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Frequency Stability Servo Modifications Made at the 40 meter Laboratory

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Contents

KEYWORDS

Pre-stabilized laser (PSL), Frequency stability servo (FSS), Frequency reference cavity (FRC), Pre-modecleaner (PMC).

1 Introduction

This document describes modifications made to the frequency stability servo at the 40 meter laboratory. The final stage of the Pockels cell path, a PA-85 high voltage op-amp, was replaced by a small daughter board. The daughter board contained another PA-85 high voltage op-amp, in parallel with an AD829 op-amp. This allowed the high voltage op-amp to provide the high dynamic range needed at frequencies from 10 kHz to 100 kHz, and the low voltage op-amp to provide fast, low dynamic range response at high frequencies. The results shown here also demonstrate the effect of the pre-modecleaner pole on the FSS loop.

2 The Frequency Stability Servo

The reference cavity is a monolithic cavity suspended in vacuum. The vacuum chamber is thermally insulated and actively temperature controlled. The design parameters for the reference cavity are given in table 1.

Design Values	
Cavity round-trip length	407 mm
Transmissivity of input/output mirrors	300 ppm
Loss of mirrors	30 ppm
Waist size	237 μ m
Free spectral range	737 MHz
Finesse	9518
FWHM	77.4 kHz
Cavity pole	38.7 kHz

Table 1: The frequency reference cavity design parameters

The laser is held resonant in the reference cavity by controlling the laser frequency using the laser PZT from DC to about 10 kHz and a broadband Pockels at 10 kHz and beyond. It is the Pockels cell feedback path which limits the gain of the FSS at high frequencies.

The modecleaner and the common mode servo actuate on the laser frequency through the FSS via the wideband actuator, an AOM in the reference cavity path. The LIGO requirement is that ”the response of the wideband actuator will be flat within 2 db out to 100 kHz with less than 20 degrees of phase lag.” If the FSS was the sole cause of delay in the wideband actuator, then the gain of the FSS would need to be at least 12 dB at 100 kHz. To ensure the FSS does not limit the wideband actuator at 100 kHz, a target of 20 dB gain at 100 kHz is usually set.

With an unmodified version of the frequency servo board revision C (D980536), the previous highest gain at 100 kHz was approximately 10 dB, with a unity gain frequency of 309 kHz. A plot of the previous open loop transfer function is shown in figure 1.

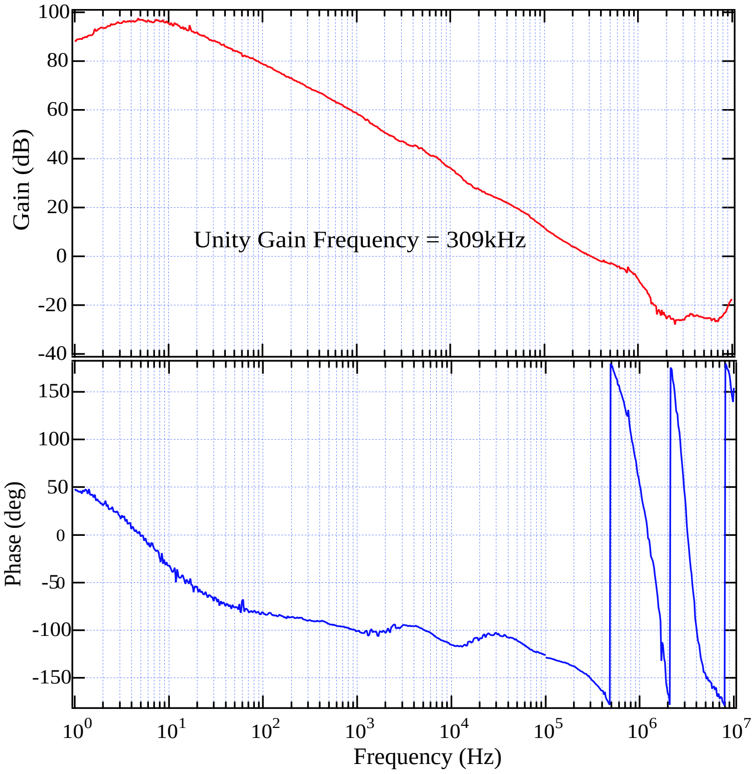


Figure 1: The open loop transfer function of the FSS with the unmodified servo board

The modification to the frequency servo board involved replacing the final stage in the Pockels cell path, the PA-85 op-amp, with a daughter board. The daughter board contained a replacement PA-85 in parallel with an AD829. The Schematic for the daughter board is shown at the end of the document.

Using the two op-amps in parallel allows the high voltage PA-85 to provide large dynamic range actuation at low frequencies (10 kHz to 100 kHz) and the low voltage AD829 to provide fast, low dynamic range actuation at high frequencies. Before installing of the daughter board, its transfer function was measured, and capacitor C8 was adjusted until there was a smooth gain profile around the crossover frequency between the PA-85 and the AD829.

The daughter board was then temporarily attached to the frequency servo board, after removing the previous PA-85. It is not necessary to remove the old PA-85, it simply needs to be disconnected by removing the input and output resistors. After the new board was put in place, the gain was set to the maximum level before oscillation occurred, and a unity gain frequency of around 700 kHz was measured. It was noted that the open loop gain was very flat after 500 kHz which meant that: (a) increasing the unity gain frequency did not increase low frequency gain much, and (b) higher frequencies were close to unity gain, and hence the system was less stable. The open loop transfer function is shown in figure 2 below.

Shortly after the installation of the daughter board, the PSL table was rearranged to reduce the number of optical components and to simplify the layout. In the new layout it was possible to pick-off light for the frequency reference cavity either before or after the PMC. With the frequency reference cavity pick-off after the PMC, the reference cavity servo will suppress any frequency noise added to the beam by the length noise of the PMC. The noise spectrum from the modecleaner indicated that PMC length noise was the dominant cause of frequency noise above a few kHz. However, if the frequency reference cavity pick-off is after the PMC, the PMC pole causes phase delay and signal attenuation at high frequencies.

It is possible to correct for compensate for the cavity pole (an optical effect) by placing an electronic zero with the same corner frequency on the servo board. It was suggested that the gain in noise performance is not worth the effort required to make this compensation. For this reason the optical layout was arranged so it was simple and quick to move the pick-off from before to after the PMC, allowing easy comparison of the two schemes. No changes were made to the servo to compensate for the PMC pole, partly because the flatness of the high frequency gain suggested the extra pole may be useful.

The FSS gain was then adjusted to maximum gain for each of the pre- and post-PMC pick-off schemes. The two open loop transfer functions were measured to determine the unity gain frequency and the gain at 100 kHz in each scheme. The PMC pole was clearly visible at around 350 kHz with the post-PMC pick-off. This pole frequency was substantially lower than the design pole frequency, but was in agreement with an independent measurement of the PMC finesse made prior to this work (LIGO technical note, T030207-00-D). As a matter of co-incidence, the DC gain was the same with the pick-off in each location. However, the post-PMC pick-off had the PMC pole in the loop, resulting in lower gain at very high frequencies - a desirable effect in this instance. Figure 2 shows the open loop transfer functions with maximum gain with the pick-off before and after the PMC.

The most important values in figure 2 are the unity gain frequency of each plot and the gain at 100 kHz. For trace (a), the pre-PMC pick-off:

$$\begin{aligned} f_{\mathrm{UG}} &= 630\,\mathrm{kHz} \\ G_{100\,\mathrm{kHz}} &= 6.28 = 16.0\,\mathrm{dB} \end{aligned} \tag{1}$$

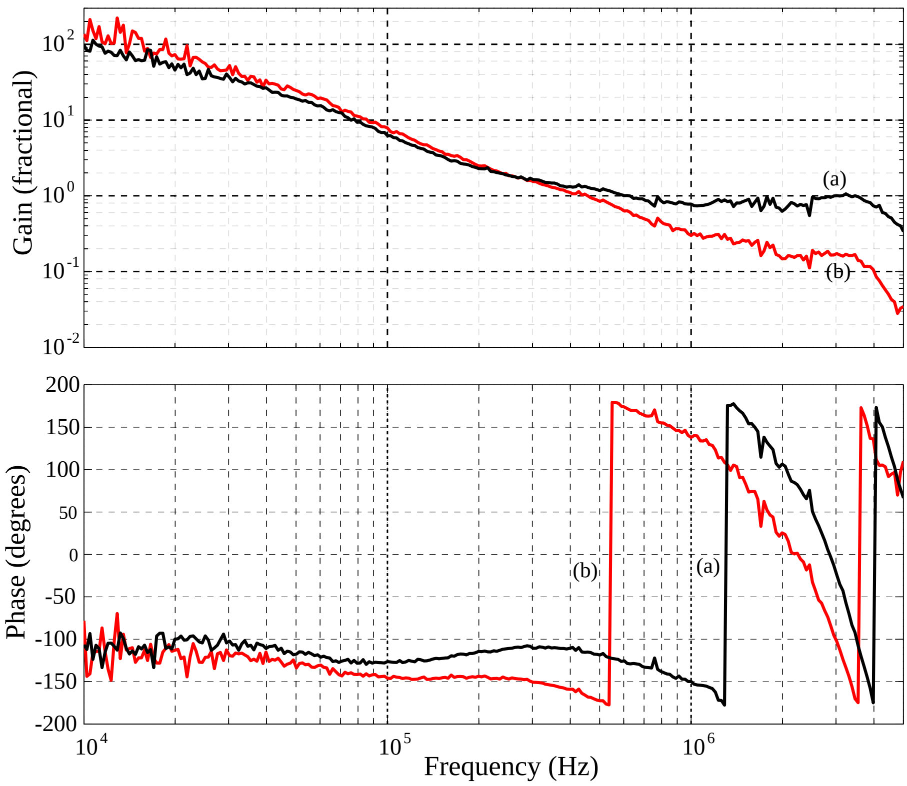


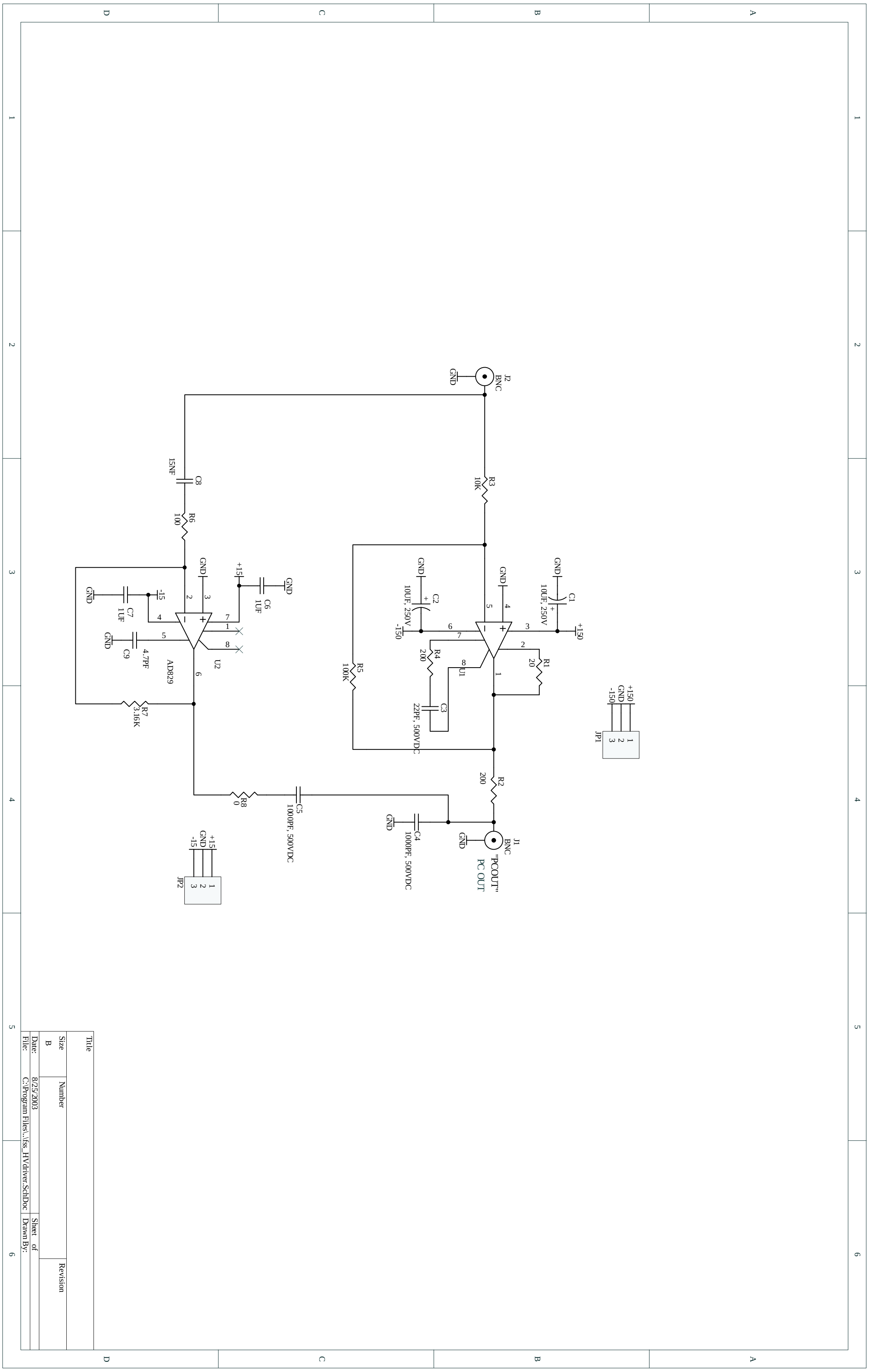
Figure 2: The open loop transfer function of the FSS with the modified servo board, with the pick-off (a) before the PMC and (b) after the PMC

and for trace (b), the post-PMC pick-off;

$$
\begin{aligned}
f_{\mathrm{UG}} &= 432\ \mathrm{kHz} \\
G_{100\,\mathrm{kHz}} &= 7.90 = 18.0\ \mathrm{dB}
\end{aligned} \tag{2}
$$

The open loop transfer functions were examined to see if there was an obvious way to change the servo poles and zeros to increase the gain at 100 kHz. Ideally, the gain would roll-off as 1/f near unity gain, such that any increase in unity gain frequency linearly increases the gain at lower frequencies. Also, frequencies outside the locking bandwidth (well above a MHz) would roll-off rapidly to ensure that, for example, the resonance of the Pockels cell at around 3.5 MHz does not cause oscillation in the servo. It was eventually decided that further changes to the filtering might allow small gains at 100 kHz in both paths, but that the further work required was not worth the effort at this stage.

With the gain so close to 20 dB at 100 kHz (a common target), further work on the FSS was halted. The daughter board was permanently mounted onto the servo card, and the open loop transfer functions were checked to ensure performance was unchanged. If further changes to the FSS are required later there are several points which can be addressed. These include: modification of the Pockels cell summing junction, filtering of Pockels cell resonance, and adjustment of Pockels cell filters to provide a smoother roll-off.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GND
C8
15NF
R6
100
R3
10K
GND
+15
-15
C7
1UF
C6
1UF
C9
4.7PF
AD829
U2
R7
3.16K
R8
0
C5
1000PF, 500VDC
C2
10UF, 250V
-150
C1
10UF, 250V
+150
R4
200
R1
20
U1
C3
22PF, 500VDC
R5
100K
R2
200
C4
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J1
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