Bore Controller

Licel GmbH

7. Oktober 2009

1 Introduction

In many LIDAR applications, daylight is among the major limiting parameters for the achievable signal range. By implementing a continuous monitoring and correction of the alignment, the telescope field of view can be reduced close to the laser beam divergence. This can improve operation of narrow field of view Raman or micropulse lidars and unattended operation. The LICEL bore sight alignment controller evaluates the image of the laser return from two user defined height ranges on a multi anode photomultiplier. It computes correction parameters for the beam steering.

The bore detection system consists of

- the detector head and
- the Ethernet controller.

The detector head includes a multi-anode PMT, a high voltage supply and the counting electronics. The Ethernet controller sends the controlling data and receives the counting data via a 2m long VHDCI cable.

1.1 Software package

In addition to the hardware Licel provides the source code for 3 typical tasks,

- Automated alignment tracking and correction for a lidar
- Live signal display
- Pulse height distribution software to determine the optimum discriminator level.

1.1.1 Alignment Software

The alignment software provides a standard shell that need to be adapted to the customer's drive control. The required changes are described in section 8 Software Preparation. Once the driver is adapted to specific drive and the opto-mechanical work outlined below is done, the lidar can be automatically kept at a predefined alignment. The idea behind the software is the following:

- The user defines a alignment as a known good position.
- The software will record the data and compute the current alignment
- Based on this data the software will move the drives so that the system goes back to that known good position.

1.1.2 Live Display

The data as it arrives is displayed and shows how the signal on the four quadrants change when the lidar alignment changes.

1.1.3 Pulse Height

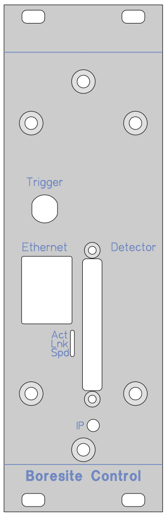
For a properly working system the discriminator level needs to be set. This level is dependent HV setting for the PMT and on the typical signal strength. In order to determine the optimum parameters the discriminator level can be varied when a constant signal level is applied and the resulting pulse height distribution can be used to determine the optimum parameter.

2 Preparations

Before installing the bore sight module the optical and mechanical layout of the detection system should be defined. The system needs the field stop imaged on the cathode surface. **Note:** This is different from the usual requirement to image the primary mirror on the detector.

The lens parameters together with the position of the lens and the detector head define the image amplification. To ensure that the laser beam is not lost the full field stop image should be slightly less than the 4 quadrants of the bore sight controller.

3 Wiring the Ethernet Controller

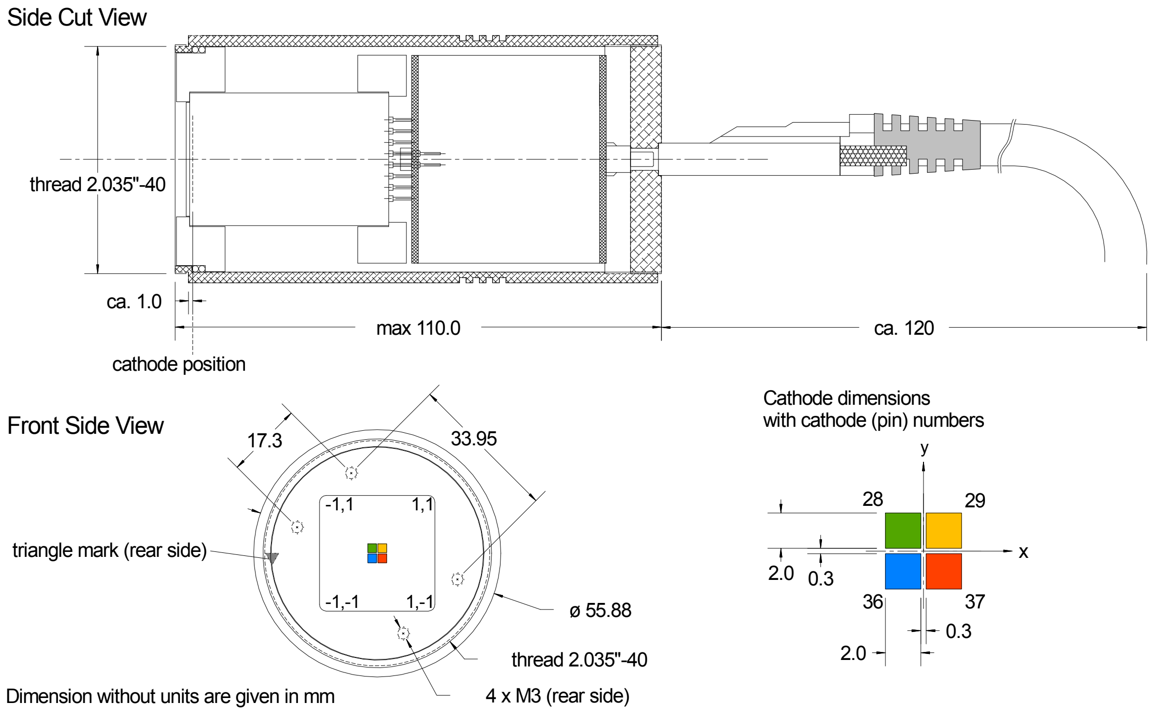


The Ethernet controller can be integrated into 19” racks (3 hight units). On the front panel 3 connectors are available:

- **Trigger** input socket (Lemo Camac, 4 V @ 1 kΩ)
- **Ethernet** connector, RJ45 connector for the connection to the controlling computer
- **Detector** socket, connector for the VHDCI cable to the detector head

At the rear panel of the controller a power supply (+15 V, 200 mA / -5 V, 200 mA / +5 V, 200 mA) must be connected, either directly to the transient recorder supply or to an appropriate external supply.

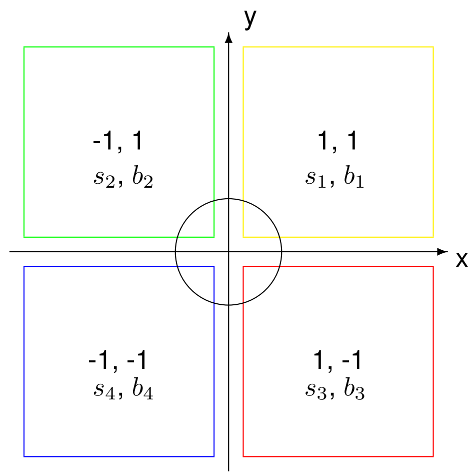
4 Mechanical Dimensions



To verify the orientation of the PMT check the triangle mark at the rear side. It designates the $-x$ axis.

5 Theory

The bore controller returns count rates for two height ranges for the four quadrants. This comes from the assumption that one part of the signal, typical the far field signal will be optimized. The background is a reference section and is needed for the offset correction. Each section has a start and a stop. Between them the counts are accumulated and averaged. So there are two sets of numbers. One set are the signal counts $S_{0...3}$ the other set are the background counts $B_{0...3}$. Both count rates can show pulse pile up and in this case need to be corrected for dead time effects.
To compute the background corrected count rates one has to subtract the B_i from the S_i first.



$$s_i = S_i - B_i \tag{1}$$

Assuming the coordinate (0,0) as the center of the four quadrant detector one can compute the center of gravity.

$$G_x = \frac{s_1 - s_2 + s_3 - s_4}{s_1 + s_2 + s_3 + s_4} \tag{2}$$

$$G_y = \frac{s_1 + s_2 - s_3 - s_4}{s_1 + s_2 + s_3 + s_4} \tag{3}$$

A shift of the beam axis $d\alpha$ will result in a shift of the beam image of over the detector by $r * d\alpha$. This shift will cause a signal reduction in one section and a signal increase in another section so that

$$dG_x \propto 2 * d\alpha_x \tag{4}$$
$$dG_y \propto 2 * d\alpha_y \tag{5}$$

Each sector can have a slightly different sensitivity. So even for equal S_i there is not guaranty that the spot is in the center. After a proper alignment is found the current G_{xy} values are used instead as reference values. During the tracking the difference between the current alignment and the reference point is used as the control parameter for correcting the drives.

$$\Delta drive_x \quad \propto \quad G_x - G_{x0} \tag{6}$$
$$\Delta drive_y \quad \propto \quad G_y - G_{y0} \tag{7}$$

The coordinate system of the detector can be tilted against the movement axes of the drives. It is preferable to avoid this otherwise one has to perform a sinus cosines transformation of the correction factor.

6 Signal to Noise considerations

The alignment requires a valid signal. This can be defined in two ways:

1. The signal is significant, this means the Poisson noise of the signal is much smaller than the signal itself.
2. The signal is much stronger than the background.

The first item can be controlled by choosing a sufficient large signal region, the signal can be as much as 1024 bins of 100ns. Further increasing the number of acquired shots will increase the SNR. However it does not make sense to increase both parameters too much:

- If the signal region is too large to much of the background will be covered or to much of the near field will be included while the far field should be optimized.
- If the shot number is too large the reaction to changes will be slow.

The software uses:

$$C = \sum S_i * (MHz\, per\, mean\, count) * (number\, of\, bins) * (number\, of\, shots) \tag{8}$$

to determine to overall number of counts in the signal. It computes the signal inherent SNR as

$$\frac{C}{\sqrt{C}} \tag{9}$$

and the SNR with respect to the background as

$$\frac{\sum s_i}{B} \tag{10}$$

and applies the same threshold to both.

7 Operation

For a successful operation of the bore sensor the following steps need to be accomplished:

1. Make a ray tracing simulation to determine the optical setup to image the field stop on to the detector
2. Prepare the software modules necessary to control the stepper drivers (see section Software preparation)
3. Mount the detector.
4. Setup the network interface of the controller following the guidelines from the Licel Ethernet Controller Installation and Reference Manual chapter 4.
5. Align manually the system to a position, which will be used as the reference position

6. Turn the high voltage of the detector on (**recommended 850-900 V, maximum 1000 V**)
7. Set the discriminator level. Use the `BorePulse` height Module to optimize the threshold level.
8. Supply a trigger signal to the Bore-Controller
9. Verify with `BoreLive` that a valid signal is received on all 4 sectors of the detector.
10. Using `BoreAlign` take a signal profile to verify the optimum positions for the background and the signal.
11. Once all of those parameters are setup, use the `BoreAlign` module and activate the `Keep Alignment` button.

8 Software preparation

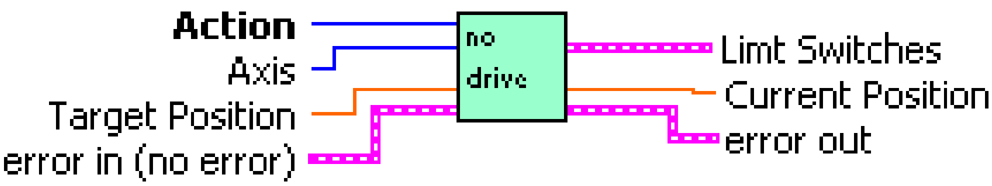
The bore controller gives the input for a steering system. The alignment application `BoreSiteAlign.vi` and a set of VIs is used to bring the system to control the stepping drives. All these VIs call *the same control VI* and pass a requested action to it. Dependent on this action the control VI organizes the communication with the drive controller.

8.1 Control VI

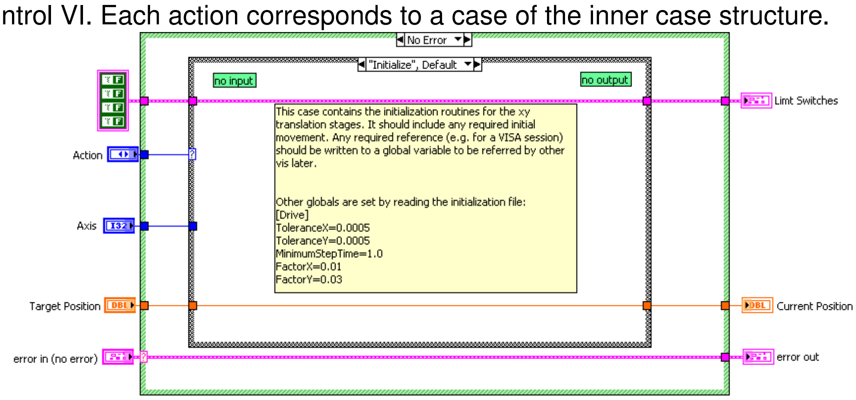
The control VI is loaded on start by `BoreSiteAlign.vi`. The following entry in the initialization file `BoreAnalysis.ini` defines the path of the control VI. The VI given here is found in any llb residing in the Bore directory.

```
[Drive]
ControlVI="BoreDrive NoDrive Control.vi"
```

Shown here is the standard entry which will result in loading `Bore Drive.llb\BoreDrive NoDrive Control.vi`. This VI will establish no communication with any drive controller but is intended to be used as a template for adding your own code in a LabVIEW case structure depending on the requested action.
The control VI must have the following wiring scheme:



The place to insert specific LabVIEW code (e.g. sub-VIs from a driver-llb) is found in the block diagram of the control VI. Each action corresponds to a case of the inner case structure.



The shell VIs calling the control VI are integrated into the `BoreAligment` module. In addition they have simulation code that interfaces with the Virtual Controller and allows to see the VI's in action without a controlling a real system.
The control VI is called by the following Shell VIs:

VI name	Action
BoreDrive InitializeDrive.vi	
BoreDrive GetCurrentPosXY.vi	
BoreDrive LimitSwitch.vi	
BoreDrive StartToXY.vi	
BoreDrive Brake.vi	
BoreDrive CloseDrive.vi	

Furthermore the shell VI BoreDrive DeviationToXY.vi is provided.

8.2 Initialize – BoreDrive InitializeDrive.vi

This vi contains the initialization routines for the xy translation stages. It should include any required initial movement. Any required reference (e.g. for a VISA session) should be written to a global variable to be referred by other vis later. It is suggested to use BoreDrive Globals.vi to store all drive related global variables. Other globals should be set here:

- X Tolerance The dead band for the drive in the x direction. If the alignment would result in movement smaller than this the movement will not be made.
- Y Tolerance The dead band for the drive in the y direction. If the alignment would result in movement smaller than this the movement will not be made.
- Minimum Time Minimum Time in seconds between two movements. This will prevent too frequent movement if a low shot number for averaging has been selected.
- StepperDriverSim This variable should be set to false to work with a real controller. If the simulation is activated the software will try to connect to a ethernet controller. This should be the Virtual Controller (a software module simulating the hardware module - see Licel Ethernet Controller Installation and Reference Manual chapter 8).

8.3 BoreDrive GetCurrentPosXY.vi

This VI should return the positions of the xy translation stages in their own coordinates (e.g. stepper counts, encoder counts...)

8.4 BoreDrive LimitSwitch.vi

This VI should return the status of the limit switches. A limit switch is considered active if a true boolean value is returned.

8.5 BoreDrive StartToXY.vi

Starts the movement of one or both drives to the desired positions

8.6 BoreDrive Brake.vi

This VI contains the routines to stop the drives.

8.7 BoreDrive CloseDrive.vi

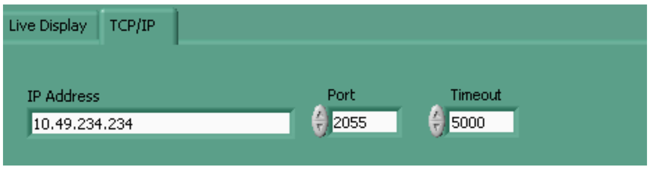
This VI contains the routines for the xy translation stages that need to be called on exit.

8.8 BoreDrive DeviationToXY.vi

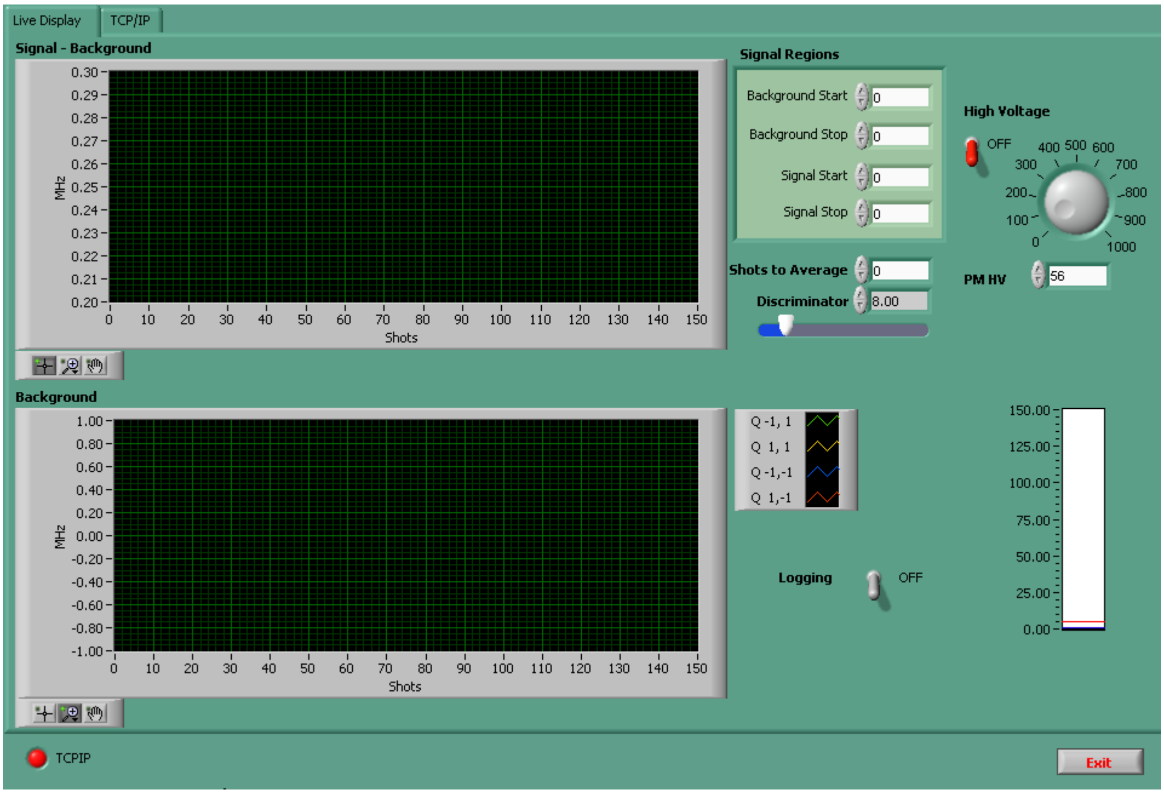
Compute the new target positions for both drives based on the current position, the target point, and the current alignment point. This VI does not have a direct hardware interface but it relates drive coordinates and the angular alignment parameter as described in Eqn. 6.

9 BoreLive.vi

You need to setup first the controller IP



Turn the detector high voltage on (a recommended value is around 850-900 V). Set the discriminator level and adjust the signal and background range to your needs.

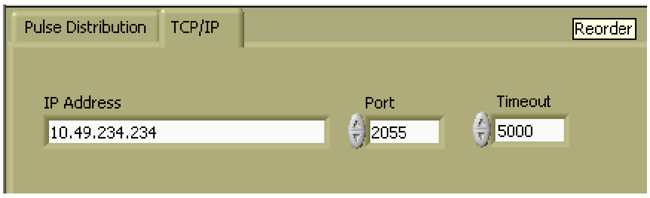


This module will give you a live sensor signal without any controlling of the drives

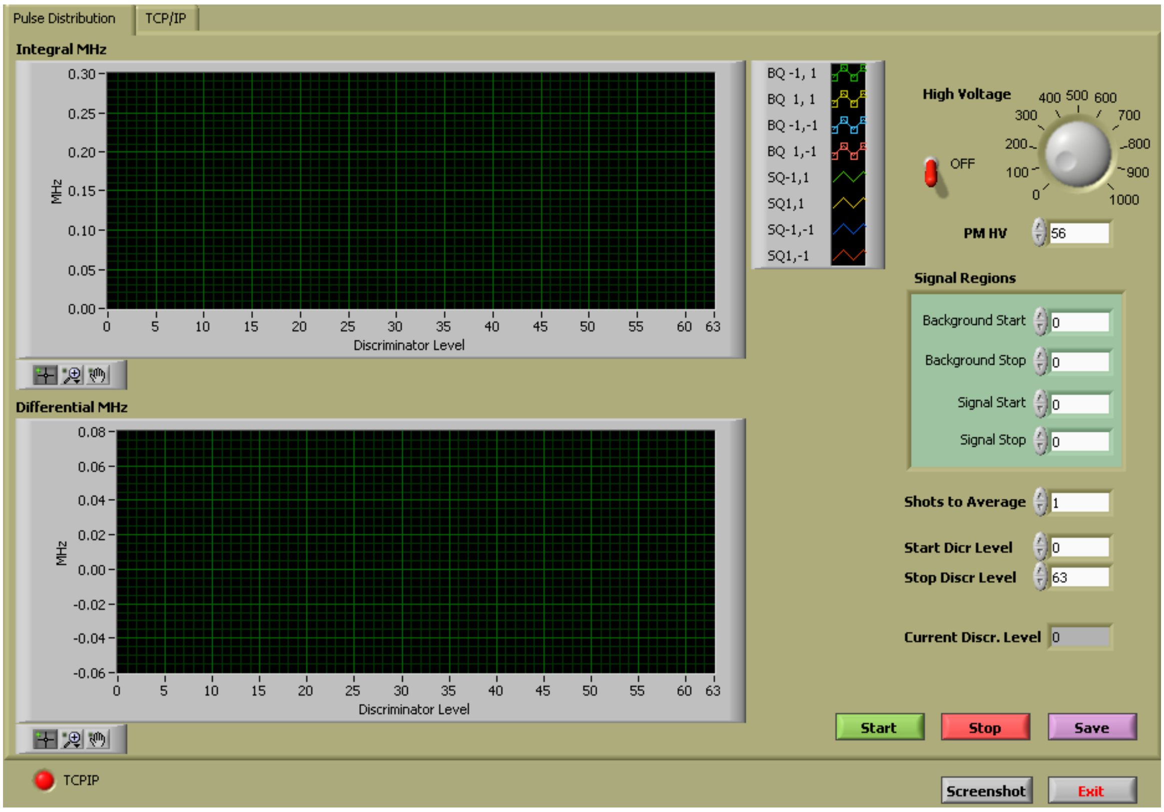
10 BorePulse.vi

This VI corresponds measures a pulse height distribution (PHD) for the detector. From the PHD one can determine the optimum discriminator level. The software is equivalent to the pulse height distribution for transient recorder.

You need to setup first the controller IP



Once the connection with the controller is established:

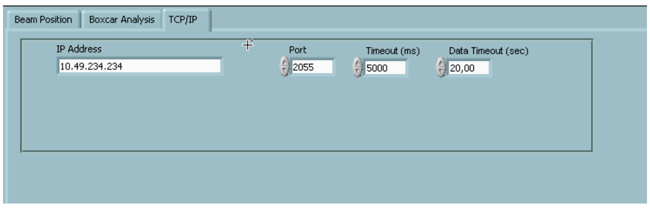


Set the high voltage for the detector, the signal region where you want to have the two range bins and the number of shots to measure. After pressing start a PHD will be recorded.

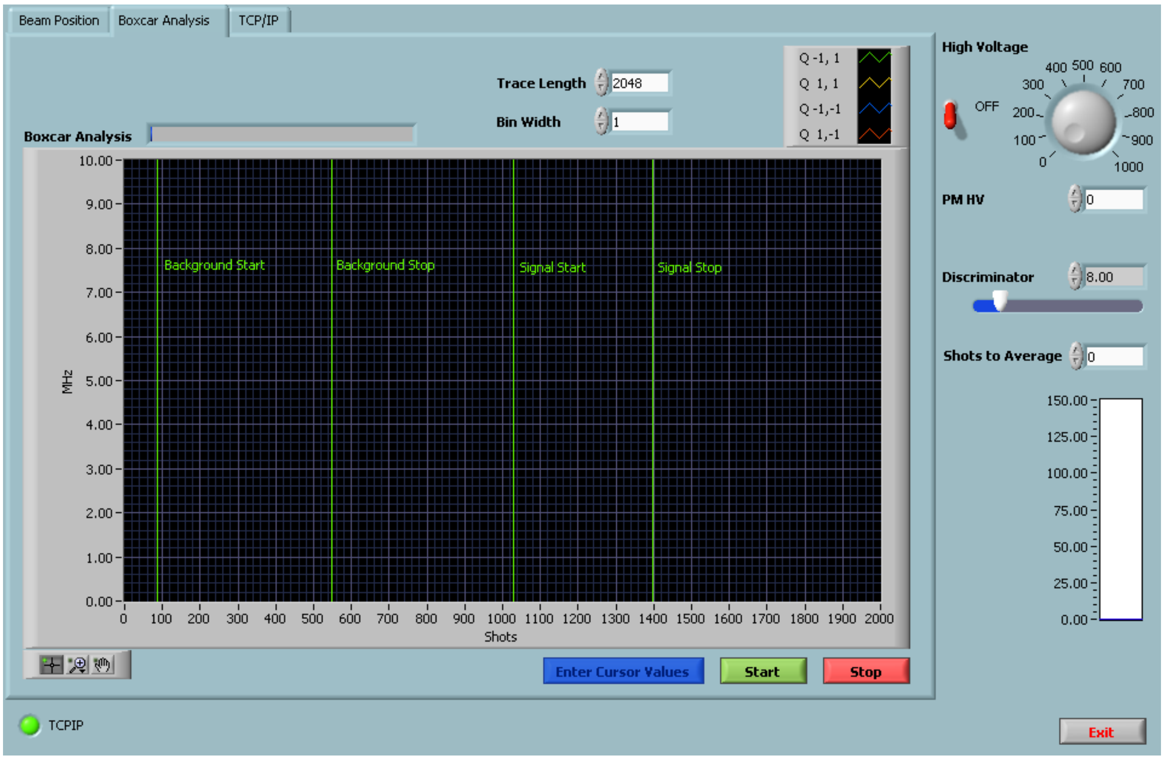
11 BoreSiteAlign.vi

This VI contains the driver control and is a example for tracking software. It has two sections the boxcar integrator mode and the tracking mode

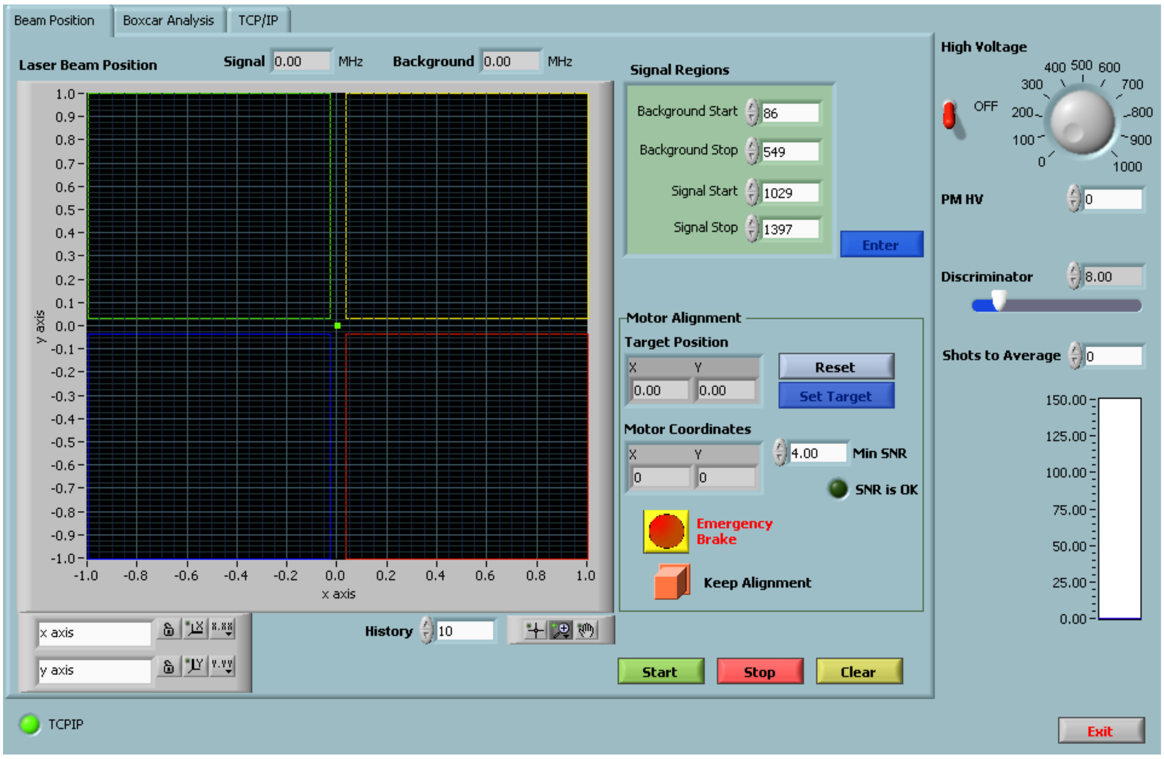
First one needs to setup the IP address for the connection



In Boxcar mode the signal and the background bins are shifted over the signal to give a impression of the signal and to help to make a decision where to place the signal and the background region. First one needs to turn the high voltage on, set the discriminator level and after pressing the start button an acquisition will start. This assumes that a trigger is supplied.



Once these regions are known, press the start button. The movement of the center of gravity position should be visible.



The next steps assume that you filled the VI's described above with your routines to control the stepper driver.

1. the current drive positions should be shown
2. assuming that you have enough signal the `SNR is OK` should become bright green. If it is not raise the number of shots to accumulate, increase the signal region or provide a better alignment.

3. once the SNR is good, you can define the current alignment as a reference point by pressing the target button.

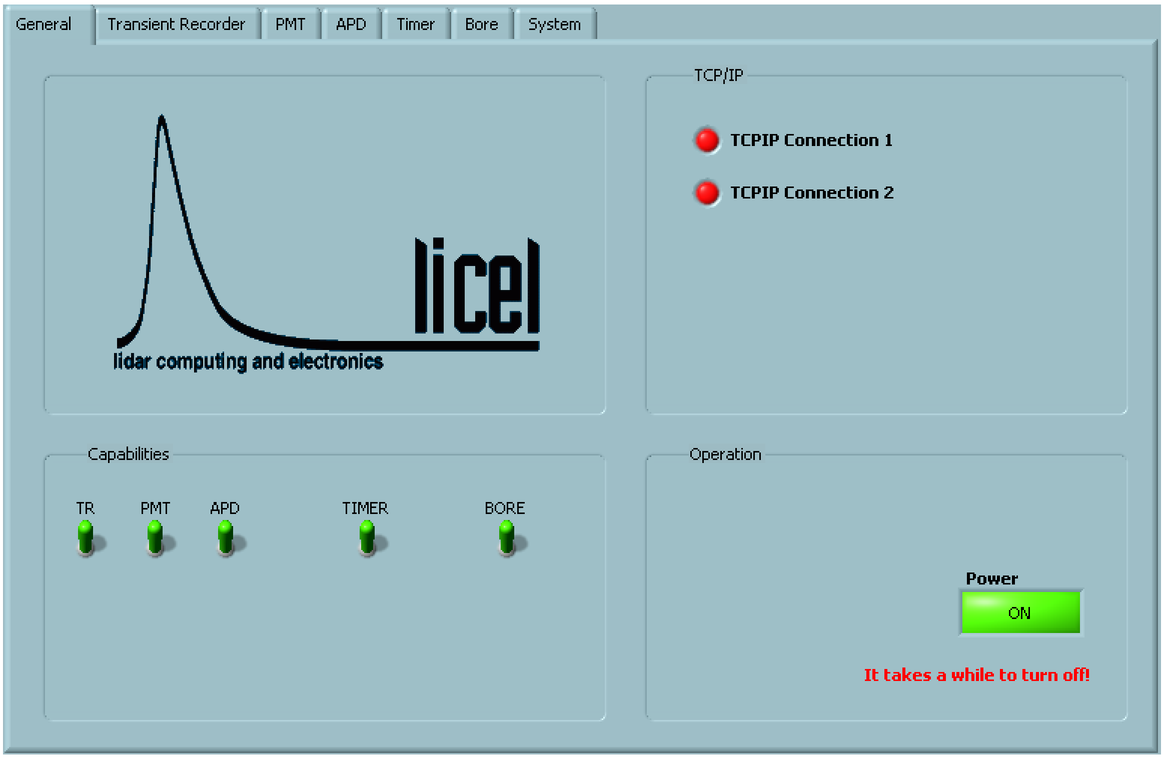
4. If this is done the tracking is activated by pressing the `Keep Alignment` button.

5. watch closely if the system starts to drift away stop the tracking by pressing the `Keep Alignment` button again so that it comes out. Probably the mathematical relation ship that you entered at `BoreDrive DeviationToXY.vi` needs to be corrected.

12 Simulation

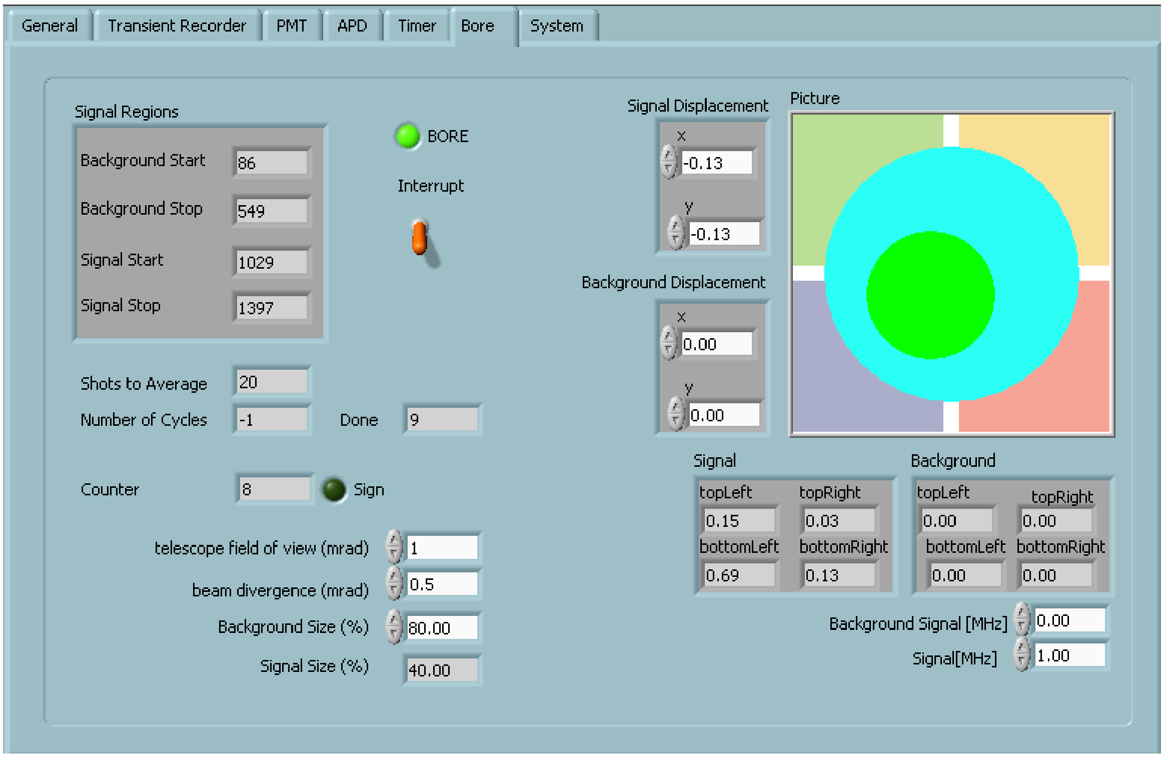
The whole Alignment Module can be also tested in Simulation mode. One needs a Virtual Controller. This is part of the executables in http://www.licel.com/download/ethernet/LVInstaller.zip

It should start up as



Please note the green `Bore` switch, indicating the support for the Bore commands. The general capabilities are described at in the Licel Ethernet Controller Installation and Reference Manual chapter 8.

In addition to the there described capabilities is one tab with the Bore support. This also provides as stepper driver simulation coupled with a alignment computation



To run the simulation start first the `Virtual Controller.exe`. Set the `StepperDriverSim` variable to true inside `BoreDrive InitializeDrive.vi`. Enter `127.0.0.1` as the IP number in the Alignment Software and start it. Once it runs the TCPIP indicators at the entrance panel should become green.

Repeat then the steps described above in the `BoreSiteAlign.vi` section. Press the start button at `BoreSiteAlign.vi` and see the simulation coming into live.

13 Low Level TCPIP access

13.1 Commands

The syntax of the commands is described in the Licel Ethernet Controller Installation and Reference Manual.

The bore controller implements the general commands:

- `*IDN?`
- `CAP?`
- `TCPIP`
- `LOGON`
- `WHITELIST`

The HV control is controlled via the PMT commands:

- `PMTSTAT?`
- `PMTGAIN`

The discriminator is controlled via

- `DISCRIMINATOR`

The following commands are unique for the controller:

- `ALIGNDATA`
- `ALIGNSIGN`
- `ALIGNTIME`

13.2 Align Sequence

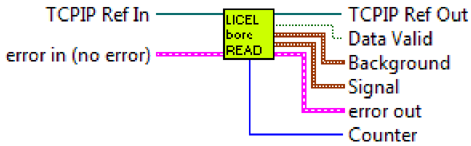
The following steps need to be executed to run the controller

1. Open the command socket - typical at 2055
2. Open the push socket - one port above the command socket
3. Set the signal and the background region with the `ALIGNTIME` command
4. Set the discriminator `DISCRIMINATOR` command
5. Turn the PMT high voltage on with the `PMTGAIN` command
6. Activate the data transmission with the `ALIGNDATA` command
7. Read the data from the push socket
8. If necessary change the alignment
9. In order to avoid to react on data that was recorded before the alignment change send the `ALIGNSIGN` command and wait till the counter sign in the received data changes.
10. Once the measurement is finished, stop the data with the `ALIGNDATA` command, turn the HV off with the `PMTGAIN` command.

13.3 LabVIEW TCPIP Bore VIs

Licel TCPIP Bore Get Data.vi

Read data transmitted by the bore sight detector.
The data has the format Align Info:id sig1 sig2 sig3 sig4 bg1 bg2 bg3 bg4, where id is a counter which absolutely increases with each transmitted data set. The sign of the counter can be toggled via the ALIGNSIGN command. sig1..4 and bg1..4 are the averaged signal and background values and for the involved channels and corresponding to the background and signal regions defined by the ALIGNTIME command



Licel TCPIP Bore Set Ranges.vi

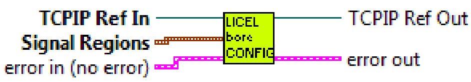
Configure the signal and background ranges at the bore sight detector using the `ALIGNTIME` command.
The input cluster **Signal Regions** contains the elements:

Background Start	Start bin of the background range
Background Stop	Stop bin of the background range
Signal Start	Start bin of the signal range
Signal Stop	Stop bin of the signal range

The following restrictions apply:

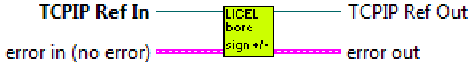
- $0 <$ Background Start < 1024
- Background Start $<$ Background Stop $< 1024 +$ Background Start
- Background Stop $<$ Signal Start $< 1024 +$ Background Stop
- Signal Start $<$ Signal Stop $< 1024 +$ Signal Start

where Background Start and Background Stop may pairwise be interchanged with Signal Start and Signal Stop.



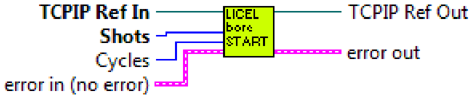
Licel TCPIP Bore Sign .vi

Changes the sign of the bore counter¡/P¿



Licel TCPIP Bore Start .vi

Start the acquisition at the bor sight detector.
Shots is the number of shots to acquire every cycle
Cycle specifies the number of acquisition cycles. When the number is reached, the controller will stop the acquisition. A value of -1 (default) has the meaning of infinite cacles i.e. the acquisition will be active until it is explicitely stopped.



Licel TCPIP Bore Stop.vi

Stop the data acquisition at the bore sight detector