TR2: Design of whitening filters for TR2

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1 Introduction

For gravitational wave detection by an interferometric detector, differential length change of the two orthogonal arms is detected as an analog signal and stored by digital devices. Photodetectors transform the intensity of light from the interferometer into photocurrent. The output signal of the photodetector is stored in a storage system by converting the analog signals to sequence of the digital numbers.

The whitening filters are important circuits to prevent from contaminating the acquired signals by noise and overflow of the Analog-To-Digital converter. The previous whitening filters for TAMA300 δL_- signal have been designed and tested on the fifth Data Taking (DT5, 2001/3/2∼8). These are called "WTF#1" and "WTF#2". The design priciples and the performances of the whitening filters have been described in the earlier documents [1, 2].

In the ongoing power-recycling experiment, the noise level of the interferometer was temporarily degraded. Therefore the whitening filters for Test Run 2 (TR2, 2002/5/9∼10) had to be modified in order not to hit the range of the HDAQ input. In this document, the circuit of the modified filters, measured transfer functions, and the result of the transfer function indentification are described.

2 Circuit

The circuit diagram of the whitening filter is shown in Figure. 1. With the current voltage level of the detector output, many range-over of the HDAQ Channels were observed. are input (±5V at the input of the HDAQ differential driver). Since there was no saturation observed in the whitening filters themselves, only the gain of the output stage has been reduced from ×51 to ×5.1. Since the input noise level of WTF#1 and WTF#2 are very good ($2 \sim 3\mathrm{nV}\sqrt{\mathrm{Hz}}$) and determined by the first two stages, this modification did not changed the noise levels of these filters.

3 Transfer function

After the modification of the filters, the gain matching at 625Hz were perfomed again. Also, the transfer funcitons of the filters were measured again.

In order to simplify the calibration process, the gains of the two whitening filters must be adjusted to be same as far as possible. The difference of the gains measured by an FFT

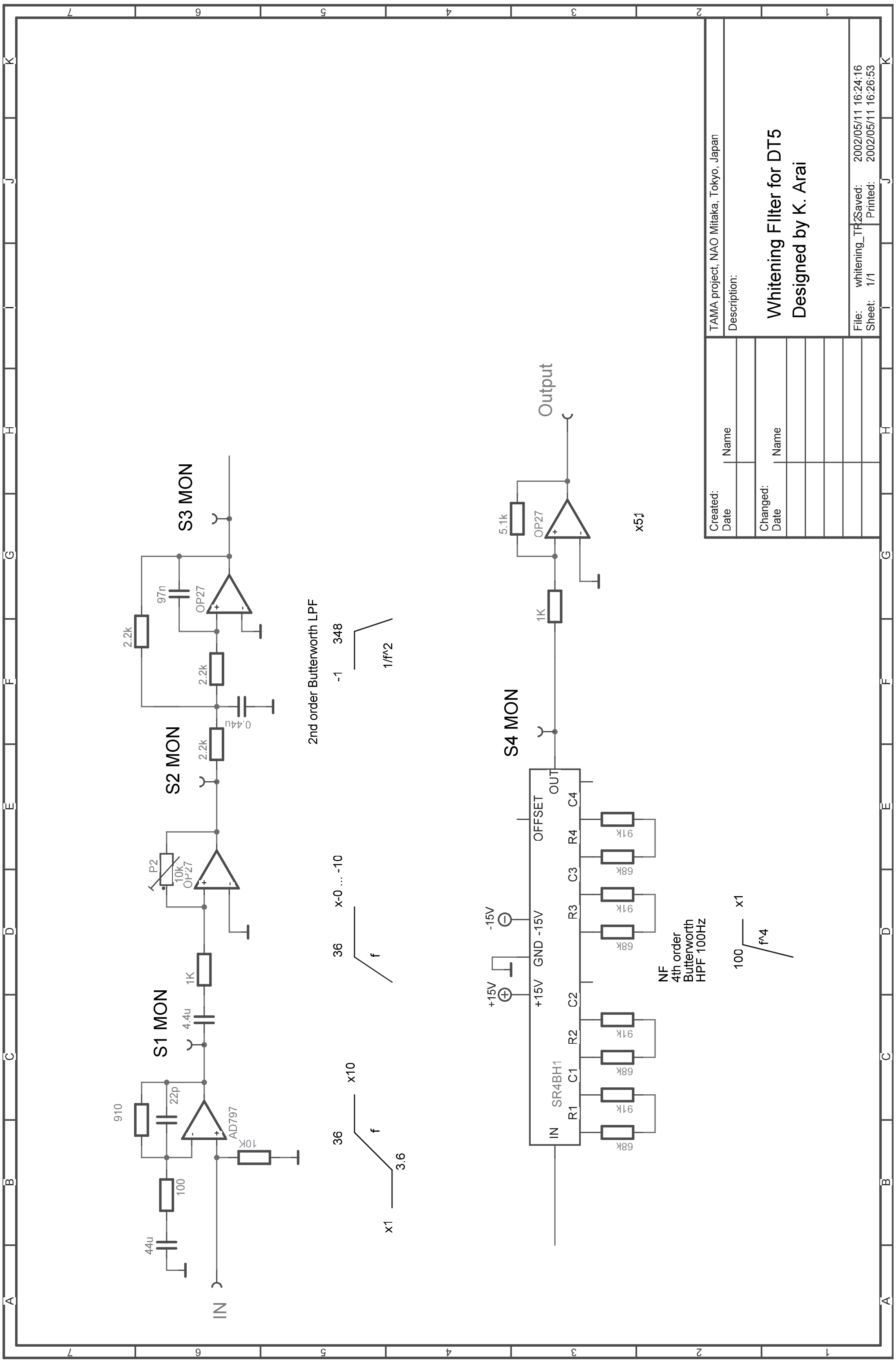

Figure 1: Circuit of the whitening filter actually used in TR2

spectrum analyzer are given by

$$|H_{\mathrm{WTF}\#2}(625\mathrm{Hz})/H_{\mathrm{WTF}\#1}(625\mathrm{Hz})| = -0.0078\,[\mathrm{dB}] \tag{1}$$

where $H_{\mathrm{WTF}\#j}(f)$ is a transfer function of WTF$\#j$. This value corresponds to difference of 0.09%.

In order to characterize the WTFs, the measured transfer functions were fitted using LISO [3]. The source code for the fitting are shown below.

```
a0 0
a1 0
a2 0
a3 0
a4 0
a5 1
zero 4.3539468
pole 102.89671
pole 37.835922
pole 351.72098 692.57935m
pole 101.75027 1.3011752
pole 86.285517 534.77896m
pole 102.51971k
factor -6.4453806n
#param a0: 1 10
#param a1: 1 10
#param a2: 1 10
#param a3: 1 10
#param a4: 1 10
#param a5: 1 10
param zero0:f 1 10
param pole0:f 20 1500
param pole1:f 20 1500
param pole2:f 200 1000
param pole2:q 0.1 10
param pole3:f 10 200
param pole3:q 0.1 10
param pole4:f 10 200
param pole4:q 0.1 10
param pole5:f 1e3 1e6
param factor 1e-15 1e-6
fit llm_WTF1_tf.bod absdeg semi
rewrite samebetter
#gnuterm cps # uncomment for making the eps file
tfoutput abs:deg
freq log 10 9.891k 400 ### from data file
```

	WTF#1	WTF#2
A	$-6.4453806n$	$-12.643198n$
f_0 (Hz)	4.3539468	4.0060725
f_1 (Hz)	37.835922	37.128395
f_2 (Hz)	102.89671	35.607634
f_3 (Hz)	351.72098	349.69349
q_3	0.69257935	0.69233685
f_4 (Hz)	101.75027	101.07655
q_4	1.3011752	1.3119331
f_5 (Hz)	86.285517	102.25272
q_5	0.53477896	0.53696242
f_6 (Hz)	102.51971k	221.72274k

Table 1: Identified poles and zeros from the measurements of the transfer functions.

Overall transfer functions were parametrized as the following:

$$H(f) = A\,\frac{h(f,f_0)}{h(f,f_1)}\,\frac{\mathrm{i}f}{h(f,f_2)}\,\frac{1}{h(f,f_3,q_3)}\,\frac{(\mathrm{i}f)^2}{h(f,f_4,q_4)}\,\frac{(\mathrm{i}f)^2}{h(f,f_5,q_5)}\,\frac{1}{h(f,f_6)}\ , \tag{2}$$

where a single pole (or zero) on the imaginary axis and a double pole pair are respectively expressed by

$$h(f,f_0) = 1 + \mathrm{i}\frac{f}{f_0} \tag{3}$$

$$h(f,f_0,q_0) = 1 + \mathrm{i}\frac{f}{f_0 q_0} - \left(\frac{f}{f_0}\right)^2\ . \tag{4}$$

Note that $1/h(f,f_6)$ was added so as to represent phase delay caused by the opamps.

The result of the fitting are shown in Table. 1. Figures. 2 and 3 show the calculated and measured transfer functions of the whitening filters. Figure. 4 shows the errors in the fitting. The fitting has errors smaller than $\pm1\%$ and ±1 degree in magnitude and phase from 20Hz to 2kHz.

4 Summary

The whitening filters for TR2 were built and tested. Two circuits has been adjusted to have a machted gain at 625Hz with precision of 0.09%. The transfer functions of the filters were measured and characterized by pole-zero models with accuracy of 1% in amplitude and 1 Degree in phase between 20Hz to 2kHz.

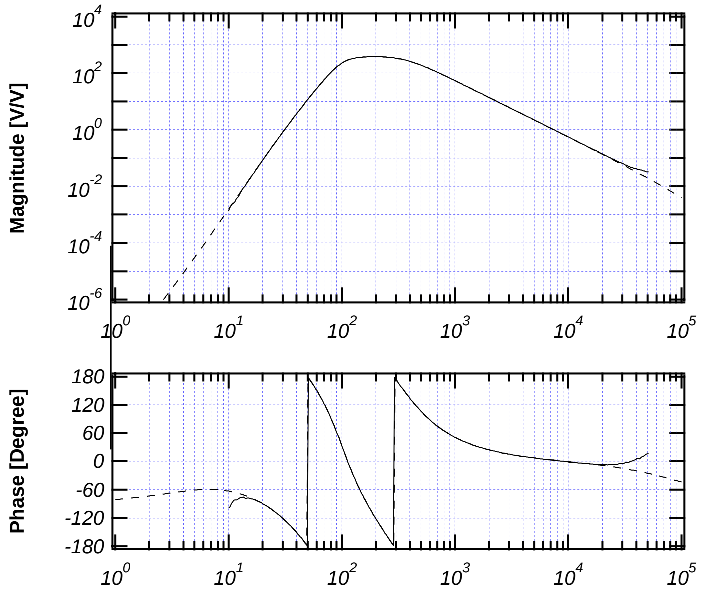

Figure 2: Measured (solid) and fitted (dashed) transfer functions of WTF#1. Values from 10Hz to 10kHz were used for the fitting.

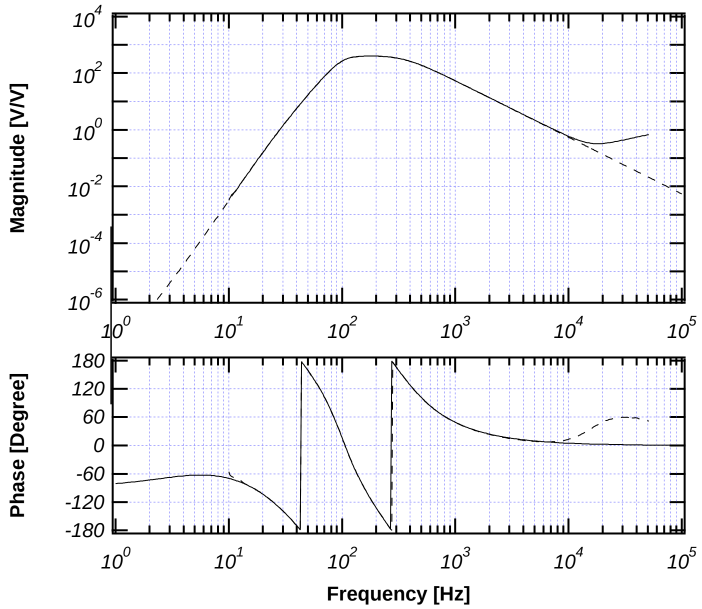

Figure 3: Measured (solid) and fitted (dashed) transfer functions of WTF#2. Values from 10Hz to 10kHz were used for the fitting.

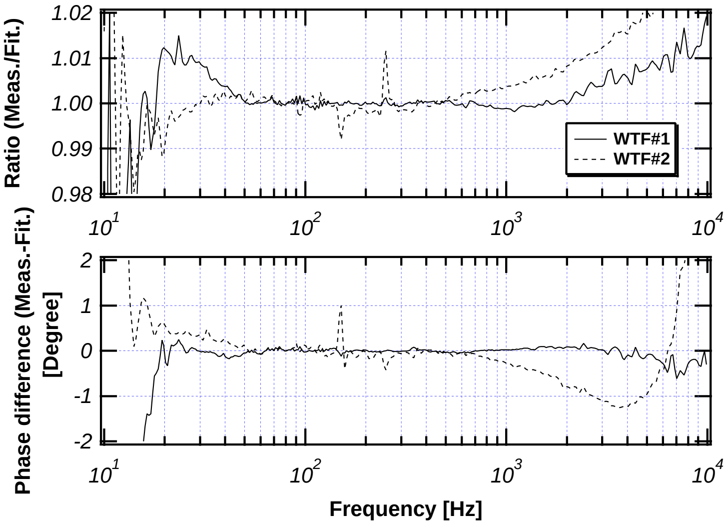

Figure 4: Comparison between the measured transfer functions and the fitted ones. Upper plots shows the magnitude ratio of the measured one and the calculated one. Lower plots show the difference of their phases.

References

[1] K. Arai, "DT5: Design of whitening filters for DT5", `http://tamago.mtk.nao.ac.jp/tama/recom/general_lib/circuits/010221_DT5_WTF/whitening.pdf`

[2] K. Arai, "DT5: Design of whitening filters for DT5 part 2", `http://tamago.mtk.nao.ac.jp/tama/recom/general_lib/circuits/010311_DT5_WTF/whitening2.pdf`

[3] G. Heinzel, "LISO - Program for Linear Simulation and Optimization of analog electronic citcuits".