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Plan for Hardware Signal Injections During the E10 and S3 Runs

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LSC UPPER LIMIT GROUPS

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Overview

All of the LSC data analysis working groups have made use of the software tools, which allow simulated signals to be injected into the LIGO interferometer hardware. The first significant use was around the time of the S1 run, when a number of burst and inspiral waveforms, as well as periods of correlated stochastic noise, were injected just before and just after the run. These proved to be very valuable for verifying the correct operation of the search algorithms, validating calibrations and simulations, and studying the coupling of gravitational waves into auxiliary interferometer channels, in particular those which were being considered for use as vetoes. The usefulness of the S1 injections was hampered by the limited number of different waveforms injected, a lack of injections into H1, and the lack of injections *during* the S1 run, leaving open the question of time variability. Based on the S1 experience, a significantly expanded program of hardware signal injections was planned and carried out before and during the S2 run.[1] In addition to several nights of studies just before the run, there were roughly a dozen half-hour "intra-run" injection sessions during the 51-day run itself. Also, during an extended session on the night of April 9-10, simulated pulsar and black hole ringdown waveforms were injected in addition to the signal types previously used.

For the S3 science run and the E10 engineering run which precedes it, we are planning one major addition to the kinds of studies which were done during S2: weak continuous signals will be injected for the entire duration of the E10 and S2 runs. The overall plan is as follows:

- We will need some dedicated shifts to perform in-depth injection studies using burst, inspiral and ringdown waveforms. Currently we anticipate needing one or two shifts during the E10 run and two to four shifts during the S3 run, but this will depend on the specific requests from the burst, inspiral, and ringdown analysis teams and on whether the interferometers cooperate by staying locked.

- As was done during S2, we will inject a fixed set of waveforms occasionally *during* the E10 and S3 runs, at predetermined pseudo-random times. Each of these injection sequences should take about 30-40 minutes. We expect to schedule three such sessions during E10 and about a dozen during S3.

- Throughout the E10 run, we will continuously inject simulated pulsar and stochastic signals. The pulsar waveform will be very weak; the stochastic waveform will be fairly weak for a period of about 12 hours, and very weak during the remainder of the run.

- Throughout the S3 run, we will continuously inject a very weak simulated pulsar signal.

[1] The S2 hardware signal injection plan is described in LIGO-T030013-00-D, and the injections actually performed are summarized at http://blue.ligo-wa.caltech.edu/scirun/S2/HardwareInjection .

General Considerations

Some of the studies require simultaneous injections while all three interferometers are locked; in other cases, it is sufficient for one or two to be locked at the time of the injections.

Waveforms and configuration files will be needed well in advance of the scheduled injections.

The calibration of the actuators (i.e. the frequency-dependent transfer function from DAC counts to physical mirror displacement) needs to be known in advance, so that waveforms can be prepared properly.

Reasonably good (but not necessarily final) calibrations for the detectors will be needed to interpret the results of the injections.

The upper limits groups are expected to analyze the injection data promptly, to make sure that the correct waveforms were injected into the correct channel(s) with the correct amplitudes, and to ensure that they are scientifically useful. Ideally, this should involve at least one appointed person other than the person(s) who performed and/or prescribed the injections. There should be an explicit statement issued shortly after the injections that the results are good or are not good; this will ensure that any problems are found and corrected early on, so that we don't waste good running time on flawed injections. (Note that this admonition was made prior to the S2 run, but was not observed by all groups.)

In-Depth Injection Studies During Dedicated Shifts

(* * * DRAFT – SUBJECT TO CHANGE * * *)

- <u>"Environmental injections"</u>: These are designed to study the coupling of external disturbances into the GW channel (and perhaps other ifo channels). These studies only require a single local locked interferometer. Radio transmitters, magnetic coils, etc. will be set up in advance.

- <u>Survey of burst waveforms:</u> Waveforms and configurations will be provided by the Burst UL group. We will use "sine-gaussians" at ~8 different frequencies and with ~8 different amplitudes. Various DZM waveforms, black hole ringdowns and GRB model based waveform will be injected as well. It is desirable for the burst injections to be simultaneous among interferometers. The detailed plan for all burst injections will be published as an attachment to this document. *Time estimate: 2 to 4 hours*

- <u>Large-amplitude burst injections:</u> Waveforms may include sine-gaussians, selected Z-M simulated waveforms. Injections are designed to look for couplings into auxiliary channels. We plan to try this with an intentional misalignment as well. *Time estimate: 2 hours*

- Survey of inspiral waveforms: Waveforms and configurations provided by Patrick Brady and Duncan Brown. It is desirable for the injections to be simultaneous. *Time estimate: 4 hours*

- Large-amplitude inspiral injections : Inject into DARM, ETMX, ETMY and CARM to look for coupling into auxiliary channels. *Time estimate: 2 hours*

- "Intra-run" injection sequence : See next section for discussion. Nominally a 30-minute injection sequence, but it will be done a few times prior to the run to determine the baseline and to work out kinks. *Time estimate: 2 hours*

Injections During the Run

The purpose of injecting waveforms during the run ("intra-run injections") is to sample the interferometer performance during the actual running conditions, and to look at long-time-scale variability. We will define a sequence of waveform injections lasting 30-40 minutes, and will execute the sequence once or twice per week, at varying times of day. These will include some large-amplitude burst and inspiral signals, to study coupling into auxiliary channels. We also plan to inject several strong lines at a range of frequencies for several seconds, to allow variations in the detector response to be tracked over short time scales.

It is not essential that all interferometers be in science mode at the time of the injection, although that is desirable, and hopefully will be the case for most of the intra-run injection sequences.

Long-Term Pulsar Injections

Bruce Allen will provide a program, which calculates simulated pulsar waveforms on demand. The waveform may be a composite of a handful of simulated pulsars. We will scale the waveform so that it is quite weak, requiring integrations over days or weeks to separate from the noise.

Long-Term Stochastic Injections

These will be done during the E10 run only. Waveform data will be generated on demand, locally at each site. The exact mechanism has not yet been worked out.