Comparison of band-limited RMS of error channel and calibrated strain in LIGO S5 data

Philip Charlton, Charles Sturt University,
for the LIGO Scientific Collaboration

1. Background

Many LIGO data analysis pipelines use either the AS_Q or DARM_ERR channels as the data source and use a response function *R(f)* to convert to strain in the frequency domain. An alternative is to use time-domain calibrated strain *h(t)*. In the current LIGO science run (S5), strain data is being published typically within half an hour of the raw data being produced, making it a viable alternative for near real-time analysis. This poster examines the quality of some representative calibrated strain data by calculating the band-limited RMS (BLRMS) difference between *h(t)* and strain $h^{DE}(t)$ calculated directly from DARM_ERR in the frequency domain.

2. Band-limited RMS norm

For a signal *x(t)* define the band-limited RMS norm weighted by $S_h(f)$ as

$$\|x\| = \sqrt{4\int_{f_0}^{f_1} \frac{|\tilde{x}(f)|^2}{S_h(f)}\,df} \qquad (1)$$

$\tilde{x}(f)$ – Fourier transform of $x(t)$
$S_h(f)$ – 1-sided power spectral density
f_0 – lower frequency limit (50 Hz)
f_1 – upper frequency limit (5000 Hz)

Since *h(t)* and $h^{DE}(t)$ differ at low frequencies where the LIGO noise spectrum is dominated by seismic contributions, the advantages of using the BLRMS are that we can

1. Restrict the comparison to frequencies in the sensitive band of the interferometer;
2. Weight the frequencies by the inverse power spectral density so that differences in each frequency bin contribute relative to the average noise power in that bin.

3. Quality measure

For a segment of data limited to a finite time interval, the figure of merit we will calculate is

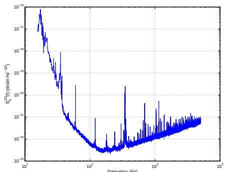
$$z = \frac{\|h^{DE} - h\|}{\|h^{DE}\|} \qquad (2)$$

In other words, we want to see how the the two estimates of strain differ compared to the overall magnitude of $h^{DE}(t)$ with respect to the BLRMS norm.

4. Sample data

The sample data set examined was chosen from S5 "playground" data in the GPS time range 818090523-822785813 (roughly Dec 8 2005 to Jan 31 2006). A data quality cut was made to remove data which was less then 30s from lock loss, and data where calibration lines were known to have dropped out was also removed. The remaining ~75 hours of data was broken down into segments of length 256 seconds from which a power spectral density was estimated from *h(t)* via Welch's method. The relative BLRMS differences *z* were then calculated for data in 16-second segments (~20 000 for each interferometer).

5. Processing pipeline



2. Calculate $S_h(f)$ from *h(t)*

strain *h(t)*

DARM_ERR *e(t)*

256 seconds

16 s

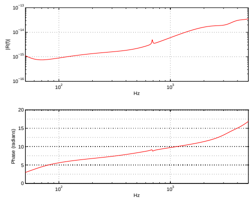
$\tilde{h}_{(1)}(f)$, $\tilde{h}_{(2)}(f)$, …, $\tilde{h}_{(16)}(f)$

$\tilde{e}_{(1)}(f)$, $\tilde{e}_{(2)}(f)$, …, $\tilde{e}_{(16)}(f)$

$\tilde{h}^{DE}_{(1)}(f) = R_{(1)}(f)\tilde{e}_{(1)}(f)$
$\tilde{h}^{DE}_{(2)}(f) = R_{(2)}(f)\tilde{e}_{(2)}(f)$
$\tilde{h}^{DE}_{(16)}(f) = R_{(16)}(f)\tilde{e}_{(16)}(f)$

$z_{(1)}$, $z_{(2)}$, …, $z_{(16)}$

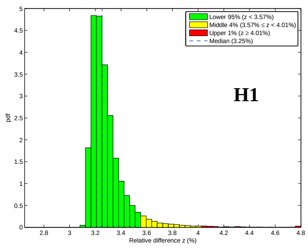
1. Break playground data for each channel into 256s intervals
3. Break interval into 16s segments
4. Window, Fourier transform and mask calibration lines
6. Apply *R(f)* to DARM_ERR segments
7. Calculate *z* values

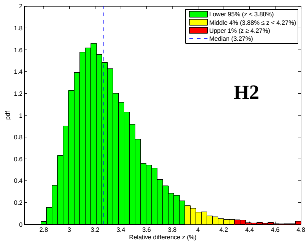


5. Construct response function *R(f)* for each segment:

$$R_{(k)}(f) = \frac{1+\gamma_{(k)}[C_0(f)R_0(f)-1]}{\gamma_{(k)}C_0(f)} \qquad (3)$$

$C_0(f)$ – sensing function
$R_0(f)$ – reference response
$\gamma_{(k)}$ – open loop gain at the start of the k^{th} segment





6. Results

The accompanying histograms show the empirical PDF of *z* for each interferometer (H1, H2 at Hanford, WA; L1 at Livingston, LA). The green areas show that the bulk of the differences were around 3%. Red areas indicate the largest 1%.

H1: Range 2.87–16.8%; median 3.25%; 99th percentile ~ 4.0%†
H2: Range 2.67–6.2%; median 3.27%; 99th percentile ~ 4.3%
L1: Range 2.05–5.7%; median 2.74%; 99th percentile ~ 3.1%

Of the the three interferometers, the range of strain differences was by far the greatest in H1, although only 13 values (< 0.08%) were above the H2 maximum of 6.2%.

†One large outlier of 203% for H1 was excluded. It is likely this is indicative of a calibration line dropout that may not be included in current data quality cuts.