Automated Input Matrix System Summary [DRAFT] T000105-00-D

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1 Acquisition States

The process of lock acquisition is often described in terms of moving the interferometer (IFO) from one locked state to another. To avoid confusion, though not repetition, I will reproduce with some modification the standard state definitions here.

State 1	None of the mirrors are controlled. This is the starting point for lock acquisition.
State 2	The beam-splitter (BS) and recycling mirror (RM) are controlled and the (first-order resonant) sidebands are resonant in the recycling cavity.
State 3	State 2 holds and one of the two end mirrors (ETMs) is controlled. The carrier is resonant in the controlled arm cavity.
State 4	State 3 holds and the other ETM is controlled. The carrier is resonant in both arm cavities and the recycling cavity.
State 5	State 4 has endured long enough for the power level to equilibrate. This is the ending point for lock acquisition, though one would hope that the controllers used to achieve this state can hold it for some time.

I have added "State 5" the the usual set of 4 states so that I can distinguish between the point at which all mirrors are controlled and the point at which stable lock has been achieved. The time between acquisition of State 4 and acquisition of State 5 for the Hanford 2k IFO is about a half second. Over the course of this half second the control signals change drastically and maintaining lock can be difficult. It is this transition which is addressed by the automated input matrix described herein.

2 Input Matrix Theory

The "input matrix" represents the decomposition of demodulated IFO outputs (Q_{as}, I_{as}, Q_{ref}, Q_{po}, I_{ref}, I_{po}) into error signals for each degree of freedom (L_-, l_-, l_+ and L_+). The gain estimators used in this decomposition are[1]

	Q_{as}	Q_{ref}	Q_{po}	I_{ref}	I_{po}
L_-	$\alpha_{L_-} A_{rec}$				
l_-		$\alpha_{l_-} A_{ref}$	$\beta_{l_-} A_{rec}$		
l_+				$\alpha_{l_+} A_{ref}$	$\beta_{l_+} A_{rec}$
L_+				$\alpha_{L_+} A_{rec}$	$\beta_{L_+} A_{rec}$

where A_{rec} is the amplitude of the carrier in the recycling cavity and A_{ref} is the amplitude of the reflected carrier.

Since the amplitude of the carrier alone is difficult to measure there are some things to keep in mind. In state 2, essentially all of the power in the recycling cavity is sideband power and essentially all of the reflected light is carrier. In states 3 and higher, essentially all of the light transmitted through the arms is carrier. In states 4 and 5, the carrier power in the recycling cavity is essentially proportional to the sum of the arm powers. (In states 4 and 5 the two arms should be fairly well balanced, if they are not more thought may need to be put into this.)

Assuming the photo-diodes are calibrated to some unit of power so that their values may be compared, these amplitudes are given by

$$A_{rec} = \frac{1}{2\sqrt{2}} \left(\sqrt{\frac{T_{ITMt}}{T_{ETMt}} P_{trt}} + \sqrt{\frac{T_{ITMr}}{T_{ETMr}} P_{trr}} \right) \tag{1}$$

and

$$A_{ref} = \sqrt{R_{RM}} A_{in} - \sqrt{T_{RM}} A_{rec}, \tag{2}$$

[1] I_{as} seems to contain little information not contained in Q_{as} and, as a result, is not used and will not be considered further.

where P_{trt} and P_{trr} are measurements of the power transmitted throught the ETMs and A_{in} is the incident carrier amplitude[2]. Assuming that both ETMs and both ITMs have similar properties, all of the optical parameters can be collapsed into a single scale factor such that

$$\bar{A}_{rec} = \sqrt{P_{trt}} + \sqrt{P_{trr}} \tag{3}$$

and

$$\bar{A}_{ref} = 1 - \gamma A_{rec}, \tag{4}$$

where

$$\gamma = \frac{1}{2A_{in}} \sqrt{\frac{T_{RM} T_{ITM}}{2R_{RM} T_{ETM}}}. \tag{5}$$

Since the scaling of these amplitudes is arbitrary, the $\bar{A}$ values may be used in place of the originals.

The αs and βs in the gain matrix include information about both the optics and the electronics. Their values are unimportant, but the ratios $g_{l_-} \equiv \beta_{l_-}/\alpha_{l_-}$, $g_{l_+} \equiv \beta_{l_+}/\alpha_{l_+}$ and $g_{L_+} \equiv \beta_{L_+}/\alpha_{L_+}$ are of some consequence.

Here are the decomposition strategies I use for each degree of freedom:

L_-	$Q_{as}/\bar{A}_{rec}$ is used throughout.
l_-	The sum $Q_{ref} + \frac{\gamma}{g_{l_-}} Q_{po}$ is used until $\bar{A}_{ref}$ crosses zero, then $\frac{Q_{po}}{g_{l_-} \bar{A}_{rec}}$ is used.
l_+	The gain matrix which takes l_+ and L_+ to I_{ref} and I_{po}, $$\mathbf{M}_+ = \begin{bmatrix} \bar{A}_{ref} & \bar{A}_{rec} \\ g_{l_+} \bar{A}_{rec} & g_{L_+} \bar{A}_{rec} \end{bmatrix} \tag{6}$$ is estimated and inverted. ${\mathbf{M}_+}^{-1}$ is used to separate L_+ from l_+ in these signals. For lack of a better solution, l_+ is set to zero as $\mathbf{M}_+$ passes through singularity.
L_+	As with l_+, ${\mathbf{M}_+}^{-1}$ is used to produce L_+ from I_{ref} and I_{po}. When the determinant of $\mathbf{M}_+$ is near zero $I_{ref}/\bar{A}_{rec}$ is used to estimate L_+.

[2]The equation for A_{rec} assumes that the primary means by which light escapes from the arm cavities is through the ITM.