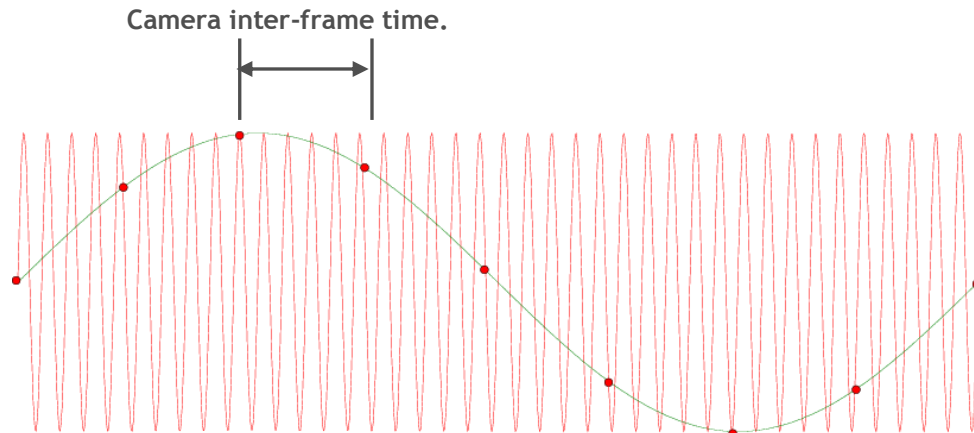Application Note AN-708

Vibration Measurements with the Vibration Synchronization Module

correlated

SOLUTIONS

Introduction

The vibration module allows complete analysis of cyclical events using low-speed cameras. This is accomplished by locking on to a drive or response signal, and taking images at user-defined phase intervals.

Camera inter-frame time.

Since the camera's frame rate may not be fast enough to image several times during a single cycle, we may skip several cycles before advancing to the next phase, but the signal is accurately tracked by the phase locking logic. For purely cyclical motion, this results in a replication of a single wave cycle.

Because the timing device used by the vibration module is very accurate, the practical limitation on the oscillation frequency is generally dependent on the camera sensitivity and the scene lighting, which both affect the system's ability to "freeze" the motion. The table below provides frequency range guidelines for several lighting options:

Light Source	Minimum Exposure Time	Recommended Frequency Range	Max Frequency
Room light	10ms	0 – 50Hz	100Hz
Halogen light	30μs	50 – 200Hz	500Hz
Stroboscope	1μs	100 – 4000 Hz	10kHz
Ultra bright stroboscope	40ns	2 – 10 kHz	50kHz

Applications for the module include:

- Tire and wheel testing
- Piston engines
- Speakers
- Flow-induced vibration
- Shake table tests
- Fatigue testing

Necessary equipment/software

Making measurements with the vibration module requires only the module, a standard Vic-3D system, and a facility for triggering the system's cameras. For most cameras this means either a simple trigger cable, or a trigger circuit such as that supplied in the ATB-5 trigger box. For events above the 500Hz range, a strobe will also be required.

The vibration module itself consists of a software module for Vic-Snap, as well as additional data acquisition hardware. This specialized hardware is used to provide highly accurate, low-latency analog triggering. Either a PCI card or an externally powered USB device can be used.

A cyclical signal corresponding to the system's drive or response is also necessary. Examples of such a signal include

- Sinusoidal drive signal to shake table
- Load signal from test frame in fatigue test
- Voltage to an audio speaker
- Once-per-revolution TTL pulse on tire test stand

The signal can be sinusoidal or otherwise as long as it's in phase with the specimen motion.

Connecting the system

At least two connections must be made in order to begin a measurement.

1) The drive signal should be connected to the "AI 0" input on the DAQ device. If present, the "FS/GS" (Floating Source/Ground Source) switch for this input should always be set to "FS".

2) The trigger output signal should be connected to the cameras or trigger box. This signal will usually be provided at either "CTR 0 Out" or "User 1".

3) Connect the trigger cables to the cameras, if you have not done so already.

See the appendix for a detailed view of these connections.

Test setup

Setting up for a vibration test begins with pointing and focusing the cameras, as with a quasi-static test. There is only one major additional concern – lighting. It will be necessary to calculate, or establish empirically, the exposure time required to freeze your motion.

In general, since Vic-3D is typically accurate to ~0.02 pixel, we would like to see motion of 0.02 pixel or less contained within the exposure time. For example, suppose we have a tire that is rotating at 120rpm, or 2Hz. The diameter of the tire is 635mm, and we want to image the whole tire using a 1m x 1m field of view, using 1024x1024 cameras.

Since we are imaging 1000mm with 1024 pixels, we have a magnification of about 1 mm/pixel. This means that we need to keep our motion below

$$0.02 \text{ pixel} * 1 \text{ mm/pixel} = .02\text{mm}.$$

Our tire has a circumference of

$$635\text{mm} * \pi = 1995\text{mm}$$

So our maximum velocity, at the rim, is

$$1995\text{mm} * 2\text{Hz} = 3990\text{mm/s}$$

This means our maximum exposure time is

$$0.02\text{mm} / 3990\text{mm/s} = .000005\text{s} = 5\mu\text{s}$$

We could accomplish this with a strobe light with a duration of <5μs. In practice, using a steady light and a camera with an exposure time of 20μs would give us very useful results; motions of .1 pixel or even .5 pixel can be accommodated at some loss of accuracy, given a properly coarse speckle pattern. Still, we would require a very strong light source in order to give a bright image with only 20μs of integration.

These calculations will be different for each test. Also, for a test where the motion is mainly out-of-plane, more motion can be tolerated because the pixel motions are relatively much smaller, compared to a test where the specimen is moving directly across the field of view.

You can check the blur visually to some extent by examining the live image, but even a barely visible blur can greatly reduce Vic-3D accuracy. The actual effect can be quantified in the **Error** score listed during correlation.

A final note - some cameras can streak at these very short exposure times, and some cameras will streak if light is present during their readout. For more information about the limits and capabilities of your specific setup, please contact Technical Support.

Software controls

To being a measurement, start Vic-Snap and click the **Fulcrum Dialog** toolbar button, or select *File… Fulcrum Dialog*. The Fulcrum control will appear in the workspace, and the cameras will be switched to hardware trigger mode.
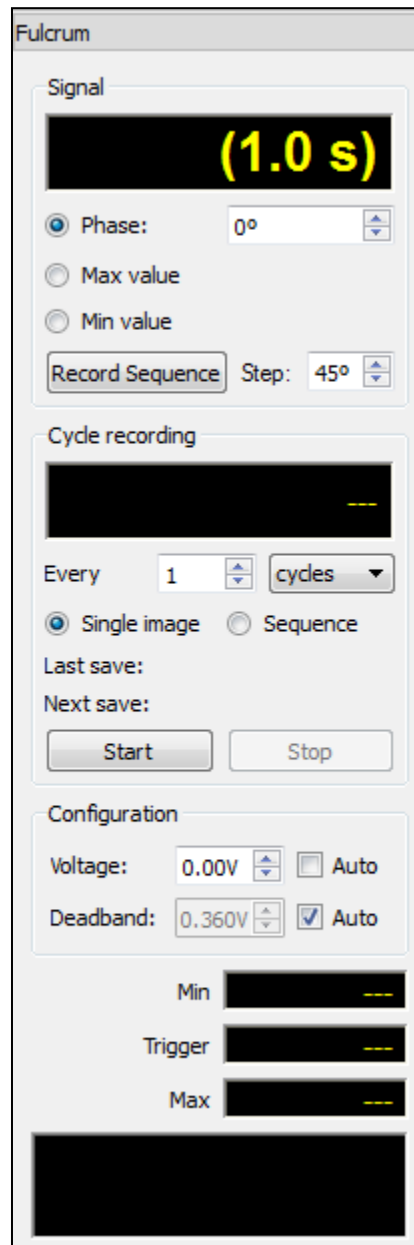
The (1.0 s) indicates that the signal is initially being sampled for 1.0 seconds to determine the levels. This time will be determined by the minimum frequency setting in the Advanced Options; for the best response, select a minimum frequency that is just lower than the lowest frequency you expect to measure. After the limits are found, the trigger voltage will be set to the mean voltage; the frequency should appear and the waveform will be displayed in the dialog.
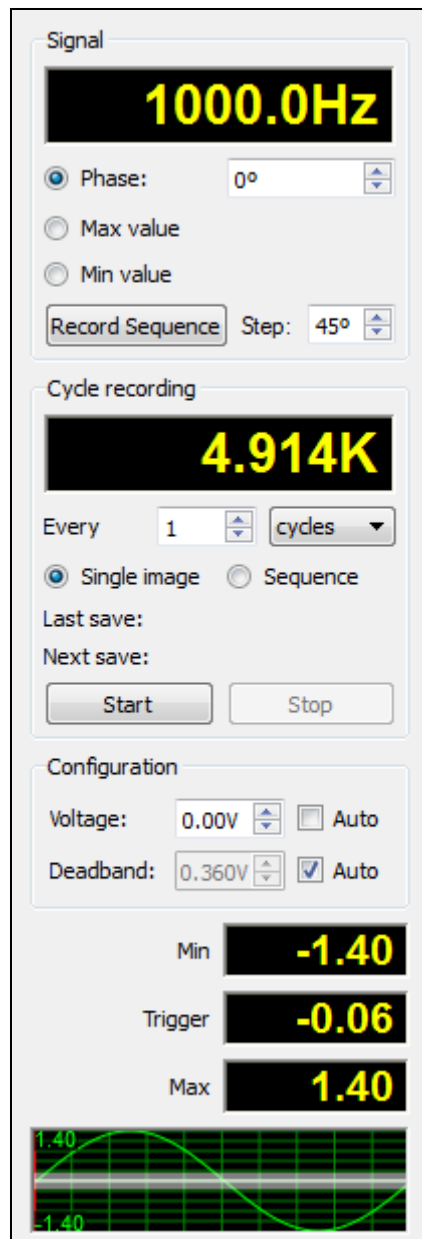
If the signal cannot be locked, the frequency box will display "---", and a piece of the waveform will be displayed to assist in diagnosis.
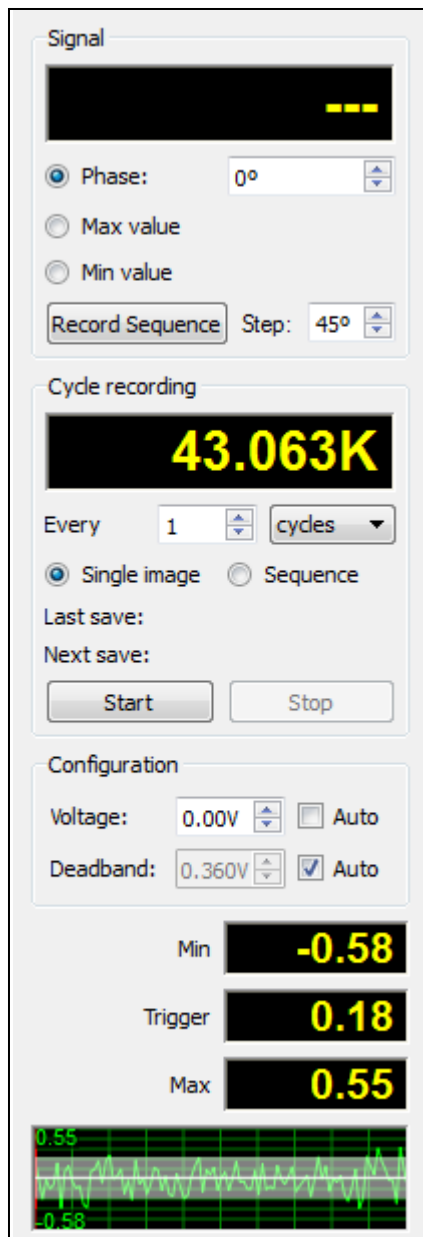
Once running, the cameras will be triggered at the specified phase (0°, to start). To change the phase that you are viewing, you can select a different value in the **Phase** control. The step for this control is determined by the **Step** control.

A sample waveform is displayed at bottom. The red vertical line in the waveform indicates the current trigger phase. The white horizontal line is the trigger voltage, and the white range is the current deadband.

Above the waveform display are indicators for the signal minimum (Min), maximum (Max), and the voltage at the trigger phase (Trigger). These values are scaled according to the scale and offset for channel 0, which can be edited from the Analog Data dialog.

To the top right, a counter displays the number of cycles that have passed since the control was opened. This count is an estimate based on the measured frequency; it should be quite accurate but is not an exact count of zero crossings. To reset this count, right-click on the value.

By default, the voltage and deadband are continuously and automatically adjusted. If you want to select a specific trigger voltage and deadband, you can clear the "Auto" checkbox and select the desired parameters.

Recording images

There are several options for recording images in the vibration module. Since the cameras are hardware triggered, always at the selected phase, you can simply use the space bar to capture individual images, as well as the timed and streaming capture modes.

To record a 360º sequence of your test, you can click **Record sequence**. The number of images taken will depend on the selected **Step**. For example, if the step is 10º, 36 images will be stored. The phase of the sequence always begins at zero; once complete, the phase will be reset to the value in the **Phase** control.

To record at specified cycles, select the interval (in cycles, kilocycles, or megacycles). You can choose to record a single image at your specified phase (**Single image**) or a 360 sequence as described above (**Sequence**). Then, click **Start.** An image will be taken immediately, and at even multiples of the selected interval. Since the Fulcrum module does not trap every single cycle, the actual cycle count at recording will be slightly higher than the target value. When testing is complete, you can click **Stop** to finish recording.


Data recording

When images are taken either manually or automatically, some relevant data is logged to the project's CSV file. The fields will be:

- Frequency: the frequency, in Hz, of the input signal

- Count: the total cycle count.

- Phase: the phase that each image was recorded at.

- Peak: the maximum voltage recorded during the cycle immediately prior to the trigger. Both scaled and raw values are recorded.

- Valley: the minimum voltage during the cycle.

- Trigger: the voltage at the trigger point.

This information can be imported into Vic-3D (***Project… Analog Data)*** and then various plots, such as phase vs. displacement, can be produced.
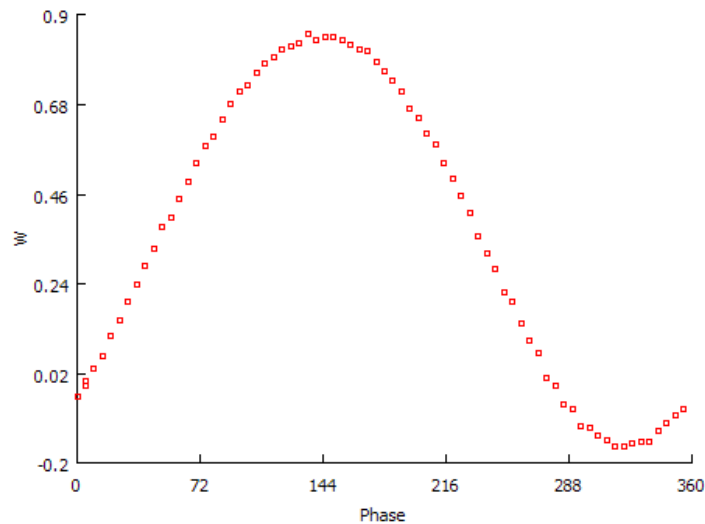
Phase vs. displacement plot for a speaker cone

**Usage Scenarios**

- **Cyclical testing**

    In this type of test, the **Record Sequence** button can be used to acquire a full sequence. Be sure that the specimen is in a stable-repeating mode before you start acquiring; acquire your sequence using whichever step you desire. You may wish to acquire multiple sequences for a given test; this will help determine whether a very weak response is actually a response, or only noise.

    You can repeat the test at different frequencies; be sure to let the system stabilize, if necessary, after a frequency change. You can also record a slow sweep, by clicking the **Auto** phase button and putting the system in **Streaming capture** mode. The sweep should be kept slow because the delay for each pulse is determined from the *previous* cycle's frequency.

    For cyclical testing, a decision needs to be made about the reference image. You can take a reference image of the system in a static/resting state in order to see strains and displacements relative to that state, or, you can select one of the moving phase images (such as the 0° image) as the reference to see results relative to this phase of the motion.

- **Fatigue testing**

    For this scenario, the phase stepping will generally not be used. Simply select the phase at which to take images – this phase is indicated by the red line on the scope display, so you can easily choose the minimum or maximum load, or a zero state, if you have a load or displacement signal. For example, here, the phase is set to record approximately at the maximum load:
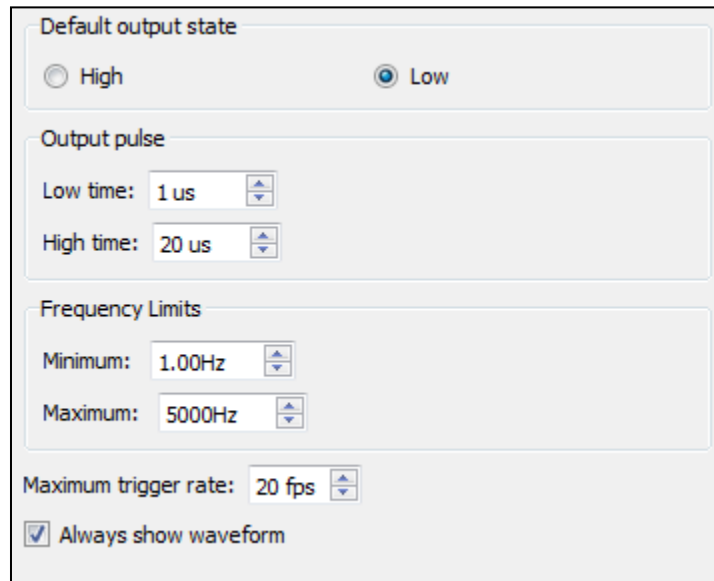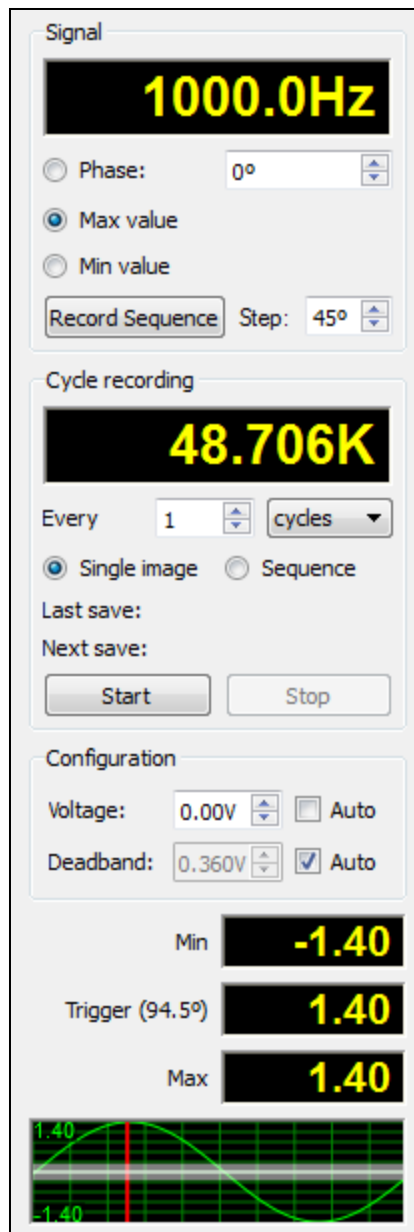
Then, use the Cycle recording interval in the Fulcrum dialog to record at set intervals. You can also use Timed Capture for this.

For this kind of test the reference image will typically be taken with the specimen unloaded or slightly preloaded, in order to give strains relative to a relaxed state. Your test requirements may vary from this, though.

Setting Advanced Options

Some adjustments will be found in the Advanced Options dialog (under *File… Advanced Options*), in the *Fulcrum* tab.

- Default output state: this controls the level of the output trigger signal in between triggers; high is TTL high, low is TTL low.

- Low time: when a trigger event occurs, this is the amount of time the output signal goes low before the pulse will be sent. If the default state is low, this will simply induce an additional delay.

- High time: when a trigger event occurs, the amount of time the output signal will stay high, after going low.

  Normally, the output state will be set low; the low time set to 0; and the high time set long enough to cause the cameras to trigger (20us generally works).

  For strobe applications, we can set the default state to **high**, and set a non-zero low time. If we set the camera to trigger on the *falling* edge of the output signal, and the strobe to trigger on the *rising* edge, we can introduce a delay so that the camera starts exposing before the strobe fires. This delay will be equal to the low time.

- Minimum frequency: set this to the lowest frequency you expect to measure. Setting this very low will increase the timeout values for the frequency and peak measuring functions, which can reduce responsiveness. For example, if this is set to 0.2Hz, the frequency function will wait a full 5 seconds before timing out and trying again.

- Maximum frequency: setting this frequency can guard against accidental triggering due to noise and lost signal. If the software measures a frequency higher than this, it will consider the signal lost. This also prevents accidentally counting erroneous cycles which can cause a false high cycle count.

- Maximum trigger rate: set this to something slightly less than the maximum frame rate of your cameras. This is important in order to avoid missed triggers.

- Always show waveform: if this is checked, the waveform display is updated every cycle. In this mode, the cameras will be triggered at most 1 cycle in every 4. With this option cleared, the waveform will only be updated when the signal is first locked; in this mode, the cameras can be triggered at most 1 cycle in every 2 (at lower frequencies).

Theory of operation

The vibration system operates by setting an analog trigger and window in the hardware DAQ device. This provides the basis of the trigger detection. To provide the phase delay, the measured period is multiplied by the selected phase to establish the delay. For example, if the frequency is measured at 1000Hz, and the requested phase is 180º, the trigger delay will be set at

$$(1/1000Hz)*(180º/360º) = 0.001s * .5 = 500\mu s.$$

This is important because it means that the phase delay has a slight lag. If the frequency of a cycle varies greatly from that of the previous cycle, the calculated delay in µs will no longer correspond to the requested phase in degrees. Very noisy signals will be subject to the same problem as the trigger will be found at slightly different points in each cycle.

Because of this effect, it's important to work with motion – and signals - that are very close to steady-state cyclical. For assistance optimizing your test, please contact Technical Support.

Support

If you have any questions about this Application Note or any other questions, comments, or concerns about your CSI system, please feel free to contact us at support@correlatedSolutions.com or visit our web site at www.correlatedsolutions.com.
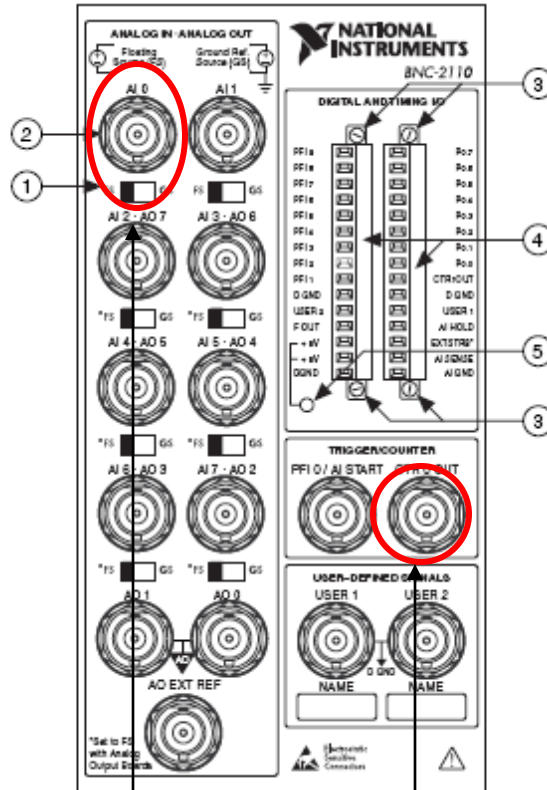
Appendix 1 – Hookup diagram (USB device)
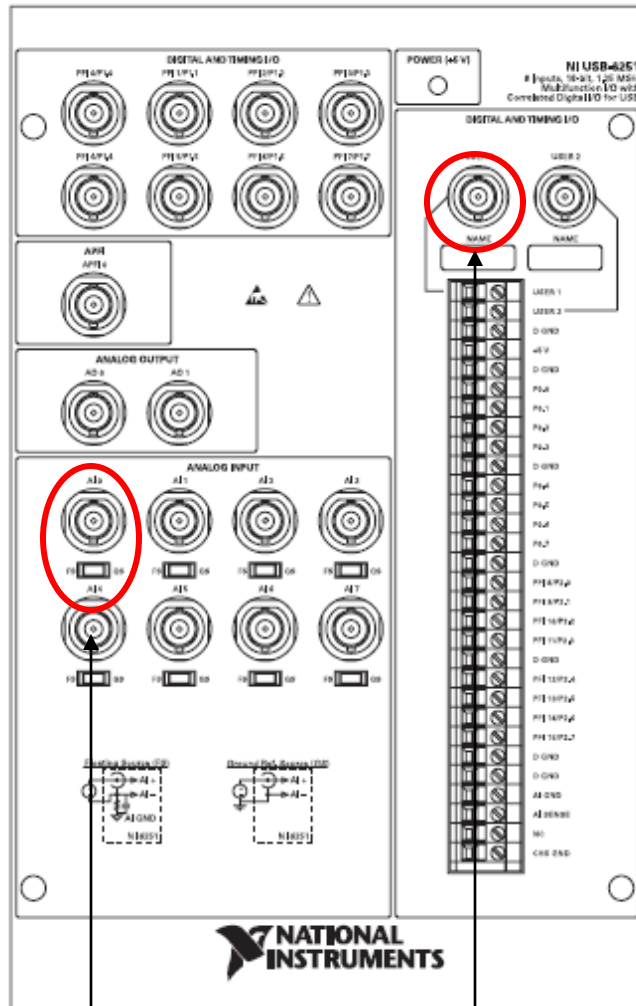
AI0. Set to 'FS', and connect input signal.
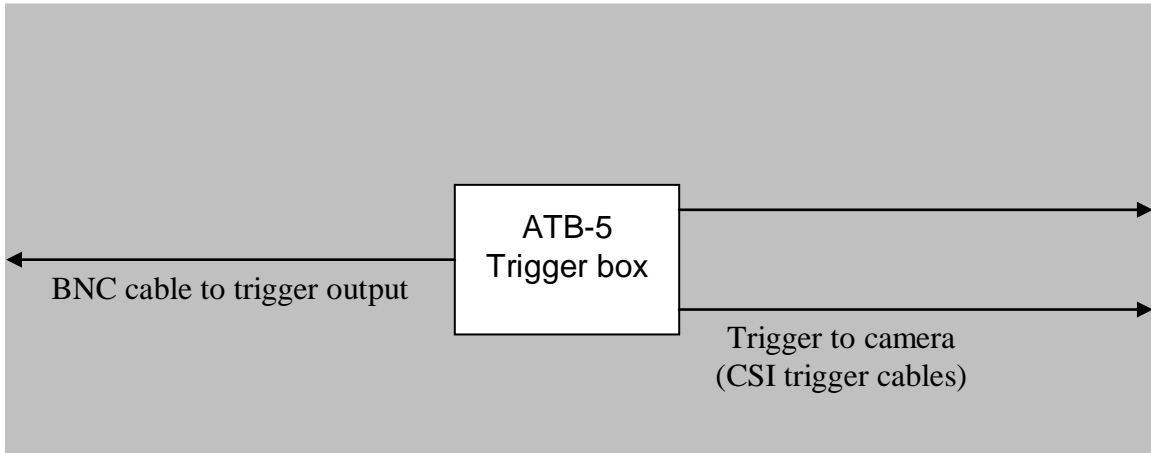
USER1. Connect to camera trigger input.
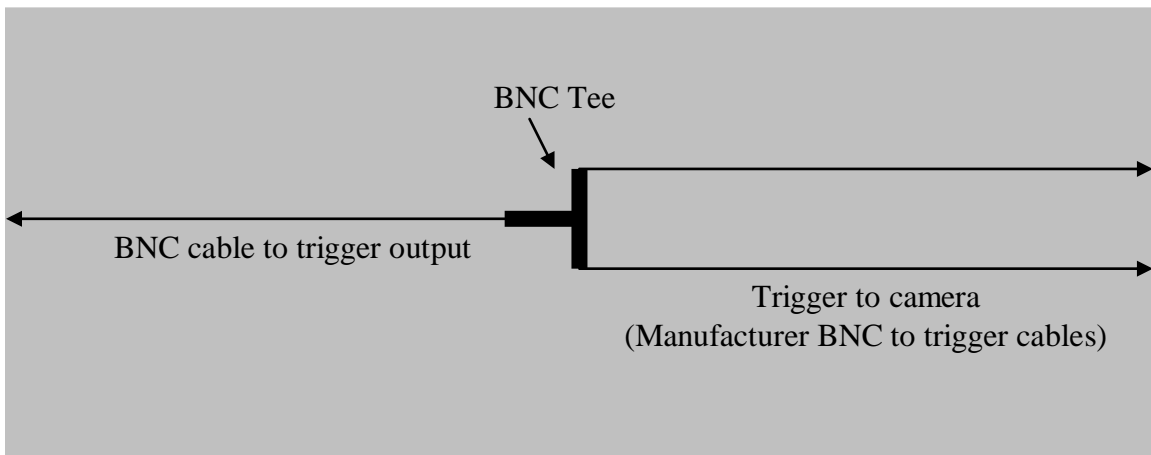
Appendix 2 – Hookup diagram (PCI device)

AI0. Set to 'FS', and connect input signal.

CTR0OUT. Connect to camera trigger input.

Appendix 3 – Hookup (trigger to cameras)

BNC cable to trigger output

ATB-5
Trigger box

Trigger to camera
(CSI trigger cables)

With ATB-5

BNC Tee

BNC cable to trigger output

Trigger to camera
(Manufacturer BNC to trigger cables)

Direct connection