Power Recycling the LIGO 40m Interferometer for Gravitational Wave Detection

Jennifer E. Logan
The LIGO Project, California Institute of Technology

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The LIGO 40m Interferometer

- an interferometer with suspended test masses and a 40m baseline
- a research instrument for the LIGO project which is currently building two 4km baseline detectors

Optical Topology:

- At the beginning of October 1997 the final configuration changes were made to the 40m. It is now operating as a Fully Suspended, Power Recycled Interferometer with Fabry Perot Arm Cavities

Experimental work carried out by:

Jennifer Logan

Robert Spero

Nergis Mavalvala

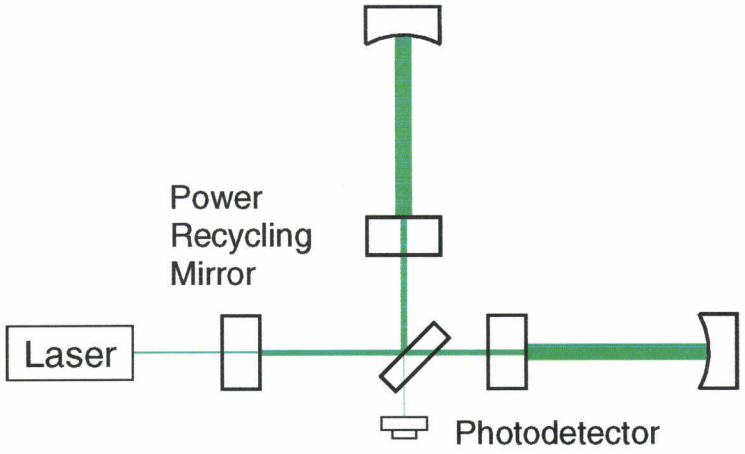
Brent Ware

Dick Gustafson

Mark Coles

Control Topology based on work by Martin Regehr (PhD Thesis, Caltech 1995)

Power Recycling - The Optical Configuration for LIGO



- Want to match storage time of light in the arm cavities to ~ half a gravitational wave period

  ›› determines transmission of arm cavity input mirror ∴ amount of light returning from arms

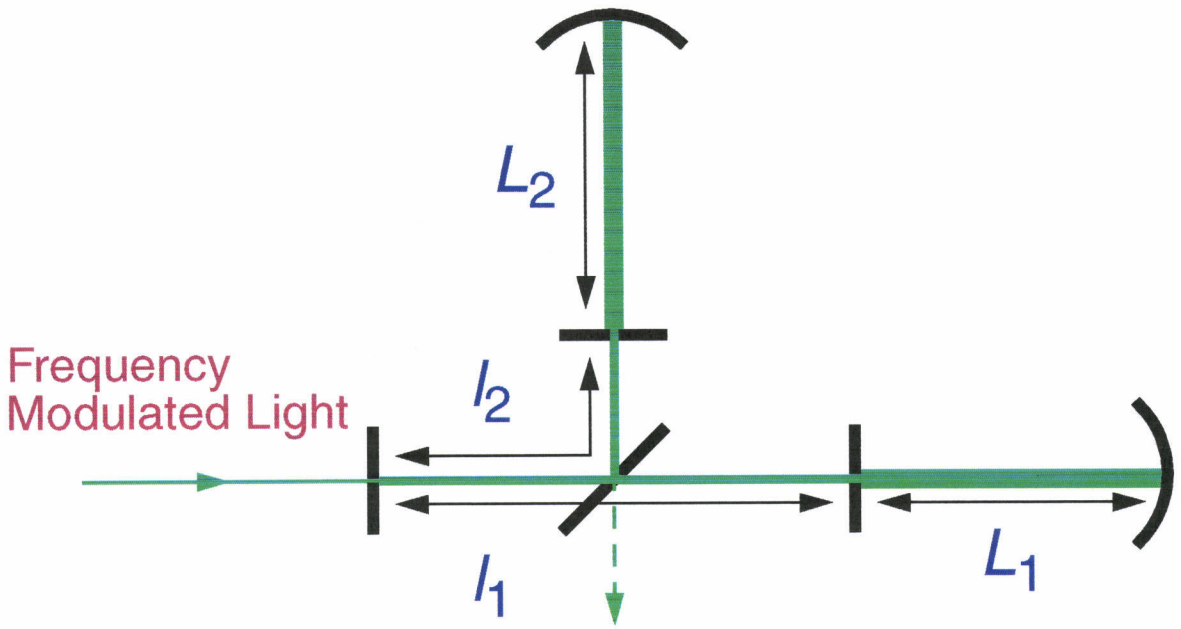
  ›› Photodetector is operated on a dark fringe ∴ returning light heads back towards the laser

  ›› recycle this light by impedance matching it with correct choice of recycling mirror

LIGO and the 40m

- Planned recycling factor for LIGO ~ 50
  40m ~ 5
  - ›› due to difference in length scales, a more modest recycling factor has been chosen for the 40m in order to keep the overall configuration similar.
  - ›› Both have recycling factors >> 1
- Control topologies essentially the same
- Both have a degenerate recycling cavity

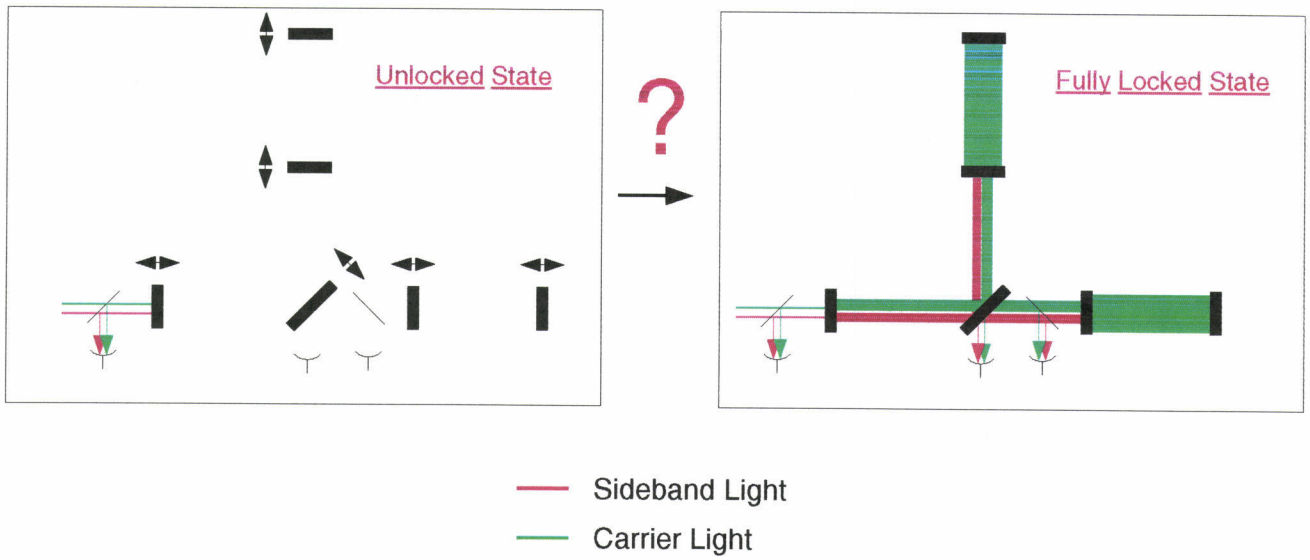
Recycled Interferometer



- Degrees of Freedom:
  - Common mode arm length = $L_1 + L_2$
  - Differential arm length (GW signal) = $L_1 - L_2$
  - Recycling cavity length = $l_1 + l_2$
  - Michelson near-mirror difference = $l_1 - l_2$
    - NB Michelson is asymmetric i.e. $l_1 \neq l_2$: Frontal Modulation Scheme

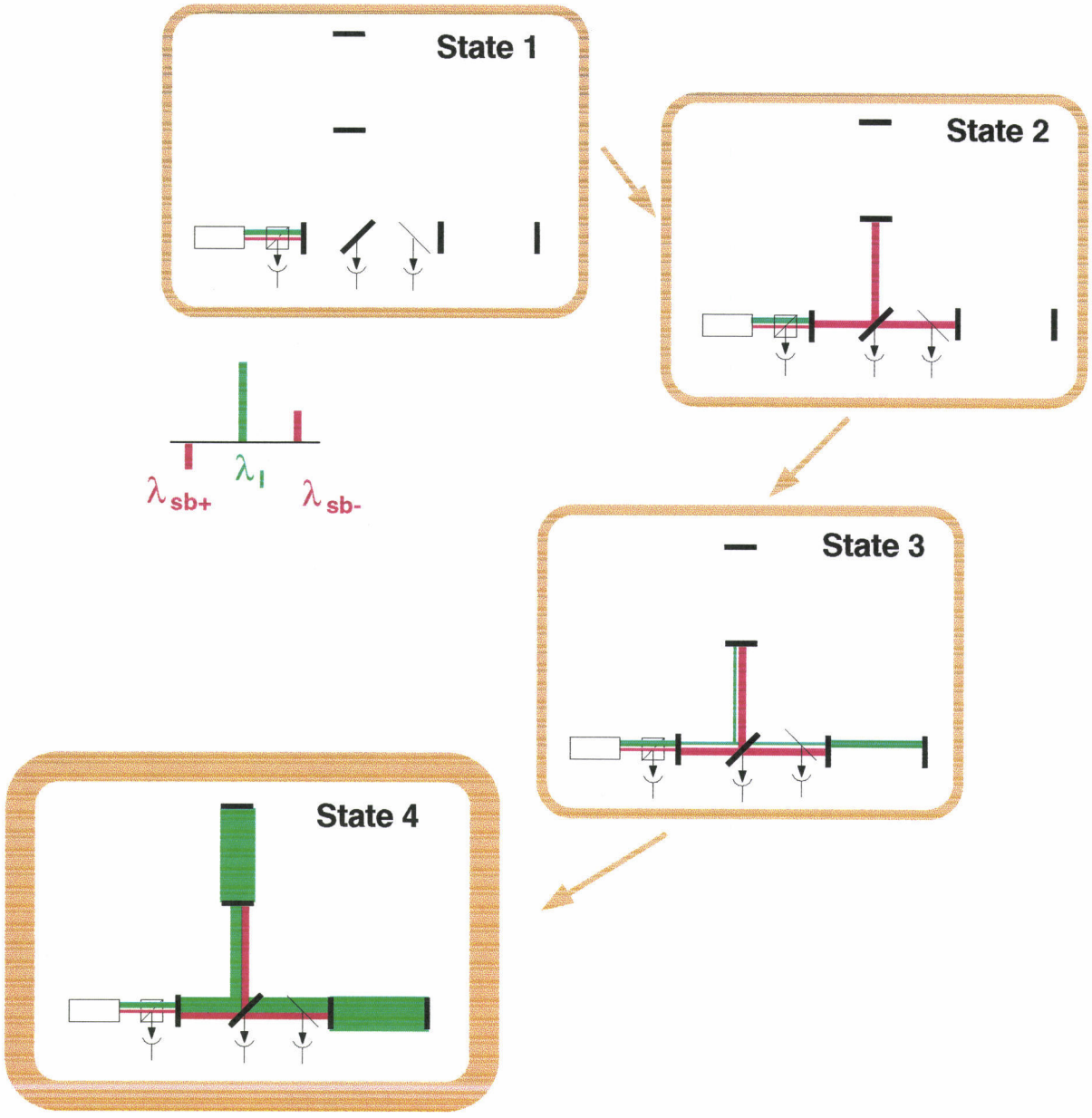
Lock Acquisition Modeling

- How do we reach the operating point i.e. light resonating in the arms and in the recycling cavity?

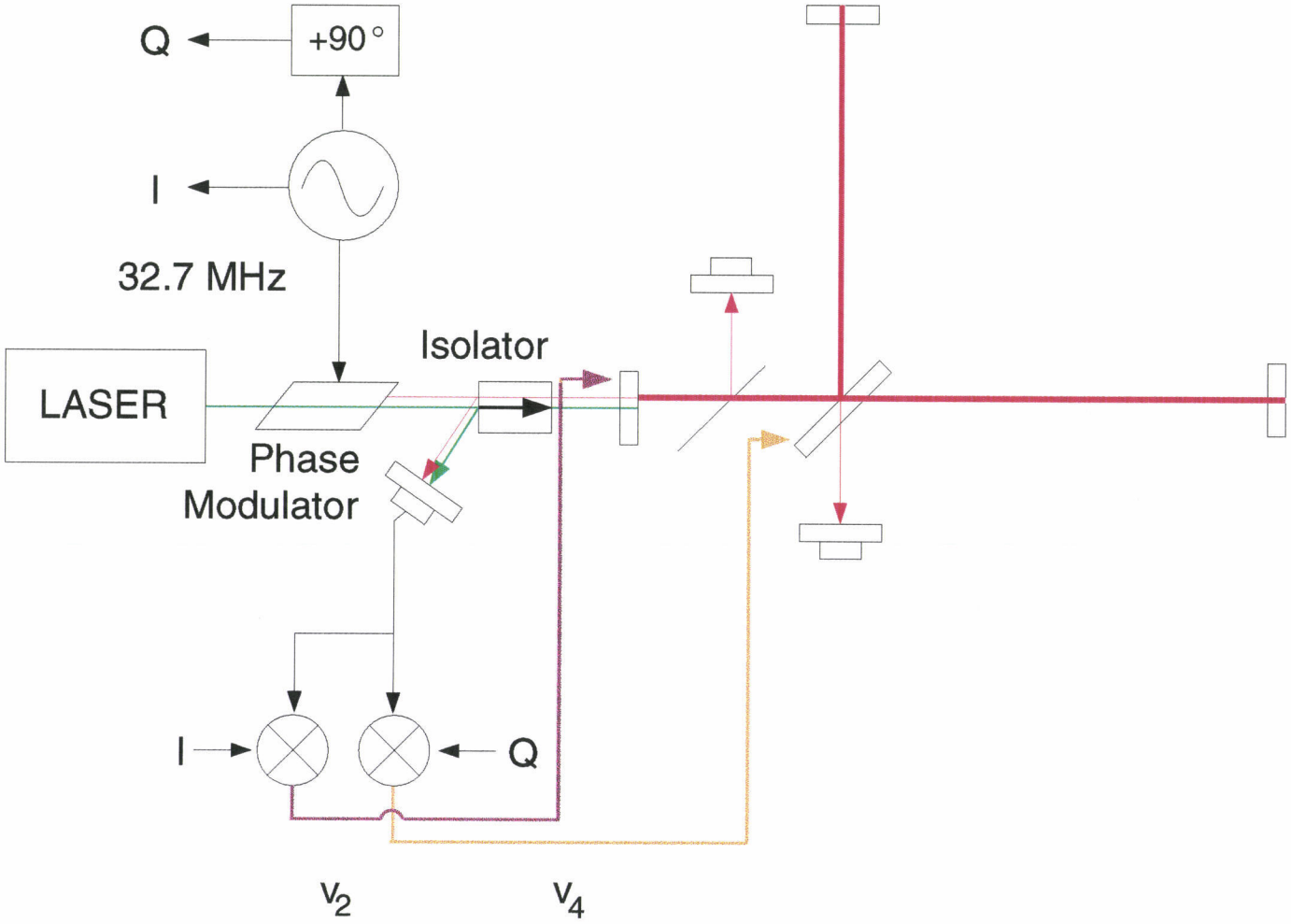


- Extensive modeling of recycled configuration (L. Sievers, D. Redding, L. Needels): SMAC - Single Mode Acquisition Code
  - ›› An aid to understanding the dynamics of the optical configuration
  - ›› Used to design the control topology

Lock Acquisition Sequence



Power Recycled Michelson Topology



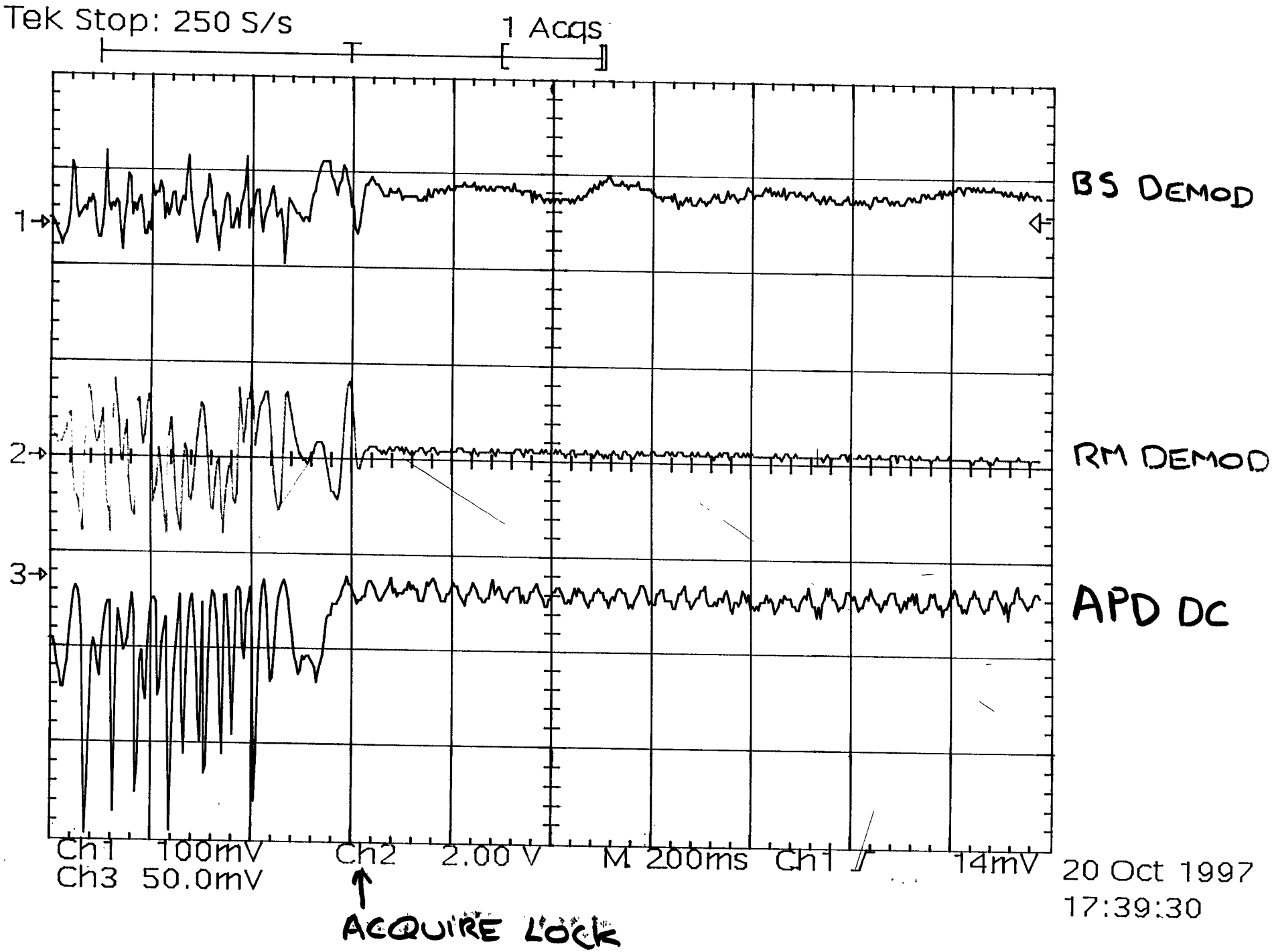
First Stage: Power Recycled Michelson

- SMAC prediction:

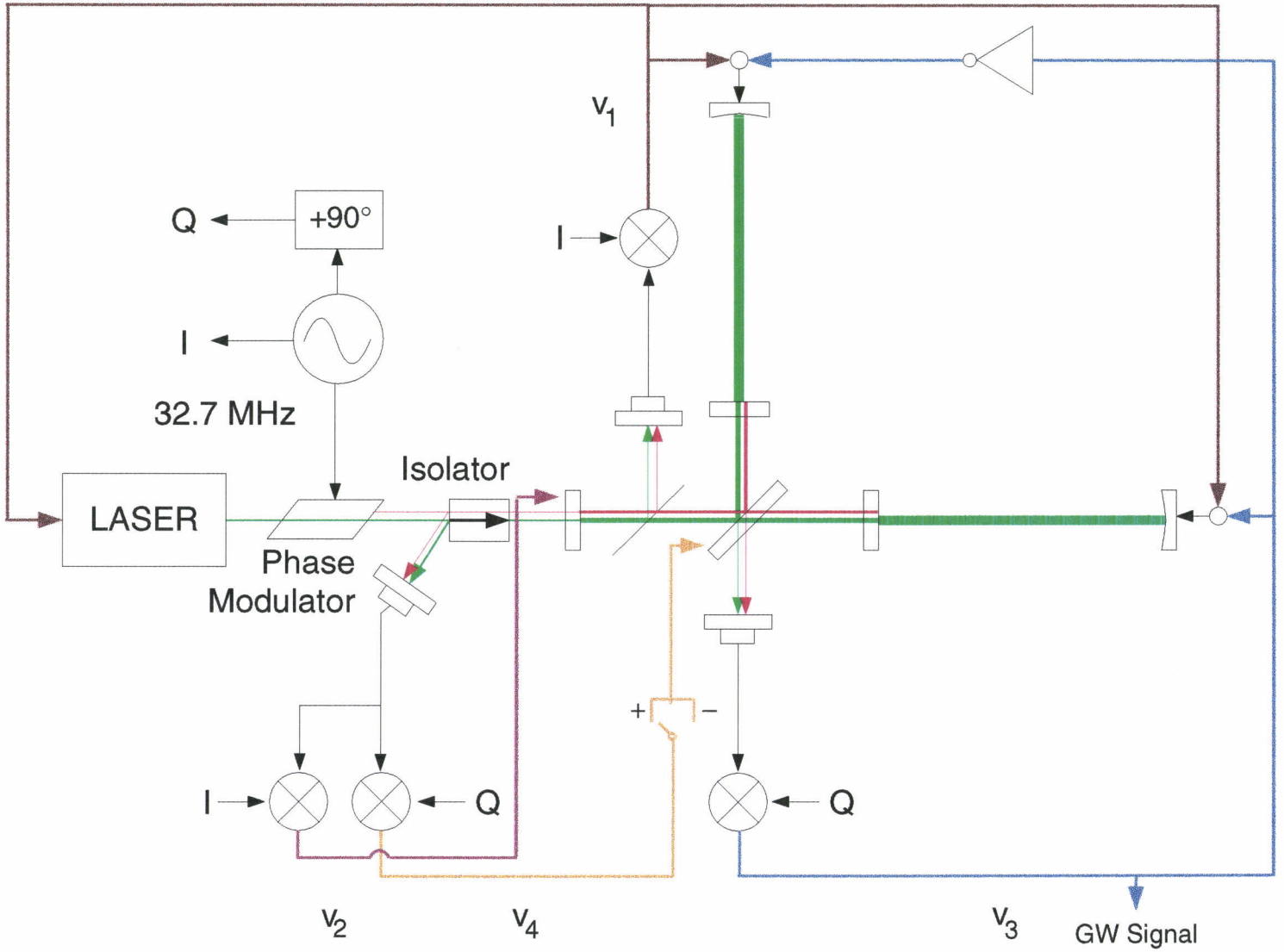
  both BS and RM lock at the same time

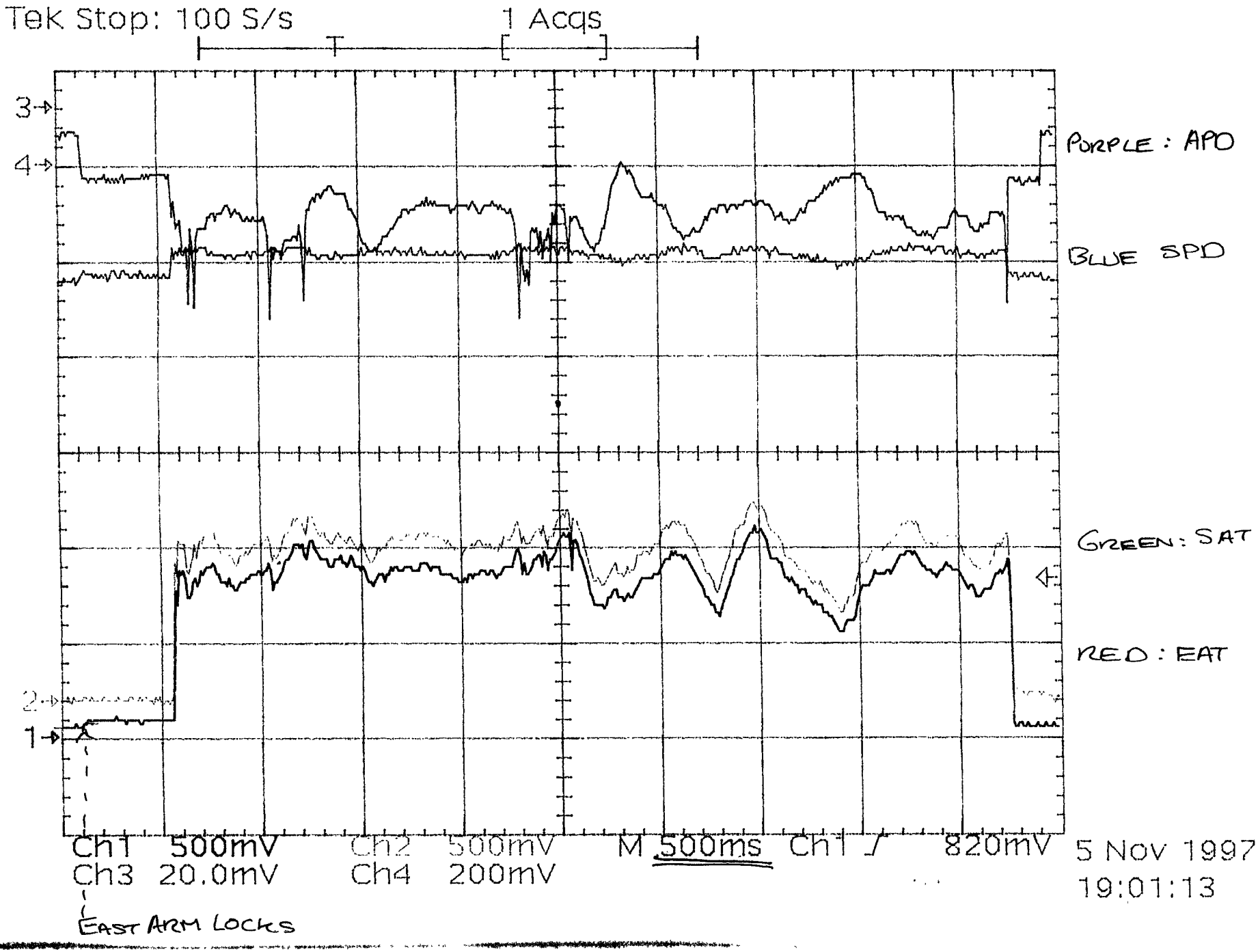
- Complicated to trouble shoot!

Power Recycled Michelson Acquiring Lock



Recycling Servo Topology




Tek Stop: 100 S/s
1 Acqs
3
4
2
1
PURPLE : APD
BLUE SPD
GREEN : SAT
RED : EAT
Ch1 500mV
Ch2 500mV
M 500ms Ch1 820mV
Ch3 20.0mV
Ch4 200mV
5 NOV 1997
19:01:13
EAST ARM LOCKS

Some Observations

- Interferometer stability appears to be dominated by alignment fluctuations
  - ›› installation of wave front sensing underway
- Observed recycling factor ~ 3 - probably limited at present by alignment

Some Initial Locking Puzzles:

Some puzzles from the first early lock sections:

- Intuition and SMAC predict that the BS should flip sign as the second arm locks
  - This is not the case experimentally!

  ›› carrier could be undercoupled or we are locking on non-mode matched light?
- Sometimes we see much higher arm cavity power than at other times for same input power - can't recover this by optimising alignment!

  ›› possibly DC offset effects?

- We are just beginning to unravel these!

Future Plans

- Installation of Wave Front Sensors (currently underway)
- Complete lock acquisition studies - full understanding of locking mechanism
- Investigation of Interferometer Noise Floor