KAGRA Frequency Stabilization Servo Modeling Report

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1 Introduction

This report is to summarize the results of KAGRA frequency stabilization servo (FSS) modeling. The modeling was done by using MATLAB Simulink based Noise Budget made by Chris Wipf [1].

The main script and the model for KAGRA FSS modeling are as follows:

- https://granite.phys.s.u-tokyo.ac.jp/svn/LCGT/trunk/kagranoisebudget/FSS/run_FSS_NB.m

- https://granite.phys.s.u-tokyo.ac.jp/svn/LCGT/trunk/kagranoisebudget/FSS/KAGRA_FSS.mdl

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

2 Model

2.1 Simulink model

The KAGRA FSS Simulink model is shown in Fig. 1. We had to use some tricks to simulate out-of-loop stability and feedback signal with Simulink Noise Budget blocks, `NbNoiseCal` and `NbNoiseSink` (see yellow and cyan areas).
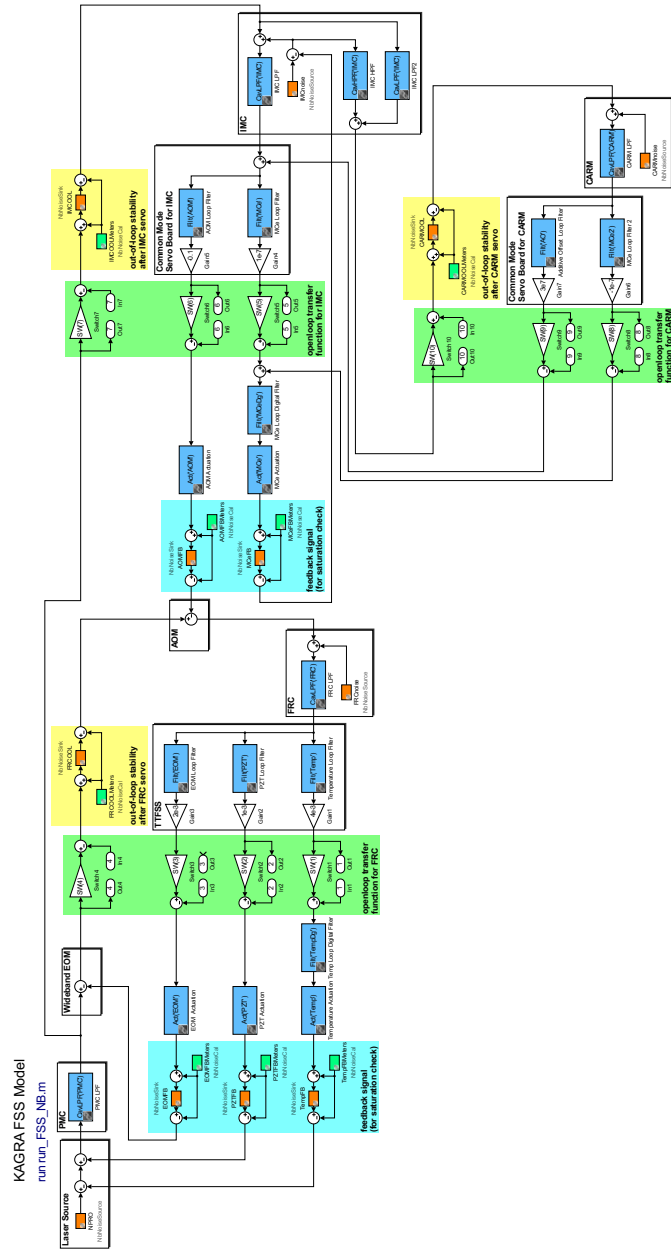
Figure 1: KAGRA FSS Simulink model. When the CARM loop is enabled, the MCe loop in the IMC loop is disabled.

2.2 KAGRA cavity parameters

The round-trip lengths L and finesses $\mathcal{F}$ of KAGRA cavities are summarized in the table below. These parameters are used to calculate the cavity pole

$$f_{\mathrm{cp}} = \frac{c}{2L\mathcal{F}} \tag{1}$$

Table 1: KAGRA cavity parameters. The round-trip length for FRC is multiplied by the refractive index of the fiber ($n = 1.46$).

Cavity	Round-trip length L	Finesse $\mathcal{F}$	Cavity pole f_{c}
PMC	0.4 m	2000?	190 kHz
FRC	1.46×5.8 m	451	39 kHz
IMC	2×26.65 m	500	5.6 kHz
Arms	2×3000 m	1530	16 Hz

2.3 Actuators

The frequency actuators we use for the FSS are summarized in the table below.

Table 2: The frequency actuators for KAGRA. Note that they are rough estimates yet!! MCe actuation efficiency was measured to be 25 μm/V by K. Arai [2].

Name	Detail	Actuation efficiency	Range
Laser temperature	NPRO	3 GHz/V	30 GHz
Laser PZT	NPRO	1 MHz/V	100 MHz
Wideband EOM	Newport 4004	$1.5 \times 10^{-5} \dfrac{if}{1\ \mathrm{Hz}}$ Hz/V	0.6 MHz
AOM	Crystal Technology 3110-197 (with driver 1110AF-AEFO-1.5)	5.3 MHz/V	40 MHz
MCe	Double pendulum	280 MHz/V at DC (on mirror)	?
ETM	7-stage pendulum	?	?

2.4 Filters

The filters are shown in the figures below. Note that the gain scales are arbitrary.
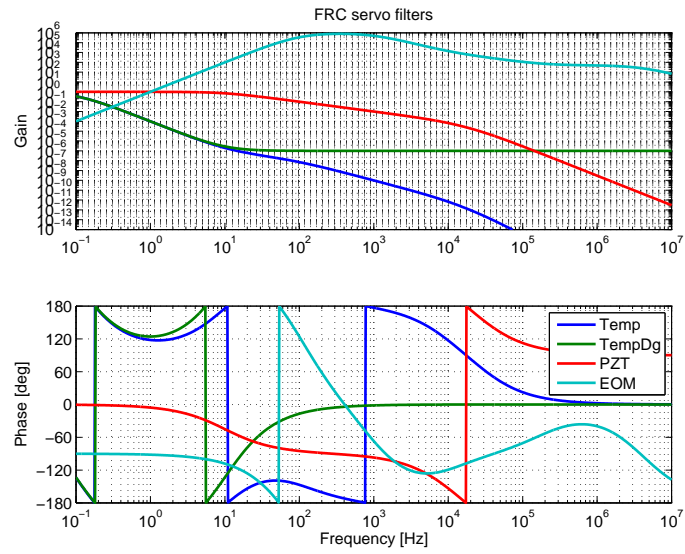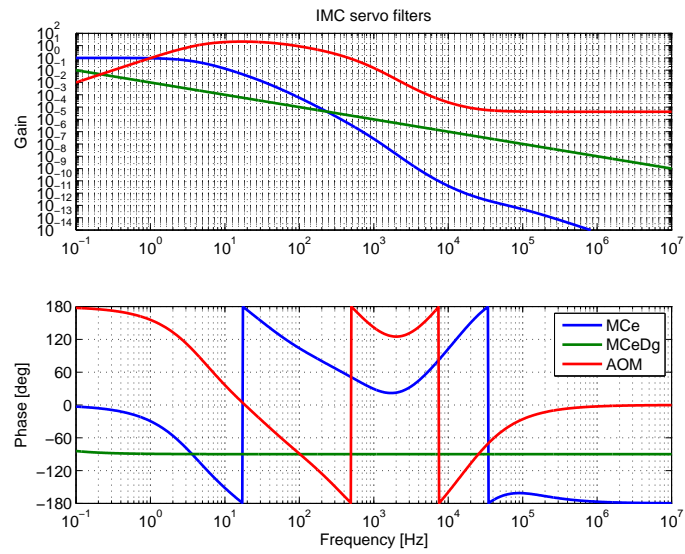
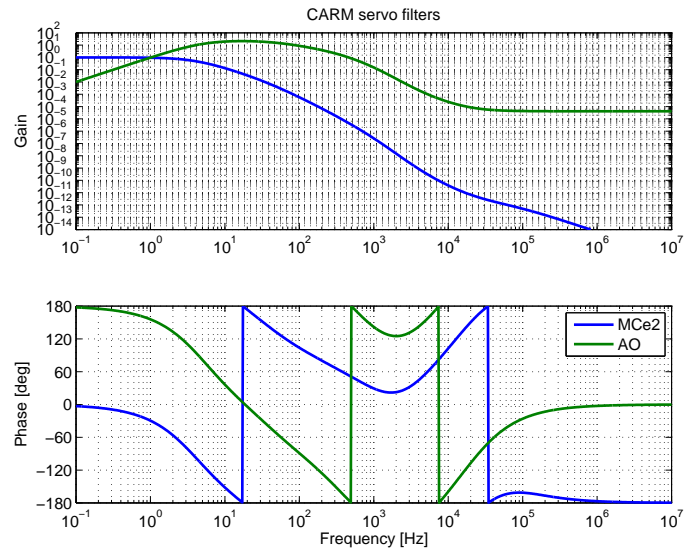Figure 2: Filters for the FRC servo.

Figure 3: Filters for the IMC servo.

Figure 4: Filters for the CARM servo.

2.5   Noises

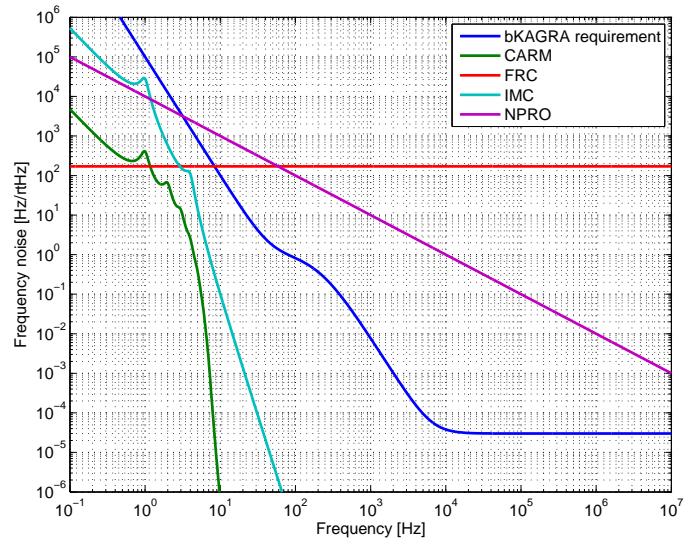The frequency noises of each component are shown in the figure below.

Figure 5: Frequency noises. FRC noise shown here is unrealistic!!

3 Result

3.1 Openloop transfer functions

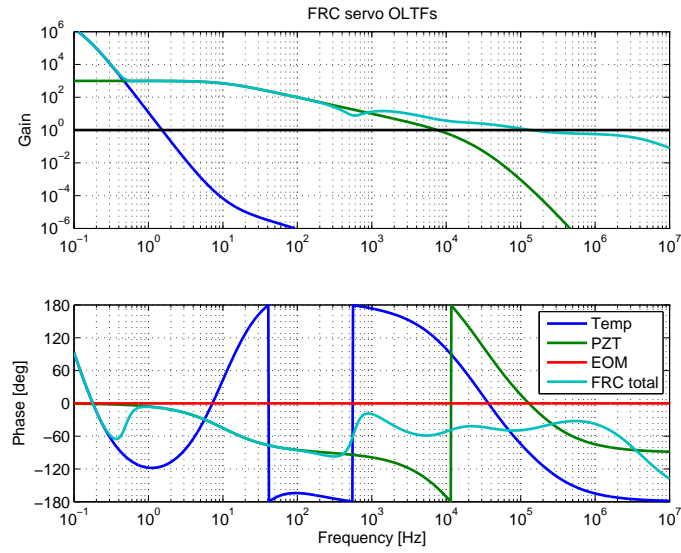The openloop transfer funtions are shown in the figures below.
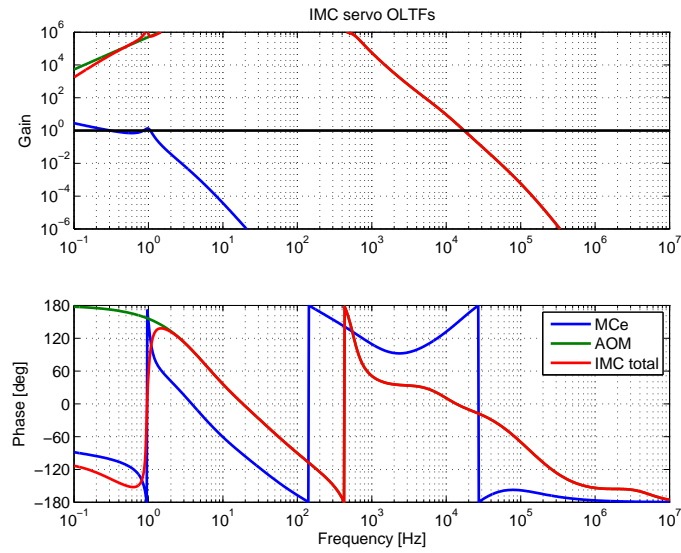

Figure 6: Openloop transfer functions for the FRC servo.

Figure 7: Openloop transfer functions for the IMC servo.
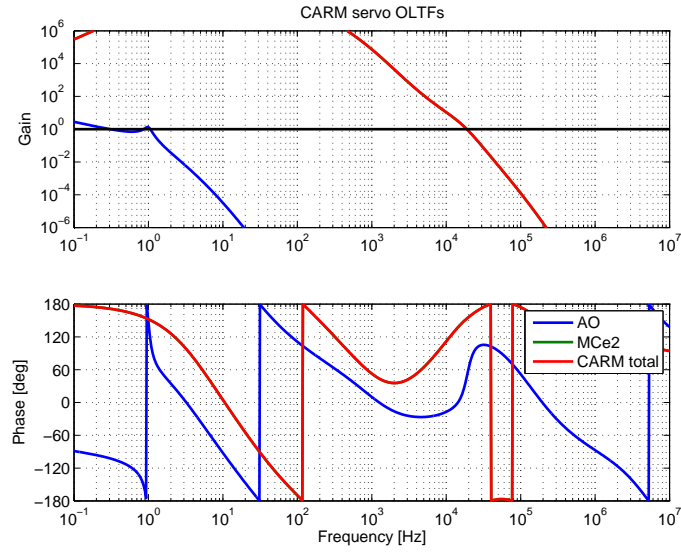
Figure 8: Openloop transfer functions for the CARM servo.

3.2 Out-of-loop frequency stability

The out-of-loop frequency stabilities are shown in the figures below. The stability shown here is the stability when the servos for the next stages are turned off. For out-of-loop stability after the FRC servo, the IMC and the CARM loop is off. For the IMC stability, the FRC loop is on, but the CARM loop is off. When th CARM loop is on, the MCe loop in the IMC loop is disabled.

The blue line labeled "Measured" shows the bKAGRA frequency noise requirement [3].
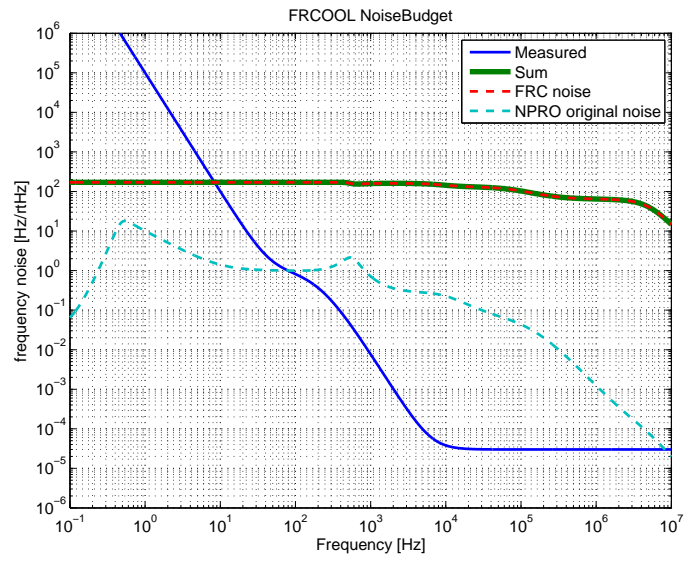
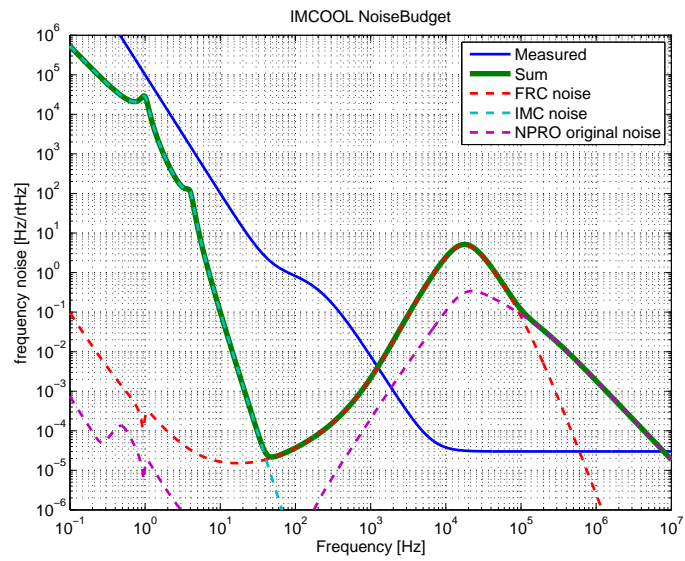Figure 9: Out-of-loop frequency stability after the FRC servo.

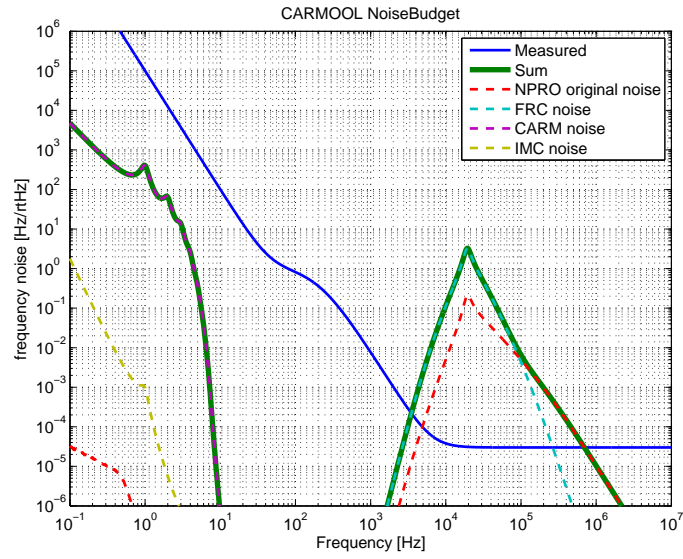Figure 10: Out-of-loop frequency stability after the IMC servo.

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Figure 11: Out-of-loop frequency stability after the CARM servo.

3.3 Feedback signal saturation check

The spectra of feedback signals are shown in the figures below. Check if they are not saturating with your eyeballs.

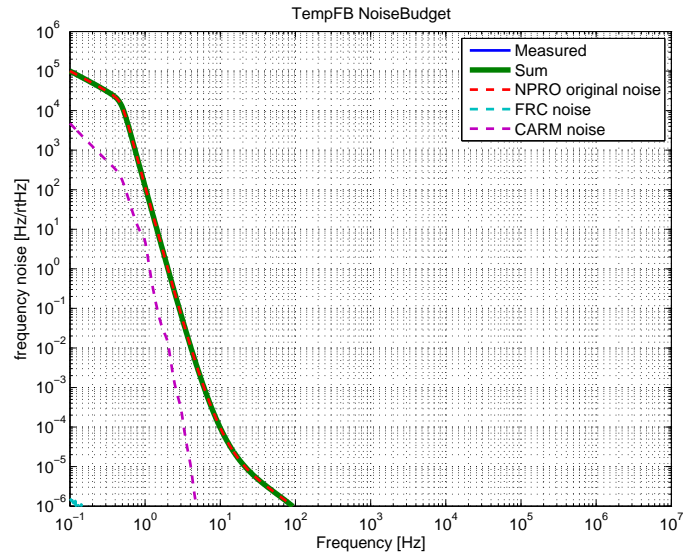The blue line labeled "Measured" shows the actuation range in Hz for each actuator.

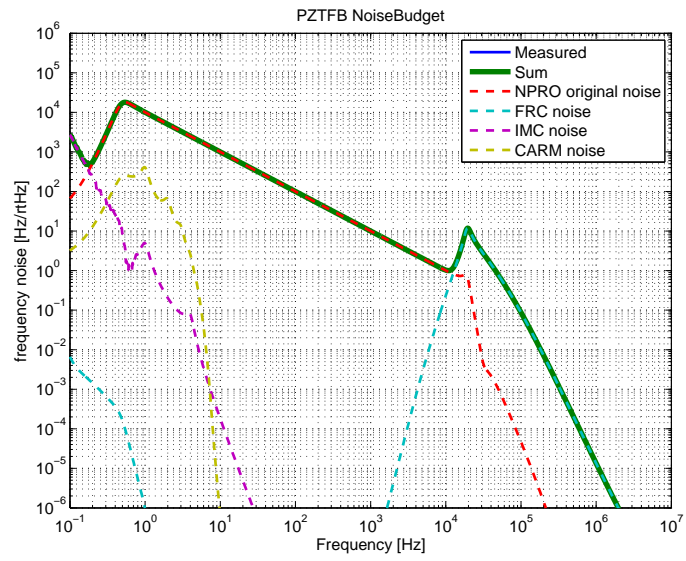Figure 12: Spectra of feedback signals for the Temp.

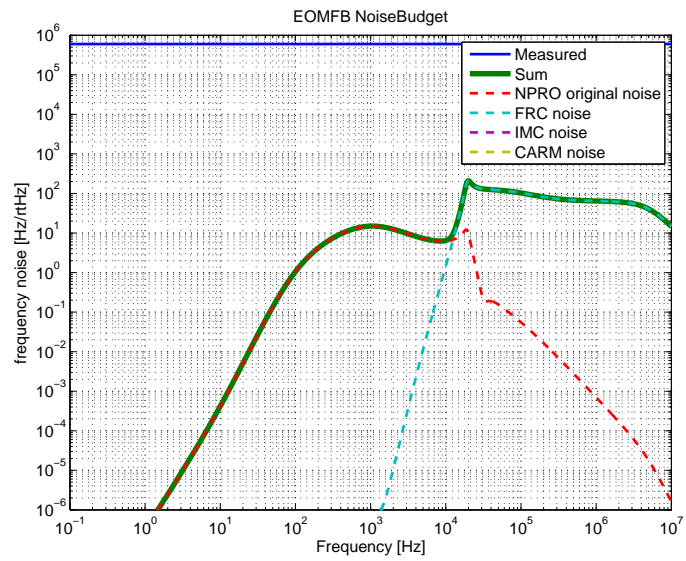Figure 13: Spectra of feedback signals for the PZT.

Figure 14: Spectra of feedback signals for the EOM.
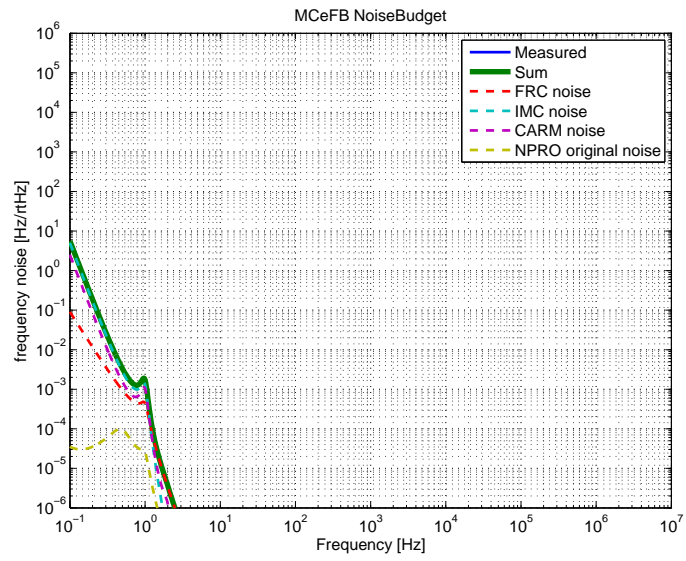
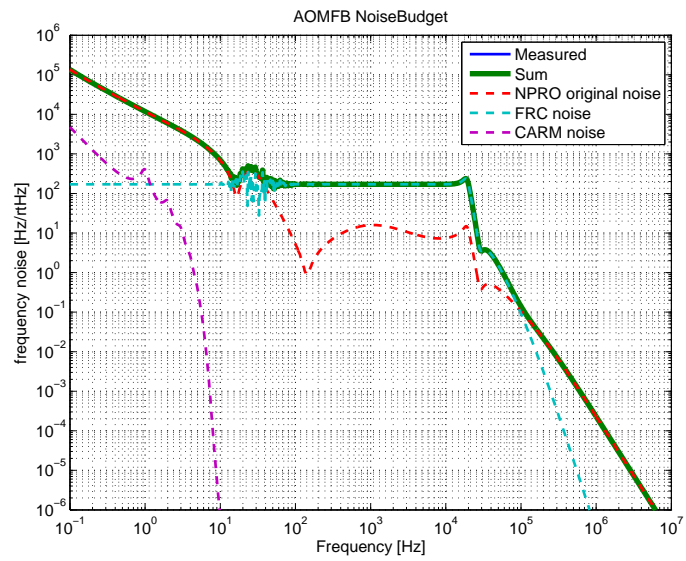Figure 15: Spectra of feedback signals for the MCe.

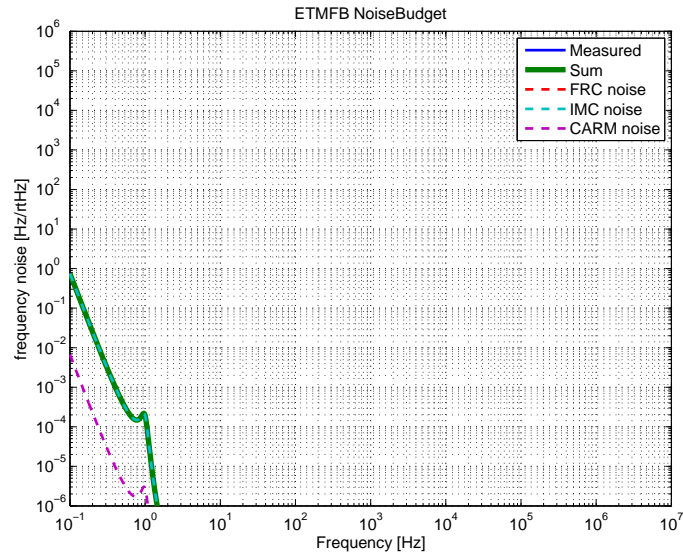Figure 16: Spectra of feedback signals for the AOM.

Figure 17: Spectra of feedback signals for the ETM.

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] Koji Arai, Shuichi Sato, Ryu Takahashi: Mode Cleaner Suspensions
    Transfer Functions.
    http://tamago.mtk.nao.ac.jp/tama/ifo/recycling1/suspension_tf/
    020322_MC/tfMC020322.pdf

[3] Yoichi Aso, Yuta Michimura, Kentaro Somiya: KAGRA Main Interferom-
    eter Design Document, JGW-T1200913.
    http://gwdoc.icrr.u-tokyo.ac.jp/cgi-bin/DocDB/ShowDocument?docid=
    913