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Plan for Hardware Signal Injections Before and During the S2 Run

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Overview

Basic infrastructure for injecting simulated astrophysical signals into the LIGO interferometers has been available for some time. A number of burst and inspiral waveforms, as well as periods of correlated stochastic noise, were injected into the interferometers just before and just after the S1 run. These have proven 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 have been considered for use as vetoes. However, the burst and inspiral analyses have been hampered by the limited number of different waveforms injected, a lack of injections into H1, and the lack of injections *during* the S1 run, which leaves open the question of how much the efficiency of the search algorithms might have varied over time.

For the S2 run, we plan to do a more systematic series of signal injections to improve on the shortcomings of the S1 injections, albeit at a price of some "in-run" time. The plan has three main components:

- In the days just before the S2 run, after the interferometer configurations are "frozen", we propose to devote ~32 hours of generally-good running time (*i.e.* nights at LLO) to hardware signal injection studies in the three interferometers. This will be closely coordinated with the activities/needs of the commissioning and calibration teams.

- We will inject a fixed set of waveforms once or twice per week *during* the S2 run, at predetermined pseudo-random times. Each of these injection sequences should take about 30 minutes.

- The last night of the run will be mostly devoted to calibration and injection studies.

These components are described in more detail below.

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. Requirements for each study will be laid out below or in future attachments.

Waveforms and configuration files will be needed well in advance of the scheduled injections, and should be reviewed by more than one person before submittal to the injection group.

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.

We will try to automate the signal injection procedure as much as possible, to make it possible for people with a wide range of experience to perform the injections. This is particularly desirable since many of the injections will occur during the middle of the night. However, given the limited time before the S2 run, we may not be able to make it as automatic as we would like.

Pre-Run Injections

We propose to devote four 8-hour periods during the nights just prior to the S2 run to hardware signal injections, including "environmental injections". Many of these will involve all three interferometers simultaneously. The interferometer configurations will have to be frozen by that time, so these studies will be made under the proper "S2" operating conditions with well-defined calibration. We will have to schedule these periods to avoid conflicts with any commissioning and calibration activities, which may also need to be done during this pre-run time window.

Here is a list of studies to be made during this time period prior to the run. The time estimates below are typically double the amount of time nominally required to perform the injections, to include some allowance for unforeseen interferometer behavior. These estimates assume that we will generally be able to take advantage of triple coincident locks.

- "Environmental injections" (Will be prescribed by Robert Schofield): 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, and then Robert estimates that it will take 4 hours for him at each site to complete the injections. It is expected that Robert will travel to LLO to do the set-up and injection studies there. The detailed plan will be published as an attachment to this document.

- Stochastic noise injections at various amplitudes: We will inject simultaneous noise into ETMX at 5 logarithmically spaced amplitudes. Each waveform will last 1024 seconds, and will require uninterrupted science-mode running during that time. Ideally, all three interferometers should be in science mode at the same time; if that proves impractical to achieve, stochastic injections can be done in pairs, but that will take significantly longer. The stochastic group is also working

to prepare waveform files only 256 seconds long, in case there are problems injecting the 1024-second ones. *Time estimate: 4 hours*

- Stochastic noise injection with an unknown time shift: Two random time shifts will be chosen and stochastic noise (of modest amplitude) will be injected into at least two interferometers with these relative time shifts. The analysis teams will not be told what the time shift is until after they analyze the data. This will test the ability of the analysis code to accurately measure a time shift. A prize will be available for the person coming up with the closest result. *Time estimate: 1 hour*

- Survey of burst waveforms: Waveforms and configurations will be provided by Alan Weinstein. We will use "sine-gaussians" at ~8 different frequencies and with ~8 different amplitudes. A few Z-M waveforms may be injected as well. It is desirable for the burst injections to be simultaneous. For some subset simultaneous injections will be required. The detailed plan for all burst injections will be published as an attachment to this document. *Time estimate: 2 hours*

- Survey of source directions and polarizations for a burst waveforms : (Configurations will be provided by Alan Weinstein) The plan is to scan over 100 source direction/polarization combinations, injecting into ETMX and ETMY with appropriate amplitudes. *Time estimate: 2 hours*

- Large-amplitude burst injections: 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*

- Auxiliary-channel couplings under non-optimal running conditions : (To be prescribed by Robert Schofield) Large burst and/or inspiral signals will be injected while the interferometer is slightly misaligned, to see whether the signals show up more strongly in auxiliary channels than in the case of good alignment. This study does not require coincident locked running. *Time estimate: 3 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*

- Inspiral injection repeatability: Two waveforms will be injected several times with fixed amplitude into ETMX and then into ETMY, to check the stability of the measured effective distances over short time scales. This will be done in a number of time blocks, typically between other studies, to give information about intermediate time scales as well, and especially to compare the beginning, middle, and end of a locked segment. *Time estimate: 3 hours*

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

- Check relevance of additional interferometer degrees of freedom : The purpose of this study is to see whether there is any detectable effect from changes to the lengths of the Michelson arms and mode cleaner; to verify that injecting into DARM is truly equivalent to injecting into ETMX-ETMY with the appropriate multipliers; etc. A detailed plan will follow. (Someone will have to check whether there is an excitation channel for the mode cleaner length, and determine the calibration of the suspension controller.) *Time estimate: 3 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 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 about 30 minutes, and will execute the sequence about once per week, at varying times of day. These will include some large-amplitude signals, to study coupling into auxiliary channels. 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.

The inspiral group would like to inject four different waveforms at three different amplitudes into ETMX, plus one into ETMY and one into DARM. This will take about 20 minutes. In addition, the thought is to inject several burst waveforms (sine-gaussians and/or Z-M waveforms).

We will schedule 12 of these intra-run injections at pseudo-random times during the run. When the appointed time comes, the injection will take place into whatever interferometers are locked at that time. Thus, we expect most to be successful for the Hanford interferometers, several to be successful for the Livingston interferometer, and at least a few to be triple-coincident.

Injections at the End of the Run

We propose to devote the last day/night of the S2 run to calibration and injection studies. We will attempt to repeat the "survey" studies done just prior to the run, but probably with a reduced scope due to time limitations. We would like to have a total of 8 hours, in all interferometers, for these studies. Here is a sketch of a plan, though it may evolve based on what we learn before and during the run:

- Inject stochastic noise, either two 1024-second waveforms or several 256-second waveforms
- The "Survey of burst waveforms" study from the pre-run injections
- The "Survey of inspiral waveforms" from the pre-run injections

- A few "intra-run" injection sequences

Software and bookkeeping enhancements

In the past, when someone killed a signal injection process with Ctrl-C, there was no record of when this was done, and it may have left the excitation system in a funny state. We would like to add signal handling to the SIStr library to trap such signals and clean up gracefully.

We would like to create some new Epics channels to record what is being done with the interferometer at any given time. This differs from the IFO state vector, which indicates when the interferometer is locked, but does not indicate what is being done with it. The channels are:

- IFO-ACTIVITY_TYPE
  An enumeration channel, taking one of the following values: "Normal running", "Calibration", "Injection", "Alignment", "Other". Other choices can be added as needed. The operator will set this via a MEDM screen. The injection software will refuse to inject anything unless the activity type is set to "Injection". The Epics code will prevent the operator from going into science mode unless the activity type is "Normal running", and as a corollary, will drop out of science mode if the activity is changed from "Normal running" to something else.

- IFO-ACTIVITY_STATE
  Takes the values "On" and "Off". Set by the signal injection library when a waveform is actually being injected.

- IFO-ACTIVITY_INDEX
  An integer value, set by a human on an MEDM screen. This will be useful for tagging the times of various studies (e.g. different injection sequences) or marking distinct epochs of data collection, e.g. times plagued with noise or disruptive human activity.

We plan to automate the signal injection as much as possible, so that it can be done by non-experts. This is especially desirable for the intra-run injections. The plan is for a window to appear on the operator's screen at the predetermined time, telling them to set the activity type to "Injection"; once they do so, the injection is performed, and then the window tells the operator to set the activity back to "Normal running". It remains to be seen whether this can be implemented in time for the S2 run.