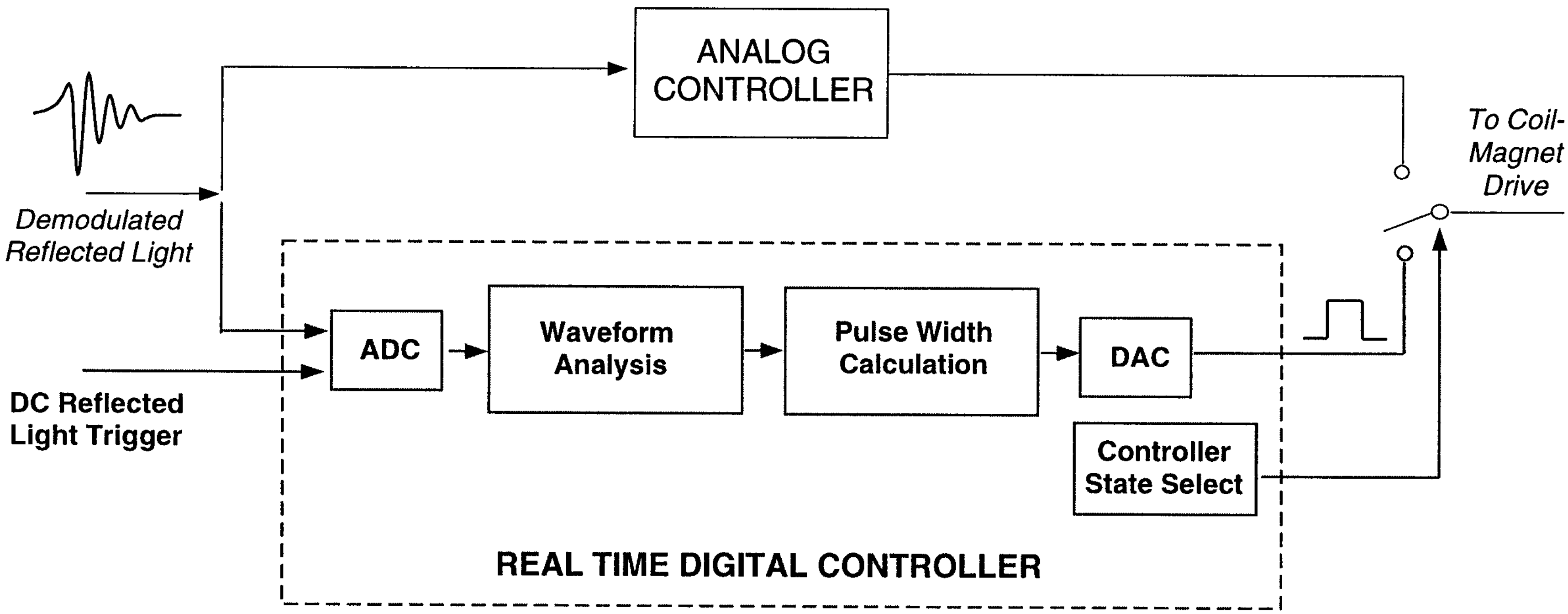


L = nλ/2
ΔL
Δv



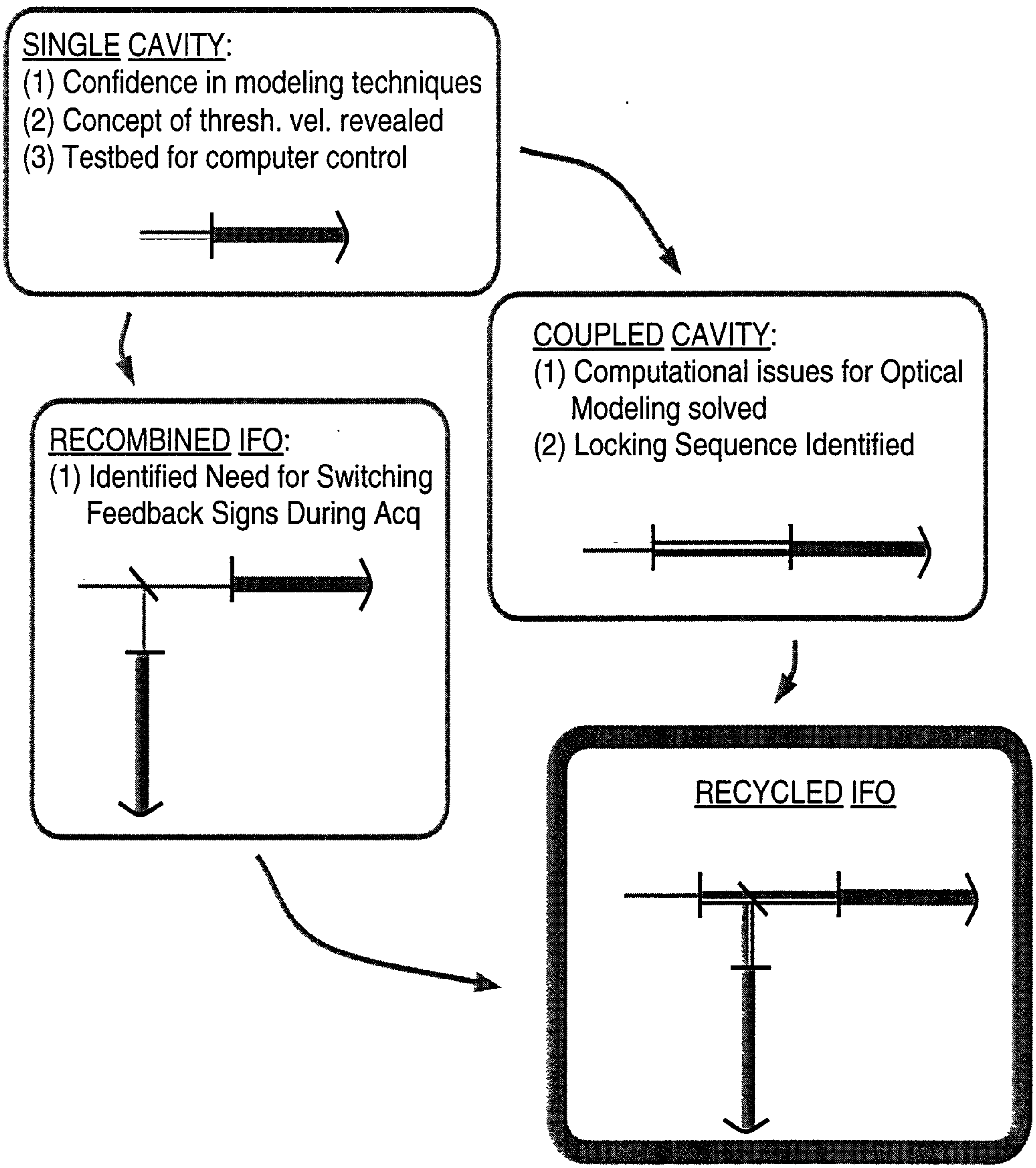
CENTER
OF FRINGE
Below Threshold
Threshold
Above Threshold
Δv
Velocity (micron/sec)
Displacement (nanometers)
ΔL
.4
.2
0
-.2
-0.5
0.5
1
.5
-.5


Error Signal vs. Time (Recycled 40m Config)
Velocity calculated from Δt between zero crossings
v = .05 microns/sec
v= 3 microns/sec
Error Signal
Time (sec)
0.03
0.02
0.01
0
−0.01
0.01
0.011
0.012
0.013
0.014
0.015
0.016
0.017



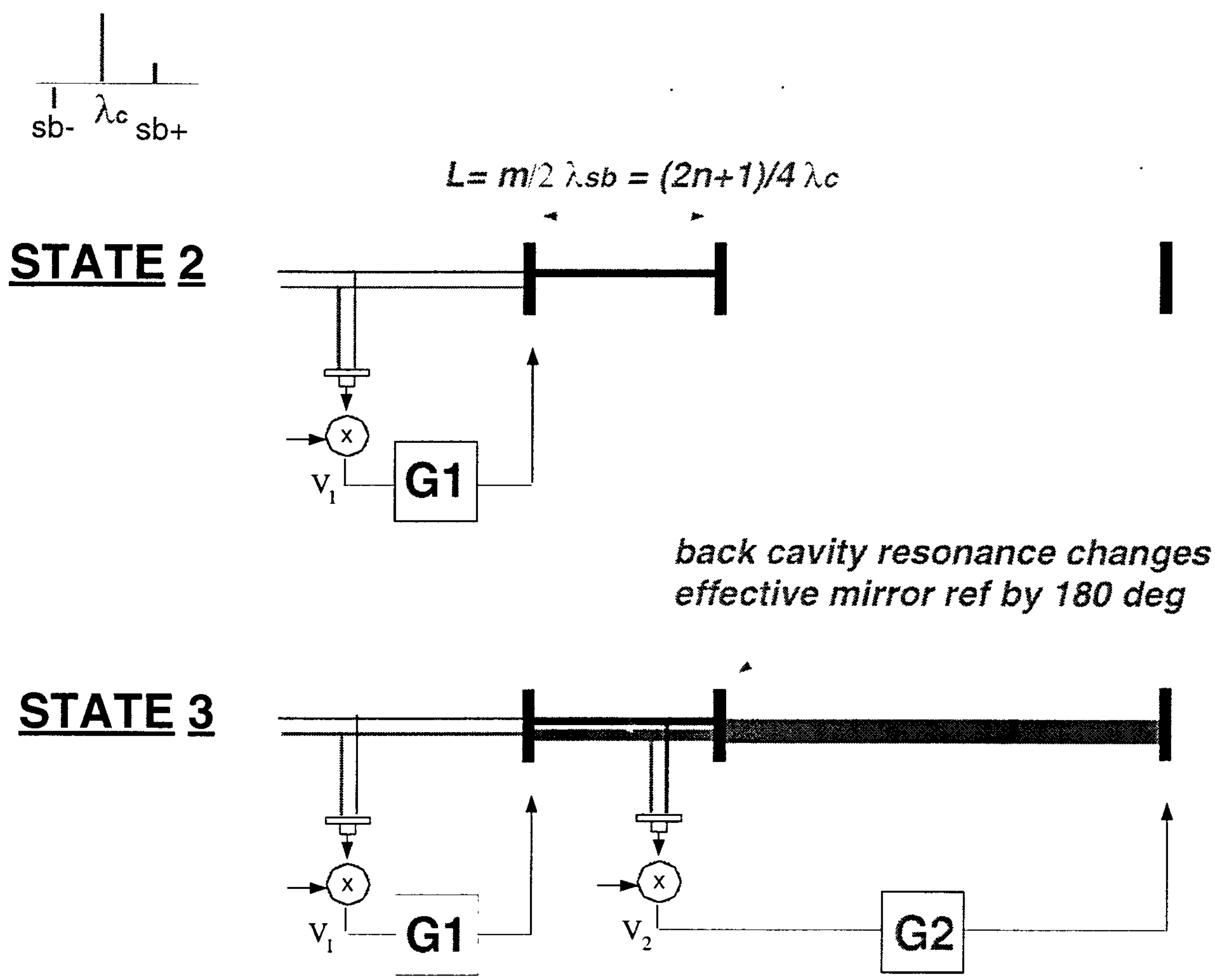
Experimental Acquisition time decreased by a factor of 10 !!!

Acquisition Modeling Program: Building Block Approach



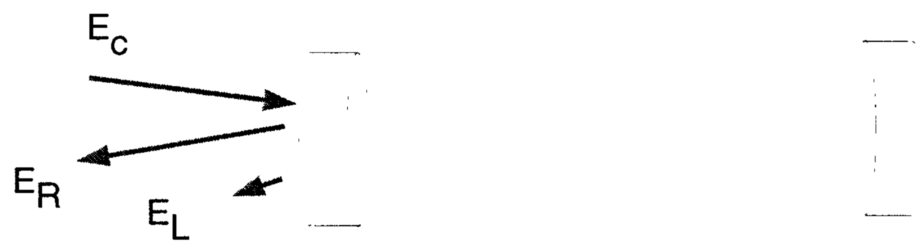
Lessons For LIGO From Coupled Cavity Modeling

- Locking sequence predetermined by ifo config.
  - ›› idea of sbs. resonating in rec. cavity first was a revelation
- Analog control design strategy became obvious



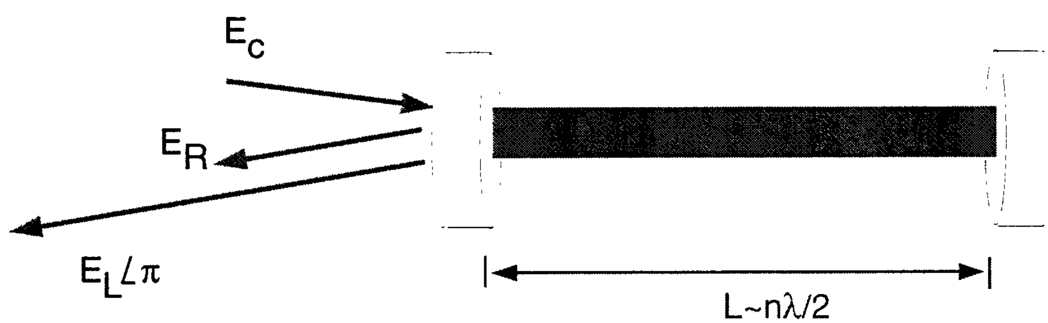
WHY DOES REFLECTIVITY OF CAVITY CHANGE BY 180 DEGS WHEN IT STARTS RESONATING?

FIELDS WHEN IFO OFF RESONANCE:



Field propogating to left is dominated by prompt reflection E_R

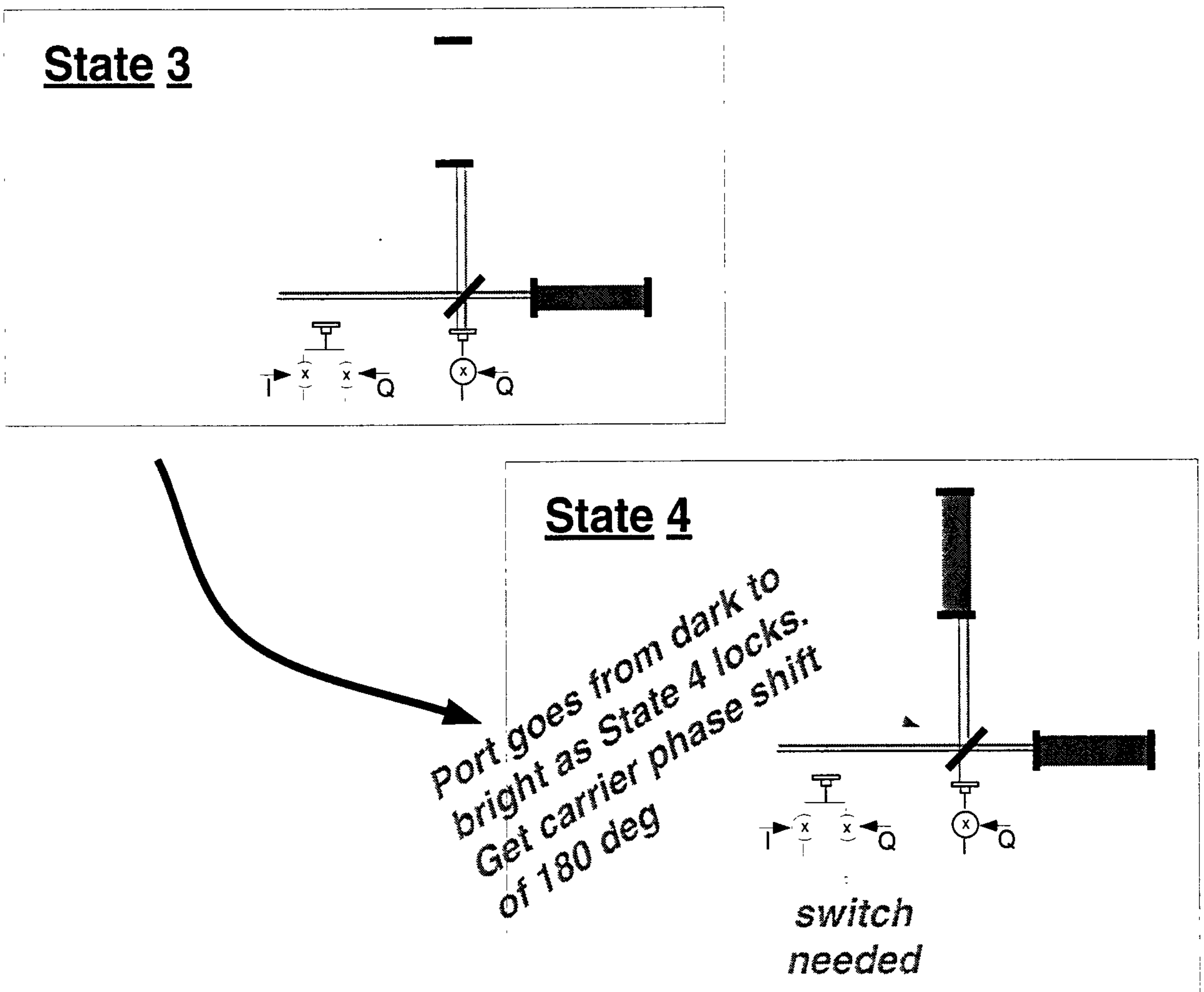
FIELDS WHEN IFO ON RESONANCE:



Field propogating to left has large component of leakage field. Leakage Field is 180 deg out of phase with prompt reflection

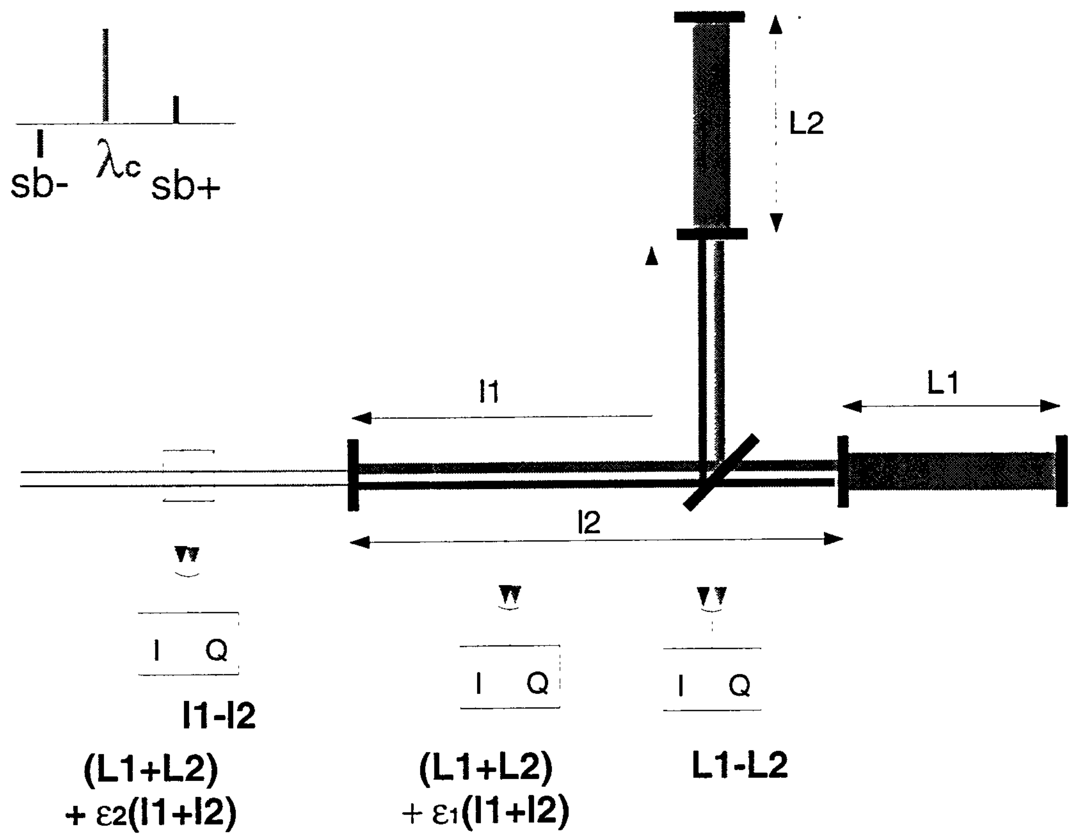
Lessons for LIGO from Recombined IFO Modeling

- Polarity of certain signals switch as ifo goes through state change



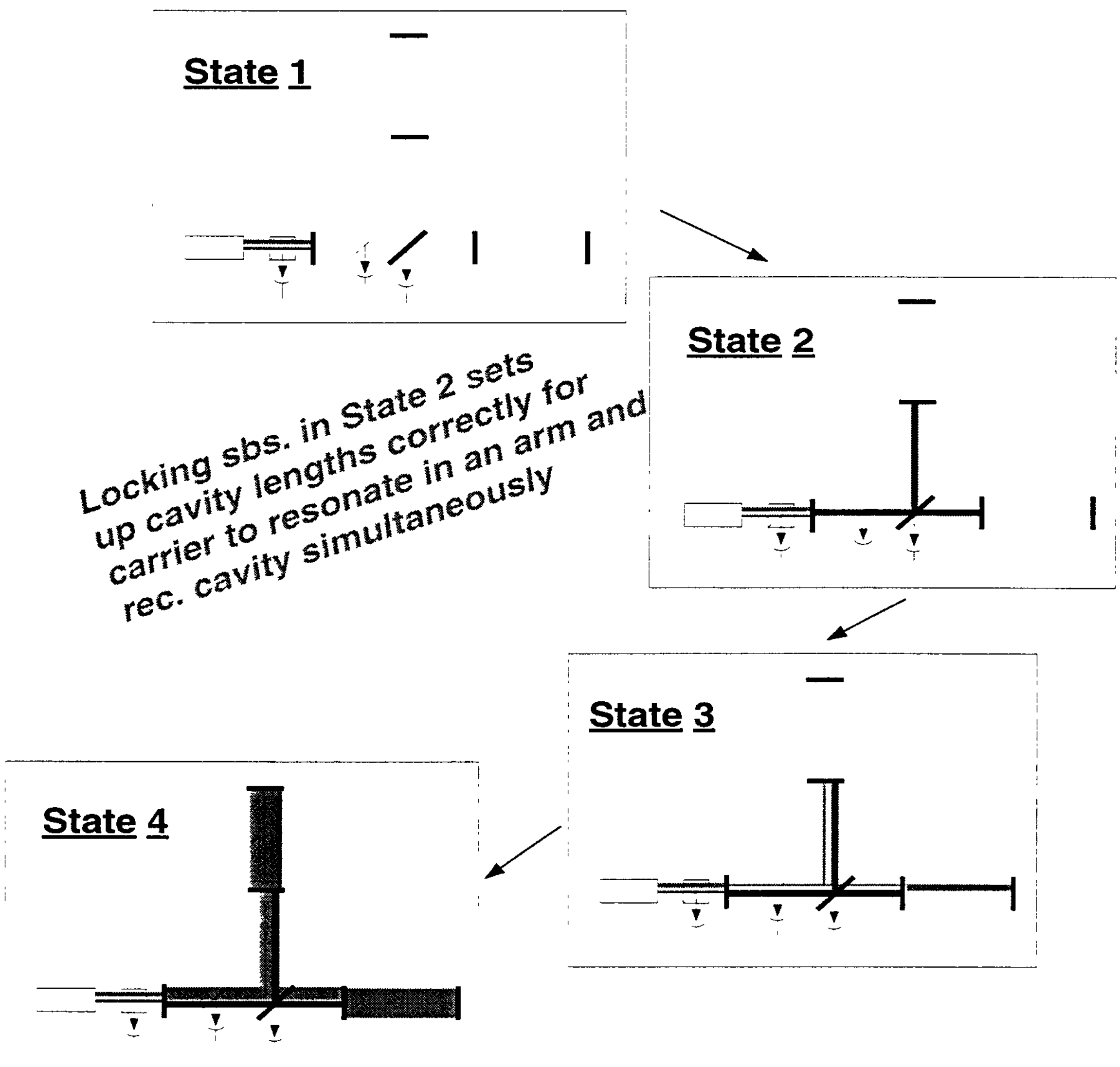
Recycled IFO Configuration for LIGO

- Quad signals proportional to differential motions
- In-phase signals proportional to common mode motions



Lessons for LIGO from Recycling Model

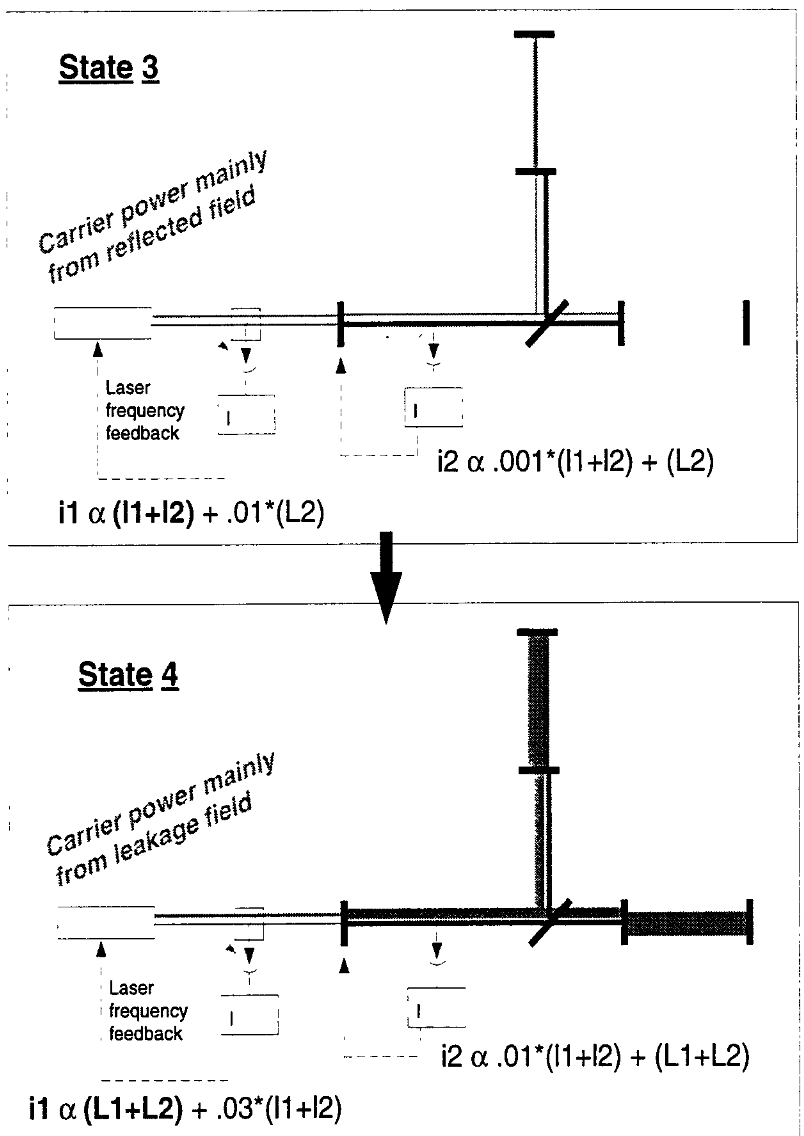
1. Only 1 locking sequence that works (profound influence on control system design)



Lessons for LIGO from Recycling Model (contd. 2)

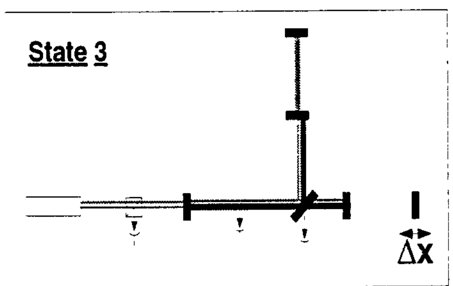
2. Sensing points must be chosen so servos stable in each state

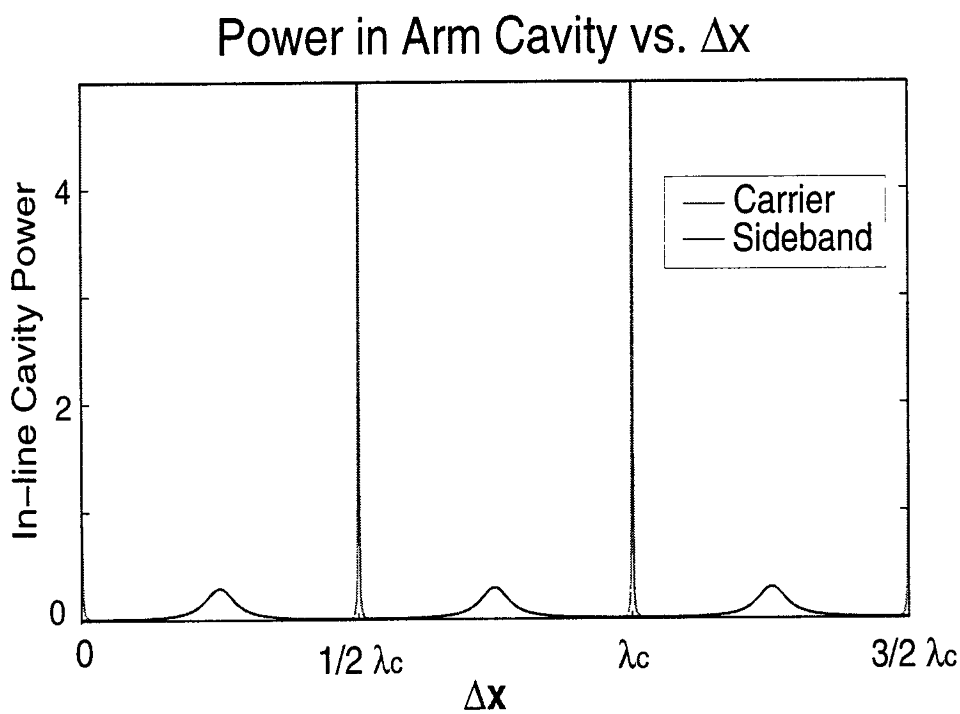
UNSTABLE



Lessons for LIGO from Recycling Model (contd. 3)

3. Ifo kicked out of lock every time sideband resonates in arm cavity (could be disastrous for "time to acquire")



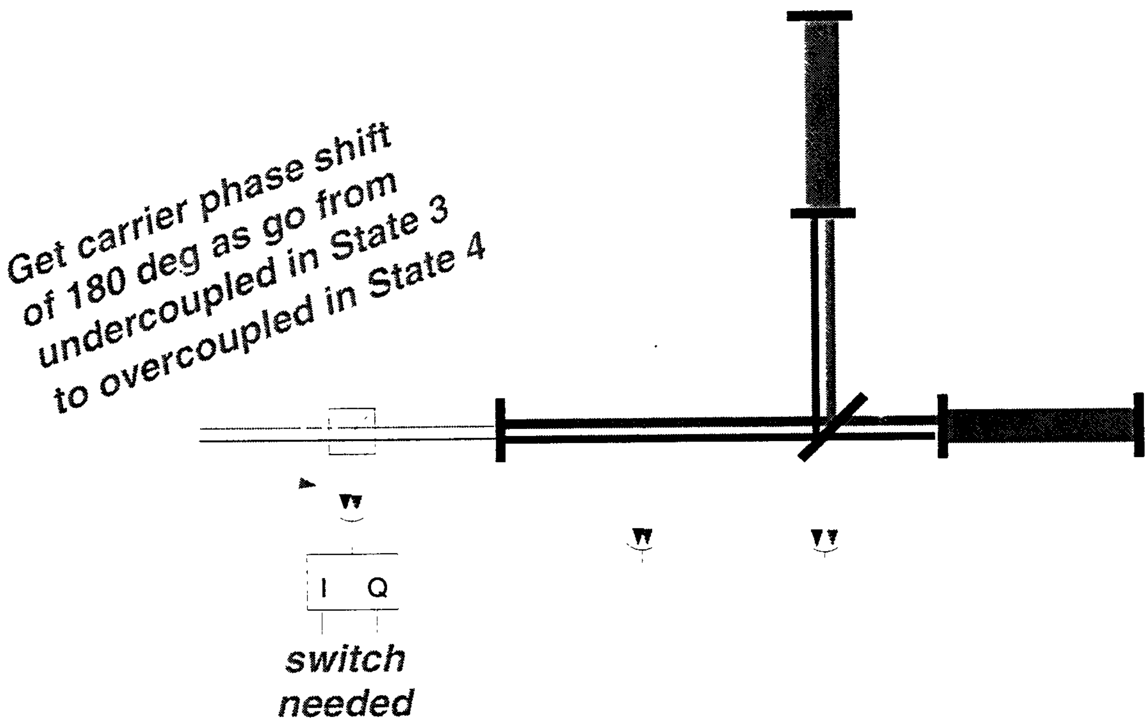


Lessons for LIGO from Recycling Model (contd. 4)

- Possible solutions to problem
  - ›› Turn off recycling cavity length controllers for brief time while back cavity goes through side band fringe
  - ›› "Pong" guided lock acquisition (play ping pong with the test mass so that it never goes more than a quarter wave from fringe central).

Lessons for LIGO from Recycling Model (contd. 5)

4. As in Recombination, servos require sign flips



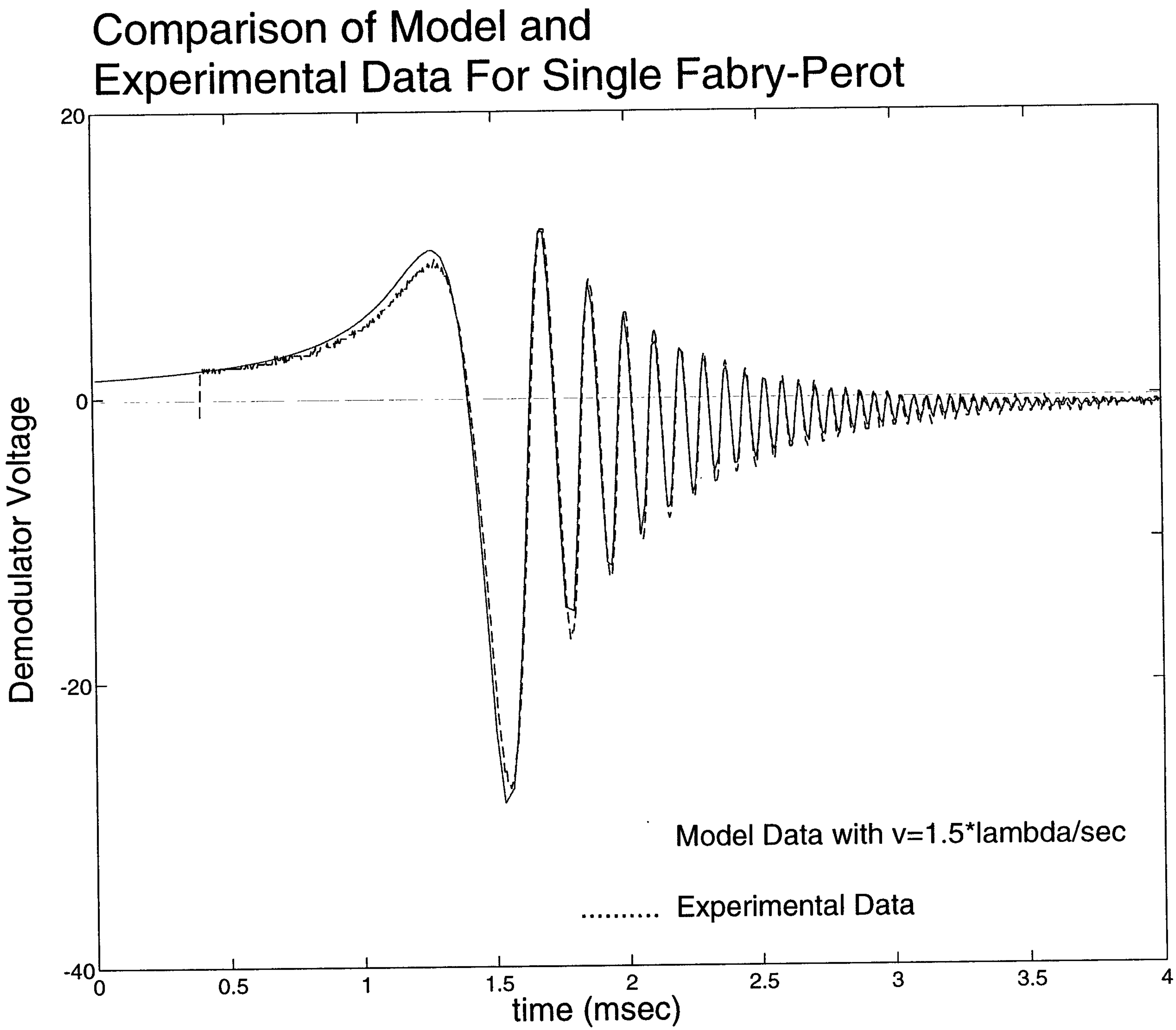
5. Big gain changes in servo loops as sequence through locking states
6. Low threshold velocity in L1-L2 loop (will require some form of "guided lock")

Major Challenges in Locking LIGO

- Speed of acquisition hampered by sidebands resonating in arm cavity---must find solution
- **Possible coupling with alignment system**
    - ›› Results to-date assume essentially perfect alignment
    - ›› Many locking problems in experimental setup tend to be alignment related
    - ›› Next step in modeling program is to add higher order modes
- Other unmodeled phenomena that rears its ugly head

Conclusions (i.e. Importance of Modeling to LIGO)

- Modeling provides fundamental understanding
  - ›› Without Model:
    - Feedback config. choice would have resulted in unlockable ifo
    - Limited knowledge of correct locking sequence and sign-flips
    - Problem of sidebands locking in arm would be solved by trial-and-error in the field
- Ability to do "State of the Art" computer control
  - ›› Without Model:
    - Speed of acquisition would be extremely slow
- Tool for trouble-shooting exp. locking problems
- Diagnostics (unexplored realm of possibilities)
  - ›› average test mass velocity
  - ›› storage time of cavities (fringe decay envelope)
  - ›› unexplored realm of possibilities: overcoupling/ undercoupling???, contrast defect???, etc.



Comparison of Model and
Experimental Data For Single Fabry-Perot
20
0
-20
-40
Demodulator Voltage
0
0.5
1
1.5
2
2.5
3
3.5
4
time (msec)
Model Data with v=1.5*lambda/sec
.... Experimental Data