

Helicity Board Generator at Jefferson Lab

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Abstract

Helicity board was designed to gene

Table of Contents

Abstract	1
Introduction	3
Why a New Helicity Board?.....	4
Helicity Board Modes.....	4
Line Sync Mode	4
Free Clock Mode	5
Helicity Board Registers	5
T_Settle Register	5
T_Stable Register	5
Helicity Pattern Register	5
Reporting Delay Register	6
Software	6
EPICS Channels.....	6
Programming	8
Pseudo-random Helicity Generator	9
Hardware Description	10
Helicity Board Inputs and Outputs.....	12
LED Signals	12
LEMO Signals.....	12
Fiber-Optic Inputs ($\lambda=820$ nm)	13
Fiber-Optic Outputs ($\lambda=820$ nm).....	13
Relative Timing of Helicity Board Outputs.....	24
Helicity Flip and Pockels Cell High Voltage	26
IA Control Signals	26
Fibers Distribution in Injector	30
Fibers Distribution to the Halls	31
How to Reduce 60 Hz Line Noise?	32
Helicity Board Tentative Configuration for PREx and Qweak.....	36
Sign of Physics Asymmetry	38
Helicity Board Circuit Diagram	39
Electronic Cross-talk and Ground Loop Elimination in the Injector.....	39

Introduction

A new Helicity Control Board was installed in November 2009. The new board provides more outputs and easier to re-program than the old one. The initial programming was chosen to meet the requirements of the current experiments. Changes are very easy to make and there is no limitation on the outputs. However, there are two main issues to keep in mind when selecting the outputs: first, the Pockels Cell response to the high voltage (HV) switching and, second, the Data Acquisition systems (DAQ) of the Halls. In specific, the choice of the T_Settle has to be long enough to allow for the Pockels Cell to “settle” and the choice of the helicity reversal frequency has to be matched with the speed of the DAQ.

The Helicity Board is an “Advanced Programmable Logic Generator”. One of its outputs (Helicity Flip signal) is used to control the high voltage (+3 kV or -3 kV) of the Pockels Cell on the Laser Table in CEBAF Injector. This change in Pockels Cell HV changes the circular polarization (left-handed or right-handed) of the laser light which in turn changes the direction of spin of the photo-emitted electrons relative to its momentum. The electron spin is either aligned parallel or anti parallel to the electron momentum; this is called electron helicity. Thus one signal from this logic generator changes the helicity of the electron beam and hence this board is called the Helicity Board.

The Helicity Board will operate at one of four timing selections. Three are fixed-frequencies of 30 Hz, 120 Hz, and 240 Hz triggered by "Line Sync". The phase locking is forced during the last T_Stable period. The T_Settle time period may be chosen from the T_Settle Register values. The T_Stable selection is disabled in this mode.


The fourth mode of operation allows the board to operate in free-running mode, where T_Settle and T_Stable values are selected from the values in the registers.

The Reporting Delay is selected from a register and determines how many windows there are between the real time Helicity Flip signal and the Delayed Helicity signal.

The Helicity Pattern may be selected to provide three pseudo-random patterns: Pair, Quartet, and Octet. In these patterns, the first window is chosen using the pseudo-random bit Shift Register. The forth pattern is pair Toggle. The free-running mode has two additional pseudo-random patterns to choose from: Hexo-Quad and Octo-Quad.

Note that when talking about frequency: it is the frequency of the T_Settle signal (f) and this will be labeled as the Helicity Board Frequency. Note that the Pair Sync signal will have $f/2$ frequency. The Pattern Sync signal will have $f/4$ when the helicity pattern is Quartet. The Delayed Helicity will have a

frequency of $f/2$ when in Toggle Pattern. When the pattern is one of the pseudo-random patterns, the frequency of the Delayed Helicity signal varies.

In this document, there are three ways to indicate a helicity state: either 0, 1 (+, -) or . Each helicity state is called a window.

Why a New Helicity Board?

It was time to upgrade the Helicity Board for the following reasons:

- I. Clean up leftovers from G0. Drop the "MPS" label.
- II. Make it easy to program and easy to choose any reversal rate and any T_Settle time.
- III. Change the Shift Register to 30-Bit. The old one is 24-Bit and would repeat in a shorter time (1 day compared to 50 days in the case when the Helicity Board frequency is 1 kHz).
- IV. Add a new pattern: Octet (+ - - + - + + - or - + + - + - - +).
- V. Add new fiber output signals:
 1. 2 additional outputs for 4-way Intensity Attenuator (IA) feedback scheme where the applied IA voltage is determined not only from the current helicity state but also from the current and previous helicity patterns.
 2. Output of the Helicity Board 20 MHz Clock signal.

Helicity Board Modes

There are two modes of the Helicity Board:

Line Sync Mode

There are three line synced fixed-frequencies of 30 Hz, 120 Hz, and 240 Hz triggered by "Line Sync". The phase locking is forced during the last T_Stable period. The T_Settle time period may be chosen from the T_Settle Register. You cannot choose T_Stable in this mode only T_Settle. Once you select Line Sync Mode, the T_Stable menu bar is disabled.

Free Clock Mode

This mode of operation allows the board to operate in free-running mode, where the T_Settle and T_Stable values are selected from the tables below. In this mode, you can select any T_Settle and any T_Stable. This is the DEFAULT Mode.

Helicity Board Registers

These registers have the listed values. We can choose whatever we want to fill them.

T_Settle Register

There is a Five-bit R/W register that determines the "T_Settle" portion of the helicity period. The settle time selections are as follows:

10 μ s, 20 μ s, 30 μ s, 40 μ s, 50 μ s, 60 μ s, 70 μ s, 80 μ s, 90 μ s, 100 μ s, 110 μ s, 120 μ s, 130 μ s, 140 μ s, 150 μ s, 160 μ s, 170 μ s, 180 μ s, 190 μ s, 200 μ s, 250 μ s, 300 μ s, 350 μ s, 400 μ s, 450 μ s, 500 μ s, 550 μ s, 600 μ s, 700 μ s, 800 μ s, 900 μ s, 1000 μ s.

T_Stable Register

There is a Five-bit R/W register that determines the "T_Stable" portion of the helicity period. The stable time selections are as follows:

400 μ s, 500 μ s, 600 μ s, 700 μ s, 800 μ s, 900 μ s, 971.65 μ s, 1000 μ s, 1001.65 μ s, 1318.90 μ s, 1348.90 μ s, 1500 μ s, 2000 μ s, 2500 μ s, 3000 μ s, 3500 μ s, 4066.65 μ s, 4500 μ s, 5000 μ s, 5500 μ s, 6000 μ s, 6500 μ s, 7000 μ s, 8233.35 μ s, 8333.35 μ s, 16567 μ s, 16667 μ s, 33230 μ s, 33330 μ s, 50000 μ s, 100000 μ s, 1000000 μ s.

Helicity Pattern Register

There is a Three-bit R/W register that determines the Helicity Pattern. The pattern selections are as follow:

Pair (+ - or - +), Quartet (- + + - or + - - +),

Octet (+ - - + - + + - or - + + - + - - +),

Hexo-Quad (+ - - + + - - + + - - + - + + - - + + - - + + - or

- + + - - + + - - + + - + - - + + - - + + - - +),

Octo-Quad (+ - - + + - - + + - - + + - - + - + + - - + + - - + + - or

- + + - - + + - - + + - - + + - + - - + + - - + + - - + + - - +),

and Toggle (+ - + - + - + - ...).

Reporting Delay Register

There is a three-bit R/W register that determines the delay of the Delayed Helicity signal relative to the real time Helicity Flip signal. The delay time in units of helicity windows is selected as follows:

No Delay, 1 window, 2 windows, 4, 8, 12, 16, 24, 32, 40, 48, 64, 72, 96, 112, and 128 windows.

For example a Quartet has 4 helicity windows.

Software

EPICS Channels

These are the old channels:

Table 1: A list of the EPICS Channels used with the old Helicity Board.

| Channel | Name | Value |
|--------------------------------|---------------|-------------|
| G0 Helicity Settle Set | HELG0TSETTLEs | 500 μ s |
| G0 Helicity Delay Set | HELG0DELAYs | 8 windows |
| G0 Helicity Pattern Set | HELG0PATTERNs | Quartet |
| G0 Helicity Random/Toggle Set | HELG0ORDERs | Random |
| | | |
| G0 Helicity Settle Read | HELG0TSETTLEd | 500 μ s |
| G0 Helicity Delay Read | HELG0DELAYd | 8 windows |
| G0 Helicity Pattern Read | HELG0PATTERNd | Quartet |
| G0 Helicity Random/Toggle Read | HELG0ORDERd | Random |

These are the new channels:

Table 2: A list of the EPICS Channels used with the new Helicity Board. These are the settings used during the PVDIS experiment.

| Channel | Name | Default Value |
|-------------------------------|-------------|---|
| Helicity Clock Set | HELCLOCKS | Free Clock |
| Helicity Reporting Delay Set | HELDELAYS | 8 windows |
| Helicity Pattern Set | HELPATTERNS | Quartet |
| | | |
| Helicity Clock Read | HELCLOCKd | Free Clock |
| Helicity T_Settle Read | HELTSETTLEd | 500 μ s |
| Helicity T_Stable Read | HELTSTABLEd | 33330 μ s |
| Helicity Reporting Delay Read | HELDELAYd | 8 windows |
| Helicity Pattern Read | HELPATTERNd | Quartet |
| Helicity Board Frequency | HELFREQ | (calculated frequency, not a readback) 29.5596 Hz |

Below is the relation between the Numeric Value and Text for the Mode (**HELCLOCKd**). Type "caget -n" to get the numeric value instead of the string:

- 0 = 30 Hz Line Sync
- 1 = 120 Hz Line Sync
- 2 = 240 Hz Line Sync
- 3 = Free Clock

Below is the relation between the Numeric Value and Text for the Helicity Pattern (**HELPATTERNd**). Type "caget -n" to get the numeric value instead of the string:

- 0 = Pair
- 1 = Quartet
- 2 = Octet
- 3 = Toggle
- 4 = Hexo-Quad
- 5 = Octo-Quad

Below is the relation between Numeric Value and Text for the Reporting Delay (**HELDELAYd**). Type "caget -n" to get the numeric value instead of the string:

- 0 = No delay
- 1 = 1 window
- 2 = 2 windows
- 3 = 4 windows
- 4 = 8 windows
- 5 = 12 windows
- 6 = 16 windows
- 7 = 24 windows
- 8 = 32 windows
- 9 = 40 windows
- 10 = 48 windows
- 11 = 64 windows
- 12 = 72 windows
- 13 = 96 windows
- 14 = 112 windows
- 15 = 128 windows

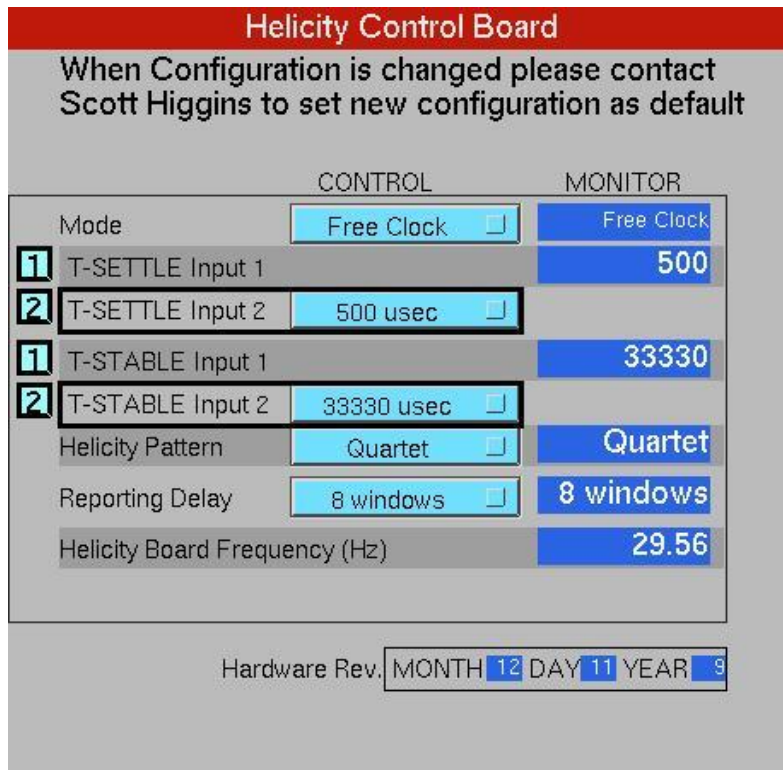


Figure 1: Helicity Board Control Screen. There are two pull-down menus for T_Settle and two menus for T_Stable. In Free Clock Mode, all menus are available. In Line Sync Mode, only the menus of T_Settle are active; T_Stable menus are inactive.

Programming

Figure 1 shows the control screen for the new Helicity Board. The following shows how to use the board.

1. Select Mode:
 - I. Line Sync (force phase-locking during last T_Stable):
 - Select Helicity Board Frequency f : 30 , 120, or 240 Hz Line Sync
 - Select T_Settle value between 10 μs – 1,000 μs
 - Display T_Stable (T_Stable selection is disabled):

$$T_{Stable} = \frac{1}{f} - T_{Settle}$$

The Line Sync jitter will show up in the last window of the pattern. For example with “240 Hz Line Sync” and Octet Pattern, the first 7 windows will have a length of 4,167 μs and the 8th window will be 4167 μs \pm Line Sync jitter. The length of this last window can be used to monitor the jitter in the 60 Hz line frequency.

II. Free Clock:

- Select T_Settle value between 10 μs – 1,000 μs
- Select T_Stable value between 400 μs – 1,000,000 μs
- Display Helicity Board Frequency (Reversal Rate):

$$f = \frac{1}{T_{\text{Settle}} + T_{\text{Stable}}}$$

2. Select Helicity Pattern:

Pair, Quartet, Octet, or Toggle. The free-running mode has two additional patterns to choose from: Hexo-Quad and Octo-Quad. If these two additional patterns were inadvertently selected with the Line Sync mode, the board will default to Toggle.

3. Select Reporting Delay: n Windows, n = 0 ... 128 windows

Pseudo-random Helicity Generator

A 30-Bit Shift Register is used to generate the pseudo-random bits: 0, 1 (or +, –) which determines the first window of a pattern. This removes any correlation between the helicity of the beam and any other device in the accelerator or in the Hall. It is a pseudo-random bit, not “random”, because it is deterministic, once a sequence of 30 bits is known, the next bits can be predicted, and it repeats after the maximal length. For any initial register value, there are $2^{30} - 1 = 1,073,741,823$ (maximal length) random bits before the sequence repeats, 50 days for 1000 Hz helicity reversal rate and a Quartet Pattern. Figure 2 shows the 30-Bit shift register.

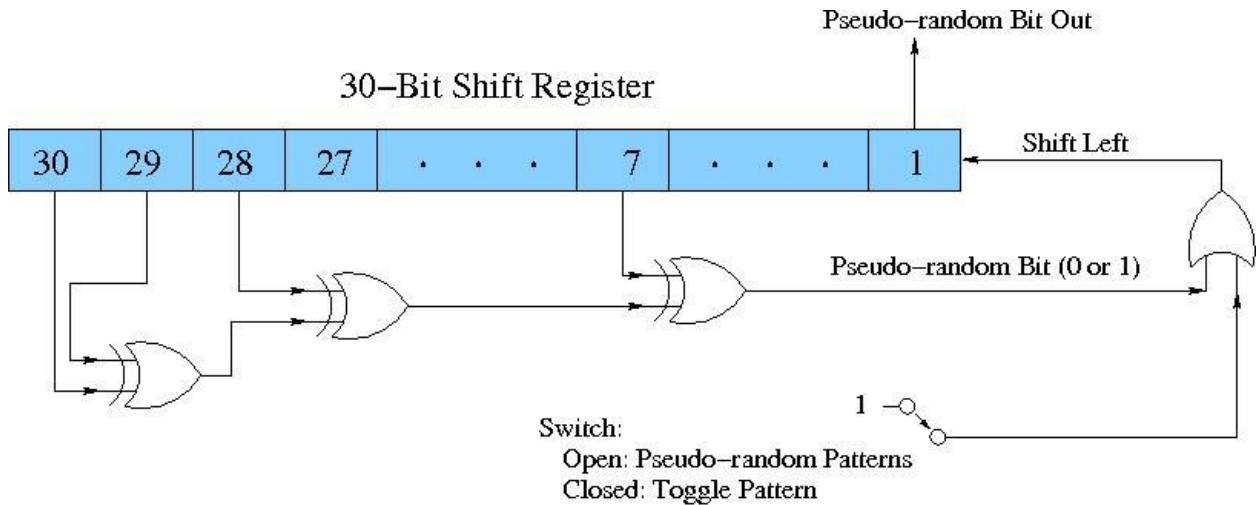


Figure 2: The 30 Bit Shift Register used to generate the pseudo-random bit. This bit is an XOR of bits 30, 29, 28, and 7.

The following C++ code can be used to initially fill the Shift Register and to predict the helicity bit:

```

UInt_t RanBit(UInt_t hRead)
{
    UInt_t bit7  = (fgShreg & 0x00000040) != 0;
    UInt_t bit28 = (fgShreg & 0x08000000) != 0;
    UInt_t bit29 = (fgShreg & 0x10000000) != 0;
    UInt_t bit30 = (fgShreg & 0x20000000) != 0;
    UInt_t newbit = (bit30 ^ bit29 ^ bit28 ^ bit7) & 0x1;
    fgShreg = ( hRead == 2 ? newbit : hRead ) | (fgShreg << 1 ) & 0x3FFFFFFF;
    return newbit;
}

```

During analysis of the parity data, the first 30 patterns of each typically 1 hour long data runs are used to initialize the Shift Register (these data patterns are thrown away). After the initialization, the analysis code can predict what the next pseudo-random bit will be. This prediction is compared to the actual helicity of the first window of each pattern in the data to make sure things are fine. Polarimeters and non-parity experiments usually do not perform this check.

Hardware Description

The Helicity Control Board is located in an isolated crate in the Injector Service Building, see Figure 3. This crate is powered by an Isolation Transformer and is floating at 65 VAC. Follow instruction posted on the rack when working there.



Fiber Cable

Isolation Transformer

Power Cable with ground pin removed

Ground Rod

Figure 3: Rack that houses the Helicity Control Board. The crate inside is powered by an Isolation Transformer and is floating at 65 VAC. Follow safety procedure when working in this rack. The ground pin of power cable from the Isolation Transformer is removed.



Figure 4: Helicity Control Board and its crate. The name of the crate is “iochelgen”. There are 12 fibers connected to this crate. The first 10 fibers carry signals to (Line Sync) and from (9 signals) the Helicity Board. Fiber 11 is iochelgen TX and Fiber 12 is iochelgen RX.

Helicity Board Inputs and Outputs

Figure 4 shows the new Helicity Control Board. The following describes the new board front panel.

LED Signals

1. HEL REQ BIT/8 (Left): Provides a visual indication of the below signal divided by 8.
2. HEL REQ BIT (Right): Provides a visual indication that a new pseudo-random bit is being requested from the generator. In free-running mode this can appear as a steady-state signal.

LEMO Signals

Upper left to lower right:

1. (Input): Hard-wired Schmitt-trigger TTL input. No connection to the FPGA logic at this time.
2. (I/O): Jumper-selectable Schmitt-trigger TTL I/O connection to the FPGA logic. Presently configured as an output with signal IA1.

3. (I/O): Jumper-selectable Schmitt-trigger TTL I/O connection to the FPGA logic. Presently configured as an output with signal Pattern Sync.
4. (I/O): Jumper-selectable Schmitt-trigger TTL I/O connection to the FPGA logic. Presently configured as an output with signal IA0.

Fiber-Optic Inputs ($\lambda=820$ nm)

1. Line Sync: This is the standard accelerator 60 Hz Line Sync signal. It is generated from the zero-crossings of Virginia Power line signal inside the 60 Hz Line Synchronization chassis in rack IN03B21.
How accurate is the line frequency? Is it 60 Hz or 60.000 Hz? The answer depends on what time span you average. The 60 Hz power line frequency is known to be relatively stable to about 59.70 ± 0.05 Hz, see Reference [?]. This gives an average period of $16,675 \pm 15$ μ s. This is not exactly Gaussian, there are also outliers.

Fiber-Optic Outputs ($\lambda=820$ nm)

The first 8 fibers have Agilent HFBR-1412 transmitters, the Clock fiber has Agilent HFBR-1414 transmitter.

1. Patter Sync (old name QRT): Indicates the start of each pattern. If the pattern is Pair, then it is identical to Pair Sync, see Figure 7. This signal goes to the users.
2. T_Settle (old name MPS): Indicates the time the DAQs will not collect data allowing for the Pockels Cell to settle. This signal goes to the users and the Helicity Magnets crate. This signal can also be called T_Stable since when it is not true the Pockels Cell is stable.
3. Helicity Flip: This is the signal that goes to the Pockels Cell and IAs. The Pockels Cell changes its voltage with this signal thus changes the circular polarization of the laser light, see Figure 26. Its length is T_Settle + T_Stable. This is the real time helicity and goes only to the Laser Hut in CEBAF Injector. The IAs used to implement helicity-correlated charge feedback receives this signal, too. For one helicity, 0 voltage is applied to the IA and for the other helicity a voltage of up to ± 60 V is applied.
4. nHelicity Flip: Complementary to the Helicity Flip signal. This way the board always draws the same current regardless of the helicity being 0 or 1 and further protects against any electrical pickup from the Helicity Board. This real time helicity signal goes to the crate that controls the Helicity Magnets. This is a floating crate located in the 5 MeV region in CEBAF Injector and powered by an isolation transformer with its power cable ground pin removed, see Figure 5.
5. Delayed Helicity: This signal is delayed by n windows, where n is chosen from Reporting Delay Register. It tells what the helicity was n windows before. This way no devices on the beamline or

in the Halls know what the real time helicity is. In analysis, the data are shifted to match it with its helicity. This signal goes to the users, iocse9 and iocse14 in BSY.

Note that the last n windows of data in each DAQ run are thrown away because the DAQ does not receive the actual helicity of these data (although it is known from helicity prediction).

6. Pair Sync: This signal toggle between 0 and 1, otherwise it looks like the helicity signal. Some DAQs used this signal to construct T_Stable (the integration window). It goes to the users.
7. IA0: This is an IA Control signal that indicates the current pattern. It goes to the Laser Hut in CEBAF Injector.
8. IA1: This is an IA Control signal that indicates the previous pattern. It goes to the Laser Hut in CEBAF Injector.
9. 20 MHz Clock: This is the internal Helicity Control Board clock. It goes to the Qweak ADCs in Injector and Hall C as external clock. It will be used as the reference clock for the ADCs. It will ensure that all the crates are sampling the same times. It is also used to sync the Hall A raster.

The Halls only receive the following signals: T_Settle, Pair Sync, Pattern Sync, and Delayed Helicity. Hall A and Hall C also receive the 20 MHz Clock signal. Only the Parity DAQs make use of the four signals and data are analyzed according to the pattern generated by the Helicity Board. Other DAQs use some of them. For example:

- I. Accelerator FFB Measurement of Charge Asymmetry and Position Differences: This measurement uses the BPMs in Hall A Arc (iocse9) and the BPMs in Hall C Arc (iocse14). The only signal these iocs receive is the Delayed Helicity. The analysis software is hard-coded to drop the first part of each helicity window that corresponds to T_Settle (assumes T_Settle is 500 μ s). Also a Reporting Delay of 8 windows is hard-coded. The data are analyzed in pairs.
- II. 100 keV/500 keV and 5 MeV Injector Mott Polarimeter DAQ: Uses only T_Settle and Delayed Helicity with Reporting Delay set to No Delay and the data are analyzed in pairs regardless of the Helicity Pattern.
- III. Hall A Spectrometer DAQ, Parity DAQ, Moller Polarimeter DAQ, and Compton Polarimeter DAQ: All use the four signals and analyze the data according to the pattern generated by the Helicity Board.
- IV. Hall B CLAS DAQ and Moller Polarimeter DAQ: Only used Delayed Helicity and Pair Sync. The Pair Sync signal was used to make a 500 μ s veto signal for the DAQ. Now, the DAQ has been changed to use T_Settle instead. Data are analyzed in pairs.
- V. Hall C QWeak Parity DAQ and Moller Polarimeter DAQ: Hall C does not receive Pair Sync signal. Data are analyzed according to the pattern generated by the Helicity Board.

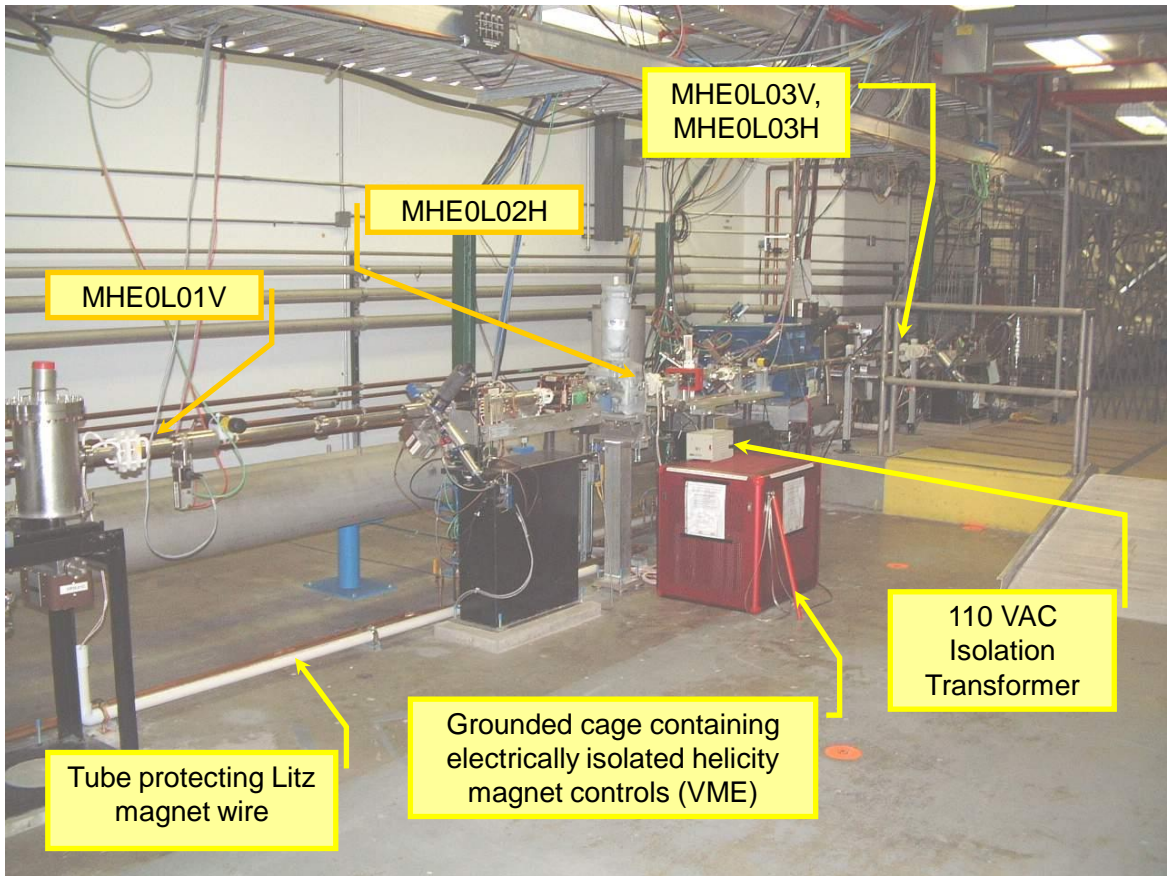


Figure 5: Rack that houses the Helicity Magnets Controller. The crate inside is powered by an Isolation Transformer with the ground pin of the power cable from the Isolation Transformer is removed. This crate receives two signals: nHelicity Flip and T_Settle.

Figure 6 - Figure 23 show the outputs of the helicity board using a scope.

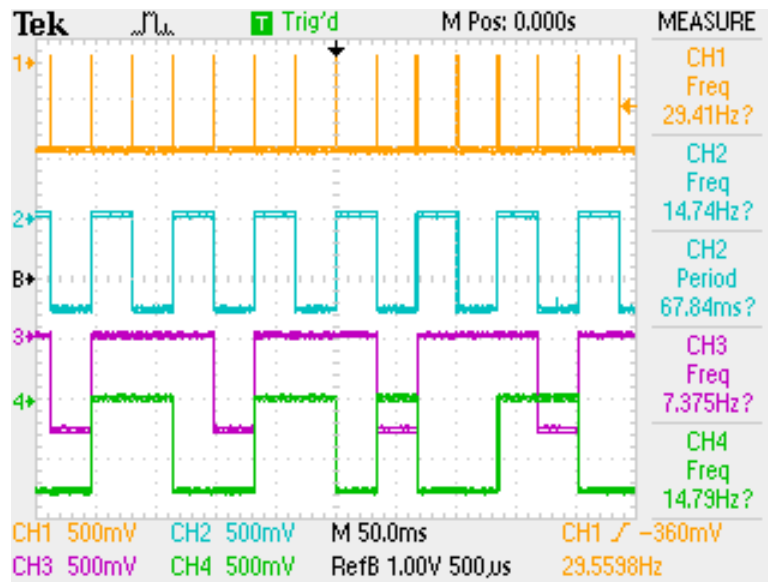


Figure 6: CH1: T_Settle, CH2: Pair Sync, CH3: Pattern Sync, CH4: Delayed Helicity. This was the configuration for Hall A PVDIS experiment.

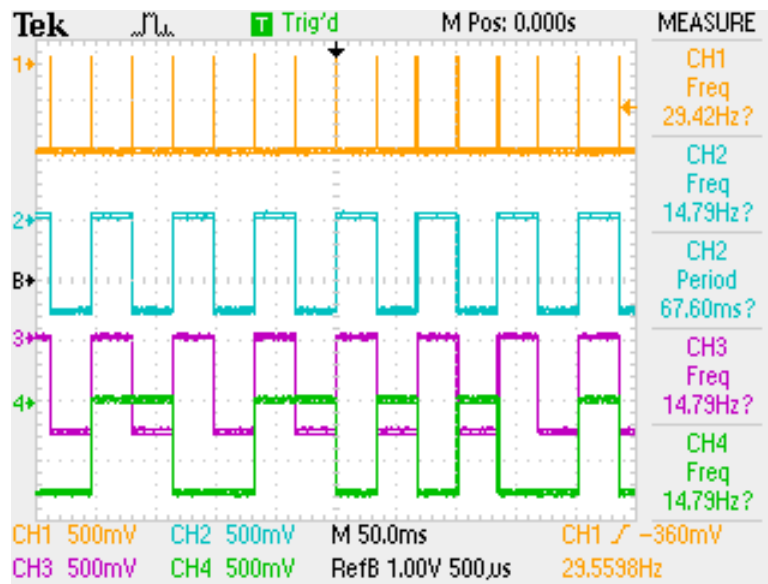


Figure 7: CH1: T_Settle, CH2: Pair Sync, CH3: Pattern Sync, CH4: Delayed Helicity. The Helicity Board settings are: Pair Pattern.

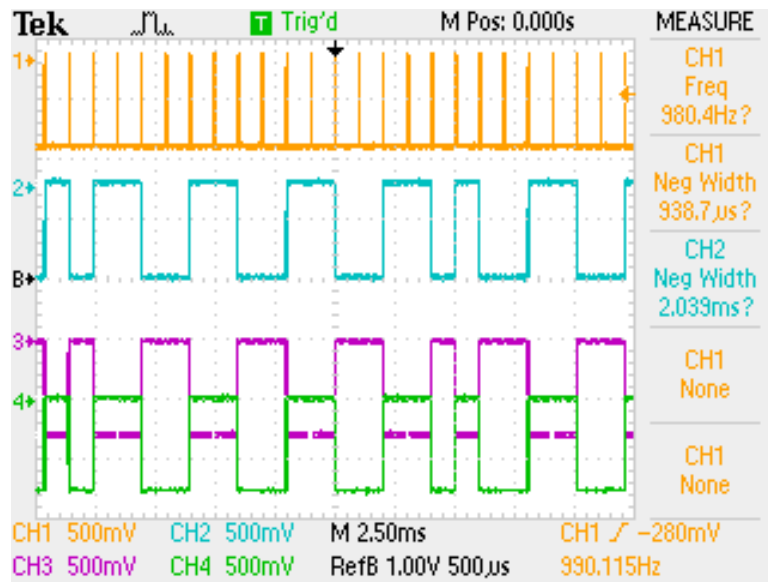


Figure 8: CH1: T_Settle, CH2: Helicity Flip, CH3: nHelicity Flip, CH4: Delayed Helicity. The Helicity Board settings are: No Delay.

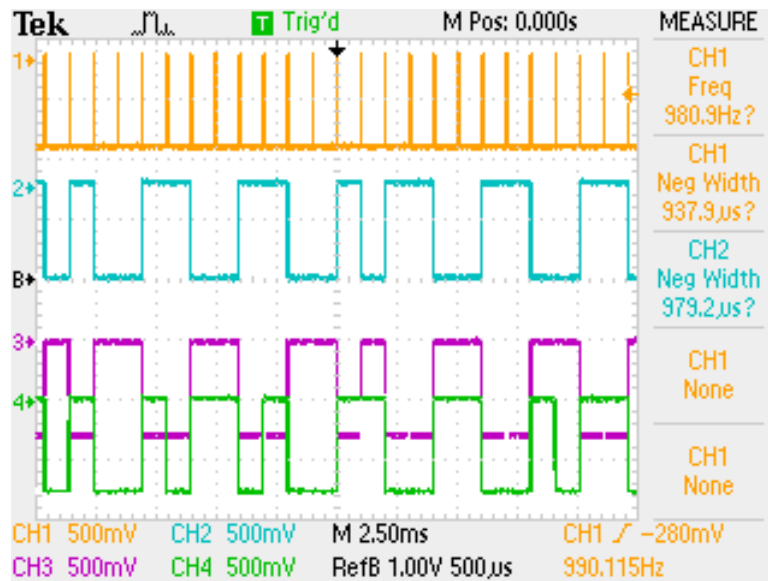


Figure 9: CH1: T_Settle, CH2: Helicity Flip, CH3: nHelicity Flip, CH4: Delayed Helicity. The Helicity Board settings are: Reporting Delay is 8 windows.

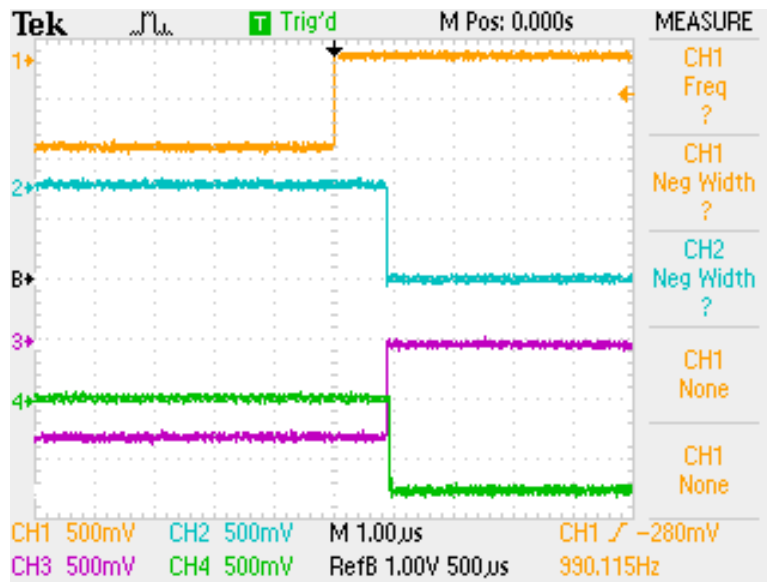


Figure 10: CH1: T_Settle, CH2: Helicity Flip, CH3: nHelicity Flip, CH4: Delayed Helicity. The delay is 8 windows.

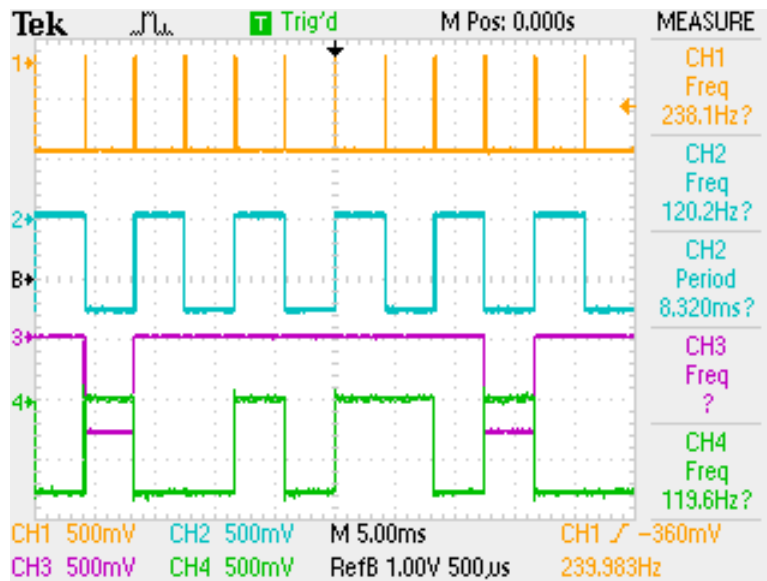


Figure 11: CH1: T_Settle, CH2: Pair Sync, CH3: Pattern Sync, CH4: Delayed Helicity. The Helicity Board settings are: T_Settle = 100 μs, T_Stable = 4067 μs, Free Clock, Octet Pattern.

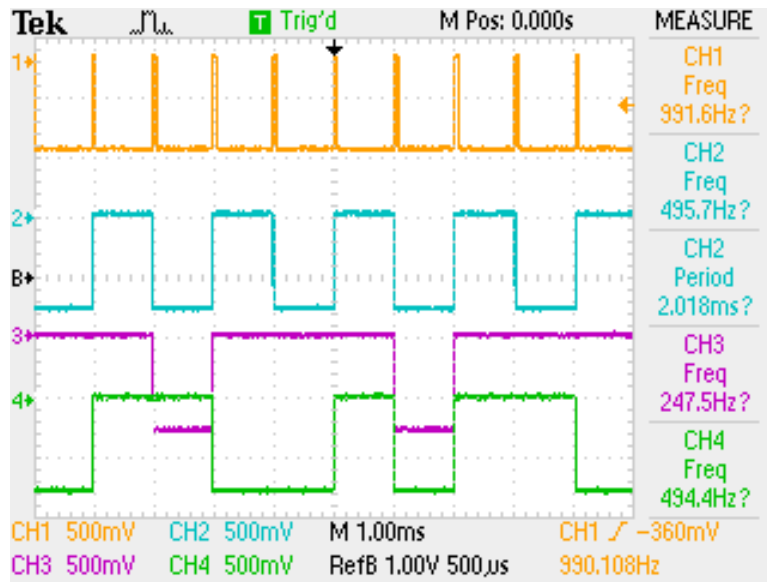


Figure 12: CH1: T_Settle, CH2: Pair Sync, CH3: Pattern Sync, CH4: Delayed Helicity. The Helicity Board settings are: T_Settle = 60 µs, T_Stable = 900 µs, Free Clock, Quartet Pattern.

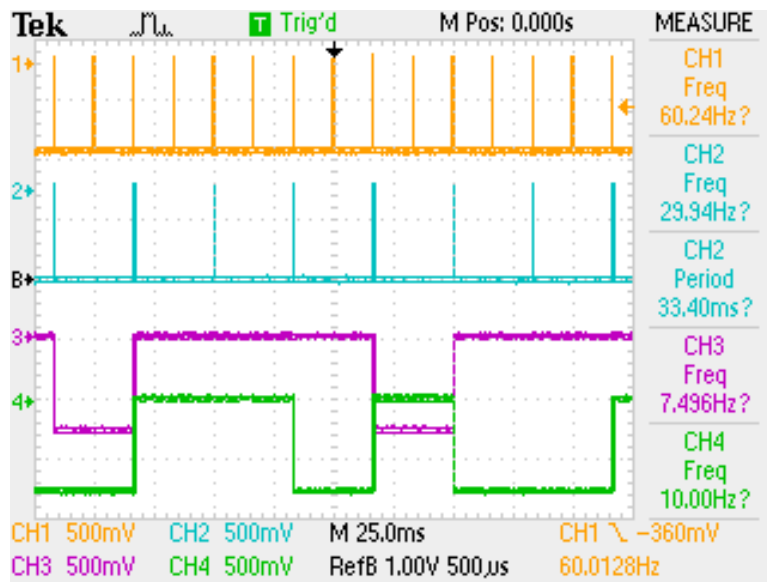


Figure 13: CH1: Line Sync, CH2: T_Settle, CH3: Pattern Sync, CH4: Delayed Helicity. The Helicity Board settings are: 30 Hz Line Sync Mode and Quartet Pattern.

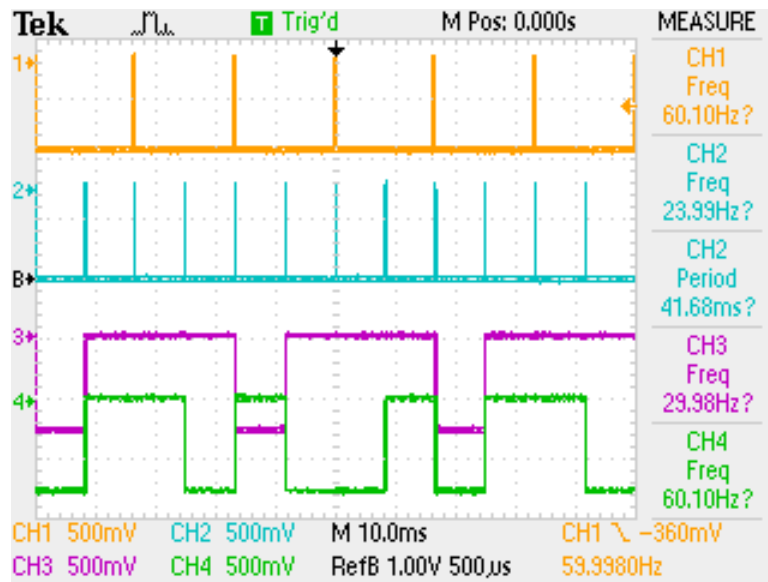


Figure 14: CH1: Line Sync, CH2: T_Settle, CH3: Pattern Sync, CH4: Delayed Helicity. The Helicity Board settings are: 120 Hz Line Sync Mode and Quartet Pattern.

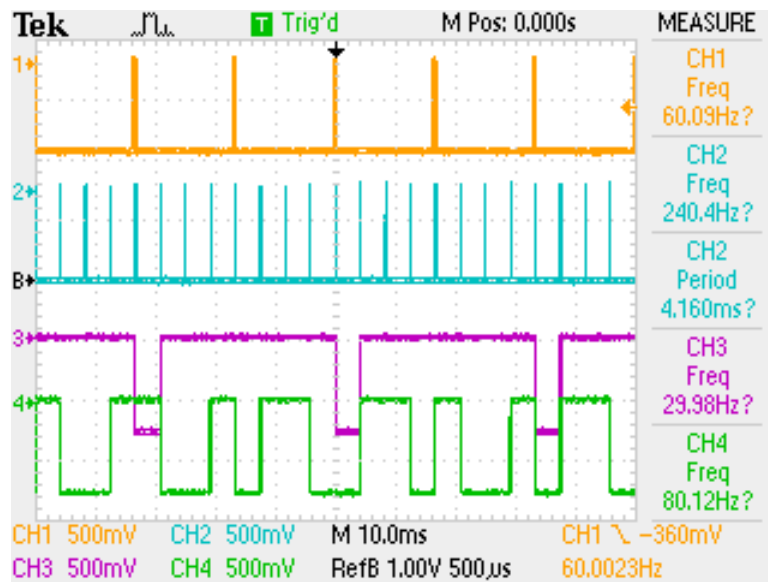


Figure 15: CH1: Line Sync, CH2: T_Settle, CH3: Pattern Sync, CH4: Delayed Helicity. The Helicity Board settings are: 240 Hz Line Sync Mode and Octet Pattern.

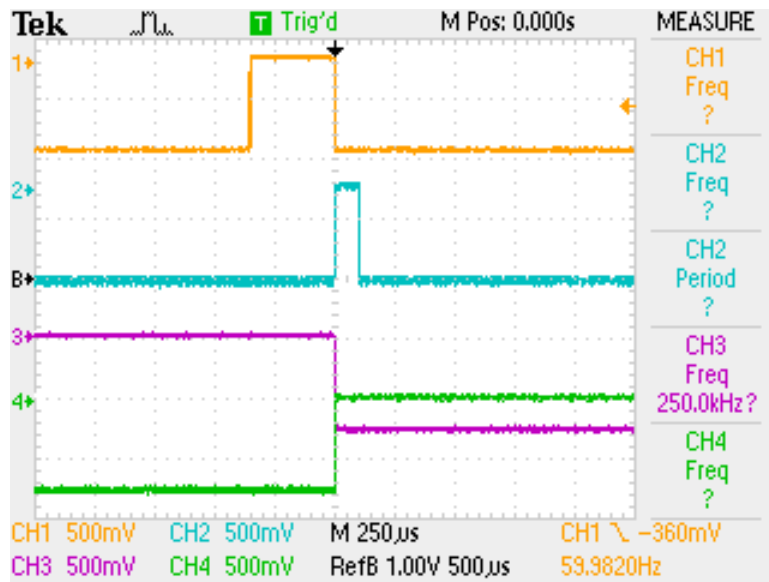


Figure 16: CH1: Line Sync, CH2: T_Settle, CH3: Pattern Sync, CH4: Delayed Helicity. The Helicity Board settings are: 240 Hz Line Sync Mode and Octet Pattern.

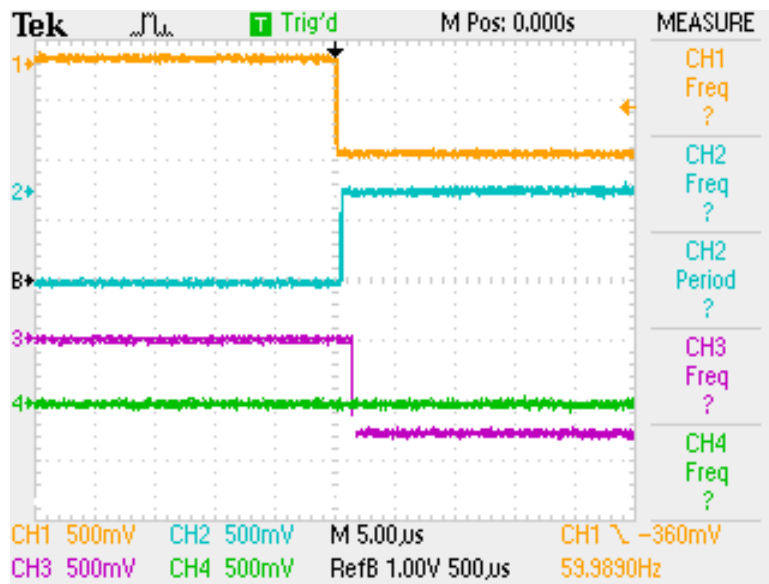


Figure 17: CH1: Line Sync, CH2: T_Settle, CH3: Pattern Sync, CH4: Delayed Helicity. The Helicity Board settings are: 240 Hz Line Sync Mode and Octet Pattern.

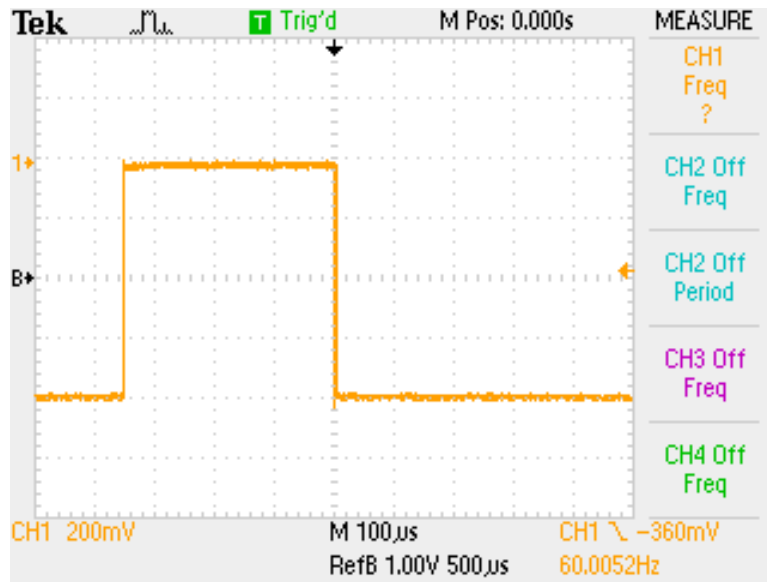


Figure 18: CH1: Line Sync.

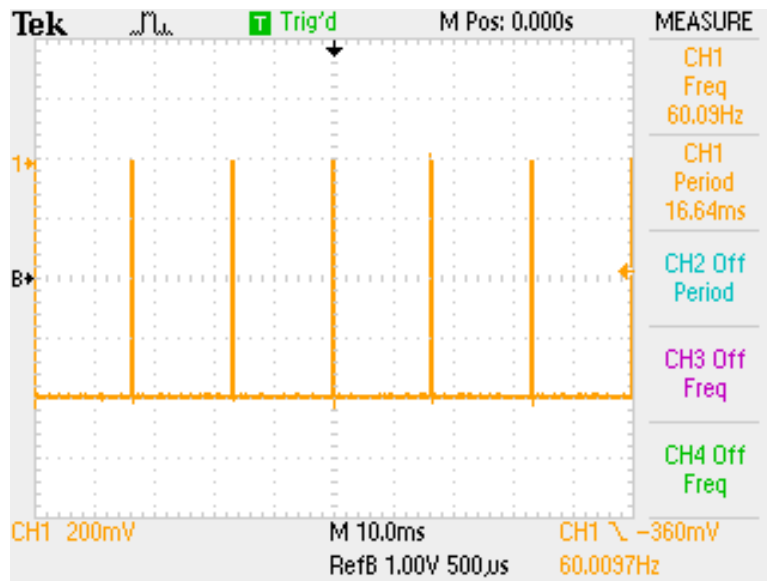


Figure 19: CH1: Line Sync.

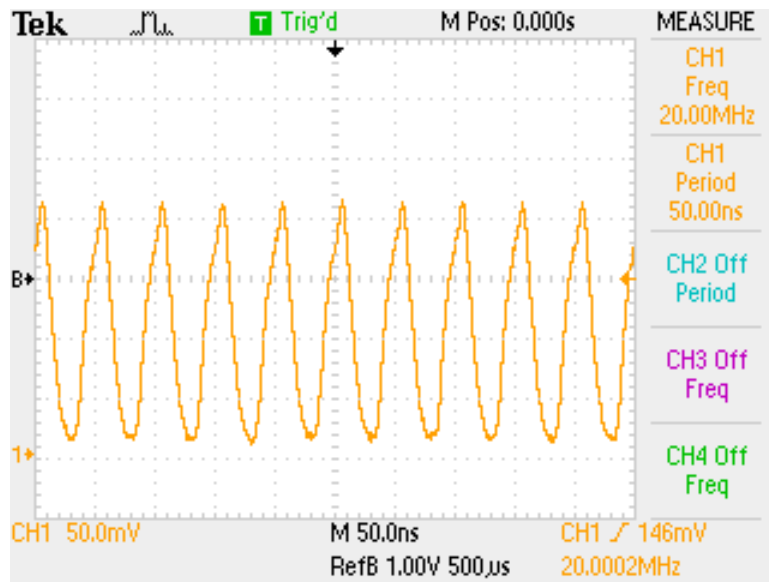


Figure 20: CH1: 20 MHz Clock.

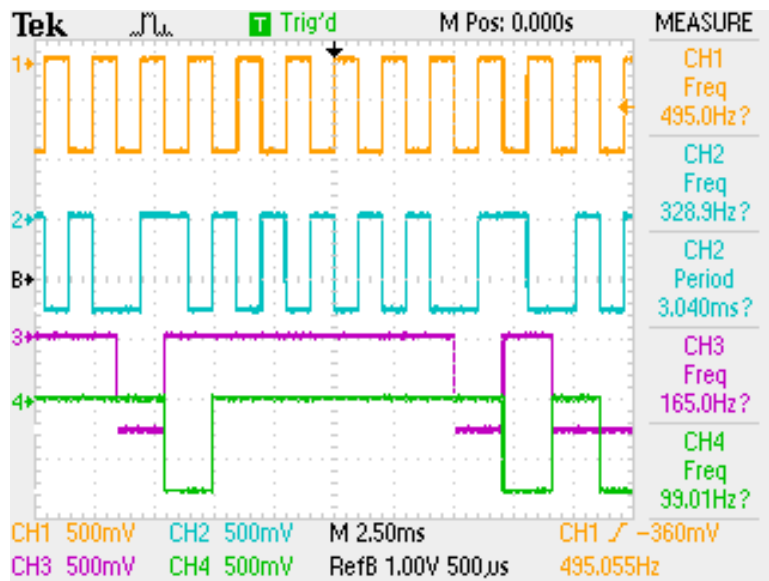


Figure 21: CH1: Pattern Sync, CH2: Helicity Flip, CH3: IA0, CH4: IA1. The Helicity Board settings are: Pair Pattern.

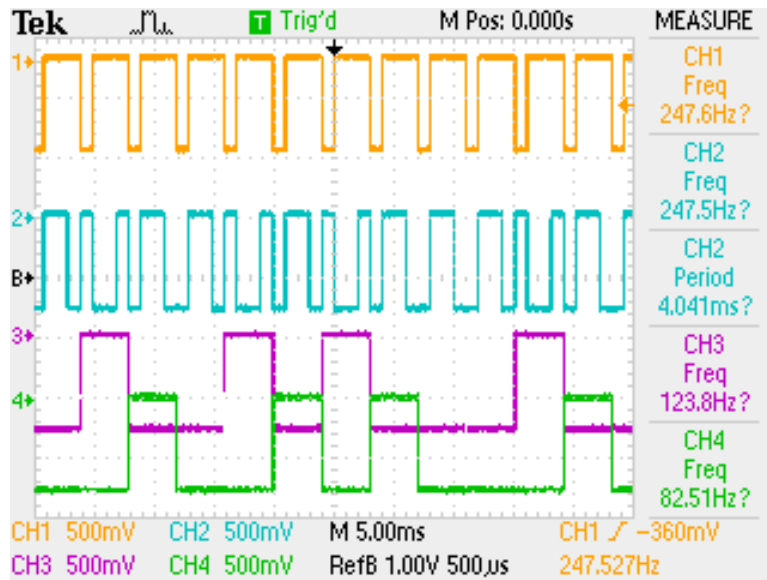


Figure 22: CH1: Pattern Sync, CH2: Helicity Flip, CH3: IA0, CH4: IA1. The Helicity Board settings are: Quartet Pattern.

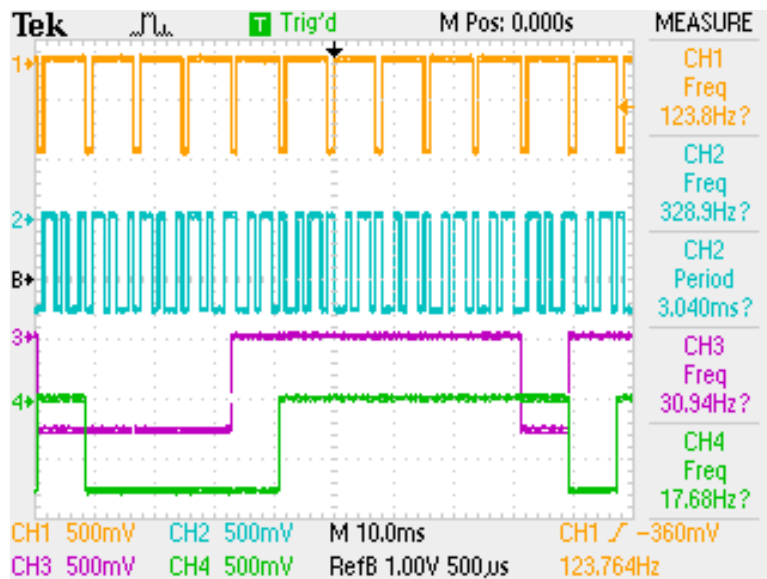


Figure 23: CH1: Pattern Sync, CH2: Helicity Flip, CH3: IA0, CH4: IA1. The Helicity Board settings are: Octet Pattern.

Relative Timing of Helicity Board Outputs

With the old helicity board, all the signals were in time. Looking at these signals in the injector or hall would show roughly 100 ns delays between them. This is mainly due to the Fiber Repeater and to the Fiber Transducer and NIM FAN IN/OUT internal delays. For the new board, the transition to T_Settle

starts $1.0 \mu\text{s}$ before all other signals, see Figure 24 and Figure 25. This is long enough to make sure the Halls know that the helicity is going to change beforehand. Actually this is not absolutely required because it takes the beam about $4.3 \mu\text{s}$ per pass to reach the Hall.

If T_{Settle} is of order of $10\text{s } \mu\text{s}$, then we should account for the time the beam reaches the hall and for the time it takes for the helicity board signals to propagate to the Laser Hut and to the Halls.

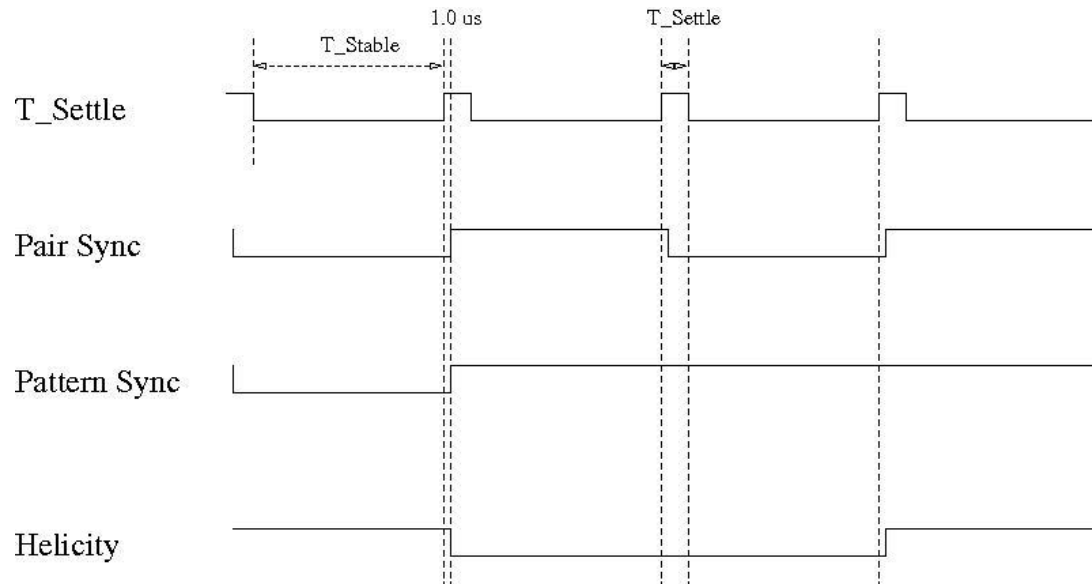


Figure 24: Helicity Board output signals timing relative to T_{Settle} . All the signals: Pair Sync, Pattern Sync, Helicity Flip, nHelicity Flip, Delayed Helicity, IA0, and IA1 start $1.0 \mu\text{s}$ after T_{Settle} .

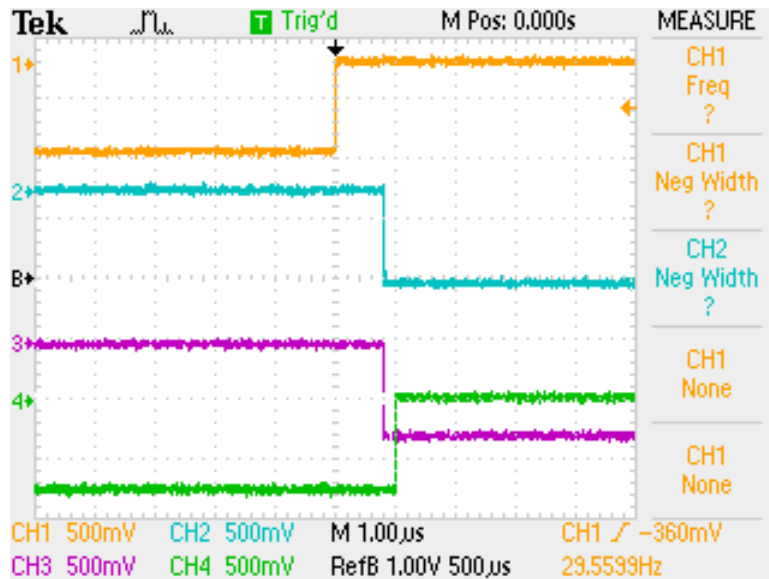


Figure 25: CH1: T_{Settle} , CH2: Pair Sync, CH3: Pattern Sync, CH4: Delayed Helicity. T_{Settle} starts $1.0 \mu\text{s}$ earlier than all other signals.

Helicity Flip and Pockels Cell High Voltage

Figure 26 shows the Pockels Cell (PC) high voltage (HV) while the helicity is flipping. The Pockels Cell HV changes between +3 kV to -3 kV.

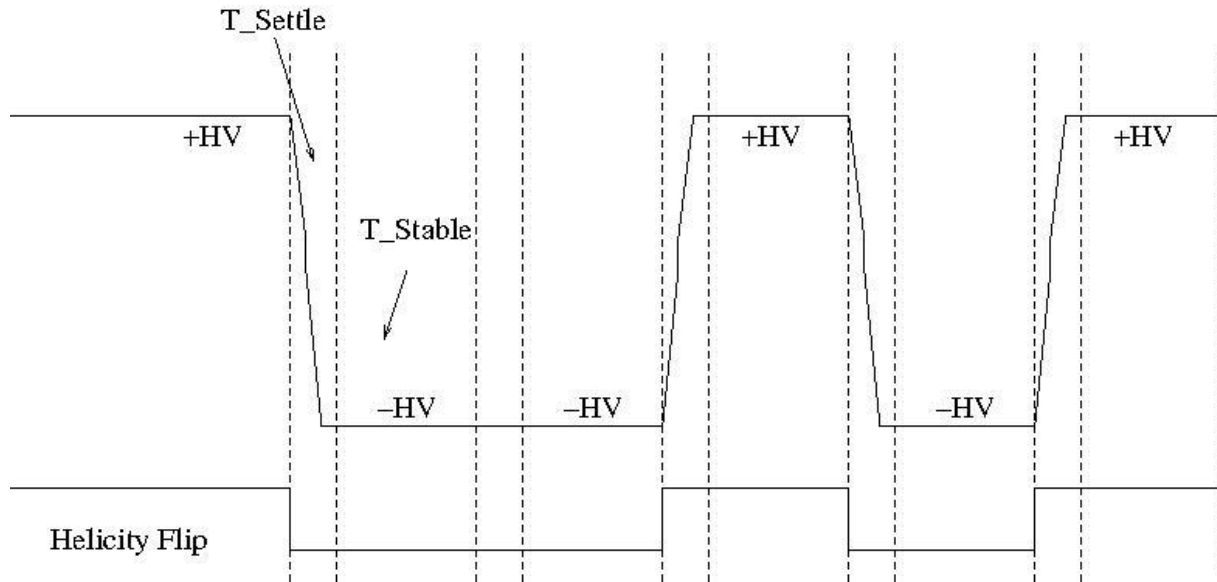


Figure 26: Pockels Cell HV showing the Helicity Flip.

IA Control Signals

To be able to do charge feedback with Intensity Attenuator (IA) and cancel the electro-optical hysteresis of the Pockels Cell, the Helicity Board has two output signals identifying the current and the previous patterns. Figure 27 shows the IA0 and IA1 signals when the Pair pattern is selected. Figure 28 shows the same when the Quartet pattern is selected. Similarly for the Octet pattern.

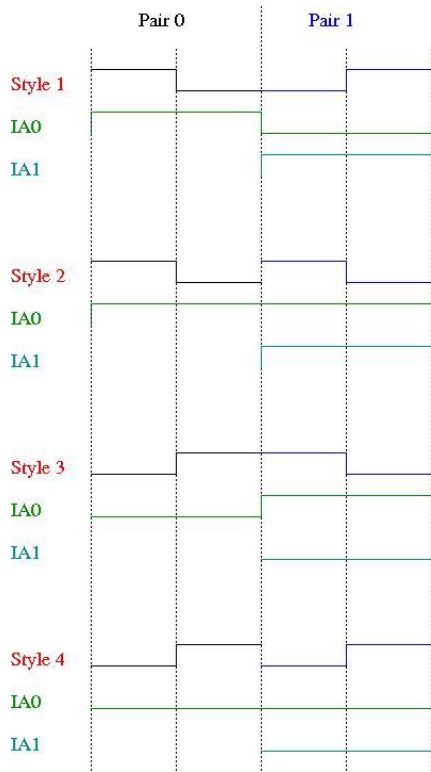


Figure 27: IA control signal IA0 and IA1 with the Pair pattern in relation to the Helicity Flip signal.

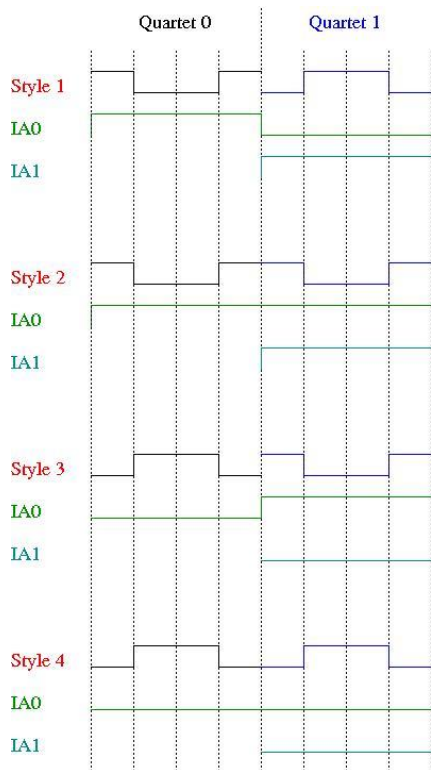


Figure 28: IA control signal IA0 and IA1 with the Quartet pattern in relation to the Helicity Flip signal.

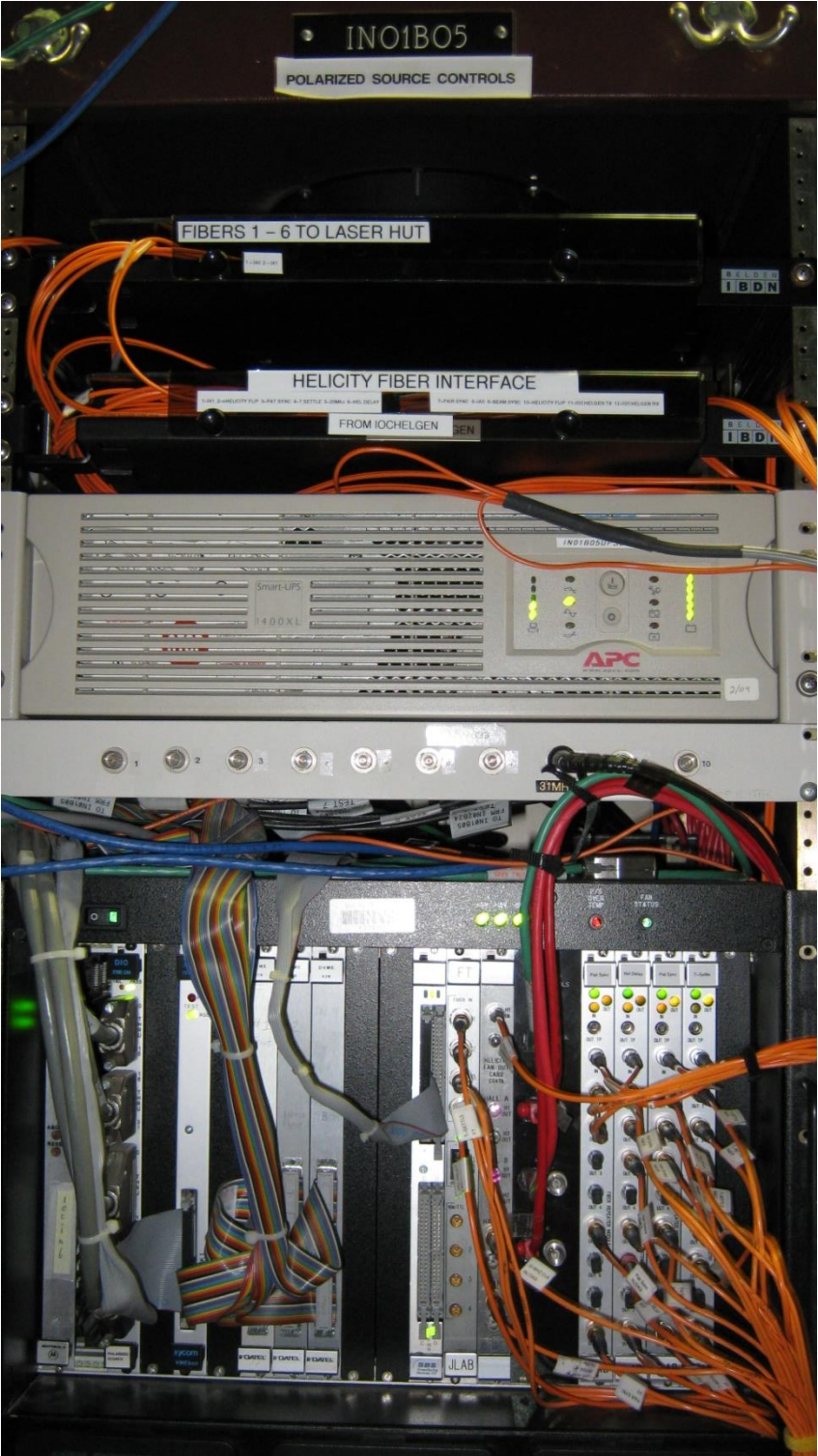


Figure 29: This is rack IN01B05. The fiber cable from the Helicity Board comes to the “Helicity Fiber Interface” patch panel in top of this rack. Five signals make it to the crate (iocin6) under the patch panel. The four Fiber Repeater cards in this crate distribute Pair Sync, Delayed Helicity, T_Settle, and Pattern Sync to the Halls and Injector DAQ. This crate is only used to provide power to the cards. There is also an FT card to be able to look at these signals on a scope. This crate also has the 20 MHz Fiber Repeater card.

Fibers Distribution in Injector

We used the existing T120 fibers to carry the 20 MHz Clock signal from IN01B05 to the Injector Parity DAQ in IN02B24 and to the Parity DAQ in Hall C. The old name of T_Settle is “MPS” and the old name of Pattern Sync is “QRT”. The Line Sync signal is also known as “Beam Sync”.

There are four Fiber Repeater cards in iocin6 crate, see Figure 29. We still need special 1 Fiber Repeater card for the 20 MHz Clock signal.

Now we have also a Fiber Transducer (FT) in this crate to change the signals from fiber to analog.

The fiber cable from the isolated rack to rack IN01B05 has 12 fibers. The first 10 are shown in Figure 30. Fiber 11 is iochelgen TX and Fiber 12 is iochelgen RX.

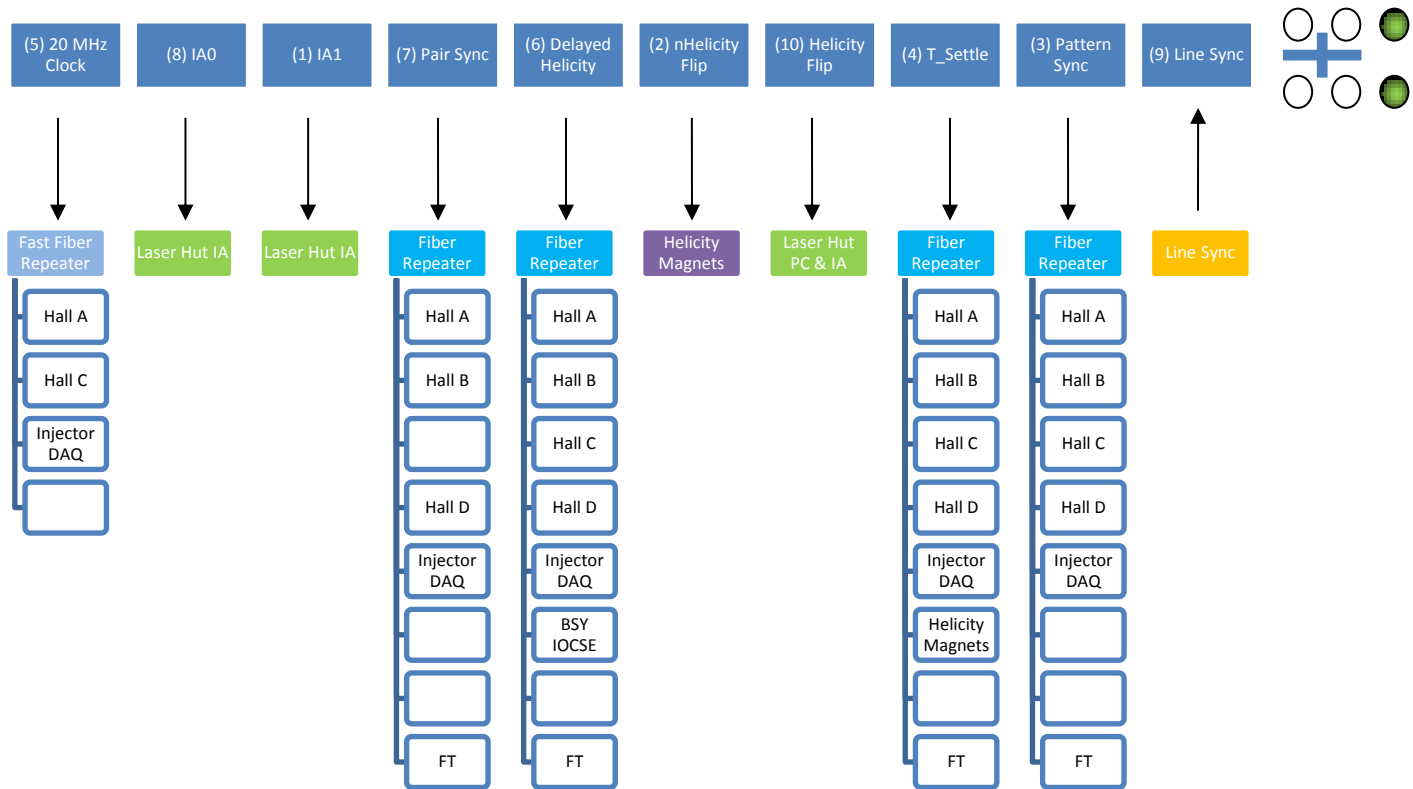


Figure 30: Helicity Control Board signals. Note that Hall C does not receive Pair Sync signal.

Fibers Distribution to the Halls

The following diagram shows the fiber distribution from the Injector to the Halls. The distance from the Injector Service Building (ISB) IN01B05 to Hall C was measured to be 1705 ft using the “20 MHz Clock” fiber.

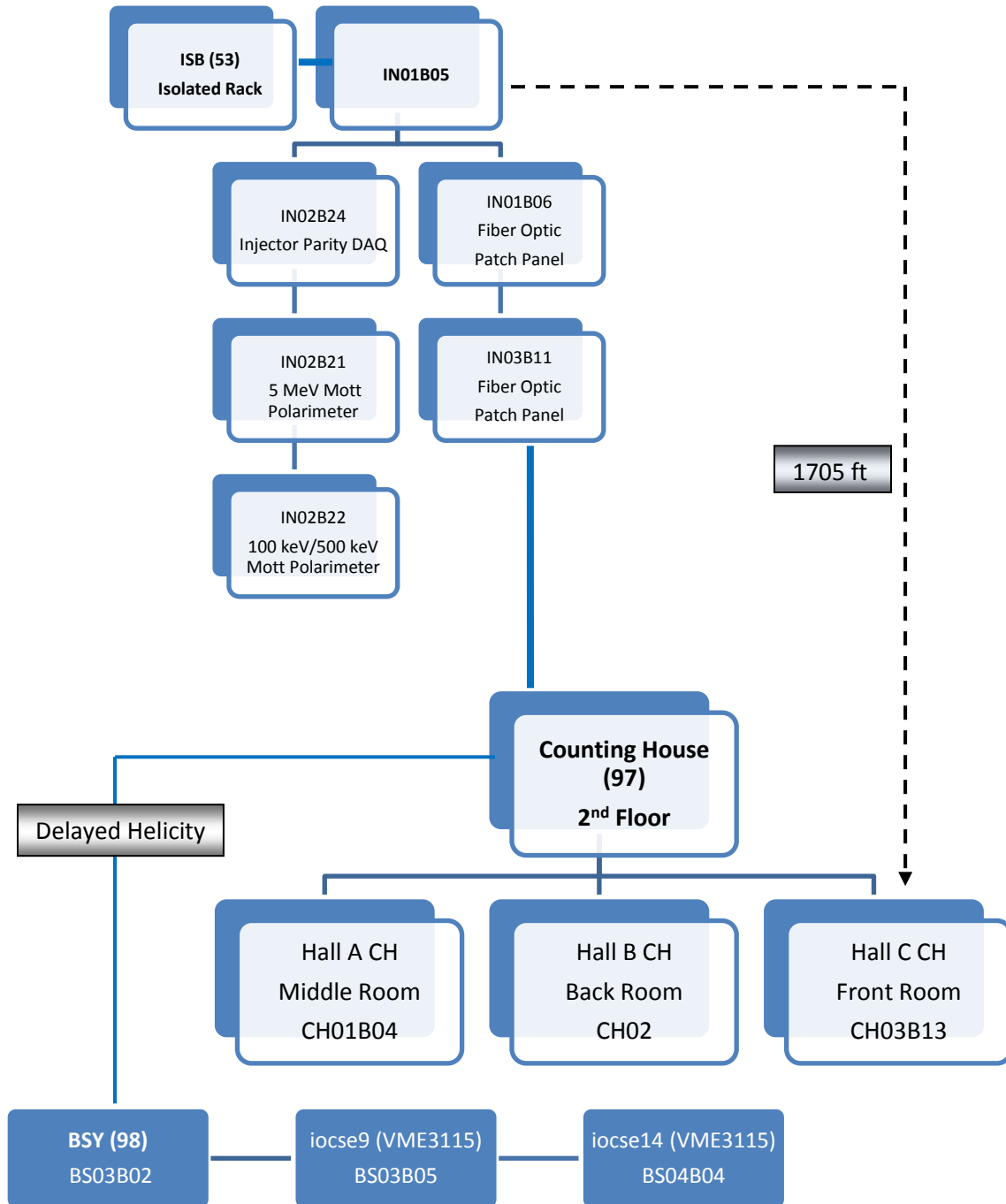


Figure 31: The distribution of the Helicity Board signals to the Halls and BSY.

How to Reduce 60 Hz Line Noise?

The 60 Hz power line noise around the beamline adds noise to beam motion as shown in Figure 32.

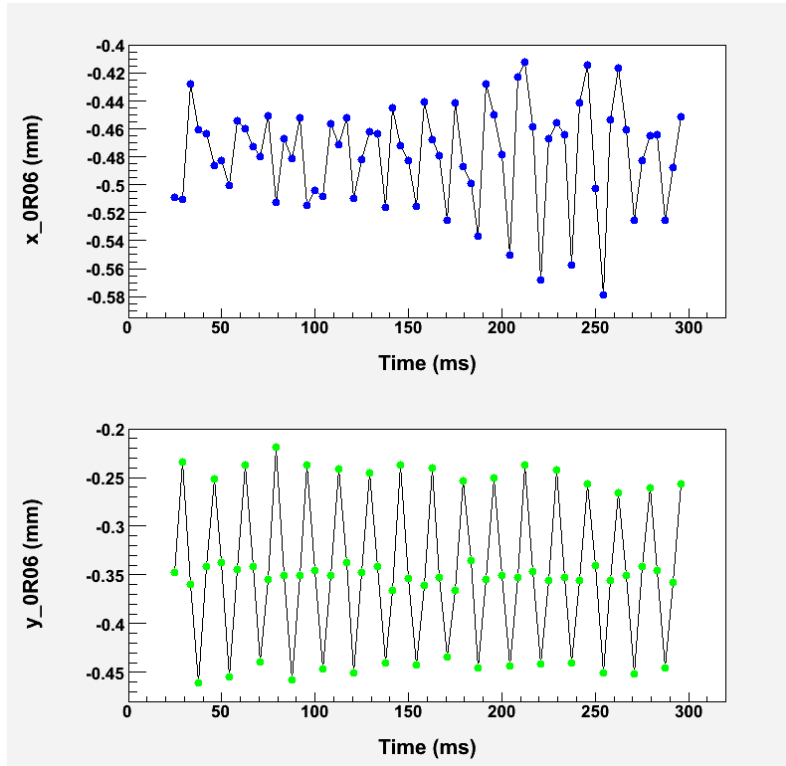


Figure 32: Beam position at OR06. Each reading represents one helicity window. This data were taken at 240 Hz helicity reversal.

There are three ways to reduce 60 Hz line noise in beam position.

1. Integrate over 60 Hz noise per helicity window (Free Clock Mode): Select $T_Stable = 33,330 \mu s$ (exactly two 60 Hz cycles). This is nearly an exact cancellation and the data collected will have no information about 60 Hz line noise. This is what all the experiments at Jefferson Lab have been using till now. It is not exact because the line frequency is not exactly 60 Hz but varies by about $\pm 0.1\%$. All phases of the 60 Hz line are sampled since there is a continuous phase slip relative to the line power. T_Settle determines the magnitude of this phase slip.

Both Pair and Quartet patterns can be selected. However, the Quartet Pattern provides exact cancellation of linear drifts over the timescale of the sequence. The Pair Pattern requires averaging over other pairs for cancellation of linear drifts.

With T_Settle of $500 \mu s$, the helicity reversal rate is 29.56 Hz. Thus the phase of the helicity signals will slip continuously with respect to the power line phase and all phases of power line will sampled every 2.3 seconds.

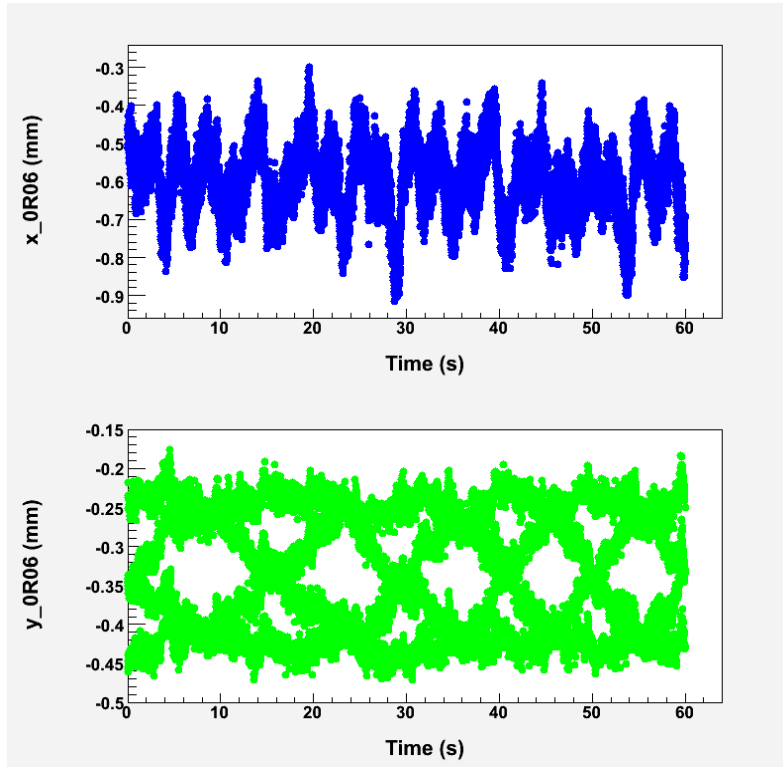


Figure 33: Phase slip

2. Select T_Stable such that: $f > 1$ kHz (Free Clock Mode). This way the Helicity Board frequency is far from the line harmonics. The contribution of the 60 Hz line noise does not change by much from one window to the next and thus cancels when calculating the asymmetries (A). Which pattern is best for cancellation? The data will still have full information about the 60 Hz line noise. This is what QWeak is planning to use.
3. Cancel 60 Hz line noise using patterns: (it does not cancel per window; however it cancels when the asymmetries are calculated).

- I. Select 30 Hz Line Sync: Select a T_Settle , then $T_Stable = 33,330 \mu s - T_Settle$

Select Pair Pattern or Quartet Pattern. If Pair Pattern is selected, then, $A = \frac{+1-2}{+1+2}$

This method remains locked to a single phase of the 60 Hz line power instead of sampling all phases as in method (1).

- II. Select 120 Hz Line Sync: Select a T_Settle , then $T_Stable = 8,330 \mu s - T_Settle$

Select Quartet Pattern. Then,

$$A = \frac{+1-2-3+4}{+1+2+3+4}$$

- III. Select 240 Hz Line Sync: Select a T_Settle , then $T_Stable = 4,167 \mu s - T_Settle$

Select Octet Pattern. Then,

$$A = \frac{+1-2-3+4-5+6+7-8}{+1+2+3+4+5+6+7+8}$$

In the Line Sync Mode, the start of each pattern is triggered by the Line Sync signal and thus each pattern always starts at the same line phase (line-phase locked). This way the Helicity Board frequency will track the line frequency and the Helicity Board frequency will have the same jitter as the line frequency.

We can also choose to run the above selections in Free Clock Mode. Slowly, the phase of the Helicity Board frequency will drift with respect to the line since the line frequency is not exactly 60 Hz on top of the fact that it has jitter. PREx will run in Free Clock Mode at 240 Hz with the Octet Pattern to cancel line noise.

What about other noises? Choice (2) will work as well for other low frequency noises including the noise from target density fluctuations. This kind of noise is peaked at low frequency because it is a mechanical noise due to gas bubbles in the Hall cryogenic liquid target. Choices (1) and (3) are geared for 60 Hz noise; other noises will not cancel. These noises will increase the width of the helicity correlated distributions as in the case of target density fluctuations. Other prominent single low frequency noises will cause double-horned peak distributions. Figure 34 and Figure 35 show the effect of 50 Hz noise when choosing method (2) or (3). Method (2) is equally effective in cancelling all noises at low frequencies. However, method (3) is geared to 60 Hz and not that effective in cancelling noises at other frequencies. For more details see (Ramsay, 2009).

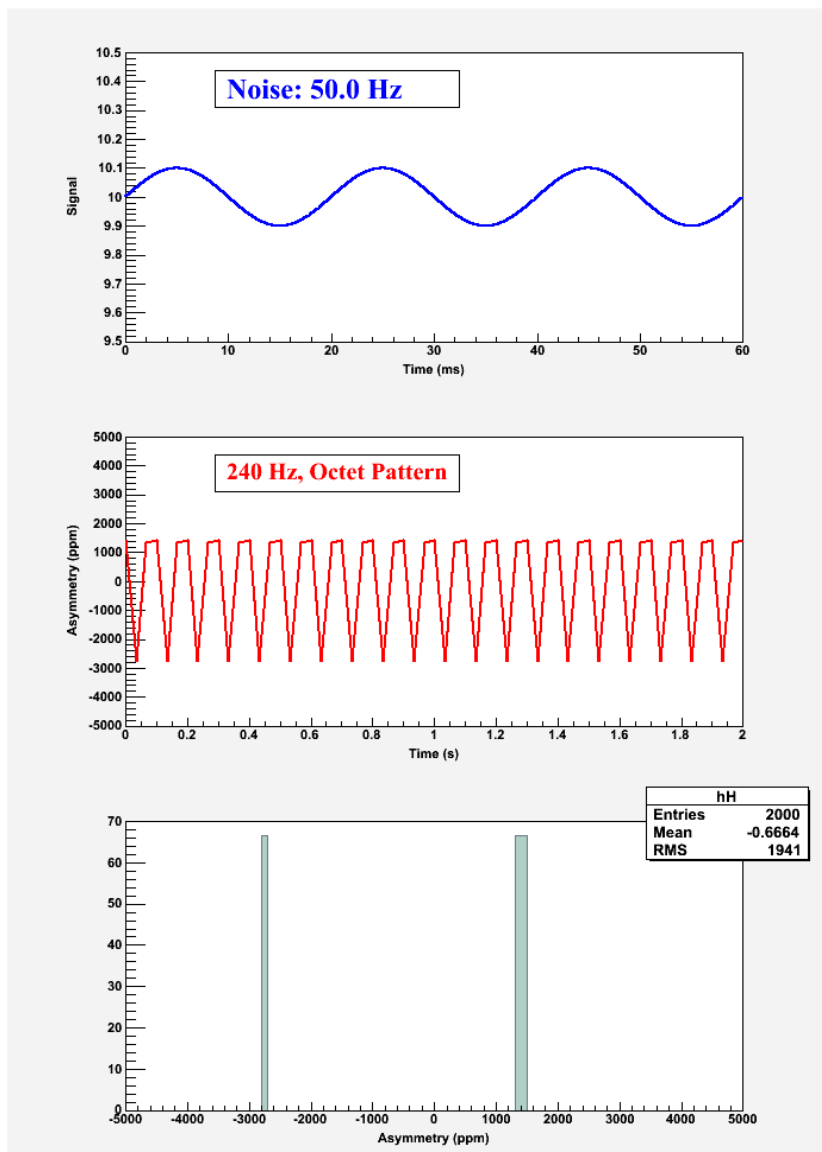


Figure 34: The effect of a prominent noise at 50 Hz on the asymmetry when the Helicity Board is set to 240 Hz and Octet Pattern. This mode cancels exactly the 60 Hz line noise but very sensitive to other frequencies.

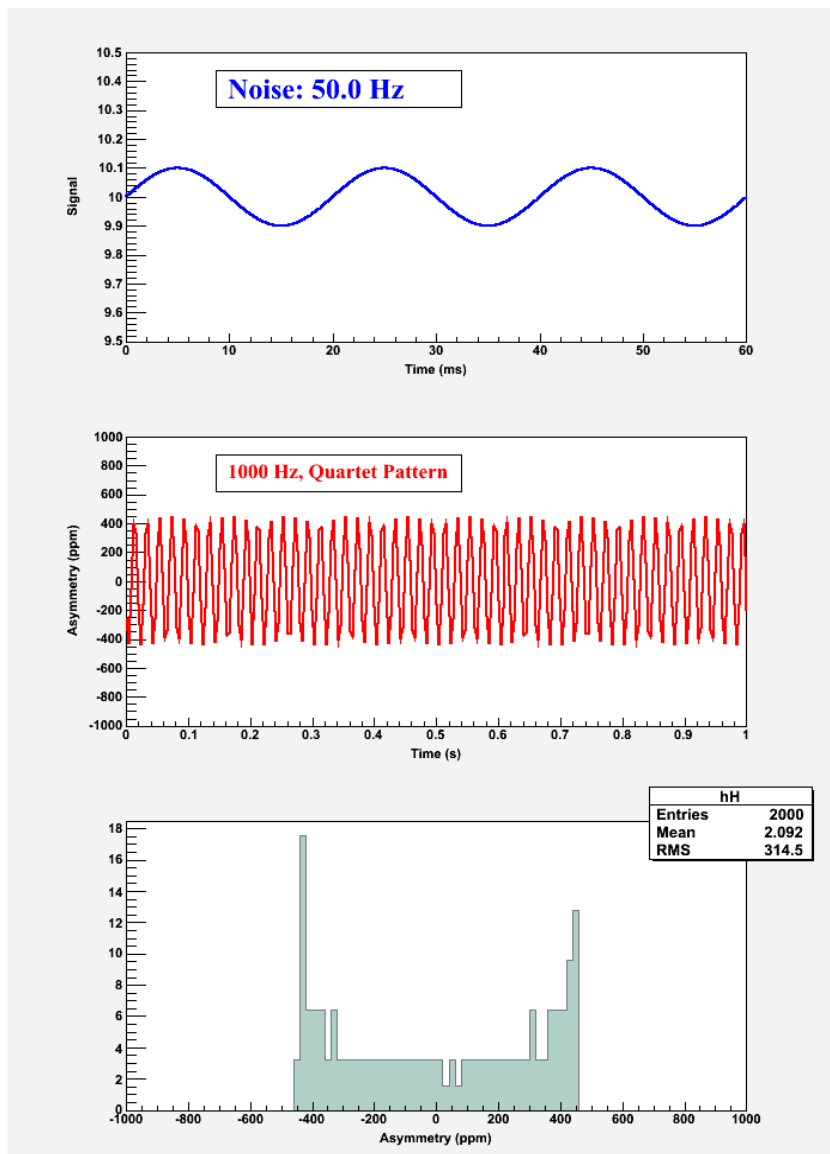


Figure 35: The effect of a prominent noise at 50 Hz on the asymmetry when the Helicity Board is set to 1000 Hz and Quartet Pattern. The effect of 60 Hz line noise is very similar.

Helicity Board Tentative Configuration for PREx and Qweak

For testing, PREx will study the 120 Hz helicity reversal as shown in Figure 36. The tentative Helicity Board configuration for PREx is shown in Figure 37 and for QWeak is shown in Figure 38. Table 3 shows the Helicity Board configuration.

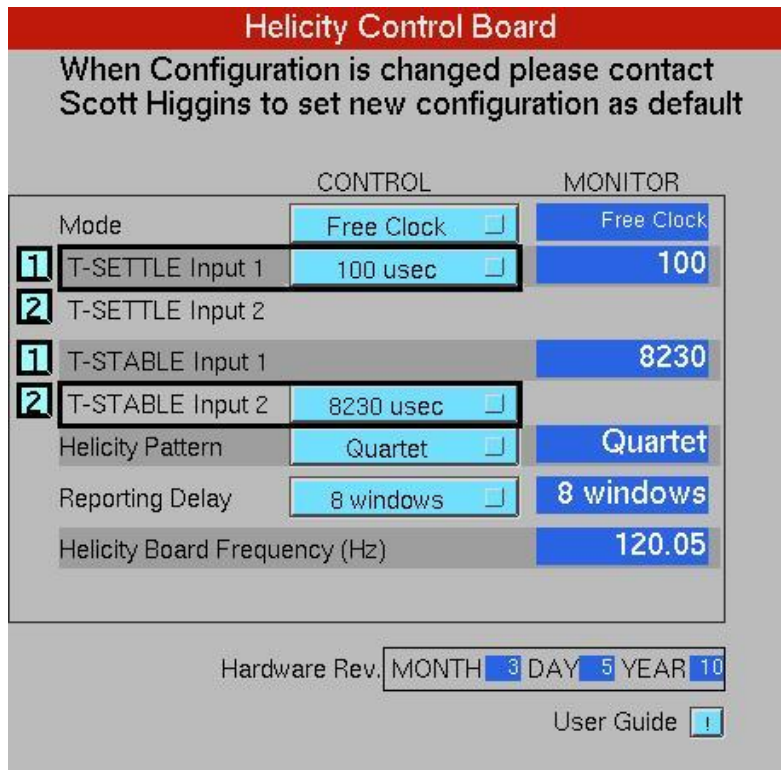


Figure 36: This is the Helicity Board settings from 120 Hz helicity reversal. This will be used for noise studies.

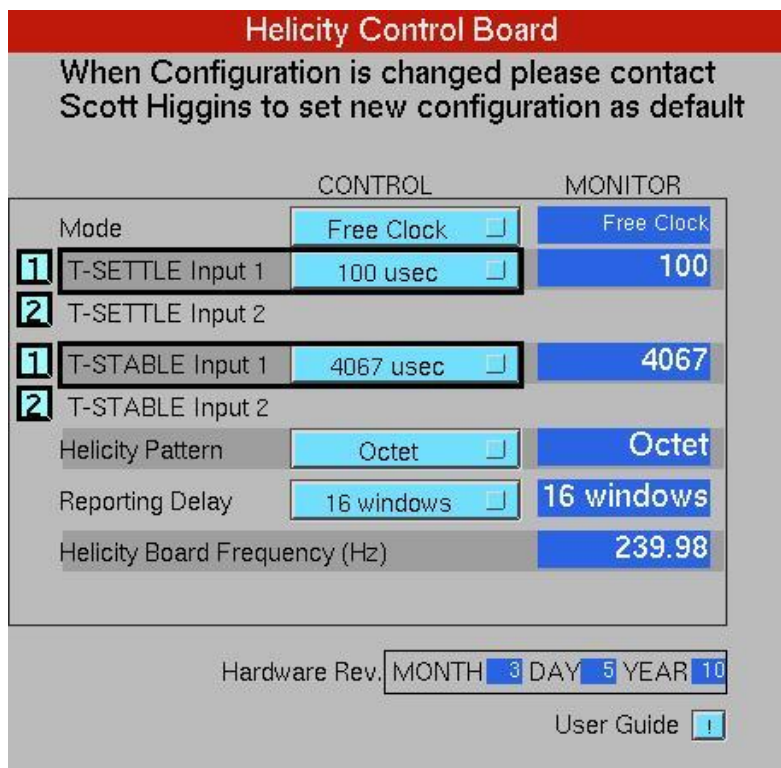


Figure 37: Helicity Board Control Screen with PReX settings.

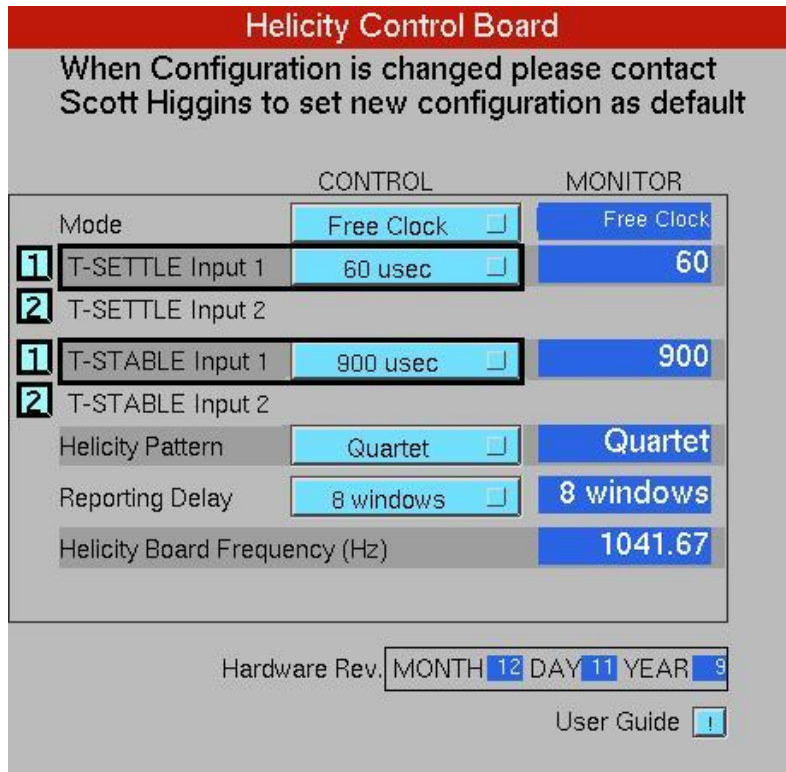


Figure 38: Helicity Board Control Screen with QWeak settings.

Table 3: The Helicity Board tentative configuration for PREx and QWeak.

| Helicity Board Setting | PREx | QWeak |
|--------------------------|---------------|-------------|
| Mode | Free Clock | Free Clock |
| T_Settle | 100 μ s | 60 μ s |
| T_Stable | 4,067 μ s | 900 μ s |
| Helicity Pattern | Octet | Quartet |
| Reporting Delay | 16 windows | 8 windows |
| Helicity Board Frequency | 240 Hz | 1042 Hz |

Sign of Physics Asymmetry

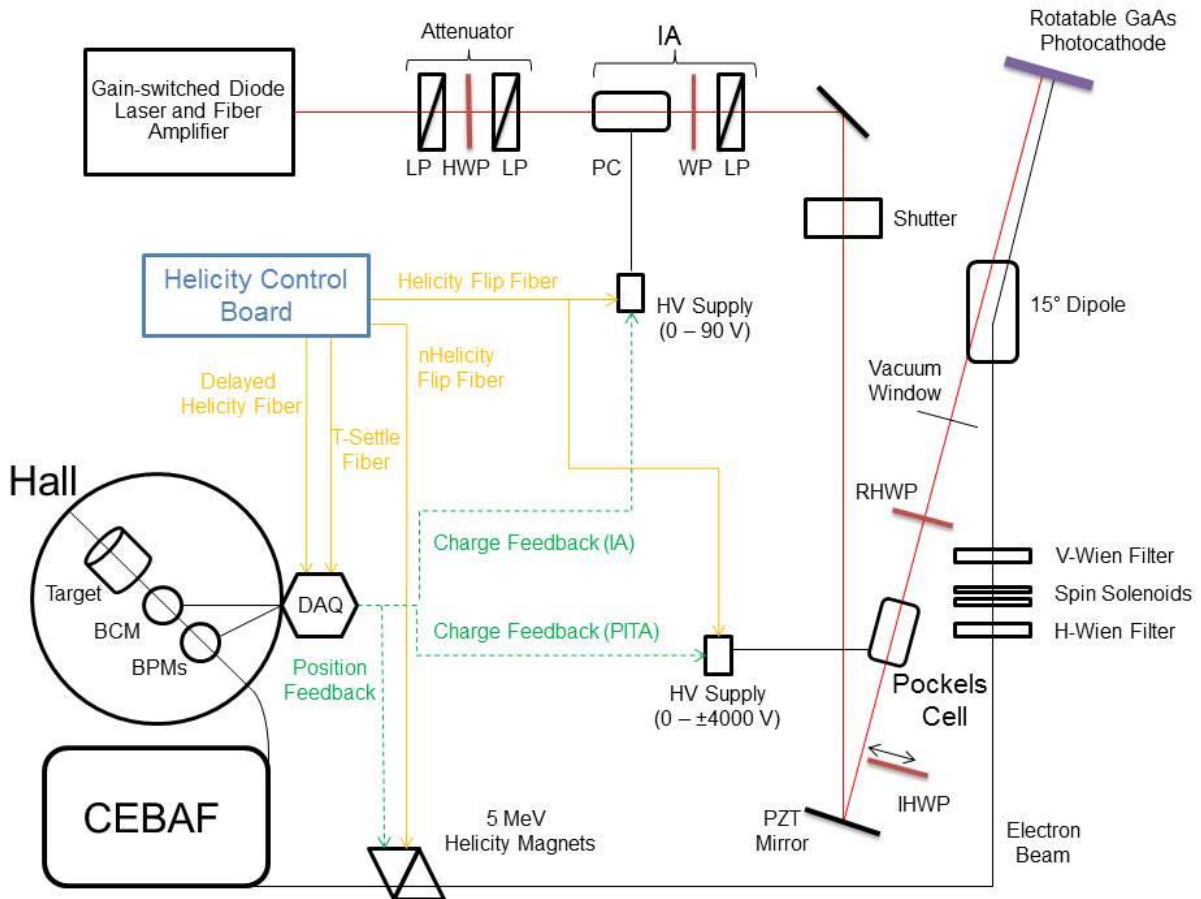
One may wonder how could we tell the actual helicity of the electrons when they interact with the target in the Hall. Parity Experiments measure very small asymmetries that can easily be positive or negative. There is standard theoretical prediction of the magnitude and sign of the physics asymmetry. However, the new physics that the experiment is trying to measure may be big enough to change the sign of the asymmetry.

This is easy: no need to keep track of all these conventions about helicity and how it is treated at each junction. This is simply done using the Moller Polarimeter in the Hall. The sign of the asymmetry measured in the Hall is decided using the Moller Polarimeter. Moller asymmetry is well understood in

theory and the sign of the measured polarization is well known. To check the relative sign between the Moller Polarimeter DAQ and the Parity DAQ, a large charge asymmetry is introduced in the injector by changing the Pockels Cell HV (PITA) and both DAQs measure this charge asymmetry at the same time to find out the relative sign.

Helicity Board Circuit Diagram

Electronic Cross-talk and Ground Loop Elimination in the Injector



While performing parity experiments it is vital to prevent electronic cross-talk that could feed real-time helicity information to the outside world. Ground loops could transmit this signal and must be eliminated. Extra effort was spent to make sure the real time helicity signals (Helicity Flip and nHelicity Flip) are isolated. These include:

- I. VME Crate of Helicity Control Board is floating and powered with isolation transformer.
- II. Helicity Board generates two real time helicity signals: Helicity Flip and nHelicity Flip. Current drawn by board does not depend on helicity state.
- III. Helicity signal is generated by pseudo-random bit generator. No correlation between helicity signal and any other signal in Accelerator or in Hall.
- IV. Outside world receives only Delayed Helicity signal. This signal tells what helicity was in the past so there is no knowledge of real time helicity.
- V. Helicity Magnets VME Crate which receives one of the two real time helicity signals (nHelicity Flip) is also floating and powered by isolation transformer.
- VI. Real time helicity signal (Helicity Flip) that goes to Laser Hut is isolated. All electronics that can see real time helicity are floating (next slide).
- VII. All helicity-correlated beam asymmetries (position, angle, charge, energy, and size – and thus beam scraping) are minimized so helicity is the only real time property of beam that is changing.
- VIII. Programming of voltage setpoints of Pockels Cell and IA's (both receive Helicity Flip signal) in Laser Hut passes through galvanic isolation card and there are no readbacks of these voltages
- IX. The crate that houses the Helicity Control Board is floating and also powered with an Isolation transformer.
- X. The Helicity Board generates two real time helicity signals: Helicity Flip and nHelicity Flip, so the current drawn by the board does not depend on the helicity state.
- XI. The outside world receives only the Delayed Helicity signal. This signal tells what the helicity was in the past so there is no knowledge of the real time helicity.
- XII. The Helicity Magnets Crate which receives one of the two real time helicity signals (nHelicity Flip) is also floating and powered by an isolation transformer.
- XIII. The real time helicity signal (Helicity Flip) that goes to the Laser Hut is isolated (see discussion below).
- XIV. The helicity signal is generated by a pseudo-random bit generator to ensure that there is no correlation between the helicity signal and any other signal in the accelerator or in the Halls.
- XV. All helicity-correlated beam asymmetries (position, angle, charge, energy, and size) are minimized so the only real time property of the beam that is changing is its helicity.

All information for programming of voltage setpoints related to the devices in the Laser Hut that receive the Helicity Flip signal (Pockels Cell and IA's) passes through a galvanic isolation card and there are no readbacks of these voltages. This card uses a precision isolation amplifier (ISO-124) to isolate signals

from -10 V to +10 V with a bandwidth of up to 50 kHz. In the Laser Hut, all circuits seeing real time helicity are floating with respect to earth ground as shown in Figure 39. The option remains to connect a single point ground if needed.

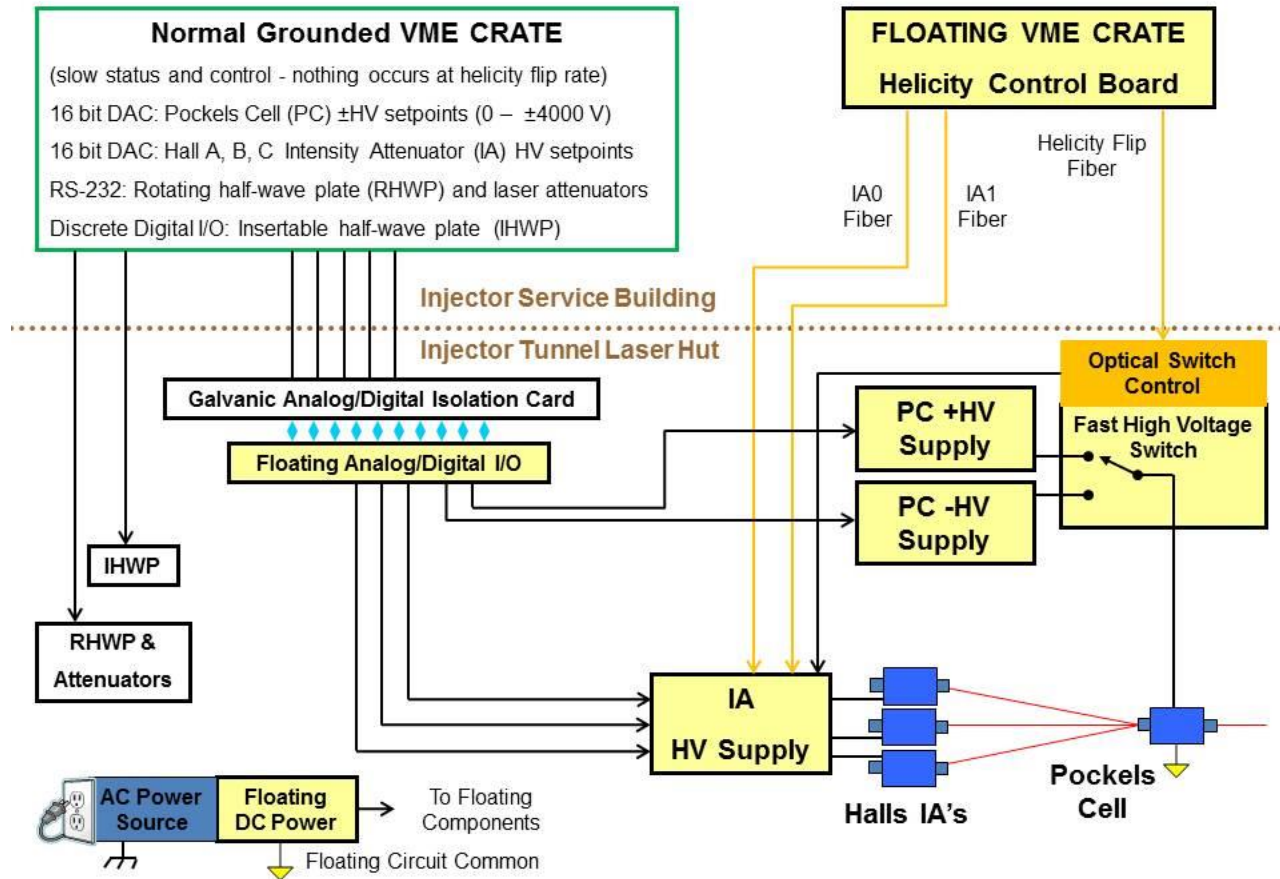


Figure 39: Ground loop elimination in the injector.

Bibliography

Ramsay, D. (2009, February 20). *False Asymmetry from Fixed-Frequency Noise in the Qweak DAQ*. Retrieved from <http://qweak.jlab.org/doc-private/ShowDocument?docid=906>