Photodetector Cable Shielding
LIGO-T1000532-v2
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8 September, 2010

1. Overview

An experiment was performed to analyze the relative performance of various shielding configurations used in the aLIGO Quadrant Photodetector (QPD) cabling. It is the nature of this type of system for single ended currents to be transmitted over long wires risking ambient noise pickup. This type of susceptibility to external noise is also possible in Suspension OSEM photodiodes and ISC DC photodetectors.

Two types of mitigation are available: shielded cables, and the use of a sense wire that runs along with the signal wire and allows for cancellation of electromagnetically induced common-mode currents. Both types of mitigation are measured and results are presented.

2. Measurement Setup and Data

In order to evaluate the performance contributions of the cable shield and the sense wire independently, four different test setups were devised. It was also a goal to measure whether the sense wire performance was markedly influenced by twisting it with the signal wire, or if this was not significant within a single bundle of wires. The following four figures illustrate the different cable scenarios used to extract the measured data.

Figure 1

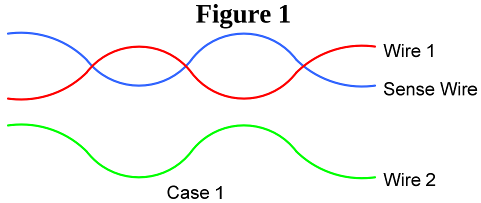


Figure 3

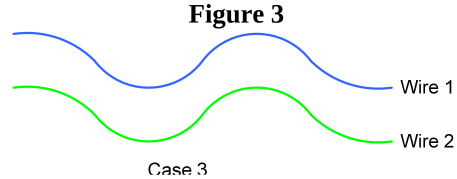


Figure 2

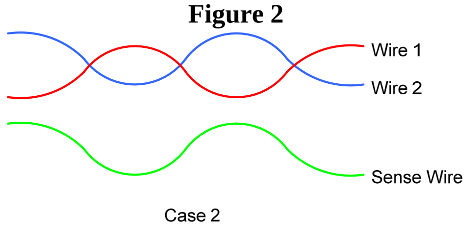
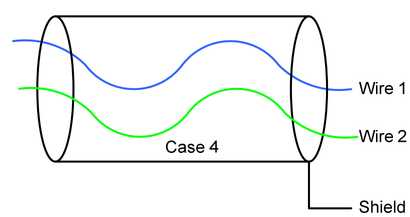


Figure 4



A 30ft length of 8-pair shielded twisted pair cable was used as the test cable (Belden-M 9508 CMG 8PR24 Shielded 8 Pair). Three of the internal conductors were isolated for use in this test, one twisted pair, and one wire from an adjacent pair, the others were unconnected. The cable shield could optionally be grounded. By choosing which of the three internal wires were connected to the QPD Transimpedance Amplifier as shown Figure 5 and Figure 6, the four test cases could be evaluated.

Figure 5

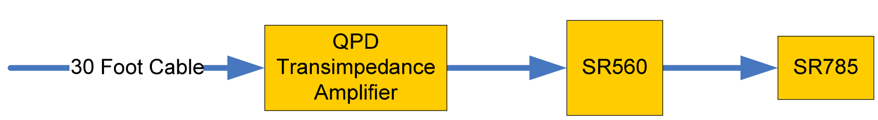
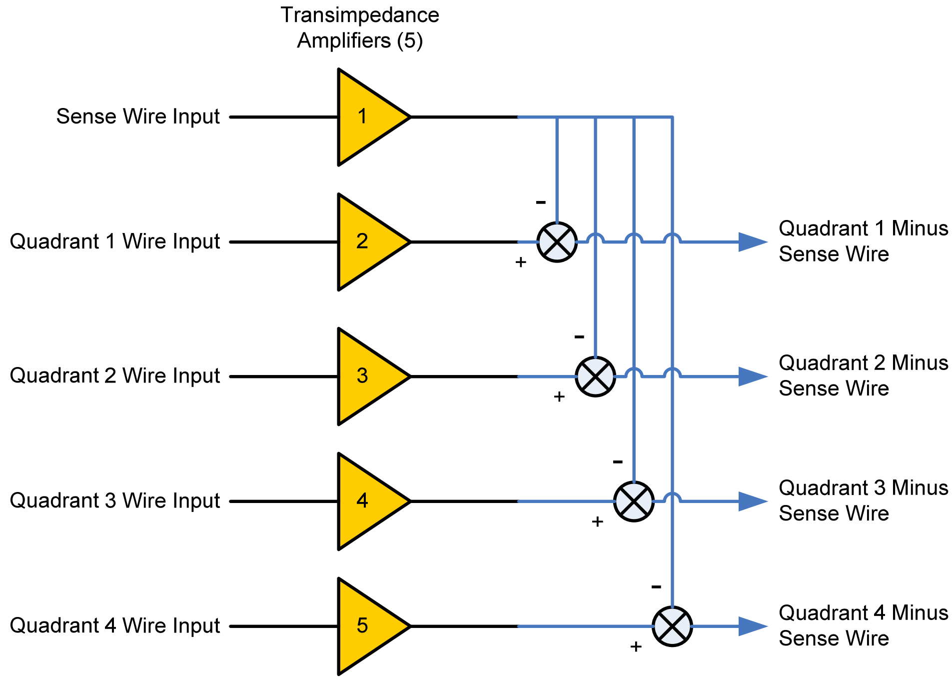


Figure 6, QPD Amp. Channels 4 and 5 not used for this test.



3. Data and Data Analysis

Table 1 shows measurements taken in the setup shown in Figure 5. Details of the QPD amp circuitry and the Quadrant 1 and 2 outputs detailed at the extreme right of Figure 6. The SR560 provided high frequency filtration with a single pole at 1 kHz. The gain of the SR560 was set to unity. Voltage readings were taken as indicated in Table 1 using an SR785 Dynamic Signal Analyzer.

Table 1

Cable Configuration (See Fig. 1-4)	QPD Amp Ch. 1 Reading @ 60Hz (wire 1)	QPD Amp Ch. 2 Reading (wire 2)
Case 1	-105 dBVrms/√Hz	-68.4 dBVrms/√Hz
Case 2	-68.2 dBVrms/√Hz	-68.2 dBVrms/√Hz
Case 3	-51.0 dBVrms/√Hz	-50.8 dBVrms/√Hz
Case 4	-93.9 dBVrms/√Hz	-97.2 dBVrms/√Hz

3.1. By looking at the differences between cases, conclusions can be drawn about the relative merit of the shield, sense wire, and twisting configuration.

3.2. Shield Effectiveness: By measuring the difference between the shielded and unshielded case, a measure of the shield effectiveness is obtained for two of the internal wires.

Case 3 minus Case 4 for wire 1 = -51.0 – (-93.9) = **42.9dB** rejection for wire 1
Case 3 minus Case 4 for wire 2 = -50.8 – (-97.2) = **46.4 dB** rejection for wire 2

3.3. **Sense Wire, Twisted vs. Untwisted Case:** By comparing the sense wire subtraction for a wire twisted with the sense wire, and a wire not twisted with the sense wire, a measure of the relative performance can be obtained to evaluate the merit of sense wire twisting with target wire.

Case 1 minus Case 3 = -105 – (-51.0) = **54 dB** for wire 1 (**twisted** case)
Case 1 minus Case 3 = -68.4 – (-50.8) = **17.6 dB** for wire 1 (**untwisted** case)

4. **Mutual Capacitance:** Postulating that mutual capacitance between the sense wire and the desired signal wire can produce unwanted cancellation of the desired signal; the mutual capacitance of each wire configuration was measured. The results are shown in Figure 7 and Table 2.

Figure 7

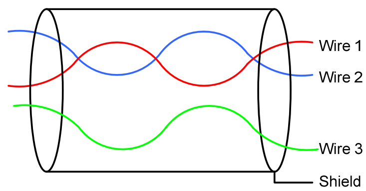


Table 2, Capacitance in pF/foot

	Wire 1	Wire 2	Wire 3	Shield
Wire 1	-	28.7pF/foot	23.9pF/foot	42.6pF/foot
Wire 2	28.7pF/foot	-	23.8pF/foot	42.4pF/foot
Wire 3	23.9pF/foot	23.8pF/foot	-	43.2pF/foot
Shield	42.6pF/foot	42.4pF/foot	43.2pF/foot	-

4.1. For the twisted pair case, the total mutual capacitance for the 30 foot cable was 862pF (wire 1 to wire 2). Assuming the input impedance to each transimpedance amplifier is 10 Ω, the pole frequency for the cancellation occurs at:

$$Cancellation\ Pole\ Frequency\ (Hz) = \frac{1}{2\pi(10\Omega)(862pF)} = 18.5\ MHz$$

4.2. Knowing the total capacitance of the twisted pair (862pF), C, the characteristic impedance (100 Ω), Z, the total series inductance, L, can be estimate as a bulk model (frequencies low enough to ignore transmission line phenomena):

$$L = z^2C = 100^2 \times 862pF \cong 10\mu H$$

The inductive reactance is insignificant when compared to the resistive term (10 Ω) at frequencies compatible with LIGO digital sampling.

5. **Conclusion**

There appears to be much to gain from the sense wire subtraction method. The twisted case yields an impressive 54 dB of rejection at 60Hz whereas much of this performance seems lost by not tightly twisting the sense wire to the signal wire. The tight capacitive coupling of the sense wire to the target wire means the desired signal will also be subtracted, but this seems insignificant given the high pole frequency.

The sense wire subtraction used in conjunction with the cable shield promises 90dB or more rejection of ambient 60Hz electromagnetic pickup. The added circuit and wiring complexity can be weighed when considering the necessary rejection of low frequency electromagnetic interference.