KAGRA Actuator Noise Modeling Report

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March 30, 2015

1 Introduction

This report is to summarize the results of actuator noise modeling for the KAGRA suspensions. The modeling was done by using MATLAB Simulink based NoiseBudget scirpt made by Chris Wipf [1].

The main script and the model for the actuator noise modeling are as follows:

- https://granite.phys.s.u-tokyo.ac.jp/svn/LCGT/trunk/kagranoisebudget/Suspensions/run_SAS_NB.m
- https://granite.phys.s.u-tokyo.ac.jp/svn/LCGT/trunk/kagranoisebudget/Suspensions/SAS.slx

You will also need `findNbSVNroot.m`, `myzpk.m`, `plotdobe.m`, and `plotspectrum.m` in the same directroy to run the script.

Although this script works similarly for all suspensions, here I plot the results only for BS (Type-B suspension), since the requirment on the displacement noise is the most stringent other than ITM/ETMs. Actuator design for ITM/ETMs is not fixed yet at this point.

2 Model

The Simulink model is shown together with the transfer functions and noises used for the simulation.

2.1 Simulink model

The actuator noise Simulink model is shown in Fig. ??. We had to use some tricks to simulate out-of-loop stability and feedback signal with Simulink NoiseBudget blocks, `NbNoiseCal` and `NbNoiseSink`. FlexTf is used for suspension transfer functions (light purple blocks) to use frequency response data (`frd`). Seismic noise from vertical coupling is also included in the model.

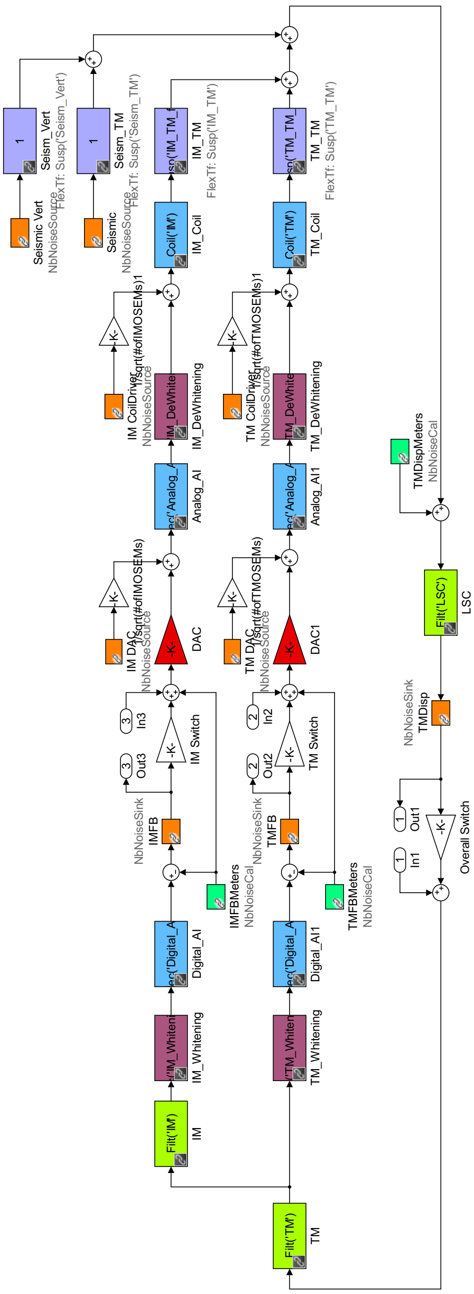

Figure 1: Actuator noise Simulink model.

2.2 Summary of KAGRA Suspensions

KAGRA suspension configurations are summarized graphically in Ref. [2]. For longitudinal degrees of freedom, we basically have actuators for IP (inverted pendulum), IM (intermediate mass), and TM (test mass).

Table 1 is the summary of the actuation for each suspension. Actuation efficiency for a Type-B/Bp coil in N/A is from Ref. [2]. Actuation efficiency for a Type-C TM coil are estimated from the measurement done by T. Saito [4]. The measurement for MCe gives 3.1×10^{-7} m/V at DC, and this gives 5.0×10^{-6} N/V assuming IMC mirror mass to be 0.47 kg and the resonant frequency to be 0.93 Hz. The V-I conversion of coil driver for IMC mirrors is 20 mA/V (50 Ω), so this means the actuation efficiency for a Type-C TM coil is 6.3×10^{-5} N/A.

2.3 Suspension transfer functions

The suspension transfer functions from actuation on IM/TM (from respective recoil masses) to TM displacement are shown below.

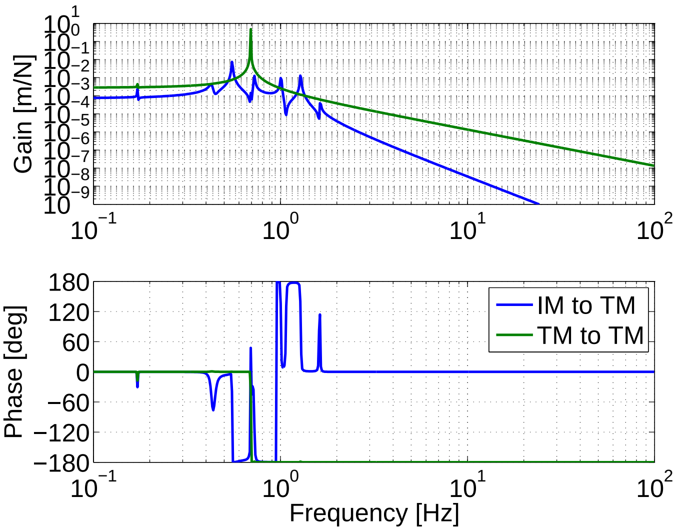

Figure 2: BS suspension transfer functions.

Table 1: KAGRA suspension actuator parameters.

Type	Type-A	Type-B (BS)	Type-B (SR)	Type-Bp	Type-C
Applicable mirrors	ITM,ETM	BS	SRM,SR2,SR3	PRM,PR2,PR3	MCi,MCo,MCe
Mirror diameter	$\phi = 220$ mm	$\phi = 370$ mm	$\phi = 250$ mm?	$\phi = 250$ mm	$\phi = 95.95$ mm
Mirror thickness	150 mm	80 mm	100 mm?	100 mm	29.5 mm
IM actuation/coil [N/A]	??	1.12	1.12	1.12	N.A.
# of IM coils for long.	??	1	1	1	0
TM actuation/coil [N/A]	??	0.129	0.129	0.129	6.3×10^{-5}
# of TM coils for long.	4	4	4	4	4

2.4 Coil drivers

We have two types of coil drivers, the high power one and the low power one. They are basically the copies of LIGO-D0902747 and LIGO-D070481, respectively, but has different dewhitening filters compared with LIGO ones. The high power one and the low power one both have switchable three-stage dewhitening filters with pole @ 1 Hz and zero @ 10 Hz (gain of 1 at DC). In the simulation, all the dewhitening filters are turned on. The high power one is used for IM coils and the low power one is used for TM coils.

V-I conversion factor for each coil driver when all the dewhitening filters are turned off is plotted in Fig. 3. The resistance of the coil is not included here, but it is included in the model (as 13 Ω). The resistances are 80 Ω for the high power one, and 7.8×10^3 Ω for the low power one.

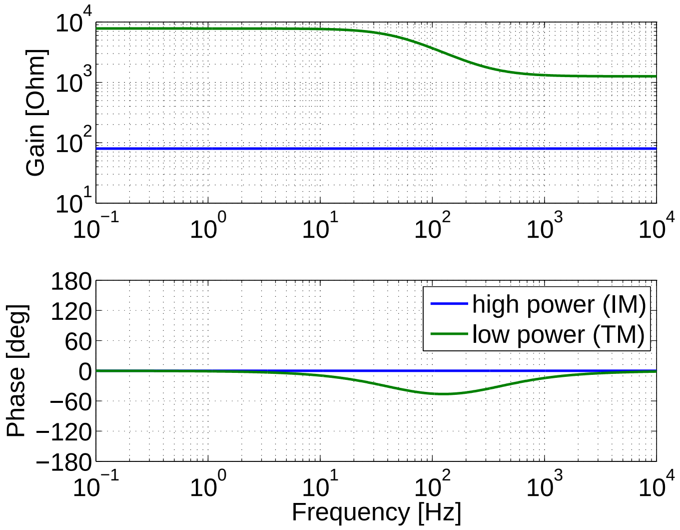

Figure 3: Inverse of V-I conversion factors for high power and low power coil drivers.

Noises of coil drivers used in the model are plotted in Fig. 4, as input equivalent noise to the V-I conversion stage. The numbers come from LIGO-T080014 and LIGO-T0900233.

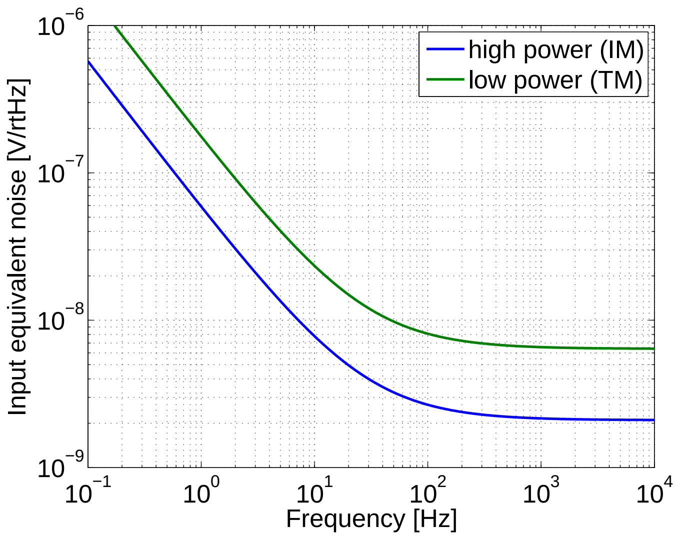

Figure 4: Input equivalent coil driver noise spectra.

2.5 DAC

DAs used for KAGRA is 16 bit and has the range of ±20 V. The DAC noise is plotted in Fig. 5.

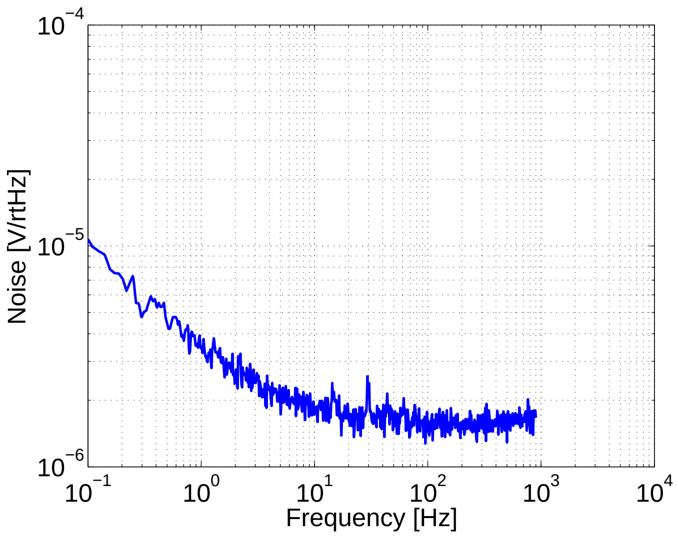

Figure 5: DAC noise.

3 Result for BS

Resulting plots for BS actuator noise modeling are shown.

3.1 Openloop transfer function

The openloop transfer funtion is shown below.

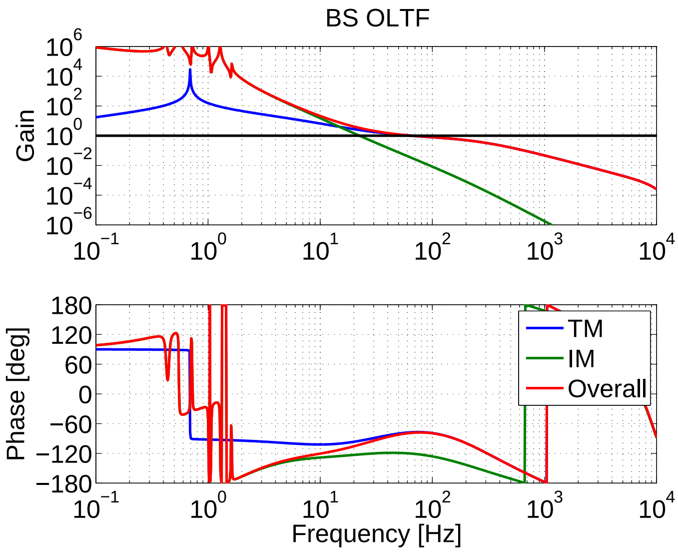

Figure 6: Openloop transfer functions for the BS length servo.

3.2 Noise budget

The displacement noise budget and the actuator noise budget are shown below. The lines labeled "Requirement" show the BS displacement noise requirement in Ref. [5], and the safety factor of 10 is included.

As you can see, the seismic noise and the actuator noise meet the requirement above 10 Hz. The most contributing noise among the actuator noises is the noise from TM coil driver.

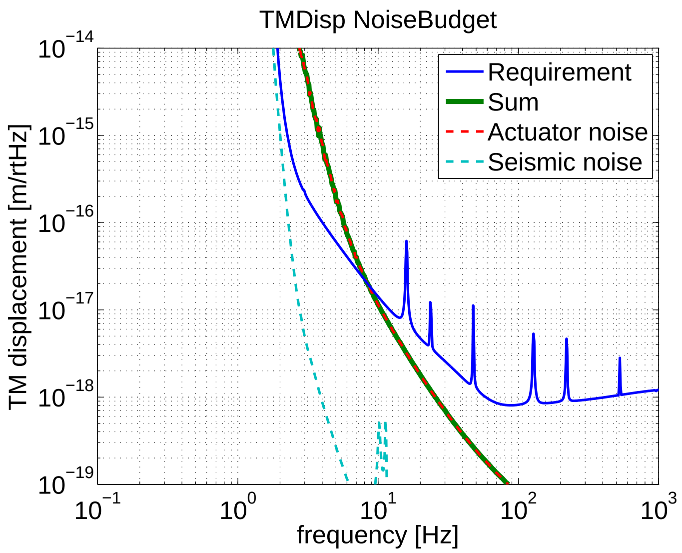

Figure 7: Displacment noise budget for BS.

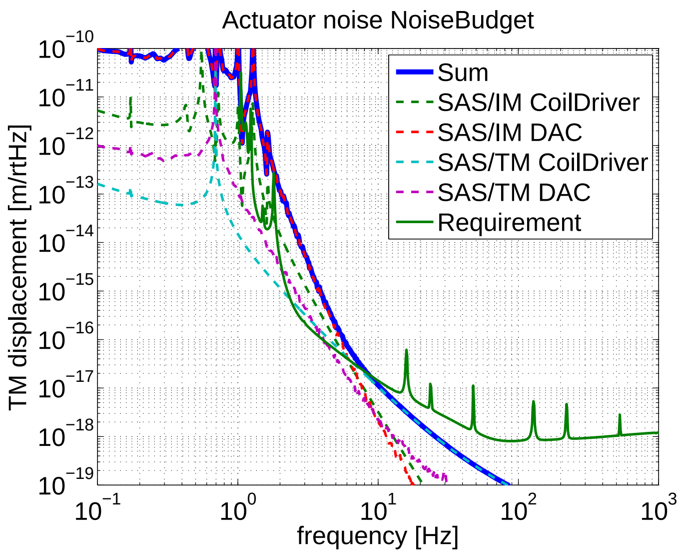

Figure 8: Actuator noise budget for BS.

3.3 Feedback signal saturation check

The spectra of feedback signals for IM and TM are shown in the figures below. The blue lines labeled "DAC limit" shows the DAC range (2^16).

As you can see, RMS of the feed back signals do not exceed the DAC limit.

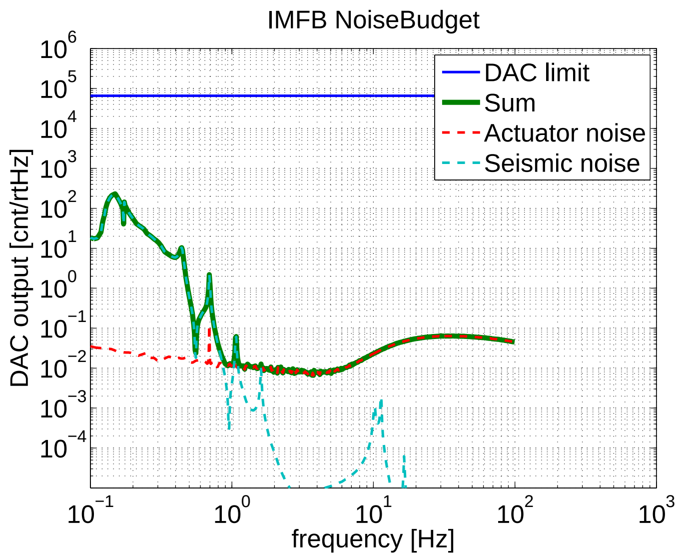

Figure 9: Spectra of feedback signals for the BSIM.

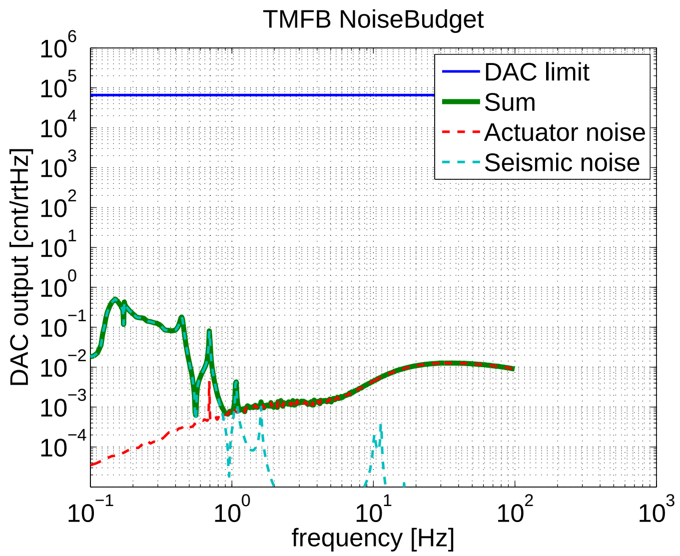

Figure 10: Spectra of feedback signals for the BSTM.

4 Magnetic noise coupling

We also have to check the magnetic noise coupling for the actuation design study. This is given elsewhere (in preparation by Ono-kun), but rough estimate show that the magnetic noise is small enough.

References

[1] The source code is available from
https://svn.ligo.caltech.edu/svn/aligonoisebudget.
Some instructions are given at
https://awiki.ligo-wa.caltech.edu/aLIGO/NoiseBudget.

[2] Yuta Michimura: Summary of Suspension Configurations, JGW-D1503415. http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/DocDB/ShowDocument?docid=3415

[3] Mark Barton: OSEM Coil/Magnet/Flag Calculation, JGW-T1503239, Table 1. http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/DocDB/ShowDocument?docid=3239

[4] Takahiro Saito: Mode-cleaner suspension installation, JGW-G1503303, p.18. http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/private/DocDB/ShowDocument?docid=3303

[5] Yoichi Aso, Yuta Michimura, Kentaro Somiya: KAGRA Main Interferometer Design Document, JGW-T1200913, Figure 4.1 and 4.2. http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/DocDB/ShowDocument?docid=913