Length Cross−Couplings During the E2 Run

Frequency Noise Task Group

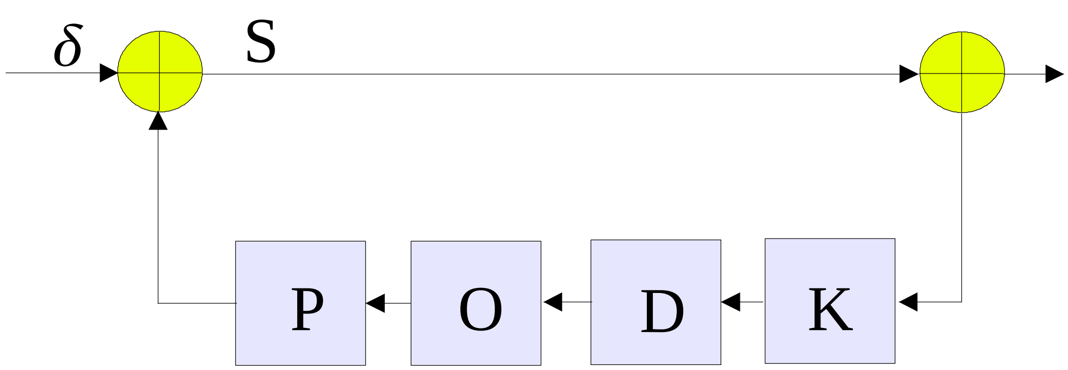
1. Overview

This document includes some preliminary information regarding the cross coupling of the Length Sensing & Control (LSC) signals during the E2 run at LHO during Nov. 8−15.

Due to some imperfections in the control software & the pre−run calibrations, spurious coupling was induced between the 3 interferometer length degrees of freedom.

2. Basic Picture

One simple way in which to picture the workings of the multiple loops is in a matrix language where all signals are vectors and all things which operate on the signals (the blue−gray boxes) are matrices.



Definitions for the figure:

S = (AS_I   AS_Q   Refl_I   Refl_Q)

δ = (junk   δLm   δlm   δLp)

K *= Sensing/Input Matrix* ***D*** *= Digital Filters Matrix*

O *= Output Matirx* ***P*** *= IFO Response*

In this picture, its clear that the way to back out the 'true' input disturbances of the system is very analogous to that of a single loop.

$$\bar{\delta} = (\boldsymbol{I} + \boldsymbol{G})\bar{S}$$

where the I is the identity matrix and the open−loop gain, $G = P\ O\ D\ K$.

2.1 Sensing/Input Matrix

The Sensing/Input is the combined front−end optical/analog gain, the digital phase shifter, and the actual Input Matrix.

During the month following the run, it was discovered that there was a problem with the digital phase shifter portion of the LSC Front End software. Ideally, the RF signal carrying the error signal is demodulated in two phases. Then these two signals, the 'I−Phase' and 'Q−Phase' signals are acquired by the A/D electronics and then the two signals are digitally processed through what should be a 2D rotation matrix:

$$\phi = \begin{bmatrix} \cos(t) & -\sin(t) \\ \sin(t) & \cos(t) \end{bmatrix}$$

Instead it was:

$$\phi = \begin{bmatrix} \cos(t) & \sin(t) \\ \sin(t) & \cos(t) \end{bmatrix}$$

where t is the rotation angle.

Which is just some weird mixing matrix. This was the case all of the phase shifters, so both the Symmetric and Anti−Symmetric port error signals are non−orthogonal. This means that one should be careful in interpreting these signals; AS_Q is not really a pure differential length signal.

2.2 Digital Filters Matrix

This is probably the best known component of the system since it is purely digital. In fact, it is a purely diagonal matrix in the scheme employed during E2 and has only 3 non−zero components. Each of these components is simply the convolution of the filters in each of the three length loops and can be characterized in terms of a series of poles, zeros, and an overall gain.

The particular transfer functions can be extracted from looking at which filters were in engaged in each loop and its overall gain during the lock stretch of interest. This information is included in the ELOG whenever it is changed as are the definitions of the particular filter buttons on the LSC screen.

2.3 Output Matrix

The Output Matrix also had problems, which have been well documented by the Calibration task group. This matrix takes the error signal vector, S, and transforms it into control signals to the 4 optics and the laser frequency via the mode cleaner. The matrix elements, as used during the run, gave imbalanced drives to the optics which resulted, for example, in common−mode noise being fed into differential arm length motion.

2.4 IFO Response

This is the frequency response of the IFO to length excitation. There is a well documented[1] way to calculate this for the case of the full IFO. The idealized response in the non−recycled, recombined configuration of E2 should just be the same, but with the reflection coefficient of the recycling mirror set to zero. It should also be noted that there is no pick−off signal during the run and that the Reflected port signal relative to the AS port signal is down by a single factor of the Recycling Mirror's power transmission.

3.Measurements

In the end, however, the entire loop gain matrix can and has been measured as noted in the LHO Detector eLog for 11/15/00. In the log entry, one can find many swept sine measurements.

In principle, one could use the existing measurements to construct G, the gain matrix. In practice, however, this is very difficult. The measurements which were taken were mainly done for the purpose of roughly measuring the SISO loop gains in the frequency bands of interest whereas to construct the full MIMO filters necessary to post−process the existing data, one would need to do some fitting to produce wide−band accurate data.

Moreover, a few of the measurements do not contain the full MIMO data, as it was not forseen that the cross terms in the matrix would be so large.

4.Conclusions

Use the existing data with the knowledge that there is practically no seperation of common & differential signals. Even at points far above the unity gain point of all the loops, where one might think of using the pure error signals, the SNR during the run was probably to poor to extract any information.

1 "Frequency Response of the LIGO Interferometer", T970084−00−D, ISC Group, D. Sigg, ed.