Reducing differential motion of Advanced LIGO seismic platforms to improve interferometer control signals

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November 11, 2019

1 Introduction

CPS sensors can be used to stabilize ISI motion: this will help to reduce the differential motion between chambers at low frequency, improve the length drive and possibly reduce the locking time of the IFO and improve stabilization during wind and earthquake conditions.
The project we are going to present is to reduce differential motion of internal seismic isolation platforms (ISIs). Studies on the CPS projections to the suspension point of HAM and BSC chambers in the Corner Station (CS) are showing that CPSs are reliable witnesses of differential motion between chambers. Will will show how it is possible to use the CPS sensors to stabilize the ISI motion and improve the LSC signals at frequencies below 0.5 Hz.
This project has been performed during an LSC fellowship program between June and November 2019. Results shown are primarily from LIGO Hanford Observatory, but similar results have been obtain at LIGO Livingston observatory.

1.1 CPS differential motions

A study on CPS differential motion between chambers along x axis has been performed. This is useful to verify the common motion of the chambers through the signal of a device sensing the same motion on every chamber.
For BSC chambers, we used the CPS on stage 1. All motions are taken from SCSUM channels.

In Fig.1, examples of differential motion between a HAM2 and HAM3 and BS and ITMX are plotted. More plots can be found on the SEI logbook post 1486. The common motion below 0.2 Hz is much better for the HAM chambers.

1.2 CPS projections

We projected the CPS of the x axis chambers to the suspension point in order to obtain PRCL and IMCL traces sensed by the CPS and show that CPSs are good representatives of LSC signals. For BSCs, we decided to sum the contributions of the CPSs on stage 1 and stage 2 and to project this sum.

To project the CPS signal we used the same elements of the CAL2EUL and the EUL2IFO matrices already used to project GS13 to suspoint.
One of the main differences betweeen the behaviour of CPS IMCL and CPS PRCL, is that the former is obviously involving only the HAM chambers. Since HAM2 and HAM3 have a very good common motion,

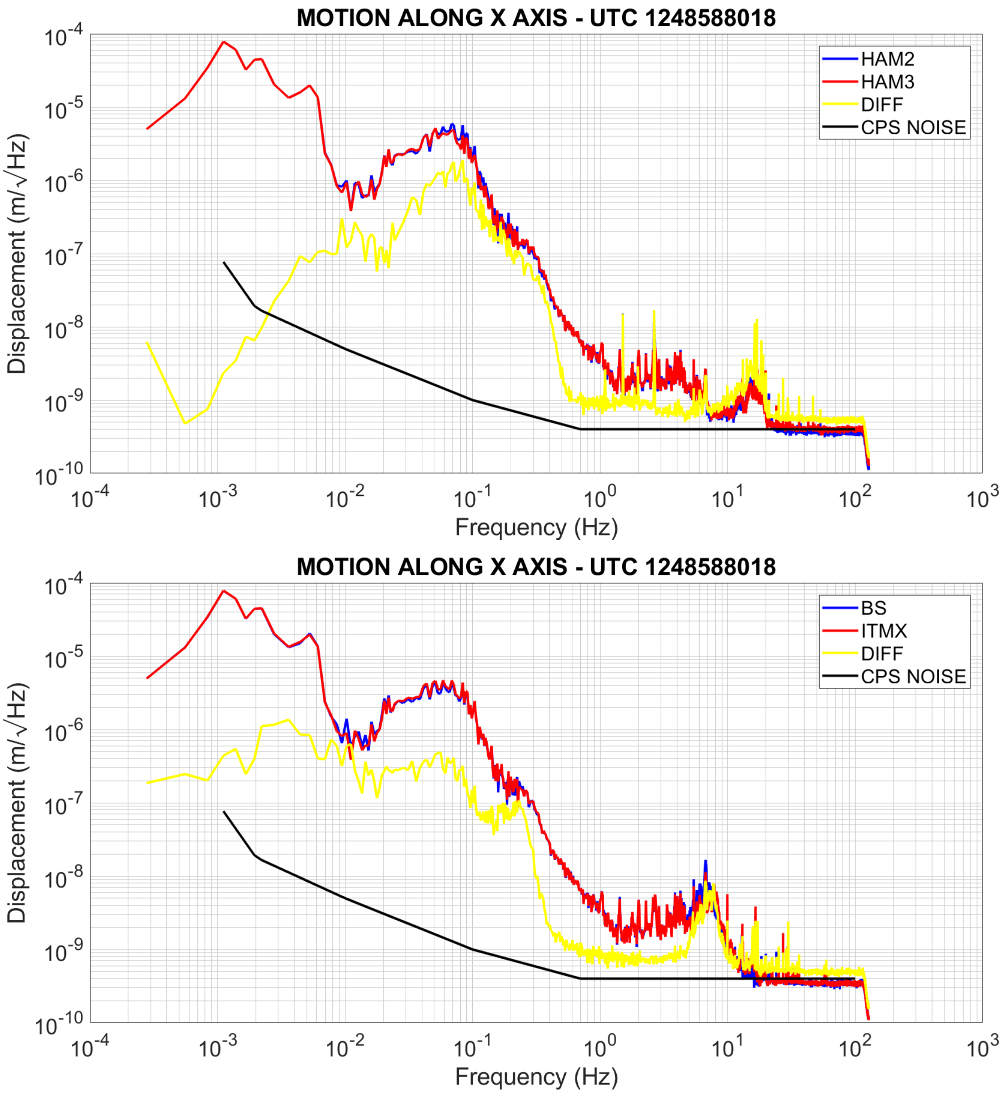

Figure 1: CPS differential motion between the HAM and BSC chambers along x axis. ISIs move in common, particularly in the same building. This can be confirmed by noting that the difference between two chambers is much lower than individual chambers.

IMCL can be considered more stable with respect to PRCL, which instead involves also BSCs. Indeed, CPS PRCL is following the only BSCs at frequencies below 0.02 Hz.
Fig.2 shows plots of PRCL and ICML by CPS projection to suspoint. More details about coherences and contributions of single elements are plotted in comments to the SEI post 1493. **This projections indicate that reducing the differential motion as seen by the CPSs will help to reduce the residual motion seen by the optical cavities.**

2 Implementation of CPS differential motion suppression

Given the above, we set up an experiment to try to use the CPSs to lock HAM2 and HAM3 together, HAM4 and HAM5 together, CS BSCs together and ETM BSCs together. This will stabilize the ISI differential motion; Reduction in differential ISI motion should also help to lock the interferometer in a shorter time.
Results will be shown in the next section.

Step 1: feeding chambers with CPS differential Our first step has been to lock the HAM2 and HAM3 chambers together by feeding HAM3 a calculated differential CPS signal. This is done in practice with an additive offset to the setpoint of the HAM3 isolation control loop. We then repeat this by feeding

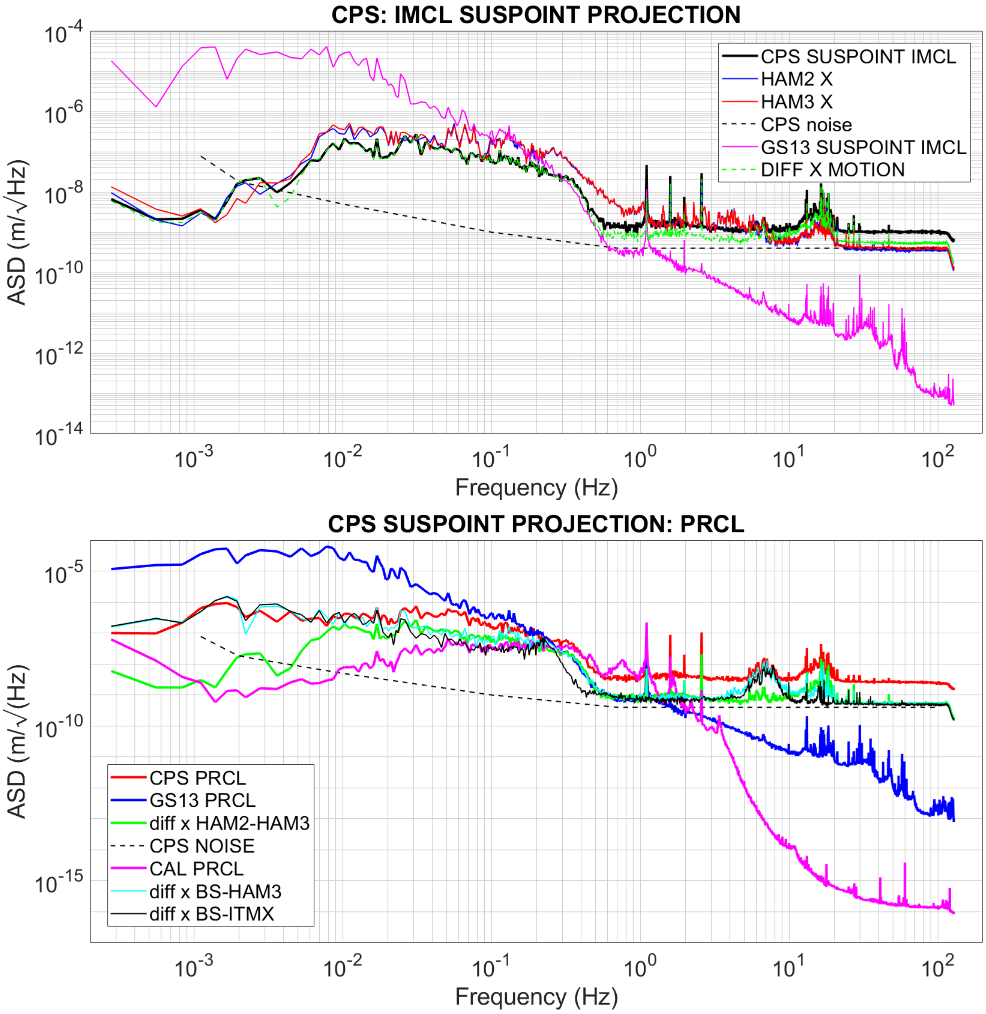

Figure 2: CPS suspoint projections: IMCL and PRCL. The calibrated PRCL trace used as comparison has been de-whitened.

HAM4 and HSM5 differential to HAM5. Concerning the BSCs, we formed a combination of the ITM and BS in a "MICH-like" way, by taking the y-axis differential of BS and ITMY and the x-axis differential of BS and ITMX. Finally, we suppressed the differential motion of individual arm cavities by feeding ETMs with the ITM-ETM signal.
In this frame, the role of IMCL would be as witness. The block diagram in Fig. 3 shows the CPS differential feeding of HAM chambers. We expect this to help lock acquisition and holding lock during windy weather or earthquakes.

Step 2: feeding HAMs with PRCL Once the IFO is locked, we also have optical cavities which, at low frequency, are essential measuring the differential motion between seismic platforms. We propose to offload the low frequency suspension motion to the ISIs, as a further improvement beyond just the CPS differential. Fig. 4 shows a block diagram of this offloading scheme for PRCL. MICH, SRCL and IMC have similar diagrams. As final result, PRCL motion should be reduced thanks to the feedback induced by the control on the HAM block.
The same principle will be used for SRCL and HAM chambers on y axis and BS for MICH.

3 Results

The new configuration for ISI motion suppression through CPS feedback has been tested. We looked at the effect on MC2 and IMC, and watched the ground motion to see if there are variations between the two measurements.

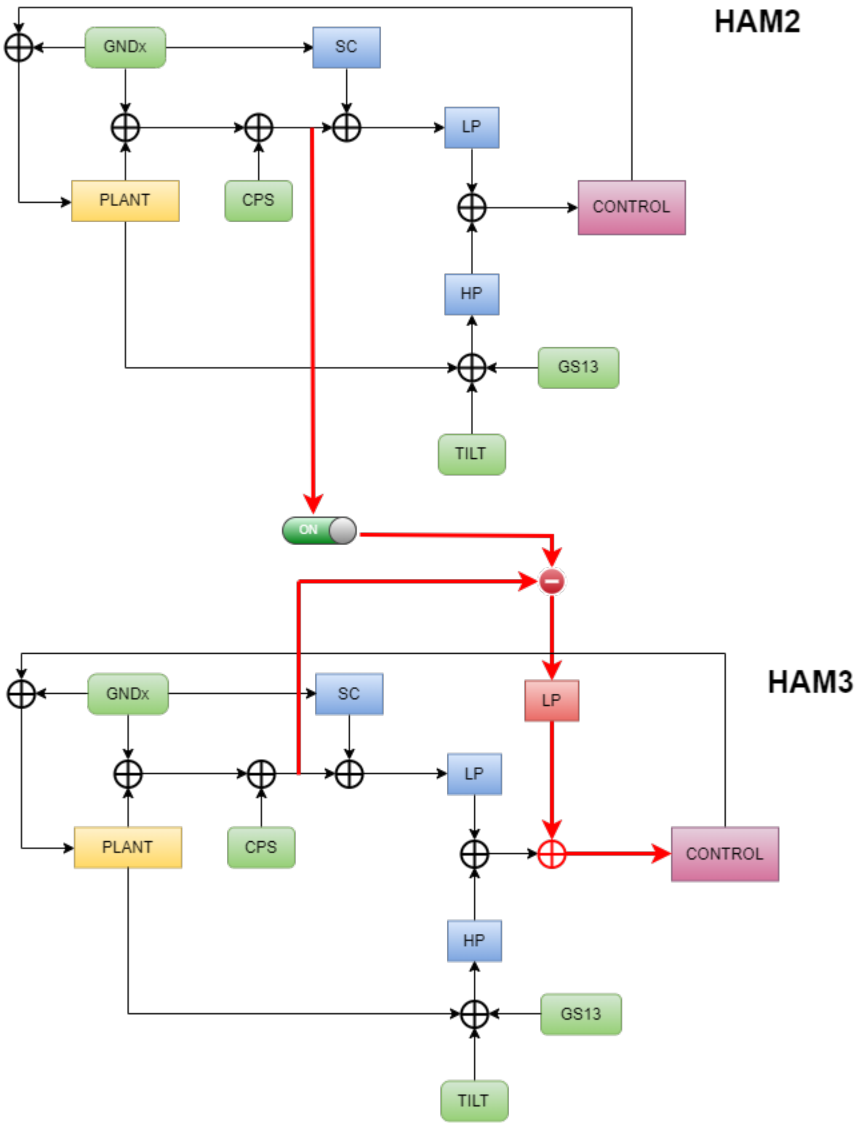

Figure 3: Block diagram of the CPS feeding concept in HAM chambers. Green blocks are input signals, common for both chambers. Yellow boxes represents HAM2 and HAM3 plants. Blue boxes are high pass, low pass and sensor correction filters. The red box represents the ISI control filters.

Fig. 5 upper side shows the result: we tested the system in OFF and ON status, with two different 100mHz low pass filters, one called *100 mHz*, the other is called *newlp*; sensor correction was off everywhere and only HAM2-HAM3 CPS differential was applied. **We got a factor of about 3 of improvement at 60mHz**.
The plot on bottom side shows DARM behaviour with all the CPS differential feedback system ON and OFF when the IFO is in full lock: there is an improvement at low frequency. Above 0.1 Hz it is a little worse but this is still under investigation. Also, the same measurement has shown that the RMS when the system is ON is always below the RMS in OFF configuration for all the suspensions.
Fig. 6 shows a test of a measurement where we have implemented MC2 offloading to HAM3, in addition to CPS diff motion reduction. Also, sensor correction is on. The two plots show the MC2 WIT and the ground motion behaviour.
The online test on MC2 shows an improvement over the offline conditions below 100mHz while the ground motion does not show any variation. It is reasonable then to think that the good effect on MC2 is entirely due to the filters.

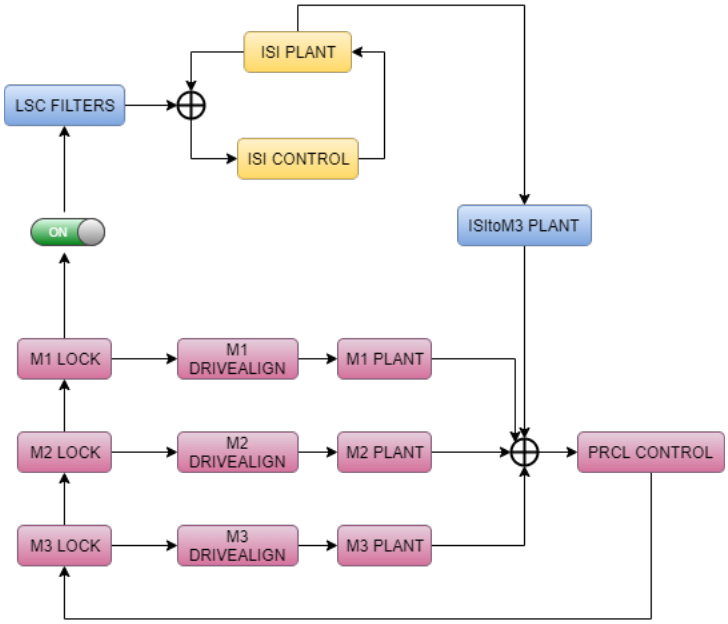

Figure 4: Block diagram of the connection of PRCL to ISI. Purple blocks represents the PRCL section, yellow block are the ISI section. Blue blocks are the sections connecting PRCL and ISI. LSC filter are the offloading filters used in sending the low frequency suspension LSC signal to the ISI. PRCL control is the canonical LSC control filters.

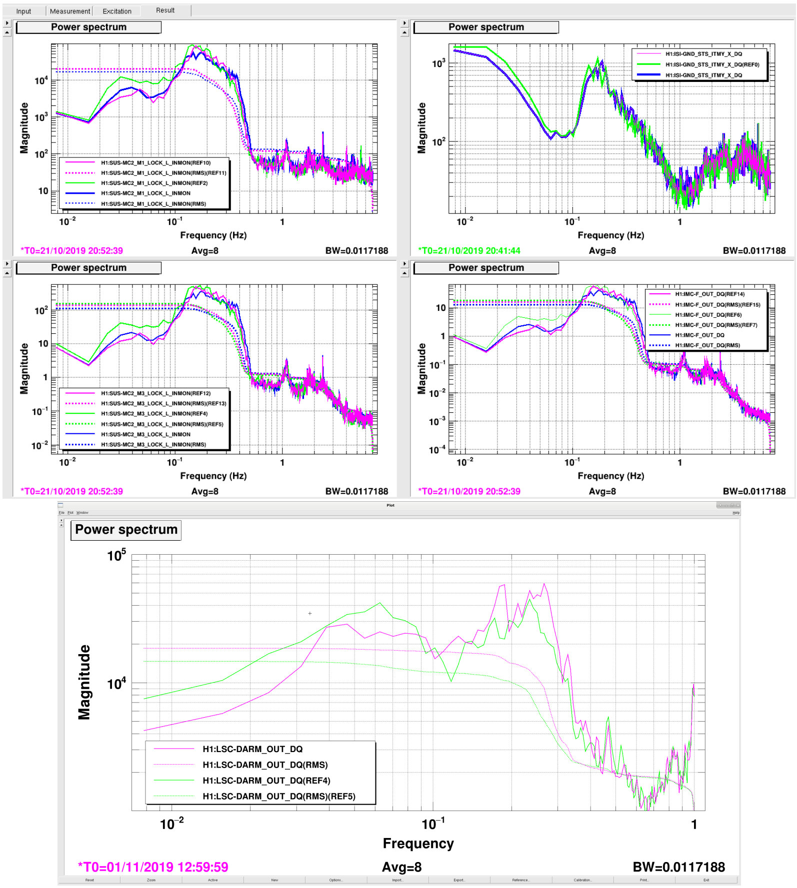

Figure 5: Test of the new ISI configuration. **Up**: test of suspensions and ground behaviour with two different filters (blue and pink traces) in ON configuration. OFF configuration is in green trace. **Down**: test of DARM behaviour in ON (pink trace) and OFF (green trace) configuration.

4 Conclusions

We have shown that it is possible to reduce the ISI motion at low frequencies using the CPS on HAM and BSC chambers. The microseismic range is the frequency band where wind and earthquakes mainly

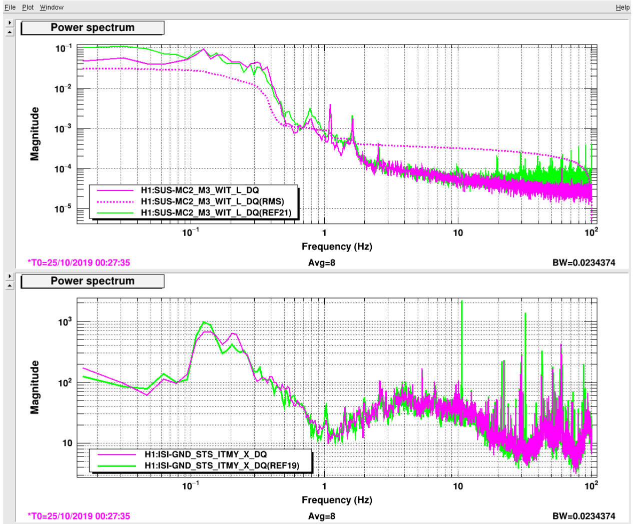

Figure 6: Test of the new ISI configuration with MC2 configuration ON and OFF. The green line is a measurement taken when the MC2 offloading was offline, while the pink trace is online.

affect the interferometer sensitivity. A reduction of this motion will allow also to stabilize PRCL, SRCL and MICH, with further improvements on DARM, and so an enhancement concerning gravitational wave detections.

It can also be seen from LHO logbook posts that this new ISI configuration has helped to lock the interferometer in a shorter time during windy weather conditions.