SM300

Version – 2025.4.2 | Target Firmware Version: v1.1.0

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Disclaimer

This user manual provides essential information for the safe and effective use of FieldLine Industries Scalar Products. Users are strongly advised to read and understand the contents of this manual before operating the device.

Intended Use

FieldLine Industry Scalar's are intended for investigational use only. Any use outside the specified intended purpose may result in unintended consequences, and the manufacturer disclaims any responsibility for such usage.

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Users are responsible for using FieldLine Industries Scalars in accordance with the provided instructions. Failure to follow the guidelines outlined in this manual may result in improper device operation and potential risks to the user.

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Only authorized personnel should perform maintenance and servicing of a FieldLine Industries Scalar. Unauthorized modifications may compromise device safety and functionality. Follow the update protocol outlined in this manual to ensure optimal device performance.

Regulatory Compliance

This device is for investigational use only and does not currently have any certification from a regulatory authority.

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FieldLine Industries provides a limited warranty as outlined in the warranty document received with any scalar purchased. Any unauthorized modifications or use outside the specified conditions may void the warranty.

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SM300 Description

The FieldLine Industries SM300 utilizes an optically pumped rubidium magnetometer. The device comes in a small form factor and is pictured below.

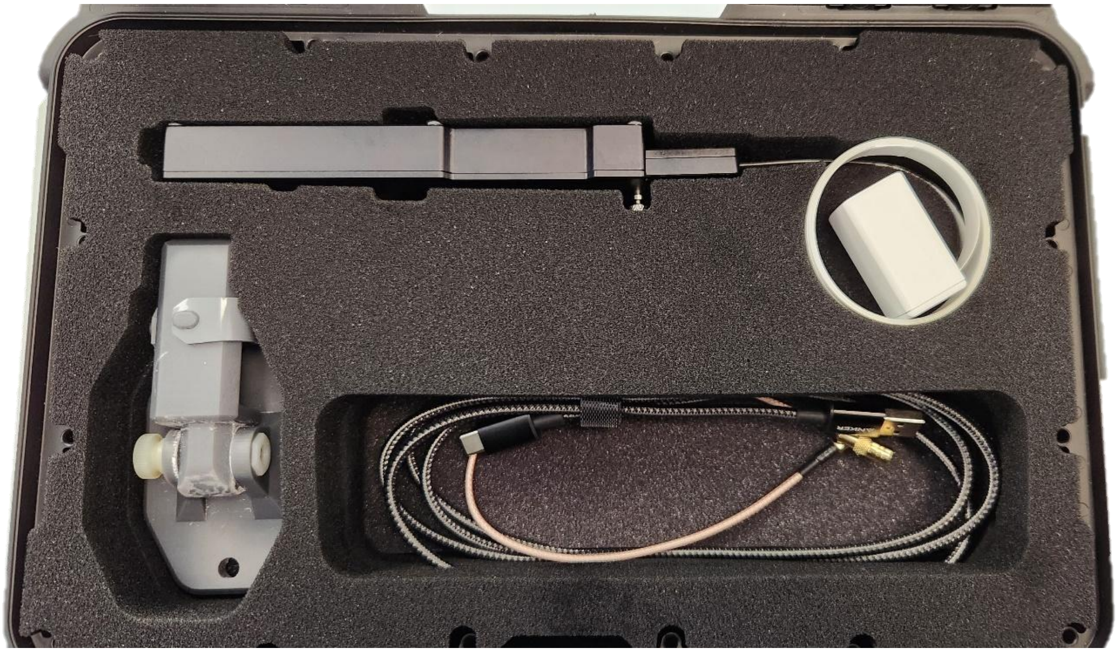


Figure 1 – FieldLine Industries Scalar Magnetometer

The SM300 communicates externally via UART. The data can be viewed using the FieldLine Industries Recorder, which automatically interprets the incoming UART data packet and displays the decoded data in real time.

The detected magnetic field is in a Frequency Coded Format. To convert the recorded frequency data (stream 18) from the SM300 to a magnetic field measurement, the following formula is provided.

$$|B| = \frac{F\ [bits] \times (4 \times 10^{6}\ [Hz])}{2^{32} [bits] \times \gamma_{Rb87} \left[\frac{Hz}{nT}\right]} = F\ [bits] \times (1.331254 * 10^{-4}\ \left[\frac{nT}{bits}\right])$$

Equation 1 - Conversion of Frequency to Magnetic Field Strength

F is the frequency code reported by the magnetometer [Bits], γ_{Rb87} is the gyromagnetic ratio of Rubidium 87 (6.99583 Hz/nT ≈ 7 Hz/nT), and |B| is the measured magnetic field [nT].

The SM300 will attempt to regain magnetic lock by continually scanning if lock is lost. The SM300 has an operational dead zone when it is perpendicular to Earth's magnetic field ±15 degrees.

The SM300 has several different states that indicate the status of the magnetometer. These states are reported by an LED light color and action on the SM300 as well as a specific data stream that encodes the state (**Table 1**).

LED Description	System Action	System State
Solid White	Idle	0
Blinking Orange	System Startup	3
Blinking Green	Heat Stabilization	4
Blinking Blue	Scanning for Magnetic Resonance	5
Solid Blue	Locked on Magnetic Resonance	6

Table 1 - LED Color and States

SM300 Operation

The SM300 can be operated in one of two ways: using the provided FLI Recorder application to view and record data or using a custom script to communicate over UART. Regardless of mode of operation, some basic hardware setup is required.

Attach the provided USB Type C cable to the USB port on the SM300 and connect it to a USB port on a computer/laptop. The USB connection provides both power and UART communication.

Figure 2 - SM300 Ports

If operating multiple sets of SM300, connect the PPS Out port of one SM300 to the PPS In port of the other SM300. This will synchronize the PPS signals across multiple SM300.

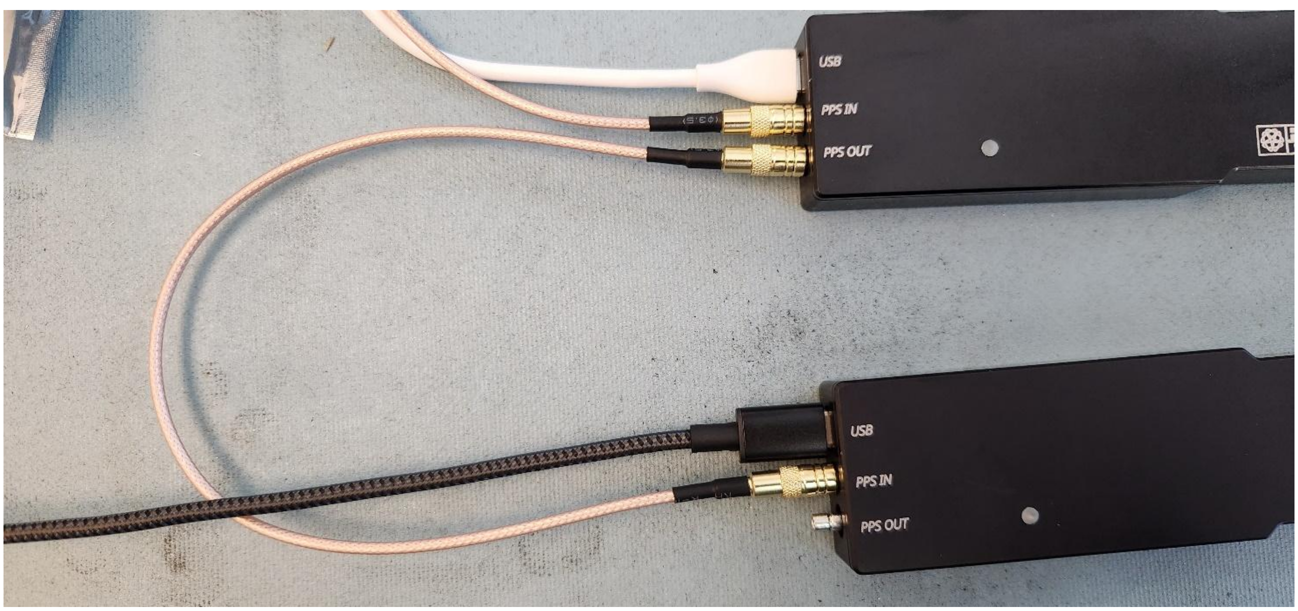


Figure 3 - PPS Connections

The SM300 should now be powered on in the Idle state and the LED indicator should be solid white.

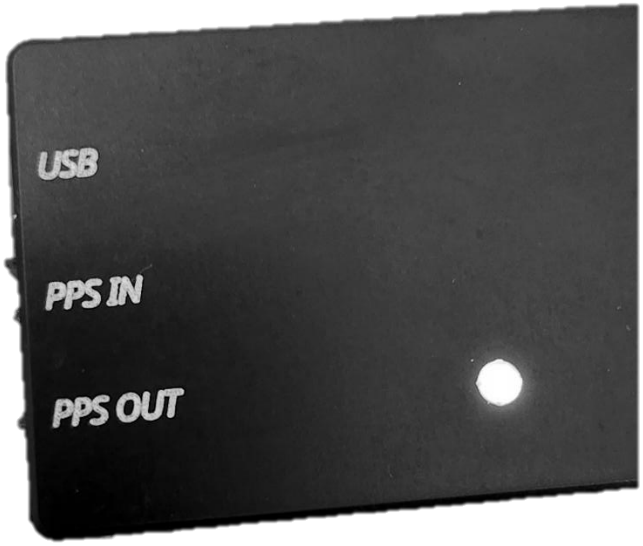


Figure 4 - Idle LED On

FLI Recorder Operation

Open the FLI Recorder application.

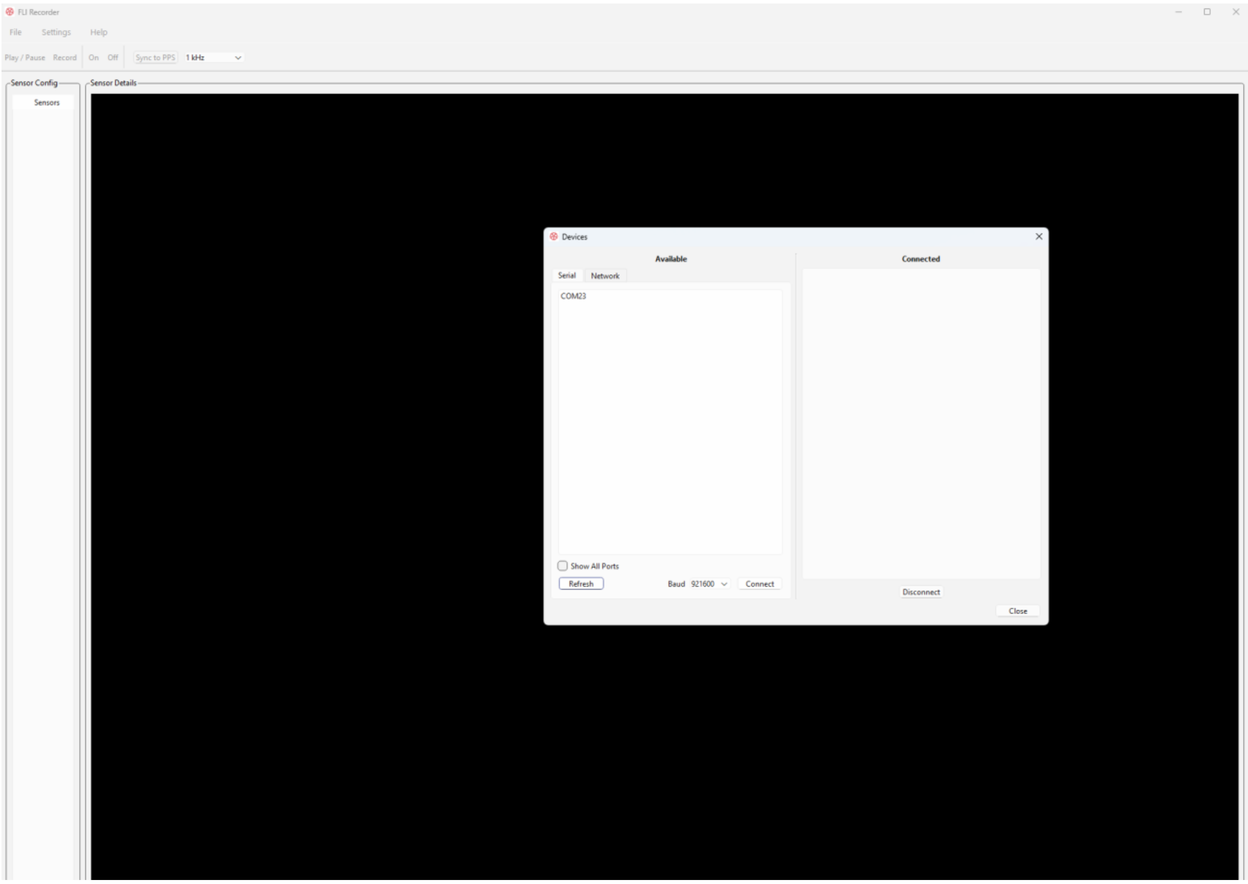


Figure 5 - FLI Recorder Start Up Window

The Devices pane is automatically launched, and a list of available devices will appear.

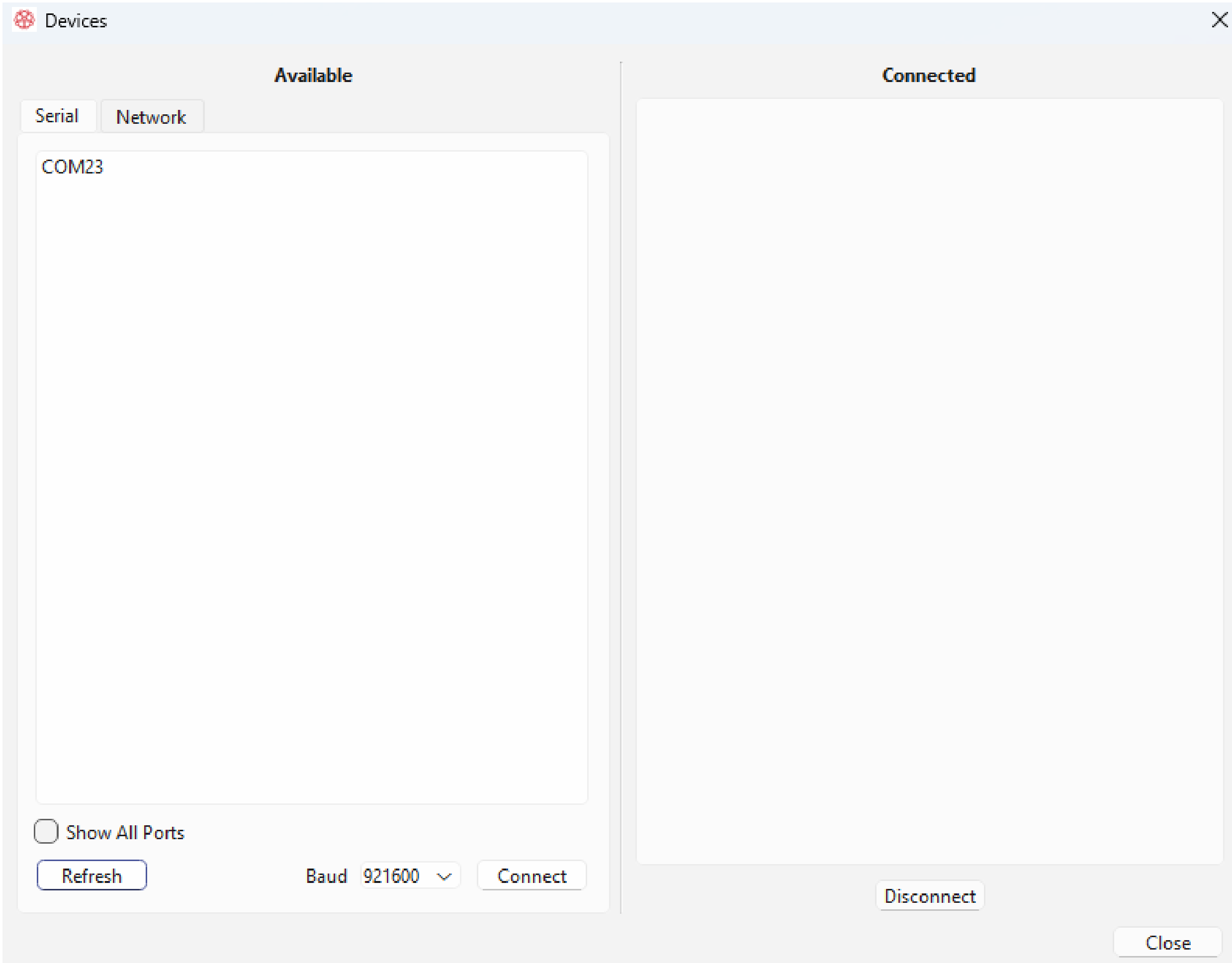


Figure 6 - Devices Pane

Select the device or devices and click “connect”.

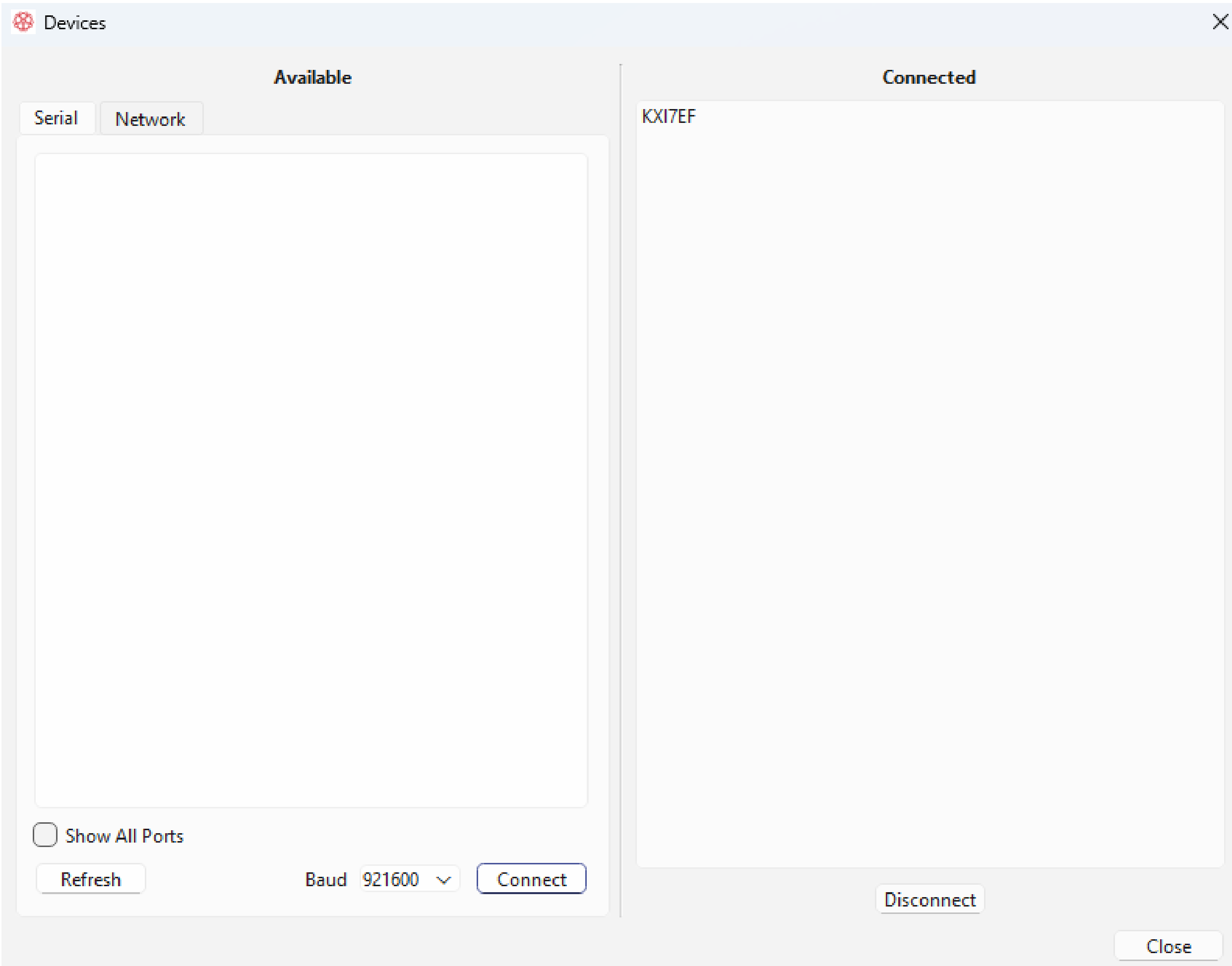
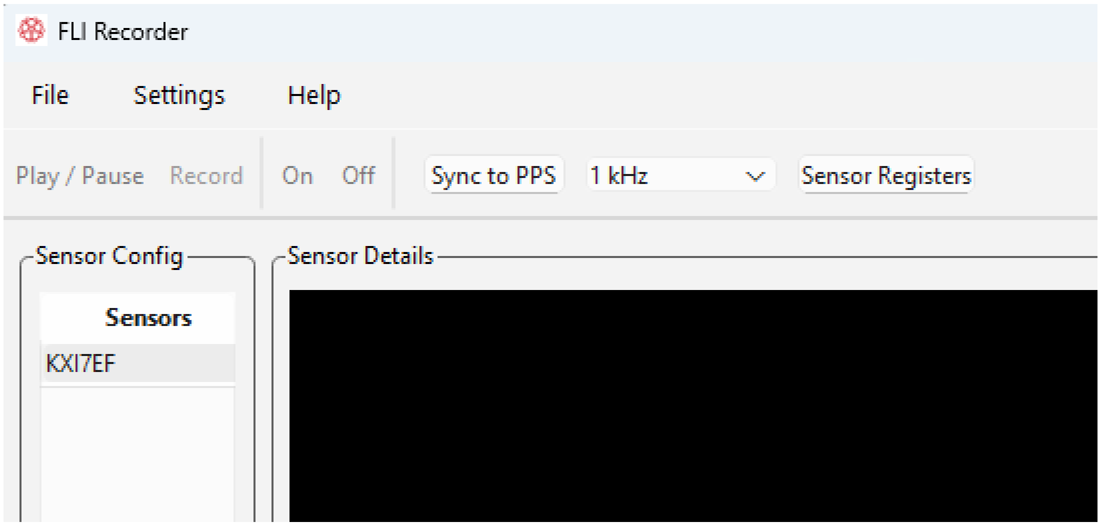


Figure 7 - Discovered Devices

Note that the total number of data streams that can be enabled at once is limited by the selected baud rate and sampling rate.

Once the desired devices are connected, select the "Close" button to return to the main window.



Connected devices will show up in the top left under "Sensor Config" as the associated sensor serial number.

Double click on each sensor to configure streams for that sensor.

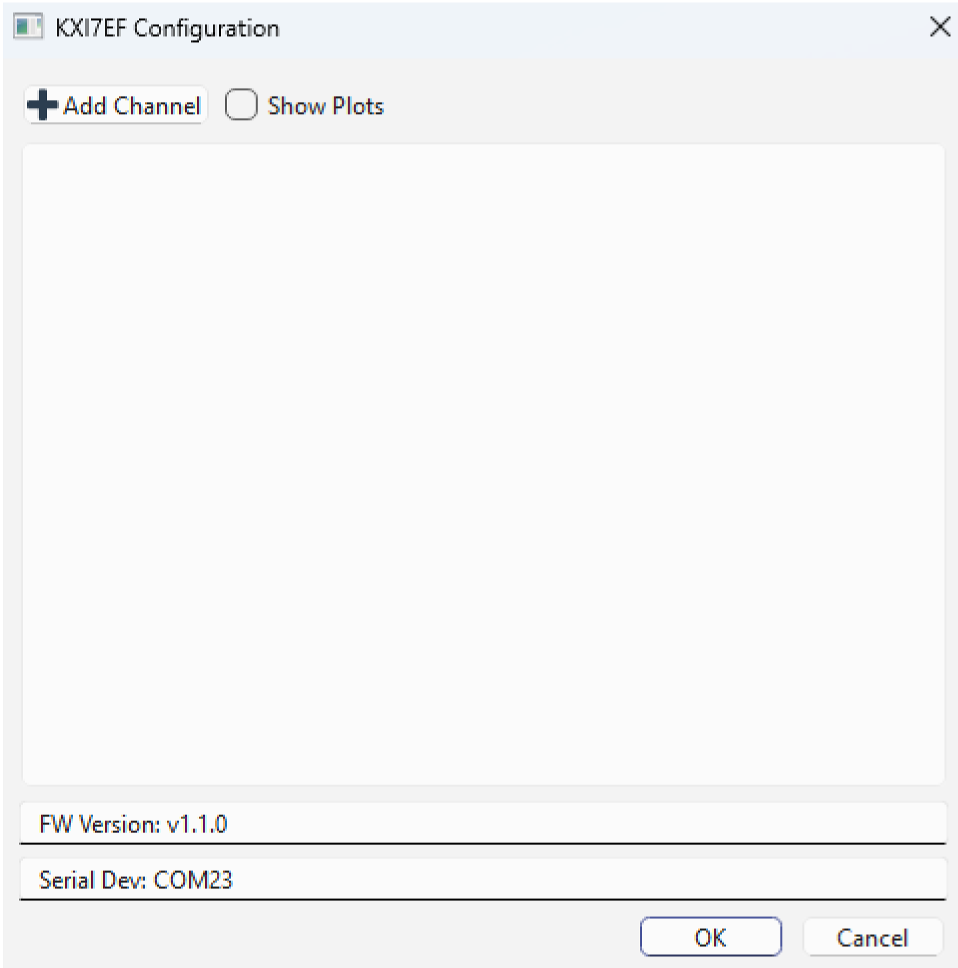


Figure 8 – Blank Configuration Pane

The "<Sensor Serial Number> Configuration" pane will appear. Streams can be added by clicking the "Add Channel" button and entering a stream number.

The Configuration pane will also show the firmware version of the connected electronics, and the serial or COM port used to connect to the device.

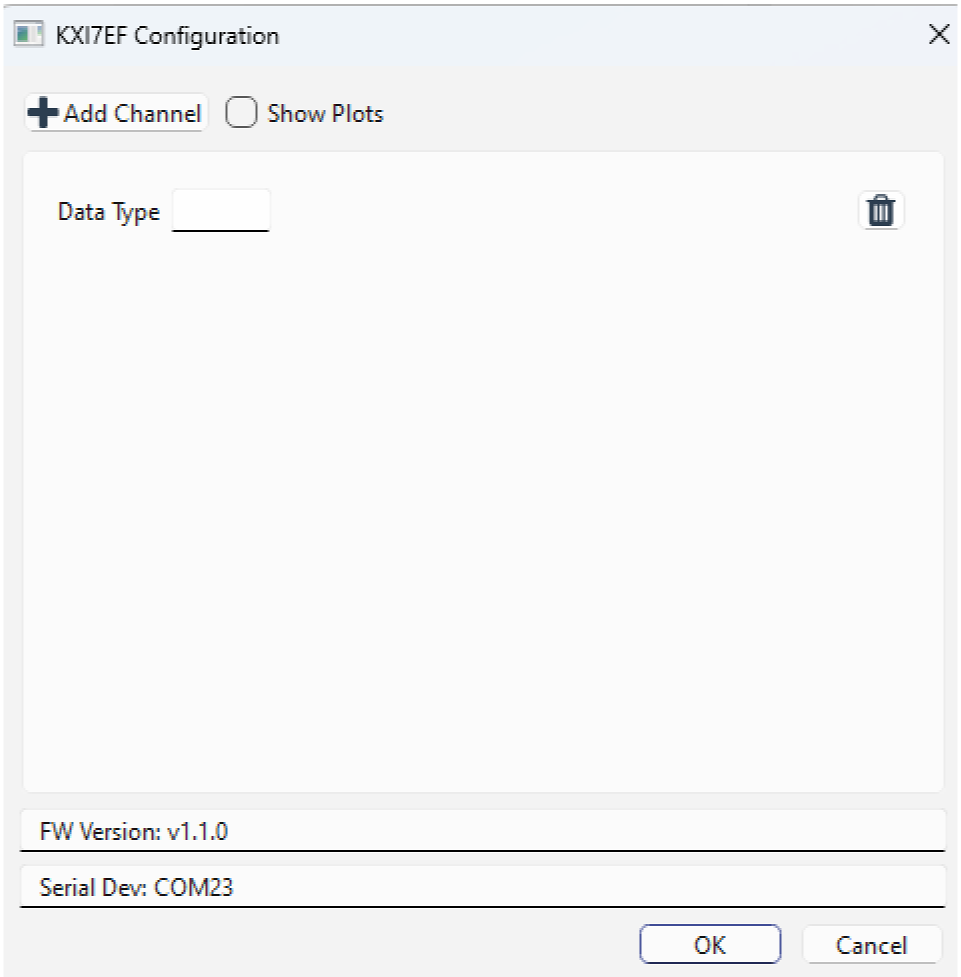


Figure 9 - Adding Data Stream

Refer to **Table 5** for a list of Streams. Note that, in the GUI, channels are referred to by their decimal address. Once all desired streams have been added, select the "OK" button to return to the main window.

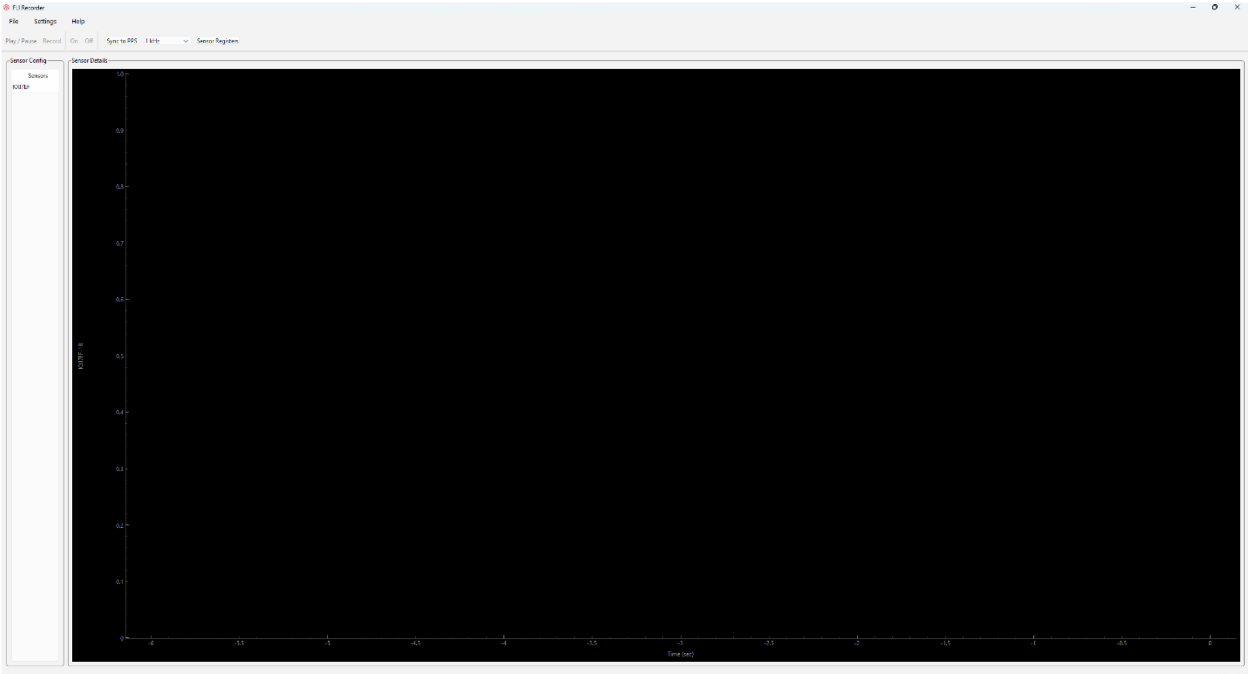


Figure 10 - Main Window with Added Stream

Note that the selected streams are automatically added to the main window. Select the sensors you want to start streaming and then click the “Play/Pause” button to start or stop displaying the data streams on the main window.

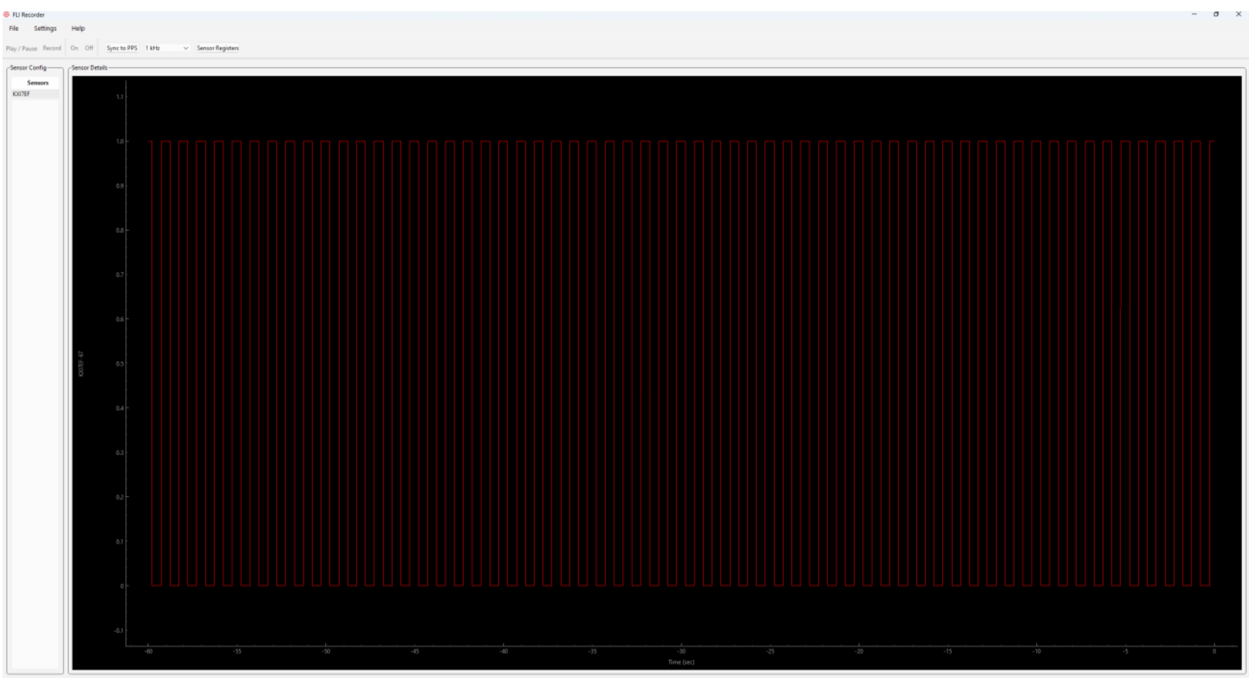


Figure 11 - Data Stream

Click on the “On” button to start the process of locking the magnetometer. This process may take a few minutes. The state of the magnetometer can be tracked with the LED behavior (see **Table 1**).

Once the magnetometer is locked, the magnetic field strength can be seen on data Stream 18.

Data streams can be recorded by pressing the Record button.

Scripted Operation

Communication with the magnetometer is over UART and thus can be scripted using a variety of programming languages. This section covers the communication format of incoming and outgoing data.

NOTE: The system does utilize an "escape byte" of 0x1b. An escape byte will precede a "special" (0x0A [START], 0x0D [STOP], or 0x1B [ESCAPE]) character. An escape byte will be inserted in front of a special character when the outbound data contains one of these 3 special characters.

Inbound Data

Commands to the SM300 **must** be in ASCII format and **must** begin with one of two specific symbols: @ or #. # precedes commands to write to internal registers, while @ precedes commands that enable external data streams. User interfaceable data streams and registers can be found in **Table 5** and **Table 6** respectively.

A diagram detailing the format of inbound data is shown below.

Byte Number	0	1:2	3:7
Byte Type	Start Byte	Address Byte[1:0]	Data Byte[3:0]

Table 2 - Inbound Data

Start Byte

The previously mentioned specific symbols: @ and #. @ precedes commands that enables external register streams. # precedes commands that writes to registers.

Address Byte

Usage of this byte changes depending on the preceding start byte. For stream commands, this byte selects which stream is output. For register commands, this byte selects which register is written to.

Data Byte

Usage of this byte changes depending on the start byte. For stream commands, the data byte will change the behavior of the outgoing stream, noted in the Outbound Data section. For register commands, the data byte will specify the data to be written to the selected register.

NOTE: It is critical that the user fills all bytes in inbound data when communicating with the FieldLine Industries SM300. For example, writing a value of 15 to register 2 would use all characters possible (#020015).

Outbound Data

Outbound data can be enabled by sending the "#" followed by the stream address and one of the three following values:

1. "FFFF" – The system will output data from this schedule exactly 1 time.
2. "0000" – This will indicate to the system to stop outputting data from this stream.

3. “XXXX” – Any other combination of bits will stream out data at the rate specified in the GUI (see Schedule Frequency Register)

The data format of a packet of outbound data without a CRC check is shown below:

Byte Number	0	1:2	3	4:7	8
Byte Type	Start Byte	Timestamp	Data Type	Data	Stop Byte

Table 3 - Outbound Data without CRC Check

With the CRC check enabled (see CRC Register), the outbound data format will be the following:

Byte Number	0	1:2	3	4:7	8	9:10
Byte Type	Start Byte	Timestamp	Data Type	Data	Stop Byte	Fletcher CRC-16

Table 4 - Outbound Data with CRC Check

Note that the above figures assume no escape characters are needed during transmission.

Examples

Below are examples of basic operations with the FieldLine Industries SM300:

One Time Read

The following commands will (1) write test data to the scratch register, (2) set the read register to the scratch and (3) then stream the data in the scratch register.

1. Send: @44f6b // writes 0x4f6b to register 4, the scratch register
2. Send: @030004 // sets the read register to 04
3. Send: #03FFFF // scheduled the one time read register for one data packet
4. Receive: {0x0A, 0x00, 0x00, 0x03, {0x00, 0x04, 0x4f, 0x6b}, 0x0d}

Typical Operation Flow (with Sync)

The following commands will start the magnetometer.

1. Send @000001 // reset sample count
2. Send: #230001 // enable status stream
3. Send: @4D001F // start magnetometer
4. Wait until status stream in in state 6 or LED is solid blue
5. Send: #230000 // disable status stream
6. Send: #120001 // enable magnetometer data

PPS Behavior

The FieldLine Industries SM300 has two PPS (Pulse Per Second) ports, one for input and output. These pulses can be used to synchronize data streams between multiple SM300 devices (see **Figure 3**).

An external PPS signal can be driven to the input PPS port for data synchronization. This signal could be from a GPS module or another SM300. When a PPS input signal is present, the SM300 will output that same signal to the PPS output port.

When a PPS input signal is not present, the SM300 will generate its own PPS signal at a 50% duty cycle and output that generated signal to the PPS output port.

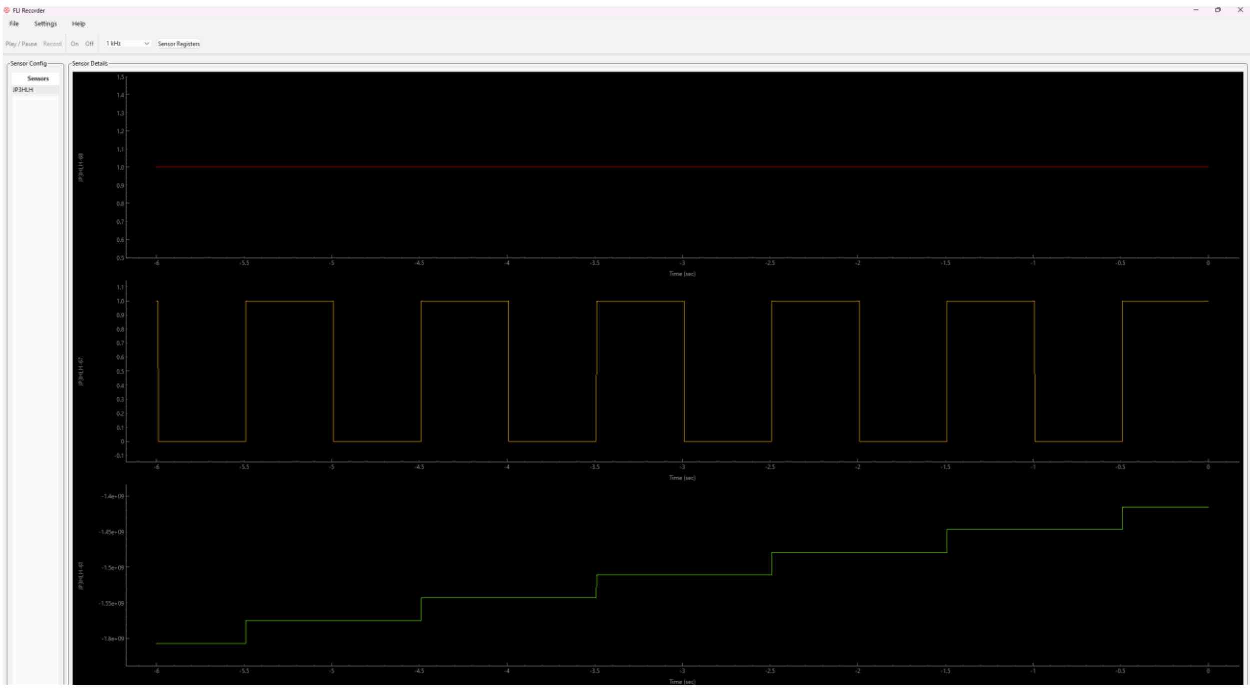


Figure 12 - PPS Behavior

The FieldLine Industries GUI also has a “Sync to PPS” button. This will issue a sync to all connected SM300 devices that will only activate on the next rising PPS edge. This allows all output data streams to be synchronized. Note that the button will disappear for 2 seconds after it is pressed to allow time for issuing the sync.

Appendices

Appendix A – Data Stream Information

Data from multiple different places along the FieldLine Industries SM300 signal chain can be streamed out at any time. Below is a list of useful streams for general debug.

Base Offset:		Stream Name	Description
0x0	0		
0x3	3	Read Value	Provides a mechanism to read registers. The register pointed to by the address stored in the "Read Register" is displayed on this stream in the following format: {8'b0, Address, Data} - where Address is the 8 bits in the Read Register, and Data is the 16 bits at the pointed Address
0x6	6	Version	The version number of the SM300. Format: Bit 31 - Dirty Bit Bit 30:26 - Major Bit 25:18 - Minor Bit 17:0 - Bug
0x7	7	Sensor Card Serial [Low]	Lower 32 bits of serial number
0x8	8	Sensor Card Serial [High]	Upper 32 bits of serial number
0x12	18	DDS Output Frequency	The frequency being applied to the RF coil. The closed loop magnetometer signal. [Unsigned 32-bit number] [~7 Hz / nT = Field]
0x17	23	Detected Magnetic Field	Magnetometer output in units of 100 fT
0x23	35	Logic Module State	Current logic module state. If state monitor is enabled the value will be accurate for the set data rate. 0: Sensor Off [Solid White] 1: Laser Check [Blinking Orange/Red] 2: Warm Up [Blinking Orange/Red] 3: Scan for resonance [Blinking Orange/Red] 4: Heater Stabilization [Blinking Green] 5: Scan for RF [Blinking Blue] 6: Magnetometer Locked [Solid Blue]

0x35	53	Electronics Serial Number LSW	The LSW of the Electronics Serial Number [Unsigned 32 bit]
0x36	54	Electronics Serial Number MSW	The MSW of the Electronics Serial Number [Unsigned 32 bit]
0x37	55	Sensor Serial Number LSW	The LSW of the Scalar Sensor Serial Number [Unsigned 32 bit]
0x38	56	Sensor Serial Number MSW	The MSW of Scalar Sensor Serial Number [Unsigned 32 bit]
0x3D	61	PPS Clock Count	A running count of the number of clock cycles. The stream is updated on the rising edge of the PPS out, and the counter only begins counting once the first PPS out edge is sent. [Unsigned 32 bit]
0x43	67	PPS Out	A stream representation of the analog PPS out signal. [Unsigned 32 bits]
0x44	68	PPS In	A stream representation of the analog PPS in signal. If there is no PPS in signal, this stream will read 32’b0.

Table 5 - Available Data Streams

Appendix B – Register Information

Registers give important information about the system and allow an interface to control the SM300. Below is a list of useful registers.

Base Offset:		Register Name	Description
0x0	**0**		
0x0	0	Control and Status Register	Basic control and status bits for the SM300
0x2	2	PCB ID	Stores information about the PCB ID and Version
0x3	3	Read Register	Sets the address of the register stream
0x4	4	Scratch Register	Scratch Register
0x17	23	Schedule Frequency	Sets data rate
0x43	67	Checksum and State Monitor	Enables Fletcher-16 Checksum and state monitor
0x44	68	UART Rate	Sets UART Baud Rate
0x4D	77	Logic Module Control	Controls state progression of the Logic Module
0x6E	110	LED Control	Controls the behavior of the LED

Table 6 - Register Map

Control and Status (CSR) Register

15	14	13	12	11	10	9	8
Reserved						RESET	PPS STATUSs
R - 0x0						R – 0x0	R -N/A
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
STATE				OP_STATUS		CLR_STR	RST_CNT
R – N/A				R - 0x0	R - 0x0	R/WClr - 0x0	R/WClr - 0x0
Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset							

Table 7 - CSR Register

Bits	Attribute	Name	Description	Default
15:10	R	Unused	Reserved	0x0
9	R/WClr	Reset PPS Count	Resets the PPS clock count on the next PPS rising edge if this bit is written to.	0x0
8	R	PPS Status	This bit is set high if within a 2 second period, a PPS rising edge is received	N/A
7:4	R	Register Block State	4’h0: Ready to receive reads and writes 4’h1: Initializing default registers 4’h2: Reading the EEPROM Device 4’h3: Waiting for EEPROM Data 4’h4: Writing to EEPROM Device	N/A
3:2	R	Operation Status	2'bX1: The magnetometer is ready to lock. 2'b1X: The magnetometer electronics have booted and is ready to receive external commands.	0x0
1	R/WClr	Clear from Reg	Clears all streams	0x0
0	R/WClr	Sync From Reg	Sync signal that resets signal chain	0x0

Table 8 - CSR Register Description

PCB ID Register

15	14	13	12	11	10	9	8
Reserved				VERSION_ID			
R - 0x0				R-N/A			
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
VALID	Reserved			BOARD_ID			
R – 0x0	R-N/A			R – N/A			
Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset							

Table 9 - PCB ID Register

Bits	Attribute	Name	Description	Default
15:12	R	Unused	Reserved	N/A
11:8	R	Version ID	Identified the version of the SM300 electronics	N/A
7	R	ID Valid	1’b0: The Board ID register is not valid 1’b1: The Board Id register is valid	0x0
6:4	R	Unused	Reserved	N/A
3:0	R	Board ID	Identifies the hardware: 4’h0: SM300 4’hX: Non-SM300	N/A

Table 10 – PCB ID Register Description

Read Register

15	14	13	12	11	10	9	8
Reserved							
Reset: N/A							
7	6	5	4	3	2	1	0
READ_ADDR							
R/W-0x0							
Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset							

Table 11 - Read Register

Bit	Attribute	Name	Description	Default
15:8	R	Unused	Reserved	0x0
7:0	R/W	Read Address	This value will indicate the address of the register to be loaded into the "one time read" data stream. This allows the user to read back the value inside a register via a data stream.	0x0

Table 12 - Read Register Description

Scratch Register

15	14	13	12	11	10	9	8
Reserved							
Reset: N/A							
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
SCRATCH_REG							
R/W-0x0							

Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset

Table 13 - Scratch Register

Bit	Attribute	Name	Description	Default
15:8	R	Unused	Reserved	0x0
7:0	R/W	Scratch Register	Scratch register to write and read data back out of. Useful for verifying one time read architecture.	0x0

Table 14 – Scratch Register Description

Schedule Frequency Register

15	14	13	12	11	10	9	8
SCHEDULE_FREQ[15:8]							
Reset: 0x0							
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
SCHEDULE_FREQ[7:0]							
R/W-0x0							
Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset							

Table 15 – Schedule Frequency Register

Bit	Attribute	Name	Description	Default
15:0	R/W	Schedule Frequency	Sets the rate data is streamed on the UART TX line. The rate is determined as: 25kHz / <register value>. NOTE: The UART protocol cannot support high data rates. Be aware.	0x0

Table 16 – Schedule Frequency Register Description

Checksum and State Monitor Register

15	14	13	12	11	10	9	8
Reserved							
Reset: N/A							
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Reserved				STATE_MON	OW_SERIAL_RESCAN		CRC
R/W-N/A				R/W-0x0	R/W-0x0		R/W-0x0

Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset

Table 17 - Checksum and State Monitor Register

Bit	Attribute	Name	Description	Default
15:4	R	Unused	Reserved	N/A
3	R/W	State Monitor	Determines the behavior of the magnetometer stream (18) when the magnetometer is not locked. 1'b0: The magnetometer stream will output data when the magnetometer is not locked 1'b1: The magnetometer will not output data when the magnetometer is not locked	0x0
2:1	R	Unused	Reserved	N/A
0	R/W	Fletcher-16 Checksum Enable	1'b0: Disable checksum 1'b1: Enable checksum NOTE: Checksum is incompatible with UART GUI. The checksum used is the Fletcher-16. https://en.wikipedia.org/wiki/Fletcher%27s_checksum	0x0

Table 18 –Checksum and State Monitor Register Description

UART Rate Register

15	14	13	12	11	10	9	8
Reserved							
Reset: N/A							
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Reserved						UART_RATE	
R/W-N/A						R/W-0x0	
Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset							

Table 19 - UART Rate Register

Bit	Attribute	Name	Description	Default
15:2	R	Unused	Reserved	N/A
1:0	R/W	UART Rate	Sets the baud rate for UART Communication. 2’b00: 115200 Baud 2’b01: 230400 Baud 2’b10: 460800 Baud 2’b11: 921600 Baud	0x0

Table 20 –UART Rate Register Description

Logic Module Control Register

15	14	13	12	11	10	9	8
Reserved							
Reset: N/A							
7	6	5	4	3	2	1	0
Reserved		IDLE	ENABLE	SCAN_RF	SCAN_DD	LASER_CHECK	LOAD_PARAM
R/W-N/A		R/W-0x0	R/W-0x0	R/W-0x0	R/W-0x0	R/W-0x0	R/W-0x0
Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset							

Table 21 - Logic Module Control Register

Bit	Attribute	Name	Description	Default
15:6	R	Unused	Reserved	N/A
5	R/W	Idle	1'b0: The system will proceed through the state machine as normal. 1'b1: The system will idle in whichever state it was in when this bit goes high.	0x0
4	R/W	Enable	1'b0: The logic module will reset to the OFF state from whichever state it is at. 1'b1: The logic module will begin transitioning through the states as determined by the lower 4 bits described below	0x0
3	R/W	Scan RF	1'b0: The system will stay in the scan diode drop state. 1'b1: The system will proceed to scan the RF after meeting the requisite thresholds for the diode drop scan state to transition. NOTE: The previous three bits must be high to reach this state.	0x0
2	R/W	Scan Diode Drop	1'b0: The enable bit the system will stay in the warm up state. 1'b1: The system will proceed to the scan diode drop state after the heater time out. NOTE: If the previous two bits are not high the state machine will not reach this point.	0x0

1	R/W	Laser Check	1'b0: The system will enable the laser and idle in with it on. 1'b1: The system will enable the laser, check against the threshold, and proceed to the warmup state. NOTE: If bit 0 is not set the state machine will not reach this point	0x0
0	R/W	Load Parameters	1'b0: On the rising edge of the enable bit the system will stay in the "OFF" state. 1'b1: On the rising edge of the enable bit the system will load sensor parameters and proceed to the laser check state.	0x0

Table 22 –Logic Module Control Register Description

LED Control Register

15	14	13	12	11	10	9	8
Brightness							
Reset: 0x10							
7	**6**	**5**	**4**	**3**	**2**	**1**	**0**
COLOR						LED_BLINK	LED CTRL
R/W-0x0						R/W-0x0	R/W-0x0

Legend: R/W = Read/Write; R = Read Only; CLR = Auto Clear; R/WClr = Read and Write to Clear -n = value after reset

Table 23 - LED Control Register

Bit	Attribute	Name	Description	Default
15:8	R/W	Brightness	Sets the brightness of the LED from 8'h0 to 8'hFF. A value of 8'h0 will turn off the LED.	0x10
7:4	R/W	Color Choice	Sets the LED color if LED Control Bit is set to 1'b0: 4'h0: Off 4'h1: Red 4'h2: Orange 4'h3: Yellow 4'h4: Lime 4'h5: Cyan 4'h6: Blue 4'h7: Purple 4'h8: Pink 4'h9: White	0x0
3:2	R	Unused	Reserved	N/A
1	R/W	LED Blink	1'b0: LED color is solid 1'b1: LED will blink is LED Control bit is 1'b1	0x0
0	R/W	LED Control	1'b0: The Logic Module state determines the LED color 1'b1: Bits 7:4 determine the LED color	0x0

Table 24 –LED Control Register Description