LIGO Laboratory Activities for LSC MOU Planning - July 2008

6. 40 meter Interferometer

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Accomplishments in FY2008 (with brief historical summary)

The 40m as AdvLIGO optical configuration prototype: The 40-meter Laboratory was rebuilt in 2001-2005 to fully develop and test the optical configuration and control scheme for Advanced LIGO, including an inital LIGO PSL, a 13 m suspended-mass mode cleaner, a detuned signal cavity (coupled to the power-recycling cavity: dual recycling), and an improved digital control system. The more complex dual-recycled optical configuration makes it significantly more difficult to control than for the initial LIGO interferometer. This makes it essential to develop a reliable scheme to bring the interferometer from an uncontrolled state into one which is optimized for gravitational-wave detection. At the beginning of FY2006, we were able to bring the interferometer into full lock in the Advanced LIGO configuration, via multiple paths of varying complexity and robustness against environmental and technical noise. We measured the optical response of the detector, (dominated by a high frequency (~4 kHz) RSE peak and a low frequency (~40 Hz) optical spring resonance, both due to the detuned signal cavity (published in CQG). The noise spectrum, however, was dominated by technical noise sources so that the expected quantum-limited sensing noise spectrum was not observed. Continued development of robust lock acquisition, including experiments with new sensing signals (eg, 3f), continued through FY2007 and FY2008.

DC Readout: In FY2006 we developed and commissioning a DC readout system. This was then used to sense and control the DARM degree of freedom. We observed a reduction in the “junk” light at the asymmetric port, and improved overall noise in the gravitational-wave channel (in comparison with RF readout), above 600 Hz; a displacement sensitivity of 2 x 10^{-18}m/rHz was achieved at approximately 1 kHz. We completed a broad range of measurements of noise couplings with DC and RF readout (laser frequency noise, intensity noise, oscillator noise, etc); it appears that the expected benefits of DC readout are being realized in practice (published in CQG). These techniques: dither alignment and length locking, in-vac cavity, in-vac photodetectors, are being used as the core features of the Enhanced LIGO upgrade.

Squeezed vacuum injection: In FY2007, Goda, Miyakawa and Sharaf implemented a vacuum squeezing apparatus for injection into the interferometer. A 3.1 dB or 43 percent increase in displacement sensitivity was observed above 30 kHz where the interferometer was limited by photon shot noise. The configuration for this experiment was a signal recycled Michelson interferometer with no Fabry-perot arms or power recycling. Since this demonstration was carried out on a prototype interferometer with suspended mirrors, and a readout and control system similar to those used in existing gravitational-wave detectors, it is a major step toward implementing squeezing enhancements on long baseline gravitational-wave interferometers (published in Nature Physics).

Dual-recycled interferometer with DC readout: By the end of FY2008 we once again achieved full lock of the 40m in the full AdvLIGO configuration: power- and signal-recycled Michelson with Fabry Perot arms, now with DC readout and control of the DARM degree of freedom. Noise spectra and noise couplings were measured and compared with predictions (thesis and publication to come soon).

Auxiliary laser locking: Work began in FY2008 to develop a method for locking the arms independently of the central part of the detector, using laser light brought to the ends of the arms via stabilized fibers and injected through the ETMs. This work is ongoing in FY2009.

Upgrade to new AdvLIGO configuration: Experience with locking and controlling the 40m in FY2004-2006 led to changes in the baseline design of Advanced LIGO: RF modulation frequencies, cavity finesse, and schemes for tuning the sensitivity. Work began in FY2008 to redesign the 40m to bring it into line with new thinking about AdvLIGO: lower RF frequencies for the control sidebands generated with AdvLIGO-like input optics; modified coupling of RF sidebands to the signal cavity; much longer power recycling and signal cavities; broadband RSE with dynamically detuned signal cavity; lower finesse arm cavities; lighter ITMs (to enhance radiation-pressure effects at the 40m); AdvLIGO-like (PCIX and Myrinet) controls architecture.

Development of digital camera network: During FY2008, GigE digital cameras were tested for use in monitoring the position and transverse profile of pickoffs from IR beamlines, as well as the scattered light from suspended mirrors. A new Gigabit ethernet network (with associated CPUs and image processing software) was designed and installed in order to acquire and real-time-process information from these cameras. Networking software and image processing software from this effort will be exported to the observatories for Enhanced LIGO.

Precision Interferometry development and diagnostics: Work during FY2008 included: development of adaptive feed-forward for noise cancellation to aid in lock acquisition, reduce certain noise couplings, and to cancel gravity gradient noise (described elsewhere in this document); testing of AdvLIGO-like RF photodiodes; development of high-power beam dumps using stainless steel “horns”; hosting the eLIGO OMC construction; development of a new RFAM monitor; development of noise budget code; development of scripts to automate suspension optimization, lock acquisition, alignment, control and other now-routine functions; and many small improvements to the 40m PSL, suspensions, environmental monitoring system, and interferometer plant.

Training, collaboration and outreach: The 40-meter team continues to work closely with the Advanced LIGO Interferometer Sensing and Control group, the enhanced LIGO group, the LIGO e2e simulation group, and LIGO Laboratory engineers and management. Numerous graduate students, REU (Research Experience for Undergraduates) summer students, visiting students, and visiting scientists have learned about interferometry and contributed to all aspects of the project over the last seven years. In particular, REU students have made major contributions to design and implementation of the DC readout and vacuum squeezing systems, as well as many other aspects of the interferometer. We will continue to involve students and visitors with all aspects of the project and its goals. The laboratory continues to be a popular tour site for local students, journalists, scientific visitors, and dignitaries.

Planned Work for FY2009

Upgrade to new AdvLIGO configuration: We will reconfigure the 40m interferometer to more closely resemble the new AdvLIGO optical/control design. This will involve the replacement of the ITMs, new layout of the recycling cavities, the addition of several in-vacuum steering mirrors, new RF electronics and electro-optics, and a new PCIX-based control system. The newly-configured interferometer will be commissioned, lock acquisition and control systems developed and optimized, and noise spectrum and noise couplings studied.

Dual-recycled interferometer with DC readout: This work will be completed, thesis written, and paper describing the results written and submitted for publication.

Continuing efforts: Work will continue in FY2009 in:

- Improved lock acquisition and control schemes, including the development of improved sensing signals during lock acquisition process.
- Development of adaptive noise cancellation feed-forward schemes to aid in lock acquisition.
- Development of an auxiliary laser arm locking system.
- Development of a digital camera network and image processing system.
- Continued optimization and automation of all systems.
- Training of and collaboration with visiting students and scientists from the GW community, and public outreach.