Portland State University

Capstone Project Report

Department of Electrical & Computer Engineering

3D Metal Printer

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1 Project Overview

The team interfaced a CNC machine with a MIG welder to create a 3D metal printer.

2 Project Proposal

2.1 Sponsor Proposal

The company is in the process of constructing an innovative 3D metal printer controlled by CNC (Computer Numerical Control). The project was a combination of two machines:

- CNC mill – (3, 4 or 5 axis CNC mill)
- MIG/TIG welding machine.

The purpose for the CNC motion control (CNC mill) is to program and control motion of the machine, and in this case, the metal deposition process. The purpose for the MIG welder is to deposit liquid metal. Many kinds of wire can be used by the welder to form the parts; carbon steel, titanium, stainless steel or aluminum. The idea for metal deposition and an example that uses a laser can be found at:
https://www.youtube.com/watch?feature=player_embedded&v=s9IdZ2pI5dA
A problem with laser use is its high cost. In this project, the welding machine used cost $400. Another example can be found here:
http://www.wired.co.uk/magazine/archive/2014/08/play/steel-sketch
AKTechnology's plan is to manufacture parts for pump and compressors, and research and develop parts for all sorts of use. The goal is to fabricate low cost and highly usable machines.

The company has CNC PC based CNC mill-motion controller.
https://www.youtube.com/watch?v=Plf3t7o951U&list=UUlGufPQeEKdN1-50F89Ejig
https://www.youtube.com/watch?v=G-jokU7v92E&list=UUlGufPQeEKdN1-50F89Ejig
https://www.youtube.com/watch?v=bPQ5UNiGA4c&list=UUlGufPQeEKdN1-50F89Ejig

The project was to upgrade this CNC motion controller – mill into 3D metal deposition printer by adding a MIG welder instead of a cutting tool spindle. The CNC motion control was reprogrammed. The MIG welder was operational.
The project will also build control to integrate CNC mill and MIG welding machine. The Welder has 2 adjustments - feed of wire and current. A stepper motor is planned to be used to control those analog data for wire feed and power current. The PLC, programmable logic controller, will join the CNC motion controller and the MIG welding machine.

2.2 The Goal

The end goal of this project is to fully integrate the MIG welder with the LinuxCNC system. Integration will include a way to control all of the functions of the welder, i.e. wire speed, maximum current output, engaging and disengaging the welder at appropriate times. In order for this to be done, electromechanical devices must be used to manipulate the knobs on the MIG welder. At the very least, the machine must be able to deposit material, reproducing a simple single object from a CAD drawing. Our aim is to produce a 1" cube. However, it is desired that the machine will be able to create complex structures on a single base. Precision of the deposition is not the primary concern, however it will be a requirement that the total amount of material deposited is more than the minimum tolerance of the part being created. This will allow for material to be machined away to a more precise tolerance.

2.3 Our Starting Point

The groundwork of this project has been completed by Aram Kasparov, the project sponsor. The project at its current state consists of a PC controlled CNC machine, a MIG welder, an infrared temperature sensor and a current measuring sensor. The PC controlling the CNC machine is running a Linux operating system. LinuxCNC an open-source software is used for programing and interfacing with the physical machine. Additional hardware is installed onto the PC, consisting of Mesa Electronics 5I20 FPGA based PCI Anything I/O card, 7i33 analog servo interface card and two 7i37-COM isolated I/O cards. The LinuxCNC software communicates the control signals and receives feedback through these cards. The CNC machine is a 3-axis machine-that is it can move in the X, Y and Z directions. Each axis is moved by a servo-motor and each servo motor is driven by a driver which receives its control commands from the PC. The machine is functional, though the motors will require some tuning and limit switches need to be programmed in (they are physically installed on the machine but not included in the program). The MIG/Flux cored welder is rated at 180 Amp-DC, 240 Volt with a duty cycle of 20% at 140 amps. The welder has current and wire feed adjustment capabilities for controlling the weld. These two knobs will be controlled by two stepper motors which have been installed onto the welder already. The current sensor has the ability to measure up to 225A. It has been demonstrated to be functional and will be used to monitor the current of the weld. The infrared non-contact temperature sensor is rated to measure temperatures up to 1800 degrees Celsius, though no tests have been performed yet.

2.4 Requirements

- Must use a wire feed welder
- Welder must have a Control System
- Must measure weld temperature
- Must measure weld current
- Must use both previous parameters to estimate current quality of weld
- Must use "G code" as inputs
- Must control when material is being deposited
- Must have user interface
- Should allow for welder thermal shutdown
- Should Measure Wire Speed from welder

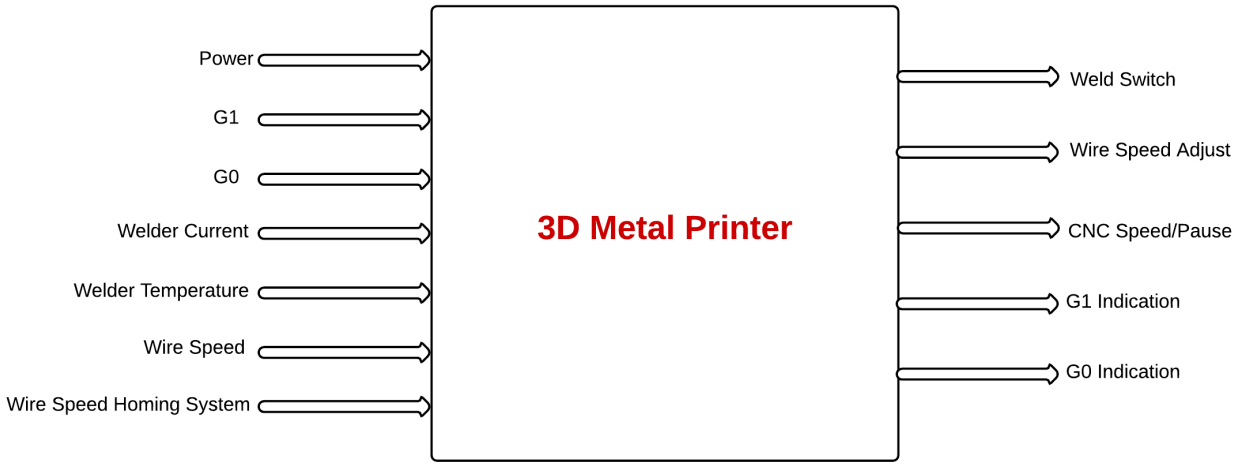


Figure 1: Level-0 Block Diagram of the 3D Metal Printer

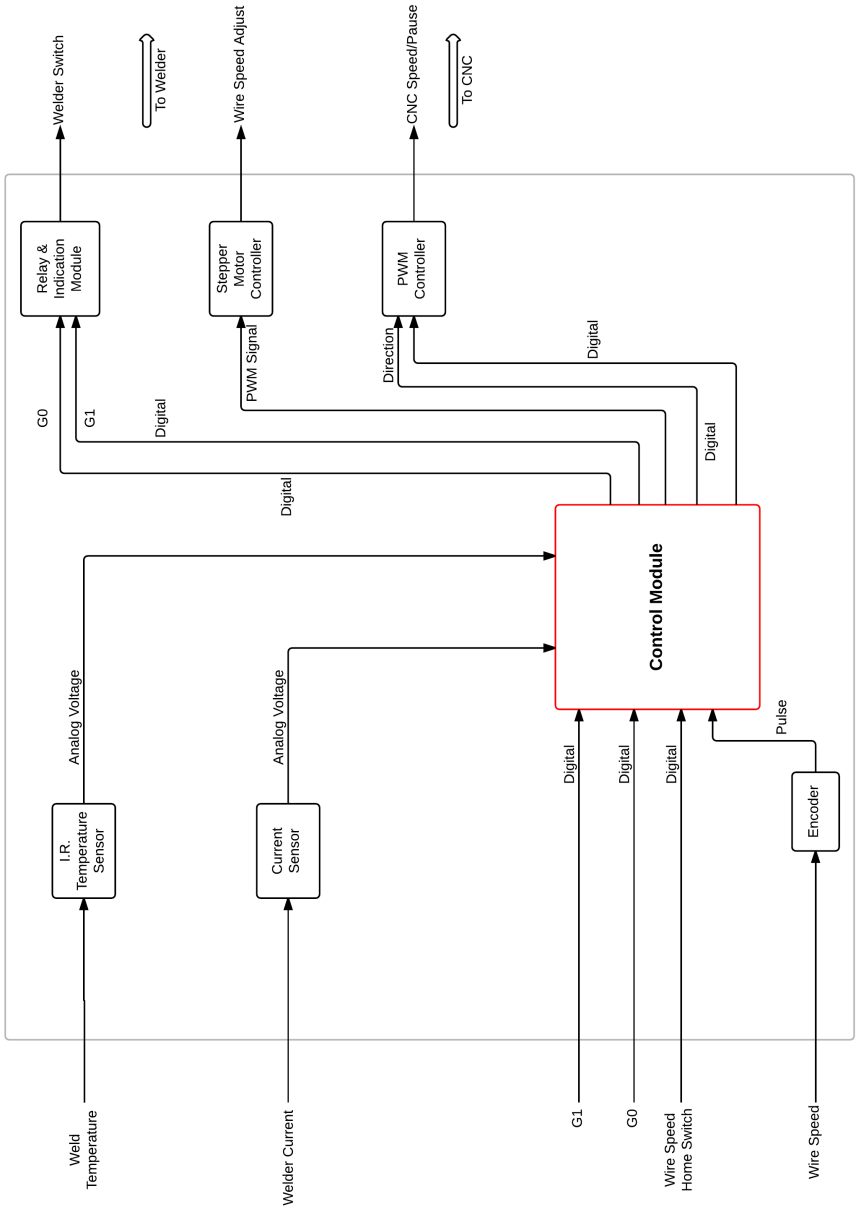
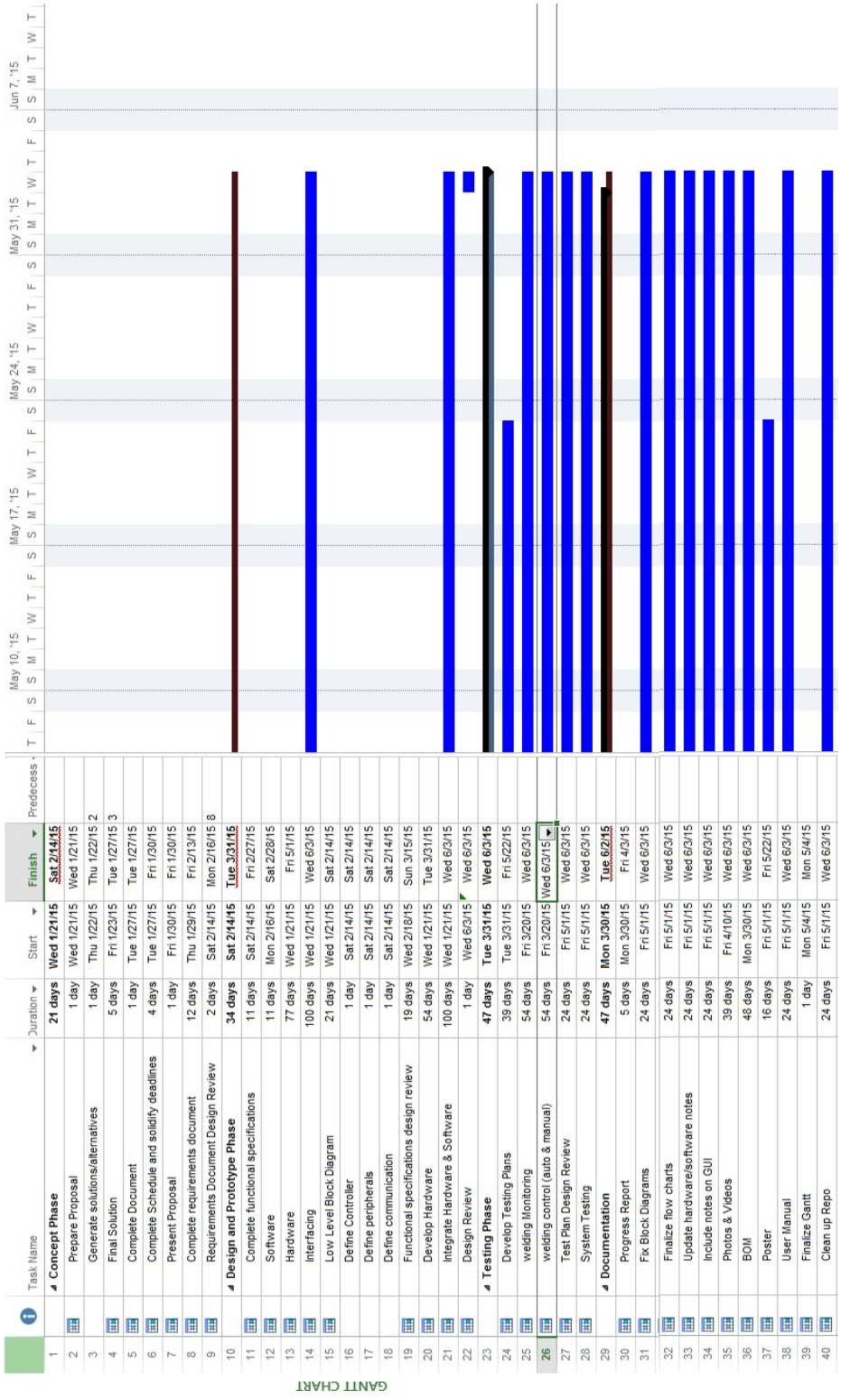


Figure 2: Level-1 Block Diagram of the 3D Metal Printer

3 Schedule



	Task Name	Duration	Start	Finish	Predecess
1	**Concept Phase**	**21 days**	**Wed 1/21/15**	**Sat 2/14/15**	
2	Prepare Proposal	1 day	Wed 1/21/15	Wed 1/21/15	
3	Generate solutions/alternatives	1 day	Thu 1/22/15	Thu 1/22/15	2
4	Final Solution	5 days	Fri 1/23/15	Tue 1/27/15	3
5	Complete Document	1 day	Tue 1/27/15	Tue 1/27/15	
6	Complete Schedule and solidify deadlines	4 days	Tue 1/27/15	Fri 1/30/15	
7	Present Proposal	1 day	Fri 1/30/15	Fri 1/30/15	
8	Complete requirements document	12 days	Thu 1/29/15	Fri 2/13/15	
9	Requirements Document Design Review	2 days	Sat 2/14/15	Mon 2/16/15	8
10	**Design and Prototype Phase**	**34 days**	**Sat 2/14/15**	**Tue 3/31/15**	
11	Complete functional specifications	11 days	Sat 2/14/15	Fri 2/27/15	
12	Software	11 days	Mon 2/16/15	Sat 2/28/15	
13	Hardware	77 days	Wed 1/21/15	Fri 5/1/15	
14	Interfacing	100 days	Wed 1/21/15	Wed 6/3/15	
15	Low Level Block Diagram	21 days	Wed 1/21/15	Sat 2/14/15	
16	Define Controller	1 day	Sat 2/14/15	Sat 2/14/15	
17	Define peripherals	1 day	Sat 2/14/15	Sat 2/14/15	
18	Define communication	1 day	Sat 2/14/15	Sat 2/14/15	
19	Functional specifications design review	19 days	Wed 2/18/15	Sun 3/15/15	
20	Develop Hardware	54 days	Wed 1/21/15	Tue 3/31/15	
21	Integrate Hardware & Software	100 days	Wed 1/21/15	Wed 6/3/15	
22	Design Review	1 day	Wed 6/3/15	Wed 6/3/15	
23	**Testing Phase**	**47 days**	**Tue 3/31/15**	**Wed 6/3/15**	
24	Develop Testing Plans	39 days	Tue 3/31/15	Fri 5/22/15	
25	welding Monitoring	54 days	Fri 3/20/15	Wed 6/3/15	
26	welding control (auto & manual)	54 days	Fri 3/20/15	Wed 6/3/15	
27	Test Plan Design Review	24 days	Fri 5/1/15	Wed 6/3/15	
28	System Testing	24 days	Fri 5/1/15	Wed 6/3/15	
29	**Documentation**	**47 days**	**Mon 3/30/15**	**Tue 6/2/15**	
30	Progress Report	5 days	Mon 3/30/15	Fri 4/3/15	
31	Fix Block Diagrams	24 days	Fri 5/1/15	Wed 6/3/15	
32	Finalize flow charts	24 days	Fri 5/1/15	Wed 6/3/15	
33	Update hardware/software notes	24 days	Fri 5/1/15	Wed 6/3/15	
34	Include notes on GUI	24 days	Fri 5/1/15	Wed 6/3/15	
35	Photos & Videos	39 days	Fri 4/10/15	Wed 6/3/15	
36	BOM	48 days	Mon 3/30/15	Wed 6/3/15	
37	Poster	16 days	Fri 5/1/15	Fri 5/22/15	
38	User Manual	24 days	Fri 5/1/15	Wed 6/3/15	
39	Finalize Gantt	1 day	Mon 5/4/15	Mon 5/4/15	
40	Clean up Repo	24 days	Fri 5/1/15	Wed 6/3/15	

Figure 3: Gantt Chart showing the schedule

4 Hardware

4.1 Welder Control

To control the welder, a central control module will be used. This was a hot topic of debate for several weeks, as the number of choices available for this project are very high. The sponsor's requirements for the project was that all of the control work was done by a separate computer from the one used by Linux CNC, this only narrowed it down to a choice between a PCIe DAC board and a single board computer. Based on the need for both analog and digital control pins and the need for future expansion, we researched and came up with several options.

Single Board Computers	**DAC**
Raspberry-Pi	Sensoray 826
Intel Galileo	MCC DAS1602/16
SBC 8600B	
Wander Board Solo	
Beagle Bone Black	

In the end we chose the Sensoray 826 board because for the price it outperforms all other boards on the market by having 16 analog inputs, 8 analog outputs, and 48 digital I/O pins. This board was chosen for the high level of future expandability that it has, and because it is a PCIe card which can be packaged into its own desktop as per request from the sponsor. To control the current to the weld and the wire speed of the welder, two stepper motors have been fitted to the manual control knobs, and are connected to a motor driver module. The Sensoray board will be controlling the motor drivers using a sequence of rising and falling edges. To allow the controller board to control at what time the welder is depositing and when it is not depositing, a relay with a transistor driver will be used.

The signal that tells the controller will be coming from the CNC machine's I/O card. It is a switch type signal which means that when the signal is sent, an internal switch will be closed, causing what ever is on the input to be shown on the output. The CNC machine uses G-Code (described below), and Linux CNC allows outputs to be asserted when a particular G-Code instruction is executed. G1 and G0 are going to be used to tell the I/O card to close and open the switch, which will assert 5V DC to the input to the control module. The control module will assert an output high or low which will open or close the welder switch, turning the welder on and off.

The Sensoray 826 I/O card has three 50 pin connectors and two 26 pin connectors. To allow easy access to these pins, a breakout board with screw terminals has been made so that wires can easily be disconnected and switched.

4.2 Breakout Boards

To easily connect to the Sensoray 826 board, several breakout boards with screw terminals were made. There are two types of break out boards, a 50-pin board and a 26-pin board. 50 pin boards are used to connect to the digital and analog pins of the control board, while 26 pin boards are used to connect to the various counter channels. Shown below are mages of the boards them selves. With the empty side of the board facing you, the screw terminals are in order from 1 to 50/26 starting on the right hand side.

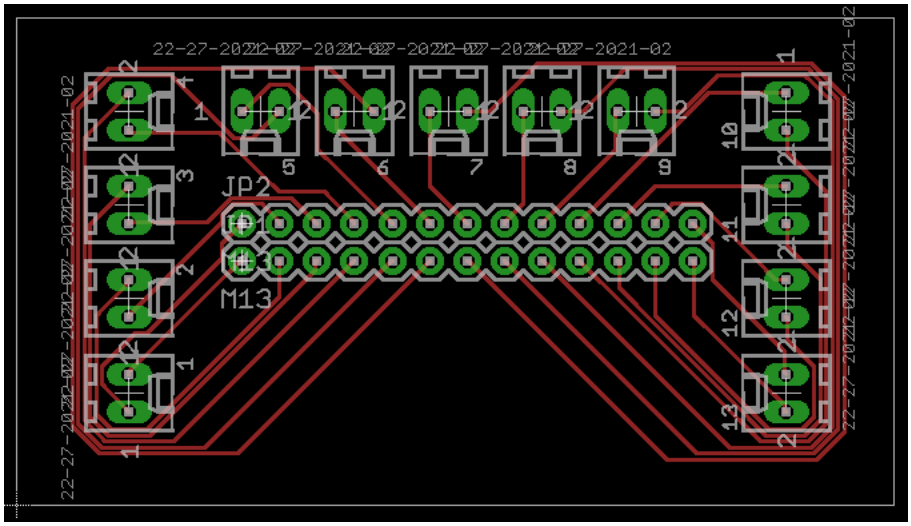


Figure 4: Board Layout of the 26 pin Breakout Board for the Sensoray 826 I/O card

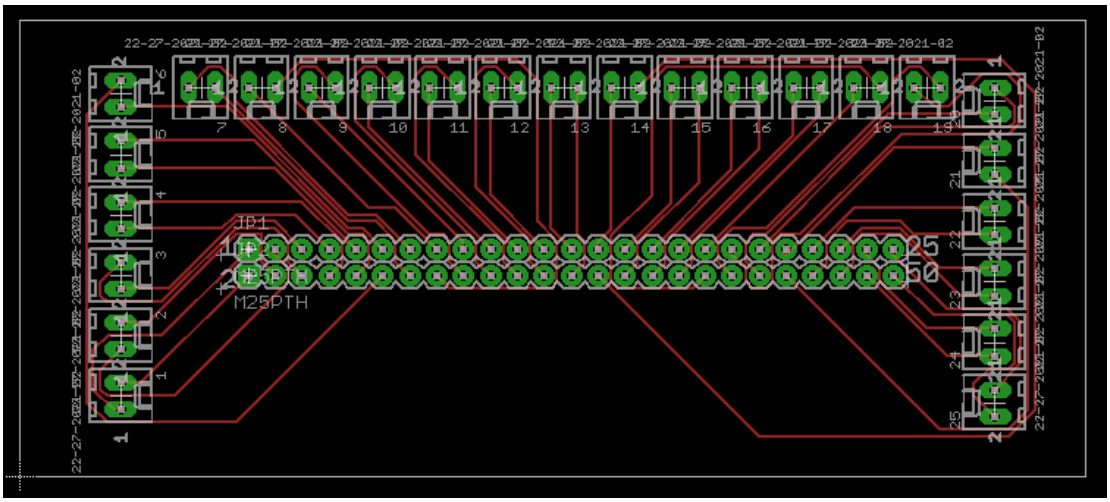


Figure 5: Board Layout of the 50 pin Breakout Board for the Sensoray 826 I/O card

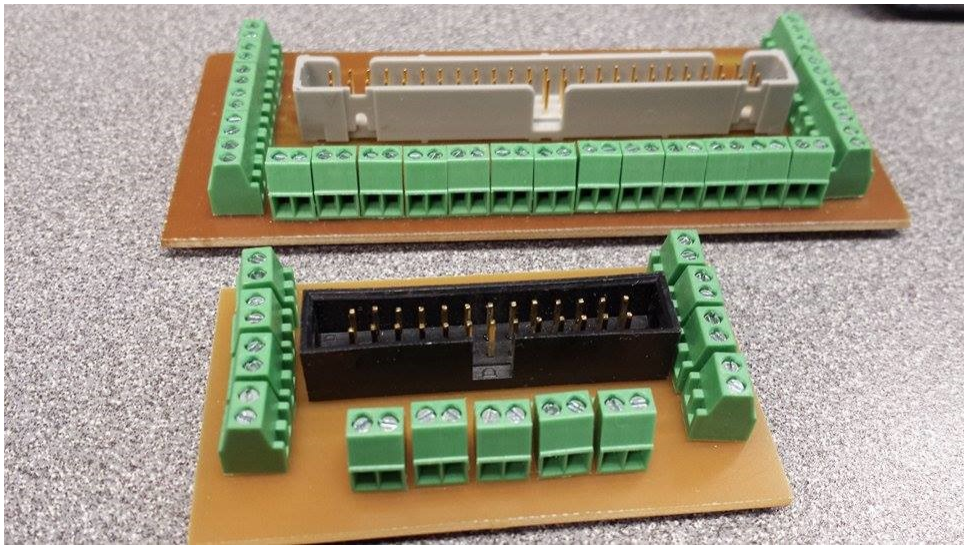


Figure 6: The 26 and 50 pin Breakout Boards with connectors for The Sensoray 826 I/O card

4.3 Temperature Sensor

An infrared temperature sensor will be used to measure the temperature surrounding the weld area. These temperature sensors typically have a higher operating range than other types of temperature sensors. The chosen sensor is the CTLM-1M-1H1-CTL-CF4 from Micro-Epsilon. This sensor was chosen of it's operating range was 800C to 2200C. It has multiple configurable output types, including current output, voltage output, and alarm outputs. This sensor also has a focus point at 450mm ($\tilde{1}8$ in) which gives considerable distance from the weld, and it is not impractically far away. Further documentation can be found (Appendix temp sens). The Sponsor has agreed to take care of mounting the sensor on the machine.

The chosen output type of the temperature sensor is chosen to be a voltage output with a full-scale range of 0V to 10V. This range was chosen because the ADC on the Sensoray 826 are configurable to accept up to +10V and another Analog input needed the input configured to +10V. Setting the output range to 0V-10V on the current sensor removed the need to write additional software to solve an issue that was solved in other means.

Figure 7: The Micro-Epsilon 1MH1-CF4 Temperature Sensor

4.4 Incremental Encoder

The Incremental Encoder is used to measure the actual wire speed of the welder wire. The encoder needed to be incremental because of the need to know speed, and that current position did not matter. The chosen encoder is the U.S. Digital S5-5000-250-IE-D-B. Initially a pulley on a shaft type encoder was going to be used. The pulley be mounted to the frame of the welder and the encoder would be placed under tension underneath the wire that is being fed to the weld. However this was not successful as there could not be any external tension placed on the wire inside the welder.

Fortunately the main drive pulley has a square drive shaft and stuck out past the edge of the pulley. A small plastic "coupler" piece was 3D printed that adapted the round end of the encoder, to the square drive shaft of the drive pulley. The CAD drawing of this part can be seen to the left. This piece allowed an accurate measurement of the actual wire speed of the welder to be interpreted by the Sensoray 826. Here, the calculations for the wire speed can be found.

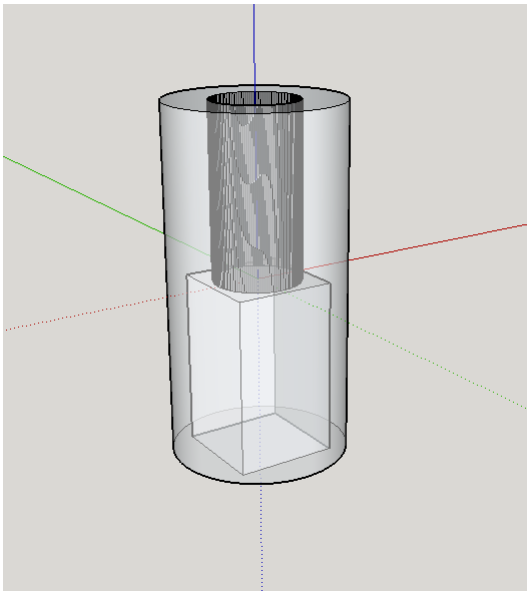


Figure 8: Schematic of the Incremental Encoder

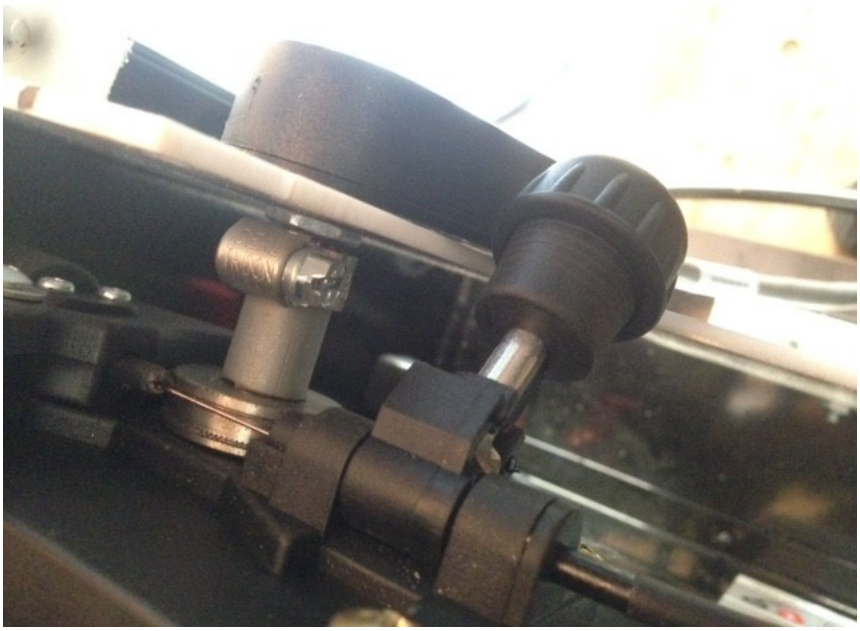


Figure 9: The US Digital S5-5000-250-IE-D-B Incremental Encoder

4.5 Relay and Indication Module

A relay was used to interface the Sensoray 826 with the welder. A relay provides isolation from any harmful voltage spike that occurs on the welder's circuit. It also acts as a mechanical switch, which is the same as the trigger on the welder gun itself. It is unknown what type of signal is passed through the welder switch weather its DC, or AC the relay will on act differently, as a transistor might. The interface circuit includes a transistor drive circuit that switches an 8V supply (which comes from a wall wart power supply) across the coil of the relay on and off. This module also includes LEDs to indicate what state the CNC machine is currently in. A schematic and an image of the final module can be seen below.

There were some issues with the relay module, where were that the Sensoray 826 has internal 10k pull up resistors, and when the machine powers up, the active low DIO pins are initialized to a 0-state, which means that the voltage is high on the pin. When connected to the welder, this meant that when there was not any code being executed the welder would be activated. To remedy this issue, an inverter was placed on the input.

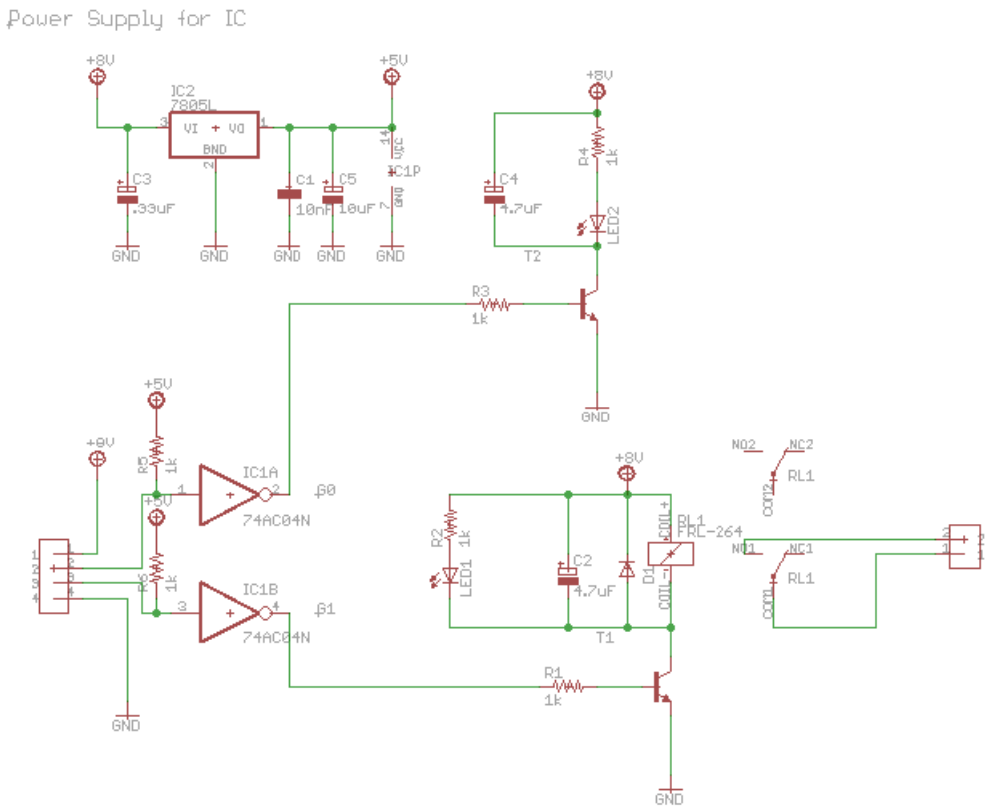


Figure 10: Schematic of the Relay & Indication Module

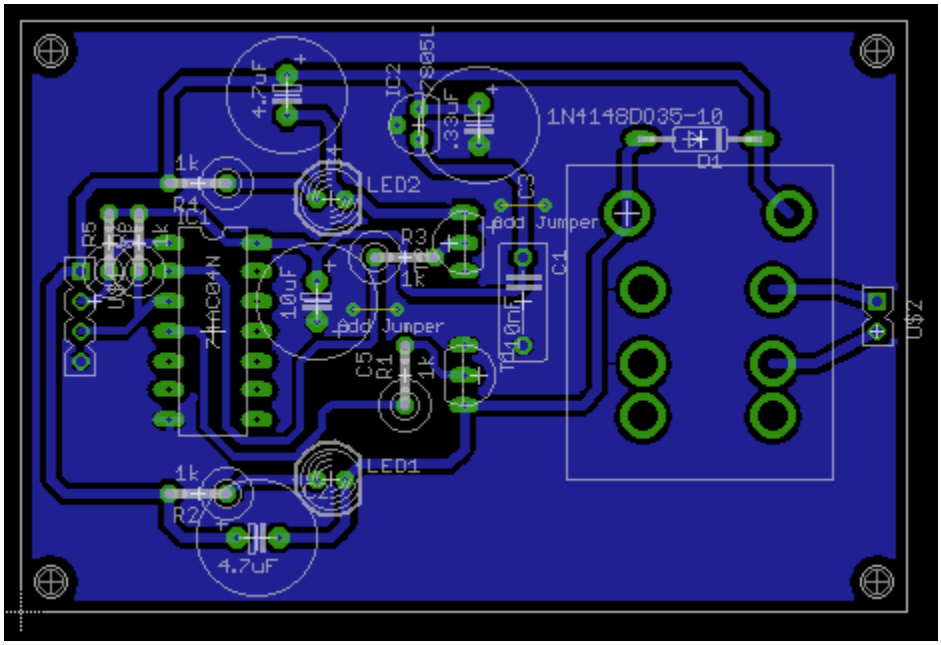


Figure 11: Board Layout of the Relay & Indication Module

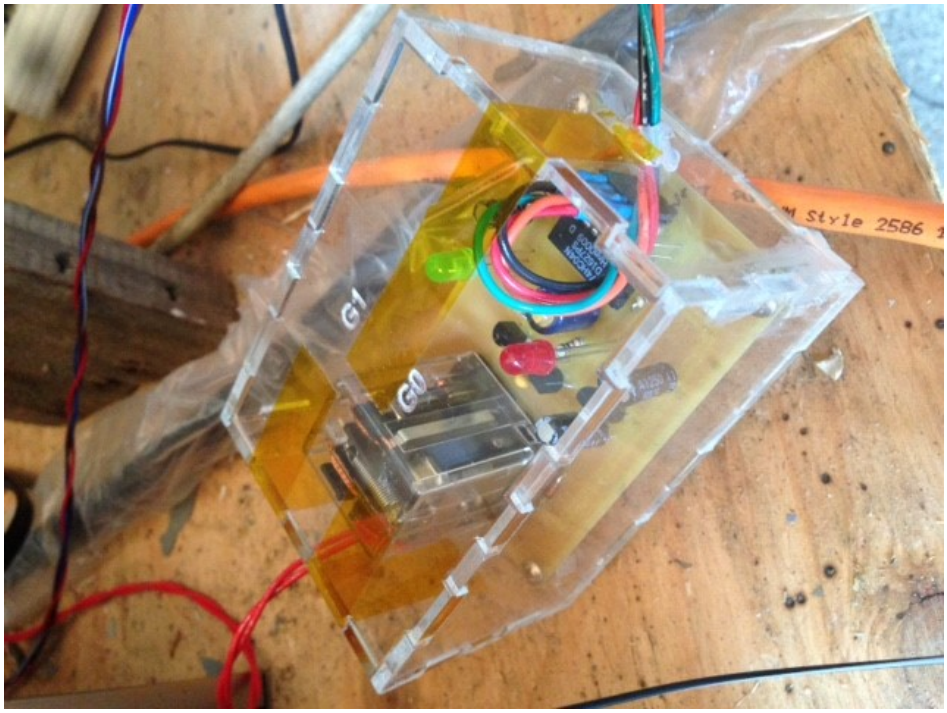


Figure 12: The Relay & Indication Module

4.6 Stepper Motor Controller

P/N:
Controller: KL-5056
Motor: KL23H2100-35-4B

The stepper motor controller is used to control a motor that adjusts the wire speed knob on the welder. From the Sensoray 826, there are two digital signals that control how much and in which direction the motor turns. To tell the motor two turn, a PWM signal with a 50% duty cycle is used. The frequency determines the speed of rotation. The direction signal is either a high or low 5V signal that will turn the motor clockwise or counterclockwise. The controller also has a programmable step resolution, which is either defined in software, or by using the DIP switched located on the side of the controller. Further documentation on the controller can be found here.

The motor is coupled to the wire speed adjustment knob via a PVC cylinder, which have elevated surfaces where the limits of the knob are. Shown below, are switches that get triggered if the motor turns too far. The limit switches are connected to the enable pin of the motor controller, so that if the motor accidentally turns too far, it will disable its self and it will not damage the knob on the welder. An additional switch is added to the PVC cylinder, which is used as a reference position of the knob. Shown below is the wiring diagram of the motor controller.

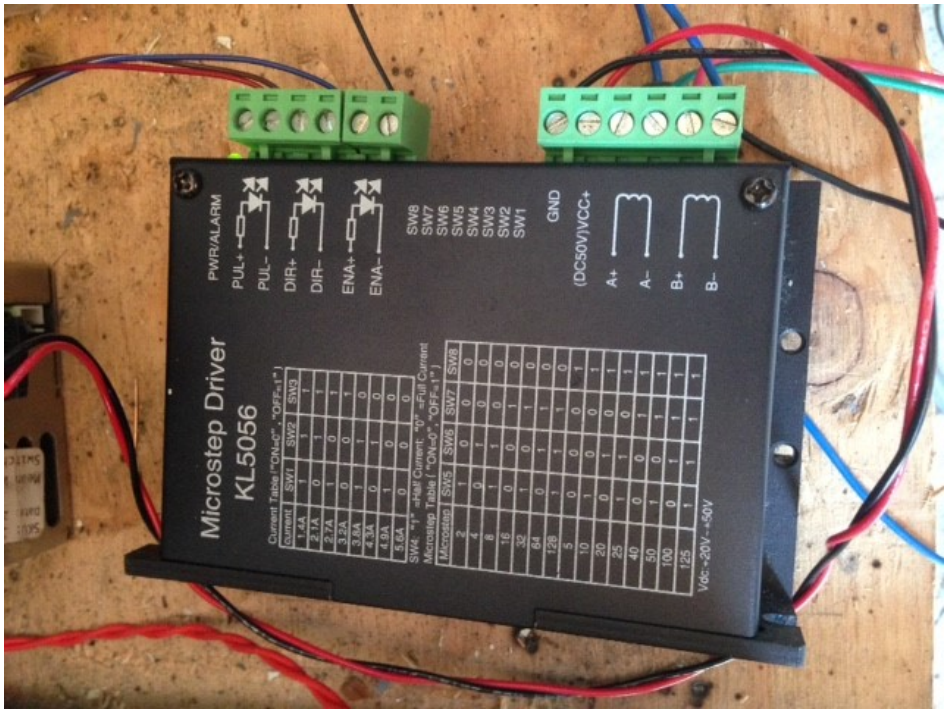


Figure 13: The Stepper Motor Controller

4.7 PWM Controller

P/N: Mesa THC A-D

The PWM controller is a voltage to frequency converter. It is used to externally start and stop the CNC machine. The voltage input of the PWM controller is connected to a digital output of the Sensoray 826. To stop the CNC Machine, a 5V signal is send and to stop it is 0V. The CNC machine is initialized to use this 5V signal in the .HAL file associated with that machine. In fact the voltage on that pin can be anywhere between 0V and 5V for further external control of the welder, however in the scope of this project, only a high or low signal needs to be sent.

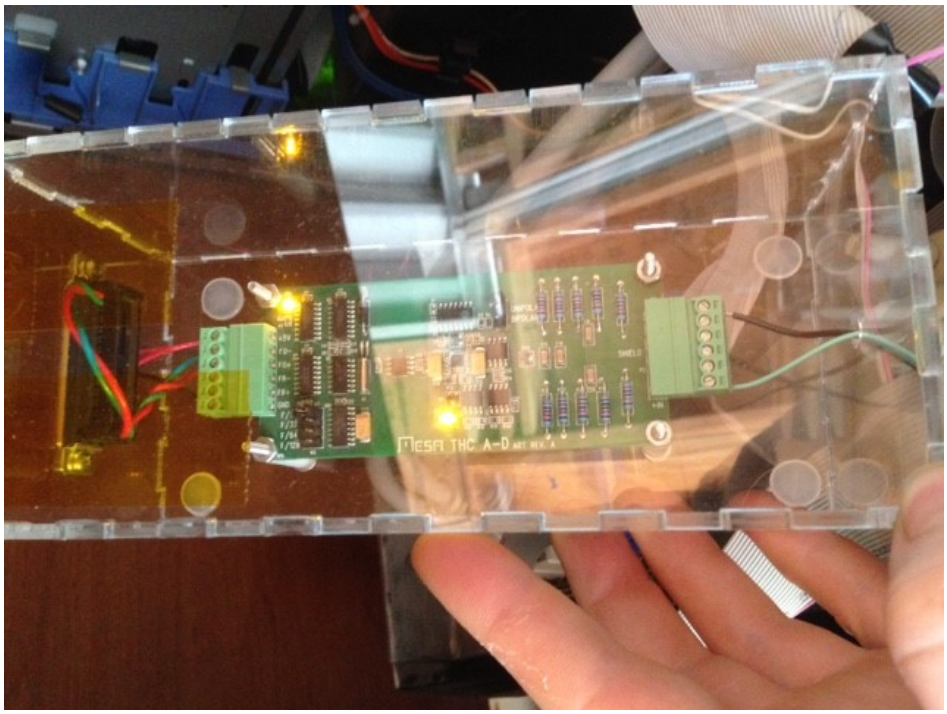


Figure 14: The Mesa THC A-D PWM controller

4.8 Current Sensor

P/N: CSLA1DJ

This current sensor has an operational range of 0 to 225A, which is well over the maximum current of the welder. It is placed in a small plastic housing, which a jumper cable is passed though. The sensor is a Hall effect sensor that is placed inside a ferrite toroid. The output of the sensor is a voltage that sits at half of the supply voltage, and will deviate above or below that level based on he magnitude and direction of the current. There is a metal lug, which the ground connection of the welder connects to. The other end of the module is a large alligator clamp that connects to the plate being welded to.

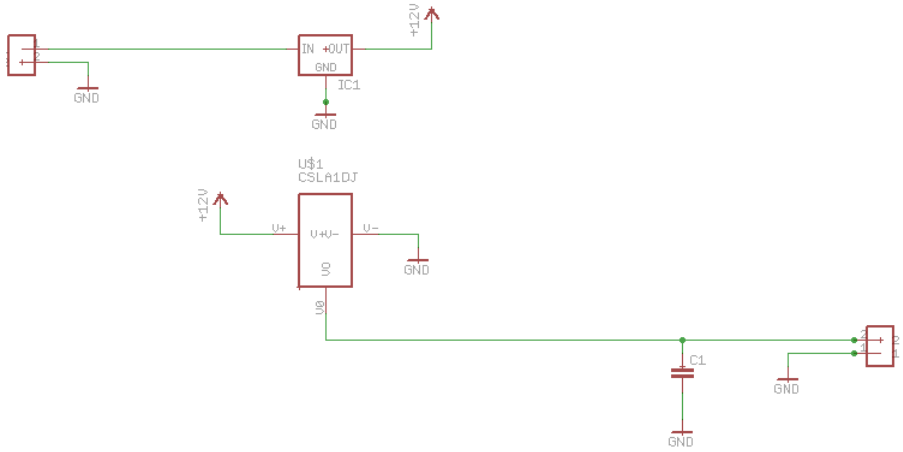


Figure 15: Schematic of the Current Sensor

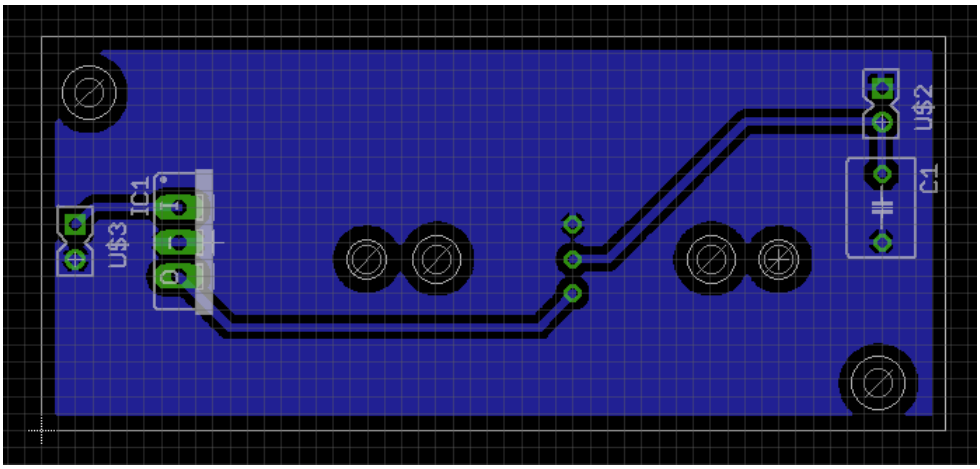
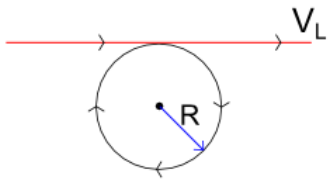


Figure 16: Board Layout of the Current Sensor

Figure 17: The CSLA1DJ Current Sensor

4.9 Wire Speed

For calculating Wire Speed with Rotary Encoder



So Angular Velocity is,

$$\boldsymbol{f = \frac{n}{Nt}}$$

n = number of up/down counts, N = number of up/down counts/rev, T = sampling time.

And Linear Velocity is,

$$v_L = \omega r$$
$$\omega = 2\pi f$$

So,

$$\boldsymbol{V = \frac{\pi nd}{NT}}$$

Connections to 826

J_4	Pin 1	+A0
	Pin 2	-A0
	Pin 3	GND
	Pin 4	+B0
	Pin 5	-B0

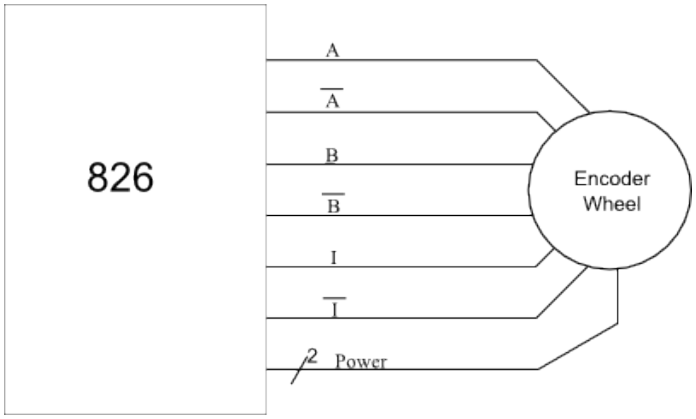


Figure 18: Encoder Connection

4.10 Pin Assignments

DIO PINS	Wire Color	Channel Number	Function
1	Teal	23	CNC Start/Stop
2	Black		GND for CNC Start/Stop
3	Blue with White Stripe	22	Direction of Stepper Motor
4	Black with White Stripe		Return path for Limit Switch
5	Brown	21	Pulse on Motor Controller
6	N/C		GND
7	Purple	20	Wire Speed Home Switch
8	Black		GND for Wire Speed Home Switch
9	Green with White Stripe	19	G1 Input (From CNC Machine)
10	N/C		GND
11	Orange with White Stripe	18	G0 Input (From CNC Machine)
12	N/C		GND
13	Green	17	G1 Output (To Relay and Ind. Module)
14	Black		GND for Relay Module
15	Orange	16	G0 Output (To Relay and Ind. Module)
16	Black		Power Supply GND for Relay Module
17		15	
18			GND
19		14	
20			GND
21		13	
22			GND
23		12	
24			GND
25		11	

DIO PINS	Wire Color	Channel Number	Function
26			GND
27		10	
28			GND
29		9	
30			GND
31		8	
32			GND
33		7	
34			GND
35		6	
36			GND
37		5	
38			GND
39		4	
40			GND
41		3	
42			GND
43		2	
44			GND
45		1	
46			GND
47		0	
48			GND
49			5V to the CNC Switching system and Motor Controller
50			GND

ANALOG PINS	**Wire Color**	**Channel Number**	**Function**
1			
2			
3	Black	0	GND for Current Sensor
4	Yellow	0	Current Sensor Signal
5	Black	1	GND for Temperature Sensor
6	Grey	1	Temperature Sensor Signal
7			
8			
9			
10			
11			
12			
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ANALOG PINS	Wire Color	Channel Number	Function
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42			
43			
44			
45			
46			
47			
48			
49			
50			

COUNTER PINS	Wire Color	Counter Channel Number	Function
1	Blue with White dots	0	A+ on Encoder
2	White with Blue dots	0	A- on Encoder
3	Green with White dots (note cable shield also connected)	0	GND on Encoder
4	Brown with White dots	0	B+ on Encoder
5	White with Brown dots	0	B- on Encoder
6	White with Green dots	0	POWER on Encoder
7	Orange with White dots	0	I+ on Encoder
8	White with Orange dots	0	I- on Encoder
9			
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5 Software

5.1 Software Description

The main program for our control system was written entirely in the programming language "C". This was chosen so as to ensure compatibility with the Sensoray 826 DAQ board used for control. The program begins by asking the user to disconnect the grounding cable of the welder and waiting for an input from the user confirming this task is completed. Upon receiving that input the machine then runs a calibration procedure by running a PWM procedure to turn the stepper motor until the system sees the homing switch is triggered. The program then turns on the welder's gun to feed wire while measuring the wire speed and setting the average of those wire speeds as the new homing offset.

The next step of the program asks the user to input the speed the CNC machine will be running at for the duration of the print in in/sec. It uses this value to find a corresponding nominal wire speed in an array of nominal wire speeds found via testing, and sets the welding machine to that wire speed. The program then waits for a signal from the CNC machine that it has switched from Relocation mode to Deposition mode. Once the system sees that we have reached Deposition mode, it stops the CNC movement and makes sure the welder is not triggered, in order to check the temperature of the base plate being welded to. If the base plate's temperature is too low the system will pause and wait for a torch to heat the base plate up to above a given threshold value.

On completion of the torch routine the system enters the main loop, this begins by reading a timestamp from the 826's onboard timestamp generator, this value in microseconds will be used to keep track of how long the machine has been in deposition mode later. The system then starts the welder and runs a check for spikes in the current seen by the Current Sensor, if it sees none the system will end the program and return an error report, otherwise the program moves on and starts the CNC's movement back up so that we can check if the machine is still in Deposition mode. If the CNC machine is still in Deposition mode at that time it moves on to take measurements of the number of "peaks" seen by the current sensor, the temperature of the weld's base plate, and the incremental encoder used to measure wire speed. Amongst the measurements it checks and updates the mode of movement seen by the CNC in order to avoid issues with our system trying to deposit while in Relocation mode.

At the end of checking all sensor measurements, the system begins comparing the observed value with the pre-programmed threshold values. The first check is to make sure that the current plate temperature is at an acceptable value. If the temperature has fallen or risen too far, the whole system stops, and runs the torch routine before starting the system back at the initial timestamp read. If the temperature is at an acceptable value, the average droplet spacing is checked against a nominal value found through testing. If the error between the two values is greater or less than 20%, the system terminates with an error, asking the user to double check that the entire system is working. The last check is to see if the droplet spacing is greater or less than a 5% tolerance, and if so the system makes an appropriate proportional adjustment to the wire speed before continuing on.

5.2 G-Code

G-code is the commonly used name to refer to a numerical programming language. As is the case with all languages, G-code has its own syntax and semantics. A line of code is referred to as a block, and a program is defined as multiple blocks. All programs start and end with the percent symbol (%). While writing G-code, the backslash (/) can be used to comment out an entire line, whereas if you want to make comments about a block, parentheses are to be used. Anything inside of a set of parentheses will be ignored by the compiler. As is the case with most other languages, G-code ignores white space, so spacing is used to clarify the code for the writer as well as future users.

All points of G code are comprised of words and numbers. A word is simply a letter. For example, the block "X0" is simply the word X and the value 0. The words X, Y, and Z refer to the three axes, while the G words refer to the movement, motion, and location. When first started up, any blocks of code will use the point (0,0,0) as home, however G54 establishes a new temporary "home" point and G52 establishes the point where the temporary reference point is to be set. In other words, the block of code "G54 G52 X100 Y100 Z0" changes the reference point from (0,0,0) to (100,100,0) and the remainder of the code will run from this point, unless a new reference point is defined.

Similarly, other G-code words can be used to define how the space between two points should be interpolated. In some instances you may want two points to be connected via a straight line, while at other times it would be better to have them connected via a circular pattern. When dealing with circular interpolation, you can set it to be done in either a clockwise or counterclockwise manner. Beyond just linear and circular interpolation, there are dozens of G-code words that determine how the code is to be run (Appendix C).

5.3 Control Program

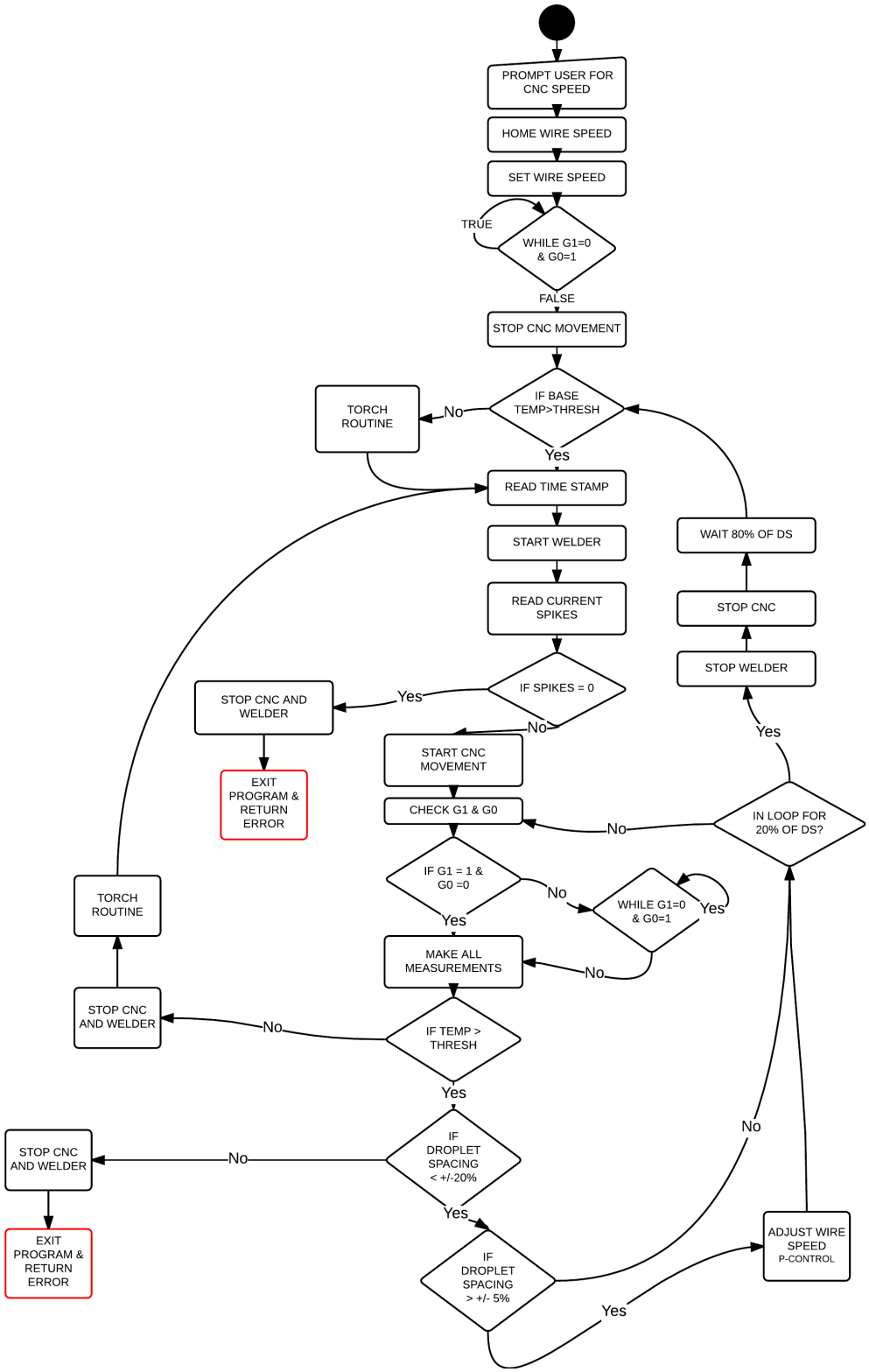


Figure 19: Control Program Flowchart

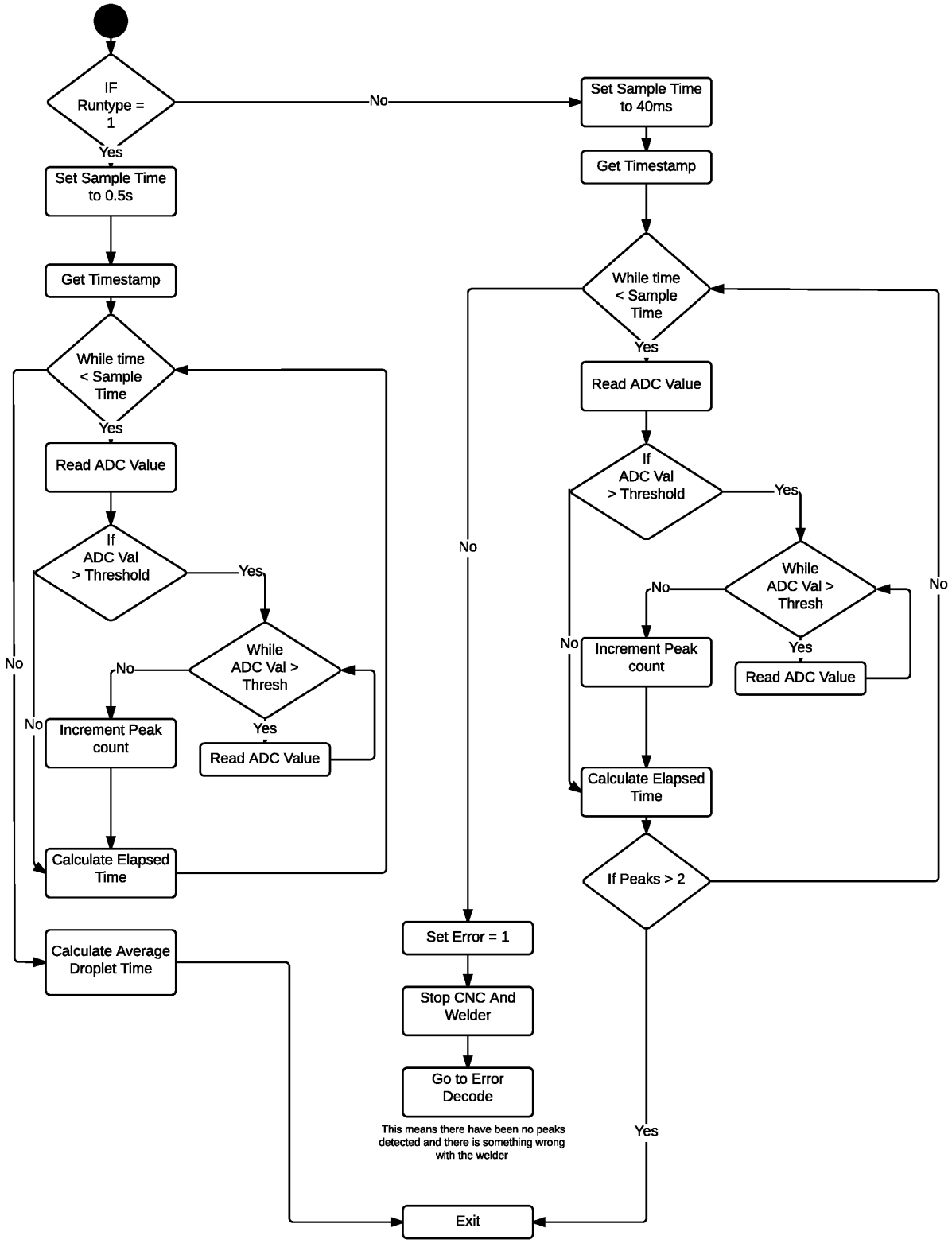


Figure 20: Droplet Spacing Flowchart

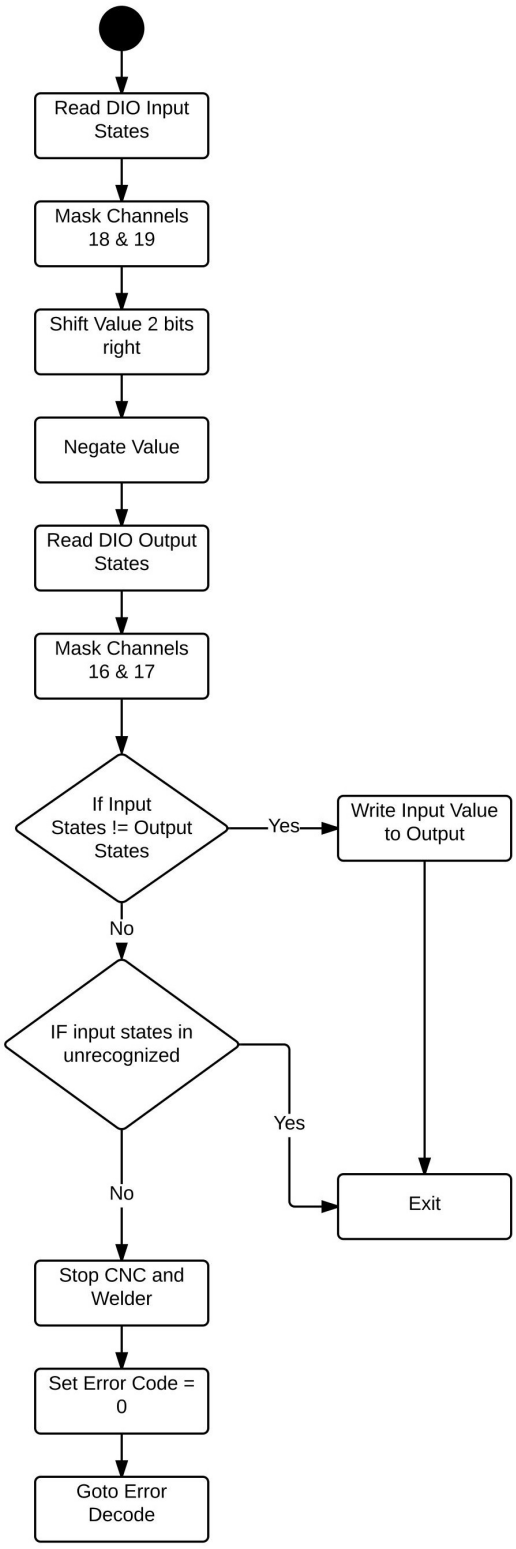


Figure 21: Getting G0 & G1 Flowchart

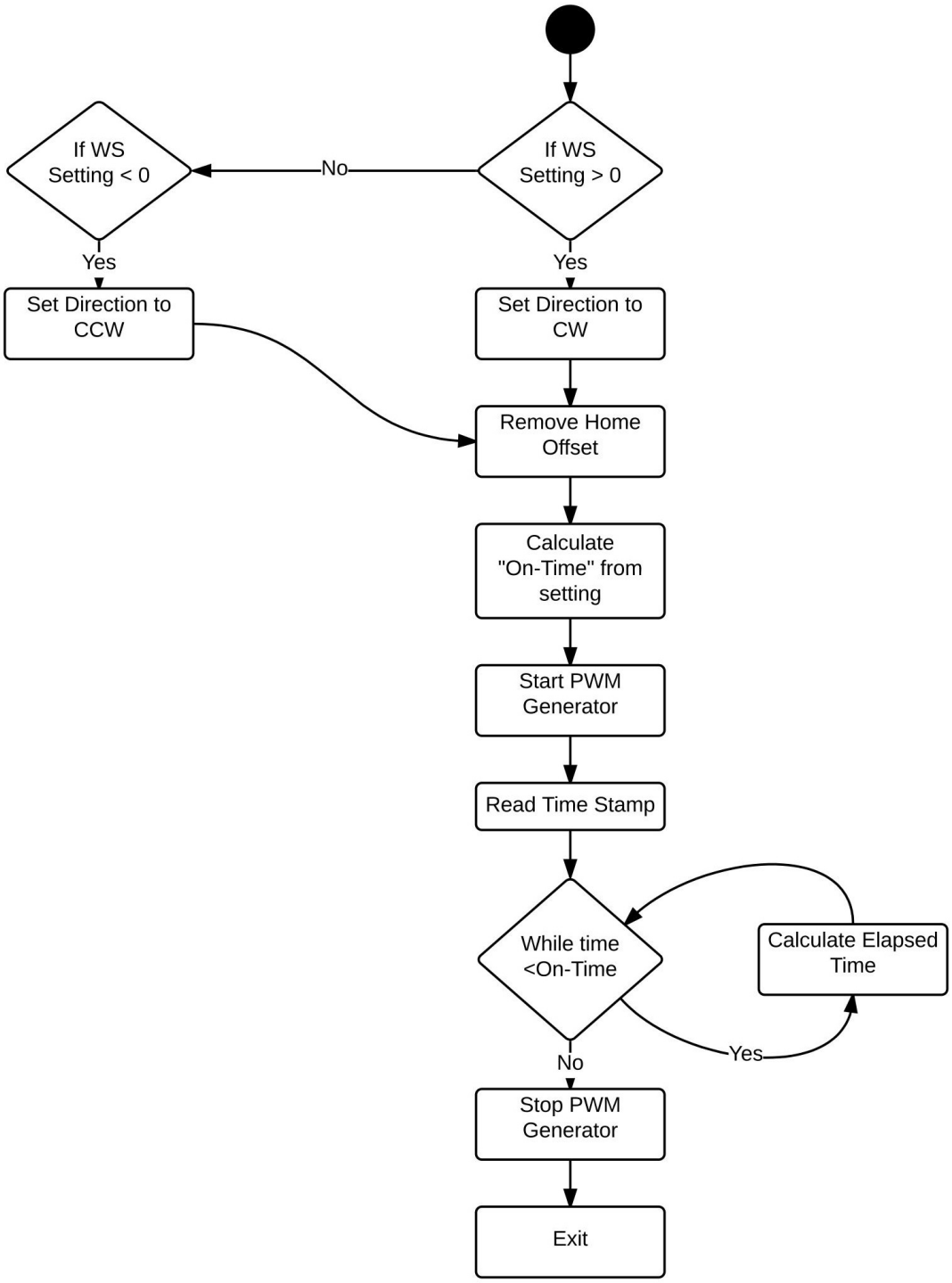


Figure 22: Set Wire Speed Flowchart

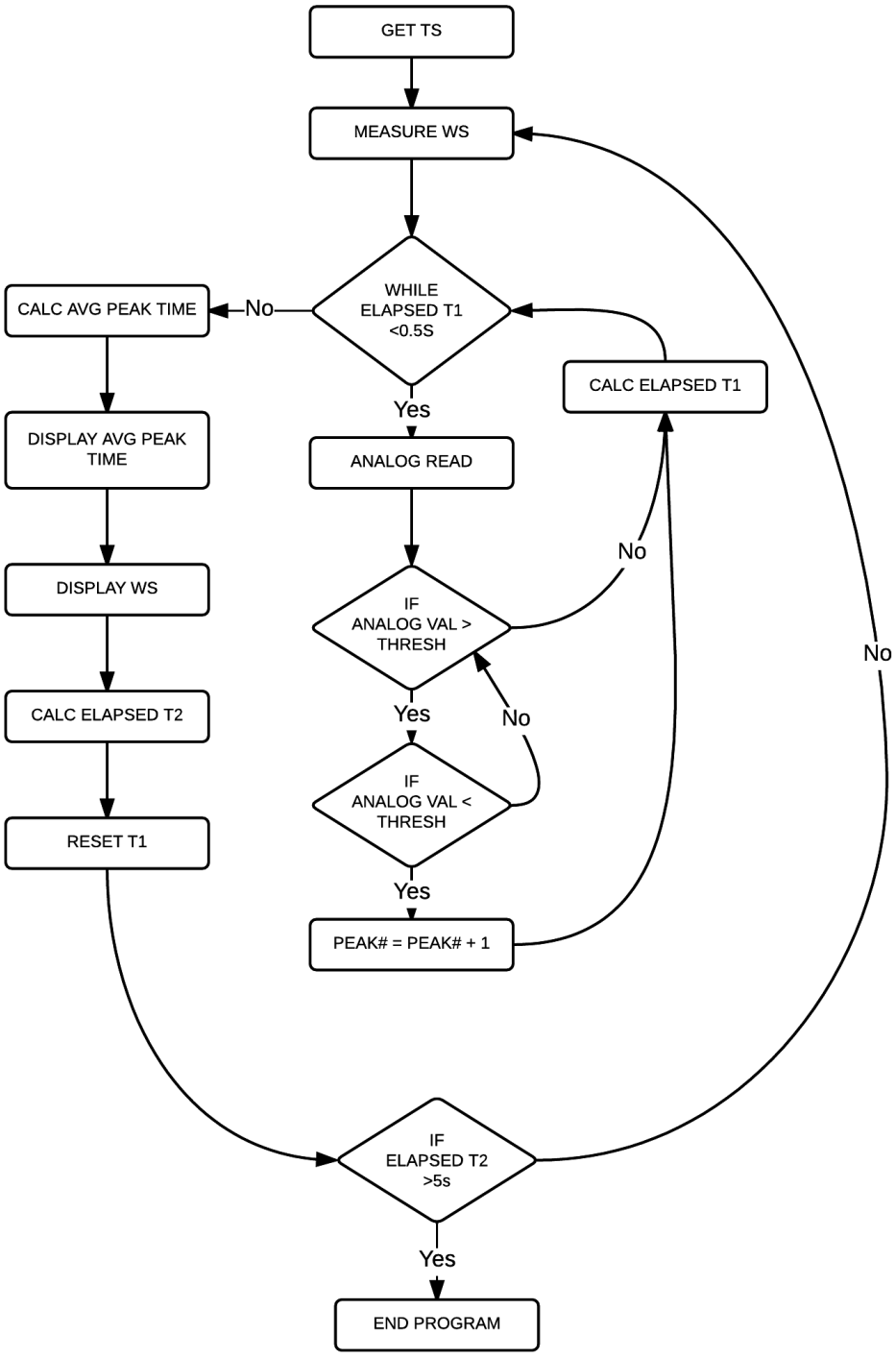


Figure 23: Wire Feed and Droplet Spacing Test Flowchart

5.4 Register Descriptions

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	IP		IM	0	0	0	TP	NR	UD	BP		OM		OP					TP						TE		TD			K			XS		
0	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0		0	1	0	0	0	0	0
0				1				6			8				2						0				2			0			

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
0				0				0			0				8						0				0			A			

Table 1: Counter Mode Register Description

where,

- Row 3 - BIN VAL For PWM Mode
- Row 4 - HEX VAL
- Row 5 - BIN VAL For Frequency Measurement Mode
- Row 6 - HEX VAL

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10
-	-	-	-	-	-	-	-	23	22	21	20	19	18	17	16	15	14	13	12	11	10
-	-	-	-	-	-	-	-	1	3	5	7	9	11	13	15	17	19	21	23	25	27
								1	3	5	7	9	11	13	15	17	19	21	23	25	27
								×	×	×	×	×	×	1	1	×	×	×	×	×	×
								×	×	×	×	0	1	×	×	×	×	×	×	×	×
								×	×	×	×	1	0	×	×	×	×	×	×	×	×
								×	1	×	×	×	×	×	×	×	×	×	×	×	×
								×	0	×	×	×	×	×	×	×	×	×	×	×	×
								×	×	0	×	×	×	×	×	×	×	×	×	×	×
								1	×	×	×	×	×	1	1	×	×	×	×	×	×
								×	×	×	×	1	0	×	×	×	×	×	×	×	×

Table 2: DIO[0] Register Description

where,

- Row 1 - Bit
- Row 2 - Channel
- Row 3 - Pin
- Row 4 - G1/G0 Read Mask
- Row 5 - G1/G0 Write Mask
- Row 6 - G1 INPUT ACTIVE
- Row 7 - G0 INPUT ACTIVE
- Row 8 - Motor CCW

- Row 9 - Motor CW
- Row 10 - Wire Speed Home Switch
- Row 11 - Weld and CNC stop
- Row 12 - CNC start

5.5 GUI Description

The initial plan was to have a GUI for our software and but was later not pursued due to time constraints. In GUI the user could see real-time graphed data coming from the current and temperature sensors as well as see the current wire speed. The system would use this feedback to automatically adjust the weld and keep it in a state that can be considered a "good weld". The plan also included manual overrides for the user to adjust the current and wire speed to their own desired result. Fig. 10 shows an initial GUI layout that we were aiming for.

5.6 The Graphical User Interface (GUI)

We were planning on using GTK+ in C programming language to generate the Graphical User Interface in order to view the different data and also control different settings.

The GTK+ is a library for creating graphical user interfaces. The library is created in C programming language. The GTK+ library is also called the GIMP toolkit. Originally, the library was created while developing the GIMP image manipulation program. Since then, the GTK+ became one of the most popular toolkits under Linux and BSD Unix. Today, most of the GUI software in the open source world is created in Qt or in GTK+. The GTK+ is an object oriented application programming interface. The object oriented system is created with the Glib object system, which is a base for the GTK+ library. The GObject also enables to create language bindings for various other programming languages. Language bindings exist for C++, Python, Perl, Java, C#, and other programming languages.

The GTK+ itself depends on the following libraries.

- Glib
- Pango
- ATK
- GDK
- GdkPixbuf
- Cairo

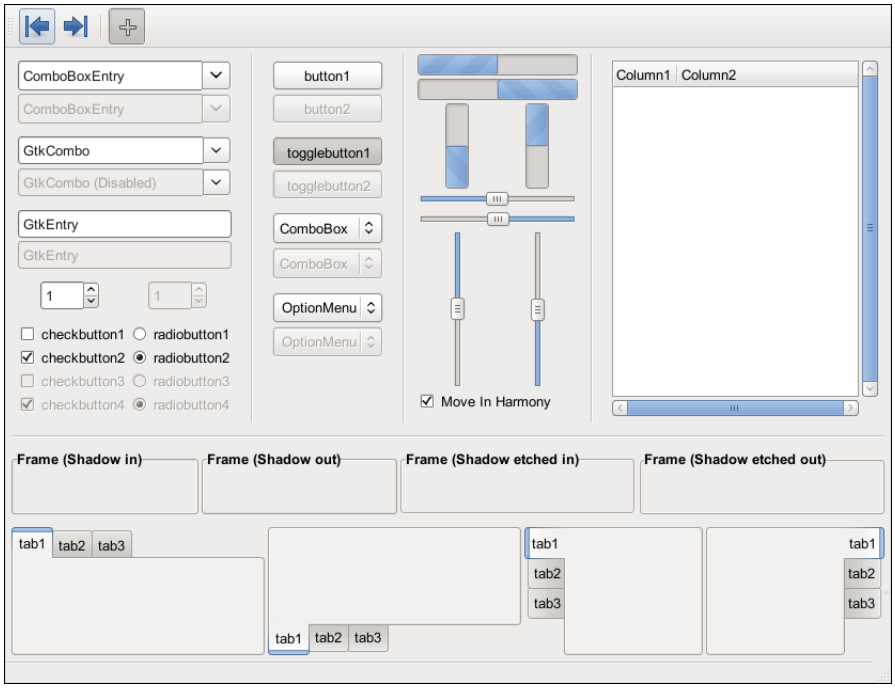
*Note: For detailed functions of each library refer to Appendix A

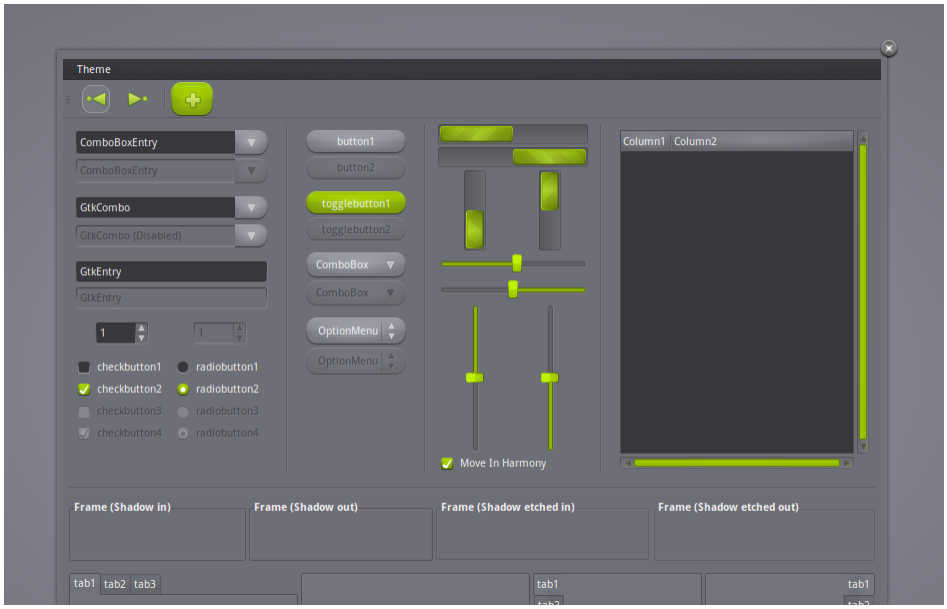
5.7 Reasons for using GTK+

- Language Bindings
  GTK+ is available in many other programming languages thanks to the language bindings available. This makes GTK+ quite an attractive toolkit for application development.

- Interfaces
  GTK+ has a comprehensive collection of core widgets and interfaces for use in your application.
  - Windows (normal window or dialog, about and assistant dialogs)
  - Displays (label, image, progress bar, status bar)
  - Buttons and toggles (check buttons, radio buttons, toggle buttons and link buttons)
  - Numerical (horizontal or vertical scales and spin buttons) and text data entry (with or without completion)
  - Multi-line text editor
  - Tree, list and icon grid viewer (with customizable renderers and model/view separation)
  - Combo box (with or without an entry)
  - Menus (with images, radio buttons and check items)
  - Toolbars (with radio buttons, toggle buttons and menu buttons)
  - GtkBuilder (creates your user interface from XML)
  - Selectors (color selection, file chooser, font selection)
  - Layouts (tabulated widget, table widget, expander widget, frames, separators and more)
  - Status icon (notification area on Linux, tray icon on Windows)
  - Printing widgets
  - Recently used documents (menu, dialog and manager)

5.8 Examples of GUIs created using GTK+





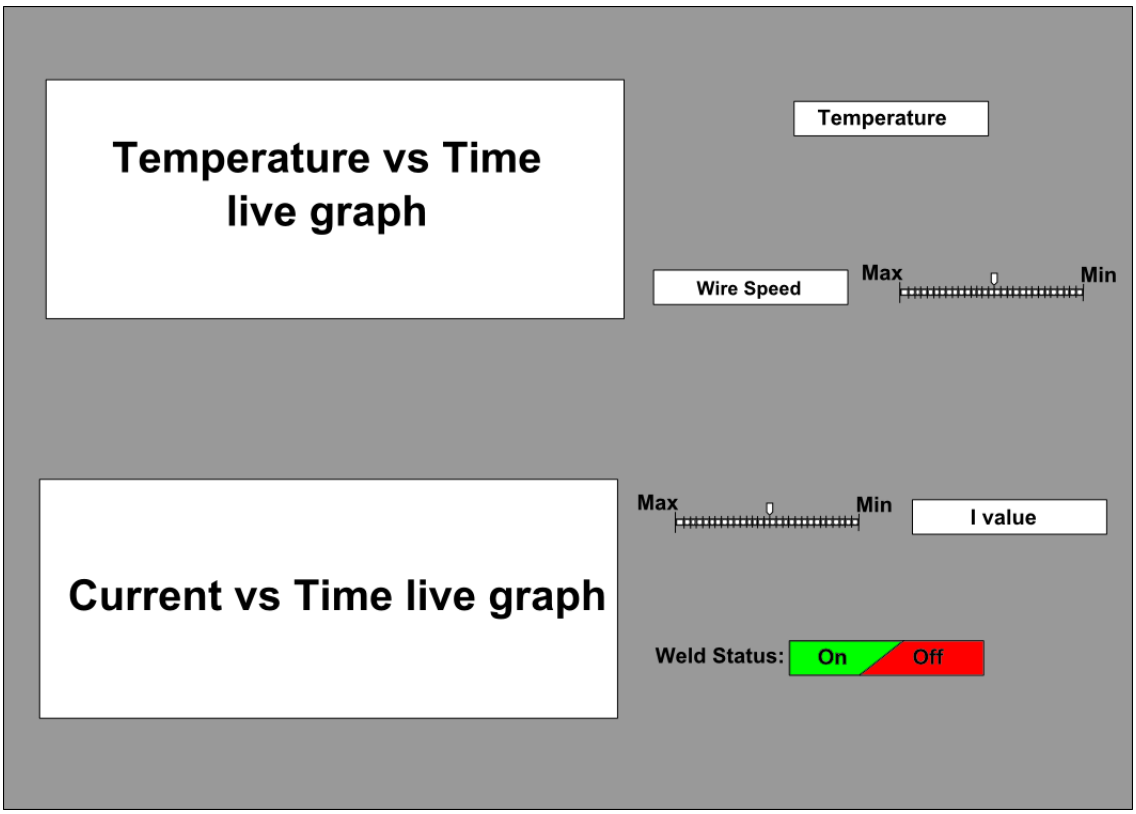


Figure 24: Proposed Rough GUI Layout

6 Testing

Testing was a constant part of this project. Many of the tests were small trouble shooting sessions where we would work on getting a specific piece of hardware or software to work. There were also several tests that were done more methodically, due to their importance of the final outcome. Some of these tests, with their test plans and results, can be seen below.

6.1 CNC Confirmation Test

Test Case # 1: CNC Confirmation Test

Test Writers: Cameron Tribe						
Test Case Name:		CNC Confirmation Test #1			**Test ID #:**	3MP-CNC-01
Description:		This test is to simply confirm that the CNC is operational in all three dimensions.			**Type:**	
Tester Information						
	Name of Tester:				**Date:**	05/30/2015
	Hardware Ver:				**Time:**	
	Setup:	Only Welder will be used, not CNC. Remove Cover of welder to ensure wire feed is properly set up. Welding will not be taking place, so be sure ground wire is not connected.				
Step	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**
1	Load G-Code into Linux CNC and run initial homing procedure					
2	Place paper on base					
3	Fix felt marker onto CNC machine at an appropriate height so that it will draw on the paper.					
4	Run CNC Machine	This test verified that the CNC machine was working properly. Fig 14 shows the reproduced image that was created by the CNC Machine.				
	Overall Test Result:					

6.2 Wire Feed Test

Test Case # 4: Wire Speed Test

Test Writers: Branden Driver						
Test Case Name:		Wire Speed Encoder Test #1			**Test ID #:**	3MP-Wire-01
Description:		Measures the actual wire speed in correlation with the wire speed encoder. This test will allow for the construction of the lookup table to be used with the main program.			**Type:**	
Tester Information						
	Name of Tester:				**Date:**	
	Hardware Ver:	Display V1.0, Main Board V1.5, Sensor V1.0			**Time:**	
	Setup:	Only Welder will be used, not CNC. Remove Cover of welder to ensure wire feed is properly set up. Welding will not be taking place, so be sure ground wire is not connected.				
Step	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**
1	Open wire feed program	Program should open				
2	Set program to run for one second	program should only run for one second				
3	Cut wire extruded from nozzle as short as possible	Very little wire should be showing				
4	Set wire feed speed nozzle to home setting	Wire feed should be at lowest setting				
5	Turn on welder	Welder should turn on				
6	Run test program	Welder should feed wire for exactly one second				
7	Turn off welder	Welder should turn off				
8	Cut wire extruded from nozzle as short as possible	Very little wire should be showing				
9	Measure length of cut wire and record value	Value determined for specified wire feed setting				
10	Repeat steps 1-9 for various values of wire speed	Determine if wire feed is linear. If so, interpolate for all wire feed speeds				
	Overall Test Result:					

Wire Speed (in/s)	Time (sec)	Expected Length (in)	Measured Length (in)
0.88	3	2.64	2.56
0.90	3	2.70	2.46
2.00	3	6.00	6.06
3.20	3	9.60	10.10
5.50	3	16.50	16.80
7.60	3	22.80	23.20
9.50	3	28.50	28.06

Table 3: Linear Velocity Program Test

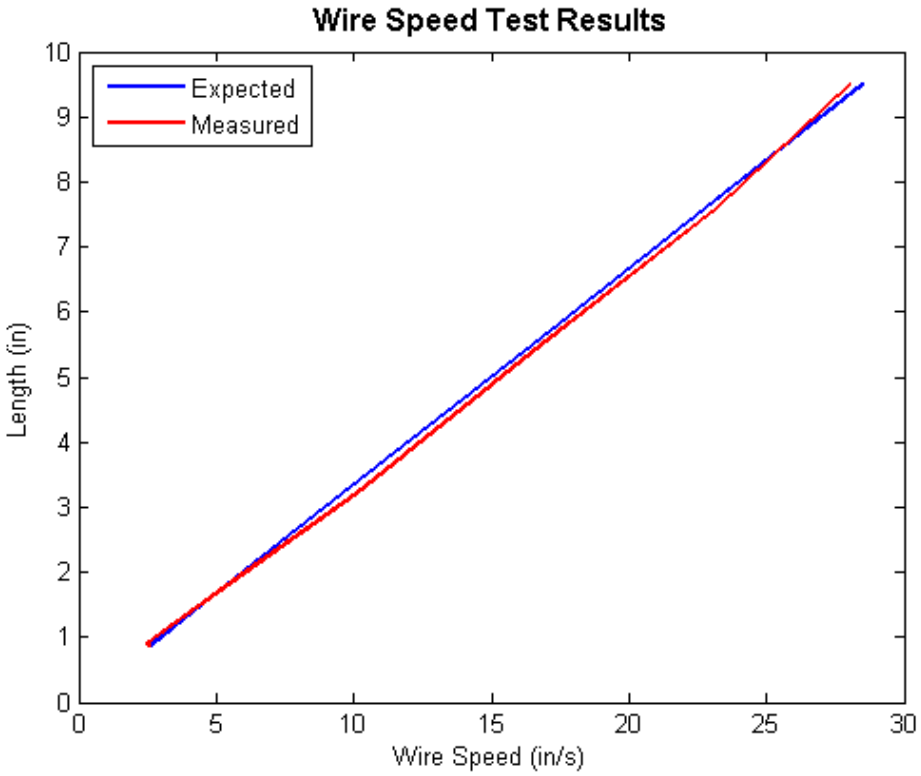


Figure 25: Wire Speed Test Results

6.3 Weld Quality Test

Test Case # 5: Weld Quality Test

Test Writers: Branden Driver						
Test Case Name:		Weld Quality Test #1			**Test ID #:**	3MP-Weld-01
Description:		This test will check the quality of the weld across a variety of currents, wire speeds, and CNC movement speeds			**Type:**	
Tester Information						
	Name of Tester:				**Date:**	
	Hardware Ver:	Display V1.0, Main Board V1.5, Sensor V1.0			**Time:**	
	Setup:	Ensure both welder and CNC are ready to use. Have at least one 1/8" baseplate on hand for each version of test you wish to run. In LinuxCNC, open file "m100". This file is a G-code program that will print seven 1-inch lines, each at a different CNC movement speed.				
Step	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**
1	Set current level	Current level selected				
2	Set wire speed around 2	Wire speed selected				
3	Run program m100	Printing will begin				
4	During weld, run droplet spacing program	Program will output wire speed from encoder and average droplet spacing				
5	Quickly record both wire speed and average droplet spacing	Data acquired				
6	Repeat steps 4-5 for each of the seven welds of the program	First run is complete				
7	Adjust wire speed to 4	Welder ready for next run				
8	Run program m200	Print will continue on same plate, next to previous run				
9	Repeat steps 4-6	Data acquired for all 7 welds, 2nd run is complete				
10	Adjust wire speed to 6	Welder ready for next run				
11	Run program m300	Print will continue on same plate, next to previous run				
12	Repeat steps 4-6	Data acquired for all 7 welds, 3rd run is complete				
13	Adjust wire speed to 8	Welder ready for next run				
13	Run program m400	Print will continue on				

		same plate, next to previous run				
14	Repeat steps 4-6	Data acquired for all 7 welds, 4th run complete				
	Adjust wire speed to 8	Welder ready for next run				
	Run program m400	Print will continue on same plate, next to previous run				
	Run program m400	Data acquired for all 7 welds, 5th run complete				
	Overall Test Result:					

Wire Speed (in/s)	CNC Speed (in/min)	Avg Droplet Spacing (μs)
4.21	2	19047
4.04	3	20619
3.88	4	22857
3.98	5	21978
4.14	6	20833
3.88	7	20943
3.95	8	18872
6.02	2	13119
5.81	3	15037
6.19	4	14084
6.06	5	12539
5.71	6	15504
5.6	7	10257
6.54	8	17621
7.5	2	12820
7.2	3	14035
7.61	4	14760
7.67	5	15267
7.61	6	17167
7.45	7	11594
6.95	8	10790
8.99	2	11364
8.82	3	13114
9.58	4	11940
10	5	11765
8.5	6	10106
9.47	7	12751
9.84	8	n/a

Wire Speed (in/s)	CNC Speed (in/min)	Avg Droplet Spacing (μs)
11	2	10582
10.86	3	9557
10.65	4	10811
10.03	5	12270
11.05	6	11007
11.49	7	12012
11.85	8	11695

Table 4: Plate 1

Wire Speed (in/s)	CNC Speed (in/min)	Avg Droplet Spacing (μs)
3.48	2	20014
3.47	3	23121
3.3	4	23530
3.3	5	27398
2.96	6	26845
3.39	7	29646
3.42	8	30534
4.07	2	24342
4.19	3	19802
3.95	4	17467
3.86	5	18868
4.14	6	14545
4.09	7	13333
3.99	8	19900
6.55	2	11267
6.8	3	11173
7.23	4	12012
6.49	5	9788
6.38	6	9389
6.3	7	9216
6.68	8	9009
9.8	2	9442
9.57	3	8928
10.28	4	9456
10.89	5	9280
9.89	6	9204
9.83	7	8050
10.01	8	9456

Wire Speed (in/s)	**CNC Speed (in/min)**	**Avg Droplet Spacing (us)**
11.49	2	8677
11.46	3	8340
11.43	4	8752
11.75	5	8798
11.6	6	9302
11.53	7	9029
11.69	8	9132

Table 5: Plate 2

Wire Speed (in/s)	CNC Speed (in/min)	Avg Droplet Spacing (us)
5.34	2	12658
4.9	3	14053
4.97	4	12317
5.18	5	16461
4.53	6	11019
4.83	7	79756
n/a	8	n/a
7.12	2	9876
6.93	3	9959
7.22	4	10315
6.82	5	9527
6.74	6	9195
6.8	7	9227
6.87	8	9852
9.3	2	8948
9.19	3	9091
9.42	4	9599
9.26	5	9466
9.31	6	9204
n/a	7	n/a
9.16	8	8180
12.58	2	8421
12.41	3	8445
12.77	4	8465
12.74	5	8792
12.56	6	8620
12.66	7	8602
12.82	8	8714
14.67	2	8477
15.19	3	8585
14.87	4	8756
14.69	5	8547
14.89	6	8677
14.32	7	8639
14.65	8	8403

Table 6: Plate 3

Wire Speed (in/s)	CNC Speed (in/min)	Avg Droplet Spacing (us)
3.83	4	9013
3.85	4.5	9828
3.89	5	9780
4	5.5	11662
3.96	6	9552
3.97	6.5	10447
3.8	7	10371
4.66	4	9860
5.07	4.5	9780
4.61	5	9569
4.64	5.5	9238
4.55	6	9501
4.59	6.5	9099
4.75	7	9287
4.77	4	9909
4.63	4.5	10032
4.6	5	9029
5.19	5.5	9784
4.56	6	n/a
4.67	6.5	9756
4.65	7	9434
5.35	4	9645
5.37	4.5	10025
5.34	5	9758
5.35	5.5	10554
5.61	6	9546
5.17	6.5	9961
5.36	7	9307
6.1	4	8877
5.98	4.5	9412
6.09	5	9615
6.03	5.5	9350
6.76	6	9863
6.35	6.5	10474
6.15	7	9198

Table 7: Plate 4

Wire Speed (in/s)	CNC Speed (in/min)	Avg Droplet Spacing (us)
4.09	4.8	9195
4.47	5	9737
4.28	5.2	10126
3.39	5.4	9623
4.25	5.6	9740
4.09	5.8	9876
3.98	6	9262
4.61	4.8	9953
4.38	5	9761
4.56	5.2	9389
4.77	5.4	10582
4.56	5.6	9661
4.53	5.8	9625
4.2	6	9183
4.71	4.8	9266
4.61	5	9569
4.94	5.2	9479
4.62	5.4	9376
4.92	5.6	9184
4.89	5.8	9324
4.86	6	9546
5.21	4.8	8994
4.97	5	9111
5.31	5.2	9595
5.21	5.4	9324
5.02	5.6	9117
5.1	5.8	9153
5.26	6	9456
5.37	4.8	9111
5.56	5	9376
5.51	5.2	9456
	5.4	
	5.6	
	5.8	
	6	

Table 8: Plate 5

Wire Speed (in/s)	CNC Speed (in/min)	Avg Droplet Spacing (us)
2.57	2	12903
2.55	3	12195
2.59	4	13559
2.48	5	15873
2.79	6	15269
2.62	7	16953
2.63	8	14760
3.38	2	10392
3.27	3	10309
3.72	4	11396
3.7	5	12232
3.39	6	11950
3.45	7	11954
3.52	8	14100
4.12	2	9464
4	3	9662
3.98	4	10000
4.26	5	10256
4.54	6	10816
4.41	7	10816
3.91	8	11665
4.47	2	9117
4.48	3	8960
4.47	4	9284
4.84	5	9756
4.39	6	9112
4.98	7	11628
4.37	8	11338
n/a	2	n/a
4.64	3	8658
4.67	4	8928
4.71	5	8565
5.07	6	11111
4.99	7	10638
5	8	10340

Table 9: Plate 6

Run #	**Initial Wire Speed (in/s)**	**Final Wire Speed (in/s)**	**Turn Amount (deg)**	**Ratio (deg/(in/s))**	**Time/deg (us)**	**Pulse On Time (us)**
Run 1	0.3	1.1	30	37.5	22222	666660
Run 2	1.1	1.8	30	42.85714286	22222	666660
Run 3	1.8	2.5	30	42.85714286	22222	666660
Run 4	2.5	3.3	30	37.5	22222	666660
Run 5	1.9	3	45	40.90909091	22222	999990
Run 6	3	4.2	45	37.5	22222	999990
Run 7	1.2	2.3	45	40.90909091	22222	999990
Run 8	2.3	3.4	45	40.90909091	22222	999990
Run 9	0.9	2.4	60	40	22222	1333320
Run 10	2.4	3.9	60	40	22222	1333320
Run 11	3.9	5.5	60	37.5	22222	1333320
Run 12	3.4	5	60	37.5	22222	1333320
Run 13	1	7	235	39.16666667	22222	5222170
			Average	**39.66179654**		

Table 10: Degree to Turn Measurements

7 Photos and Videos of Progress

Demo of the Printer
https://www.youtube.com/watch?v=Ypetogtn1Iw

One of the fist things done in this project was to confirm the operation of the CNC machine. To do this, G-Code of a 2D image was uploaded to the machine. A felt marker was used to draw the image below.

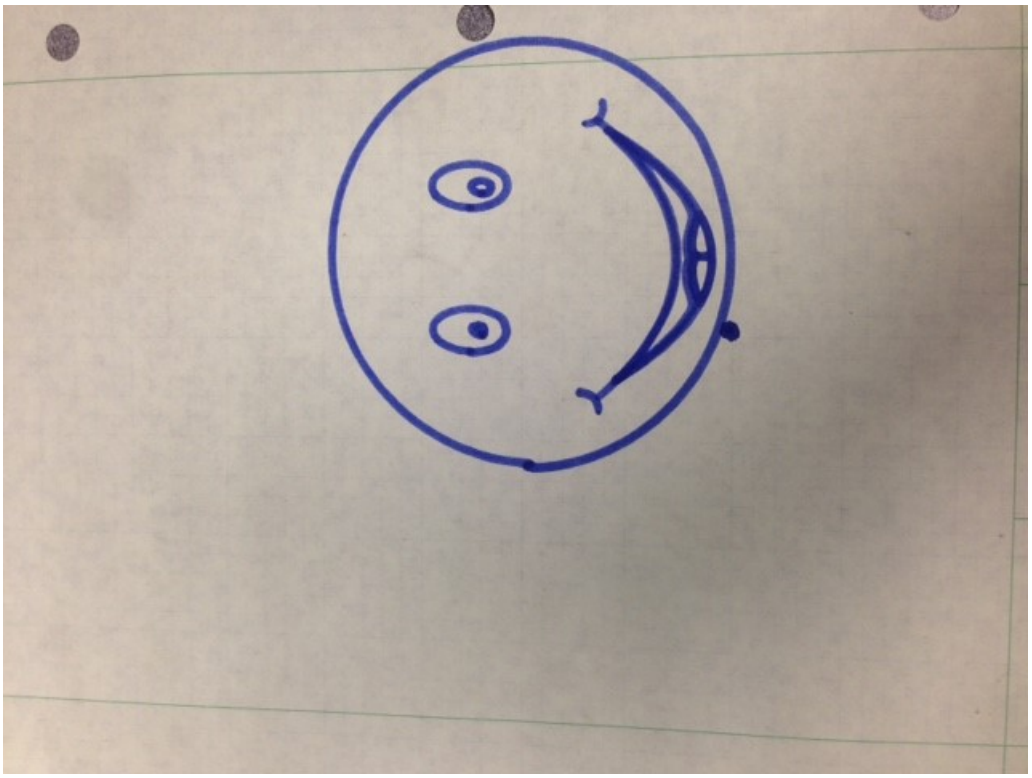


Figure 26: aaaaa

Next, we fitted the welder to the machine, and placed a metal base plate to weld on. To control the welder we just used our hand to active the weld while the machine was moving.

After this, we connected the relay switch circuit in parallel with the manual welder switch, using G-Code to activate the switch. Shown Below is the result of letting the CNC Machine control the weld.

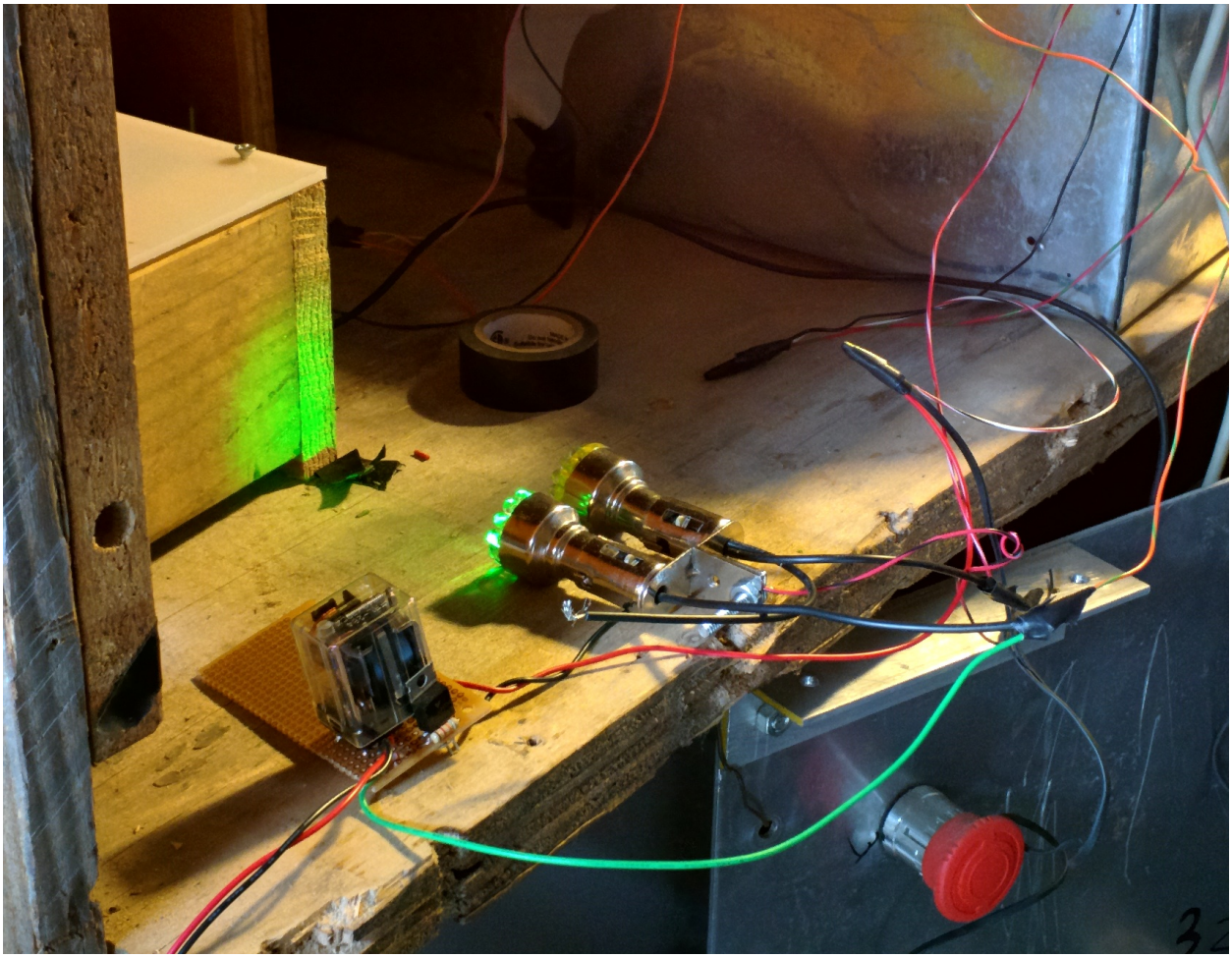


Figure 27: Proposed Rough GUI Layout

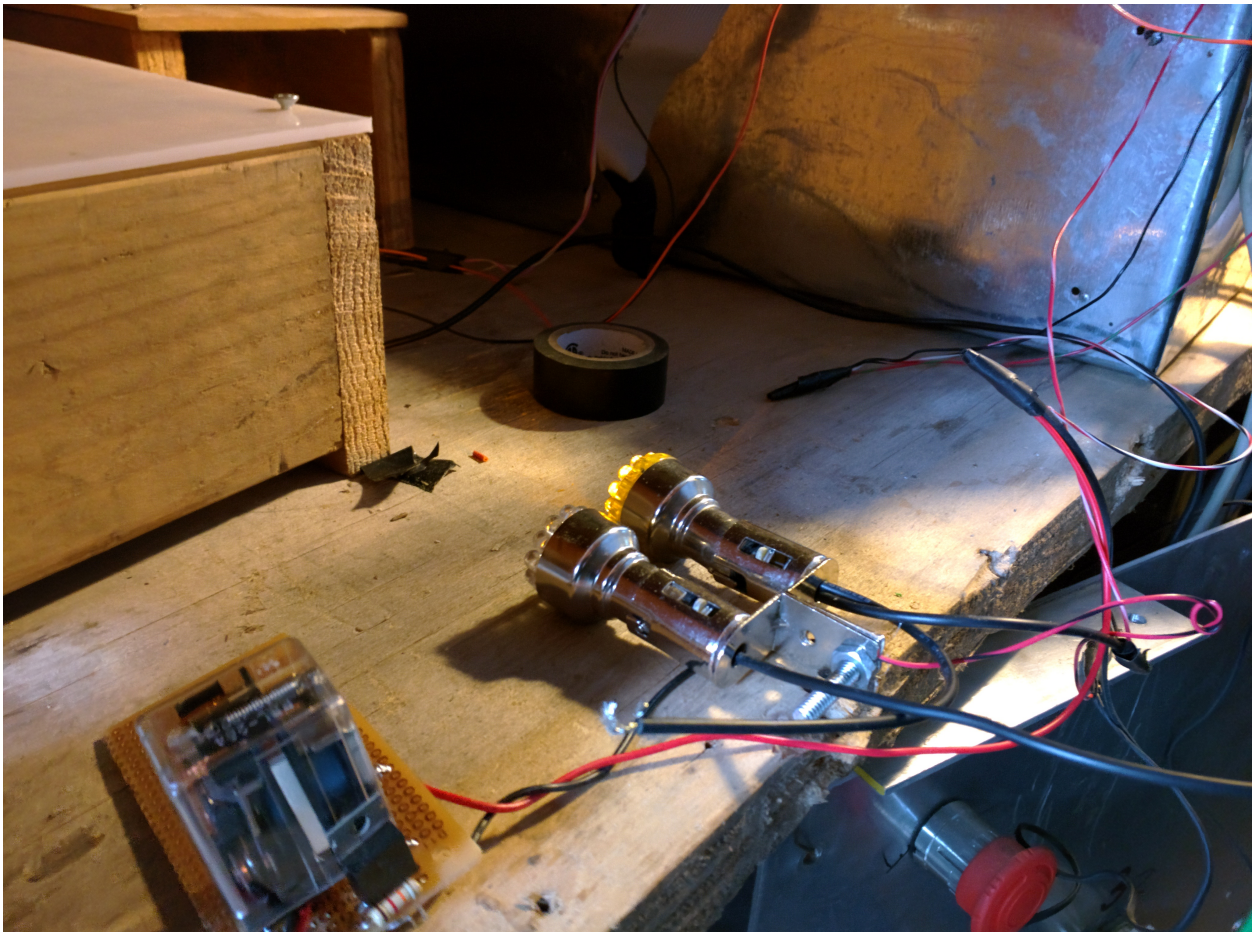


Figure 28: Proposed Rough GUI Layout

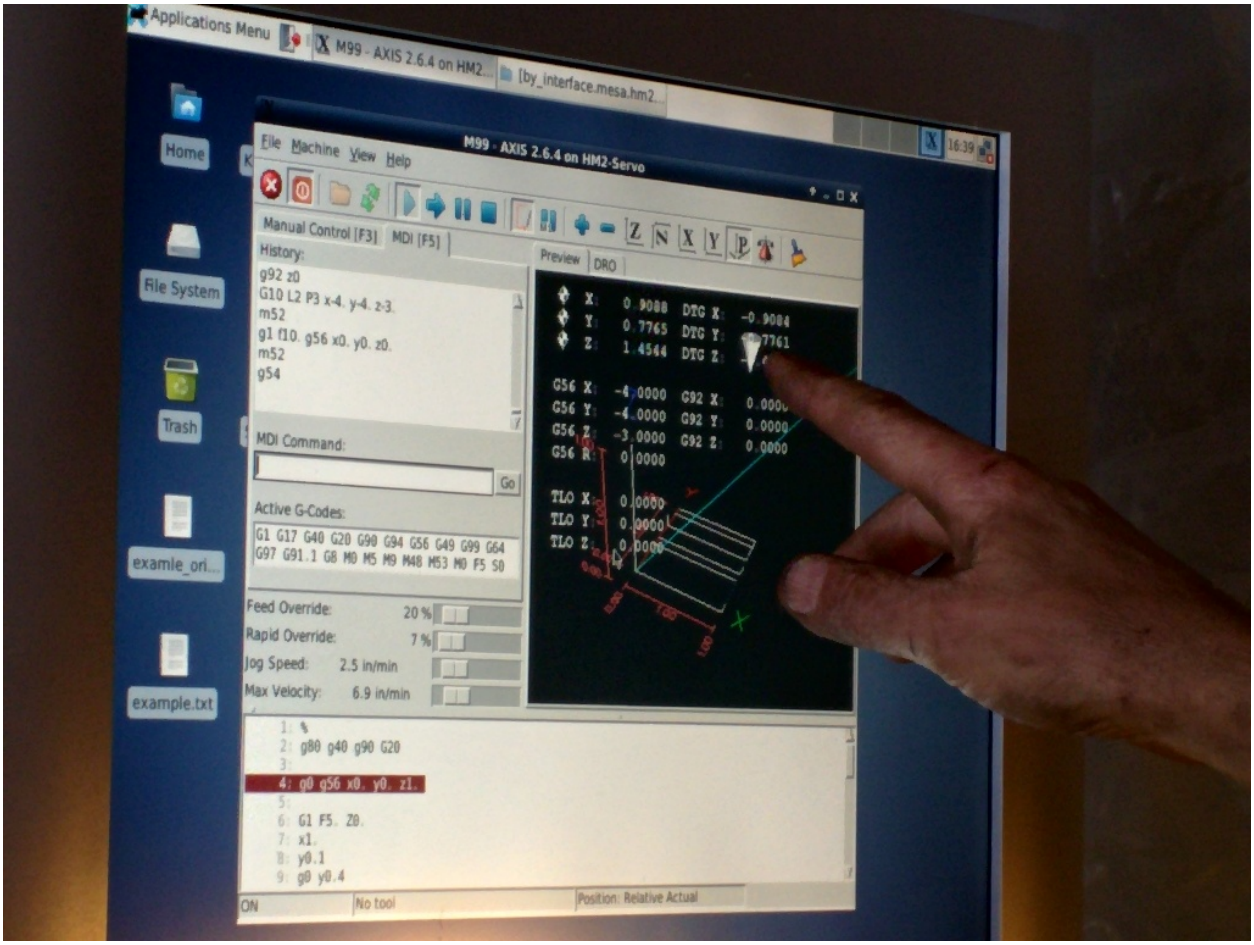


Figure 29: Proposed Rough GUI Layout

Figure 30: Proposed Rough GUI Layout

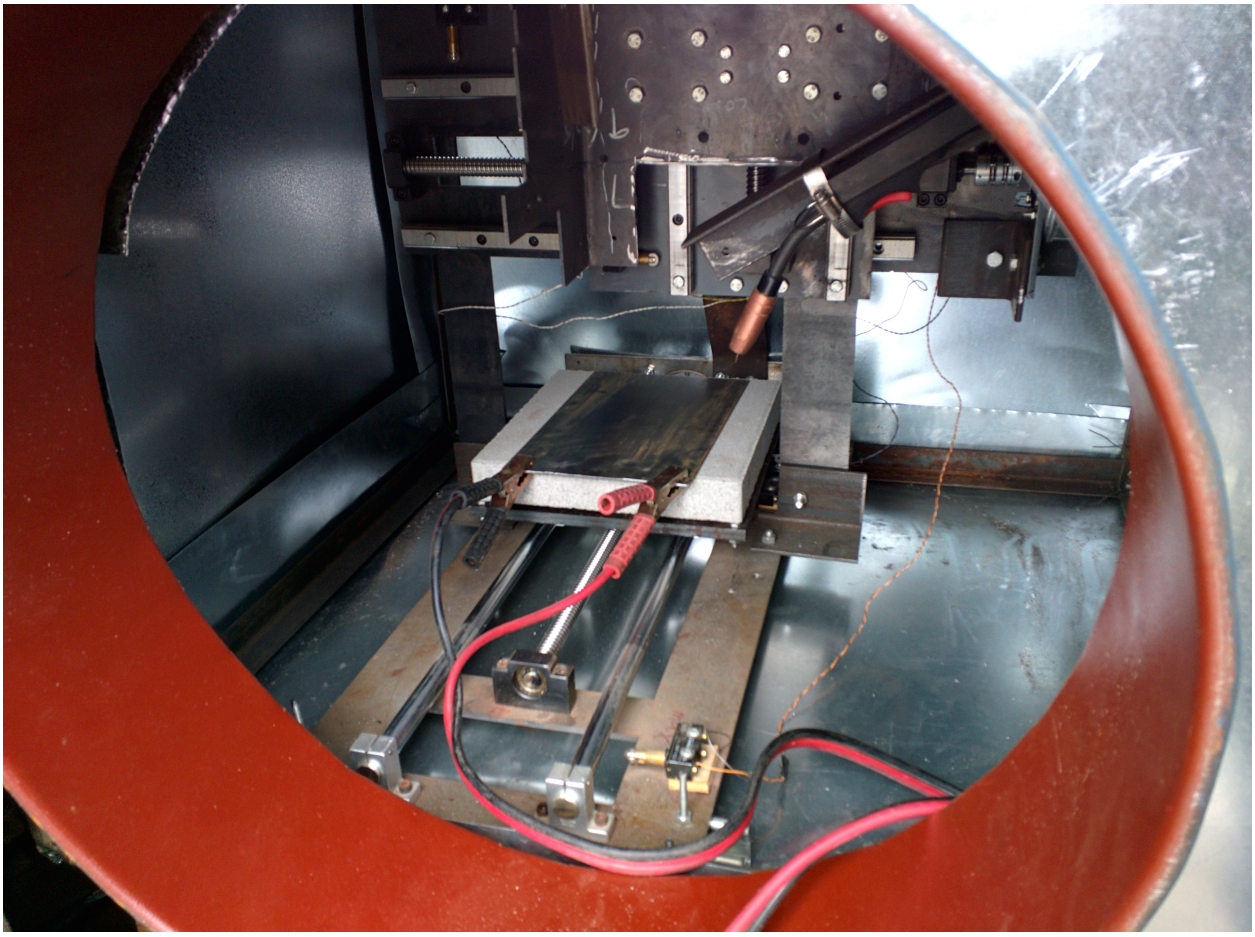


Figure 31: Proposed Rough GUI Layout

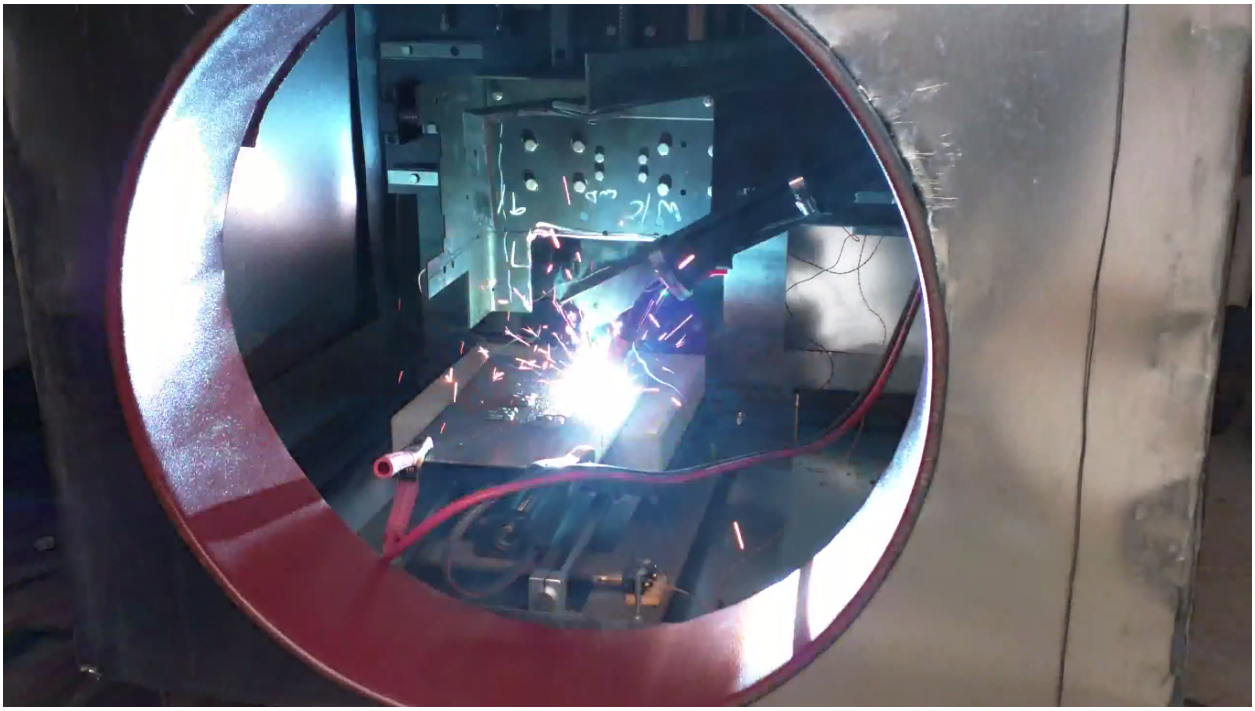


Figure 32: Proposed Rough GUI Layout

8 Bill of Materials (BOM)

Item	Quantity	Part Number	Mfg	Price	Description
CNC Machine	1	NPN	Aram Kasparov	~$500	
- X-Stepper Motor	1	IG34CK-32-IE8192-SB213	Servo Dynamics	$400	Stepper Motor for the X axis
- Y-Stepper Motor	1	HJ130E8-1308	Servo Dynamics	$800	Stepper Motor for the Y axis
- Z-Stepper Motor	1	IG34CK-32-IE8192-SB213	Servo Dynamics	$450	Stepper Motor for the Z axis
- Motor Driver	3	SD94	Servo Dynamics	$550	Motor driver for XYZ axis motors.
Limit and Home Switches	11	Z15G1308	HIGHLY	$10	Any limit and home switch used on the machine
PCI I/O Card	1	5I20	Mesa Electronics	$250	Part of the CNC system
Servo Interface Card	1	7i33	Mesa Electronics	$100	Interface Card for communicating with servo motors
Isolated I/O Card	2	7i37	Mesa Electronics	$100	I/O card used for limit and home switches
50 Pin Breakout Board	3	NPN		~$10	To connect to analog & digital channels of the Sensoray
Screw Terminals		NPN	Capstone 2015 Team		
50 Pin Connector		NPN	Capstone 2015 Team		

Item	Quantity	Part Number	Mfg	Price	Description
26 Pin Breakout Board	2	NPN		∼$10	To connect to the counter channels of the Sensoray
Screw Terminals		NPN	Capstone 2015 Team		
26 Pin Connector		NPN	Capstone 2015 Team		
Incremental Encoder	1	S5-5000-250-IE-D-B	US Digital	$140	Used for measuring the wire speed of the welder
PCIe DAQ	1	826	Sensoray	$677	PCI I/O Card with Digital and Analog I/O
Temperature Sensor	1	1MH1-CF4	Micro-Epsilon	$1400	Temp range x-x
Current Sensor	1	c20058	Honeywell	$30	Outputs a single Voltage
MIG Welder	1	MIG 180	Chicago Electric	$270	Wire Feed Welder that uses inert shielding gas
Motor Controller	2	KL-5056D	Keling Technology Inc	$80	To control the motors on the welder control knobs
Stepper Motors	1	KL23H2100-35-4B	Keling Technology Inc	$50	To control the knobs on the welder
PWM Module	1	THC-AD	Mesa Electronics	$80	To externally set CNC speed
Controller PC	1	NPN	N/A	$80	Computer used to control welder
Relay Module	1	NPN	Capstone 2015 Team	∼$20	
Current Sensor Module	1	NPN	Capstone 2015 Team	∼$5	
			Total	**∼$6,012**	

Appendix A: GTK+

- **Glib**
  GLib provides the core application building blocks for libraries and applications written in C. It provides the core object system used in GNOME, the main loop implementation, and a large set of utility functions for strings and common data structures.

  Description

  - New types which are not part of standard C (but are defined in various C standard library header files) - gboolean, gsize, gssize,goffset, gintptr, guintptr.
  - Integer types which are guaranteed to be the same size across all platforms - gint8, guint8, gint16, guint16, gint32, guint32,gint64, guint64.
  - Types which are easier to use than their standard C counterparts - gpointer, gconstpointer, guchar, guint, gushort, gulong.

  GLib also defines macros for the limits of some of the standard integer and floating point types, as well as macros for suitableprintf() formats for these types.

  Standard Macros — commonly-used macros
  Type Conversion Macros — portably storing integers in pointer variables
  Byte Order Macros — a portable way to convert between different byte orders
  Numerical Definitions — mathematical constants, and floating point decomposition
  Miscellaneous Macros — specialized macros which are not used often
  Atomic Operations — basic atomic integer and pointer operations

  GLib Core Application Support

  - **The Main Event Loop** — manages all available sources of events
  - **Threads** — portable support for threads, mutexes, locks, conditions and thread private data
  - **Thread Pools** — pools of threads to execute work concurrently
  - **Asynchronous Queues** — asynchronous communication between threads
  - **Dynamic Loading of Modules** — portable method for dynamically loading 'plug-ins'
  - **Memory Allocation** — general memory-handling
  - **Memory Slices** — efficient way to allocate groups of equal-sized chunks of memory
  - **IO Channels** — portable support for using files, pipes and sockets
  - **Error Reporting** — a system for reporting errors
  - **Message Output and Debugging Functions** — functions to output messages and help debug applications
  - **Message Logging** — versatile support for logging messages with different levels of importance

GLib Utilities

- **String Utility Functions** — various string-related functions
- **Character Set Conversion** — convert strings between different character sets
- **Unicode Manipulation** — functions operating on Unicode characters and UTF-8 strings
- **Base64 Encoding** — encodes and decodes data in Base64 format
- **Data Checksums** — computes the checksum for data
- **Secure HMAC Digests** — computes the HMAC for data
- **Internationalization** — gettext support macros
- **Date and Time Functions** — calendrical calculations and miscellaneous time stuff
- **GTimeZone** — a structure representing a time zone
- **GDateTime** — a structure representing Date and Time
- **Random Numbers** — pseudo-random number generator
- **Hook Functions** — support for manipulating lists of hook functions
- **Miscellaneous Utility Functions** — a selection of portable utility functions
- **Lexical Scanner** — a general purpose lexical scanner
- **Timers** — keep track of elapsed time
- **Spawning Processes** — process launching
- **File Utilities** — various file-related functions
- **URI Functions** — manipulating URIs
- **Hostname Utilities** — Internet hostname utilities
- **Shell-related Utilities** — shell-like commandline handling
- **Commandline option parser** — parses commandline options
- **Glob-style pattern matching** — matches strings against patterns containing '*' (wildcard) and '?' (joker)
- **Perl-compatible regular expressions** — matches strings against regular expressions
- **Regular expression syntax** — syntax and semantics of regular expressions supported by GRegex
- **Simple XML Subset Parser** — parses a subset of XML
- **Key-value file parser** — parses .ini-like config files
- **Bookmark file parser** — parses files containing bookmarks
- **Testing** — a test framework
- **UNIX-specific utilities and integration** — pipes, signal handling

- **Windows Compatibility Functions** — UNIX emulation on Windows

GLib Data Types

- **Doubly-Linked Lists** — linked lists that can be iterated over in both directions
- **Singly-Linked Lists** — linked lists that can be iterated in one direction
- **Double-ended Queues** — double-ended queue data structure
- **Sequences** — scalable lists
- **Trash Stacks** — maintain a stack of unused allocated memory chunks
- **Hash Tables** — associations between keys and values so that given a key the value can be found quickly
- **Strings** — text buffers which grow automatically as text is added
- **String Chunks** — efficient storage of groups of strings
- **Arrays** — arrays of arbitrary elements which grow automatically as elements are added
- **Pointer Arrays** — arrays of pointers to any type of data, which grow automatically as new elements are added
- **Byte Arrays** — arrays of bytes
- **Balanced Binary Trees** — a sorted collection of key/value pairs optimized for searching and traversing in order
- **N-ary Trees**— trees of data with any number of branches
- **Quarks** — a 2-way association between a string and a unique integer identifier
- **Keyed Data Lists** — lists of data elements which are accessible by a string or GQuark identifier
- **Datasets** — associate groups of data elements with particular memory locations
- **GVariantType** — introduction to the GVariant type system
- **GVariant** — strongly typed value datatype
- **GVariant Format Strings** — varargs conversion of GVariants
- **GVariant Text Format** — textual representation of GVariants

Deprecated APIs

- **Deprecated thread API** — old thread APIs (for reference only)
- **Caches** — caches allow sharing of complex data structures to save resources
- **Relations and Tuples** — tables of data which can be indexed on any number of fields
- **Automatic String Completion** — support for automatic completion using a group of target strings

GLib Tools

- **glib-gettextize** — gettext internationalization utility
- **gtester** — test running utility
- **gtester-report** — test report formatting utility

- **Pango**

  Pango is a library for laying out and rendering of text, with an emphasis on internationalization. Pango can be used anywhere that text layout is needed, though most of the work on Pango so far has been done in the context of the GTK+ widget toolkit. Pango forms the core of text and font handling for GTK+-2.x.

  Pango is designed to be modular; the core Pango layout engine can be used with different font backends. There are three basic backends, with multiple options for rendering with each.

  - Client side fonts using the FreeType and fontconfig libraries, using HarfBuzz for complex-text handling. Rendering can be with with Cairo or Xft libraries, or directly to an in-memory buffer with no additional libraries.
  - Native fonts on Microsoft Windows using Uniscribe for complex-text handling. Rendering can be done via Cairo or directly using the native Win32 API.
  - Native fonts on MacOS X using CoreText for complex-text handling, rendering via Cairo.

  The integration of Pango with Cairo provides a complete solution with high quality text handling and graphics rendering.

  Dynamically loaded modules then handle text layout for particular combinations of script and font backend. Pango ships with a wide selection of modules, including modules for Hebrew, Arabic, Hangul, Thai, and a number of Indic scripts. Virtually all of the world's major scripts are supported. As well as the low level layout rendering routines, Pango includes PangoLayout, a high level driver for laying out entire blocks of text, and routines to assist in editing internationalized text. Pango depends on 2.x series of the GLib library.

- **ATK**

  ATK provides the set of accessibility interfaces that are implemented by other toolkits and applications. Using the ATK interfaces, accessibility tools have full access to view and control running applications.

  Base accessibility object

  - **AtkObject** — The base object class for the Accessibility Toolkit API.

Event and Toolkit Support

- **AtkUtil** — A set of ATK utility functions for event and toolkit support

ATK Interfaces

- **AtkAction** — The ATK interface provided by UI components which the user can activate/interact with.
- **AtkComponent** — The ATK interface provided by UI components which occupy a physical area on the screen. which the user can activate/interact with.
- **AtkDocument** — The ATK interface which represents the toplevel container for document content.
- **AtkEditableText** — The ATK interface implemented by components containing user-editable text content.
- **AtkHyperlinImpl** — An interface from which the AtkHyperlink associated with an AtkObject may be obtained.
- **AtkHypertext** — The ATK interface which provides standard mechanism for manipulating hyperlinks.
- **AtkImage** — The ATK Interface implemented by components which expose image or pixmap content on-screen.
- **AtkSelection** - The ATK interface implemented by container objects whose AtkObject children can be selected.
- **AtkStreamableContent** — The ATK interface which provides access to streamable content.
- **AtkTable** — The ATK interface implemented for UI components which contain tabular or row/column information.
- **AtkTableCell** - The ATK interface implemented for a cell inside a two-dimentional AtkTable
- **AtkText** — The ATK interface implemented by components with text content.
- **AtkValue** — The ATK interface implemented by valuators and components which display or select a value from a bounded range of values.
- **AtkWindow** — The ATK Interface provided by UI components that represent a top-level window.

Basic accessible data types

- **AtkRange** - A given range or subrange, to be used with AtkValue
- **AtkRelation** — An object used to describe a relation between a object and one or more other objects.
- **AtkRelationSet** — A set of AtkRelations, normally the set of AtkRelations which an AtkObject has.
- **AtkState** — An AtkState describes a single state of an object.
- **AtkStateSet** — An AtkStateSet contains the states of an object.

Custom accessible objects

- **AtkGObjectAccessible** — This object class is derived from AtkObject and can be used as a basis implementing accessible objects.
- **AtkHyperlink** — An ATK object which encapsulates a link or set of links in a hypertext document.
- **AtkNoOpObject** — An AtkObject which purports to implement all ATK interfaces.
- **AtkPlug** — Toplevel for embedding into other processes
- **AtkSocket** — Container for AtkPlug objects from other processes

Utilities

- **AtkNoOpObjectFactory** — The AtkObjectFactory which creates an AtkNoOpObject.
- **AtkObjectFactory** — The base object class for a factory used to create accessible objects for objects of a specific GType.
- **AtkRegistry** — An object used to store the GType of the factories used to create an accessible object for an object of a particular GType.
- **Versioning macros** — Variables and functions to check the ATK version

Deprecated Interfaces

- **AtkMisc** — A set of ATK utility functions for thread locking

- **GDK**

  I **API Reference**

  - **General** — Library initialization and miscellaneous functions
  - **GdkDisplayManager** — Maintains a list of all open GdkDisplays
  - **GdkDisplay** — Controls a set of GdkScreens and their associated input devices
  - **GdkScreen** — Object representing a physical screen
  - **GdkDeviceManager** — Functions for handling input devices
  - **GdkDevice** — Object representing an input device
  - **Points and Rectangles** — Simple graphical data types
  - **Pixbufs** — Functions for obtaining pixbufs
  - **RGBA Colors** — RGBA colors
  - **Visuals** — Low-level display hardware information
  - **Cursors** — Standard and pixmap cursors
  - **Windows** — Onscreen display areas in the target window system
  - **Frame clock** — Frame clock syncs painting to a window or display

- **Frame timings** — Object holding timing information for a single frame
- **GdkGLContext** — OpenGL context
- **Events** — Functions for handling events from the window system
- **Event Structures** — Data structures specific to each type of event
- **Key Values** — Functions for manipulating keyboard codes
- **Selections** — Functions for transfering data via the X selection mechanism
- **Drag And Drop** — Functions for controlling drag and drop handling
- **Properties and Atoms** — Functions to manipulate properties on windows
- **Threads** — Functions for using GDK in multi-threaded programs
- **Pango Interaction** — Using Pango in GDK
- **Cairo Interaction** — Functions to support using cairo
- **X Window System Interaction** — X backend-specific functions
- **Wayland Interaction** — Wayland backend-specific functions
- **Application launching** — Startup notification for applications
- **Testing** — Test utilities

II **Deprecated**

- **Colors** — Manipulation of colors

- **GdkPixbuf**

I **API Reference**

- **Initialization and Versions** — Library version numbers.
- **The GdkPixbuf Structure** — Information that describes an image.
- **Reference Counting and Memory Management** — Functions for reference counting and memory management on pixbufs.
- **File Loading** — Loading a pixbuf from a file.
- **File saving** — Saving a pixbuf to a file.
- **Image Data in Memory** — Creating a pixbuf from image data that is already in memory.
- **Inline data** — Functions for inlined pixbuf handling.
- **Scaling** — Scaling pixbufs and scaling and compositing pixbufs
- **Rendering** — Rendering a pixbuf to a GDK drawable.
- **Drawables to Pixbufs** — Getting parts of a GDK drawable's image data into a pixbuf.
- **Utilities** — Utility and miscellaneous convenience functions.
- **Animations** — Animated images.
- **GdkPixbufLoader** — Application-driven progressive image loading.
- **Module Interface** — Extending GdkPixBuf
- **gdk-pixbuf Xlib initialization** — Initializing the gdk-pixbuf Xlib library.

- **Xlib Rendering** — Rendering a pixbuf to an X drawable.
- **X Drawables to Pixbufs** — Getting parts of an X drawable's image data into a pixbuf.
- **XlibRGB** — Rendering RGB buffers to X drawables.

II **Tools Reference**

- **gdk-pixbuf-csource** — C code generation utility for GdkPixbuf images
- **gdk-pixbuf-query-loaders** — GdkPixbuf loader registration utility

- **Cairo**

  A Vector Graphics Library.

  Drawing

  - **cairo_t** — The cairo drawing context
  - **Paths** — Creating paths and manipulating path data
  - **cairo_pattern_t** — Sources for drawing
  - **Regions** — Representing a pixel-aligned area
  - **Transformations** — Manipulating the current transformation matrix
  - **text** — Rendering text and glyphs
  - **Raster Sources** — Supplying arbitrary image data

  Fonts

  - **cairo_font_face_t** — Base class for font faces
  - **cairo_scaled_font_t** — Font face at particular size and options
  - **cairo_font_options_t** — How a font should be rendered
  - **FreeType Fonts** — Font support for FreeType
  - **Win32 Fonts** — Font support for Microsoft Windows
  - **Quartz (CGFont) Fonts** — Font support via CGFont on OS X
  - **User Fonts** — Font support with font data provided by the user

  Surfaces

  - **cairo_device_t** — interface to underlying rendering system
  - **cairo_surface_t** — Base class for surfaces
  - **Image Surfaces** — Rendering to memory buffers
  - **PDF Surfaces** — Rendering PDF documents
  - **PNG Support** — Reading and writing PNG images

- **PostScript Surfaces** — Rendering PostScript documents
- **Recording Surfaces** — Records all drawing operations
- **Win32 Surfaces** — Microsoft Windows surface support
- **SVG Surfaces** — Rendering SVG documents
- **Quartz Surfaces** — Rendering to Quartz surfaces
- **XCB Surfaces** — X Window System rendering using the XCB library
- **XLib Surfaces** — X Window System rendering using XLib
- **XLib-XRender Backend** — X Window System rendering using XLib and the X Render extension
- **Script Surfaces** — Rendering to replayable scripts

Utilities

- **cairo_matrix_t** — Generic matrix operations
- **Error handling** — Decoding cairo's status
- **Version Information** — Compile-time and run-time version checks.
- **Types** — Generic data types

Appendix B: Sensoray 826i Manual

PCI Express Multifunction I/O Board Instruction Manual

Model 826 | Rev.3.0.5 | November 2013

SENSORAY | embedded electronics

Designed and manufactured in the U.S.A.

SENSORAY | p. 503.684.8005 | email: info@SENSORAY.com | www.SENSORAY.com

7313 SW Tech Center Drive | Portland, OR 97203

Table of Contents

Chapter 1: Preliminary

1.1 Limited Warranty

Sensoray Company, Incorporated (Sensoray) warrants the Model 826 hardware to be free from defects in material and workmanship and perform to applicable published Sensoray specifications for two years from the date of shipment to purchaser. Sensoray will, at its option, repair or replace equipment that proves to be defective during the warranty period. This warranty includes parts and labor.

The warranty provided herein does not cover equipment subjected to abuse, misuse, accident, alteration, neglect, or unauthorized repair or installation. Sensoray shall have the right of final determination as to the existence and cause of defect.

As for items repaired or replaced under warranty, the warranty shall continue in effect for the remainder of the original warranty period, or for ninety days following date of shipment by Sensoray of the repaired or replaced part, whichever period is longer.

A Return Material Authorization (RMA) number must be obtained from the factory and clearly marked on the outside of the package before any equipment will be accepted for warranty work. Sensoray will pay the shipping costs of returning to the owner parts that are covered by warranty. A restocking charge of 25% of the product purchase price will be charged for returning a product to stock.

Sensoray believes that the information in this manual is accurate. The document has been carefully reviewed for technical accuracy. In the event that technical or typographical errors exist, Sensoray reserves the right to make changes to subsequent editions of this document without prior notice to holders of this edition.

The reader should consult Sensoray if errors are suspected. In no event shall Sensoray be liable for any damages arising out of or related to this document or the information contained in it.

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1.2 Handling Instructions

The Model 826 circuit board contains electronic circuitry that is sensitive to Electrostatic Discharge (ESD).

Special care should be taken in handling, transporting, and installing circuit board to prevent ESD damage to the board. In particular:

- Do not remove the circuit board from its protective packaging until you are ready to install it.
- Handle the circuit board only at grounded, ESD protected stations.
- Remove power from the equipment before installing or removing the circuit board. In particular, disconnect all field wiring from the board before installing or removing the board from the backplane.

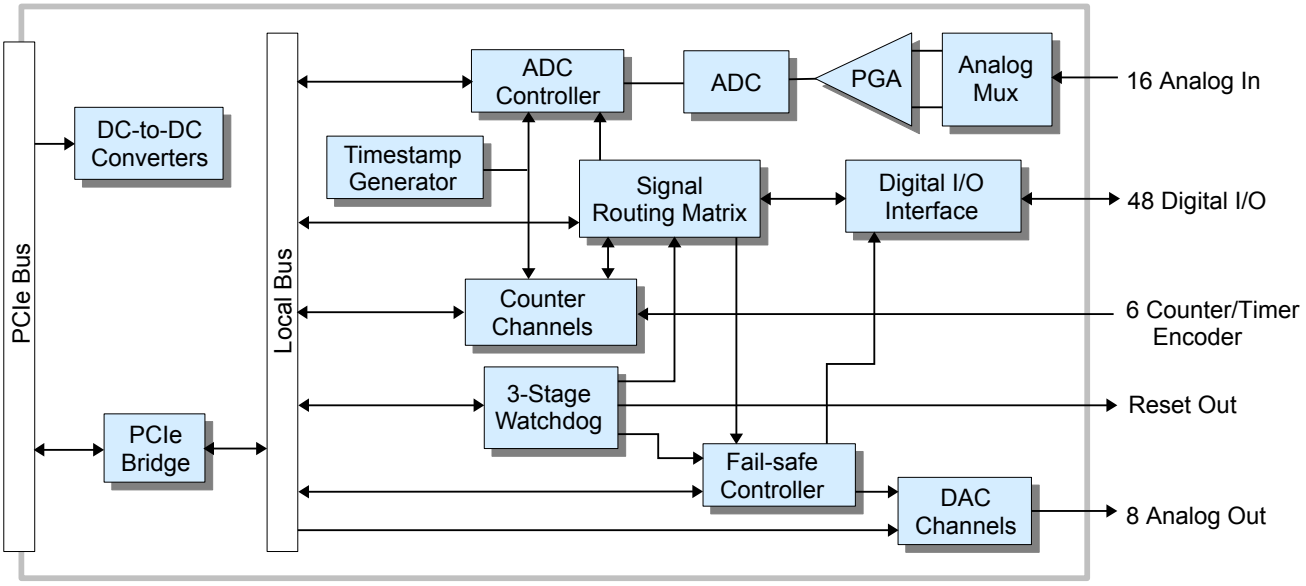
Chapter 2: Introduction

2.1 Overview

Model 826 is a PCI Express board that features an assortment of I/O interfaces commonly used in measurement and control applications:

- **48 bidirectional digital I/O channels** with edge detection and fail-safe output control.
- **Eight 16-bit analog outputs** (±10V, ±5V, 0-10V, 0-5V) with fail-safe output control.
- **Sixteen 16-bit differential analog inputs** (±10V, ±5V, ±2V, ±1V) with hardware and software triggering.
- **Six 32-bit counters**. Clock inputs may be driven from external quadrature-encoded (e.g., incremental encoder) or single-phase sources. Inputs accept differential RS-422 or standard TTL/CMOS single-ended signals. Auxiliary inputs and outputs can be internally routed to digital I/O channels.
- **Multistage watchdog timer** that can activate fail-safe outputs and generate service requests.
- **Fail-safe controller** switches outputs to safe states upon watchdog timeout or external trigger.
- **Signal routing matrix** allows software to interconnect interfaces without external wiring.

Figure 1: Model 826 block diagram



Sensoray provides a free, comprehensive API (application programming interface) to facilitate the rapid development of polled, event-driven, or mixed-mode programs for Model 826. The API works in concert with the board's advanced architecture to support complex, high performance applications.

Standard headers are provided for connecting on-board peripherals to external circuitry. The board's low-profile headers allow it to fit comfortably into high-density systems, and an integral cable clamp keeps cables secure and organized.

On-board LEDs provide visual indications of the board's condition. The PWR indicator is lit when the on-board power supplies are operating. Six LEDs are used to indicate counter clock activity as explained in Status LEDs.

2.1.1 Timestamp Generator

A timestamp generator is shared by the analog input system and counter channels. The timestamp generator is a free-running 32-bit counter that increments every microsecond. The generator starts at zero counts upon board reset and overflows every 2^{32} microseconds (approximately 71.6 minutes). The timestamp counter is not writable, but the current timestamp counts can be read by calling the S826_TimestampRead function.

2.1.2 Board Reset

Upon power-up, or in response to a hardware reset, all interfaces and outputs are forced to default initial states. The initial conditions of the interfaces are discussed in the interface chapters.

2.2 Hardware Configuration

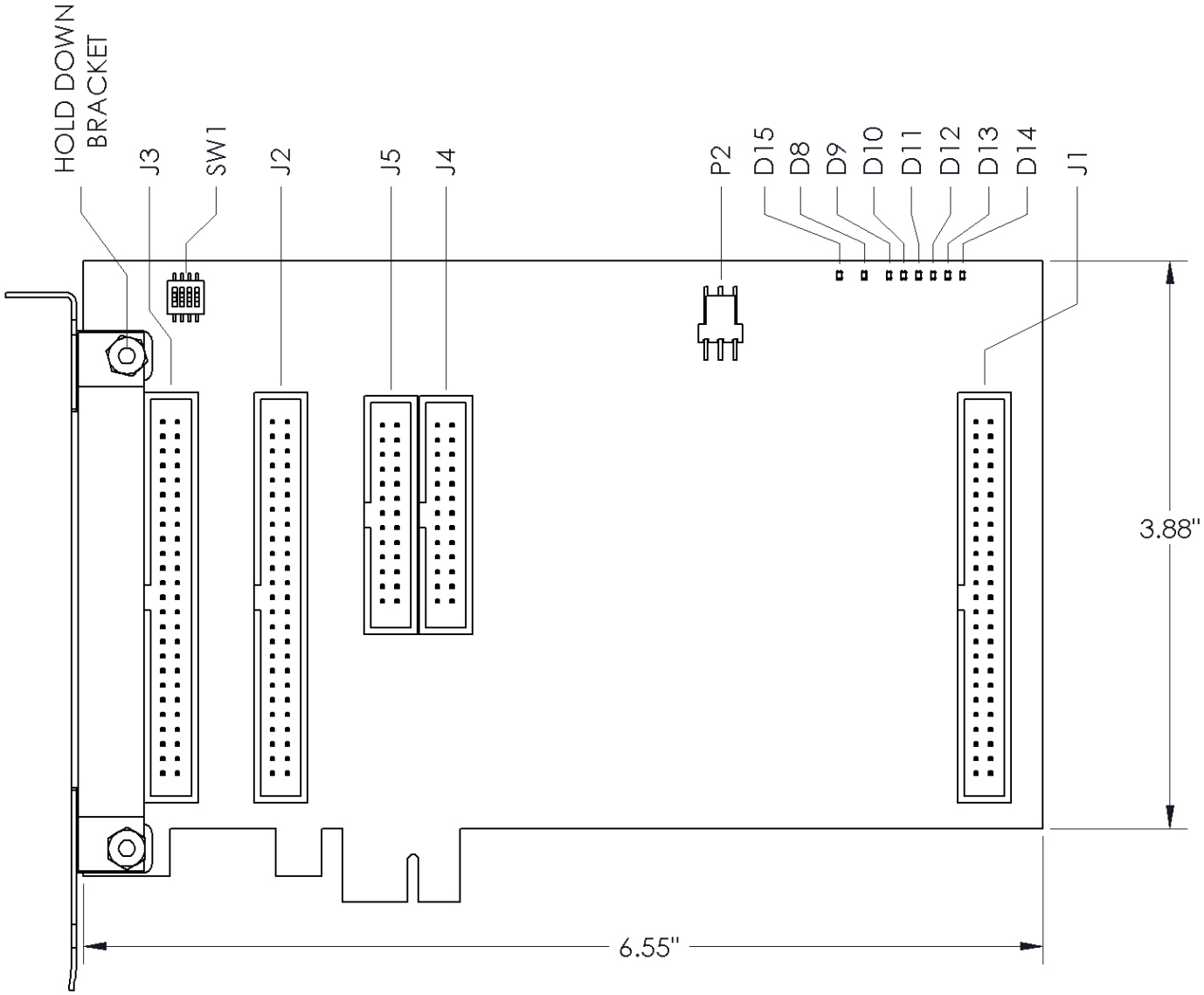
Up to sixteen model 826 boards can coexist in a single host computer. When more than one board is used in a system, each board must be configured before installation; this is done by setting quad dip switch SW1 to assign a unique identifier (board number) in the range 0 to 15 to the board.

By default, all model 826 boards are factory configured as board number 0. No reconfiguration is necessary if there is only one 826 board in the host computer; simply leave it configured at its default board number.

If more than one 826 board will be plugged into a common backplane, the boards must be configured so that each board has a unique board number. Board numbers are typically contiguous, though this is not required. For example, board numbers 0 and 3 could be assigned in a two-board system, though it would be more common to assign board numbers 0 and 1. This table shows the relationship between board number and switch settings:

Board Number	SW1-4	SW1-3	SW1-2	SW1-1	Notes
0	OFF	OFF	OFF	OFF	Factory default
1	OFF	OFF	OFF	ON	
2	OFF	OFF	ON	OFF	
3	OFF	OFF	ON	ON	
4	OFF	ON	OFF	OFF	
5	OFF	ON	OFF	ON	
6	OFF	ON	ON	OFF	
7	OFF	ON	ON	ON	
8	ON	OFF	OFF	OFF	
9	ON	OFF	OFF	ON	
10	ON	OFF	ON	OFF	
11	ON	OFF	ON	ON	
12	ON	ON	OFF	OFF	
13	ON	ON	OFF	ON	
14	ON	ON	ON	OFF	
15	ON	ON	ON	ON	

2.3 Board Layout



2.4 Cable Installation

The 826 board should be connected to external circuitry with Sensoray cables, model 826C1 (26 conductor, for counters) and 826C2 (50 conductor, for analog and digital I/O), which are specifically designed for this purpose. These cables feature thin, flat cable and low profile headers that allow the board to fit into high-density systems when loaded with a complete complement of five cables.

To install the cables (see above diagram):

- Loosen and remove the board's cable clamp (part of the hold-down bracket assembly).
- Pass each cable's low-profile end through the hold-down bracket (from left of bracket) and plug it into its connector.
- Install and tighten the cable clamp.

Chapter 3: Programming

A software developers kit (SDK) for Model 826 is available for download from Sensoray's web site. The SDK includes Linux and Windows device drivers, sample application programs, and an application programming interface (API) that is supplied as a both a Windows dynamic link library (DLL) and a Linux static library. The API core is available in source code form to OEMs who need to port the API to other operating systems.

This chapter provides an overview of the API and discusses functions that are used in all applications. Later chapters discuss API functions that are specific to the board's I/O systems.

3.1 Thread Safety

API functions are thread and process safe when they are not used to access shared hardware resources. For example, consider the case of an API function that is used to control general-purpose digital I/O (DIO) outputs where two threads or processes can call the function simultaneously. The function is guaranteed to be thread and process safe if those threads or processes interact with mutually exclusive DIOs. However, if the threads or processes attempt to manipulate the same DIO, that DIO will be a shared resource and the function is not guaranteed to be thread/process safe.

3.1.1 Atomic Read-Modify-Write

To facilitate high-performance thread-safe behavior, many of the API functions include a “mode” argument that specifies how a register write operation is to be performed. The mode argument works in conjunction with a bit-set and bit-clear hardware function that is implemented on many of the board's interface control registers.

mode	Operation
0	Write all data bits unconditionally. All register bits are programmed to explicit values.
1	Clear (program to '0') all register bits that have '1' in the corresponding data bit. All other register bits are unaffected.
2	Set (program to '1') all register bits that have '1' in the corresponding data bit. All other register bits are unaffected.

For example, if mode=2 and the data value is 0x00000003, register bits 0 and 1 will be set to '1' and all other register bits will retain their previous values.

3.2 Event-Driven Applications

Event-driven applications can be implemented by calling the API's blocking functions: S826_CounterSnapshotRead, S826_AdcRead, S826_DioCapRead, and S826_WatchdogEventWait. These functions can be used to block the calling thread while it waits for hardware signal events. Blocking functions will return immediately (without blocking) if the event occurs before the function is called.

All of the blocking functions include a “tmax” argument that specifies how long, in microseconds, to wait for events:

tmax	Blocking function behavior
0	Return immediately even if event has not occurred (never blocks).
1 to 4294967294	Block until event occurs or tmax microseconds elapse, whichever comes first. This corresponds to times ranging from 1 microsecond to approximately 71.6 minutes.
S826_WAIT_INFINITE	Block until event occurs, with no time limit.

Note that non-realtime operating systems (such as Windows) may not respond to events with deterministic timing. The responsiveness of such systems can depend on a number of factors including CPU loading, thread and process priorities, memory capacity and architecture, core architecture and count, and clock frequency.

3.3 Error Codes

Most of the API functions return an error code. These functions return zero if no errors are detected, otherwise a negative value will be returned that indicates the type of error that occurred.

Error Code	Value	Description
S826_ERR_OK	0	No errors.
S826_ERR_BOARD	-1	Invalid board number.
S826_ERR_VALUE	-2	Illegal argument value.
S826_ERR_NOTREADY	-3	Device was busy or unavailable, or wait timed out.
S826_ERR_CANCELLED	-4	Blocking function was canceled.
S826_ERR_DRIVER	-5	Driver call failed.
S826_ERR_MISSEDTRIG	-6	ADC trigger occurred while previous conversion burst was in progress.
S826_ERR_DUPADDR	-9	Two 826 boards are set to the same board number. Change DIP switch settings.
S826_ERR_BOARDCLOSED	-10	Addressed board is not open.
S826_ERR_CREATEMUTEX	-11	Failed to create internal mutex.
S826_ERR_MEMORYMAP	-12	Failed to map board into memory space.
S826_ERR_MALLOC	-13	Failed to allocate memory.
S826_ERR_FIFOOVERFLOW	-15	Counter channel's snapshot FIFO overflowed.
S826_ERR_OSSPECIFIC	-1xx	Error specific to the operating system. Contact Sensoray.

3.4 Open/Close Functions

3.4.1 S826_SystemOpen

The S826_SystemOpen function detects all Model 826 boards and enables communication with the boards.

```
int S826_SystemOpen(void);
```

Return Values

If the function succeeds, the return value is a set of bit flags indicating all detected 826 boards. Each bit position corresponds to the board number programmed onto a board's switches (see "Hardware Configuration"). For example, bit 0 will be set if an 826 with board number 0 is detected. The return value will be zero if no boards are detected, or positive if one or more boards are detected without error.

If the function fails, the return value is an error code (always a negative value). S826_ERR_DUPADDR will be returned if two boards are detected that have the same board number.

Remarks

This function must be called by a process before interacting with any 826 boards. The function allocates system resources that are used internally by other API functions. S826_SystemClose must be called once, for each call to S826_SystemOpen, to free the resources when they are no longer needed (e.g., when the 826 application program terminates). The board's circuitry is not reset by this function; all registers and I/O states are preserved.

S826_SystemOpen should be called once by every process that will use the 826 API. In a multi-threaded process, call the function once before any other API functions are called; all threads belonging to the process will then have access to all 826 boards in the system.

3.4.2 S826_SystemClose

The S826_SystemClose function frees all of the system resources that were allocated by S826_SystemOpen and disables communication with all 826 boards.

```
int S826_SystemClose();
```

Return Values

The return value is always zero.

Remarks

This function should be called when a process (e.g., an application program) has finished interacting with the board's I/O interfaces, to free system resources that are no longer needed. Any API functions that are blocking will return immediately, with return value S826_ERR_SYSCLOSED. The board's circuitry is not reset by this function; all registers and I/O states are preserved.

3.5 Status Functions

3.5.1 S826_VersionRead

The S826_VersionRead function returns API, driver, and board version information.

```
int S826_VersionRead(
  uint board,       // board identifier
  uint *api,        // API version
  uint *driver,     // driver version
  uint *bdrev,      // circuit board version
  uint *fpgarev     // FPGA version
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

api
Pointer to a buffer that will receive the API version info. The hexadecimal value is formatted as 0xXXYYZZZZ, where XX = major version, YY = minor version, and ZZZZ = build.

driver
Pointer to a buffer that will receive the driver version info. The hexadecimal info is formatted as 0xXXYYZZZZ, where XX = major version, YY = minor version, and ZZZZ = build.

boardrev
Pointer to a buffer that will receive the version number of the 826's circuit board.

fpgarev
Pointer to a buffer that will receive the board's FPGA version info. The hexadecimal info is formatted as 0xXXYYZZZZ, where XX = major version, YY = minor version, and ZZZZ = build.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

3.5.2 S826_TimestampRead

The S826_TimestampRead function returns the current value of the timestamp generator.

```
int S826_TimestampRead(
  uint board,       // board identifier
  uint *timestamp   // current timestamp
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

timestamp
Pointer to buffer that will receive the timestamp. The returned value is the contents of the timestamp generator at the moment the function executes.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function can be used to monitor elapsed times with microsecond level resolution, independent of the type of operating system being used.

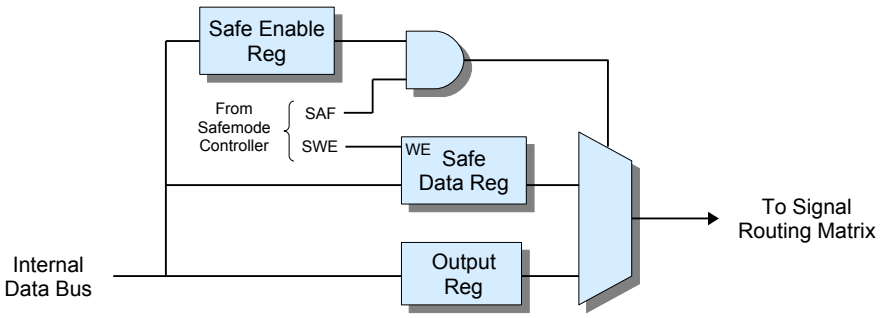
Chapter 4: Virtual Outputs

4.1 Introduction

The board has six virtual digital output channels, numbered 0 to 5, that can be used by software to signal various interfaces on the board. The virtual output channels are physical circuits that are architecturally similar to the board's general-purpose digital output channels, but they cannot be routed to the board's headers or connected to external circuitry.

Each virtual output channel is connected to the board's internal signal routing matrix, which in turn routes the channel's output signal to other on-board interfaces under program control. A virtual output channel can be routed to the ExtIn input of one or more counter channels, or to the ADC trigger input, or to combinations of these.

Figure 2: Virtual output channel (1 of 6)



4.1.1 Safemode

Safemode is activated when the SAF signal (see Figure 2) is asserted. When operating in safemode, the virtual output state is determined by the Safe Enable and Safe Data registers: when Safe Enable equals '1' the pin will be driven to the fail-safe value stored in Safe Data; when Safe Enable equals '0' the pin will output the normal runmode signal from its output register.

Upon board reset, the Safe Enable register is set to '1' so that the virtual output will exhibit fail-safe behavior by default (i.e., it will output the contents of the Safe Data register when SAF is asserted). Fail-safe operation can be disabled for a virtual output channel by programming its Safe Enable register to '0'.

The Safe Data register is typically programmed once (or left at its default value) by the application when it starts, though it may be changed at any time if required by the application. It can be written to only when the SWE bit is set to '1'. See “Safemode Controller” for more information about safemode.

4.2 Programming

The virtual output API functions employ individual bits to convey information about the virtual output channels, wherein each bit represents the information for one channel. The information is organized into a single quadlet as follows (e.g., “v5” = virtual output channel 5):

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	v5	v4	v3	v2	v1	v0

4.2.1 S826_VirtualWrite

The S826_VirtualWrite function programs the virtual output registers.

```
int S826_VirtualWrite(
  uint board,     // board identifier
  uint data,      // data to write
  uint mode       // 0=write, 1=clear bits, 2=set bits
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Normal (runmode) output data for the six virtual channels (see Section 4.2).

mode
Write mode for data: 0 = write, 1 = clear bits, 2 = set bits (see "Atomic Read-Modify-Write").

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

In mode zero, this function will unconditionally write new values to all virtual output registers. In modes one and two, the function will selectively clear or set any arbitrary combination of output registers; data bits that contain logic '1' indicate virtual output registers that are to be modified, while all other output registers will remain unchanged. Modes one and two can be used to ensure thread-safe operation as they atomically set or clear the specified bits.

4.2.2 S826_VirtualRead

The S826_VirtualRead function reads the programmed states of all virtual output registers.

```
int S826_VirtualRead(
  uint board,    // board identifier
  uint *data     // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to a buffer (see Section 4.2) that will receive the output register states.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function returns the output register states.

4.2.3 S826_VirtualSafeWrite

The S826_VirtualSafeWrite function programs the virtual output channel Safe registers.

```
int S826_VirtualSafeWrite(
  uint board,     // board identifier
  uint data,      // safemode data
  uint mode       // 0=write, 1=clear bits, 2=set bits
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to data array (see Section 4.2) to be programmed into the Safe registers.

mode
Write mode for data: 0 = write, 1 = clear bits, 2 = set bits (see "Atomic Read-Modify-Write").

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function should only be called when the SWE bit is set (see S826_SafeWrenWrite). The function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1).

4.2.4 S826_VirtualSafeRead

The S826_VirtualSafeRead function returns the contents of the virtual output channel Safe registers.

```
int S826_VirtualSafeRead(
  uint board,    // board identifier
  uint *data     // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to a buffer (see Section 4.2) that will receive the Safe register states.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

4.2.5 S826_VirtualSafeEnablesWrite

The S826_VirtualSafeEnablesWrite function programs the virtual output channel Safe Enable registers.

```
int S826_VirtualSafeEnablesWrite(
  uint board,       // board identifier
  uint enables      // safemode enables
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

enables
Pointer to array of values (see Section 4.2) to be programmed into the Safe Enable registers.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function should only be called when the SWE bit is set (see S826_SafeWrenWrite). The function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1).

4.2.6 S826_VirtualSafeEnablesRead

The S826_VirtualSafeEnablesRead function returns the contents of the virtual output channel Safe Enable registers.

```
int S826_VirtualSafeEnablesRead(
  uint board,      // board identifier
  uint *enables    // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

enables
Pointer to a buffer (see Section 4.2) that will receive the Safe Enable register contents.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

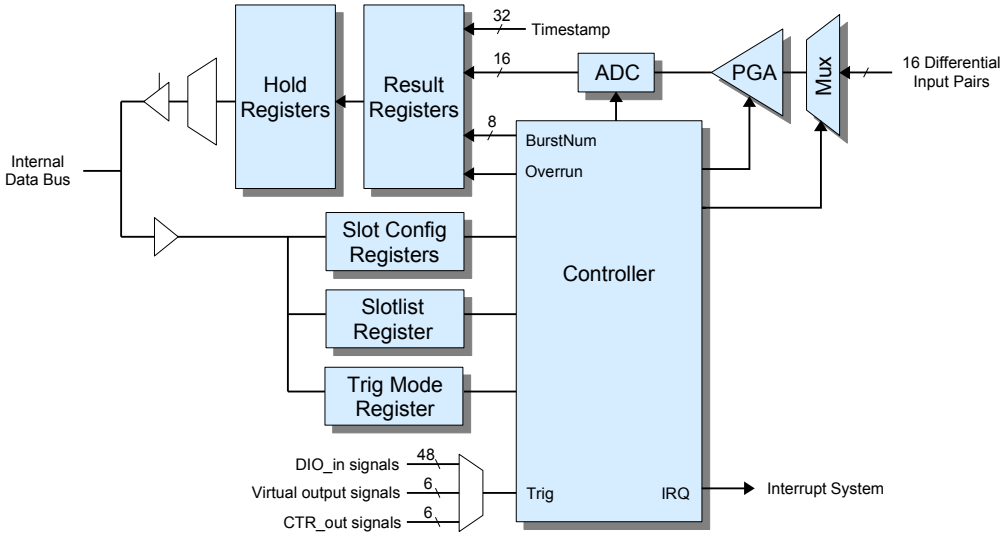
Chapter 5: Analog Inputs

5.1 Introduction

The board's analog input system consists of the following major elements:

- **Analog multiplexer (Mux)** - selects one of 16 differential input pairs (channels) for conversion.
- **Programmable gain amplifier (PGA)** - applies voltage gain of 1, 2, 5, or 10 to the selected input.
- **Analog-to-digital converter (ADC)** - performs an analog-to-digital conversion in three microseconds or less.
- **Controller** - manages operation of the analog input system.

Figure 3: Analog input system



Analog-to-digital (A/D) conversions are performed in bursts of up to 16 conversions. Each conversion takes place in a timeslot (called a *slot*), which is a reserved time interval within a burst. During a burst, slots are processed in numerical order beginning with slot 0 and ending with slot 15.

Every slot has three attributes that are programmed into its slot configuration register via the S826_AdcSlotConfigWrite function:

- **Analog channel number:** designates the analog input channel that will be digitized when the slot is processed. Any of the 16 channels may be assigned to any slot. A channel may be assigned to two or more slots if desired.
- **PGA gain:** specifies the analog gain to apply to the analog input signal.
- **Settling time:** specifies the delay from analog multiplexer switching to start of digitization.

The slotlist register designates each slot as either active or inactive; this is programmed via the S826_AdcSlotlistWrite function. When a burst occurs, each slot is processed according to the slotlist. An active slot is processed by performing one A/D conversion; its total time is the sum of its settling time plus a fixed conversion time. Inactive slots are skipped and consume no time during a burst (the slot configuration register is ignored for an inactive slot). The total processing time of each slot is configurable, from zero (inactive slot) to approximately 335 milliseconds, in one-microsecond increments.

ADC conversions are disabled upon board reset. Typically, an application program will configure the ADC system (by programming slotlist and slot configuration registers) before enabling conversions, though this is not required. The slotlist and slot configuration registers may be reprogrammed at any time, even when conversions are enabled.

5.1.1 Triggering

The trigger mode register determines which of two triggering modes, *triggered* or *continuous*, will be used to initiate conversion bursts. In triggered mode each burst must be initiated by a trigger signal, whereas in continuous mode the trigger signal is ignored and conversion bursts will automatically execute one after another with no idle time between bursts. The trigger mode and trigger signal source are programmed by calling S826_AdcTrigModeWrite.

When operating in triggered mode, S826_AdcTrigModeWrite selects one of the following signals to serve as the trigger:

- Any of the 48 general purpose digital I/O (DIO) channels. This enables an external digital signal to trigger bursts. When a DIO channel is used to trigger A/D conversions, the timing of the trigger signal is constrained by the DIO subsystem. See DIO “Pin Timing” for more information.
- Any of the six counter ExtOut signals. This enables a counter to periodically trigger ADC bursts. The selected counter output is internally routed to the ADC trigger input; no external wiring is required.
- Any of the six virtual digital outputs. This enables software to trigger ADC bursts by writing to a virtual output. See Virtual Outputs for more information. The selected virtual output is internally routed to the ADC trigger input; no external wiring is required.

5.1.2 Burst Counter

The controller maintains an 8-bit burst counter that indicates the number of conversion bursts since the ADC was enabled. The burst counter is zeroed upon board reset and whenever the ADC is disabled. The counter increments at the end of each burst and overflows to zero when incrementing from 255. The burst count is passed to the host along with every ADC sample so that the program can determine which burst a sample belongs to.

In triggered mode, the burst count can be used to keep track of the number of received triggers. If a trigger occurs while a burst is in progress, a MissedTrigger flag is set and the trigger will be ignored. After this happens, the burst count will no longer accurately indicate the number of received triggers (accuracy can be restored by disabling and then re-enabling ADC conversions).

5.1.3 Result Registers

Each slot has a result register that stores the slot's most recently acquired result, which is a set of four values: ADC output data, timestamp (which indicates the time the result was acquired), burst count, and overrun flag. Each slot also has a hold register that caches a result while it is being read by the host computer. The hold register ensures that the result's four component values will remain correlated if a new result is captured while the previous result is being read.

During a burst, the controller processes each slot by performing a sequence of operations. First it switches the analog multiplexer to the desired differential input pair and programs the gain and then, if the slot has a non-zero settling time, it waits for the settling time to elapse. When the settling time has elapsed, the controller starts an analog-to-digital conversion. At the moment the conversion completes, the four component values that comprise the result are simultaneously sampled and copied to the result register.

A new result will always overwrite the previous result, even if the previous result has not been read. If the previous result has not yet been read when a new result is written, the overrun flag will be set to '1'; otherwise it will be set to '0'.

Sixteen hardware status flags (one per slot) indicate unread results. A status flag is set when the controller writes a new result to the associated result register, and reset when the program reads the result. Results are read by calling the S826_AdcRead function. The S826_AdcStatusRead function can be called to check the status flags without returning results or altering status flags.

5.2 Connector J1

All analog input and output signals are available at connector J1.

J1 Pinout

Pin	Name	Function
1	GND	Power supply common
2	GND	Power supply common
3	-AIN0	Analog input (-) channel 0
4	+AIN0	Analog input (+) channel 0
5	-AIN1	Analog input (-) channel 1
6	+AIN1	Analog input (+) channel 1
7	-AIN2	Analog input (-) channel 2
8	+AIN2	Analog input (+) channel 2
9	-AIN3	Analog input (-) channel 3
10	+AIN3	Analog input (+) channel 3
11	-AIN4	Analog input (-) channel 4
12	+AIN4	Analog input (+) channel 4
13	-AIN5	Analog input (-) channel 5
14	+AIN5	Analog input (+) channel 5
15	-AIN6	Analog input (-) channel 6
16	+AIN6	Analog input (+) channel 6
17	-AIN7	Analog input (-) channel 7
18	+AIN7	Analog input (+) channel 7
19	GND	Power supply common
20	GND	Power supply common
21	-AIN8	Analog input (-) channel 8
22	+AIN8	Analog input (+) channel 8
23	-AIN9	Analog input (-) channel 9
24	+AIN9	Analog input (+) channel 9
25	-AIN10	Analog input (-) channel 10

Pin	Name	Function
26	+AIN10	Analog input (+) channel 10
27	-AIN11	Analog input (-) channel 11
28	+AIN11	Analog input (+) channel 11
29	-AIN12	Analog input (-) channel 12
30	+AIN12	Analog input (+) channel 12
31	-AIN13	Analog input (-) channel 13
32	+AIN13	Analog input (+) channel 13
33	-AIN14	Analog input (-) channel 14
34	+AIN14	Analog input (+) channel 14
35	-AIN15	Analog input (-) channel 15
36	SH15	Analog input (+) channel 15
37	GND	Power supply common
38	GND	Power supply common
39	GND	Power supply common
40	GND	Power supply common
41	AOUT4	Analog output channel 4
42	AOUT0	Analog output channel 0
43	AOUT5	Analog output channel 5
44	AOUT1	Analog output channel 1
45	AOUT6	Analog output channel 6
46	AOUT2	Analog output channel 2
47	AOUT7	Analog output channel 7
48	AOUT3	Analog output channel 3
49	GND	Power supply common
50	GND	Power supply common

5.3 Programming

5.3.1 S826_AdcSlotConfigWrite

The S826_AdcSlotConfigWrite function configures a timeslot.

```
int S826_AdcSlotConfigWrite(
  uint board,    // board identifier
  uint slot,     // timeslot number
  uint chan,     // analog input channel number
  uint tsettle,  // settling time in microseconds
  uint range     // input range code
);
```

Parameters

board

826 board number. This must match the settings of the board's dip switches as described in section 2.2.

slot

Timeslot number in the range 0 to 15.

chan
Analog input channel number in the range 0 to 15.

tsettle
Microseconds to allow the analog input to settle before conversion, in the range 0 to 335,544.

range
Enumerated value that specifies the analog input voltage range. This determines the analog gain that will be applied to the input signal before digitization.

range	PGA Gain	Analog Input Range	Notes
0	x1	-10V to +10V	Default upon reset
1	x2	-5V to +5V	
2	x5	-2V to +2V	
3	x10	-1V to +1V	

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

The settings established by this function will be used the next time the slot is converted and remain in effect until changed by another call to this function or a board reset.

The maximum total time for each slot is *tsettle*+3 µs. Sufficient settling time must be allowed when different channels are being digitized so that each input signal has time to stabilize before digitization. If a single channel is being digitized in multiple, consecutive slots, only the first of its slots must allow for settling time; subsequent slots may have zero settling time because the channel will already be settled. Similarly, if only one channel is being digitized (even if it is being digitized multiple times in different slots), all settling times may be set to zero because no channel switching will occur.

The ADC data latency is greater than the slot time because an additional 1µs is needed to fetch the digitized data after each conversion. The data latency is only incurred once per burst, because the ADC controller always fetches data from the previous conversion while the next conversion is in progress. Consequently, the elapsed time from hardware trigger to burst completion (in microseconds) is

$$t_{burst} \leq 1 + 3 \cdot NumTimeslots + \sum t_{settle}$$

5.3.2 S826_AdcSlotConfigRead

The S826_AdcSlotConfigRead function returns the configuration of a timeslot.

```
int S826_AdcSlotConfigRead(
  uint board,     // board identifier
  uint slot,      // timeslot number
  uint *chan,     // analog input channel number
  uint *tsettle,  // settling time in microseconds
  uint *range     // input range code
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

slot
Timeslot number in the range 0 to 15.

chan
Buffer that will receive the analog input channel number.

tsettle
Buffer that will receive the analog settling time in microseconds.

range
Buffer that will receive the analog input voltage range code, as specified in S826_AdcSlotConfigWrite.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function returns the settings established by a board reset or previous call to S826_AdcSlotConfigWrite.

5.3.3 S826_AdcSlotlistWrite

The S826_AdcSlotlistWrite function programs the conversion slot list.

```
int S826_AdcSlotlistWrite(
  uint board,      // board identifier
  uint slotlist,   // conversion slot list
  uint mode        // write mode
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

slotlist
List of slots to be digitized during subsequent conversion bursts, one bit per slot. Bits 0 to 15 correspond to slots 0 to 15, respectively. Each bit that is set to logic '1' will cause the corresponding slot to be digitized, while '0' will cause the slot to be skipped.

mode
Write mode for slotlist: 0 = write, 1 = clear bits, 2 = set bits (see “Atomic Read-Modify-Write”).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

The settings established by this function will be used the next time a slot is digitized and remain in effect until changed by another call to this function or a board reset.

In mode zero, this function will unconditionally write a new slotlist. In modes one and two, the function will selectively set or clear any arbitrary combination of slots; slotlist bits that contain logic '1' indicate slots that are to be modified, while all other slots will remain unchanged. Modes one and two can be used to guarantee thread-safe operation as they atomically enable or disable the specified slots without affecting any other slots.

5.3.4 S826_AdcSlotlistRead

The S826_AdcSlotlistRead function returns the conversion slot list.

```
int S826_AdcSlotlistRead(
  uint board,       // board identifier
  uint *slotlist    // conversion slot list
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

slotlist
Pointer to a buffer that will receive the slotlist. In the received value, bits 0 to 15 correspond to slots 0 to 15. For each bit: '1' = active (slot will be digitized during bursts), '0' = inactive (slot will be skipped during bursts).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function returns the current slotlist, which was previously programmed by S826_AdcSlotlistWrite or cleared by a board reset.

5.3.5 S826_AdcTrigModeWrite

The S826_AdcTrigModeWrite function programs the ADC triggering mode.

```
int S826_AdcTrigModeWrite(
  uint board,      // board identifier
  uint trigmode    // hardware trigger mode
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

trigmode
Hardware trigger configuration:

Bit	Function	Description
31-8	Reserved	Set all bits to 0.
7	Trigger enable	Set to 1 to enable hardware triggering (triggered mode), or 0 to disable hardware triggering (continuous mode).
6	Trigger polarity	1 selects rising edge; 0 selects falling edge. This is ignored if hardware triggering is disabled.
5-0	Trigger source	Hardware trigger signal source (ignored if hardware triggering is disabled): 0-47 = DIO channel 0-47. 48-53 = ExtOut signal from counter channel 0-5. 54-59 = Virtual digital output channel 0-5.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

The settings established by this function take effect upon the next conversion burst and remain in effect until changed by another call to this function or a board reset. Hardware triggering is disabled upon board reset.

5.3.6 S826_AdcTrigModeRead

The S826_AdcTrigModeRead function reads the ADC triggering mode.

```
int S826_AdcTrigModeRead(
  uint board,      // board identifier
  uint *trigmode   // hardware trigger mode
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

trigmode
Pointer to a buffer that will receive the hardware trigger configuration. See S826_AdcTrigModeWrite for the format of this value.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

5.3.7 S826_AdcEnableWrite

The S826_AdcEnableWrite function enables or disables ADC conversions.

```
int S826_AdcEnableWrite(
  uint board,    // board identifier
  uint enable    // enable conversions when true
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

enable
Set to 1 to enable, or 0 to disable ADC conversion bursts. Conversion bursts are disabled by default upon board reset.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

When enable is false, any conversion burst that is currently in progress will be terminated and all results and overrun status flags are reset. When enable is true, the resulting behavior depends on the trigger mode:

Continuous mode
The first conversion burst will begin immediately, followed by additional bursts. Each subsequent burst begins immediately after the preceding burst ends. Back-to-back bursts will continue until ADC conversions are disabled.

Triggered mode
A single conversion burst will begin in response to the next trigger and conversions will cease upon completion of that burst. Each subsequent trigger will cause another single burst. Triggers have no effect when ADC conversions are disabled.

5.3.8 S826_AdcEnableRead

The S826_AdcEnableRead function returns the enable status of the ADC system.

```
int S826_AdcEnableRead(
  uint board,    // board identifier
  uint *enable   // enable status
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

enable
Buffer that will receive the ADC system enable status: 1 = enabled, 0 = disabled.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function returns the ADC system's enable status that was previously configured by a board reset or a call to S826_AdcEnableWrite.

5.3.9 S826_AdcStatusRead

The S826_AdcStatusRead function reads the ADC conversion status.

```
int S826_AdcStatusRead(
  uint board,       // board identifier
  uint *status      // conversion status
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

status
Pointer to a buffer that will receive the conversion status for all slots. Each bit corresponds to one slot; bits 0 to 15 correspond to slots 0 to 15. A bit will be set to '1' if new (unread) data is available in the slot's result register, or '0' when the result register is empty (or has been read).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function returns status information without altering the state of the ADC system.

5.3.10 S826_AdcRead

The S826_AdcRead function fetches ADC data from one or more timeslots.

```
int S826_AdcRead(
  uint board,       // board identifier
  int buf[16],      // pointer to adc result buffer
  uint tstamp[16],  // pointer to timestamps buffer
  uint *slotlist,   // pointer to slotlist
  uint tmax         // maximum time to wait
);
```

Parameters

board

826 board number. This must match the settings of the board's dip switches as described in section 2.2.

buf

Pointer to a buffer that will receive ADC results for the sixteen possible slots. The buffer must be large enough to accommodate sixteen values regardless of the number of active slots. Each slot is represented by a 32-bit value, which is stored at buf[SlotNumber]:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
BSTNUM								V	0000000							ADCVAL															

Field	Description
BSTNUM	Burst number. This indicates the ADC burst number corresponding to the ADC data. It can be used to time-correlate the ADC data if V = '1'. The burst number is incremented at the end of each burst; it restarts at zero at the end of burst number 255.
V	Data Overwritten flag. When set to '1' this indicates the previous ADC result was overwritten by a new result before it was read.
ADCVAL	ADC data, expressed as 16-bit signed integer:

Analog Voltage	ADCVAL
-10V to +10V	0x8000 to 0x7FFF
-5V to +5V	0x8000 to 0x7FFF
-2V to +2V	0x8000 to 0x7FFF
-1V to +1V	0x8000 to 0x7FFF

tstamp

Pointer to a buffer that will receive the timestamps corresponding to ADC results. The buffer must be large enough to accommodate sixteen values regardless of the number of active slots. Each timestamp indicates the moment in time that its corresponding ADCVAL was acquired. For any given slot, the slot's timestamp will be stored in tstamp[SlotNumber]. The application may set this to NULL if timestamps are not needed.

slotlist

Pointer to a buffer containing bit flags, one bit per slot, that indicate slots of interest. Bits 0-15 correspond to slots 0-15. Before calling the function, set to '1' all bits that correspond to slots of interest. When the function returns, the buffer contents will have been changed so that '1' indicates a slot has new data in buf and '0' indicates no new data.

tmax

Maximum time, in microseconds, to wait for ADC data. See “Event-Driven Applications” for details.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function reads the result registers of an arbitrary set of slots and copies the results to buf. As many as sixteen results (one per slot) may be copied to buf each time the function is called. Over-range and under-range conditions are indicated by maximum or minimum data values for the selected input range, respectively; there are no special status flags that indicate these conditions.

Before calling the function, one or more slotlist bits must be set to indicate the slots of interest. Only new, unread results are copied to buf. If a slot is not of interest or has not been converted since it was last read, its buf value will not change. In all cases (even when the function returns an error), when the function returns, slotlist will indicate the slots of interest that have new buf values.

The function will operate in either blocking or non-blocking mode depending on the value of tmax. If tmax is zero, the function will return immediately. If tmax is greater than zero, the calling thread will block until all requested data is available or tmax elapses. In either case, the function will copy to buf all data from slots of interest that have a new result. The function will return S826_ERR_NOTREADY if any of the requested slot data is unavailable.

This function will return S826_ERR_CANCELLED if, while it is blocking, another thread calls S826_AdcWaitCancel to cancel waits on any of the slots of interest. It will return immediately if the wait criteria is completely satisfied due to the wait cancellations, otherwise it will continue to block and return when all remaining wait criteria is satisfied. S826_ERR_BOARDCLOSED will be returned immediately if S826_SystemClose executes while this function is blocking. In either case, no result data will be copied to buf.

In triggered mode, the board's internal MissedTrigger error flag will be set if a trigger occurs while an ADC burst is in progress. When the MissedTrigger flag is active, S826_AdcRead will wait for the requested slot data to arrive and then it will clear the MissedTrigger flag and return S826_ERR_MISSEDTRIG. If multiple threads are waiting in S826_AdcRead, only the first thread to return will receive S826_ERR_MISSEDTRIG; the other waiting threads will not receive this error.

Thread-safe operation is guaranteed only if the slots of interest for any given thread do not coincide with those of another thread. For example, thread safety would be assured if one thread designates slots 1 and 3-5 as slots of interest while another thread designates slots 2 and 9. Thread safety would be compromised, though, if both threads shared a common slot of interest.

5.3.11 S826_AdcWaitCancel

The S826_AdcWaitCancel function cancels a blocking wait on one or more slots.

```
int S826_AdcWaitCancel(
  uint board,      // board identifier
  uint slotlist    // slots to cancel
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

slotlist
Set of bit flags, one bit per slot, that indicate slots for which waiting is to be canceled. Bits 0-15 correspond to slots 0-15.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function cancels blocking for an arbitrary set of slots so that another thread, which is blocked by S826_AdcRead while waiting for adc data to arrive, will return immediately with S826_ERR_CANCELLED.

Chapter 6: Analog Outputs

6.1 Introduction

The 826 board has eight 16-bit, single-ended digital-to-analog converter (DAC) channels. Each channel can be independently configured to generate output voltages across one of four output voltage ranges: 0 to +5V (default upon reset), 0 to +10V, -5 to +5V, and -10 to +10V.

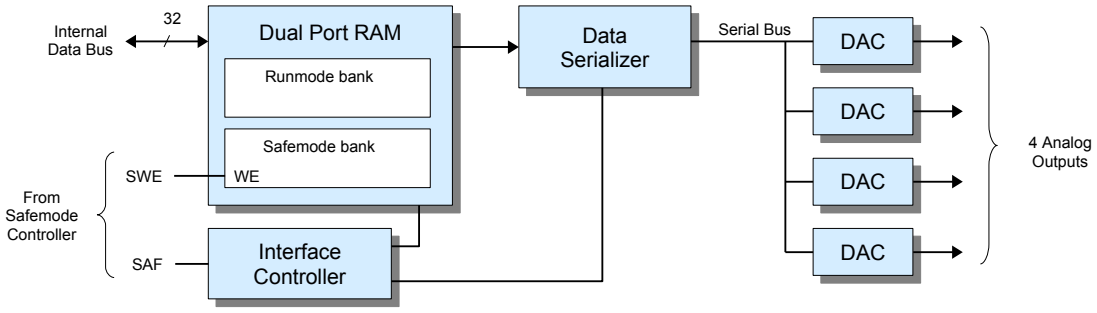
Each DAC channel has a setpoint and configuration register. A channel's output voltage is programmed by writing to its setpoint register. Before programming the setpoint, the DAC must be configured for the desired output range by writing to its configuration register.

Setpoint and configuration values are serially transmitted to the DAC devices over a high speed serial bus (Figure 4). The interface includes a dual-port RAM that allows the host to write setpoint and configuration values to the board while the serial bus is busy. If multiple untransmitted values are pending in the RAM, the controller will employ round-robin arbitration to ensure all pending values are transmitted in a fair and timely fashion. The data serializer requires 1.04 µs to transmit each setpoint or configuration value.

The board has two identical DAC interfaces as shown in Figure 4. Each interface manages a group of four DAC channels. One interface manages channels 0 to 3 and the other interface manages channels 4 to 7. The two interfaces operate concurrently, thus making it possible to simultaneously write to two DACs that reside in different four-channel groups. For example, DAC channels 0 and 4 can be written to simultaneously.

The host may write setpoint and configuration values to the board at any time. If a new value is written to the RAM for a particular channel before that channel's previously written value has been transmitted, the previous RAM value will be overwritten and only the new value will be transmitted. Consequently, the host is allowed to write setpoint data at a rate that exceeds the serial bus bandwidth, though doing so will result in dropped samples.

Figure 4: Analog output interface (1 of 2)



6.1.1 Safemode

The dual-port RAM has two memory banks, one for normal operation (“runmode”) and another for “safemode” operation. The runmode bank stores the setpoint and configuration values that are used during normal operation; these values may be changed at any time as required by the application. The safemode bank contains alternate fail-safe settings that are typically programmed once during program initialization (or left at their default settings). Setpoint and configuration values can be written to the runmode bank at any time, but the safemode bank can only be written when SWE = '1'

The safemode signal (SAF) determines which RAM bank is being used by the interface controller ('1' = safemode, '0' = runmode). When SAF changes state, the appropriate RAM bank is selected and all of the DAC channels are reprogrammed to the settings stored in that bank. See “Safemode Controller” for more information about the fail-safe system.

6.1.2 Reset State

Upon reset, all DAC outputs and all channels in both RAM banks are programmed to 0V with the output range set to 0 to +5V.

6.2 Connector J1

DAC output signals are available on the analog I/O connector J1, which is shared with the ADC system. See Section 5.2 for the connector pinout.

Each DAC channel has a single-ended output signal that is referenced to the board's power supply common. The output and common signals are available on the analog I/O connector. DAC output signals are sensed at the connector; no external sense inputs are available on the connector.

6.3 Programming

6.3.1 S826_DacRangeWrite

The S826_DacRangeWrite function programs the voltage range of an analog output channel.

```
int S826_DacRangeWrite(
  uint board,    // board identifier
  uint chan,     // channel number
  uint range,    // output range
  uint safemode  // RAM bank select
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
DAC channel number in the range 0 to 7.

range
Enumerated value that specifies the output voltage range:

range	Analog Output Range	Notes
0	0 to +5V	Default upon reset
1	0 to +10V	
2	-5 to +5V	
3	-10 to +10V	

safemode
Specifies the RAM bank to be written: '0' = runmode, '1' = safemode.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function configures a channel's output voltage range and programs the setpoint to zero volts. It can be called at any time, though it is typically called once per channel during program initialization for the runmode bank and, if necessary, once per channel for the safemode bank as well (if default safemode values are not suitable).

The SWE bit must be set (see S826_SafeWrenWrite) to allow writing to the safemode bank. This function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1) when writing to the safemode bank.

6.3.2 S826_DacDataWrite

The S826_DacDataWrite function programs the output voltage of a DAC channel.

```
int S826_DacDataWrite(
  uint board,     // board identifier
  uint chan,      // channel number
  uint setpoint,  // output level
  uint safemode   // RAM bank select
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
DAC channel number in the range 0 to 7.

setpoint
Analog output level. This is a value ranging from 0x0000 to 0xFFFF. The resulting output voltage depends on the channel's previously programmed output range.

Analog output range	setpoint range
0 to +5V	0x0000 to 0xFFFF
0 to +10V	0x0000 to 0xFFFF
-5V to +5V	0x0000 to 0xFFFF
-10V to +10V	0x0000 to 0xFFFF

safemode
Specifies the RAM bank to be written: '0' = runmode, '1' = safemode.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function programs a channel's runmode or safemode output voltage level. If the output range will also be changed, the range should be changed first, before calling this function. This function is frequently used to change a runmode setpoint whenever an output level change is required. It can also be used to change a safemode setpoint; this is typically done once per channel when the application starts, after programming the channel's safemode output range.

The SWE bit must be set (see S826_SafeWrenWrite) to allow writing to the safemode bank. This function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1) when writing to the safemode bank.

6.3.3 S826_DacRead

The S826_DacRead function returns the output range and setpoint of an analog output channel.

```
int S826_DacRead(
  uint board,     // board identifier
  uint chan,      // channel number
  uint *range,    // output range
  uint *setpoint, // output level
  uint safemode   // RAM bank select
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
DAC channel number in the range 0 to 7.

range
Pointer to a buffer that will receive the output range code as described in Section 5.3.1.

setpoint
Pointer to a buffer that will receive the output level as described in Section 5.3.2.

safemode
Specifies the RAM bank to be written: '0' = runmode, '1' = safemode.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function can be used to determine whether previously written configuration data has been sent to the DAC device. The value S826_ERR_NOTREADY will be returned if the range or setpoint is not yet active (i.e., one or both values have not yet been transmitted to the DAC device).

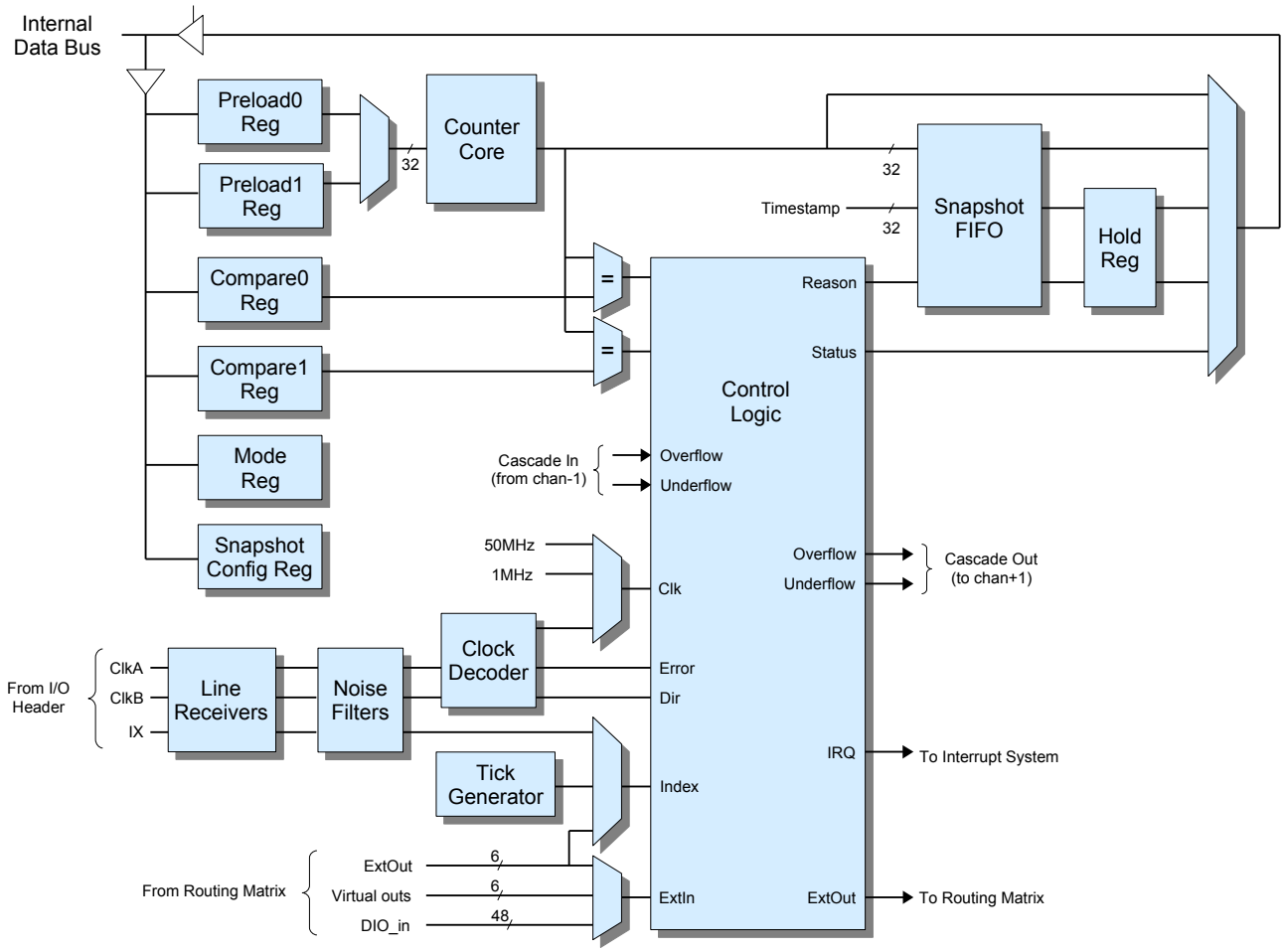
Chapter 7: Counters

7.1 Introduction

The model 826 board has six identical 32-bit programmable counter channels, numbered 0 to 5. Each counter channel can implement a complete solution for a variety of common applications, including incremental encoder interface, event counter, timer, pulse generator, PWM generator, pulse width measurement, period measurement, and frequency measurement. See “Application Connections” for tips on connecting external signals to counter channels, and “Common Applications” for programming strategies.

As shown in Figure 5, each channel can connect to as many as five external signals. Three input signals (ClkA, ClkB, and IX) are accessible through dedicated header pins. Two additional signals (input ExtIn and output ExtOut) can be routed to general-purpose digital I/O pins if physical access to these signals is needed.

Figure 5: Counter channel (1 of 6)



7.1.1 ClkA, ClkB and IX Signals

A channel can accept external signals on its ClkA and ClkB inputs consisting of either a single-phase or quadrature-encoded clocks. The maximum count rate is 25MHz regardless of external clock type. Single-phase clocks having exactly 50 percent duty rate can be counted at up to 25MHz; the maximum count frequency must be derated for other duty rates (see Specifications for details). Quadrature clocks up to 25 MHz (x1 multiplier), 12.5 MHz (x2), and 6.25 MHz (x4) are supported, with suitable derating for deviations from 90 degree clock phasing.

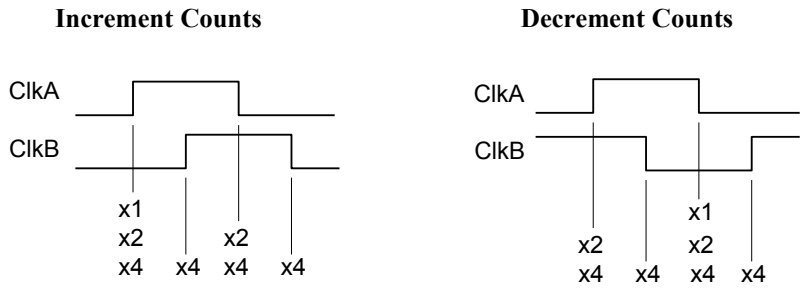
The ClkA, ClkB, and IX inputs employ differential RS-422 line receivers for buffering and noise immunity. All line receivers have built-in termination resistors. The clock and IX inputs are compatible with differential RS-422 signal pairs as well as single-ended TTL and 5V CMOS signals.

Each line receiver is followed by a noise filter that can be used to remove glitches. See S826_CounterFilterWrite for details.

7.1.2 Quadrature Decoder

When connected to quadrature-encoded clock signals, the ClkA and ClkB signals are processed by a quadrature decoder circuit to produce count direction, count enable, and quadrature error signals. Figure 6 shows the clock events that affect counting for each of the possible clock multipliers.

Figure 6: Quadrature Decoding



For example, with a x1 (“times 1”) multiplier, the counts will only change when ClkB is low; the core will count up on the rising edge of ClkA and down on the falling edge of ClkA.

If the decoder detects an encoding error, it will generate a special error snapshot (see Snapshots below) and set an internal error flag. This will happen when ClkA and ClkB transition within 20 ns of each other (which should never occur in normal operation). This can be caused by various conditions, including signal noise on ClkA/ClkB or excessively high input clock frequency. The error snapshot serves as a warning that the counter core may no longer contain an accurate counts value.

7.1.3 ExtIn Signal

Some applications may require an additional external input (ExtIn) signal. If needed, this signal can be routed from any general-purpose digital I/O (DIO) channel, any virtual digital output channel, or the ExtOut signal of any counter channel (see Section 7.3.12 for details). When ExtIn is routed from a DIO channel, the signal appearing on the DIO channel's connector pin must conform to the timing constraints of the DIO subsystem as explained in “Pin Timing”.

The ExtIn signal can be configured to behave as either a count or preload permissive by programming the IM field in the Mode register. See S826_CounterModeWrite for details.

7.1.4 ExtOut Signal

Some counter applications (e.g., pulse or PWM generator) may require a physical output from the counter. In such cases, the counter's ExtOut signal may be routed to a general-purpose DIO channel (see Section 8.3.12 for details). When so routed, the DIO channel will act as a dedicated counter output, while the DIO input and edge detection functions continue to operate normally.

When routed to a DIO, the ExtOut signal timing is constrained by the DIO subsystem as explained in “Pin Timing”. In particular, the ExtOut signal may be delayed up to 20 ns before it appears on the DIO connector pin. Note also that short, positive output pulses may require the addition of external, supplemental pull-up resistance on the DIO pin to attain sufficiently fast rise time.

A channel's ExtOut signal will be asserted only when the channel is running. When the channel is halted, ExtOut is held at the inactive state, as defined by its configured polarity.

7.1.5 Snapshots

A “snapshot” consists of three values that are simultaneously sampled in response to a trigger: the counts contained in the counter core, the timestamp (which indicates the time the snapshot was captured), and a set of “reason” flags that indicate the type of event (or types of events, if multiple events occurred at the same time) that triggered the snapshot.

Snapshots are stored in the Snapshot FIFO. Snapshots are written to the FIFO as they occur, whereas the host may read them from the FIFO at any convenient time. The FIFO stores up to 16 snapshots. When the FIFO is full, a subsequent trigger will cause a new snapshot to be stored in the FIFO and the oldest snapshot in the FIFO will be deleted.

The Hold register caches a snapshot while it is being read by the host. The snapshot timestamp and reason code are copied to the Hold register when the snapshot counts are read. The host will then read the cached timestamp and reason code from the Hold register, thus ensuring the three snapshot values will remain correlated if a FIFO overflow occurs while the snapshot is being read.

A snapshot may be captured in response to various types of hardware and software triggers. All of the hardware trigger types can be individually enabled through the snapshot configuration register. Snapshots may be triggered when:

- The S826_CounterSnapshot function is called (i.e., a “soft” snapshot).
- The counter matches a compare register.
- Transitions occur on the Index input.
- Transitions occur on the ExtIn input.
- The counter reaches zero counts.
- A quadrature clock encoding error is detected. Once this happens, no further error-triggered snapshots can be captured until the error is cleared. The resulting error snapshot enables the application to determine the counts at the moment the error occurred. See S826_CounterSnapshotRead for further information.

Multiple counters can use the same snapshot trigger source or sources. For example, two or more counters could be configured to capture snapshots in response to a signal from a common DIO channel, thus enabling an external signal to simultaneously trigger snapshots on all affected counters. Similarly, a virtual digital output channel could be used as a common trigger, thereby allowing software to simultaneously trigger snapshots on the affected counters.

7.1.6 Preloading

The counter core can be “preloaded” (parallel-loaded) from the Preload0 and Preload1 registers in response to various hardware and software preload triggers. All of the hardware triggers can be individually enabled through the mode register. Preloads may be triggered:

- When the S826_CounterPreload function is called (i.e., a “soft” preload).
- When the channel state switches from halted to running.
- When the counter reaches zero counts.
- When the counter matches a compare register.
- When transitions occur on the Index input.
- While the Index input is held at its active level. This has the effect of holding the counter core at the preload value while Index is asserted.

The mode register's BP bit specifies whether both preload registers will be used or only Preload0. Preload0 is active (selected) by default when the channel state switches from halted to running. When a preload occurs, the core is first preloaded from the preload register and then the active register selector will change.

The preload mechanism behaves as shown in the following table. For example, if both preload registers are being used (BP=1) and a preload occurs because the counts reached zero, the core will be preloaded from the active preload register and then the other preload register will be activated.

Preload Behavior

Mode Register BP bit	Preload Trigger Type	Counter Core Loads From	Activated After Preload
0	Any	Preload0	Preload0
1	Zero Counts Reached	Active preload	Alternate preload
	Any except Zero Counts Reached	Preload0	Preload1

Preload triggers are prioritized. If two simultaneous preload triggers occur, the one with the highest priority is considered to be the cause of the preload and the preload mechanism will behave accordingly.

Some types of preload triggers are enabled and disabled by ExtIn when ExtIn is configured as a preload permissive (see "ExtIn Signal"). These triggers are disabled when ExtIn is negated and enabled with ExtIn is asserted.

Preload Trigger Type	Priority	Enabled/Disabled by ExtIn (when ExtIn is configured as preload permissive)
Channel switched to running state	7 (highest)	No
Zero counts reached	6	No
Compare1 match	5	Yes
Compare0 match	4	Yes
Index rising edge	3	Yes
Index falling edge	2	Yes
Index active level	1	Yes
Soft preload	0 (lowest)	Yes

7.1.7 Tick Generator

Each counter channel has an independent tick generator that can be used to create counting gates; this is useful for frequency measuring applications. The generator can produce periodic pulses at intervals ranging from one microsecond to ten seconds in decade steps. The channel's external IX input or the ExtOut output from any counter channel can be used in lieu of the internal tick generator if a custom gate time is needed.

7.1.8 Cascading

Limited cascading of counter channels is supported. Each channel receives overflow and underflow signals from the adjacent lower channel (channel 0 receives from channel 5). A channel may be cascaded onto the adjacent lower channel by setting K=4 in its mode register (see S826_CounterModeWrite). Note that when two channels are cascaded, only the count function is extended; the snapshot and preload mechanisms will continue to operate independently. Each cascade is limited to two counters.

7.1.9 Status LEDs

Each counter channel is associated with a status LED that indicates clock pulses are detected on that channel. The LED flashes at a constant rate while the clock signal is toggling. The LEDs are labeled E0-E5, corresponding to counter channels 0-5 respectively.

7.1.10 Reset State

Upon board reset, all counter channels are set to the "halted" state (see S826_CounterStateWrite for details). In addition, a board reset will also zero the Mode, Preload, and Compare registers.

7.2 Connectors J4/J5

Two 26-pin headers, J4 and J5, bring out connections from the board's six counter channels to external field wiring. J4 is used for counter channels 0-2 and J5 for channels 3-5.

J4 and J5 Pinouts

J4 - Encoder channels 0-2			
Pin	**Name**	**Function**	**Chan**
1	+A0	Differential A clock inputs	0
2	-A0		
3	GND	Power supply return	
4	+B0	Differential B clock inputs	
5	-B0		
6	+5V	+5V power output	
7	+I0	Differential IX inputs	
8	-I0		
9	GND	Power supply return	
10	+A1	Differential A clock inputs	1
11	-A1		
12	+5V	+5V power output	
13	+B1	Differential B clock inputs	
14	-B1		
15	GND	Power supply return	
16	+I1	Differential IX inputs	
17	-I1		
18	+5V	+5V power output	
19	+A2	Differential A clock inputs	2
20	-A2		
21	GND	Power supply return	
22	+B2	Differential B clock inputs	
23	-B2		
24	+5V	+5V power output	
25	+I2	Differential IX inputs	
26	-I2		

J5 - Encoder channels 3-5			
Pin	**Name**	**Function**	**Chan**
1	+A3	Differential A clock inputs	3
2	-A3		
3	GND	Power supply return	
4	+B3	Differential B clock inputs	
5	-B3		
6	+5V	+5V power output	
7	+I3	Differential IX inputs	
8	-I3		
9	GND	Power supply return	
10	+A4	Differential A clock inputs	4
11	-A4		
12	+5V	+5V power output	
13	+B4	Differential B clock inputs	
14	-B4		
15	GND	Power supply return	
16	+I4	Differential IX inputs	
17	-I4		
18	+5V	+5V power output	
19	+A5	Differential A clock inputs	5
20	-A5		
21	GND	Power supply return	
22	+B5	Differential B clock inputs	
23	-B5		
24	+5V	+5V power output	
25	+I5	Differential IX inputs	
26	-I5		

7.2.1 Counter Signals

Each counter channel has six input signals on its header connector: A+, A-, B+, B-, X+, and X-. The header also has power and ground pins that can be used to supply operating power to external devices such as incremental encoders. The following table details the header pins that are available for each channel and their recommended usage.

External signal connections to a counter channel

Function	Pin Name	Signal Type	Clock Source		
			Quadrature	Single-phase	Internal
ClkA	A+	RS-422	ClockA+	Clock+	NC
		TTL/CMOS	ClockA	Clock	NC
	A-	RS-422	ClockA-	Clock-	NC
		TTL/CMOS	NC	NC	NC
ClkB	B+	RS-422	ClockB+	NC	NC
		TTL/CMOS	ClockB	NC	NC
	B-	RS-422	ClockB-	NC	NC
		TTL/CMOS	NC	NC	NC
			NC		
			NC	Internal / None	
IX	X+	RS-422	NC	NC	
		TTL/CMOS	IX	NC	
	X-	RS-422	IX-	NC	
		TTL/CMOS	NC	NC	
ExtIn	Note 1		Auxiliary counter input. The behavior of this signal is configurable.		
ExtOut	Note 1		Counter output. The behavior of this signal is programmable.		
Device Power	GND	POWER	5V power supply return and ground reference for all logic signals.		
	+5V	POWER	+5VDC power. This can be used to power external devices such as incremental encoders. The total 5V current for all six counter channels is limited to 500mA.		

Notes

1. **If used, this signal must connect to a DIO channel through the board's DIO signal routing matrix. Refer to the DIO documentation for details of the routing matrix and electrical characteristics of the DIO channels.**

7.2.2 Application Connections

Typical counter connections for common applications

Application	Signals				
	ClkA	ClkB	IX	ExtIn	ExtOut
Encoder Interface	Phase A clock	Phase B clock	Snapshot trigger | Preload trigger | NC	Count enable | NC	NC
Event Counter	Event clock	NC	Snapshot trigger | Preload trigger | NC	Count enable | NC	NC
Pulse Generator	NC	NC	Pulse trigger | NC	Pulse trigger | NC	Pulse output
PWM Generator	NC	NC	Output enable | NC	NC	PWM output
Pulse Width Measurement	NC	NC	Signal to measure	NC	NC
Period Measurement	NC	NC	Signal to measure	NC	NC
Frequency Measurement	NC	NC	External time gate | NC	NC	NC

7.3 Programming

7.3.1 S826_CounterSnapshotRead

The S826_CounterSnapshotRead function reads a snapshot from a counter channel.

```
int S826_CounterSnapshotRead(
  uint board,     // board identifier
  uint chan,      // channel number
  uint *counts,   // pointer to counts buffer
  uint *tstamp,   // pointer to timestamp buffer
  uint *reason,   // pointer to reason buffer
  uint tmax       // maximum time to wait
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

counts
Pointer to a buffer that will receive the latched counts value. Set to NULL to ignore counts.

tstamp
Pointer to a buffer that will receive the timestamp. Set to NULL to ignore timestamp.

reason
Pointer to a buffer that will receive the reason flags, which indicate what caused the snapshot. When a flag bit = '1', the snapshot was caused by that event type. More than one event may have occurred at the same time, so multiple bits may be set.

bit	Description
8	Quadrature error
7	Soft snapshot (caused by calling S826_CounterSnapshot)
6	ExtIn rising edge
5	ExtIn falling edge
4	Index rising edge
3	Index falling edge
2	Zero counts reached
1	Compare1 match
0	Compare0 match

Set to NULL to ignore the reason.

tmax
Maximum time, in microseconds, to wait for data. See Event-Driven Applications for details.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function reads a previously acquired snapshot from the snapshot FIFO, consisting of the counts at a particular moment in time and the associated timestamp and reason flags. Each snapshot can be read only one time; when a snapshot is read, it is removed from the FIFO and cannot be read again.

Snapshots may be acquired in response to asynchronous events. In such cases, snapshots may occur at any time. However, if snapshots are not automatically acquired, or for some other reason it is necessary to invoke a snapshot under program control, the application program must call S826_CounterSnapshot to capture a new snapshot before calling this function to read the snapshot.

The reason flags indicate the type of event that caused the snapshot. If two or more simultaneous events would each cause a snapshot, all of the associated reason flags will be set.

Quadrature-encoded clocks are monitored for encoding errors as described in Quadrature Decoder. When an encoding error is detected, a snapshot is captured (with reason bit 8 set) and an internal error flag is set. While the error flag remains set, subsequent encoding errors will be ignored and will not trigger new snapshots (though other types of triggers will continue to cause snapshots). The error flag is automatically cleared when this function reads the error-triggered snapshot, or when the channel is halted, or when the snapshot FIFO becomes empty. The latter case ensures that the error flag will be cleared if the error-triggered snapshot is lost due to FIFO overflow.

This function can operate in either blocking or non-blocking mode, depending on the value of tmax. If tmax is zero, the function will return immediately. If tmax is greater than zero, the calling thread will block until a snapshot is available or tmax elapses. The function will return either S826_ERR_OK or S826_ERR_FIFOOVERFLOW if a snapshot was read, or S826_ERR_NOTREADY if no snapshot is available. S826_ERR_ FIFOOVERFLOW indicates that a snapshot was successfully read, but the channel's snapshot FIFO overflowed (one or more snapshots were lost); the FIFO overflow status will be automatically cleared when the function returns.

When this function is blocking, it will immediately return S826_ERR_CANCELLED if S826_CounterWaitCancel is called by another thread, or S826_ERR_BOARDCLOSED if S826_SystemClose is called. In either case, the counts, tstamp and reason values will be invalid.

7.3.2 S826_CounterWaitCancel

The S826_CounterWaitCancel function cancels a blocking wait on a counter channel.

```
int S826_CounterWaitCancel(
  uint board,    // board identifier
  uint chan      // channel number
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5, for which waiting is to be canceled.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function cancels blocking on a counter channel so that another thread, which is blocked by S826_CounterSnapshotRead while waiting for a snapshot, will return immediately with S826_ERR_CANCELLED.

7.3.3 S826_CounterCompareWrite

The S826_CounterCompareWrite function writes to a compare register.

```
int S826_CounterCompareWrite(
  uint board,    // board identifier
  uint chan,     // channel number
  uint regid,    // register identifier
  uint counts    // counts value
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

regid
Selects Compare register: 1 = Compare1 register, 0 = Compare0 register.

counts
Value to be written to the Compare register.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.4 S826_CounterCompareRead

The S826_CounterCompareRead function returns the contents of a compare register.

```
int S826_CounterCompareRead(
  uint board,    // board identifier
  uint chan,     // channel number
  uint regid,    // register identifier
  uint *counts   // counts value
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

regid
Selects Compare register: 1 = Compare1 register, 0 = Compare0 register.

counts
Pointer to a buffer that will receive the contents of the selected Compare register.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.5 S826_CounterSnapshot

The S826_CounterSnapshot function invokes an immediate snapshot.

```
int S826_CounterSnapshot(
  uint board,    // board identifier
  uint chan      // channel number
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function forces a snapshot to be captured immediately. It is typically used to capture a snapshot under program control prior to reading a counter. This is one of two methods of reading the core's instantaneous counts; the other method is S826_CounterRead. This function may be called at any time when the counter channel is running.

7.3.6 S826_CounterRead

The S826_CounterRead function reads the counter core's instantaneous counts.

```
int S826_CounterRead(
  uint board,    // board identifier
  uint chan,     // channel number
  uint *counts   // counts value
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

counts
Pointer to a buffer that will receive the instantaneous counts from the counter core.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function directly reads and returns the value currently stored in the counter core. If a timestamp is also needed, the application can call this function and also call S826_TimestampRead, or it may trigger a soft snapshot and then read the snapshot.

7.3.7 S826_CounterPreloadWrite

The S826_CounterPreloadWrite function writes to a preload register.

```
int S826_CounterPreloadWrite(
  uint board,   // board identifier
  uint chan,    // channel number
  uint reg,     // register identifier
  uint counts   // counts value
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

reg
Selects the preload register to write to: 0 = Preload0 register, 1 = Preload1 register.

counts
The 32-bit value to be written to the selected Preload register.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

The counts value is immediately written to the selected preload register when this function executes. The counter core is not affected until the next core preload occurs.

7.3.8 S826_CounterPreloadRead

The S826_CounterPreloadRead function reads a preload register.

```
int S826_CounterPreloadRead(
  uint board,   // board identifier
  uint chan,    // channel number
  uint reg,     // register identifier
  uint *counts  // counts value
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

reg
Selects the preload register to write to: 0 = Preload0 register, 1 = Preload1 register.

counts
Pointer to a buffer that will receive the counts from the selected Preload register.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.9 S826_CounterPreload

The S826_CounterPreload function manually invokes a core preload from the Preload0 register.

```
int S826_CounterPreload(
  uint board,   // board identifier
  uint chan,    // channel number
  uint level,   // preload signal level
  uint sticky   // make level "sticky"
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

level
Effective preload signal level: 1 = invoke preload, 0 =don't invoke preload. This is ignored if sticky=0.

sticky
Persistence: 1 = maintain level until reprogrammed, 0 = strobe trigger (level is ignored).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

If sticky is false, the level will be ignored. In this case, the channel's software preload command will be strobed active and then immediately return to its inactive state, thus causing Preload0 to be copied to the counter core.

If sticky is true, the specified level will be continuously applied to the channel's software preload command until changed by a subsequent call to this function. Typically, sticky will only be asserted if the counter is operating as a Pulse Generator, and only when output retriggering is enabled. When sticky and level are both '1', the counter will continuously preload from Preload0, thus causing the pulse output to go active and remain active until the function is called again to set the level to '0'; at that time, the counter will be allowed to resume counting.

7.3.10 S826_CounterStateWrite

The S826_CounterStateWrite function starts or stops channel operation.

```
int S826_CounterStateWrite(
  uint board,   // board identifier
  uint chan,    // channel number
  uint state    // channel state
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

state
Channel state: 0 = halted, 1 = running.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function is used to start and stop counter channel operation, thus placing the channel in either the “running” or “halted” state. A channel's operating mode should be configured before switching it to the running state; this is done by calling S826_CounterModeWrite. A channel will operate as specified by the mode register while it is in the running state.

In the halted state:

- Counting and preloading are not allowed.
- Counter core is reset to zero counts.
- Snapshot register is marked empty.
- Output is held inactive.
- Quadrature error is reset.

The mode, preload, compare, and snapshot configuration registers are not affected when a channel transitions between halted and running states. This function has no effect if used to start a channel that is already running, or to stop a channel that is already halted.

This function can be used to zero the counter core by calling it once to halt the channel (and zero the counts) and again to start the channel running. Another way to zero the counts is to zero to the Preload0 register (by calling S826_CounterPreloadWrite) and then transfer the preload value to the core (via S826_CounterPreload).

7.3.11 S826_CounterStatusRead

The S826_CounterStatusRead function returns information about a counter channel's status.

```
int S826_CounterStatusRead(
  uint board,    // board identifier
  uint chan,     // channel number
  uint *status   // channel status info
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

status
Pointer to a buffer that will receive the status:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	RUN	0	ST	0	0	0	0	0	0	0	0	0	0	PLS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Bit	Description
RUN	Channel enable: '1' = running, '0' = halted. This is controlled by S826_CounterStateWrite.
ST	Sticky preload command. This is controlled by S826_CounterPreload.
PLS	Preload selector. This indicates the active preload register: '1' = Preload1, '0' = Preload0. PLS can be '1' only if mode register bit BP=1 (see S826_CounterModeWrite).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.12 S826_CounterExtInRoutingWrite

The S826_CounterExtInRoutingWrite function selects the signal source for a counter channel's ExtIn input.

```
int S826_CounterExtInRoutingWrite(
  uint board,    // board identifier
  uint chan,     // counter channel number
  uint route     // routing configuration
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

route
Signal to be connected to ExtIn (this is ignored if mode register field IM=0):
0 to 47 = DIO channel 0 to 47;
48 to 53 = counter channel 0 to 5 ExtOut;
54 to 59 = virtual digital output channel 0 to 5.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function will route the counter channel's ExtIn input to a general-purpose digital I/O (DIO) channel so that an external signal (applied to the DIO channel's I/O pin) can control the channel's ExtIn input. Alternatively, the ExtIn input may internally routed to any counter channel's ExtOut output, or to any virtual digital output channel.

7.3.13 S826_CounterExtInRoutingRead

The S826_CounterExtInRoutingRead function returns a counter channel's ExtIn signal routing configuration.

```
int S826_CounterExtInRoutingRead(
  uint board,    // board identifier
  uint chan,     // counter channel number
  uint *route    // routing configuration
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

route
Pointer to buffer that will receive the ExtIn routing configuration. The format of the returned value is identical to the route argument used in the S826_CounterExtInRoutingWrite function.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.14 S826_CounterSnapshotConfigWrite

The S826_CounterSnapshotConfigWrite function programs the snapshot configuration register.

```
int S826_CounterSnapshotConfigWrite(
  uint board,    // board identifier
  uint chan,     // counter channel number
  uint cfg,      // snapshot configuration flags
  uint mode      // 0=write, 1=clear bits, 2=set bits
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

cfg

Flags with 'E' prefix determine the types of events that will capture snapshots: '1' = enable capturing, '0' = disable capturing. Each flag with 'R' prefix determines whether the corresponding 'E' flag will be automatically cleared upon snapshot capture, thus preventing subsequent events of that type from invoking snapshots.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	RER	REF	RXR	RXF	RZ	RM1	RMO	0	0	0	0	0	0	0	0	0	EER	EEF	EXR	EXF	EZ	EM1	EM0

Flag	Snapshot trigger event
ER	ExtIn leading edge
EF	ExtIn falling edge
XR	Index leading edge
XF	Index falling edge
Z	Zero counts reached
M1	Compare1 register matches counter core
M0	Compare0 register matches counter core

mode

Write mode for cfg: 0 = write, 1 = clear bits, 2 = set bits (see “Atomic Read-Modify-Write”).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function programs the snapshot configuration register. A snapshot will be captured when an 'E' flag is programmed to '1' and the corresponding event occurs. Upon snapshot capture, the associated 'E' flag will be automatically cleared if the corresponding 'R' flag is set.

Independent of these flags, snapshots may also be captured upon quadrature clock error or in response to calls to S826_CounterSnapshot.

7.3.15 S826_CounterSnapshotConfigRead

The S826_CounterSnapshotConfigRead function reads the snapshot configuration register.

```
int S826_CounterSnapshotConfigRead(
  uint board,    // board identifier
  uint chan,     // counter channel number
  uint *cfg      // configuration flags
);
```

Parameters

board

826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan

Counter channel number in the range 0 to 5.

cfg

Pointer to buffer that will receive the configuration flags. The format of the returned value is identical to the events value used in the S826_CounterSnapshotConfigWrite function. Note that 'E' flags (flags with 'E' name prefix) may be automatically reset in response to captured snapshots.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.16 S826_CounterFilterWrite

The S826_CounterFilterWrite function configures the IX, CLKA, and CLKB noise filters.

```
int S826_CounterFilterWrite(
  uint board,    // board identifier
  uint chan,     // counter channel number
  uint cfg       // filter configuration
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

cfg
Filter configuration:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
IX	CK	0														T															

Field	Description
IX	Enable IX filter: '1' = enable, '0' = disable.
CK	Enable CLKA/CLKB filters: '1' = enable, '0' = disable.
T	Filter time interval specified as multiple of 20ns, common to IX, CLKA and CLKB input filters.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

Each of the IX, CLKA, and CLKB input signals has a dedicated noise filter. This function enables and disables the filters and programs the filter time interval. The CLKA and CLKB filters are enabled or disabled as a group, whereas the IX filter is independently enabled or disabled. The filter time interval, T, is common to all enabled filters.

A filter's output will not change state until its input has held a constant state for T * 20ns. The maximum T value is 65535, corresponding to a filter time of 1.3107ms. When a filter is enabled, it will delay its input signal by T * 20ns. Note that when the noise filter is enabled for the CLKA/CLKB inputs (CK = '1'), the counter's maximum clock frequency is reduced; the maximum frequency reduction is inversely proportional to T.

7.3.17 S826_CounterFilterRead

The S826_CounterFilterRead function reads the configuration of the IX, CLKA, and CLKB noise filters.

```
int S826_CounterFilterRead(
  uint board,    // board identifier
  uint chan,     // counter channel number
  uint *cfg      // filter configuration
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

cfg
Pointer to buffer that will receive the configuration. The format of the returned value is identical to the cfg value used in the S826_CounterFilterWrite function.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.18 S826_CounterModeWrite

The S826_**Counter**ModeWrite function configures a counter channel's operating mode.

```
int S826_CounterModeWrite(
  uint board,    // board identifier
  uint chan,     // channel number
  uint mode      // operating mode
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

mode
Channel operating mode (see “Common Applications” for examples):

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	IP	IM		0	0	0	TP	NR	UD	BP	OM			OP	TP						TE		TD		K			XS			

IP	ExtIn signal polarity. This is ignored if IM=0.
0	Normal polarity.
1	Inverted polarity.

IM	ExtIn mode. If IM>0 then ExtIn is routed to a DIO pin as specified by S826_CounterExtInRoutingWrite.
0	ExtIn input is not used. The counter's ExtIn input will effectively be hardwired to logic '1'.
1	ExtIn input is a count enable permissive. This is typically used with incremental encoders and event counting, with ExtIn acting as a count enable.
2	ExtIn input is a preload enable permissive. This is typically used when operating as a pulse generator, with ExtIn used as a pulse trigger.

TP bit	Preload enables. Determines event(s) that will cause a preload register to be copied to the counter. Each bit enables preloads for one type of event: ‘1’ = enable, ‘0’ = disable.
24	Preload upon start (when channel switches from halted to running)
16	Preload upon Index active level.
15	Preload upon Index leading edge.
14	Preload upon Index falling edge.
13	Preload upon zero counts reached.
12	Preload when Compare1 matches the counter core.
11	Preload when Compare0 matches the counter core.

NR	Preload permissive. Typically used for “one-shot” pulse generator applications.
0	Allow preloading any time. This can be used for applications such as a retriggerable one-shot.
1	Allow preloading only when counts equal zero. This can be used for applications such as a non-retriggerable one-shot. This applies to both hardware- and software-induced (via S826_CounterPreload function) preloads.

UD	Count direction
0	Normal count direction.
1	Reverse count direction.

BP	Preload toggle enable.
0	Use only Preload0. The Preload1 register will not be used.
1	Use both preload registers. This is typically used for PWM output.

OM	ExtOut mode. Determines when the channel's ExtOut output signal is active. The ExtOut signal may be routed to a DIO pin by calling S826_DioOutputSourceWrite.
0	Output always inactive.
1	Output pulses active upon Compare register snapshot.
2	Output active when Preload1 register is selected. This is typically used for PWM output.
3	Output active when the counts are not zero; useful for pulse generator applications.
4	Output active when the counts are zero; useful for watchdog timer applications.

OP	ExtOut signal polarity.
0	Normal polarity
1	Inverted

TE	Count enable trigger. Determines event(s) that will cause counting to be enabled.
0	Enable counting at start-up (i.e., when S826_CounterModeWrite is called to switch to running mode).
1	Enable counting upon Index leading edge.
2	Enable counting upon preload.
3	reserved -- do not use.

TD	Count disable trigger. Determines event(s) that will cause counting to be disabled.
0	Never disable counting.
1	Disable counting upon Index falling edge.
2	Disable counting upon zero counts reached.
3	reserved -- do not use

K	Clock mode.
0	External single-phase clock, increment on ClkA rising edge.
1	External single-phase clock, increment on ClkA falling edge.
2	Internal 1 MHz clock, increment every microsecond.
3	Internal 50 MHz clock, increment every 40 nanoseconds.
4	Link to adjacent channel's overflow/underflow outputs to this channel's overflow/underflow inputs (see “Cascading”). The adjacent channel's overflow/underflow output signals will cause this channel to increment/decrement. For channel 0, channel 5 is the adjacent channel; for all other channels N, the adjacent channel is N-1.
5	External quadrature clock, x1 multiplier.
6	External quadrature clock, x2 multiplier.
7	External quadrature clock, x4 multiplier.

XS	Index source.
0	External IX input, normal polarity.
1	External IX input, inverted.
2-7	ExtOut from counter channel 0-5 (e.g., 3 = ExtOut from channel 1).
8-15	Internal tick generator: 8 = 0.1 Hz, 9 = 1 Hz, 10 = 10 Hz, 11 = 100 Hz, 12 = 1 KHz, 13 = 10 KHz, 14 = 100 KHz, 15 = 1 MHz.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.19 S826_CounterModeRead

The S826_**Counter**ModeRead function returns a counter channel's operating mode.

```
int S826_CounterModeRead(
  uint board,    // board identifier
  uint chan,     // channel number
  uint *mode     // operating mode
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chan
Counter channel number in the range 0 to 5.

mode
Buffer that will receive the channel operating mode, as defined in "S826_CounterModeWrite".

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

7.3.20 Common Applications

This section shows simple examples of how to configure and operate counter channels for common applications. In most cases there are other ways to configure the counters to achieve similar functionality, and numerous variations are possible that are not discussed here.

Encoder Interface

Monitor a quadrature-encoded device (e.g., incremental encoder) using x4 clock multiplier. Capture a snapshot at any time by calling S826_CounterSnapshot.

Register	Value
Mode	0x00000070

Event Counter

Count pulses applied to the ClkA input. Capture a snapshot at any time by calling S826_CounterSnapshot. Reset the counts to zero by calling S826_CounterPreload.

Register	Value
Mode	0x00000000
Preload0	0x00000000

Periodic Timer

Periodically capture snapshots.

Register	Value
Mode	0x00402020
Snapshot Configuration	0x00000004
Preload0	Period in µs

Delay Timer

Call S826_CounterPreload to start the timer, then S826_CounterSnapshotRead to wait for the delay time to elapse.

Register	Value
Mode	0x00400520
Snapshot Configuration	0x00000004
Preload0	Delay in µs

Frequency Measurement

Measure frequency by counting clocks applied to the ClkA input for one second intervals. At the end of each interval, a snapshot is captured and the next measurement begins automatically. The snapshot counts indicate measured frequency in Hz.

Register	Value
Mode	0x00008009
Snapshot Configuration	0x00000010
Preload0	0x00000000

Period Measurement

Measure the period of a signal applied to the IX input by counting internal clocks during one input cycle. At the end of each cycle, a snapshot is captured and the next measurement begins automatically. The snapshot counts indicate measured period in µs.

Register	Value
Mode	0x00008020
Snapshot Configuration	0x00000010
Preload0	0x00000000

Pulse Width Measurement

Measure the width of pulses applied to the IX input by counting internal clocks during one pulse. At the end of each pulse, a snapshot is captured and the next measurement begins automatically. The snapshot counts will indicate the measured pulse width in µs.

Register	Value
Mode	0x00008020
Snapshot Configuration	0x00000009
Preload0	0x00000000

Pulse Generator

Generate an output pulse on ExtOut in response to a trigger signal applied to the IX input. Also, a software trigger can be invoked by calling S826_CounterPreload. ExtOut must be routed to a DIO channel (see S826_DioOutputSourceWrite).

Register	Value
Mode	0x004C0520 (retriggerable), or 0x00CC0520 (non-retriggerable)
Preload0	Pulse duration in µs

PWM Generator

Output a pulse width modulation (PWM) signal on ExtOut, which must be routed to a DIO channel through the DIO_out signal routing matrix (see S826_DioOutputSourceWrite).

Register	Value
Mode	0x01682020
Preload0	PWM “on” time in µs
Preload1	PWM “off” time in µs

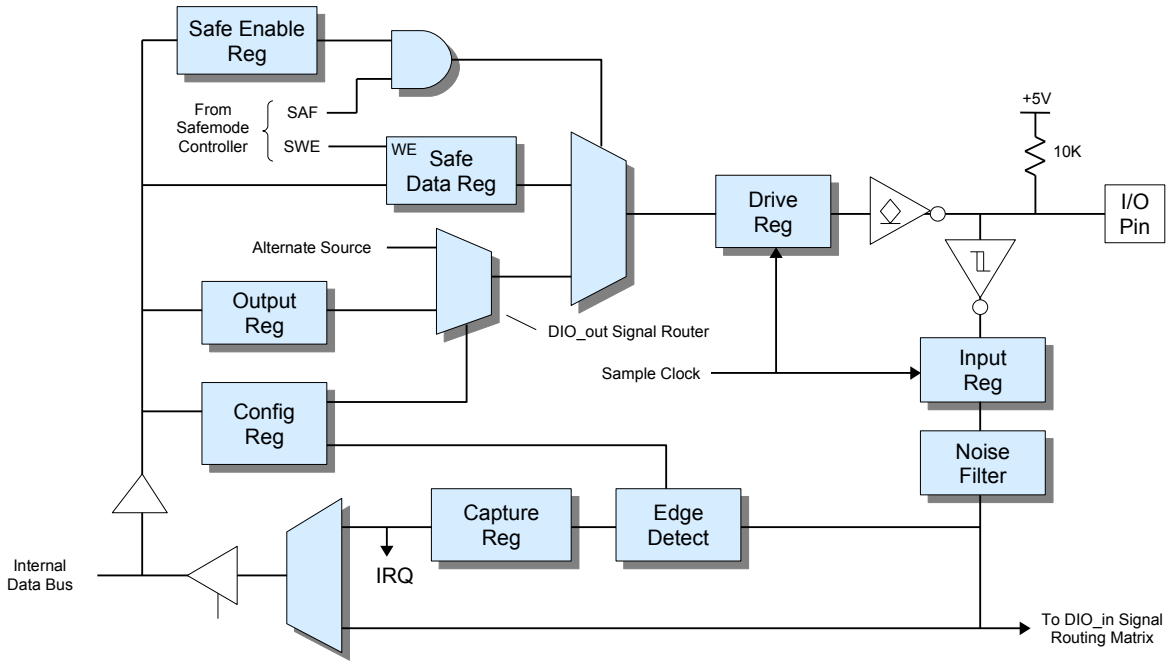
Synchronized PWM generators can be implemented by configuring the PWM channels as hardware triggered one-shots (pulse generators). Use an additional channel to generate a common trigger for the PWM channels; this channel should be configured to generate periodic output pulses at the desired PWM frequency. The duty cycle of each PWM channel is controlled by adjusting its output pulse width.

Chapter 8: Digital I/O

8.1 Introduction

The 826 board has 48 general-purpose digital I/O (DIO) channels. On the output side, each channel has a one-bit, writable output register, a synchronous drive register, and an inverting open-drain buffer that drives the channel's I/O pin. The open-drain buffer enables the pin to be driven low by the channel's output buffer or by an external signal. The pin, when not driven, is pulled up to +5V by a 10 kohm resistor. The output is high impedance when the board is unpowered so as to prevent unintended activation of an external solid state relay, if one is connected. The pin's physical state is sampled by an input register and then processed by a noise/debounce filter. The filter output is monitored by an edge detector and can also be directly read by the host computer.

Figure 7: DIO channel (1 of 48)



DIO signals are active-high on the local bus and active-low on the I/O pin. Writing a '1' to the output register causes the I/O pin to be driven low, whereas writing '0' allows the pin to be internally pulled up or driven high or low by an external circuit. Logic '0' must be written to the output register if the pin will be driven high by an external circuit; this will prevent high currents that could potentially damage the pin's output buffer.

The value read from a DIO channel indicates the filtered, sampled physical state of the I/O pin. If no external signals are driving the pin then the read value will equal the value stored in the drive register. The read value will differ from the drive register value if the drive register contains '0' while an external circuit drives the pin low.

Most of the host-accessible DIO registers support masked write operations so as to implement the atomic bit set and clear functions required for high performance, thread-safe operation.

8.1.1 Signal Routing Matrix

Each DIO channel connects to the board's internal signal routing matrix as shown in Figure 7. The matrix can be programmed to route the DIO connector pin to or from another interface (e.g., counter, watchdog, analog input system) so that the pin will act as a physical input or output for that interface.

The channel's DIO_out signal router consists of a data selector that can route either the DIO output register or an alternate source to the I/O pin. The pin will function as a general-purpose digital output when the DIO output register is selected. If the alternate source is selected, the pin state will be controlled by the alternate signal, but all DIO input functions (read, edge detection) will continue to operate normally. Each DIO is associated with a specific alternate source as explained in S826_DioOutputSourceWrite.

The DIO_in routing matrix connects the sampled DIO pin signal to other interfaces. The ADC trigger input and the six counter ExtIn inputs are connected to the DIO_in matrix so that any of these signals can be sourced from a DIO pin. When a DIO signal is routed to another interface via the DIO_in matrix, all of the DIO channel's input and output functions will continue to operate normally.

8.1.2 Safemode

Safemode is activated when the SAF signal (see Figure 7) is asserted. When operating in safemode, the DIO pin state is determined by the Safe Enable and Safe Data registers: when Safe Enable equals '1', the pin will be driven to the fail-safe value stored in Safe Data; when Safe Enable equals '0' the pin will output its normal runmode signal.

Upon board reset, the Safe Enable register is set to '1' so that the DIO pin will exhibit fail-safe behavior by default (i.e., it will output the contents of the Safe Data register when SAF is asserted). Fail-safe operation can be disabled for a DIO pin by programming its Safe Enable register to '0'.

The Safe Data register is typically programmed once (or left at its default value) by the application when it starts, though it may be changed at any time if required by the application. It can be written to only when the SWE bit is set to '1'. See “Safemode Controller” for more information about safemode.

8.1.3 Edge Capture

Every DIO channel includes an edge detection circuit and a capture flag register. When edge capturing is enabled, a channel's capture flag will be set when an edge is detected on its I/O pin. Each channel may be programmed to capture rising edges, falling edges, or both edges, or capturing may be disabled.

The API allows capture flags to be monitored by polling or, if the application is event driven, the calling thread can block while it waits for captured events. When blocking on edge capture events, the calling thread can specify a set of capture flags to wait for, and it can wait for either all of the events or any one event in the set.

When read by the host, capture flags are reset but remain enabled to capture future events. Edge events that occur on a channel while its capture flag is set will be lost. An input signal must hold for at least 20 ns after a transition for the transition to be reliably detected.

8.1.4 Pin Timing

The DIO subsystem is a fully synchronous system that is controlled by a 50 MHz sampling clock. The DIO pin drivers are updated and pin receivers are sampled once per cycle. As a result, outputs cannot change faster than the cycle time and inputs cannot be sampled faster than the cycle time.

Output registers are organized as two 24-channel groups. When these registers are written (via S826_DioOutputWrite), channels 0-23 will change simultaneously and channels 24-47 will also change simultaneously, but these two 24-channel groups are not guaranteed to change output states at the same time. Also, a DIO pin does not change output state immediately when its signal source (DIO output register or counter ExtOut) changes; it will be delayed for 20 ns due to the sampling clock.

When used as inputs, all 48 DIO channels are sampled simultaneously every 20 ns. As a result, the received signal on a DIO pin may be delayed up to 20 ns en route to its destination (e.g., DIO edge detector or read data, counter ExtIn input, or ADC trigger input), and input signal pulses shorter than 20 ns may not be recognized. The host reads pin states (via S826_DioInputRead) as two 24-channel groups (channels 0-23 and 24-47) in two separate read cycles. Consequently, channels within each group are guaranteed to be sampled simultaneously, but the two groups are not guaranteed to be associated with the same sample clock.

8.1.4.1 Noise Filter

Each DIO channel input circuit includes a noise filter that can be used to filter glitches (see S826_DioFilterWrite). A filter's output will change state only when its input has held constant for time T, the filter time interval. Consequently, when a DIO channel's filter is enabled, the sampled input signal will be delayed for an additional T * 20 ns en route to its destination, and input signal pulses shorter than T * 20 ns will not be recognized.

8.1.5 Reset State

DIO channels are forced to the following condition upon board reset:

- Output and Safe Data registers programmed to zero.
- Safe Enable registers programmed to all 1's.
- Output register is selected as I/O pin data source.
- Event capture disabled.

8.2 Connectors J2/J3

J2 Pinout - DIO channels 24-47

Pin	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	Even
DIO Channel	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	30	30	29	28	27	26	25	24	+5V	GND

J3 Pinout - DIO channels 0-23

Pin	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	Even
DIO Channel	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	+5V	GND

All even pin numbers on J2 and J3 connect to the power supply return. Odd pin numbers 1-47 are the active-low DIO channel I/O pins. Pin 49 is a +5V power output for low power loads such as solid state relay racks.

8.3 Programming

The DIO functions use individual bits to convey information about the DIO channels, wherein each bit represents the information for one channel. In such cases, the information for the 48 DIO channels is organized as an array of two bit quadlets (32-bit values), with each quadlet containing the information for 24 DIO channels:

The quadlet at array[0] is associated with DIO channels 0 to 23:

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIO	-	-	-	-	-	-	-	-	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

The quadlet at array[1] is associated with DIO channels 24 to 47:

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIO	-	-	-	-	-	-	-	-	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24

Typically, the DIO functions expect a pointer to a two-quadlet array, which must have been previously allocated by the program.

Although the DIO functions read or write values for all 48 DIO channels, the physical read or write operation is performed in steps; channels 0 to 23 first, as a group, and then channels 24 to 47 as another group. As a result, reads and writes do not sample or update all channels simultaneously. In general, channels 0 to 23 are sampled or updated concurrently as a group, and channels 24 to 47 are sampled or updated concurrently as a separate group.

8.3.1 S826_DioOutputWrite

The S826_DioOutputWrite function programs the DIO output registers.

```
int S826_DioOutputWrite(
  uint board,     // board identifier
  uint data[2],   // pointer to DIO data
  uint mode       // 0=write, 1=clear bits, 2=set bits
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to data array (see Section 8.3).

mode
Write mode for data: 0 = write, 1 = clear bits, 2 = set bits (see “Atomic Read-Modify-Write”).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

In mode zero, this function will unconditionally write new values to all DIO output registers. In modes one and two, the function will selectively clear or set any arbitrary combination of output registers; data bits that contain logic '1' indicate DIO output registers that are to be modified, while all other output registers will remain unchanged. Modes one and two can be used to ensure thread-safe operation as they atomically set or clear the specified bits.

8.3.2 S826_DioOutputRead

The S826_DioOutputRead function reads the programmed states of all DIO output registers.

```
int S826_DioOutputRead(
  uint board,    // board identifier
  uint data[2]   // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to a buffer (see Section 8.3) that will receive the output register states.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function returns the output register states. Note that the returned values may not be the same as the physical I/O pin states in the case of pins that are externally driven or routed to a counter channel's output signal.

8.3.3 S826_DioInputRead

The S826_DioInputRead function reads the physical states of all DIO channel I/O pins.

```
int S826_DioInputRead(
  uint board,    // board identifier
  uint data[2]   // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to a buffer (see Section 8.3) that will receive the physical I/O pin states.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function returns the sampled physical states of all DIO pins in the data buffer.

If this function is called immediately after calling S826_DioOutputWrite, the read data (sampled pin states) may not accurately reflect the previously written data. This happens because the DIO pins are driven by open-drain buffers with pull-up resistors. A pin will change state quickly when driven low, but when it is switched high, the state cannot change as quickly because additional time is required for the circuit capacitance to be charged through the pull-up resistor. The amount of time required for this depends on circuit capacitance; it can be shortened by decreasing the capacitance or by decreasing the pull-up resistance (by adding an external pull-up resistor).

In some applications, it may be desirable to have a DIO write function that will not return until all pins are stable. This can be implemented by calling S826_DioOutputWrite, and then polling with S826_DioInputRead until the expected states are read.

8.3.4 S826_DioSafeWrite

The S826_DioSafeWrite function programs the DIO Safe registers.

```
int S826_DioSafeWrite(
  uint board,     // board identifier
  uint data[2],   // pointer to safemode data
  uint mode       // 0=write, 1=clear bits, 2=set bits
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to data array (see Section 8.3) to be programmed into the Safe registers.

mode
Write mode for data: 0 = write, 1 = clear bits, 2 = set bits (see “Atomic Read-Modify-Write”).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function should only be called when the SWE bit is set (see S826_SafeWrenWrite). The function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1).

8.3.5 S826_DioSafeRead

The S826_DioSafeRead function returns the contents of the DIO Safe registers.

```
int S826_DioSafeRead(
  uint board,    // board identifier
  uint data[2]   // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to a buffer (see Section 8.3) that will receive the Safe register states.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

8.3.6 S826_DioSafeEnablesWrite

The S826_DioSafeEnablesWrite function programs the DIO Safe Enable registers.

```
int S826_DioSafeEnablesWrite(
  uint board,       // board identifier
  uint enables[2]   // pointer to safemode enables
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

enables
Pointer to array of values (see Section 8.3) to be programmed into the Safe Enable registers.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function should only be called when the SWE bit is set (see S826_SafeWrenWrite). The function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1).

8.3.7 S826_DioSafeEnablesRead

The S826_DioSafeEnablesRead function returns the contents of the DIO Safe Enable registers.

```
int S826_DioSafeEnablesRead(
  uint board,      // board identifier
  uint enables[2]  // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

enables
Pointer to a buffer (see Section 8.3) that will receive the Safe Enable register contents.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

8.3.8 S826_DioCapEnablesWrite

The S826_DioCapEnablessWrite function programs the edge sensitivity for DIO edge capturing.

```
int S826_DioCapEnablesWrite(
  uint board,       // board identifier
  uint rising[2],   // pointer to data buffer
  uint falling[2],  // pointer to data buffer
  uint mode         // write mode
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

rising
Pointer to a buffer (see Section 8.3) that specifies rising edge sensitivity: '1'=capture rising edges, '0'=don't capture rising edges.

falling
Pointer to a buffer (see Section 8.3) that specifies falling edge sensitivity: '1'=capture falling edges, '0'=don't capture falling edges.

mode
Write mode for rising/falling: 0 = write, 1 = clear bits, 2 = set bits (see “Atomic Read-Modify-Write”).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function specifies the edges to be captured on DIO channels. It defines the edge sensitivity for each DIO channel in terms of the I/O pin voltage. For example, if falling edge sensitivity is enabled, edge capturing will occur when the I/O pin voltage transitions from 5V to 0V.

When mode is zero, all data flags are directly written to the capture enable registers. In modes one and two, the data flags determine which of the 48 DIO channels are to be affected; any flag that contains a logic '1' will cause the associated channel to be affected, while '0' will leave the channel unmodified.

After capturing has been enabled, it will remain enabled until disabled by this function or a board reset. Capturing is disabled on all channels following a board reset.

8.3.9 S826_DioCapEnablesRead

The S826_DioCapEnablesRead function returns the programmed edge sensitivity for DIO edge capturing.

```
int S826_DioCapEnablesRead(
  uint board,       // board identifier
  uint rising[2],   // pointer to data buffer
  uint falling[2]   // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

rising
Pointer to a buffer (see Section 8.3) that receives rising edge sensitivity: '1'=capture rising edges, '0'=don't capture rising edges.

falling
Pointer to a buffer (see Section 8.3) that receives falling edge sensitivity: '1'=capture falling edges, '0'=don't capture falling edges.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function receives information about the types of edge events that will be captured, which were previously programmed by calling This function returns the sampled physical states of all DIO pins in the data buffer..

8.3.10 S826_DioCapRead

The S826_DioCapRead function waits for edge events on one or more DIO channels.

```
int S826_DioCapRead(
  uint board,         // board identifier
  uint chanlist[2],   // pointer to channel flags
  uint waitall,       // logic operator: 1=and (all), 0=or (any)
  uint tmax           // maximum time to wait
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chanlist
Pointer to channel flag bits (see Section 8.3). Upon entry, set flags indicate channels of interest. Upon exit, set flags indicate channels with captured edges.

waitall
Logic operator to apply to channels of interest: 1 = AND (return when all channels have events), 0 = OR (return when any channel has an event). This is ignored if tmax = 0.

tmax
Maximum time, in microseconds, to wait for the events of interest. See “Event-Driven Applications“ for details.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function waits for edge events to be captured on an arbitrary set of DIO channels (the “channels of interest”) and then returns information about the events. Event capturing must have been previously enabled for channels of interest by calling S826_DioCapEnablesWrite.

Before calling the function, one or more chanlist bits must be set to identify the channels of interest. The function will modify chanlist to indicate channels of interest that have captured events, and it will reset the capture flag registers for all such indicated channels, thus re-enabling event capturing on those channels.

The function operates in either blocking or non-blocking mode depending on the value of tmax. If tmax is zero (non-blocking mode), the function will return immediately. If tmax is greater than zero (blocking mode), the calling thread will block until the capture criteria is satisfied or tmax elapses. In either case, some channels of interest may have captured events while others may not have; these will be indicated by chanlist when the function returns.

In blocking mode, the capture criteria is specified by waitall. Depending on waitall, the function will wait for events to be captured on either any, or all channels of interest. When waitall is true, the function will return when all channels of interest have captured events. When waitall is false, the function will return when any channel of interest has captured an event. The function will return S826_ERR_NOTREADY if tmax elapses before the capture criteria is satisfied.

In non-blocking mode, waitall is ignored and the function will never return S826_ERR_NOTREADY.

This function will return S826_ERR_CANCELLED if, while it is blocking, another thread calls S826_DioWaitCancel to cancel waits on any of the blocking channels. It will return immediately if the wait criteria is completely satisfied due to the wait cancellations, otherwise it will continue to block and return when all remaining wait criteria is satisfied. S826_ERR_BOARDCLOSED will be returned immediately if S826_SystemClose executes while this function is blocking. In either case, chanlist will be invalid when the function returns.

Thread-safe operation is guaranteed if the channels of interest for any given thread do not coincide with those of another thread. For example, thread safety is assured if a thread designates channels 1 and 3-5 as channels of interest while another thread designates channels 2 and 9.

8.3.11 S826_DioWaitCancel

The S826_DioWaitCancel function cancels a blocking wait on one or more DIO channels.

```
int S826_DioWaitCancel(
  uint board,          // board identifier
  uint chanlist[2]     // pointer to channel flags
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

chanlist
Pointer to DIO channel flag bits (see Section 8.3) that indicate channels for which waiting is to be cancelled.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function cancels blocking for an arbitrary set of DIO channels so that another thread, which is blocked by S826_DioCapRead while waiting for DIO edge events to be captured, will return immediately with S826_ERR_CANCELLED.

8.3.12 S826_DioOutputSourceWrite

The S826_DioOutputSourceWrite function assigns the signal sources for all DIO pins.

```
int S826_DioOutputSourceWrite(
  uint board,     // board identifier
  uint data[2]    // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to a buffer (see Section 8.3) that specifies signal sources: 0=DIO output register, 1=alternate source.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function specifies the signal source that will be used to drive each DIO pin. Each DIO pin may be driven by its output register or by its alternate signal source. Upon board reset, all DIO channels assume their default configuration so that all DIO pins are driven by the DIO output registers (vs. alternate sources).

A DIO pin's signal source is determined by the corresponding bit in the data buffer. When the bit is set to '1' the pin will be driven by the channel's alternate signal source; when set to '0' (default) the pin will behave as a standard digital output, driven by the channel's output register.

The data[0] quadlet selects the signal sources for DIO channels 0 to 23:

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIO	-	-	-	-	-	-	-	-	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Src	-	-	-	-	-	-	-	-	NMI	RST	C5	C4	C3	C2	C1	C0	NMI	RST	C5	C4	C3	C2	C1	C0	NMI	RST	C5	C4	C3	C2	C1	C0

The data[1] quadlet selects the signal sources for DIO channels 24 to 47:

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
DIO	-	-	-	-	-	-	-	-	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24
Src	-	-	-	-	-	-	-	-	NMI	RST	C5	C4	C3	C2	C1	C0	NMI	RST	C5	C4	C3	C2	C1	C0	NMI	RST	C5	C4	C3	C2	C1	C0

Every DIO channel is associated with one of eight alternate signal sources as shown in the above tables. The tables use the following abbreviations for alternate signal sources:

Symbol	Signal Source
C0	Counter 0 ExtOut
C1	Counter 1 ExtOut
C2	Counter 2 ExtOut
C3	Counter 3 ExtOut
C4	Counter 4 ExtOut
C5	Counter 5 ExtOut
RST	Watchdog RST (Timer2) output
NMI	Watchdog NMI (Timer1) output

Examples:

- When data[1] bit 2 is set, DIO26 will be driven by the ExtOut signal from counter channel 2.
- When data[0] bit 14 is set, DIO14 will be driven by the Watchdog RST output signal.

Each of the eight alternate signal sources is associated with six DIO channels. For example, the watchdog RST signal is associated with DIO channels, 6, 14, 22, 30, 38, and 46. Typically, an alternate source is either not used or it is routed to one of its associated DIO pins, though it may be simultaneously routed to any combination of its associated pins.

This function should only be called when the SWE bit is set (see S826_SafeWrenWrite). The function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1).

8.3.13 S826_DioOutputSourceRead

The S826_DioOutputSourceRead function reads the signal sources assigned to all DIO channels.

```
int S826_DioOutputSourceRead(
  uint board,    // board identifier
  uint data[2]   // pointer to data buffer
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Pointer to a buffer (see Section8.3) that will receive the signal source assignments for all DIO channels.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

8.3.14 S826_DioFilterWrite

The S826_DioFilterWrite function configures the DIO input noise filters.

```
int S826_DioFilterWrite(
  uint board,       // board identifier
  uint interval,    // filter interval (T)
  uint enables[2]   // filter enable flags
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

interval
Filter time interval in range 1 to 65535, specified as a multiple of 20ns. This is common to all DIO channels.

enables
Pointer to a buffer (see Section 8.3) that specifies filter enables for the DIO channels: '1'=enable, '0'=disable.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

Each DIO has an input noise filter that can be independently enabled or disabled. This function selectively enables and disables the individual filters and programs the filter time interval T, which is common to all DIO filters.

A filter's output will not change state until its input has held a constant state for T * 20ns. The maximum T value is 65535, corresponding to a filter time of 1.3107ms. When a DIO channel's noise filter is enabled, its input signal will be delayed by T * 20ns and input pulses shorter than T * 20ns will not be recognized.

8.3.15 S826_DioFilterRead

The S826_DioFilterRead function reads the configuration of the DIO input noise filters.

```
int S826_DioFilterRead(
  uint board,       // board identifier
  uint *interval,   // filter interval (T)
  uint enables[2]   // filter enable flags
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

interval
Pointer to a buffer that will receive the filter time interval as described in S826_DioFilterWrite.

enables
Pointer to a buffer (see Section 8.3) that will receive filter enable flags for the DIO channels: '1'=enable, '0'=disable.

Return Values

If the function succeeds, the return value is zero.

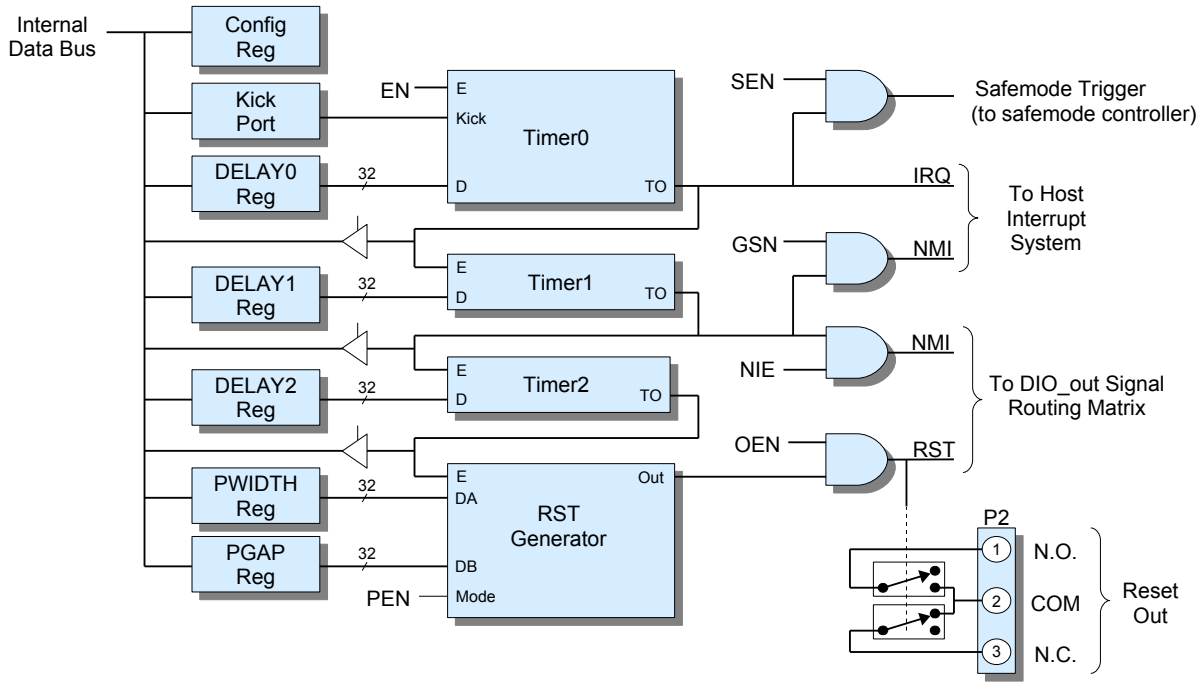
If the function fails, the return value is an error code.

Chapter 9: Watchdog Timer

9.1 Introduction

The model 826 board has a multistage watchdog timer that can activate the board's safemode system and generate service requests. The watchdog has three timer stages that generate timeout events in sequence according to user-defined timing. Each event is associated with an output signal. Typically, the event signals are utilized in such a way that successive events will generate service requests of progressively higher priority.

Figure 8: Watchdog system



9.1.1 Operation

When the watchdog system is disabled (default upon board reset), the three timers are halted and loaded from their associated DELAY registers. When the system becomes enabled (EN='1') by calling S826_WatchdogEnableWrite, initially only Timer0 is enabled so that it will count down towards zero while the other timers remain idle. During normal operation, the program regularly “kicks” the watchdog by writing to the Kick port, thus reloading Timer0 from DELAY0 before it can count down to zero.

If a fault condition prevents the program from kicking the watchdog, Timer0 will count down to zero and assert its timeout (TO) signal. After this event occurs, all subsequent kicks will be ignored. This event enables Timer1 and generates an interrupt request, and if SEN='1', it switches all control outputs to fail-safe states by triggering the safemode system. The program can wait for the interrupt by calling S826_WatchdogEventWait.

Timer1 asserts its TO signal upon counting down to zero. This event enables Timer2 and, if NIE='1', it asserts the NMI net of the DIO_out signal routing matrix, which in turn may route the net to a DIO pin (see S826_DioOutputSourceWrite). When GSN='1', a Timer1 event will cause the board to issue a PCI Express fatal error message; this can be used to generate a system non-maskable interrupt request if the system has been appropriately configured. Refer to your system documentation for information about generating NMI in response to a PCI Express fatal error message.

Timer2 asserts its TO signal upon counting down to zero, thus activating the RST signal generator. If OEN='1', the RST generator's output is routed to the RST net of the DIO_out signal routing matrix and to the board's Reset Out circuit. The RST generator can produce a continuous (non-pulsed) output or pulsed output. When generating a pulsed output, PWIDTH

determines the pulse duration and PGAP determines the gap time between pulses. The RST signal is not internally connected to the host computer's system reset input; if desired, this must be implemented by externally routing the selected DIO pin to the computer's reset input.

9.1.2 Reset Out Circuit

Two solid state relays (SSRs) are provided for controlling external reset circuits. Both SSRs are energized when the watchdog RST generator is asserting its output signal. One SSR has normally open contacts and the other normally closed contacts. The SSRs are galvanically isolated from other board circuitry.

9.1.3 Initialization

Before enabling the watchdog, the program must initialize it by writing to the configuration register and the five timing control registers (DELAY0-DELAY2, PWIDTH, and PGAP). This is done by calling S826_WatchdogConfigWrite. The DELAY registers determine the time intervals of their three associated timers, whereas the PWIDTH and PGAP registers determine the timing of the RST output signal.

9.2 Connector P2

Connector P2 interfaces external circuitry to the Reset Out solid state relay. Refer to the block diagram in section 9.1 for connector pinout.

9.3 Programming

9.3.1 S826_WatchdogConfigWrite

The S826_WatchdogConfigWrite function configures the watchdog system.

```
int S826_WatchdogConfigWrite(
  uint board,     // board identifier
  uint cfg,       // configuration flags
  uint timing[5]  // time intervals
);
```

Parameters

board

826 board number. This must match the settings of the board's dip switches as described in section 2.2.

cfg

Configuration flags: '1' = enable feature, '0' = disable feature.

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	GSN	0	SEN	NIE	PEN	0	OEN

Flag	Function
GSN	Generate host system NMI upon Timer1 event.
SEN	Activate safemode upon Timer0 event.
NIE	Connect Timer1 event signal to the DIO_out routing matrix NMI net.
PEN	Enable RST output to pulse (vs. continuous active level).
OEN	Connect RST generator to the DIO_out routing matrix RST net.

timing

Pointer to array of five quadlets that define the watchdog's time intervals. Each quadlet is written to one of the watchdog timing control registers as shown below. All times are specified as multiples of 20 nanoseconds. For example, use the value 50,000,000 for a one-second time interval.

Quadlet	Register	Function
timing[0]	DELAY0	Timer0 interval. The program must kick the watchdog within this interval to prevent a watchdog timeout. This must be set to a non-zero value; set to 1 for shortest possible delay.
timing[1]	DELAY1	Timer1 interval. This specifies the elapsed time from Timer1 timeout to Timer2 timeout. This must be set to a non-zero value; set to 1 for shortest possible delay.
timing[2]	DELAY2	Timer2 interval. This specifies the elapsed time from Timer2 timeout to RST generator enable. This must be set to a non-zero value; set to 1 for shortest possible delay.
timing[3]	PWIDTH	RST pulse width. This is ignored if PEN='0'.
timing[4]	PGAP	Time gap between RST pulses. This is ignored if PEN='0'.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function programs the watchdog configuration register and timing control registers. To ensure reliable operation, it should be called only when the watchdog is disabled.

The function should only be called when the SWE bit is set (see S826_SafeWrenWrite). The function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1).

9.3.2 S826_WatchdogConfigRead

The S826_WatchdogConfigRead function reads the watchdog configuration.

```
int S826_WatchdogConfigRead(
  uint board,     // board identifier
  uint *cfg,      // configuration flags
  uint timing[5]  // time intervals
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

cfg
Pointer to buffer that will receive the watchdog configuration flags.

timing
Pointer to array of five quadlets that will receive the watchdog time intervals.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

See Section 9.3.1 for details about the returned cfg and timing values.

9.3.3 S826_WatchdogEnableWrite

The S826_WatchdogEnableWrite function enables or disables the watchdog system.

```
int S826_WatchdogEnableWrite(
  uint board,    // board identifier
  uint enable    // enable watchdog when true
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

enable
Set to '1' to enable, or '0' to disable the watchdog. The watchdog is disabled by default upon board reset.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function should only be called when the SWE bit is set (see S826_SafeWrenWrite). The function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1).

9.3.4 S826_WatchdogEnableRead

The S826_WatchdogEnableRead function returns the enable status of the watchdog system.

```
int S826_WatchdogEnableRead(
  uint board,    // board identifier
  uint *enable   // enable status
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

enable
Buffer that will receive the watchdog system enable status: '1' = enabled, '0' = disabled.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

9.3.5 S826_WatchdogStatusRead

The S826_WatchdogStatusRead function reads the watchdog timeout status.

```
int S826_WatchdogStatusRead(
  uint board,       // board identifier
  uint *status      // watchdog status
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

status
Pointer to a quadlet buffer that will receive the watchdog status. Each status bit indicates the timeout status of one watchdog timer stage ('1' = timed out):

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	TO2	TO1	TO0

Flag	Function
TO2	Timer2 timeout
TO1	Timer1 timeout
TO0	Timer0 timeout

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

9.3.6 S826_WatchdogKick

The S826_WatchdogKick function reads the watchdog timeout status.

```
int S826_WatchdogKick(
  uint board,      // board identifier
  uint data        // valid signature
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

data
Valid signature. This must be 0x5A55AA5A to kick the watchdog; any other value will fail to kick the watchdog, although no error will be returned.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

When the watchdog system is running, the program should call this function to prevent a watchdog timeout. The DELAY0 value determines how often this function must be called to prevent a timeout.

9.3.7 S826_WatchdogEventWait

The S826_WatchdogEventWait function waits for a watchdog event (timeout) on Timer1.

```
int S826_WatchdogEventWait(
  uint board,     // board identifier
  uint tmax       // maximum time to wait
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

tmax
Maximum time, in microseconds, to wait for data. See “Event-Driven Applications” for details.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function can operate in either blocking or non-blocking mode. If tmax is zero, the function will return immediately. If tmax is greater than zero, the calling thread will block until a watchdog event or tmax elapses. The function will return zero if a watchdog timeout event occurred, or S826_ERR_NOTREADY if the watchdog has not timed out.

When this function is blocking, it will return immediately with return code S826_ERR_CANCELLED if S826_WatchdogWaitCancel is called by another thread, or with S826_ERR_BOARDCLOSED if S826_SystemClose is called by another thread.

9.3.8 S826_WatchdogWaitCancel

The S826_WatchdogWaitCancel function cancels a blocking wait on watchdog Timer1.

```
int S826_WatchdogWaitCancel(
  uint board    // board identifier
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

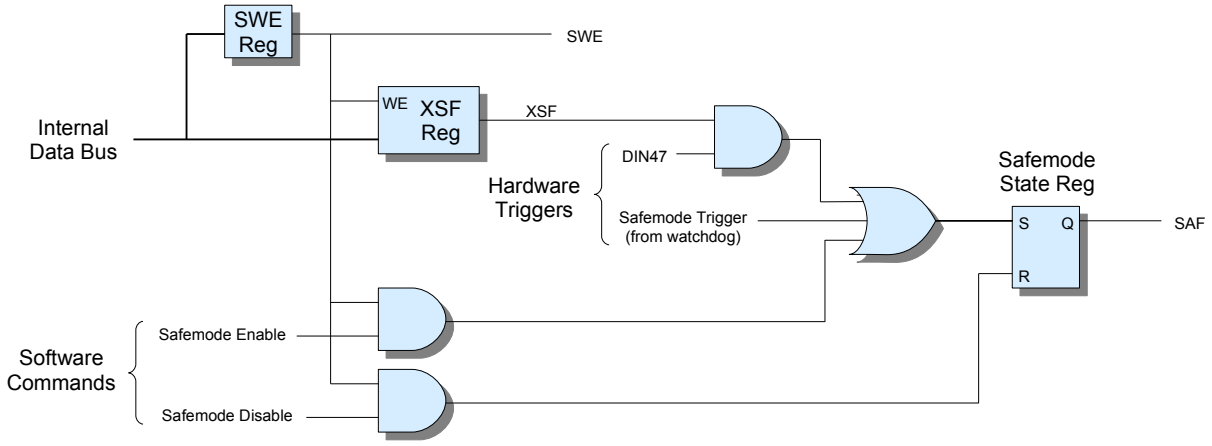
This function cancels blocking on the watchdog so that another thread, which is blocked by S826_WatchdogEventWait while waiting for a watchdog timeout event, will return immediately with S826_ERR_CANCELLED.

Chapter 10: Safemode Controller

10.1 Introduction

The 826 board features a fail-safe controller that forces analog and digital outputs to predetermined levels in response to hardware triggers. The controller works in concert with the watchdog timer and external devices such as emergency shutdown contacts to switch the board's outputs to fail-safe levels without software intervention.

Figure 9: Safemode Controller



The controller consists of configuration (XSF) and write protection control (SWE) registers, triggering logic, and a state register. When safemode is active (SAF = '1'), the board's analog and digital outputs are automatically switched to their fail-safe states. SAF can be set by the program and in response to hardware triggers, but only the program can reset SAF to turn off safemode. Upon power-up or board reset, SAF is reset.

If the watchdog is allowed to activate safemode (see S826_WatchdogConfigWrite), it will assert the Safemode Trigger signal upon Timer0 event, thus setting SAF. Once asserted, the trigger will remain asserted until the watchdog is disabled. Consequently, the program cannot reset SAF until the watchdog is disabled.

When XSF = '1', safemode can be triggered by an active-low signal applied to the DIO channel 47 connector pin (DIO47). When this happens, the program cannot reset SAF until DIO47 is negated or XSF is cleared.

Additional information about safemode can be found in Section 6.1.1 (analog outputs) and Section 8.1.2 (DIO outputs).

10.1.1 Write Protection

The SWE register controls write protection for registers associated with the watchdog and safemode controller. All affected registers are write-protected when SWE = '0'; this is the default state of SWE at power-up and upon system reset. The SWE register state does not change when the board is opened or closed.

Before writing to protected registers, the program must set SWE (by calling S826_SafeWrenWrite) to allow writes to the registers. During initialization, the program will typically disable write protection, write all fail-safe states as required by the application, and then re-enable write protection to prevent modification of the registers due to subsequent wayward software execution.

Several of the API functions write to SWE protected registers. These functions can fail without notification if called while SWE = '0' (they will return S826_ERR_OK if no other errors are detected, but the protected register will not be written). If it is necessary to detect a failed write to a write-protected register, the program should read the register after writing to it and compare the read and written values; a failed write is indicated when the read and written values are not equal. Each of the write functions has a corresponding read function that can be used to read back the programmed register state; these are not affected by the state of the SWE register.

These API functions write to SWE protected registers:

- S826_DacRangeWrite and S826_DacDataWrite (when safemode argument = '1')
- S826_DioOutputSourceWrite, S826_DioSafeWrite, and S826_DioSafeEnablesWrite
- S826_WatchdogConfigWrite, S826_WatchdogEnableWrite
- S826_SafeControlWrite
- S826_VirtualSafeWrite and S826_VirtualSafeEnablesWrite

10.2 Programming

10.2.1 S826_SafeControlWrite

The S826_SafeControlWrite function programs the board's fail-safe configuration and state.

```
int S826_SafeControlWrite(
  uint board,     // board identifier
  uint settings,  // safemode settings
  uint mode       // write mode
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

settings
Safemode configuration and state bits:

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	XSF	0	SAF	0

Bit	Function
XSF	DIO47 trigger enable. Programmed to '0' upon reset. When '1', a low level (0 volts) on the DIO channel 47 header pin will set the SAF bit. When '0', DIO47 will not affect the SAF bit. When XSF=1, a thread can block on DIO47 falling edge events to receive notification when safemode is triggered. Alternatively,the program can poll SAF.
SAF	Safemode state. Programmed to '0' upon reset. '1' = safemode active, '0' = runmode active. This can be written by the application program. This bit can also be set by DIO47 when XSF=1, or by a timeout event on watchdog Timer0.

mode
Write mode: 0 = write, 1 = clear bits, 2 = set bits (see “Atomic Read-Modify-Write”).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

This function should only be called when the SWE bit is set (see S826_SafeWrenWrite). The function will fail without notification (return S826_ERR_OK) if SWE=0 (see Section 10.1.1).

10.2.2 S826_SafeControlRead

The S826_SafeControlRead function returns the board's fail-safe configuration and state.

```
int S826_SafeControlRead(
  uint board,     // board identifier
  uint *settings  // safemode settings
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

settings
Pointer to buffer that will receive the safemode configuration and state as detailed in S826_SafeControlWrite.

mode
Write mode: 0 = write, 1 = clear bits, 2 = set bits (see “Atomic Read-Modify-Write”).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

10.2.3 S826_SafeWrenWrite

The S826_SafeWrenWrite function enables or disables write protection for safemode-related registers.

```
int S826_SafeWrenWrite(
  uint board,     // board identifier
  uint wren       // write enable/disable
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

wren
1 = write protect (default upon board reset), 2 = write enable, other values have no effect. When writes are disabled (write protected), attempts to write to protected registers will without notification (return S826_ERR_OK).

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Remarks

See “Write Protection” for a list of registers that are write protected/enabled by this function.

10.2.4 S826_SafeWrenRead

The S826_SafeWrenRead function returns the board's fail-safe configuration and control settings.

```
int S826_SafeWrenRead(
  uint board,     // board identifier
  uint *wren      // write protection status
);
```

Parameters

board
826 board number. This must match the settings of the board's dip switches as described in section 2.2.

wren
Pointer to buffer that will receive the write protection status: 0 = write protected, 2 = write enabled.

Return Values

If the function succeeds, the return value is zero.

If the function fails, the return value is an error code.

Chapter 11: Specifications

Digital I/O		
Channels	Number/type	48 bi-directional
	Signal levels	5 V TTL/CMOS
	Sampling rate	50 Ms/s
Output	Driver type	Open drain, active-low sink driver
	Internal pull-up impedance	10 kΩ, 5%
	On-state sink current (maximum)	24 mA
	Sink current when board unpowered	< 20 µA
	Fail-safe mode	Yes
Input	Receiver type	Schmitt trigger
	Noise/debounce filter	Interval: 0 to 1.3107 ms in 20 ns steps, common to all channels. Enable/disable: per channel.

Counters		
Channels	Number/type	6 multifunction
	Resolution	32 bits
	Count rate (maximum)	25 MHz (external clock), 50 MHz (internal clock)
	Operating modes	Incremental encoder, event counter, frequency counter, pulse width measure, PWM generator, pulse generator, custom
Clock frequency	Internal	50 MHz, 50 ppm
	External (maximum)	Derate for deviations from 50% duty cycle: 6.25 MHz @ quadrature x4 12.5 MHz @ quadrature/mono x2 25 MHz @ quadrature/mono x1
Inputs (CLK, IX)	Receiver type	RS-422 differential
	Signal levels	Differential: RS-422, ±7 V CMV maximum Single ended: 5 V TTL/CMOS
	Noise/debounce filter	Interval: 0 to 1.3107 ms in 20 ns steps, common per channel. Enable/disable: independent IX, CLK pair.

Analog Inputs		
Channels	Number/type	16 differential
ADC	Resolution	16 bits
	Conversion time	≤ 3 µs
Input	Differential voltage measurement ranges	±1 V, ±2 V, ±5 V, ±10 V
	Absolute input voltage (signal + CMV, max)	±11 V off GND
	CMRR	> 80 dB @ 1 kHz, > 65 dB @ 10 kHz
	Input impedance	>10 MΩ in parallel with 100 pF
	Settling time for multichannel measurements	4µs max. @ < 1 kΩ input Z with no gain change
Triggering	Modes	Hardware: 48 external digital inputs, 6 internal counter outputs. Software: 6 virtual digital outputs. Untriggered (free-running).

Analog Outputs		
Channels	Number/type	8 single ended, with local (on-board) sense
DAC	Resolution	16 bits
	Conversion time (serializer transmission + analog conversion)	1.04 µs
Output	Voltage ranges	0 to +5 V, 0 to +10 V, ±5 V, ±10 V
	Load current (maximum)	2 mA
	Fail-safe mode	Yes

Watchdog Timer		
Timer stages	Number	3
	Interval (per stage)	Programmable from 1 to 2^{32}-1 * 20 ns (20 ns to ~85.9 s)
	Output events	Stage 0: Fail-safe trigger, IRQ Stage 1: NMI out via digital output, PCIe Fatal Error Stage 2: Reset via digital output or onboard solid state relay (SSR)
Solid state relay (Reset out)	On-state resistance (I_L = 10mA)	20 ohms typical, 30 Ω max.
	Off-state leakage current	0.03 µA typical, 1.0 µA max.
	Applied voltage (maximum)	200 V
	Load current (maximum)	100 mA

Power and Environmental		
Power	Input power	350 mA (+12V) and 450 mA (+3.3V), nominal, with no loads
	Encoder power out	5 VDC ±5%, 400 mA max. (total for all encoders)
Temperature	Operating	0 to 70°C
Mating Connectors (not included)	Counters	Sullins SFH210-PPPC-D13-ID-BK or equivalent (qty. 2)
	Analog I/O	Sullins SFH210-PPPC-D25-ID-BK or equivalent (qty. 1)
	Digital I/O	Sullins SFH210-PPPC-D25-ID-BK or equivalent (qty. 2)

Appendix C: Linux CNC

LinuxCNC User Manual Download

Appendix D: Visual Studio 2013 on the 826i

How to Create a New Project in Visual Studio 2013 on the 826 board

Creating a Program in C

Our group is doing all of our coding is C, and since VS doesn't have C as one of its default languages, special care should be taken when setting up a new project to be sure that it will compile in C.

1. Open VS
2. Select File -> New -> Project
3. When the New Project dialog box appears, select Visual C++ in the left pane.
4. In the Project window, select Win32 Console Application.
5. Name to Project.
6. When the Win32 Application Wizard box appears, click Next on the Welcome Page.
7. On the Application Settings, make sure the following are selected:
    a. Application Type: Console Application
    b. Additional Options: Empty Project
8. Click Finish

You now have a C project. Now we need to make the C files:

1. If Solution Explorer is not visible, go to View -> Solution Explorer.
2. Right click the Source Files folder in the Solution Explorer and select Add -> New Item
3. The New Item dialog box should appear.
4. Select C++ File(.cpp) and give it a name, but be sure to add the .c extension (for example, your file name might be 826controller.c)
5. Your source file is now in C, and you can start programming.

Compiling the Program

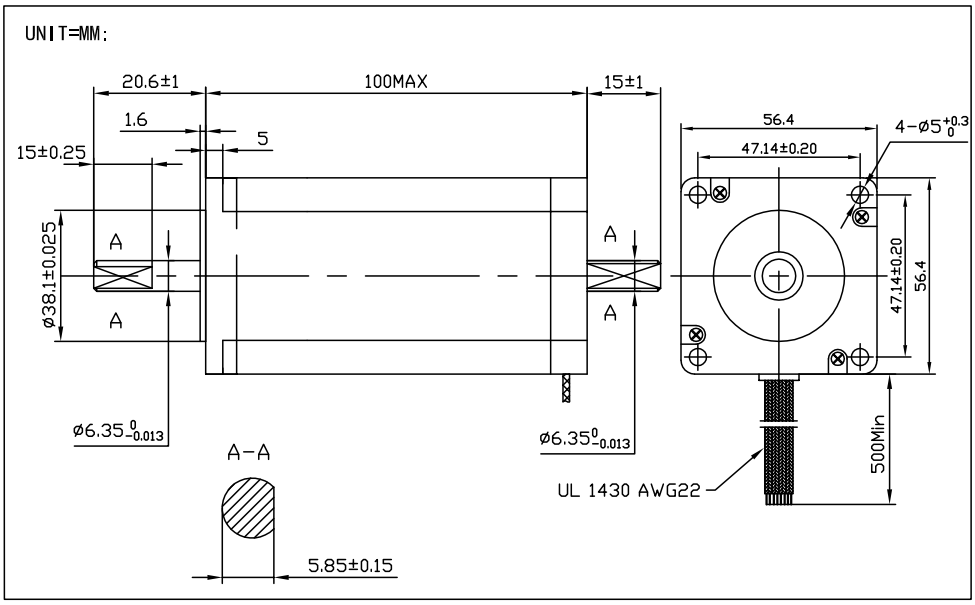
The only thing that needs to be done differently that compiling a normal program in VS is you need to add the DLL .lib file so VS can call on all the board's functions.

1. Click on Debug from the menubar and select "Project Name" Properties
2. When the dialog box opens, expand Linker on the left pane
3. Click on General
    a. On the right hand side find Additional File Directories and click the down arrow on the far right to edit.
    b. Type (or paste) in the address to the file where the .lib and .dll files are located.
4. Click on Input on the left pane
    a. Select Additional Dependencies and click the down arrow to edit
    b. Type (or paste) in the address of the .lib file
5. Close the Properties dialog box.
6. Your program is now ready to compile and talk to the 826 board

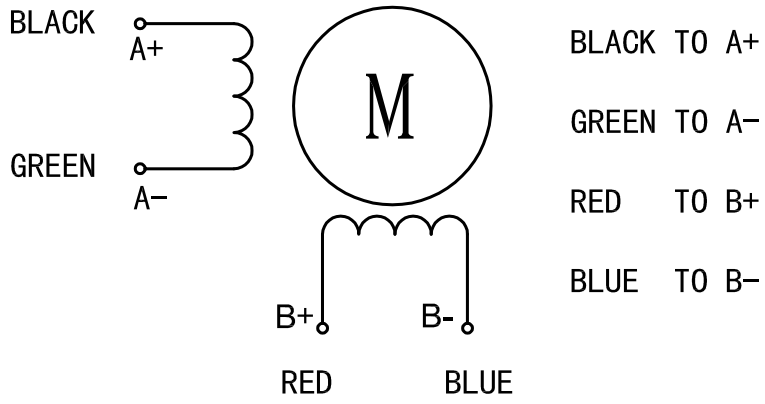
Appendix E: Stepper Motor and Driver

Hybrid Stepper Motor

KL23H2100-35-4B



PHASE	STEP ANGLE	RATED VOLTAGE	CURRENT	RESISTANCE	INDUCTANCE	HOLDING TORQUE	WEIGHT
	DEG/STEP	V	A	ohms	mH	OZ-IN	Kg
2	1.8	2.55	3.5	0.73	2.8	381	1.5



1430-AWG18#LENGTH310mm

KL-5056D

Fully Digital Stepping Driver

Attention: Please read this manual carefully before using the driver!

Table of Contents

1. Introduction, Features and Applications

Introduction

The KL-5056D is a versatility fully digital stepping driver based on a DSP with advanced control algorithm. The KL-5056D is the next generation of digital stepping motor controls. It brings a unique level of system smoothness, providing optimum torque and nulls mid-range instability. Motor self-test and parameter auto-setup technology offers optimum responses with different motors and easy-to-use. The driven motors can run with much smaller noise, lower heating, smoother movement than most of the drivers in the markets. Its unique features make the KL-5056D an ideal solution for applications that require low-speed smoothness.

Features

- Anti-Resonance, provides optimum torque and nulls mid-range instability
- Motor self-test and parameter auto-setup technology, offers optimum responses with different motors
- Multi-Stepping allows a low resolution step input to produce a higher microstep output for smooth system performance
- Microstep resolutions programmable, from full-step to 102,400 steps/rev
- Supply voltage up to +50 VDC
- Output current programmable, from 0.5A to 5.6A
- Pulse input frequency up to 200 KHz
- TTL compatible and optically isolated input
- Automatic idle-current reduction
- Suitable for 2-phase and 4-phase motors
- Support PUL/DIR and CW/CCW modes
- Over-voltage, over-current, phase-error protections

Applications

Suitable for a wide range of stepping motors, from NEMA frame size 17 to 34. It can be used in various kinds of machines, such as laser cutters, laser markers, high precision X-Y tables, labeling machines, and so on. Its unique features make the KL-5056D an ideal solution for applications that require both low-speed smoothness and high speed performances.

2. Specifications

Electrical Specifications (T_j = 25℃/77℉)

Parameters	KL-5056D			
	Min	Typical	Max	Unit
Output current	0.5	-	5.6 (4.0 RMS)	A
Supply voltage	+20	+36	+50	VDC
Logic signal current	7	10	16	mA
Pulse input frequency	0	-	200	kHz
Isolation resistance	500			MΩ

Mechanical Specifications (unit: mm [inch])

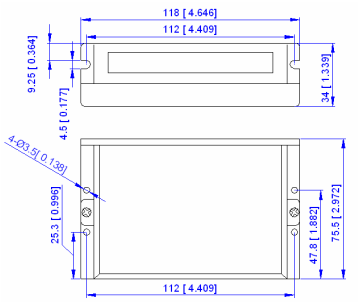


Figure 1: Mechanical specifications

Elimination of Heat

- Driver's reliable working temperature should be <70℃(158℉), and motor working temperature should be <80℃(176℉);
- It is recommended to use automatic idle-current mode, namely current automatically reduce to 60% when motor stops, so as to reduce driver heating and motor heating;
- It is recommended to mount the driver vertically to maximize heat sink area. Use forced cooling method to cool the system if necessary.

Operating Environment and other Specifications

Cooling	Natural Cooling or Forced cooling	
Operating Environment	Environment	Avoid dust, oil fog and corrosive gases
	Ambient Temperature	0℃ — 50℃ (32℉ — 122℉)
	Humidity	40%RH — 90%RH
	Operating Temperature	70℃ (158℉) Max
	Vibration	5.9m/s^2 Max
Storage Temperature	-20℃ — 65℃ (-4℉ — 149℉)	
Weight	Approx. 280g (10 oz)	

3. Pin Assignment and Description

The KL-5056D has two connectors, connector P1 for control signals connections, and connector P2 for power and motor connections. The following tables are brief descriptions of the two connectors. More detailed descriptions of the pins and related issues are presented in section 4, 5, 9.

Connector P1 Configurations

Pin Function	Details
PUL+	Pulse signal: In single pulse (pulse/direction) mode, this input represents pulse signal, each rising or falling edge active (software configurable); 4-5V when PUL-HIGH, 0-0.5V when PUL-LOW. In double pulse mode (pulse/pulse) , this input represents clockwise (CW) pulse，active both at high level and low level (software configurable). For reliable response, pulse width should be longer than 2.5μs. Series connect resistors for current-limiting when +12V or +24V used. The same as DIR and ENA signals.
PUL-	
DIR+	DIR signal: In single-pulse mode, this signal has low/high voltage levels, representing two directions of motor rotation; in double-pulse mode (software configurable), this signal is counter-clock (CCW) pulse，active both at high level and low level (software configurable). For reliable motion response, DIR signal should be ahead of PUL signal by 5μs at least. 4-5V when DIR-HIGH, 0-0.5V when DIR-LOW. Please note that rotation direction is also related to motor-driver wiring match. Exchanging the connection of two wires for a coil to the driver will reverse motion direction.
DIR-	
ENA+	Enable signal: This signal is used for enabling/disabling the driver. High level (NPN control signal, PNP and Differential control signals are on the contrary, namely Low level for enabling.) for enabling the driver and low level for disabling the driver. Usually left **UNCONNECTED (ENABLED)**.
ENA-	

Selecting Active Pulse Edge and Control Signal Mode

The KL-5056D supports PUL/DIR and CW/CCW modes and pulse actives at rising or falling edge. See more information about these settings in Section 13. Default setting is PUL/DIR mode and rising edge active (NPN, and PNP control signal is on the contrary).

Connector P2 Configurations

Pin Function	Details
+Vdc	Power supply, 20~50 VDC, Including voltage fluctuation and EMF voltage.
GND	Power Ground.
A+, A-	Motor Phase A
B+, B-	Motor Phase B

4. Control Signal Connector (P1) Interface

The KL-5056D can accept differential and single-ended inputs (including open-collector and PNP output). The KL-5056D has 3 optically isolated logic inputs which are located on connector P1 to accept line driver control signals. These inputs are isolated to minimize or eliminate electrical noises coupled onto the drive control signals. Recommend use line driver control signals to increase noise immunity of the driver in interference environments. In the following figures, connections to open-collector and PNP signals are illustrated.

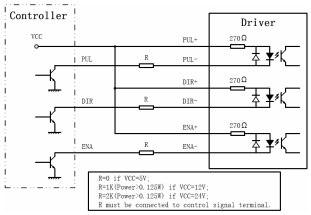


Figure 2: Connections to open-collector signal (common-anode)

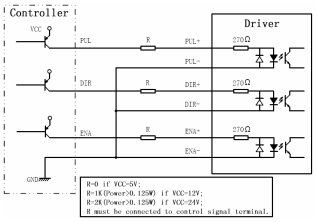


Figure 3: Connection to PNP signal (common-cathode)

5. Connecting the Motor

The KL-5056D can drive any 2-pahse and 4-pahse hybrid stepping motors.

Connections to 4-lead Motors

4 lead motors are the least flexible but easiest to wire. Speed and torque will depend on winding inductance. In setting the driver output current, multiply the specified phase current by 1.4 to determine the peak output current.

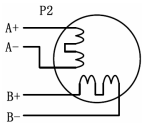


Figure 4: 4-lead Motor Connections

Connections to 6-lead Motors

Like 8 lead stepping motors, 6 lead motors have two configurations available for high speed or high torque operation. The higher speed configuration, or half coil, is so described because it uses one half of the motor's inductor windings. The higher torque configuration, or full coil, uses the full windings of the phases.

Half Coil Configurations

As previously stated, the half coil configuration uses 50% of the motor phase windings. This gives lower inductance, hence, lower torque output. Like the parallel connection of 8 lead motor, the torque output will be more stable at higher speeds. This configuration is also referred to as half chopper. In

setting the driver output current multiply the specified per phase (or unipolar) current rating by 1.4 to determine the peak output current.

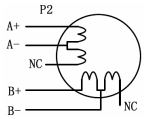


Figure 5: 6-lead motor half coil (higher speed) connections

Full Coil Configurations

The full coil configuration on a six lead motor should be used in applications where higher torque at lower speeds is desired. This configuration is also referred to as full copper. In full coil mode, the motors should be run at only 70% of their rated current to prevent over heating.

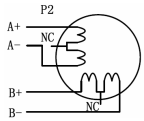


Figure 6: 6-lead motor full coil (higher torque) connections

Connections to 8-lead Motors

8 lead motors offer a high degree of flexibility to the system designer in that they may be connected in series or parallel, thus satisfying a wide range of applications.

Series Connections

A series motor configuration would typically be used in applications where a higher torque at lower speeds is required. Because this configuration has the most inductance, the performance will start to degrade at higher speeds. In series mode, the motors should also be run at only 70% of their rated current to prevent over heating.

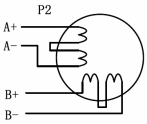


Figure 7: 8-lead motor series connections

Parallel Connections

An 8 lead motor in a parallel configuration offers a more stable, but lower torque at lower speeds. But because of the lower inductance, there will be higher torque at higher speeds. Multiply the per phase (or unipolar) current rating by 1.96, or the bipolar current rating by 1.4, to determine the peak output current.

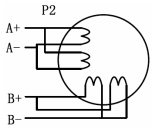


Figure 8: 8-lead motor parallel connections

NEVER disconnect or connect the motor while the power source is energized.

6. Power Supply Selection

The KL-5056D can match medium and small size stepping motors (from NEMA frame size 14 to 34) made by Keling or other motor manufactures around the world. To achieve good driving performances, it is important to select supply voltage and output current properly. Generally speaking, supply voltage determines the high speed performance of the motor, while output current determines the output torque of the driven motor (particularly at lower speed). Higher supply voltage will allow higher motor speed to be achieved, at the price of more noise and heating. If the motion speed requirement is low, it's better to use lower supply voltage to decrease noise, heating and improve reliability.

Regulated or Unregulated Power Supply

Both regulated and unregulated power supplies can be used to supply the driver. However, unregulated power supplies are preferred due to their ability to withstand current surge. If regulated power supplies (such as most switching supplies.) are indeed used, it is important to have large current output rating to avoid problems like current clamp, for example using 4A supply for 3A motor-driver operation. On the other hand, if unregulated supply is used, one may use a power supply of lower current rating than that of motor (typically 50%～70% of motor current). The reason is that the driver draws current from the power supply capacitor of the unregulated supply only during the ON duration of the PWM cycle, but not during the OFF duration. Therefore, the average current withdrawn from power supply is considerably less than motor current. For example, two 3A motors can be well supplied by one power supply of 4A rating.

Multiple Drivers

It is recommended to have multiple drivers to share one power supply to reduce cost, if the supply has enough capacity. To avoid cross interference, **DO NOT** daisy-chain the power supply input pins of the drivers. Instead, please connect them to power supply separately.

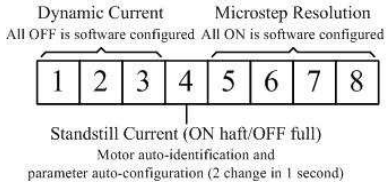
Selecting Supply Voltage

The power MOSFETS inside the KL-5056D can actually operate within +20 ~ +50VDC, including power input fluctuation and back EMF voltage generated by motor coils during motor shaft deceleration. Higher supply voltage can increase motor torque at higher speeds, thus helpful for avoiding losing steps. However, higher voltage may cause bigger motor vibration at lower speed, and it may also cause over-voltage protection or even driver damage. Therefore, it is suggested to choose only sufficiently high supply voltage for intended applications, and it is suggested to use power supplies with theoretical output voltage of +20 ~ +46VDC, leaving room for power fluctuation and back-EMF.

7. Selecting Microstep Resolution and Driver Output Current

Microstep resolutions and output current are programmable, the former can be set from full-step to 102,400 steps/rev and the latter can be set from 0.5A to 5.6A. See more information about **Microstep and Output Current Setting** in Section 13.

However, when it's not in software configured mode, this driver uses an 8-bit DIP switch to set microstep resolution, and motor operating current, as shown below:



Microstep Resolution Selection

When it's not in software configured mode, microstep resolution is set by SW5, 6, 7, 8 of the DIP switch as shown in the following table:

Microstep	Steps/rev.(for 1.8°motor)	SW5	SW6	SW7	SW8
1 to 512	Default/Software configured	ON	ON	ON	ON
2	400	OFF	ON	ON	ON
4	800	ON	OFF	ON	ON
8	1600	OFF	OFF	ON	ON
16	3200	ON	ON	OFF	ON
32	6400	OFF	ON	OFF	ON
64	12800	ON	OFF	OFF	ON
128	25600	OFF	OFF	OFF	ON
5	1000	ON	ON	ON	OFF
10	2000	OFF	ON	ON	OFF
20	4000	ON	OFF	ON	OFF
25	5000	OFF	OFF	ON	OFF
40	8000	ON	ON	OFF	OFF
50	10000	OFF	ON	OFF	OFF
100	20000	ON	OFF	OFF	OFF
125	25000	OFF	OFF	OFF	OFF

Current Settings

For a given motor, higher driver current will make the motor to output more torque, but at the same time causes more heating in the motor and driver. Therefore, output current is generally set to be such that the motor will not overheat for long time operation. Since parallel and serial connections of motor coils will significantly change resulting inductance and resistance, it is therefore important to set driver output current depending on motor phase current, motor leads and connection methods. Phase current rating supplied by motor manufacturer is important in selecting driver current, however the selection also depends on leads and connections.

When it's not in software configured mode, the first three bits (SW1, 2, 3) of the DIP switch are used to set the dynamic current. Select a setting closest to your motor's required current.

Dynamic current setting

Peak Current	RMS Current	SW1	SW2	SW3
Default/Software configured (0.5 to 5.6A)		**OFF**	**OFF**	**OFF**
2.1A	**1.5A**	ON	OFF	OFF
2.7A	**1.9A**	OFF	ON	OFF
3.2A	**2.3A**	ON	ON	OFF
3.8A	**2.7A**	OFF	OFF	ON
4.3A	**3.1A**	ON	OFF	ON
4.9A	**3.5A**	OFF	ON	ON
5.6A	**4.0A**	ON	ON	ON

Notes: Due to motor inductance, the actual current in the coil may be smaller than the dynamic current setting, particularly under high speed condition.

Standstill current setting

SW4 is used for this purpose. OFF meaning that the standstill current is set to be half of the selected dynamic current, and ON meaning that standstill current is set to be the same as the selected dynamic current.

The current automatically reduced to 60% of the selected dynamic current one second after the last pulse. Theoretically, this will reduce motor heating to 36% (due to $P=I^2*R$) of the original value. If the application needs a different standstill current, please contact Keling.

8. Wiring Notes

- In order to improve anti-interference performance of the driver, it is recommended to use twisted pair shield cable.
- To prevent noise incurred in PUL/DIR signal, pulse/direction signal wires and motor wires should not be tied up together. It is better to separate them by at least 10 cm, otherwise the disturbing signals generated by motor will easily disturb pulse direction signals, causing motor position error, system instability and other failures.
- If a power supply serves several drivers, separately connecting the drivers is recommended instead of daisy-chaining.
- It is prohibited to pull and plug connector P2 while the driver is powered ON, because there is high current flowing through motor coils (even when motor is at standstill). Pulling or plugging

connector P2 with power on will cause extremely high back-EMF voltage surge, which may damage the driver.

9. Typical Connection

A complete stepping system should include stepping motor, stepping driver, power supply and controller (pulse generator). A typical connection is shown as figure 9.

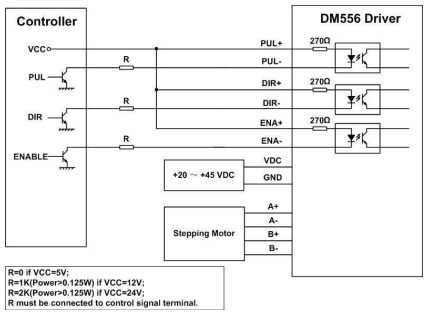


Figure 9: Typical connection

10. Sequence Chart of Control Signals

In order to avoid some fault operations and deviations, PUL, DIR and ENA should abide by some rules, shown as following diagram:

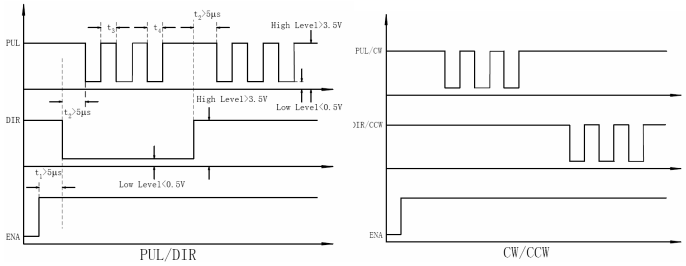


Figure 10: Sequence chart of control signals

Remark:

a) t1: ENA must be ahead of DIR by at least 5μs. Usually, ENA+ and ENA- are NC (not connected). See "Connector P1 Configurations" for more information.

b) t2: DIR must be ahead of PUL active edge by 5μs to ensure correct direction;

c) t3: Pulse width not less than 2.5μs;

d) t4: Low level width not less than 2.5μs.

11. Protection Functions

To improve reliability, the driver incorporates some built-in protection functions. The KL-5056D uses one RED LED to indicate what protection has been activated. The periodic time of RED is 3 s (seconds), and how many times the RED turns on indicates what protection has been activated. Because only one protection can be displayed by RED LED, so the driver will decide what error to display according to their priorities. See the following **Protection Indications** table for displaying priorities.

Over-current Protection

Over-current protection will be activated when continuous current exceeds 16A or in case of short circuit between motor coils or between motor coil and ground, and RED LED will turn on once within each periodic time (3 s).

Over-voltage Protection

When power supply voltage exceeds 52±1 VDC, protection will be activated and RED LED will turn on twice within each periodic time (3 s).

Phase Error Protection

Motor power lines wrong & not connected will activate this protection. RED LED will turn on four times within each periodic time (3 s).

Attention: When above protections are active, the motor shaft will be free or the LED will turn red. Reset the driver by repowering it to make it function properly after removing above problems. Since there is no protection against power leads (+, -) reversal, it is critical to make sure that power supply leads correctly connected to driver. Otherwise, the driver will be damaged instantly.

Protection Indications

Priority	Time(s) of ON	Sequence wave of RED LED	Description
1st	1		Over-current protection
2nd	2		Over-voltage protection
3rd	4		Phase error protection

12. Frequently Asked Questions

In the event that your driver doesn't operate properly, the first step is to identify whether the problem is electrical or mechanical in nature. The next step is to isolate the system component that is causing the problem. As part of this process you may have to disconnect the individual components that make up your system and verify that they operate independently. It is important to document each step in the troubleshooting process. You may need this documentation to refer back to at a later date, and these details will greatly assist our Technical Support staff in determining the problem should you need assistance.

Many of the problems that affect motion control systems can be traced to electrical noise, controller software errors, or mistake in wiring.

Problem Symptoms and Possible Causes

Symptoms	Possible Problems
Motor is not rotating	No power
	Microstep resolution setting is wrong
	DIP switch current setting is wrong
	Fault condition exists
	The driver is disabled
Motor rotates in the wrong direction	Motor phases may be connected in reverse
The driver in fault	DIP switch current setting is wrong
	Something wrong with motor coil

Erratic motor motion	Control signal is too weak
	Control signal is interfered
	Wrong motor connection
	Something wrong with motor coil
	Current setting is too small, losing steps
Motor stalls during acceleration	Current setting is too small
	Motor is undersized for the application
	Acceleration is set too high
	Power supply voltage too low
Excessive motor and driver heating	Inadequate heat sinking / cooling
	Automatic current reduction function not being utilized
	Current is set too high

13. Professional Tuning Software ProTuner

Introduction

This section will provide an overview of connection and basic setup instructions for Keling's digital stepping driver KL-5056D using the **ProTuner** software. These instructions will walk you through the following steps necessary to start up your driver and motor. This section is intended for setting up the driver with the **ProTuner**.

Software Installation

The **ProTuner** is windows based setup software for tuning Keling's digital stepper driver KL-5056D. It can run in windows systems, including Win95/Win98/WindowsNT/ Windows 2000/Windows XP. And the selected PC should have 1 serial port at least for communicating with the driver.

Double click "**ProTuner_All_Setup_V1.0.exe**" to begin installing the **ProTuner**. See Figure 11. Click **Next** to enter the "License Agreement" window. See Figure 12.

Figure 11: Begin to install the ProTuner

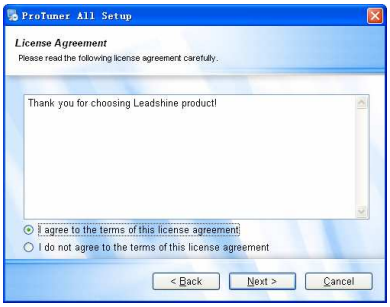


Figure 12: License agreement

Choose “I agree to the terms of this license agreement” and click **Next** to continue installation. The user can enter user’s information in the following window. See Figure 13. After entering the user’s information, click **Next** to select installation folder, where you would like to install the **ProTuner**. See Figure 14.

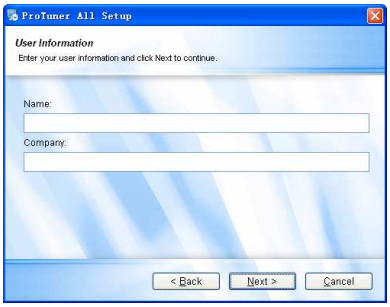


Figure 13: User’s information settings

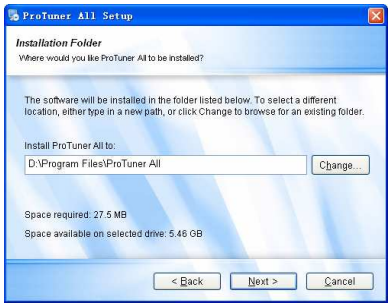


Figure 14: Installation folder settings

Figure 15: Shortcut folder setting

Set the “Shortcut Folder” in Figure 15 and continue to install the **ProTuner** by following Figure 16 and Figure 17. An **Installation Successful** window will appear if the **ProTuner** is installed successfully. See Figure 18.

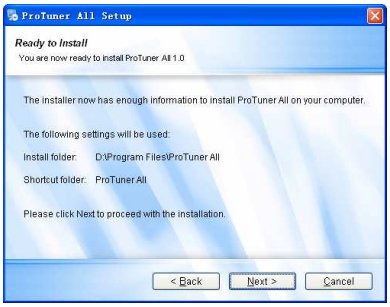


Figure 16: Installation information summarization

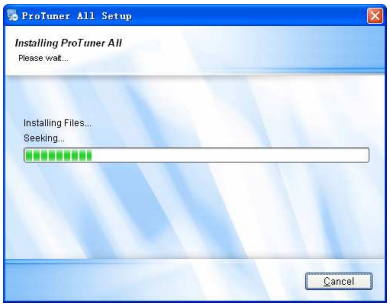


Figure 17: Installing the ProTuner

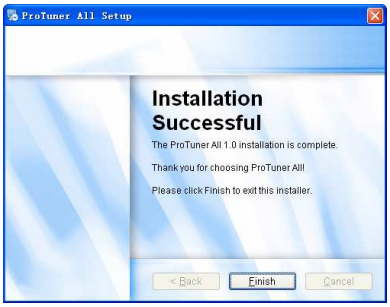


Figure 18: Finish installation

Connections and Testing

Connect the stepping system according to the contents in previous sections and connect the PC to the driver as the following figure.

RS232 Interface Connection

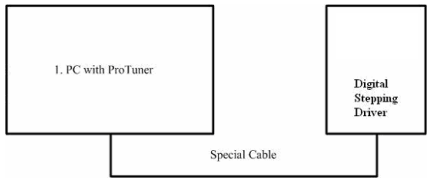


Figure 19: RS232 interface connection

Testing the Stepping System

Turn on the power supply, the green (Power) LED will light. The KL-5056D has default parameters stored in the driver. If the system has no hardware and wirings problem, the motor should be locked and the driver should be ready.

If the red LED immediately turns on (flickers), then check power supply, the motor, motor wirings

and try again. Open the tuning software **ProTuner** and check driver status by clicking **Err_check**. If it's **Phase Error**, check the motor, motor wirings and try again. If it still doesn't work after you followed all of the previous steps, please contact us at **kelinginc@kelinginc.net**

If the RED LED is off and the motor is normal, then you can start to tune the servo with **ProTuner**. However, we recommend you see the following contents before starting tuning.

Software Introduction

ProTuner Main Window

➢ **Option**

The user can choose three drop-down menus by clicking "**Option**", including **Com Confi**g, **SaveToDriver** and **Exit**.

- **Com Config**: Configure Com communication interface.
- **SaveToDriver:** Download the current parameter settings to the driver.
- **Exit:** Exit the **ProTuner**.

Com Config Window

Figure 21: RS232 communication configuration window

Serial Port: Select the serial communication port to which the driver is connected. The factory default setting is COM1.

Baud Rate: Select the communication baud rate. The factory default setting is 38400.

Click **Open** button to establish a connection with the specified settings. When connecting, you can

choose **SaveToDrive** to download the current parameter settings to the driver, or to upload the stored driver settings into the **ProTuner** by clicking **Tuning** > **Position Loop** on the menu bar.

Tuning

The user can choose one or two drop-down menu(s) by clicking **Tuning**, including **CurrentLoop** and **SystemConfig**.

- **CurrentLoop**: In Current Tuning window, the user can tune the **Kp** (**Proportional Gain**) and **Ki** (**Integral Gain)** of driver's current loop to optimize responses with different motors. Start/Restart a Step Response test to get an optimum response.

Kp: Proportional Gain. Proportional Gain determines the response of the driver to current setting command. Low Proportional Gain provides a stable system (doesn't oscillate), has low stiffness, and large current error, causing poor performances in tracking current setting command in each step like Figure 23. Too large Proportional Gain values will cause oscillations and unstable systems.

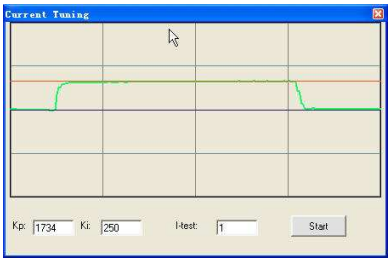


Figure 22: Current Tuning window

Ki: Integral Gain. Integral Gain helps the driver to overcome static current errors. A low or zero value for the Integral Gain may have current errors at rest. Increasing the Integral Gain can reduce the error. If the Integral Gain is too large, the systems may "hunt" (oscillate) about the desired position.

Start button: The user can start a Step Response test by clicking this button. Start/Restart a Step

Response test to get an optimum response like Figure 22, and remember to save the settings to the driver when finish tuning. See Figure 24.

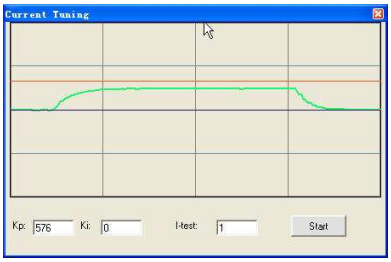


Figure 23: Kp=2604, Ki=0 (poor performances)

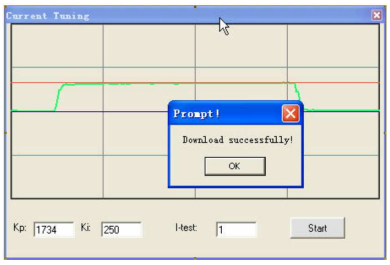


Figure 24: Finish tuning and save setting to the driver

Notes:

However, if the user does not want to tune the current loop after changing a different stepping motor, then **Motor auto-identification and parameter auto-configuration** technology of the KL-5056D can replace manual tuning the driver with **ProTuner**. Just changes SW4 two times in 1 second, and then the driver will auto-identify the new motor and auto-configure related control parameters for optimum responses. **Recommend** use this function after changing the driven motor.

- **SystemConfig**:

In **SystemConfig** window, the user can configure Peak Current, Microstep, Command Type, Active Edge, and eliminate motor resonance. A built-in pulse generator can be used for test during tuning. See Picture 25.

PeakCur: Peak Current. The value is the peak current to the selected motor and can be set from 0.5 to 5.6 A. The user can set the peak current with **ProTuner** or DIP switches, see more information about setting output current of the driver in section 5 "**Connecting the Motor**" and section 7 "**Selecting Microstep Resolution and Driver Output Current**".

MicroStep: Microstep Resolution. The value is driver's microstep resolution setting and can be set from 1 to 512. The user can set the microstep with **ProTuner** or DIP switches, See more information about setting output current of the driver in section 7 "**Selecting Microstep Resolution and Driver Output Current**".

ElecDamp: Electronic Damping Coefficient. The electronic damping restrain resonance of the system and prevent amplitude of the oscillation from increasing to the extend that it makes the motor out of control. The optimal value depends on the system, and the default value is 3000.

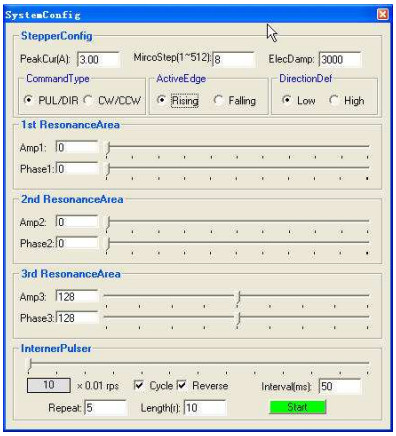


Figure 25: SystemConfig window

CommandType: Command Type of control signal, including PUL/DIR and CW/CCW. Set this parameter according to **Command Type** of motion controller.

ActiveEdge: Active Edge. The user can set the triggered edge of pulse command signal in this panel. When the driver works in CW/CCW mode, no matter what level is at fixed level terminal, the driver can works properly.

DirectionDef: Direction Definition. Relate the default running direction to **a HIGH** level input in DIR or **Low** level input in DIR. This panel is used for PUL/DIR command type only. Please note that the default direction is also related to motor coil connections.

Anti-Resonance Introduction

Step motors are highly resonant, which results in vibration and ringing. The ringing utilizes a large fraction of the motor's available torque – thereby wasting performance. Furthermore, at mid-range velocities, the resonance can become so severe that the motor looses synchronization and stalls. The KL-5056D driver provides robust anti-resonance control to stop the vibrations and maintain equilibrium. This feature requires that the driver be configured with respect to the total inertia in the system. If set improperly, the effectiveness of the feature may be diminished.

The user can invoke or disable the feature by setting **Amp** and **Phase** values in **SystemConfig** window. **Amp** and **Phase** values all zero is to disable the feature, otherwise is to invoke the feature. It should be enabled unless the system configuration either does not need it or cannot tolerate it. A system with loose couplings or viscous loading generally does not need this feature. If a system has compliant (springy) coupling and is absent appreciably viscosity, it may not respond well to the active, anti-resonant loop in the drive. The anti-resonant feature is not designed to damp such a 4th order system. If the application of anti-resonance results in degradation or instability, it should be disabled.

1st ResonanceArea: Parameters for 1st resonance area. Usually between 0.6rps and 1.2rps.

Amp1 is Amplitude adjustment for 1st resonance area.

Phase1 is Phase adjustment for 1st resonance area. The user can enter a value directly in the text box or move the slider bar back and forth to get an optimum value.

2nd ResonanceArea: Parameters for 2nd resonance area. Usually between 1.2rps and 2.4rps. Default **Amp2** and **Phase2** values are zero.

3rd ResonanceArea: Parameters for 3rd resonance area. Usually between 2.4rps and 4.8rps. Default **Amp3** and **Phase3** values are 128.

InternerPulser: There is an internal pulse generator designed for driver self-testing and anti-resonance tuning. You can issue a motion by this simple controller.

Cycle check box: The motion will repeat if this box is checked.

Reverse check box: The motor shaft will reverse direction if this box is checked.

Interval edit box: The stop time between each cycle, unit is **millisecond**.

Repeat edit box: Total motion cycles.

Length edit box: Move distance of each cycle, unit is **revolution**.

Start/Stop button: The user can Start/Stop a motion test by clicking this button.

Procedure for Achieving Optimum Performance

Step 1: Start the motion test by clicking **Start/Stop** button. Find a resonance speed by slightly moving the slider bar of internal pulse generator back and forth. See Figure 26.

Step 2: Run the motor at the resonance speed and verify the motor smoothness. You may find a better smoothing value by slightly moving the slider bars of **AMP**(s) and **Phase**(s) back and forth.

It is very important to make the **AMP**(s) and **Phase**(s) adjustments at the proper test speeds with an unloaded motor. Running at an incorrect test speed will not excite the motor at its peak resonance, making it more difficult to find proper adjustment values. Optimum **AMP**(s) and **Phase**(s) values may be a little different between running the tests with an unloaded motor and a load motor.

Please remember to click **SavetoDrive** to download the final parameter settings to the driver when finish tuning. See Figure 27.

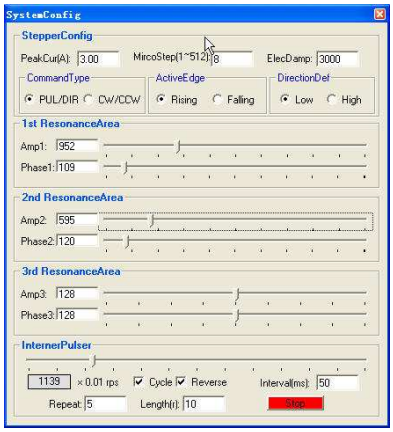


Figure 26: Anti-resonance tuning

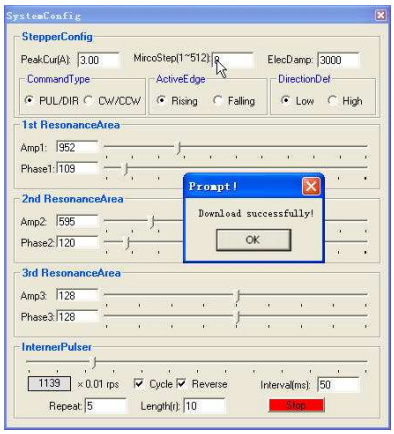


Figure 27: Finishing tuning and download parameter settings to the driver

➢ **Err_check**

- **Error Check**: This window shows both the present status of each error event and their history. Current error event(s) can be reset by clicking **Erase Current Err!** button, and all error events can be reset by clicking **Erase All!** button. List of the last ten drive faults. #0 being the most recent, #9 is the oldest. See Figure 28.

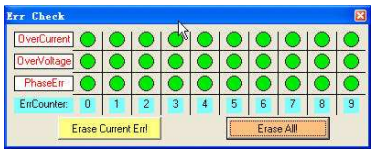


Figure 28: Error check window

OverCurrent: Over-current Protection. Protection will be activated when continuous current exceeds 16A.

OverVoltage: Over-voltage Protection. When power supply voltage exceeds 52±1 VDC, protection will be activated.

PhaseErr: Phase Error Protection. Motor power lines wrong & not connected will activate this protection.

ErrCounter: Displays current error(s) and current error history.

Erase Current Err!: Erase Current Err button. The user can clear current error(s) by clicking this button.

Erase All!: Erase All! button. The user can clear all error(s) including error history by clicking this button.

➢ **About**

The user can choose two drop-down menus by clicking "**About**", including **Product Information** and

Contact Us.

- **Product Information** window: Shows some product information about ProTuner.

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Appendix F: Optical Shaft Encoder

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Description

The **S5** series optical shaft encoder is a non-contacting rotary to digital converter. Useful for position feedback or manual interface, the encoder converts real-time shaft angle, speed, and direction into TTL-compatible quadrature outputs with or without index. The encoder utilizes a mylar disk, metal shaft and bushing, LED light source, and monolithic electronics. It operates from a single +5VDC supply.

Three shaft torque versions are available. The standard torque version has a sleeve bushing lubricated with a viscous motion control gel to provide torque and feel that is ideal for front panel human interface applications.

The no torque added option has a sleeve bushing and a low viscosity lubricant (that does not intentionally add torque) for low RPM applications where a small amount of torque is acceptable.

The ball bearing version uses miniature precision ball bearings that are suitable for high speed and ultra low torque applications.

A secure connection to the **S5** series encoder is made through a 5-pin (single-ended version) or 10-pin (differential version) finger-latching connector (sold separately). The mating connectors are available from US Digital with several cable options and lengths.

For differential version: the internal differential line driver (26C31) can source and sink 20mA at TTL levels. The recommended receiver is industry standard 26C32. Maximum noise immunity is achieved when the differential receiver is terminated with a 150 Ω resistor in series with a .0047 μF capacitor placed across each differential pair. The capacitor simply conserves power; otherwise power consumption would increase by approximately 20mA per pair, or 60mA for 3 pairs.

Features

- Small size
- Low cost
- Optional differential / line-driver output
- Positive finger-latching connector
- 2-channel quadrature, TTL squarewave outputs
- 3rd channel index option
- Ball bearing option tracks to 10,000 RPM
- -25 to +100C operating temperature
- Single +5VDC supply

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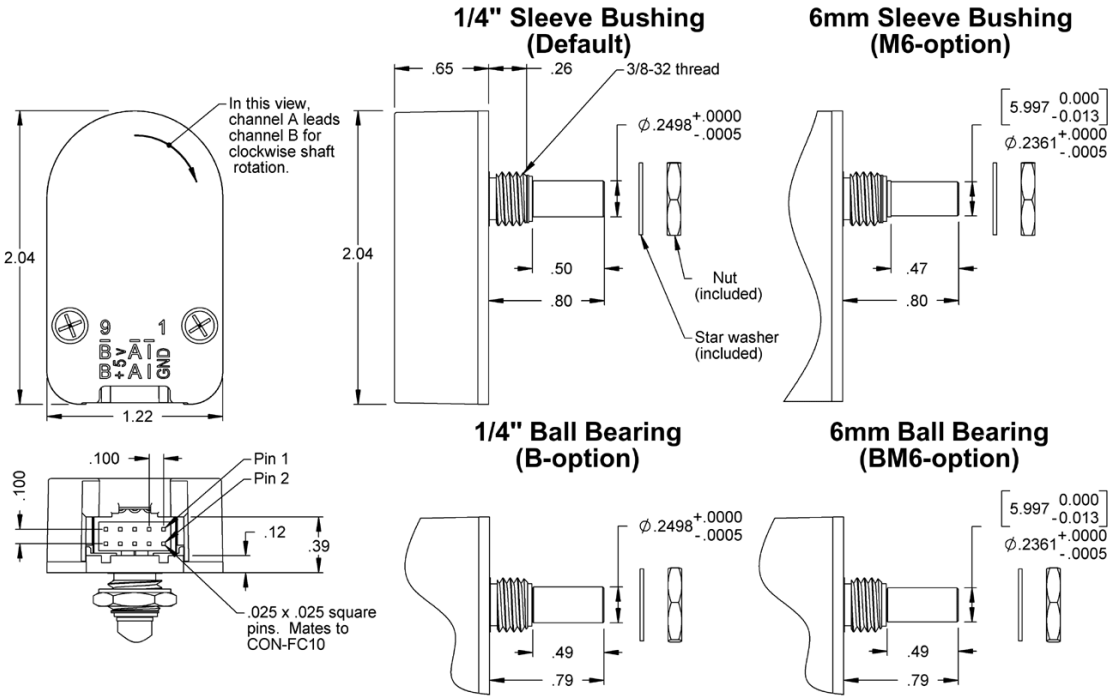
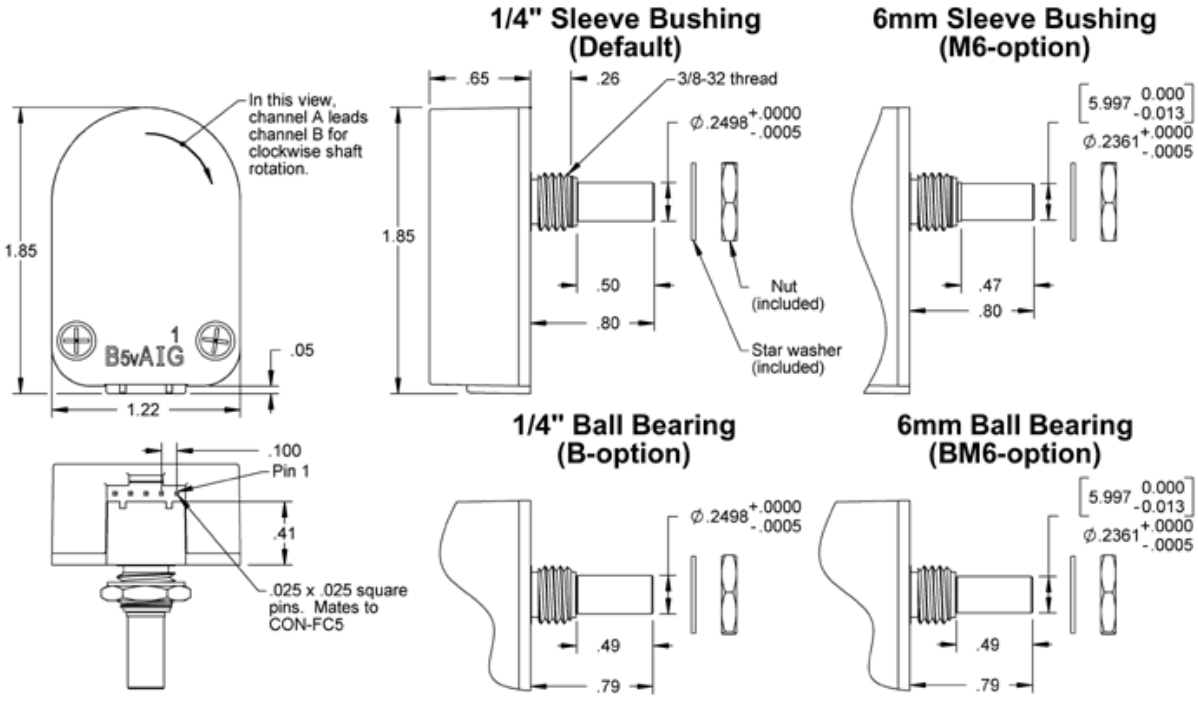
Differential



Single-Ended



Environmental

Parameter	Value	Units
Operating Temperature, CPR < 2000	-40 to 100	C
Operating Temperature, CPR ≥ 2000	-25 to 100	C
Vibration (5Hz to 2kHz)	20	G
Electrostatic Discharge, Human Body Model	± 4	kV

Mechanical

Parameter	Sleeve Bushing	Ball Bearing
Max. Acceleration	250000 rad/sec²	250000 rad/sec²
Max. Shaft Speed	100 rpm	10000 rpm
Max. Shaft Torque	0.5 ± 0.2 in-oz 0.3 in-oz (**N**-option)	0.05 in-oz
Max. Shaft Loading	2 lbs. dynamic 20 lbs. static	1 lb.
Bearing Life	> 1000000 revolutions	$L10 = (19.3/Fr)^3$ * Where $L10$ = bearing life in millions of revs, and Fr = radial shaft loading in pounds
Weight Single-ended Differential	 1.01 oz. 1.28 oz.	 1.15 oz. 1.42 oz.
Max. Shaft Total Indicated Runout	0.0015 in.	0.0015 in.
Max. Panel Nut Tightening Torque	20 in-lbs	20 in-lbs
Technical Bulletin TB1001 - Shaft and Bore Tolerances		Download

* only valid with negligible axial shaft loading.

Phase Relationship

B leads A for clockwise shaft rotation, and A leads B for counterclockwise rotation viewed from the shaft side of the encoder (*see the EM1 page*).

Single-ended Electrical

- Specifications apply over entire operating temperature range.
- Typical values are specified at Vcc = 5.0Vdc and 25 ° C.
- For complete details, see the EM1 or EM2 product pages.

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Parameter	Min.	Typ.	Max.	Units	Conditions
Supply Voltage	4.5	5.0	5.5	V	
Supply Current		27	33	mA	CPR < 500, no load
		54	62	mA	CPR ≥ 500 and <2000, no load
		72	85	mA	CPR ≥ 2000, no load
Low-level Output			0.5	V	I_{OL} = 8mA max., CPR < 2000
			0.5	V	I_{OL} = 5mA max., CPR ≥ 2000
		0.25		V	no load, CPR ≥ 2000
High-level Output	2.0			V	I_{OH} = -8mA max. and CPR < 2000
	2.0			V	I_{OH} = -5mA max. and CPR ≥ 2000
		4.8		V	no load and CPR < 2000
		3.5		V	no load and CPR ≥ 2000
Output Current Per Channel	-8		8	mA	CPR < 2000
	-5		5	mA	CPR ≥ 2000
Output Rise Time		110		nS	CPR < 2000
		50		nS	CPR ≥ 2000, ± 5mA load
Output Fall Time		100		nS	CPR < 2000
		50		nS	CPR ≥ 2000, ± 5mA load

Differential Electrical

- Specifications apply over entire operating temperature range.
- Typical values are specified at Vcc = 5.0Vdc and 25 ° C.
- For complete details, see the EM1 product page.

Parameter	Min.	Typ.	Max.	Units	Conditions
Supply Voltage	4.5	5.0	5.5	V	
Supply Current		29	36	mA	CPR < 500, no load
		57	65	mA	CPR ≥ 500 and < 2000, no load
		73	88	mA	CPR ≥ 2000, no load
Low-level Output		0.2	0.4	V	I_{OL} = 20mA max.
High-level Output	2.4	3.4		V	I_{OH} = -20mA max.
Differential Output Rise/Fall Time			15	nS	

Pin-outs

5-pin Single-ended: (1)

Pin	Description
1	Ground
2	Index
3	A channel
4	+5VDC power
5	B channel

10-pin Differential Standard: (2)

Pin	Description
1	Ground
2	Ground
3	Index-
4	Index+
5	A- channel
6	A+ channel
7	+5VDC power
8	+5VDC power
9	B- channel
10	B+ channel

(1) 5-pin single-ended mating connector isCON-FC5.
(2) 10-pin differential mating connector is CON-FC10.

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Ordering Information

S5 - [ ] - [ ] - [ ] - [ ] - [ ]

CPR	Shaft	Index	Output	Torque
32 =	236 =*Metric 6mm diameter shaft*	NE =*No Index*	S =*Single-ended*	D =*Default*
50 =	250 =*1/4" diameter*	IE =*Index*	D =*Differential*	B =*Ball Bearing*
96 =				N =*No torque added*
100 =				
192 =				
200 =				
250 =				
256 =				
360 =				
400 =				
500 =				
512 =				
540 =				
720 =				
900 =				
1000 =				
1024 =				
1250 =				
2000 =				
2048 =				
2500 =				
4000 =				
4096 =				
5000 =				

Notes

- Cables and connectors are not included and must be ordered separately.
- For ordering information please see the Compatible Cables / Connectors section above.
- US Digital warrants its products against defects in materials and workmanship for two years. See complete warranty for details.

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Base Pricing

Quantity	Price
1	$87.50
5	$64.85
10	$55.87

For volume discounts, please contact us at sales@usdigital.com or 800.736.0194.

- Add 11% per unit for **CPR** of , , , , or
- Add $1.00 per unit for **Shaft** of Metric 6mm diameter shaft
- Add 23% per unit for **Output** of Differential
- Add $5.80 per unit for **Torque** of Ball Bearing
- Add 17% per unit for **Index** of IE or **CPR** greater than or equal to 1000.

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