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Update on h(t) uncertainties during O3

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Contents

1 Abstract

We recently found that uncertainties around 50 Hz during O3, and mainly during O3b, are higher than the 5%/35 mrad given so far. This note summarizes some investigations on this effect.

The estimated uncertainty on Virgo $h(t)$ is concluded to be, in the range 20 Hz to 2 kHz:

- $\pm 5\%$ in amplitude
- ± 35 mrad in phase
- $\pm 10\,\mu$s in timing

EXCEPT in the range 46 Hz to 51 Hz:

- during O3a:
  - do not use the range 49.5 Hz to 50.5 Hz
- during O3b:
  - do not use the range 49.5 Hz to 50.5 Hz
  - $\pm 40\%$ in amplitude in the range 46 Hz to 51 Hz
  - ± 600 mrad in phase in the range 46 Hz to 51 Hz

2 Check of overall h(t) uncertainties with hardware injections

The weekly averaged h_{raw}/h_{inj} transfer functions computed with sinusoidal hardware injections via the electromagnetic (EM) and photon calibrator (PCal) actuators of NE and WE mirrors are superposed in the figure 1, showing only statistical uncertainties. The red lines indicate the frequency-independent band used to estimate uncertainties, at the level 3.5% and 30 mrad.

The data measured every week have shown some time variability, estimated to be below 1% in modulus and 6 mrad in phase.

On top of these averages and bands, we add some systematic uncertainties coming from uncertainties on the actuator used for the hardware injections (2.6% from difference between photon calibrator and free swinging Michelson techniques) and from the time variations of the measurement itself.

3 Effects in the band 46-51 Hz

Two different errors on h(t) have been found: (i) one at 50 Hz, related to the main power lines and the online loop setup during O3 for its subtraction in DARM, and (ii) one in the band 46-51 Hz related to the online loop setup between O3a and O3b to damp some mechanical resonances of the suspensions at 48 Hz. It was first seen analysing the Newtonian calibrator (NCal) O3b data [1] and confirmed with further analysis of injections done with PCal and EM actuators [2].

Data with broad-band noise injections via the different actuators have been used. Two kind of analysis have been done:

1. compute the ratio h_{rec}/h_{inj}, similar as in previous section but over all frequencies,
2. compute FFTs of h_{rec} over the duration of the injections.

3.1 Ratio h_{rec}/h_{inj}

Figure 2 shows the result of analysis 1 for injections done with NE mirror electromagnetic actuators, during O3a (left) and O3b (right). Data from different weeks are shown in different colors. The results are similar when using other end mirror actuators.

One can see that, during O3a, only a few bins around 50 Hz are not within the red lines, mainly due to a lack of coherence between h_{rec} and h_{inj}.

During O3b, an additional effect appeared, with a bias in modulus and phase on a larger frequency band, which reach 40% in modulus and 600 mrad in phase (top right plot). From the zoom at the bottom-right, one can see that the bias exceeds the standard limits between 46 Hz and 51 Hz.

3.2 Long FFTs of h(t)

Figure 3 shows the FFTs of different h signals during a broad band noise injection using the WE PCal during O3b (such injections were not done during O3a). The reconstructed signal before subtraction of the hardware injection (red curve) matches the hardware injection level (green curve). The final h_{rec} channel (blue curve) is computed after subtraction of the hardware injection.

Some structure is seen around 50 Hz, and a zoom is shown in the right plot:

- some differences between the injected (green) and reconstructed (red) signals are seen in the range 46 to 51 Hz, which is consistent with the measurements shown in previous section during O3b.
- at 50 Hz, there is a hole in the reconstructed signal while some signal is injected via the WE PCAL actuator: the signal at this frequency is suppressed by about a factor 10 by the 50 Hz feedfoward loop setup during O3.

A similar analysis has been done using broadband noise injections via the NE EM actuator, both during O3a and O3b. The results are shown in figure 4. The same conclusions can be drawn from the O3b injection (right plots).

During O3a (left plots), the signal at 50 Hz, within less than 0.1 Hz, is suppressed, as during O3b, but no weird effect is seen in the larger 46 to 51 Hz band.

Similar tests, done with the NCal, can be found in [1, 2].

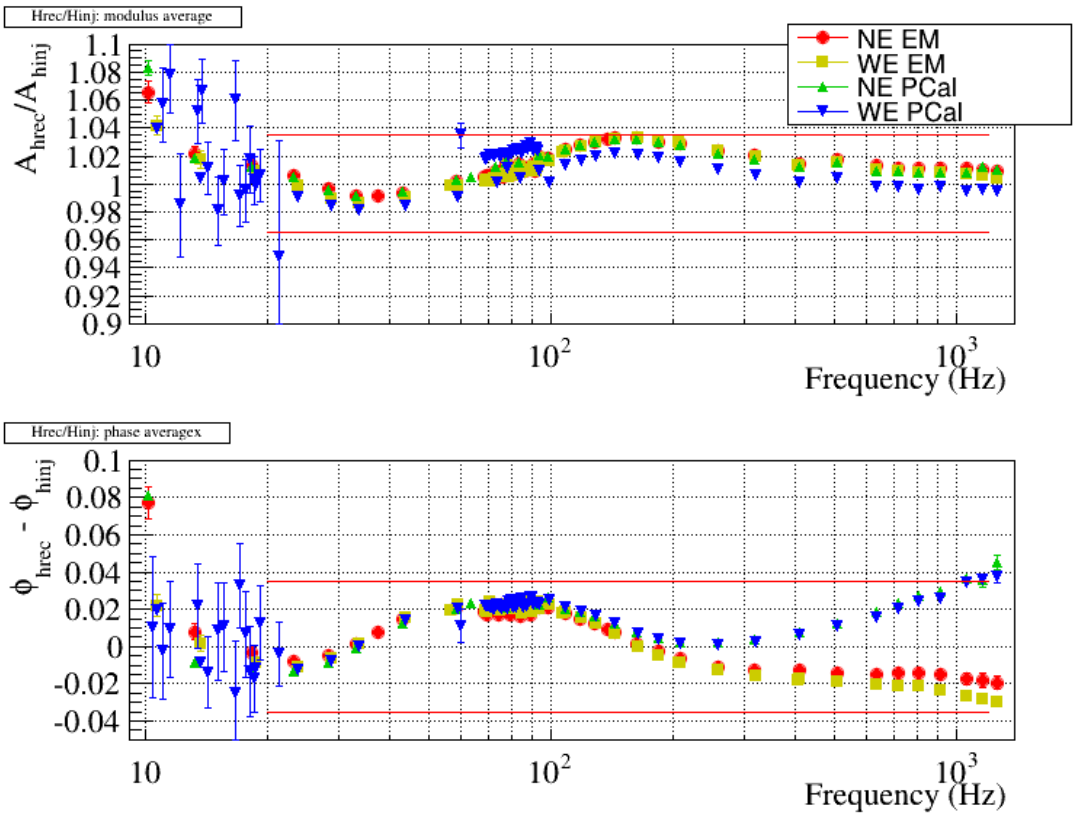
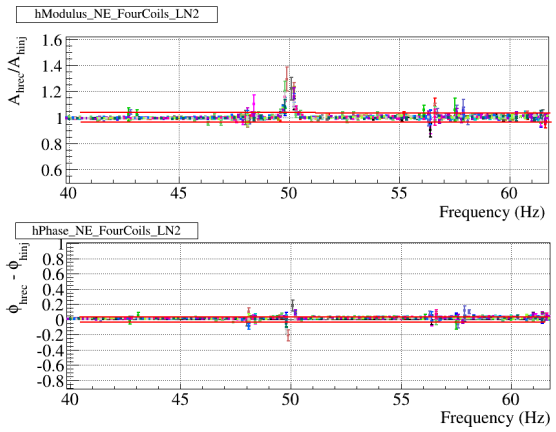
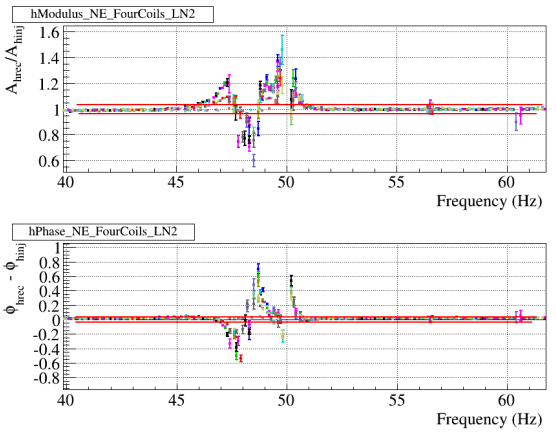


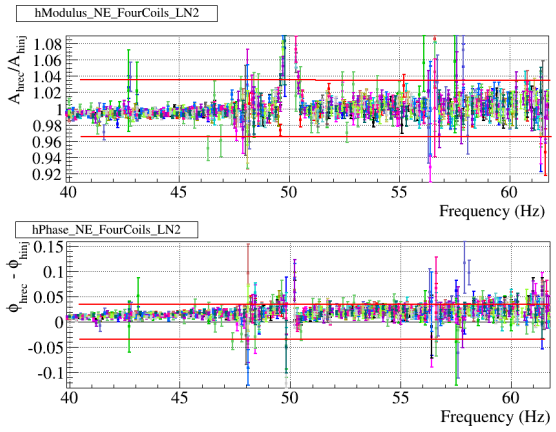
Figure 1: Superposition of the weekly averaged h_{raw}/h_{inj} transfer functions measured with different injections on NE and WE EM and PCal actuators. The red lines indicate the bands that are used to estimate the $h(t)$ uncertainties.



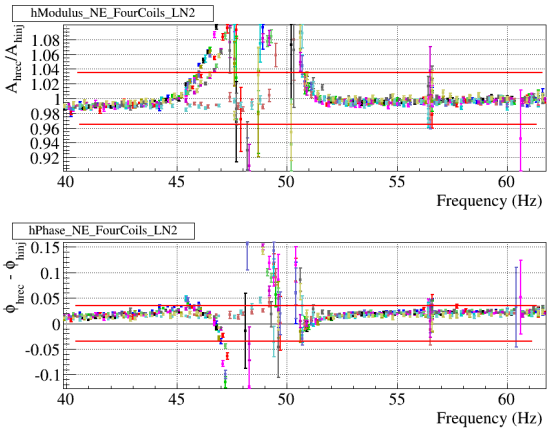
(a) O3a, injections with NE EM actuator



(b) O3b, injections with NE EM actuator

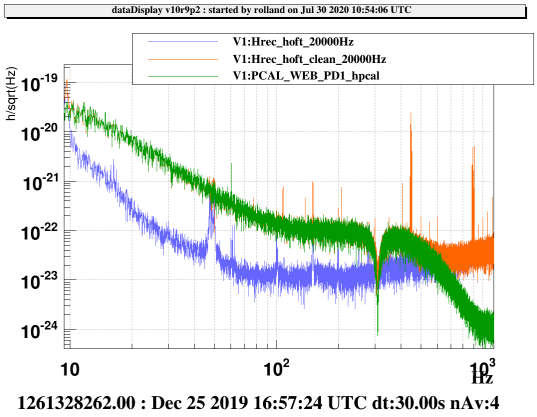


(c) O3a, injections with NE EM actuator: zoom

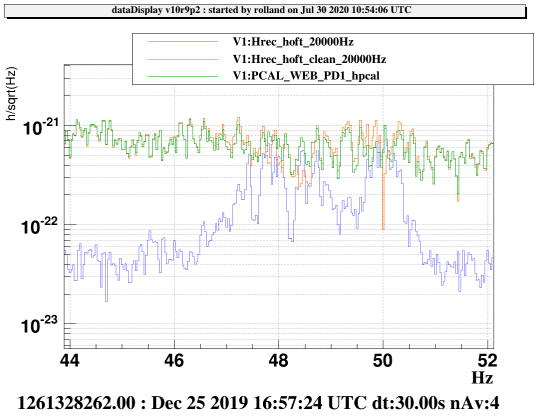


(d) O3b, injections with NE EM actuator: zoom

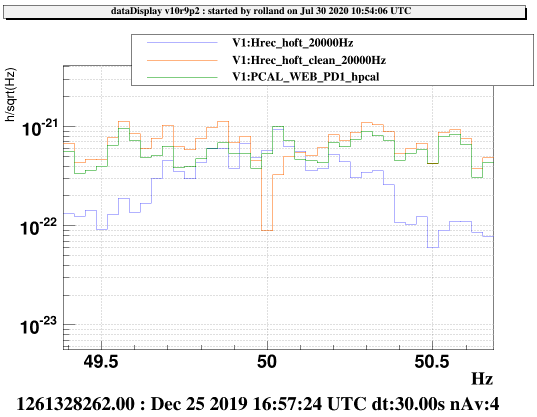
Figure 2: Comparison of the reconstructed raw $h(t)$ vs the $h(t)$ injected with the NE EM actuator, zoomed in the band 40 to 60 Hz. Left: during O3a. Right: during O3b. Top: full y-scale. Bottom: zoom on y-scale. Weekly measurements shown in different colors.



(a) Full band.

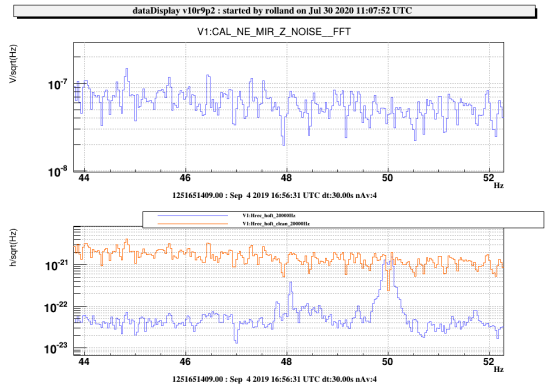


(b) Zoom around 44-52 Hz

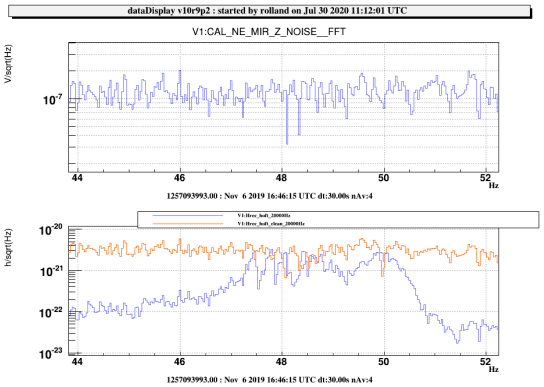


(c) Zoom around 50 Hz

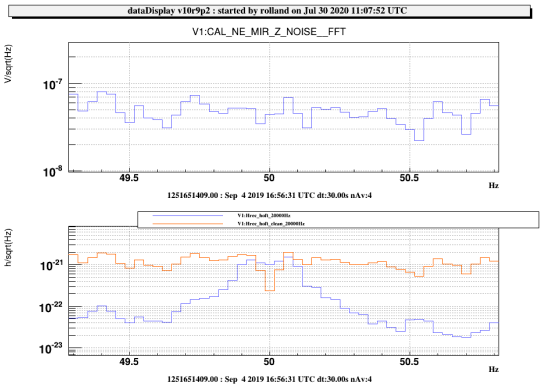
Figure 3: Boadband injections with WE Pcal actuator during O3b (GPS 1261328217): 30 s long FFTs average over 1 minute. The green curve shows the injected signal h_{inj}. The red curve shows the reconstructed "clean" signal $h_{rec,clean}$ after noise subtraction but for hardware injections. The blue curve shows the final reconstructed signal h_{rec} after subtraction of the hardware injections.



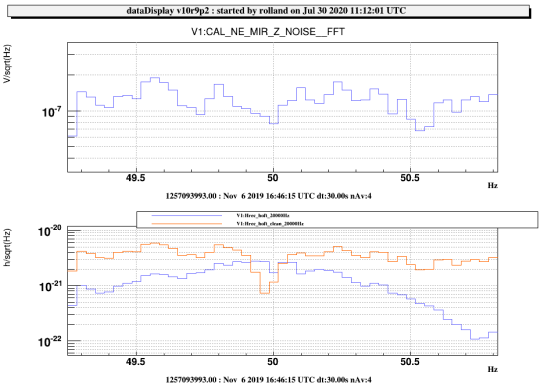
(a) O3a, zoom around 44-52 Hz



(b) O3b, Zoom around 54-52 Hz



(c) O3a, zoom around 50 Hz



(d) O3b, Zoom around 50 Hz

Figure 4: Boadband injections with NE EM actuator during O3a (left, GPS 1251651364) and O3b (right, GPS 1257093948). 30 s long FFTs average over 1 minute. The red curve shows the reconstructed "clean" signal $h_{rec,clean}$ after noise subtraction but for hardware injections. The blue curve shows the final reconstructed signal h_{rec} after subtraction of the hardware injections.

References

[1] T. Pradier *et al.*, "O3 ncal investigations," *Virgo note*, vol. VIR-0604A-20, July 2020.

[2] L. Rolland *et al.*, "About the h(t) uncertainties around 48 hz during o3," *Virgo note*, vol. VIR-0683A-20, July 2020.