Editorial comment February 25, 2008

In this file is a collection of the reports written on situ measurements of the up-conversion. The measurements have been carried out by a trick invented by Rana in which the test masses are driven sinusoidally at low frequency sequentially. The technique allows the interferometer to remain in lock and causes only small perturbations in the operating point of the interferometer.

The data shows the usual $1/f^4$ up-conversion spectrum and now identifies the up conversion as a function of the test mass. The scaling of the in-situ measurements to the quiescent spectrum involves the convolution of the quiescent coil drive current spectrum with $1/((f-f_0) * f^3)$ using the measured up-conversion scaling from the in-situ measurements. Another estimate comes from the data of the Barkhausen noise experiment with the assumption that the PAM/control magnet spacing was 8mm (using the point dipole approximation).

Once PAM/control magnet spacings, at least for the ITM at both LLO and LHO had been measured, it became clear that the point dipole approximation is not correct although I did use it in the earlier reports.

The last report uses the finite dipole calculation which gives good agreement between the measurements and the scaling of the up-conversion as due to Barkhausen noise.

Analysis of In-Situ Upconversion Measurements On the Test Masses at LLO and LHO

R. Weiss November 23, 2007

Summary: A new technique to excite the up-conversion in the test masses was devised by Rana Adhikari and applied to the test masses at LLO and LHO. The technique involves driving an ETM with motions of HEPI (at LLO) and PEPI (at LHO) at 1.37Hz with an amplitude comparable to the quiescent rms motion of the test mass. A resonant gain filter tuned to the drive frequency is inserted into the control loop of any one of the four test masses in such a manner that all the control current at the drive frequency is fed to a chosen mass. The technique keeps the interferometer in lock while simultaneously transferring the servo control current at 1.37 HZ to each of the test masses in turn.

The intent of the experiment is to determine the amount of up-conversion contributed by the individual masses to allow an assessment of whether it is sensible to replace only the magnets of the ETM. The contribution is dependent on the spacing of the PAM and control magnets and on the amount of control current in the coils. The results of the measurement are:

1) Although there are variations in the up-conversion between the different test masses at both LLO and LHO, the contributions from the ITM are small enough, given that the quiescent control currents are much smaller in the ITM than in the ETM, that it is safe to only change the magnets on the ETM. It may be useful to look at the PAM magnets on the LHO ITMY.

2) The direct measurement of the upconversion shows:

a) the upconversion amplitude spectrum is close to proportional to the 3/2 power of the control current

b) the upconversion spectrum varies as approximately $1/f^4$

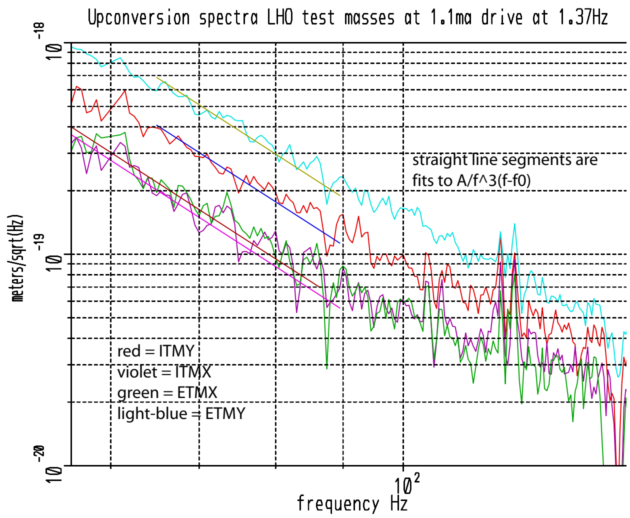
c) the up-conversion noise is a major component, if not responsible, for the current interferometer performance between 40 to 90 Hz.

d) within the uncertainties of the apparatus parameters, the bridge and the in-situ measurements are consistent with each other.

Results: The upconversion spectra for both LLO and LHO are shown in **Figures 1a** and **b .** The figures show the difference between the calibrated DARM_ERR with and without drive to HEPI or PEPI for each of the test masses. The straight line segments superposed on the spectra are fits to the function

$$x(f) = \frac{A}{f^3(f - f_0)}$$

where A is the fitting variable, f_0 is the drive frequency and f is the frequency.



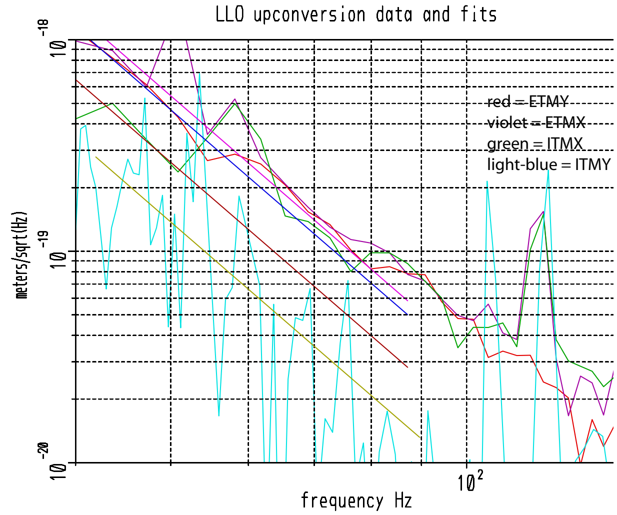


Figure 1a on the left shows the upconversion spectra with 1.1ma rms drive per coil at 1.37 Hz on the test masses at LHO. The test masses on the Y arm have larger up conversion than those on the X arm. **Table 1** gives the fit functions. **Figure 1b** on the right shows the upconversion spectra with between 0.5 to 0.7ma drive (see **Table 1** for details) at LLO. The data looks scruffier as less averaging was done at LLO than at LHO.

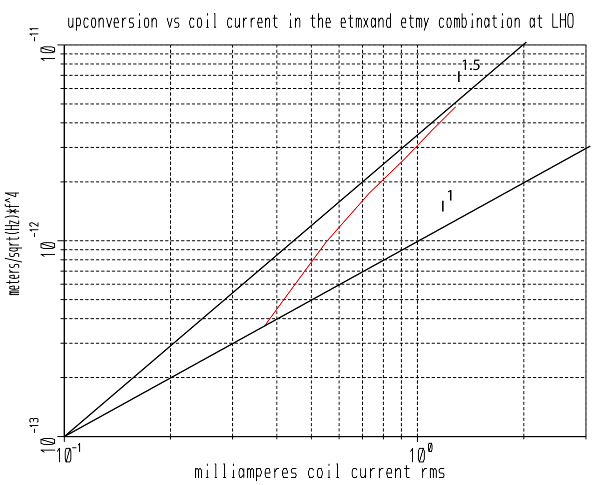


Figure 2 (left) shows the amplitude, A, of the power law fit vs the coil current in the ETM at LHO. The fit is to the difference between the upconversion spectrum and the quiescent spectrum without drive. The raw spectra are distorted by the pitch motion induced in the test masses by the drive which cause the light intensity on the photodetector to increase at frequencies above 100 Hz . The fits to establish the current dependence are made between 40 to 90Hz. In the region of interest for both the quiescent spectra as well as the driven spectra, the upconversion varies more steeply with current than linearly ultimately varying as the current to the 3/2 power. l

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Table 1: Upconversion by the test masses at LHO and LLO when driven at 1.37Hz

test mass	current ma rms/coil	A m*f^4/sqrt(Hz)
LHO ITMX	1.1	$3.5 x 10^{-12}$
LHO ITMY	1.1	$7.1 x 10^{-12}$
LHO ETMX	1.1	$3.8 x 10^{-12}$
LHO ETMY	1.1	$1.2 x 10^{-11}$
LLO ITMX	0.7	$1.6 x 10^{-12}$
LLO ITMY	0.7	$8.4 x 10^{-13}$
LLO ETMX	0.5	$3.4 x 10^{-12}$
LLO ETMY	0.6	$2.8 x 10^{-12}$

up-conversion occurs with the currents in the test masses of LHO Y arm. It will be interesting to see if the PAM magnet-control magnet spacings are consistent with the variations seen in the table and in the **Figure 3a** and **3b**.

Noise projections: Using the data in table 1 and the fact that the quiescent rms currents in LLO = 1.5ma and LHO = 2.1ma, the contribution of up-conversion to the quiescent displacement spectrum at LLO , A = $1.0 x 10^{-11}$, and at LHO, A = $1.7 x 10^{-11}$ meters*f^4 /sqrt(Hz).

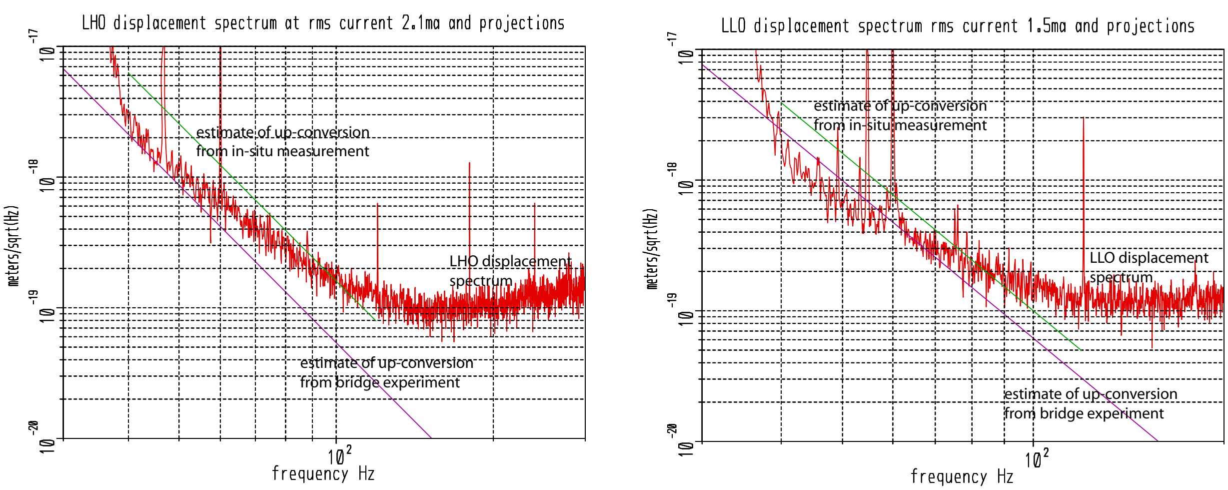


Figure 3a and 3b The quiescent displacement spectra of the LHO and LLO interferometers. The estimates are made by scaling the up-conversion by the 3/2 power of the current and using the $1/f^4$ power law dependence of the up-conversion. The estimate for the bridge experiment assumes one PAM magnet is as close as 0.8 cm to a control magnet. The power law is not correct for the actual spectrum and there are additional noise sources near 100 Hz. Nevertheless, we need to fix this.

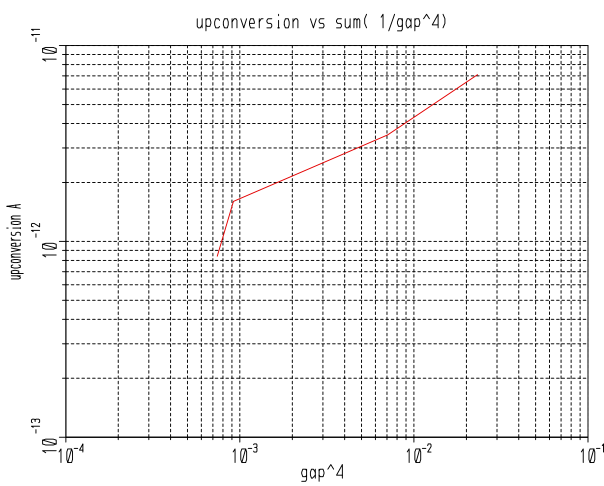
Summary of magnet gap spacing measurements and how they relate to the measured up-conversion
Dec 13, 2007 modified Dec 17, 2007

The gap spacings on the ITMs at Hanford and Livingston are given in **Table 1**

Table 1: Magnet gap spacing in mm

variable	LLO ITMX	LLO ITMY	LHO ITMX	LHO ITMY
UL n =1	7.6 ±0.5	8.9 ±0.5	4.0	2.7
UR n=2	7.6 ±0.5	8.9 ±0.5	5.2	4.2
LL n=3	8.9 ±0.5	7.6 ±0.5	5.6	6.2
LR n=4	8.9 ±0.5	9.5 ±0.5	6.0	6.8
$\sum \frac{1}{gap^4}$	9.2×10^{-4}	7.4×10^{-4}	7.1×10^{-3}	2.3×10^{-2}
Up-conversion in situ measurement	1.6×10^{-12}	8.4×10^{-13}	3.5×10^{-12}	7.1×10^{-12}

The up-conversion is expected to vary as the sum of $1/gap^4$, the sum of the gradients in the field from the PAM magnets. The row labelled up-conversion is the amplitude A of the power law of the up-conversion spectrum measured in situ normalized for the same current in the OSEM coil. If the theory of the up-conversion is to hold up, the entries in the 5th and 6th row of the table should be proportional . The entries grow together but are not proportional.



Note on the Scaling of the Barkhausen noise with PAM/Control Magnet Spacing
R. Weiss February 23, 2008

During the meeting presenting the case for the replacement of the magnets I was asked whether the recent measurements of the PAM/control magnet spacings of the ITM at both LHO and LLO were consistent with the Barkhausen noise hypothesis for the up-conversion. I did not answer the question well at the meeting. This note is intended to do a better job.

The question forced a better understanding of the variation of the force between the magnets as a function of their separation. In prior estimates, I assumed the force varied as simply the product of the gradient of the magnetic field of one magnet pushing on the magnetic moment of the other. The magnets were considered as point dipoles and the force varied as the reciprocal fourth power of their separations. With the close magnet spacings measured at LHO, the point dipole approximation fails significantly and it becomes necessary to calculate the magnetic force between the magnets taking into account their 3 mm length. I did this by numerical methods using the Amperian current construction giving the result shown in **Figure 1**.

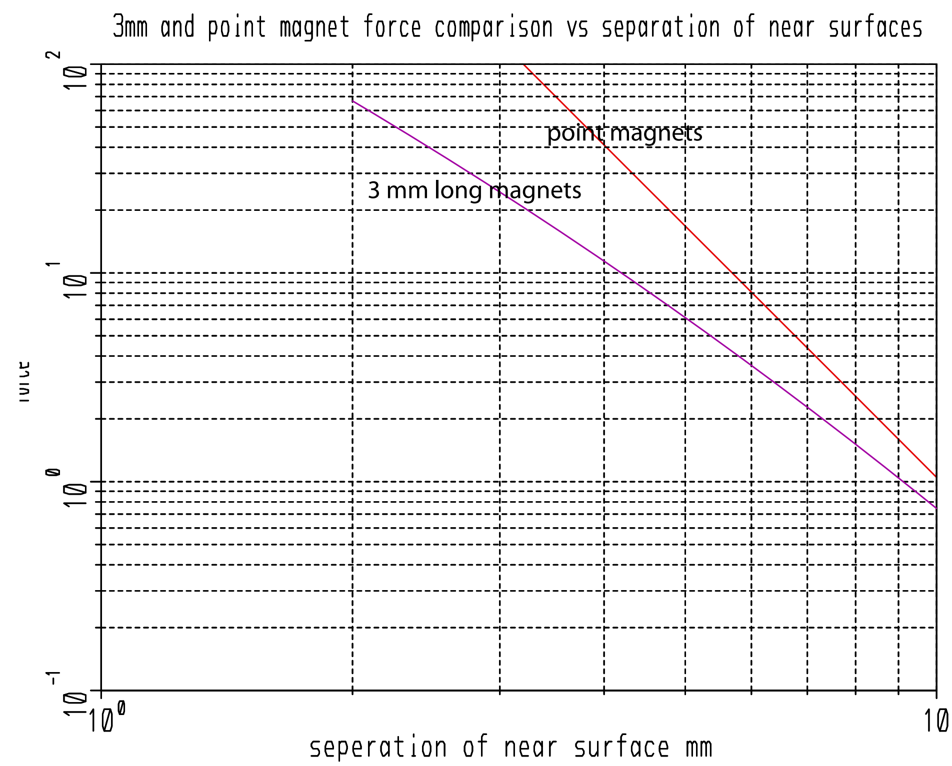


Figure 1 Scaling of the force with separation between 3mm long magnets and the scaling of point magnets.

As one would expect, the point dipole approximation gets better as the spacing of the magnets increases. With spacings as small as 4mm between facing magnet ends, the point dipole approximation is too strong by a factor of 4.

The in-situ upconversion measurements at both LLO and LHO are shown in **Figure 2.** The figure shows the up-conversion occuring at each mass and a power law fit to the up-conversion spectra.

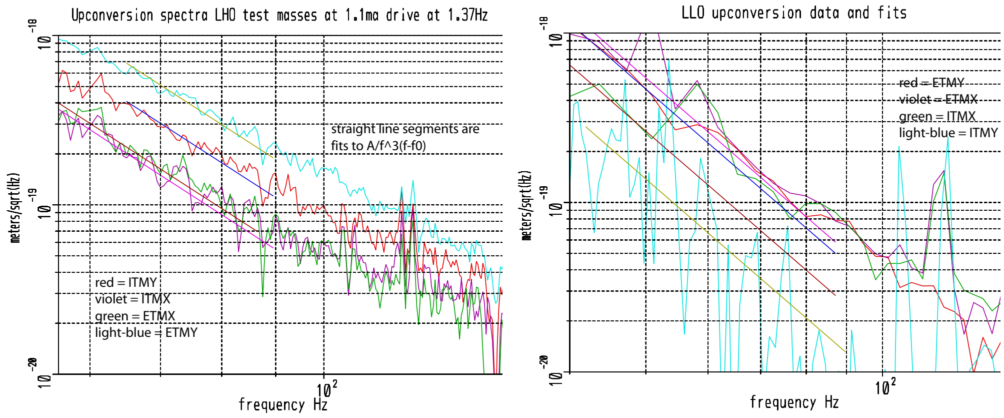


Figure 1a on the left shows the upconversion spectra with 1.1ma rms drive per coil at 1.37 Hz on the test masses at LHO. The test masses on the Y arm have larger up conversion than those on the X arm. **Table 1** gives the fit functions. **Figure 1b** on the right shows the upconversion spectra with between 0.5 to 0.7ma drive (see **Table 1** for details) at LLO. The data looks scruffier as less averaging was done at LLO than at LHO.

Figure 2 (Taken from a report where it had a different figure number)

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LLO ETMX	0.5	3.4 x 10^{-12}
LLO ETMY	0.6	2.8 x 10^{-12}

Table 1 The power law fit values to the up-conversion spectra shown in **Figure 2.**

Table 1: Magnet gap spacing in mm evaluated with 3mm magnets

variable	LLO ITMX	LLO ITMY	LHO ITMX	LHO ITMY
UL n =1	7.6 ±0.5	8.9 ±0.5	4.0	2.7
UR n=2	7.6 ±0.5	8.9 ±0.5	5.2	4.2
LL n=3	8.9 ±0.5	7.6 ±0.5	5.6	6.2
LR n=4	8.9 ±0.5	9.5 ±0.5	6.0	6.8
$\sum F_n$ 3mm magnets	2.98	2.5	12.7	24.2
Up-conversion in situ measurement	1.6×10^{-12}	8.4×10^{-13}	3.5×10^{-12}	7.1×10^{-12}
up-conv/$\sum F_n$	5.3×10^{-13}	3.4×10^{-13}	2.8×10^{-13}	2.9×10^{-13}

The up-conversion is expected to vary as the sum of the terms in figure 1 , the sum of the gradients in the field from the PAM magnets. The row labelled up-conversion is the amplitude A of the power law of the up-conversion spectrum measured in situ normalized for the same current in the OSEM coil. If the theory of the up-conversion is to hold up, the entries in the 5th and 6th row of the table should be proportional as seen in the 7th row.

Table 2 (Again a table from another report) The spacings of the magnets measured at LLO and LHO recently is given in the first 4 rows in mm. The spacing is between near faces of the magnets. The LHO spacings are uncomfortably small and the up-conversion spectra are correspondingly larger than at LLO. The ratio between the up-conversion spectrum to the force between the magnets is close to being the same for all the test masses for which we know the spacing. New evidence will soon come from measuring the magnet spacings at the ends. An earlier version of this table used the point dipole approximation and the ratio of the up-conversion to the estimated force between the magnets (bottom row) was not as well behaved.