TAMA300 interferometer development

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Abstract. In recent years, a gravitational wave detector TAMA300 has been upgraded for low frequency noise reduction. Its main subject is to install new seismic attenuation system TAMA SAS for all of four test mass mirrors. To benefit from the excellent performance of TAMA SAS, digital control systems are necessary to damp low frequency resonances. However, the digital control system has a demerit of large ADC and DAC noises. To reduce such digital control noises, pre-emphasis and de-emphasis filters are introduced. By applying these systems, the detector noise reduction below 100 Hz was realized. In this paper, I would like to present the current status of the digital control system and of the new analog filters to reduce digital control noises.

1. Introduction
In recent years, a gravitational wave detector TAMA300 [1] has been upgraded for low frequency noise reduction. Its main subject is to install new seismic attenuation system TAMA SAS [2, 3] for all of four test mass mirrors. To obtain excellent attenuation at 100 Hz region, the system has many low frequency resonances. Actually, horizontal filter of an inverted pendulum has a resonance of 30 mHz and vertical filters of monolithic geometrical anti-spring (MGAS) have resonances of 0.5 Hz. Such a system has large natural motion at low frequencies without any servo systems. Therefore, digital control systems are necessary for stable and excellent performance of TAMA SASs.

In this paper, I would like to present the current status of the digital control system and of new analog filters to reduce digital control noises.

2. Digital control systems
We adopt LabVIEW based digital systems for the inverted-pendulum and test mass alignment controls. About 10 filter banks of pole and zero pair can be applied for each test mass control servo. It is useful for parameter tuning of the servo system. By using such complicating servos, mirror angular motions can be suppressed to a level of sub-micron meter in root-mean-square. It is sufficient for stable interferometer operation.

The digital control system has some demerits. First, delay time of digital processing limits controlled bandwidth. In the case of 1 kHz sampling, the phase delay is 10 degrees at 5 Hz and increases in proportion to the frequency. Therefore, a unity-gain frequency is limited to 5–10 Hz practically. For length control of arm cavities, a unity-gain frequency of 800Hz is needed. A digital signal processor (DSP) of 200 kHz sampling is used for the servo and utilizes for widen linear range of the error signal by a factor of 3. With the help of this digital servo system, the arm cavity is locked stably.
Second, both of ADC and DAC have large electric noises. Our LabVIEW based digital systems have noise levels of about $10^{-5}$ V/$\sqrt{\text{Hz}}$. In comparison with analog filters, these are 2 or 3 orders of magnitude larger. To benefit from the excellent performance of TAMA SAS, the DAC noises should be reduced by four orders of magnitude at 100 Hz.

3. Pairs of pre-emphasis and de-emphasis filters

To reduce ADC and DAC noises, pre-emphasis (PE) and de-emphasis (DE) filters are introduced to the servo loops as shown in Fig. 1. The pre-emphasis filter amplifies sensor output so as to exceed the ADC noise level. Therefore, the noise contribution of ADC could be negligible. The pre-emphasis filter for each sensor should be optimized, since the sensitivities are different. Because an anti pre-emphasis filter compensates for the pre-emphasis one, the servo loop is not influenced in totality. On the other hand, the de-emphasis filter has a role of DAC noise reduction. Similar to the pre-emphasis filters, the anti de-emphasis filter compensates for the de-emphasis one.

![Figure 1](image_url)

Figure 1. A schematic view of a mirror control servo system including pre-emphasis and de-emphasis filters.

For lock acquisition, high dynamic ranges are necessary for most of electric circuits. Especially for alignment control, optical lever sensors are helpful because of its high dynamic range and robustness for interferometer conditions. Furthermore, to avoid saturation of the signals, some of the filters should be switched to through filter (no-gain buffer amplifier) by external digital control. After the lock acquisition, a simple gain-up filter may cause saturation of the analog signal. Therefore, the filters should have an appropriate frequency dependence so as not to do. To satisfy all of the above requirements, a lot of pre-emphasis and de-emphasis filters with the digital control switch are implemented to the mirror control servo system as shown in Fig. 1.

4. Results

By installation of TAMA SAS and implementation of pre-emphasis and de-emphasis filters, the detector noise reduction below 100 Hz was realized as shown in Fig. 2. The detector noise on 30 August, 2007 is limited not by ADC or DAC noises, but by the sensor noise of optical lever...
below 50 Hz. The shot noise level of a displacement sensor is worse than that of the previous best sensitivity on 4 November, 2003, since incident laser power is not full.

![Displacement noise spectrum](image)

**Figure 2.** Displacement noise spectrum of TAMA300 detector

To archive the target sensitivity, we need to increase the incident laser power. Laser power is necessary not only for the displacement sensor but also alignment sensors. When laser power becomes to be maximum, wavefront sensors (WFSs) are expected to have about 100 times better noise level than that at the current. By switching the alignment sensor from optical lever to wavefront sensor, further noise reduction will be realized.

5. Summary
To reduce low frequency noises, new seismic attenuation system TAMA SAS was installed. To benefit from the excellent performance of TAMA SAS, digital control system is necessary. Pairs of pre-emphasis and de-emphasis filters are also introduced to reduce the ADC and DAC noises. By applying these systems, the detector noise reduction below 100 Hz is realized. For further noise reduction, detector is under tuning.

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References
[1] Tatsumi D et al 2007 *Class. Quantum Grav.* **24** S399-403
[2] Márka S et al 2002 *Class. Quantum Grav.* **19** 1605-14
[3] Takamori A et al 2002 *Class. Quantum Grav.* **19** 1615-21