LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

-LIGO-

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LLO Training Quad Vacuum Cable Test Results

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1 Introduction

This document describes the test results and recommendations for the aLIGO Quad Suspension vacuum cabling conducted at LLO in September of 2010.

2 Test Setup

2.1 Setup

Prototype vacuum cables were fabricated according to the drawings listed below. These cables were then installed on the reaction chain of the training quad at LLO. The LLO BSC Test Stand, associated software and electronics were then used to determine if the installed cables compromised the performance of the suspension chain. During the tests the main suspension chain was clamped using the earthquake stops, but the reaction chain was roughly aligned and hanging freely. All measurements were taken using the Top stage BOSEMs of the reaction chain. No real attempt was made to align the lower stage AOSEMs as they were only installed in an effort to account for the proper weight.

2.2 Cable Types Fabricated

The types of cables fabricated for the testing can be grouped in to the following categories.

- Top Stage Cables
- 25 Conductor Extension Cables
- OSEM Fanout Cables
- Electro-Static Driver (ESD) Cables

Each type is described in the sections below.

2.2.1 Top Stage Cables

These cables are used to connect the BOSEMs of the Top Stage. These cables have a 25 pin Dsub cable on one end and the internal wires are fanned out to 4 each 9 pin uDsub cables that connect to the BOSEMs. These cables were fabricated according to the drawings listed below.

- D1000234-v2
- D1000236-v1

As can be seen from these drawings the individual wires are arranged in twisted pairs. There is an overall copper braid used for shielding and an overall PEEK braid used to provide electrical isolation from the suspension structure.

2.2.2 25 Conductor Extension Cables

These cables are used for routing of signals from the 25 pin Dsub connector mounted on the optics table down through the suspension structure and to the lower stages. The lower end connector is a 25 pin uDsub. Connections from the 25 pin Dsub on the optics table to the lower 25 pin uDsub are made using twisted pair wires. These cables were fabricated according to the drawing D1000566-v3.

As can be seen from these drawings the individual wires are arranged in twisted pairs. There is an overall copper braid used for shielding and an overall PEEK braid used to provide electrical isolation from the suspension structure.

2.2.3 OSEM Fanout Cables

These cables are used to connect the BOSEMs or AOSEMs of the Upper Intermediate Mass (UIM) and Penultimate Mass (PUM) stages. The 25 pin uDsub connector on the one end connects to the appropriate 25 conductor extension cable (see previous section). The other ends connect to the BOSEMs or AOSEMs. These cables were fabricated according to the following drawings.

- D1000562-v2
- D1000563-v2
- D1000564-v2
- D1000565-v2

As can be seen from these drawings each of these cables are virtually identical with the following exceptions:

- D1000563 and D1000565 do not have the PEEK overbraid. These cables were produced as a backup. If it was determined during the testing that the cables using the PEEK overbraid were too stiff or degraded the suspension performance, these cables would then be tried.
- D1000562 and D1000563 are both 23 inches in length. D1000564 and D1000565 are 33 inches in length.

The 23-inch cables are used for the UIM connections and the 33-inch cables are used for the PUM connections.

2.2.4 ESD Cables

The ESD cables and connectors used for the tests were Accuglass part number 602262. These cables consist of five individual kapton insulated 32 AWG coaxial cables with Dsub style multiple coax connectors on each end. The pigtail ESD cables used were Accuglass part number 602105.

2.3 Procedure

The test procedure can be divided into three steps.

- Reference Transfer Functions
- Transfer Functions with OSEM cables installed
- Transfer Functions with OSEM and ESD Cables installed

Each is described in the sections below, but in general the philosophy for determining if the vacuum cables were acceptable was to take reference transfer functions for each degree of freedom with no cables installed. These with transfer functions would then be compared with those taken with cables installed. If there was no degradation in performance, i.e. mode frequencies remain the same, the cables are considered to be acceptable.

2.3.1 Reference Transfer Functions

Top Stage cables were installed and connected to the appropriate BOSEMs. These cables were then connected to the LLO BSC Test Stand and proper operation of the BOSEMs verified. The Reaction chain was made to hang freely and all Top Stage BOSEMs roughly aligned, zeroed and set to mid-range using the operator screens on the Test Stand. Reference transfer functions were then taken and stored using DTT.

2.3.2 Transfer Functions with OSEM Cables Installed

The 25 conductor extension cables and the OSEM fanout cables were then installed and routed down the reaction chain to the appropriate stages. The cables were clamped using the new UK cable clamps (D1001040, D1001041, D1001042) at the top and bottom of each stage through which they passed. It was at this point that we realized that the original connection and clamping scheme would be not be optimal. In the original scheme the connection between the extension cables and OSEM fanout cables for the UIM and PUM stages was to be made at the bottom of the Top stage. The fanout cables (4 each for each stage) were then to be routed down the remaining stages to the appropriate OSEMs. This connection scheme made for a large number of cables bundles (8 total) to be clamped and routed. A more optimal routing scheme was used for the tests. In this more optimal method the extension cables are routed from the optics table, down each stage to their “terminal” stage where they are connected to the fanout cables for that stage. Using this method the 4 fanout cable bundles for a particular stage are only routed on the terminal stage and therefore can not affect the suspension performance. It is also much easier to route and clamp the single extension cables.

The figure below shows schematically how the cables were routed and the location of the connectors and clamps.

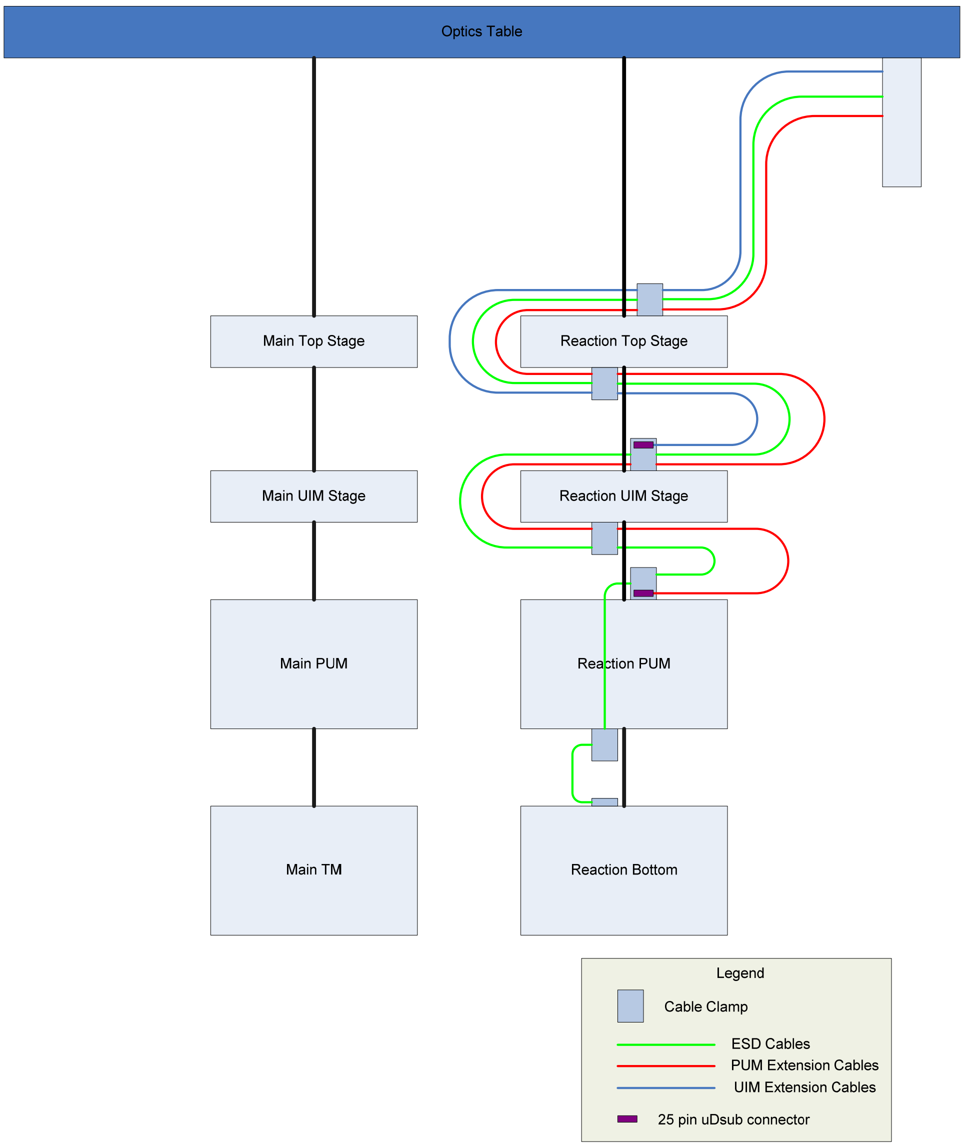

Figure 1: ESD and 25 pin Extension Cable Routing on Reaction Chain

The picture below shows both Extension cables and the UIM Fanout cable clamped on the top of the UIM. Note that in the final system it is recommended that the UIM Extension 25 pin uDsub Connector be clamped in a separate layer of the clamp stack (reference Figure 4: PUM Stage

Cabling, below). In this case it was not possible due to the length of the screws and the parts available.

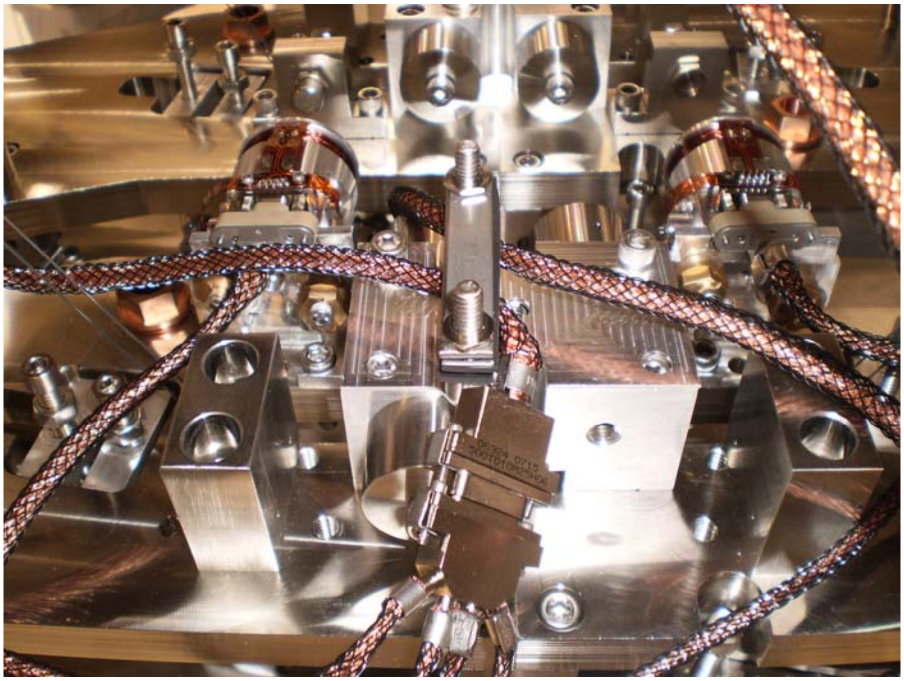

Figure 2: Clamp Holding Cables on Top of UIM

The picture below shows the Extension Cable that goes to the PUM as it is routed from the top of the UIM to the bottom the UIM. The routing takes it between the main and reaction chains. As can be seen in the picture, the UIM OSEM flags have been removed. This was done in an effort to make alignment and testing easier as it does not affect the reaction chain measurements.

Figure 3: PUM Extension Cable Routed from Top to Bottom of UIM

The picture below shows the PUM OSEM fanout and extension cable connection made at the top of the PUM stage. Also visible in the top left of the picture (see red arrow) is the fanout cable connection to one of the UIM OSEMs. Note how the 25 pin uDsub connector on the Extension Cable is clamped in the cable clamp.

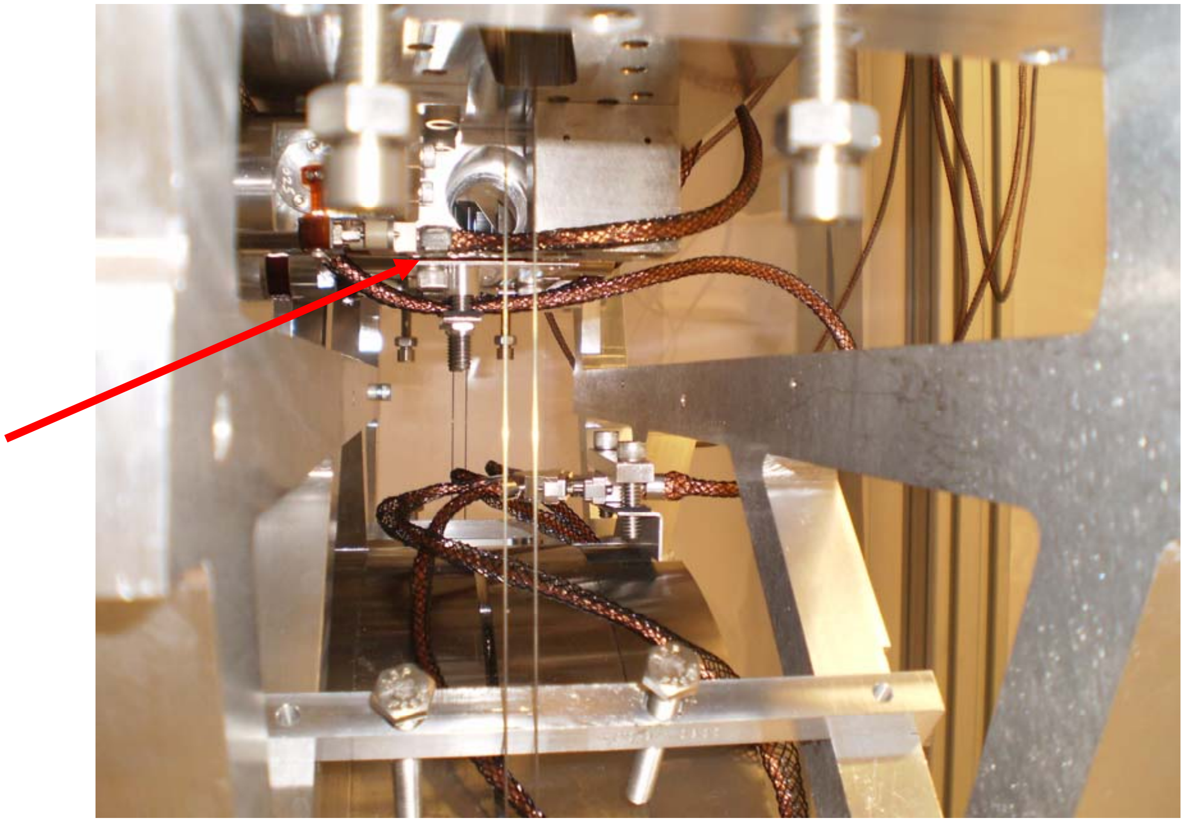

Figure 4: PUM Stage Cabling

2.3.3 Transfer Function with OSEM and ESD Cables Installed

The Accuglass cables were installed in parallel with the other cables used in the previous tests. These coax cables were routed in the same manner and using the same clamps as above. The figure below shows the clamping and routing of both sets of cables from the bottom clamp on the UIM to the top clamp on the PUM. Note how the coax cables are clamped in a separate layer of the clamp. The large bend in each cable set should clear other mechanical pieces in the suspension structure that are not installed on the training quad.

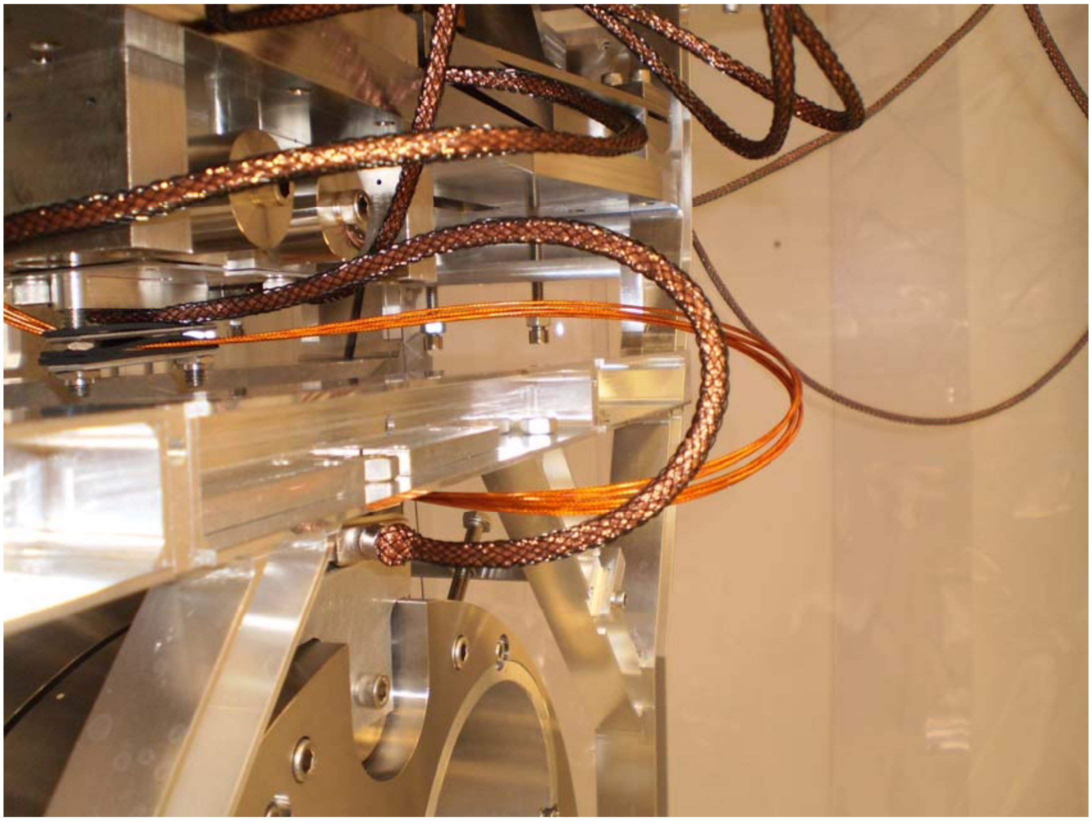

Figure 5: Routing and Clamping of Cables from UIM to PUM

The final connector on the coax cable bundle was clamped to the bottom of the R0 PUM. As there was not a clamp available, taping the connector to the mass simulated the clamp. It is recommended that a clamp be added to this location so that the ESD cables and connectors can be secured at this point. Note that the orientation of this connector and clamp is rotated 90 degrees relative to the other clamps. From that point, a mating connector with coax pigtails was used to simulate the connection to the Bottom Mass. These connections were simulated using tape. The picture below shows these connections.

Figure 6: ESD Connections to Bottom Mass

Coax cables on the PUM stage were routed around the barrel of the PUM. This is shown in the picture below.

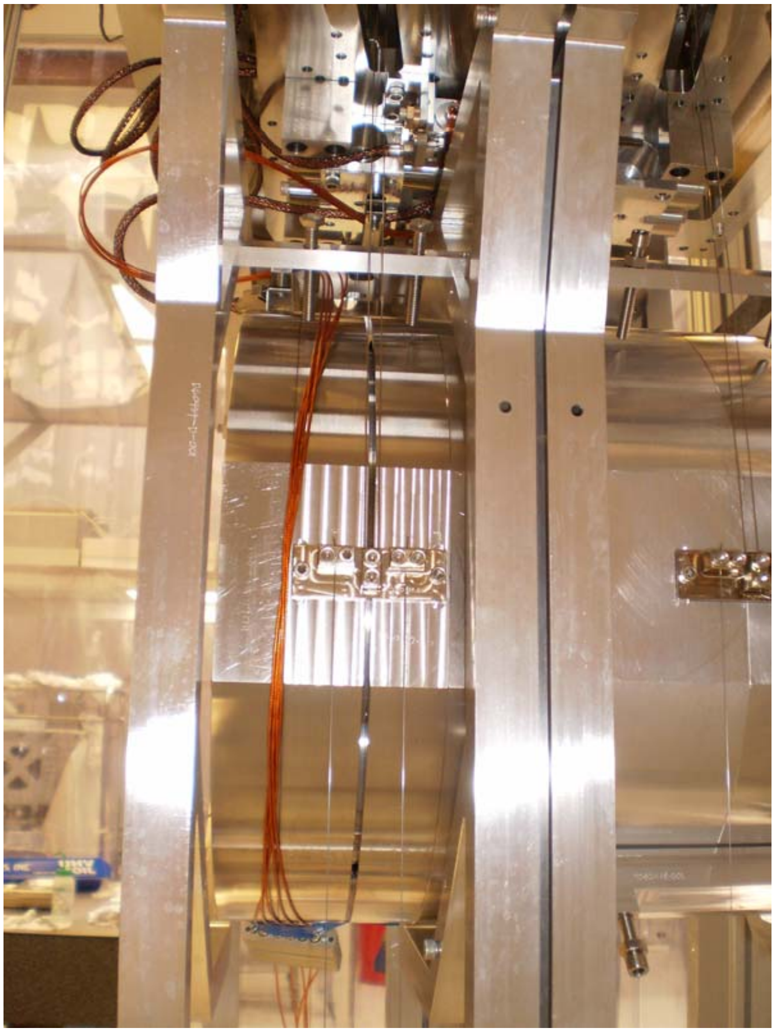

Figure 7: ESD Cables Routed Around PUM Barrel

The picture below shows the ESD connector that is clamped at the bottom of the Top Mass. This connector was placed at this point due to cable length limits. It may be advantageous to lengthen this cable and move this connector to the Top of the Top Mass.

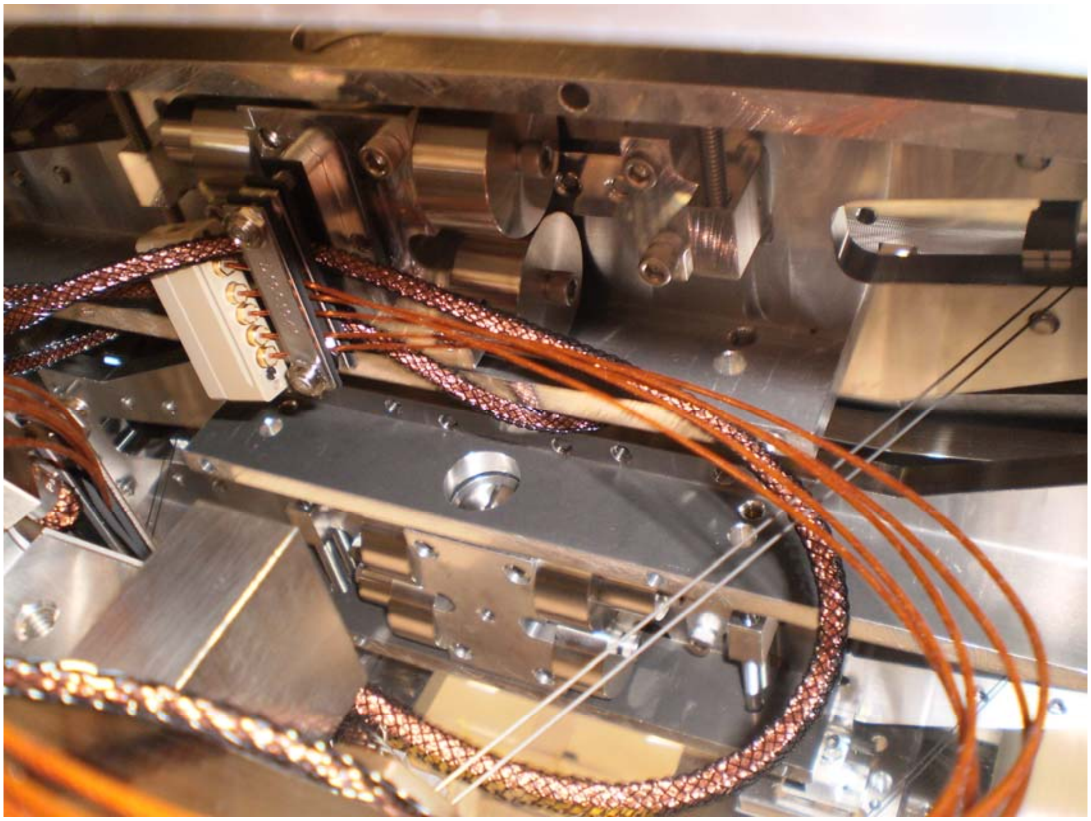

Figure 8: ESD Connector on Bottom of Top Mass

3 Test Results

The transfer function comparisons for each degree of freedom can be seen in the figures below. It should be noted that due to what appear to be acceptable results for the cables that use the PEEK overbraid, the non-overbraid cables were not tested.

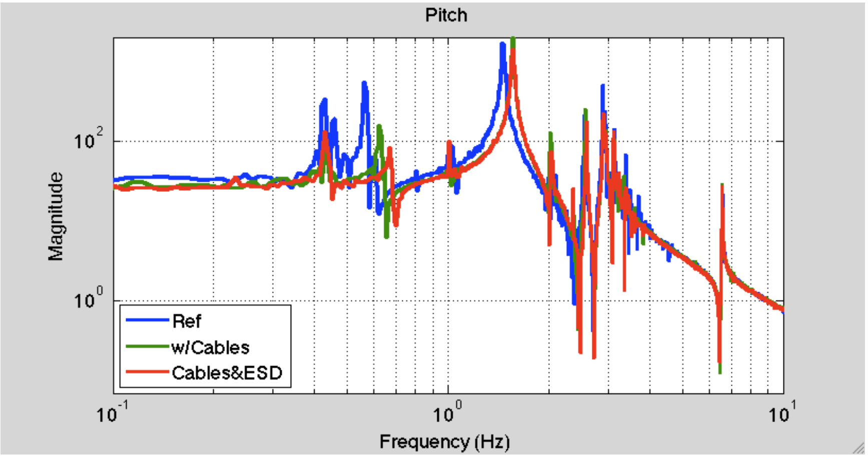

Figure 9: Pitch Degree of Freedom

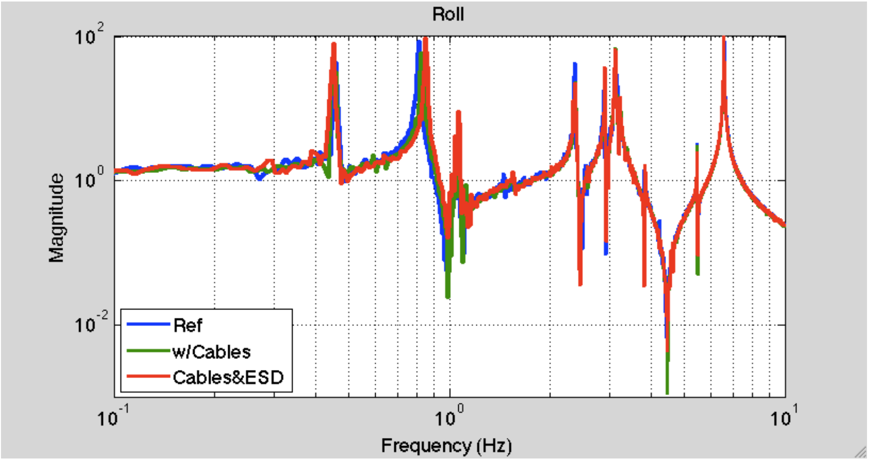

Figure 10: Roll Degree of Freedom

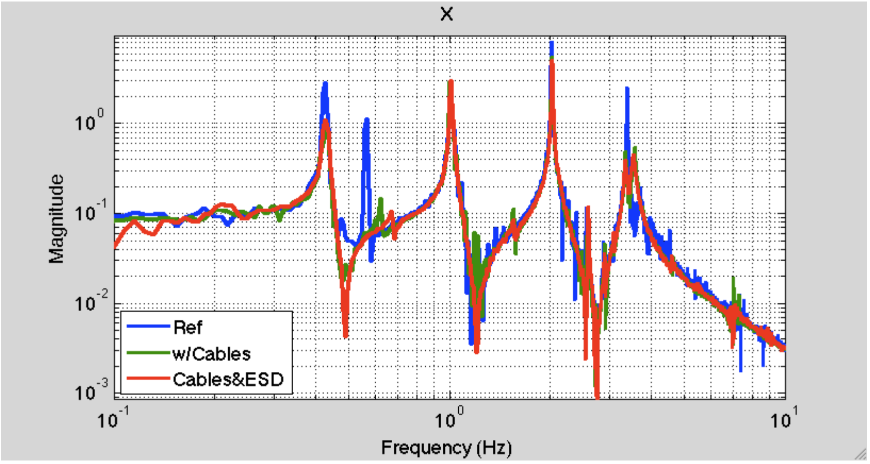

Figure 11: X Degree of Freedom

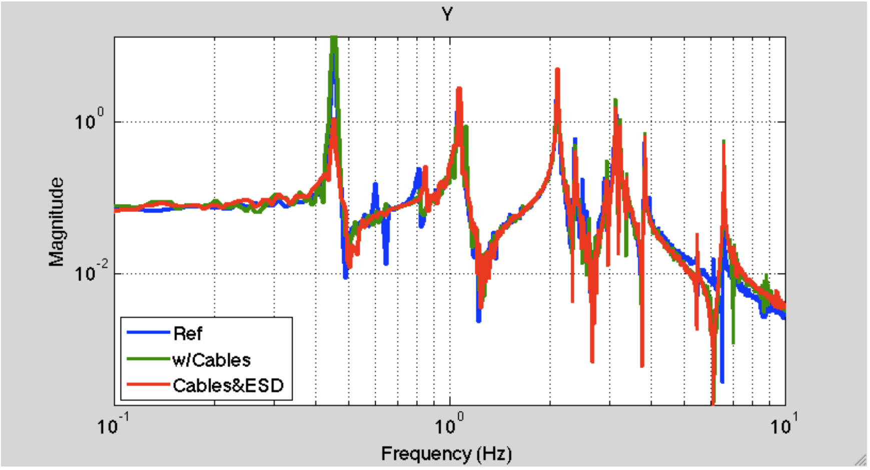

Figure 12: Y Degree of Freedom

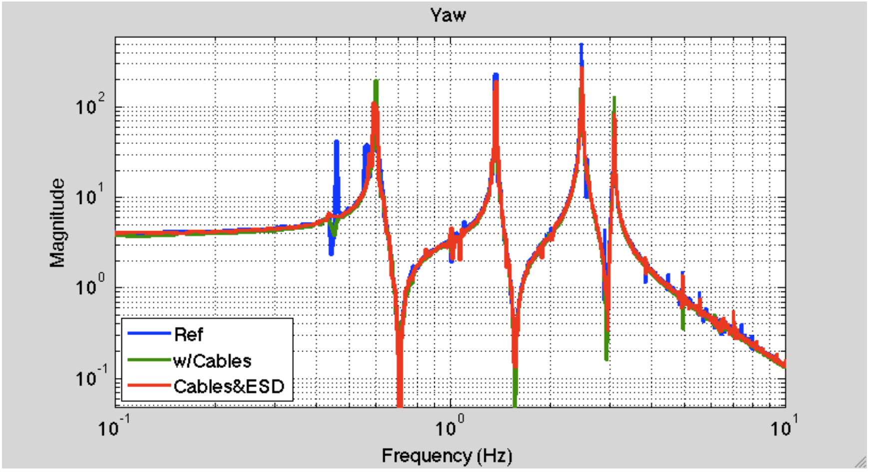

Figure 13: Yaw Degree of Freedom

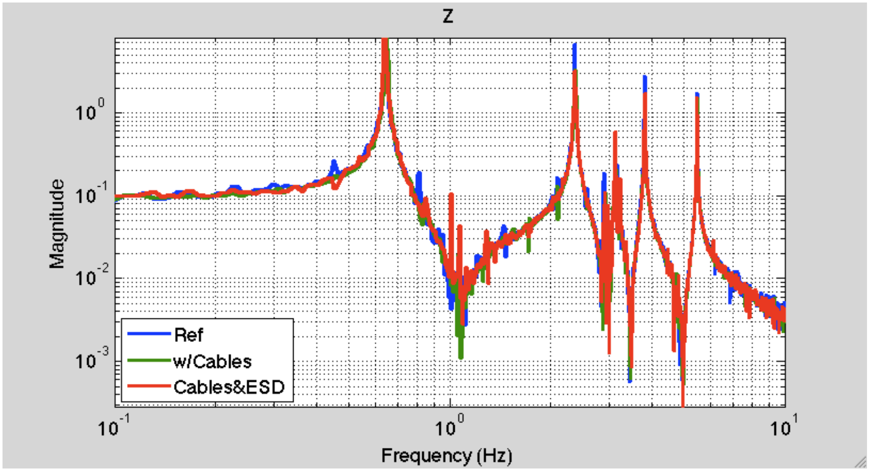

Figure 14: Z Degree of Freedom

As can be seen from the previous figures the transfer functions for all three measurements match very well. The only exceptions are:

- Pitch (figure 9)- Reference pitch frequencies at ~0.58Hz and ~1.5Hz have been shifted up most likely due to the increased weight added by the cables. This weight was not accounted for when the reference transfer functions were made.
- X (figure 11)- There is a peak at ~0.58Hz in the reference trace that does not appear in the other traces. This is most likely a cross coupling to the pitch degree of freedom.
- Yaw (figure 13)- There is a peak at ~0.45Hz in the reference trace that does not appear in the other traces. This most likely a cross coupling to the pitch degree of freedom.

4 Conclusions and Recommendations

The cables as modified and installed during the testing described in this document do not appear to degrade the performance of the suspension system. These modifications and recommendations are:

- One Cable is Better than Four- The cable routing method described above should be adopted. This will require that the lengths of each type of cable be adjusted. In particular the 25 conductor extension cables will need to be lengthened. An estimate of the new lengths for these cables was made, but will need to be confirmed as adequate once the final placement of the connector bracket on the optics table has been made. The “new” nominal lengths for these extension cables are 90 inches and 110 inches for the UIM and PUM cables, respectively. It needs to be confirmed that these new nominal lengths are adequate to reach the location of the 25 pin Dsub bracket installed on the optics table. This method also shortens the fanout cables for the UIM and PUM stages. The “new” nominal lengths for these cables are 12 inches and 17 inches for the UIM and PUM stages, respectively.

- The new cable clamp/bracket parts (D1001040, D1001041, D1001042) provided by Joe Odell appear to work. The only possible modification that may be useful would be to increase the size of the holes in the Divider Shim (D1001041) as they tend to bind on the mounting bolts when they are installed.
- An additional clamp should be added to the bottom of the PUM mass on the reaction chain. This clamp will be used to clamp the ESD cables. The orientation of this new clamp should be rotated 90 degrees relative to the other clamps. This will facilitate connection of the ESD pigtail cable to the bottom mass.
- The top clamp on the PUM should be remade to be like others or made shorter. This will allow the cables more room to bend around and clear the suspension structural member (reference Figure 4: PUM Stage Cabling).
- The 72 inch ESD cables we tested made it from the bottom of the PUM to the bottom of the top mass. We may want to add another 18 inches to get to top of top mass where the connection to the cable that leads to the vacuum flange can be made.
- It may be possible to use some of the ¼ x 20 holes on the back of the R0 PUM to mount the PEEK cable clamps and help secure the connections to the OSEMs.