Current Status of TAMA300

Shuichi Sato[1] and the TAMA collaboaration
(1) National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan

Abstract

A Japanese laser interferometer gravitational wave antenna, TAMA300, has been developed and recently a power recycling system was implemented. The interferometer is finally operating in the designed optical configuration, with improved sensitivity, 1×10^{-18} mHz$^{-1/2}$ in displacement at around 1 kHz. With this sensitivity the antenna can be expected to have an ability to sense the spacetime strain caused by the coalescence of neutron star binaries within our galaxy with a signal to noise ratio better than 40. In this paper, the implementation of the recycling system and the corresponding improvement in the sensitivity are reported in addition to the review of the system.

1. Overview

The TAMA project is a major Japanese effort in the field of gravitational wave detection, including the construction, development, and operation of a laser interferometer gravitational wave antenna of baseline length of 300 m, as well as R&D for a future full-scale antenna. Another scope of the project is to be a global leader in observation of various source of gravitational waves (GWs) in our galaxy. The antenna has been developed at the Mitaka campus of the National Astronomical Observatory, Tokyo (35°40'N,139°32'E). The project was begun in 1995 [1]. The infrastructure was completed in 1996, the vacuum system in 1997. After developments of indispensable subsystems, we succeeded to operate the Fabry-Perot Michelson interferometer in 1999. Various improvements of the system and the sensitivity were made in the succeeding period, to perform several engineering and observational runs (called Data Taking). In the end of 2001, the power recycling system [2] was installed as a final step to realize the designed optical configuration. After a period of time when noise reduction was being performed, 1000 hours of observational data was collected from February to April 2003 (DT8). The designed sensitivity limit of TAMA300 is $h_{\rm rms} \sim 3 \times 10^{-21}$ at 300 Hz with a bandwidth of 300 Hz, which corresponds to $h = 2 \times 10^{-22}$ Hz$^{-1/2}$ in the power spectrum density.

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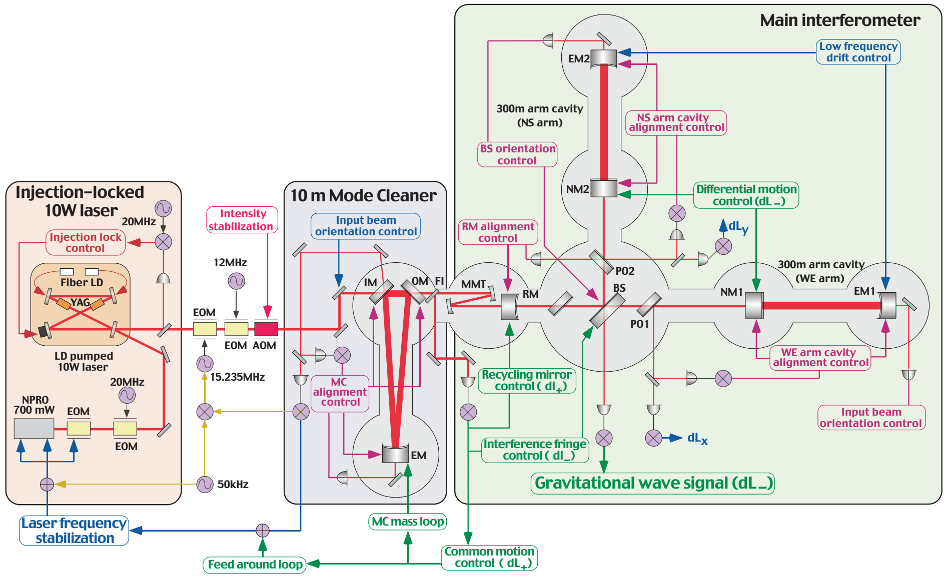

Fig. 1. Schematic diagram of interferometer configuration of TAMA300.

1.1. Interferometer system

2. Interferometer System Review

The fundamental optical design of TAMA300 is based on a Michelson interferometer with 300-m baseline length Fabry-Perot cavities in its arms (FPMI) [3] as shown in Fig. 1. The power recycling system had also been installed in order to enhance the effective laser power for better sensitivity. With the addition of the recycling mirror, the main interferometer becomes a complicated optical system, composed of coupled cavities. The light source is a diode-pumped Nd:YAG master-slave laser system running at 1064 nm. The slave laser, which is injection-locked to a stable master laser, commercial NPRO with 700 mW output power, yields 10 W of output power. The emitted light is spatially filtered and stabilized in frequency by a 10-m long triangular optical resonator, Mode Cleaner, before illuminating the main interferometer. The four test masses comprising two Fabry-Perot arm cavities, together with other mirrors of importance are made of both optically and mechanically high quality fused silica substrates with high quality dielectric multi-layer reflection coatings. These optics are supported with three stages of suspension systems in order to be isolated from seismic motion; an actively controlled isolation system, three-layers of stack system consisting of a mass-elastic sandwich structure, and a double pendulum system. These optical systems are housed in a vacuum system, which consist of eight chambers connected by 400 mm diameter tubes, for reduction of air and acoustic effects on an optical interference. A vacuum pressure of less than 10^{-6} Pa is maintained by 16

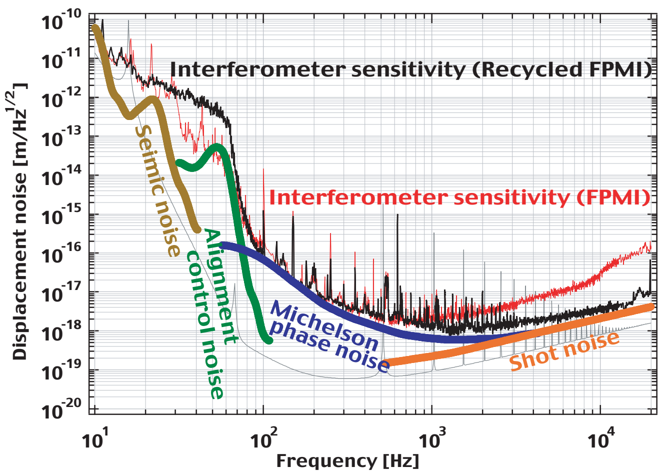

Fig. 2. Noise curve of the power recycled TAMA300 interferometer (black) in comparison with non-recycled FPMI interferometer (red). Several noise sources contributing to the total noise curve are shown. The designed sensitivity is also shown by the thin gray curve.

ion pumps during operational runs.

The control systems are carefully designed to keep the interferometer operable by maintaining high sensitivity as well as excellent stability. The longitudinal control system adopts a Schnupp (frontal) modulation technique [2] using a modulation frequency of 15.235 MHz, which is imposed by an Electro-Optic modulator in the input optics chain before the Mode Cleaner. Wave Front Sensing (WFS) scheme-based alignment control systems for every optic play an important role in achieving high sensitivity and also for providing short- and long-term stability. Currently, the alignment of all of the test masses, the recycling mirror, and Mode Cleaner mirrors, are actively controlled. A mechanical modulation scheme was temporarily used for the recycling mirror control, though this control loop will be replaced by a WFS-based system. In addition, the orientation control system for controlling the laser beam injection angle into the main interferometer and the beamsplitter orientation for beam pointing to the perpendicular arm cavity are indispensable for long-term operation. In order to reduce alignment control-induced noise via beam mis-centering, these loops keep the laser beams center on the end mirrors of both arm cavities.

3. Sensitivity

The latest noise curve of the power-recycled Fabry-Perot Michelson interferometer together with the non-recycled FPMI is shown in Fig. 2. Though the sensitivity of the non-recycled FPMI interferometer was limited by photodetector and laser frequency noise in the high frequency region above around 1 kHz, it was greatly improved by implementing power recycling. Signal enhancement by power recycling, a modified laser frequency stabilization system, and an improved laser intensity stabilization system contributed to improving this sensitivity. The resulting noise curve has a best sensitivity of 1×10^{-18} mHz$^{-1/2}$ in displacement which corresponds to 3×10^{-21} Hz$^{-1/2}$ in strain. There are several known noise sources which limits the current noise spectrum: seismic noise in the low frequency region up around a few Hz, alignment control noise, and the Michelson phase detection noise in the floor region. In the high frequency region, the interferometer is near the shot-noise level that can be achieved with the current optical configuration with finite optical losses. With this spectral sensitivity, a signal to noise ratio exceeding 40 is expected on matched-filter analysis [4] for searching chirp signals generated by coalescence of 1.4 $M_\odot$ neutron star binaries in our galaxy.

4. Stability

In the latest observational run (DT8), the power recycled interferometer showed sufficient stability for long-term operation. The interferometer was operated for 1158 hours out of 1424 hours during DT8. Even though the interferometer had became a complicated coupled cavity system, the duty cycle reached 81.3%, which was comparable with that of the non-recycled FPMI system (86.5%). Before implementing the alignment control servo for the recycling mirror, we observed a decline of the optical power in the cavities, followed by loss of lock of the interferometer, which was caused by misalignment of recycling mirror. However, owing to the alignment control systems for all the mirrors including the recycling mirror, the recycling gain variation was suppressed to a few percent resulting in a longest stretch of continuous interferometer lock of 20.5 hours. A more precise report on the interferometer stability will be given in a related paper in this volume.

5. References

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