論文の内容の要旨

Interferometer Locking Scheme for Advanced Gravitational-Wave Detectors and Beyond (現在および将来の重力波検出器の干渉計の動作点引き込み法)

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Since the first observation, direct observations of gravitational waves (GWs) by currently operating ground-based interferometric detectors have brought unique astrophysical information. It is expected that the planned detectors, namely the third generation detectors, which are about ten times more sensitive than the current detectors, will provide significant advances in GW astronomy. Current GW detectors, such as Advanced LIGO, Advanced Virgo, and KAGRA, require multiply coupled optical cavities to be controlled at their resonances. Thus the lock acquisition process, where all the cavities are brought to their operation points against the cross-coupling of the cavities, is essential for their operation and astrophysical observation. In particular, it is the most challenging to achieve the resonances of the arm cavities, because the kilometer-long arms result in narrow frequency linewidths; the arm cavity provides meaningful error signals only within its linewidth. In the third generation detectors, which will have longer arms leading to narrower linewidths, the lock acquisition process will be even more challenging. In lock acquisition of Advanced LIGO, a scheme called arm length stabilization (ALS) has been used, where auxiliary lasers having different wavelength than that of the main laser independently control the arms within their linewidths in a decoupled way. However, it is not trivial to scale up the system of Advanced LIGO to the third generation detectors due to the configuration of the system; optical fibers having the same length to the arms are involved, and thus to scale it up would increase optical phase noise and loss in the fibers.

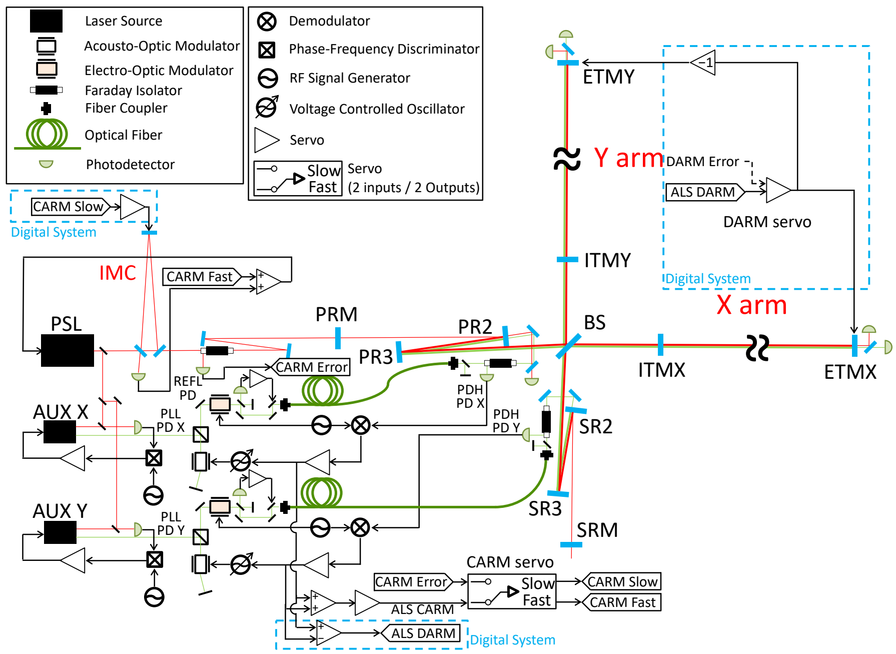

Figure 1: Schematic view of the ALS system of KAGRA.

To address this issue, a new type of the ALS system was designed for KAGRA. The new configuration is simple with significantly shorter fiber length and thus it is compatible with the third generation detectors. Along with a design study on the noise performance, an experimental test of the new ALS system was performed in KAGRA. The test revealed that the residual fluctuations of the arm cavities were evaluated to be less than 5 Hz in terms of root mean square, which are smaller than the linewidth of the arm. With this level of the noise performance, lock acquisition of the Fabry–Perot Michelson interferometer of KAGRA was achieved using the ALS system (Figure 2). This achievement demonstrated that the system is ready for bringing the KAGRA full interferometer to the operation mode as soon as the other part of the interferometer is available.

Utilizing the results obtained in KAGRA, the performance of the ALS system in third generation detectors was simulated, along with discussions on necessary modifications to the KAGRA ALS system. The necessary modifications include new schemes for controlling one laser to follow another under the condition that their wavelengths are different (Figure 3). The results indicated that lock acquisition of third generation detectors will be feasible by scaling the KAGRA ALS system. We also point out that a new scheme with a sub-carrier field will make the lock acquisition process more reliable.

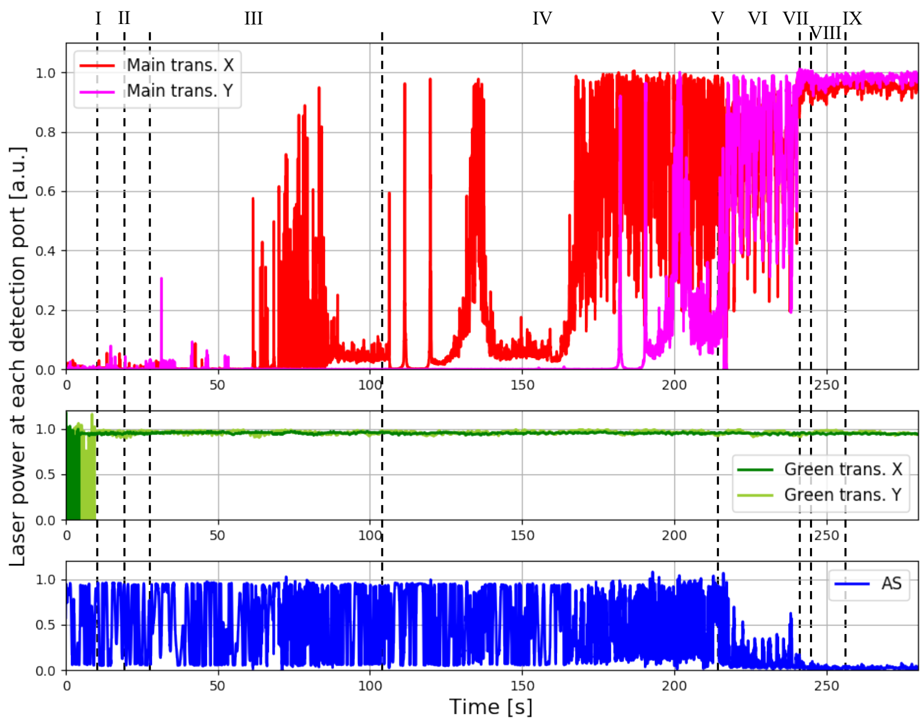

Figure 2: Demonstration of the newly-developed ALS system.

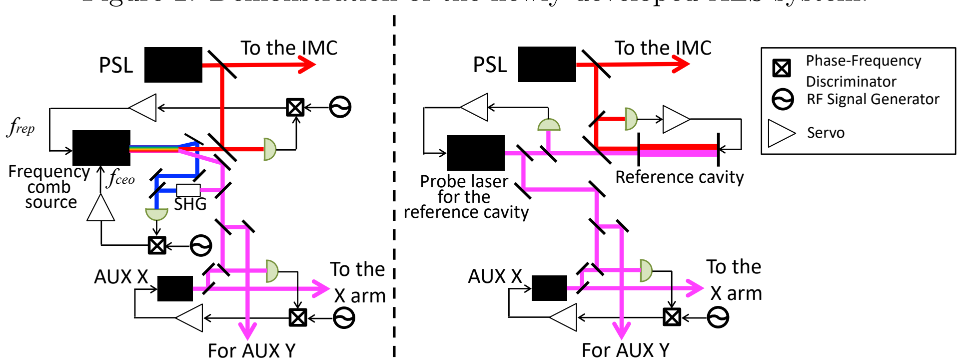

Figure 3: Possible schemes for wavelength conversion.