No More Flipping

–or–

Triggering the Q-Switcher from the SLM to Control the Phase of the Excitation Distribution of the O-SAM Instrument

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0 In brief—how to use the new system

- Set the Q-switcher mode to `EXT TRIG.Q`.
- Ensure that the **Laser A/B** signal is set up: run the `laser_ab_qswitcher` script if in doubt (though the computer *should* remember).
- Ensure the SLM flipping rate is set as fast as it will go (1015Hz); the `laser_ab_qswitcher` script will do this.
- No need to acquire the state of **True/$\overline{\textbf{Inverse}}$** on channel 7 of the A/D when acquiring data.

1 Introduction

This document describes some of the timing and triggering issues of the O-SAM* instrument, specifically to do with the SLM and the excitation laser Q-switch acousto-optic driver—henceforth referred to as simply "the Q-switcher."

Up to now, the Q-switcher has used an internal clock to trigger when the Q-switch would open, and the rate could be set within the range of a few hundred Hz to tens of kHz via a knob on the front of the Q-switcher box; typically, the Q-switcher has been run at a rate of 1 or 2 kHz. This mode of operation is known as *internal Q-switched* mode, and is the default mode of the Q-switcher on power-up.

*Abbreviations are listed in the Appendix

Meanwhile, the SLM must invert the image displayed at a rate of between 0.1Hz and 1015Hz to ensure an average DC balance across each pixel. This "flipping rate," is also known as the SLM time period within programs such as `manual_bns` and `set_bns`.

Historically, the Q-switcher repetition rate and the SLM flipping rate have been asynchronous. Operating like this, the laser could 'fire' (i.e. the Q-switch could open) when the SLM image was either true, inverted, or in the process of switching between the two states.

The effect that inverting the SLM image has on the SAWs produced depends on the nature of the excitation image. An image consisting of equal proportions of 'black' and 'white' areas will produce SAWs whose phase changes by 180° when the image flips. If we know the state ('true' or 'false') of the SLM when the laser fires, then we can adjust the measured signal to account for the 180° phase shift. The SLM state is represented by a **True/$\overline{\textbf{Inverse}}$** signal from the electronics that controls the SLM. An additional signal from the SLM electronics can be made to indicate whether the SLM is currently 'flipping;' if the laser fires during this flipping period, then the state of the pixels on the SLM is undetermined, which severely affects the amplitude and phase of the generated SAWs—obviously very undesirable. The combination of these two signals allowed us to acquire data, flip the phase by 180° if necessary, and to effectively throw away any data produced whilst the SLM was in the process of flipping.

Images which consist of fringes that do *not* have a mark : space ratio of 1:1 will produce SAWs of different characteristics not only in terms of phase, but also frequency content and amplitude, when the SLM image is inverted. This is clearly a problem if we wish to use these "fancy patterns" to control the SAW frequency content, for instance. We could simply discard any data produced when the SLM was in its inverted state (or in the process of flipping) but this would be very wasteful of events and data.

The alternative that has recently been implemented is to synchronise the Q-switcher and the SLM, so that the laser fires *only* when the SLM is in a certain state (the 'true' state), and never when the SLM is in the inverted state or is in the process of flipping between the two states. This document describes both the physical changes made to the hardware to implement the change; changes in instrument operation; changes in software and data-gathering techniques; and issues concerning reverting the system back to 'the old way' if required.

2 How the change has been implemented

Several steps have been taken to implement the changes:

1. Adjusting the timing characteristics of one of the signals from the SLM electronics, to act as a suitable Q-switcher trigger

2. Connecting the signal to the Q-switcher
3. Changing the Q-switcher mode of operation
4. Change the SLM flip rate
5. Change the way data is gathered

2.1 'Laser A/B'—a suitable trigger signal

The SLM and the Q-switcher are synchronised by getting the SLM to trigger the Q-switcher—it does not appear to be possible to get the Q-switcher to trigger the SLM.

There are essentially three time-varying electronic signals emerging from the SLM control electronics:

True/$\overline{\textbf{Inverse}}$ '1' when a true image is displayed, '0' when a false image is displayed.

A/$\overline{\textbf{B}}$ Essentially the same as above, with very slight differences in timing.

Laser A/B Aspects of this analogue signal, including amplitude and some timing characteristics, can be adjusted via software. It is this signal that is used as the Q-switcher trigger.

Figure 1 illustrates the characteristics of **Laser A/B** that can be adjusted, with respect to the **True/$\overline{\textbf{Inverse}}$** signal.

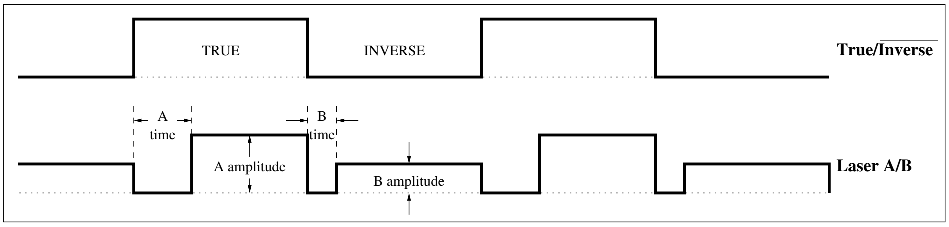

Figure 1: Examples of **True/$\overline{\textbf{Inverse}}$** and **Laser A/B** signals.

As shown, the height of a pulse in the 'true' or 'inverted' portion of the signal can be independently set. The time delay between the point at which the image flips and the pulse going high can also be independently set for the two pulses. These four characteristics are termed *a_time, b_time, a_amplitude* and *b_amplitude.*

We wish to trigger the Q-switcher *only* when the SLM has 'settled' on a 'true' image (ie *not* when the SLM is still flipping). The Q-switcher requires a TTL-level signal for external triggering, and it is triggered on a **positive edge.** The required **Laser A/B** signal is therefore shown in figure 2.

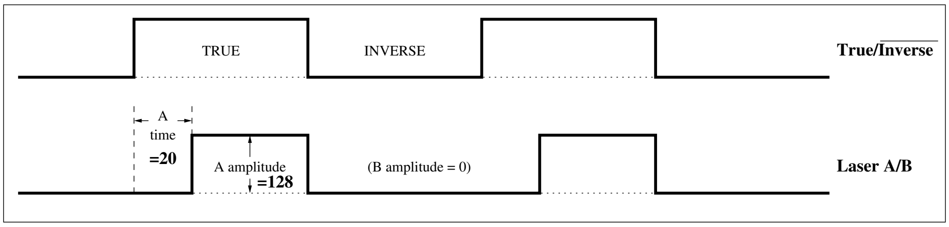

Figure 2: The **Laser A/B** signal required for successful triggering of the Q-switcher, with respect to the **True/$\overline{\textbf{Inverse}}$** signal.

The height of *a_amplitude* is an integer between 0 and 255, representing a voltage between 0 and 5V. The value to be used is **128**; this is because the impedance of the Q-switch trigger input is very low (240Ω) and the SLM electronics are unable to supply enough current to output at the full 5V. A value of 128 produces a pulse of amplitude 2.5V, which is enough to trigger the Q-switcher.

The time delay, *a_time* is an integer representing $\frac{1}{16}$ of frame periods. A *frame period* is the length of time required to upload a frame to the SLM. The maximum 'flip rate' of the SLM occurs when there are six frame periods per image period, where an *image period* consists of the total time spent in the 'true' state plus the total time spent in the 'false' state. If there are six frame period in an image period, this corresponds to the fastest flipping rate of 1015Hz. For the first frame period of each state ('true' or 'false') the state of the SLM pixels is indeterminate, and we clearly do not want to fire the Q-switcher in this period. Figure 3 illustrates this.

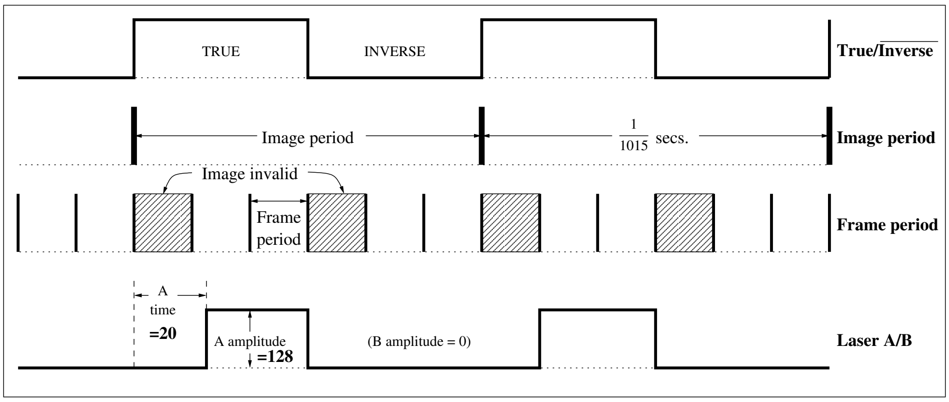

Figure 3: Timing diagram illustrating *frame periods* and *image periods*, including times where there is no valid image on the SLM.

Because the **Laser A/B** time delay is defined in $\frac{1}{16}$ of a frame period, *a_time* is set to a value of **20**.

In summary:

a_amp = 128
a_time = 20
b_amp = 0
(***b_time*** = whatever, since *b_amp* = 0)

2.2 Connecting the Laser A/B signal to the Q-switcher

The Q-switcher has a 15-pin female D-sub connector on the back, with a variety of signal inputs and outputs. The pin-out of the connector is shown in figure 4.

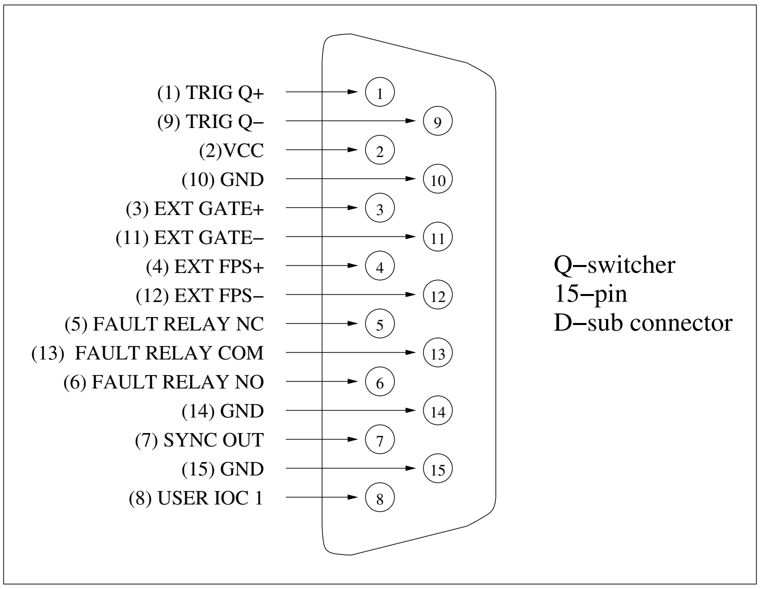

Figure 4: Q-switcher 15-pin D-sub connector pinout.

Pins 8 and 15 have always been linked, as far as I know, although I don't know why. They have remained linked now that the D-sub connector is being used for other purposes.

The pins relevant to getting the Q-switcher to trigger from the SLM are the **TRIG Q+/−** and **EXT GATE+/−** pins. Basically, the gate input (EXT GATE+) must be tied high with respect to EXT GATE–, and the **Laser A/B** signal should be applied to the TRIG Q+ pin. The four pins mentioned are fully electrically isolated from the Q-switcher via opto-coupler chips (hence the TRIG Q– and EXT GATE– pins) and have an input impedance of 240Ω.

To get the Q-switcher to respond to a trigger signal from the SLM, the pins are connected as follows:

Pin **1** (TRIG Q+) to **Laser A/B**
Pin **9** (TRIG Q–) to **SLM GND**
Pin **3** (EXT GATE+) to pin **2** (VCC)
Pin **11** (EXT GATE–) to pin **10** (GND)
Pin **8** (USER IOC 1) to pin **15** (GND)

Problems with noise

The switched-mode power supply in the main laser PSU emits lots of high frequency electrical noise spikes, with a variable repetition rate in the region of 300kHz—this has always been a problem, and is apparent on both the O-SAM and the ARRO-SAM systems.

If the **Laser A/B** signal is observed on a scope whilst connected to the Q-switcher via the 15-pin connector, the electrical noise is very large, especially when the laser lamp has a high current flowing through it. The noise can be as large as the signal itself, and so steps must be taken to reduce the noise. If this is not done, then it is possible for the Q-switcher to trigger on the noise, rather than the genuine signal from the SLM.

To eliminate some of the noise, a simple low-pass RC filter is used between the **Laser A/B** signal from the SLM and the 15-pin D-sub connector on the back of the Q-switcher. On the O-SAM instrument, this is physically located inside the cover of the D-sub connector on the back of the Q-switcher. Figure 5 illustrates the wiring used.

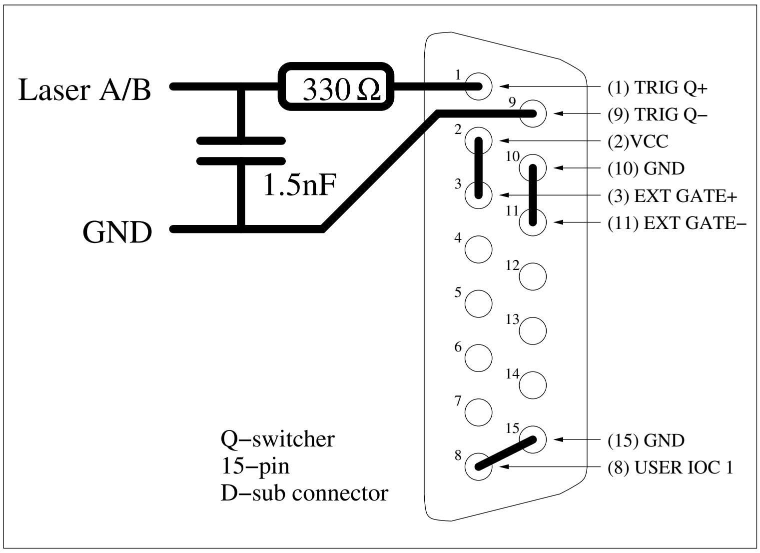

Figure 5: SLM Laser A/B to Q-switcher wiring diagram.

At the SLM end

The **Laser A/B** signal was previously used as part of the rather complicated triggering and timing system, required *(a)* to ascertain the state of the SLM, *(b)* to ascertain if the image was 'valid' (ie the SLM was not currently flipping), *(c)* to trigger the sample/hold chips in the analogue amplitude and phase detection circuitry, *provided* that the image was valid, and *(d)* to trigger the A/D inside the host computer, to acquire the data at the correct point in time (again, provided that the image was valid). To achieve these four tasks, a 'timing card' circuit was constructed. This took the coherent trigger signal (from the photodiode at the end of the generation laser) and, *provided the image was valid* produced trigger signals for the sample/hold chips and the A/D. The 'image valid' signal would come from the **Laser A/B** signal, which was set such that *a_amp* and *b_amp* were both 255, with relatively long delays on *a_time* and *b_time*. The **True/$\overline{\textbf{Inverse}}$** signal was then fed into channel 7 of the A/D, and this was used by the `c_scan` software to ascertain the state of the SLM, to adjust the measured phase of the SAW signal accordingly.

Parts *(c)* and *(d)* (the sample/hold and A/D triggers) are still required, and parts *(a)* and *(b)* are no longer required. **Fortunately, no changes are required to the timing card electronics** now that the purpose of **Laser A/B** has changed. The **Laser A/B** signal is still routed via the timing card and, because the Q-switcher and SLM are now synchronised, it will always be 'high' when the laser fires (since the laser now fires on a low-to-high transition of **Laser A/B**) and thus the timing card will now *always* produce sample/hold and A/D triggers each time the laser fires.

The **Laser A/B** signal is therefore taken from the SMB connector on the timing card, and fed into the Q-switcher as described above.

2.3 The Q-switcher mode of operation

The Q-switcher has several modes of operation, including 'internal Q-switched,' 'internal CW,' 'gated CW,' 'gated Q-switched' and 'gated triggered Q-switched.' The one we want to use is the last one on the list.

2.4 The SLM flipping rate

For the highest speed of data acquisition, the SLM flipping rate should be set to be as high as possible, ie 1015Hz. The laser will then also fire at this rate.

2.5 The way data is gathered

With the Q-switcher triggered by the SLM, the laser will only fire when the SLM is displaying a 'true' image. It is therefore no longer required to acquire the **True/$\overline{\textbf{Inverse}}$** signal on channel 7 of the A/D, to ascertain the state of the SLM, and to adjust the measured phase if the SLM is in the 'false' state.

3 Step-by-step guide to using the new system configuration

3.1 Changes to power-up procedure

Upon power-up, the Q-switcher defaults to 'internal Q-switched' mode. In this mode, the laser fires at a rate determined by the settings on the front of the Q-switcher panel, and will be asynchronous to the SLM. The mode of operation must therefore be changed *each time the Q-switcher is turned on* and should become part of the standard start-up procedure. It is very easy to do, and is done as follows:

1. Ensure that the laser shutter is closed.
2. Press the **MODE SELECT** button on the front of the Q-switcher until the display reads `GAT TRIG.Q` (O-SAM) or `EXT TRIG.Q` (ARRO-SAM)—you will need to press the button three times.
3. Press the **MODE ENABLE** button, ensuring that the text above this button now reads `OK` rather than `Inhibited`.

The laser shutter can now be opened, and the Q-switcher will be locked to the SLM (provided the correct **Laser A/B** signal is being produced).

3.2 Setting up Laser A/B and SLM flipping rate

The characteristic values for the **Laser A/B** signal are described in section 2.1. These can be set manually using either `manual_bns` or `bns_laser_ab` or automatically using the `laser_ab_qswitcher` script. The script also sets the SLM flipping rate to its maximum permitted rate of 1015Hz.

3.3 `c_scan` control files

It is no longer required to acquire the **True/$\overline{\textbf{Inverse}}$** on channel 7 of the A/D, to ascertain the state of the SLM, and to adjust the measured phase if the SLM is in the 'false' state. This is done by the `c_scan` software by the inclusion of the command `inv_ch 7` in the control-file. This line is no longer necessary.

4 Further issues and possibilities

4.1 'True' or 'inverted' image?

If **Laser A/B** is set up as described above, using the `laser_ab_qswitcher` script, the image on the SLM at the moment the laser fires will always be the real 'true' image, ie the image *as it is constructed within Matlab, or with the characteristics as defined by* `manual_bns`. This is important to know; for instance, if the mark : space ratio is adjusted in `manual_bns` to be 0.1, this should appear as 'skinny lines' on the sample, and indeed it does.

4.2 Using the 'inverted' image

It is of course possible to get the laser to fire only when the image is inverted. This can be achieved by setting *a_amp* = 0 and *b_amp* = 128 (also, *b_time* = 20). This can be done using the `laser_ab_qswitcher_inverted` script.

4.3 Increasing the data acquisition rate

The maximum flipping rate of the SLM is 1015Hz. However, by setting both *a_amp* and *b_amp* = 128, the laser will fire alternately when the SLM image is 'true' or 'inverted.' As long as the **True/$\overline{\text{Inverse}}$** signal is acquired with the data, and the SLM image contains equal portions of black and white (ie simple excitation patterns) then the data can be collected in the same manner as before; the advantage is that the laser will never fire when the SLM is flipping, and thus all the data will be valid.

4.4 Reverting to 'the bad old days'

It may be desirable for the odd experiment to fire the laser at a very high repetition rate (> 2kHz) and so you may want to trigger the Q-switcher internally, and have it behave asynchronously to the SLM. Several steps are required to revert the system to this mode of operation:

1. Select the `INT QSW` mode on the Q-switcher (this is the default power-up mode). Adjust the Q-switch rate to your desired repetition frequency.

2. Run the `laser_ab_image_valid` script. This adjusts the characteristics of **Laser A/B** such that it behaves as an 'image valid' signal. It will also reduce the SLM flipping rate†.

†The faster the SLM flipping rate, the greater the chance that the laser will fire when the image is not valid. Thus reducing the SLM flipping rate allows for much quicker data acquisition.

3. Ensure that the [delayed] **True/$\overline{\textbf{Inverse}}$** signal from the timing card is plugged into the appropriate A/D channel (traditionally channel 7).

4. Include the `inv_ch 7` instruction within the 'a2d action' in your `c_scan` control file.

4.5 Low Q-switch rates—light leakage

It has been determined that in the absence of a Q-switcher trigger signal, and for low Q-switch rates, a certain amount of CW light is emitted from the laser cavity. The amount of leaked light is, on average, approximately 20% of the average Q-switched output power. This manifests itself in the SLM image—projected onto the sample—as collected by the ccd camera, particularly on the ARRO-SAM system where the image is very sharp and clear. The camera shutter is not synchronised to the SLM, and so it is sensitive to the average light intensity. Since there is a certain amount of CW light leakage, a 'flipping' image is observed by the ccd camera for 'slow' repetition rates, ie rates < 100Hz.

In conclusion, the following points should be noted:

- The laser is **NOT** eye-safe if no trigger signal is applied to the Q-switcher—the mean output power is somewhere in the region of 400mW.

- For low flipping rates, a 'flipping' image will be observed by the ccd camera. However, the Q-switch is opening (ie the laser is firing) *only* when the SLM is in its 'true' state.

A Appendix—common terms and abbreviations

O-SAM Optical Scanning Acoustic Microscope

ARRO-SAM Adaptive Rolls Royce Optical Scanning Acoustic Microscope

SLM Spatial Light Modulator

QSW Q-switched

CW Continuous wave (on all the time, not Q-switched)

SAWs Surface acoustic waves

A/D Analogue to digital converter

PSU Power supply unit

ccd Charge coupled device

B Appendix—location of this document

`/home/share/documentation/o-sam/no_more_flipping.pdf`