New Folder Name Servo Design Update

LIGO Recycled Interferometer Servo Design Update
3/18/94 Lisa Sievers

I have made a list of tasks that have been completed in the past couple of weeks for the LIGO Servo Design effort. I am hoping this memo fulfills a couple of functions. One function is to keep group members updated on what I am doing so as to keep the servo effort visible enough that others may correct errors or assumptions that I am using. A second is to informally document specifications, control design philosophies, and control designs so that there is a reference for future servo design work. I will continue the update every few weeks or so, depending on when there is something new to report.

1. Made a list of specifications for doing the feedback loop design using performance requirements generated by some combination of Martin and David. There is some documentation on how the specs were generated but it is incomplete. I plan on completing the documentation (with Martin's and David's help) in the near future.

i. Arm cavity differential mode loop

- $|L_2 - L_1| \leq 6 \times 10^{-11} \mathrm{m_{rms}}$
- Loop gain < 10^{-7} at 10 KHz (first test mass resonance)

ii. Recycling cavity differential mode loop

- $|l_2 - l_1| \leq 1.2 \times 10^{-9} \mathrm{m_{rms}}$
- Loop gain < .01 at 100 Hz to counteract beam splitter shot noise sensitivity
- Loop gain < 10^{-7} at 10 KHz (first test mass resonance)

iii. Arm cavity common mode loop

- $|L_2 + L_1| \leq 3 \times 10^{-11} \mathrm{m_{rms}}$
- Unity gain frequency at 10 Khz
- DC gain in loop has to be a minimum of a factor of 130 (preferably more) greater than DC gain in recycling cavity common mode loop

iv. Recycling cavity common mode loop

- $|l_2 + l_1| \leq 4 \times 10^{-9} \mathrm{m_{rms}}$
- Loop gain < 10^{-7} at 10 Khz (first test mass resonance)

2. Generated a Matlab data file with the expected motion in m/rhz of a test mass in LIGO. The data file is in ~lisa/Modtop/LIGOServoDesign/matlab/dspec.m. This set of data is used in the calculations for the expected closed loop rms motion of the common mode and differential mode motions of a recycled interferometer. This data set was generated assuming the following about the system:

i. 4 layer viton stack (used Joe's measured transfer functions)

ii. LIGO standard spectrum (f^3 roll-off between .1-1 Hz, 10^{-9} m/rhz between 1-10 Hz, and f^2 roll-off above 10 Hz

iii. 1 Hz horizontal pendulum rolling-off as f^2

iv. 15 Hz vertical pendulum rolling-off as f^2, with .0005 vertical coupling factor

3. The topology I have been using to do the trial controller design is the asymmetry gravity wave sensing topology. I chose to go ahead with this topology since

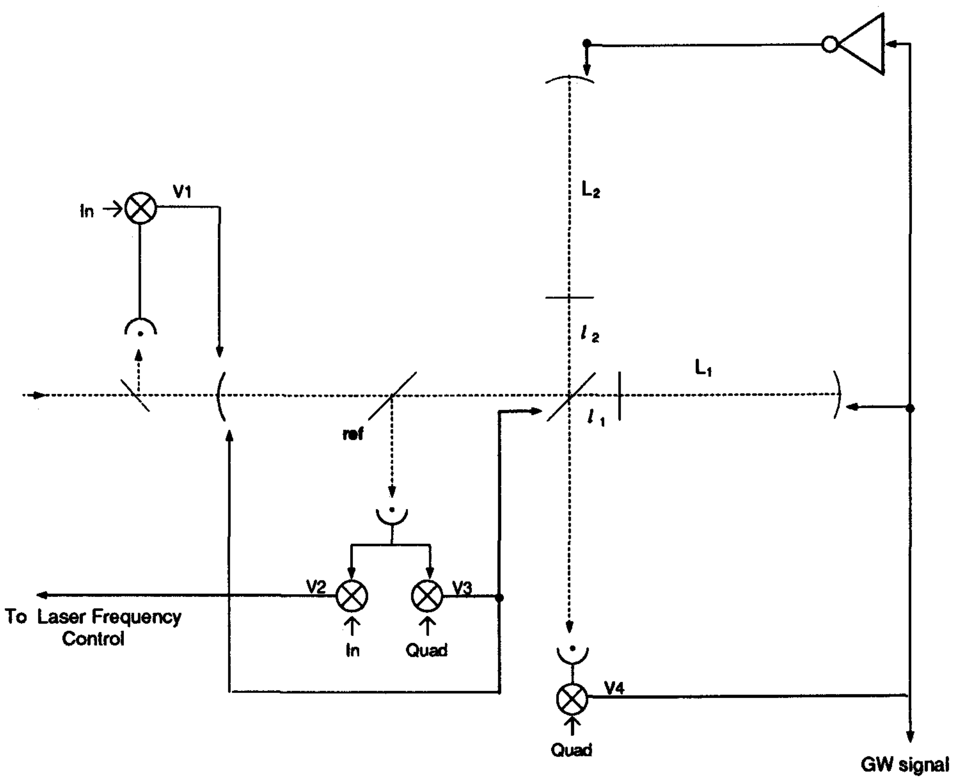

Figure 1. Asymmetry servo topology.

(from a servo perspective) the only important difference between the FSSC and the asymmetry with perfect phases is that the recycling mirror loop sensor is sensitive to the arm cavity lengths. This in principle makes it more difficult to satisfy performance requirements, but in practice the difference is small if the appropriate gain ratio is met. If I can design a controller for the asymmetry scheme I think designing the controller for the FSSC will be a trivial extension; vice versa is not true.

4. I used the following servo design strategy for the 4x4 system:

   i. Assumed that the plant behaves as a diagonal system, so designed a (SISO) single-input single-output controller for each of the diagonal transfer functions (Martin was the originator of this strategy).

   ii. Checked for stability and performance of the 4x4 system after connecting the 4x4 diagonal controller to the 4x4 plant model.

   iii. Calculated the rms motion of the common mode and differential mode motions in the closed loop system using the 4x4 closed loop system model.

5. Code written for servo design and analysis:

   i. Have written and documented Matlab code that will form and plot the plant transfer function, controller transfer function, and loop gain of each of the SISO common mode and differential mode feedback loops (l1+l2, L1+L2, l1–l2, and L1–L2). It will also read in the expected seismic noise disturbance data of a LIGO test mass and calculate the expected closed loop rms motion of l1+l2, L1+L2, l1–l2, and L1–L2, assuming all of the loops are independent.

   ii. Have written and documented Matlab code that will form and plot the full MIMO (multi-input multi-output) plant transfer function, diagonal controller transfer function designed using code in (5–i), and loop gain of the full 4x4 system. It can be used for checking performance and stability of the 4x4 system. It will also read in the expected seismic noise disturbance of a LIGO test mass and calculate the expected closed loop rms motion of l1+l2 due to seismic noise introduced at l1+l2, L1+L2, l1–l2, or L1–L2; similarly it will calculate the closed loop rms motion of the other common mode and differential mode signals due to the different excitation sources.

6. Trial controller design for a LIGO recycled interferometer:

   i. Have designed a diagonal 4x4 controller for a recycled interferometer. Martin generated the plant model using his modeling code for the Asymmetry topology. Martin has assured me that the parameters he used are typical of what we believe will be used for the LIGO interferometers.

   ii. Table 1 shows the performance of the system with this controller in the feedback loop. I was able, without much difficulty, to meet all of the specs defined in (1) of this memo. The design needs to be rechecked (I plan on working with Martin on this) but I feel optimistic that we have a feasible design strategy and that our performance objectives are achievable.

	$l_1 + l_2$ loop	$L_1 + L_2$ loop	$l_1 - l_2$ loop	$L_1 - L_2$ loop
DC Loop Gain	2×10^3	10^{10}	10^3	10^5
Unity Gain Frequency (Hz)	10	10^4	5	35
Phase Margin	70^o	$85 - 30^o = 55$ (-30^o lag due to sidebands)	60^o	65^o
Gain at 100 Hz			.01	
Gain at 10 KHz	10^{-7}		10^{-8}	10^{-7}
Total Closed Loop RMS Motion	$6 \times 10^{-10} m_{rms}$	$1.4 \times 10^{-12} m_{rms}$	$1.2 \times 10^{-9} m_{rms}$	$4.4 \times 10^{-11} m_{rms}$
Poles and Zeros in plant (Hz)	p=[1.7] z=[.06]	p=[1.7] z=[ ]	p=[ ] z=[ ]	p=[90] z=[ ]
Poles and zeros in feedback loop (Hz)	p=[.06 .1 .1 100 100] z=[1.7 2]	p=[1 1 1] z=[1.7 1000 1000]	p=[.1 .1 50 50] z=[2]	p=[.1 .1 1 600 600 1000 1000] z=[5 5 90]

Table 1. Table showing performance in each loop. DC Loop Gain, Unity Gain Frequency, Gain at 100 Hz, and Gain at 10 KHz all refer to the situation where all loops are closed but the one listed in the column heading. Table also shows plant and feedback loop pole and zero locations.

7. Work to be completed in next few weeks:

i. Include the pendulum transfer function and actuator dynamics in the model.

ii. Complete documentation of how each of the performance specifications was derived.

iii. Develop a perturbation model of the interferometer. Will first test the controller design using a few of the "easy to analyze perturbations" to see if system is still stable and performance is not degraded (e.g. variation in phase of demodulator).