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Evaluation of proposed changes to the suspension sensor electronics

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1 ABSTRACT

Proposed changes to the suspension sensor electronics are investigated. These changes include replacing the current split photodiode with a single element diode, and moving the pre-amp away from the suspension sensor head, outside the vacuum. Replacing the photodiode has, as a consequence, the loss of the ability to actively stabilize the light power from the LED. It is demonstrated that the intensity noise from the LED can be lower than the shot noise generated in the photodiode by the LED light. The position of the pre-amp has, as a related concern, the pickup of environmental noise by the typically long transmission cable. In the shielded environment of the vacuum chambers, it is expected that there will be virtually none of this environmental noise. It is shown that in a similar environment, the dominant noise, which is due to the 60 Hz and associated harmonics, is below the noise of the photodiode electronics.

2 OVERVIEW

The current suspension sensor electronics, which are used in the beam splitter and circulator controls in the 40 m, and for all the masses in the 12 m mode cleaner, consists of an LED and a split photodiode. A vane with a slot in it is between these two elements, which directs the light from the LED, through the slot, onto the split photodiode. The vane itself is attached to a magnet which in turn is attached to the optical element whose motion is being controlled. The photodiode is monitored in a differential output mode to indicate motion of the optical element. The signal must travel ~ 5 meters to reach the external electronics in the 40 m. Because the long transmission cable will be susceptible to capacitive and electromagnetic pick-up of environmental noise (most notably 60 Hz and it's associated harmonics), the signal is amplified at the suspension sensor head, which increases the signal to noise ratio with respect to the coupled environmental noise. The photodiode is also monitored in a common mode. This signal is used to stabilize the power output of the LED.[1]

Although the current system works, there are several problems associated with it. Thermal noise considerations force the addition of a small standoff between the optical element and the magnet in future designs. The standoff-magnet-vane assembly would have a resonant frequency around 1 kHz, which would degrade the performance of the servo. The vane also fits too snugly within the suspension sensor head, which has made installation and alignment difficult, since it is easy to break the vane off. Also, there are three zero signal positions, which provides additional difficulty in alignment procedures. The presence of electronics in the vacuum introduces several potential problems, such as outgassing and residual magnetism of electonic components, and the difficulty of repair in case of failure. Furthermore, the intensity stabilization has frequently in the past exhibited mysterious, unexplained misbehavior in the 40 m interferometer.

There are two proposed changes to the described electronics. First, the split photodiode is to be replaced with a single photodiode element. Motion sensing is accomplished by monitoring intensity fluctuations from the single diode. This change will address the resonant frequency (smaller-

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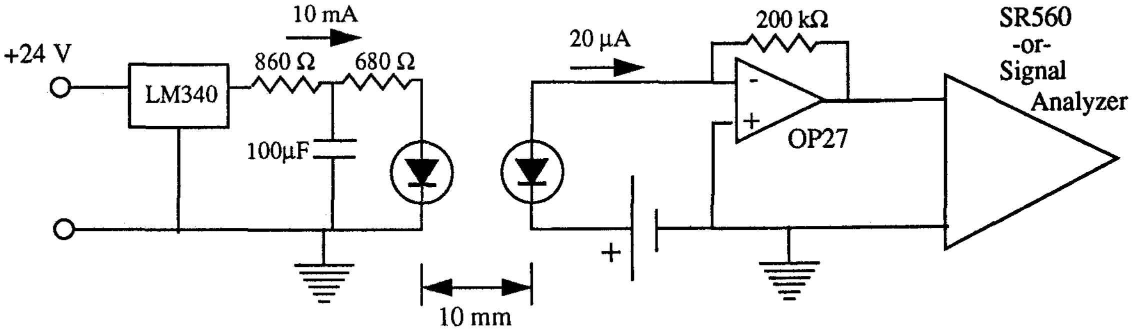
[1] This is necessary since the feedback to position has no gain at DC. Variation in intensities will have high common mode rejection in the differential output only if equal amounts of light fall on each panel of the split photodiode, in other words, if the feedback is operated in a null signal mode, which requires gain at DC.

assembly) and the alignment problems. It will also simplify the system, providing a more reliable and easier to diagnose system. The implication is that the output of the LED needs to be stabilized by some other means. Second, it is proposed that the pre-amp currently mounted on the suspension sensor/actuator head be moved outside the vacuum. This leaves open the possibility that the environmental noise which couples to the transmission line may seriously reduce the signal to noise by the time the signal reaches an amplifier, at which point both signal and noise will be amplified equally. The coupled noise needs to be measured and compared to the minimum signal.

3 POWER STABILIZATION

If the fluctuations in the intensity output of the LED and noise in the photodiode electronics are both neglected, the fundamental noise limit of the sensing electronics would be the shot noise $\delta I_{PD} = \sqrt{2eI_{PD}}$ associated with the current generated by the photodiode. It needs to be shown that these conditions can be met. It is intended that the current to the LED will come from a NIM bin voltage supply through a resistor. A circuit was built to mimic the intended design, using an LM340 voltage regulator, which puts out 15 volts, and about 1500 Ω resistance to generate ~ 10mA for the LED. A pole was placed at about 2 Hz to reduce voltage fluctuations at higher frequencies. The photodiode was biased, and approximately 20μA was generated by the photodiode.



Experiments were carried out which demonstrated that the current across the feedback resistor was shot noise limited above about 50 Hz, using the circuit diagramed above. The numbers were 400 nV/ Hz, which, at 1.5 mm/4 V corresponds to 10^{-10} m/ Hz at 100 Hz. Below 50 Hz, the spectrum rises approximately as $1/\sqrt{f}$, while below 1 Hz the spectrum seems to approach 1/f. Some concern was raised about the level of noise at 1 Hz, since it is required that the output voltage noise is not converted into motion by the controller at a level greater than that of the seismic noise. The measurement of RMS noise at 1 Hz with a 1 Hz bandwidth showed 1nm_{RMS}.[1]

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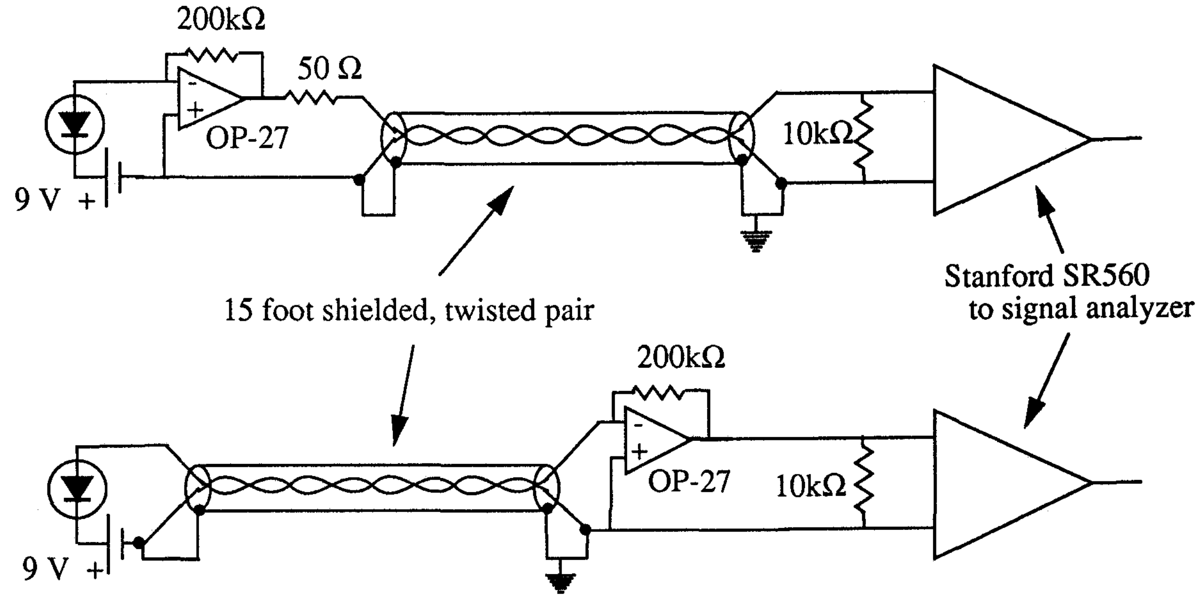
[1] This initially was not the case. The experiments were carried out in air, and it was subsequently discovered that intensity noise from the LED was sensitive to air currents. When the setup was covered by a thick cloth, the measured spectra from the photodiode dropped dramatically below 2-3 Hz - at 1 Hz, more than -15 dB improvement was noticed.

4 REMOVAL OF THE PRE-AMP FROM THE SENSOR HEAD

In order to determine whether the pre-amp can be removed from the suspension sensor head, measurements were made to compare the noise in the right half circuit in the above diagram, under two conditions. First, replicating the current setup, a long transmission cable was placed between the op-amp and the signal analyzer, so the pre-amp and photodiode were together at the head of the cable. Second, mimicing the proposed setup, the transmission cable was placed between the photodiode and the pre-amp, so the pre-amp was at the foot of the cable.



The transmission cable was 15 feet of a shielded twisted pair. The wire and shielding used were the same as what is used currently in the suspension sensor control - teflon coated Kunner wire and braided metal shielding. The signals of interest were the 60 Hz and associated harmonics due to capacitive and/or electromagnetic pickup. If the op-amp is to be moved outside the chamber, the level of the 60 Hz spikes needs to be below the shot noise from the LED, which is about 500 $\text{nV}/\sqrt{Hz}$ for the nominal 20 μA output of the photodiode, and the feedback resistance used in this experiment.[1]

Measurements were made that showed, in a quiet environment, the level of the 60 Hz family of line spikes were even below the Johnson noise of the 200kΩ resistor, which is at about 60 $\text{nV}/\sqrt{Hz}$ The "quiet environment" was a 5 m pipe, 3 cm in diameter, in the 40 m lab, since tests in the actual vacuum chambers were impractical. It is expected that the environment within the vacuum

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[1] The values chosen for the circuit that was tested were based on communications from the Japanese group, where the same photodiode and LED that were tested here have been in use.

chambers will be a quiet, shielded environment, so that such a test would be a reasonable approximation.

In general, measurements comparing the positions of the pre-amp showed two things. First, the absolute level of the 60 Hz spikes was extremely dependent on the position of the cable. For example, measurements were made in West Bridge 058f[1], with the head at two different positions in the room, separated by about 2 m. Differences in 60 Hz line spikes were as much as 30 dB. Second, placing the pre-amp at the head of the circuit consistently showed 10 to 20 dB quieter 60 Hz line spikes, than with the pre-amp at the foot, when line spikes were visible.

5 CONCLUSION

It has been shown that the proposed design works. First, active stabilization of the LED intensity output is not necessary. Simply providing a voltage source with low enough noise in the bandwidth of interest is sufficient to limit intensity noise below the detectable limit set by the shot noise in the photodetecting circuit. This shot noise limitation extends down to about 10 Hz, where presumably *intrinsic noise* of the LED begin to dominate. It has also been shown that, although the noise rises with diminishing frequency, it does not appear to rise enough to dominate the noise contribution due to seismic disturbances. Second, it has also been demonstrated that the pre-amp can be moved outside of the vacuum chamber, as long as the environment inside the chamber is sufficiently free of 60 Hz noise.

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[1] These measurements made in the optics lab of West Bridge did not use any external shielding in an attempt to mimic a "quiet" environment. These variations were not noticed in the 40 m lab, where the best results were obtained.