SUN DEVIL

ROCKETRY

Avionics Hardware Design Team

Valve Controller Hardware Documentation

PCB Part No.	L0005
Current Revision	2.0
Project:	Liquid Engine
Design Engineer(s)	Colton Acosta
Test Engineer(s)	Colton Acosta

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LISTING OF ALL ACRONYMS

Acronym	Definition
AC	Alternating current
ARM	Advanced RISC Machines, refers to processor architecture
ADC	Analog to Digital Converter, refers to MCU peripheral
DC	Direct Current
ESR	Equivalent Series Resistance
GPIO	General Purpose Input Output, refers to MCU pin configuration
IDC	Insulation-Displacement Contact, refers to cable header and harness assembly
IO	Input/Output
LED	Light-Emitting Diode

RTC	Real Time Clock, refers to MCU peripheral
MCU	Microcontroller
NC	Not connected
NXP	Semiconductor manufacturing company
PCB	Printed Circuit Board
PWM	Pulse Width Modulation, refers to both the MCU peripheral and process of pulsing a voltage high and low at a predetermined rate and duty cycle
PWR	Power
RMS	Root Mean Squared
RLC	Resistor (R), Inductor (L), Capacitor (C) series circuit
SDR	Sun Devil Rocketry
SSR	Solid State Relay
SWD	Serial Wire Debug, refers to MCU programming and debug interface/pins
UART	Universal Asynchronous Receiver-Transmitter, refers to MCU peripheral
USB	Universal Serial Bus

PCB NAMING CONVENTIONS

All PCBs designed by Sun Devil Rocketry follow the same five character naming convention. Each board has its own unique part number which consists of a letter followed by a four digit number. The letter indicates the project focus, and the number indicates the order in which the boards were designed with lower numbers being assigned to older boards. The letter designations are listed in the table below.

Sun Devil Rocketry PCB Letter Designations

Letter	Definition
A	Avionics - General purpose boards to be used

	internally by the avionics team or non-propulsion avionics projects
H	Hybrids - Boards used in the projects of the hybrid propulsion team
L	Liquids - Boards used by SDR's liquid engine
S	Solids - Boards used by the solid propulsion team's projects

A complete listing of all Sun Devil Rocketry PCBs can be found on the Sun Devil Rocketry website.

PCB DESIGN FILES

The working directory for the L0005 design files can be found here for Sun Devil Rocketry members. The most up-to-date design files can also be downloaded by anyone on the Sun Devil Rocketry GitHub (link).

1. DESIGN OVERVIEW:

The liquid engine's valve controller (L0005) contains the processor responsible for managing valve actuation commands issued by the liquid engine controller (L0002). The board functions as an input/output processor in order to reduce the complexity of the L0002 firmware and to limit the amount of hardware needed on L0002. The board contains opto-isolated solid state relays for solenoid actuation and a pulse width modulation interface that issues stepper motor commands for ball-valve actuation. All valve-related sensor outputs are handled by the valve controller, unless requested by L0002 in which case data is transferred using the UART interface. The system requirements for the design are the following:

1. The controller shall interface with L0002 via a bi-directional serial interface.

2. The controller shall be capable of controlling six 120V AC, 50-60 Hz actuated solenoids.

3. The controller shall be capable of controlling two stepper motors.

4. The controller shall be capable of recording measurements from two quadrature rotary

encoders.

5. The controller shall be capable of recording analog sensor measurements from two sensors.

Design decisions were made with the availability of the motors/solenoids given the highest priority for financial reasons. Availability of the microcontroller was given the next highest priority, due to the limited availability of many MCU chips as a result of the chip shortage.

2. CONTROLLER ARCHITECTURE:

The high-level functionality of the valve-controller hardware is defined by the block diagram shown in Fig. 2.1. The information and power relationships between each component/subsystem are denoted by the arrows with the indicated directionality. Adjacent blocks sharing a border without a connecting arrow indicate separate functional components bundled together mechanically and/or electrically by a subassembly.

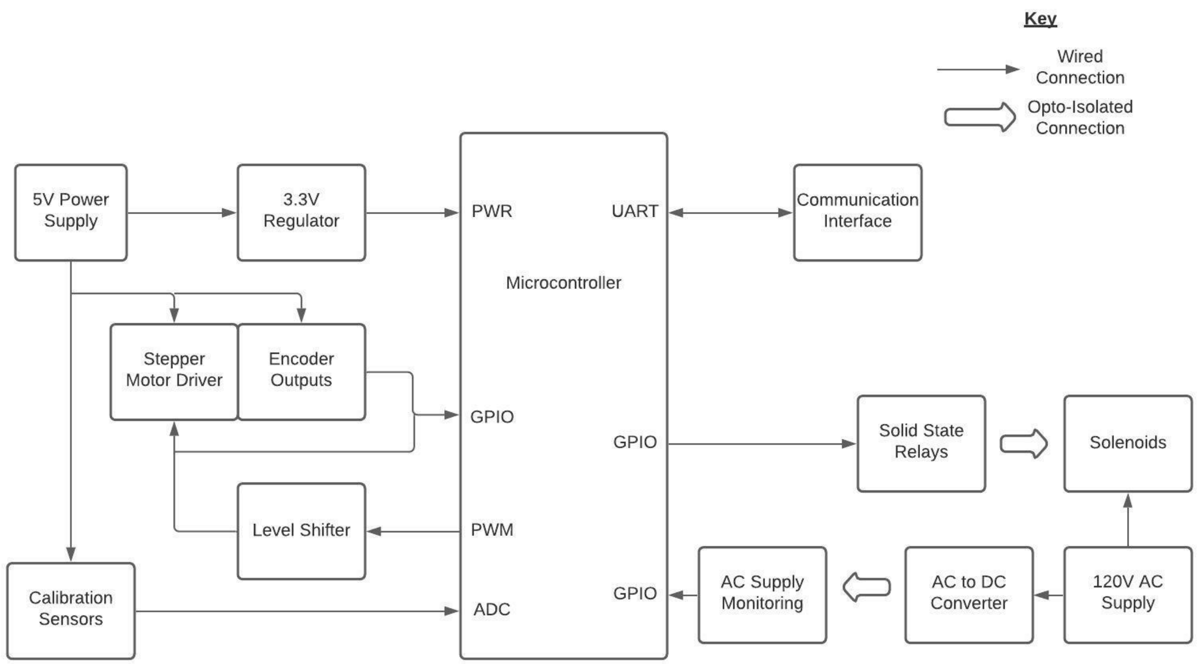

Figure 2.1 Valve Controller Architecture Diagram

The AC to DC converter is an external module not included on L0005, and is included in the block diagram only for the purpose of demonstrating how the AC supply will be monitored using MCU GPIO.

The 5V power supply is needed in order to communicate with the MA860H servo motor driver, which operates on open-drain 5V logic. Modules connected to both the MCU and the 5V supply communicate in an open drain configuration, with the only exception being the calibration sensors which have their own 3.3V regulator embedded within the photogate PCB (L0004).

3. POWER SUPPLY:

Linear Voltage Regulator:

The valve controller draws power from the 5V power supply on L0002 in order to enable the MCU to communicate with the MA860H stepper motor driver using 5V logic. The MCU has a maximum supply voltage of 3.6V (datasheet Table 12, pg. 48), so a linear voltage regulator is used to supply 3.3V to the MCU and other components on the board. The supply schematic is shown in Fig. 3.1. As recommended by the regulator datasheet, two 10uF tantalum capacitors are connected between the power and ground terminals of the regulator in order to reduce noise on the power rails and supply current during transient loading and/or supply events. An LED is attached to the 3.3V rail to provide visual indication when power is being supplied to the MCU. The current-limiting resistor was chosen to make the LED current approximately 5mA.

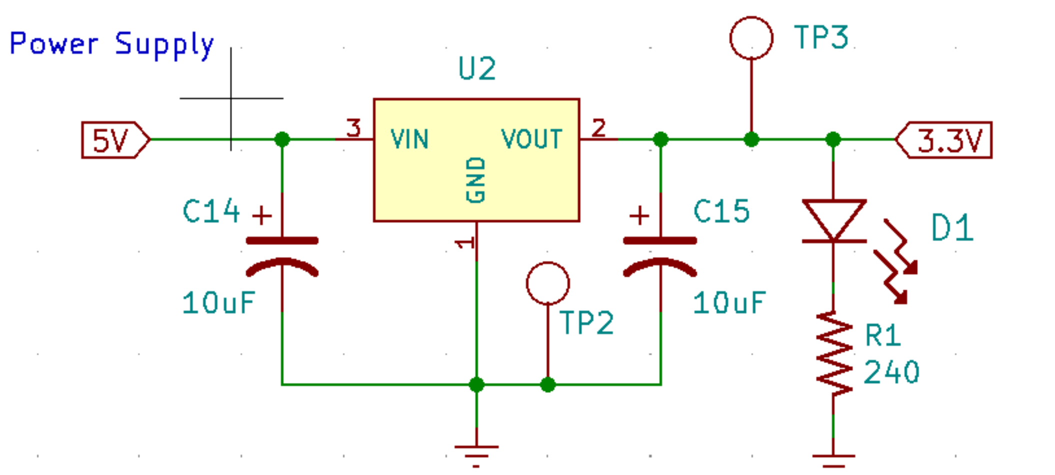

Figure 3.1. 3.3V Regulator Circuit with LED Power Indication

Microcontroller Power Scheme:

In order to ensure the MCU receives a stable voltage from the regulator circuit despite the presence of parasitics present in the PCB routing, a number of ceramic, low-ESR, decoupling capacitors are used as recommended by the datasheet. In the PCB layout design, they are placed as close to the MCU pins as possible in order to minimize the trace lengths. The number of decoupling capacitors and the capacitance of each were chosen according to the datasheet recommendations. The recommended connections and capacitances are shown in Fig. 3.4. These capacitors are grouped together on the schematic to save whitespace, and are shown in Fig. 3.5.

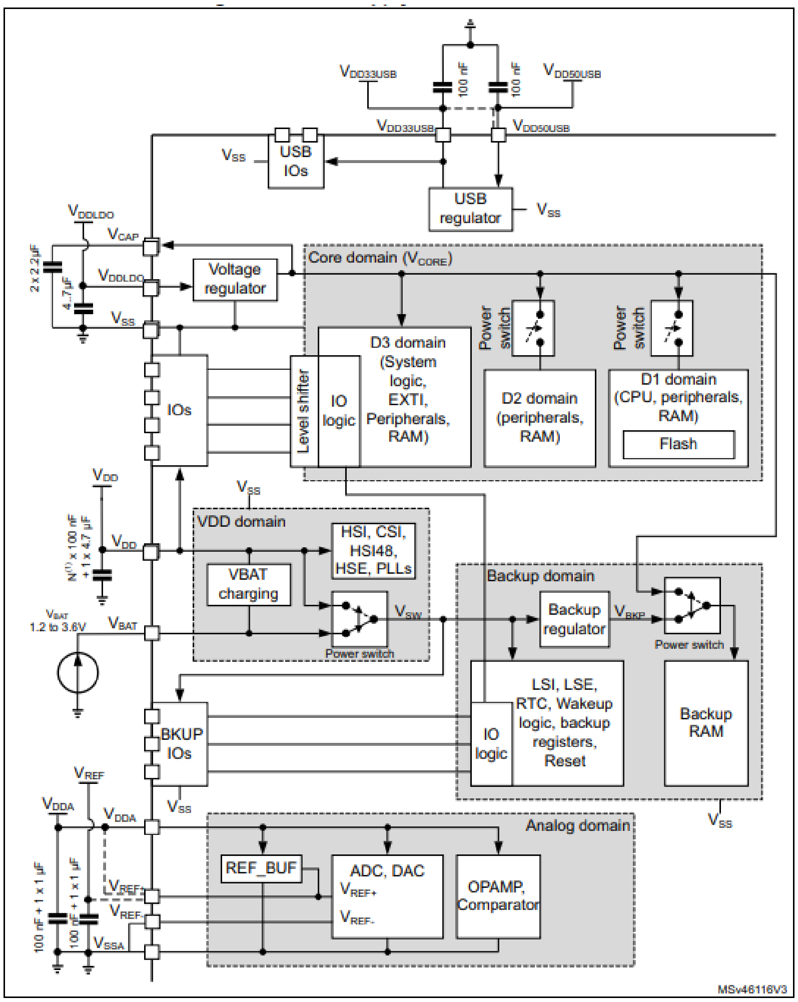

Figure 3.4 MCU Power Supply Scheme (Datasheet 6.1.6, pg. 92)

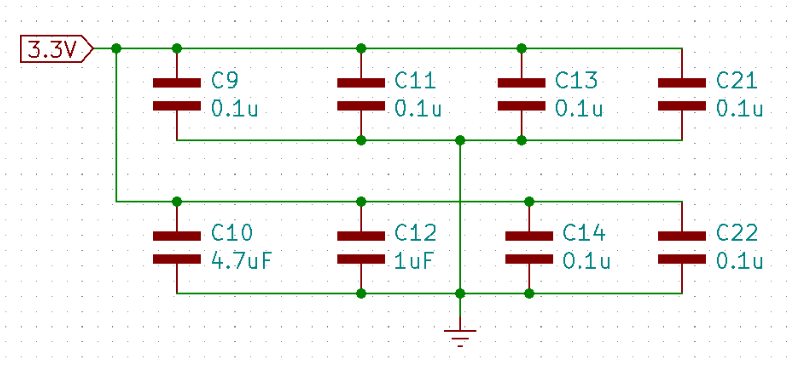

Figure 3.5. Microcontroller Decoupling Capacitors in Schematic

The USB and VDDLDO pins shown in Fig. 3.4 are not included with the chosen MCU, and therefore these capacitors are left out of the schematic. Additionally, the internal regulator of the MCU requires external 2.2 uF low ESR ceramic capacitors for stability (Datasheet 6.3.2 pg. 96). These capacitors are grouped separately from the decoupling capacitors to distinguish them from the other MCU capacitors, although they are also placed very close to the MCU in the PCB layout. The MCU stability capacitors' schematic are shown in Fig. 3.6.

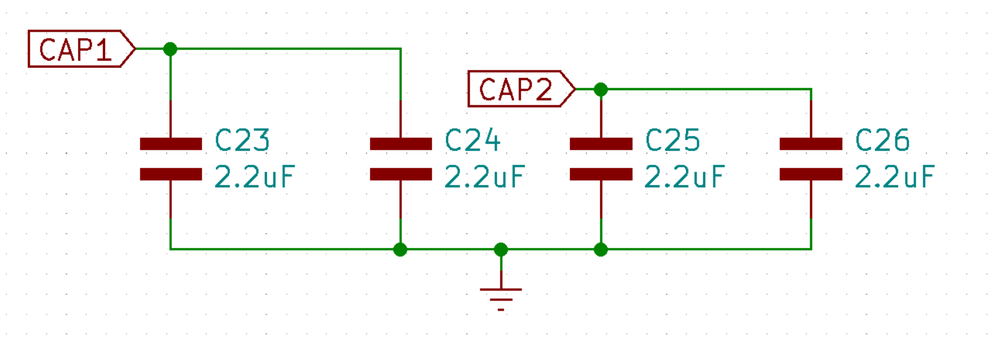

Figure 3.6. MCU Regulator Stabilization Capacitors

4. MICROCONTROLLER:

TThe engine controller uses an STMicroelectronics STM32H750VBT6 microcontroller, with a single-core ARM Cortex-M7 processor. The MCU was chosen for its maximum clock speed of 480 MHz, since the timing of the engine sequencing is a critical performance factor that influences design decisions. Although the MCU has limited availability and a high per-unit price, the thorough documentation available offsets these costs. The peripheral usage of the MCU is given in Table 4.1.

Table 4.1 Microcontroller Peripheral Functionality

Peripheral	Usage
Pulse Width Modulation (PWM)	Sends pulses to stepper motor driver
Analog to Digital Converter (ADC)	Reads motor calibration sensors
Universal Asynchronous Receiver Transmitter (UART)	Serial communication with L0002
General Purpose Input/Output (GPIO)	Read encoder pulses, monitor AC supply voltage, set stepper motor direction, turn on firmware indication LEDs

Programmer:

The MCU is programmed using an SWD interface and the standard 20 pin ARM IDC programming cables. The programmer used is the ST-Link V2 (source), chosen for its affordability and compatibility with ST microcontrollers. A 0.05” (1.27mm) pitch mating IDC connector is used for its small form factor, which requires an adapter (A0004) to connect to the 0.1” (2.54mm) IDC header on the ST-Link.

Figure 4.1 ST-Link V2 Programmer

Figure 4.2 IDC Programming Cable

The SWD pinout of the ST-Link V2 is shown in Figure 4.3, which is taken from the ST-Link datasheet (pg. 13). The “Not Connected” pins are used for JTAG, and therefore are not needed for this application. The ST-Link pins used during SWD programming and debugging are listed in Table 4.2.

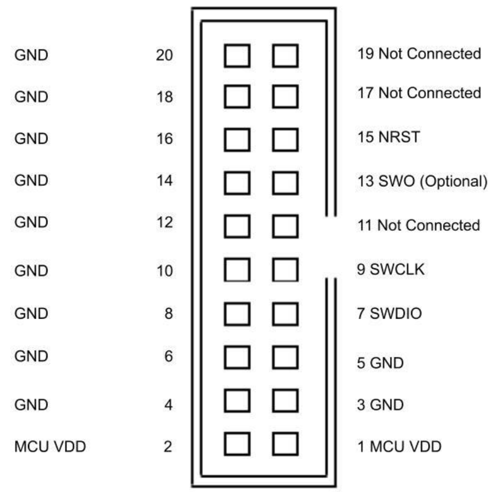

Figure 4.3. ST-Link V2 Programmer Pinout (ST-Link Datasheet, pg. 13)

Table 4.2. ST-Link V2 SWD Pinout Descriptions (ST-Link datasheet, pg. 12)

Pin Number	Name	Description
1-2	MCU VDD	Target reference voltage, connected to MCU supply voltage (3.3V)
7	SWDIO	Bi-directional data, pulled up to 3.3V
9	SWCLK	Clock signal, pulled up to 3.3V
13	SWO	Serial Wire Output trace port
15	NRST	Reset signal, active low

The programmer schematic is shown in Fig. 4.4. The SWDIO and SWCLK signals use 100 kOhm pull up resistors as recommended by the MCU reference manual (pg. 3061).

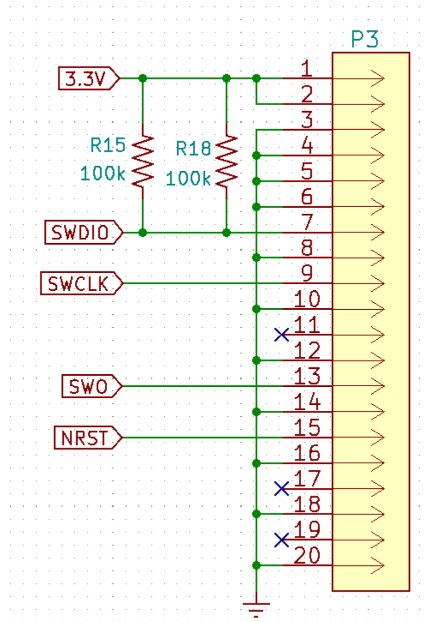

Figure 4.4. SWD Programming Connector Schematic

Microcontroller Pinout Considerations:

The MCU pinout provided in the MCU datasheet (pg. 53) is shown in Fig. 4.5.

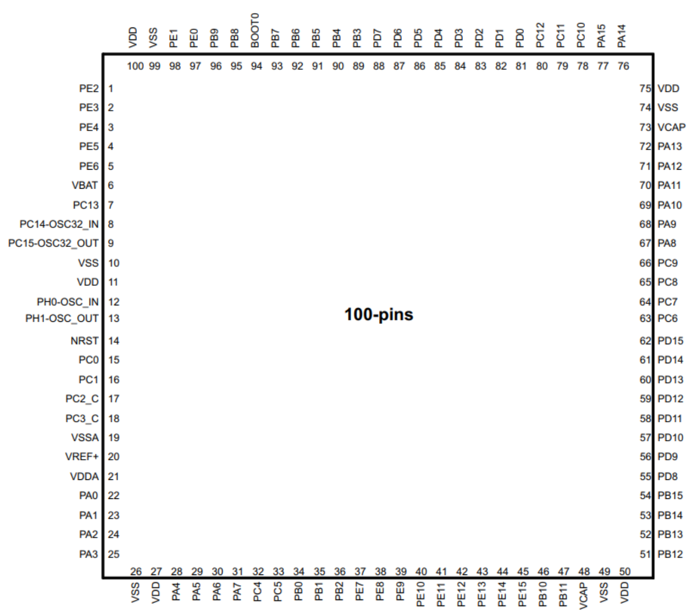

Figure 4.5 Microcontroller Pinout (MCU datasheet, pg. 53)

To improve the readability of the MCU schematic and PCB layout, each MCU pin used in the design is attached to a global net label. The labels used are shown in the MCU schematic shown in Fig. 4.6, and are listed in Table 4.3. Enumerated signals in Table 4.3 use lowercase “n” to indicate the signal number. The signals detailed in Table 4.3 can also be found in a google sheet “cheat sheet” in the L0002 design folder for more convenient access and reference.

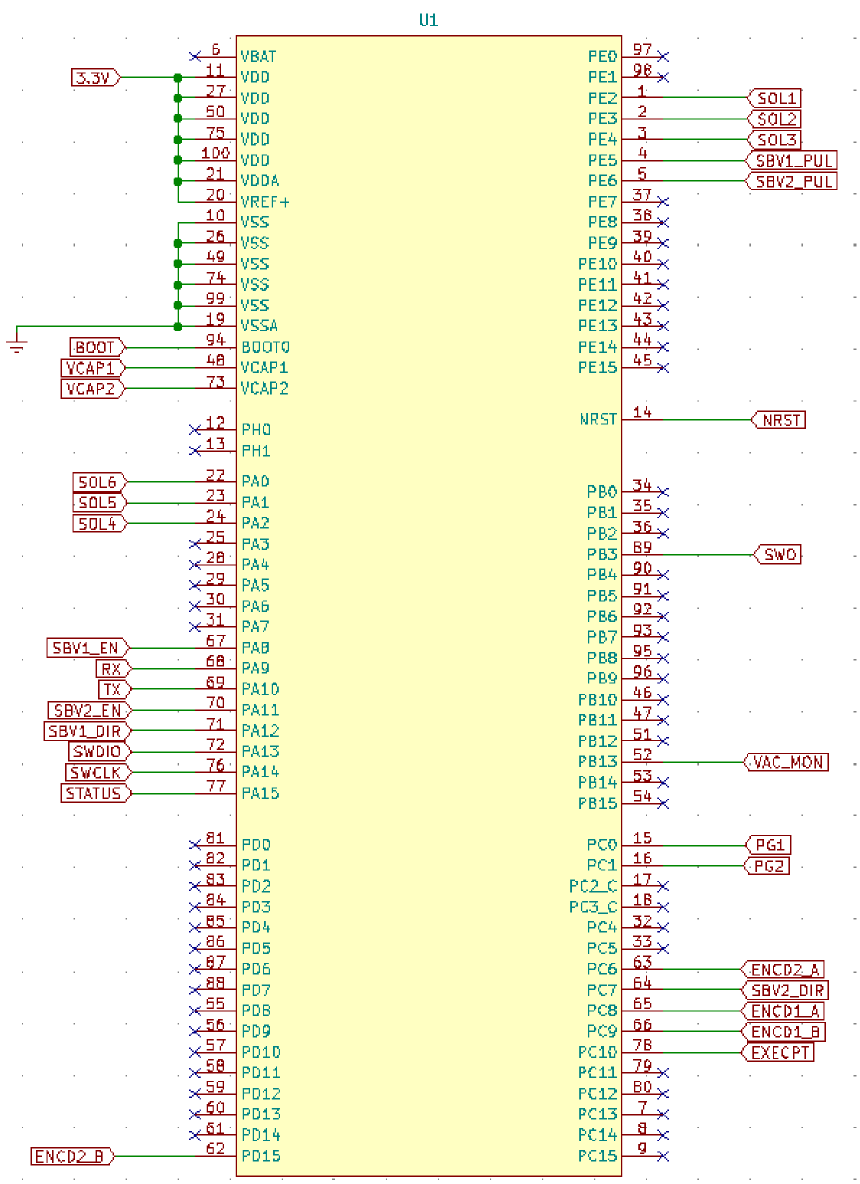

Figure 4.6. Microcontroller and Signals Schematic

Table 4.4 Microcontroller Signal Names and Definitions

Signal Name	Signal Type	Definition
STATUS	Digital Output	Displays MCU firmware status. Can be turned on or blinked to show MCU startup is functional
EXCEPT	Digital Output	Indicates a software exception by lighting the exception LED
RX	Serial Communication	UART: Valve controller receive, liquid engine controller transmit
TX	Serial Communication	UART: Valve controller transmit, liquid engine controller receive
SOLn	Digital Output	Solenoid actuation signals, HIGH signal applies power to solenoid n=1-6
SBVn_EN	Digital Output	Servo-actuated ball valve enable, HIGH signal enables motor driver n=1 or 2
SBVn_DIR	Digital Output	Servo-actuated ball valve direction control. See firmware documentation for signal direction assignment. n=1 or 2
SBVn_PUL	Digital Output	Servo-actuated ball valve pulse/step signal. Sets motor speed. n= 1 or 2
VAC_MON	Digital Input	AC power monitoring. HIGH signal indicates when AC power is being applied to the board.
PGn	Digital/Analog Input	Photogate signal, pulled LOW when sensor path is blocked. n=1 or 2

It should be noted that asserting the SOLn signals merely applies AC power to the solenoids. The state of the solenoid (open/closed) depends on the solenoid type (normally open/closed).

LED Indication:

L0005 also includes two on-board LEDs for firmware status indication. An amber LED is used for general indication such as startup status or process initiation. A red LED is used to indicate that an exception has occurred in the software. The current limiting resistances were chosen such that the LED current is approximately 5mA. The LED indication schematic is shown in Fig. 4.7.

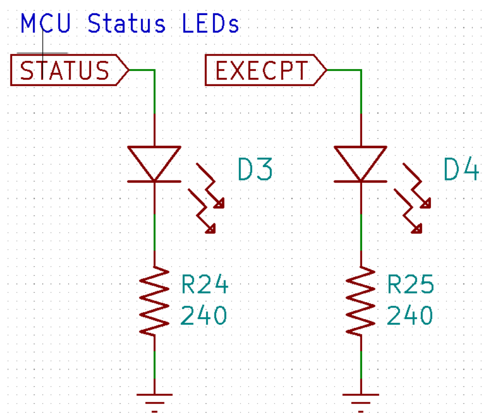

Figure 4.7. LED Indication Schematic

Microcontroller Reset:

The microcontroller reset pin is driven by the SWD programmer and a tactile button that allows the MCU to be reset without removing the power supply. A 0.1 uF ceramic capacitor is used to prevent unwanted MCU resets due to voltage spikes on the reset pin. The reset circuit is shown in Fig. 4.7.

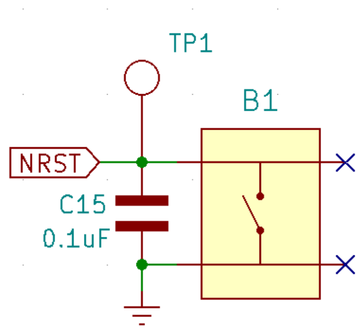

Figure 4.8. Microcontroller Reset Button

Boot Setting:

The boot mode of the MCU can be changed from the default setting by pulling the BOOT pin of the MCU low. Although the default boot mode is used in this application, a jumper connecting the BOOT pin to ground is included in case the developer wishes to use the non-default boot setting. The schematic is shown in Fig. 4.9.

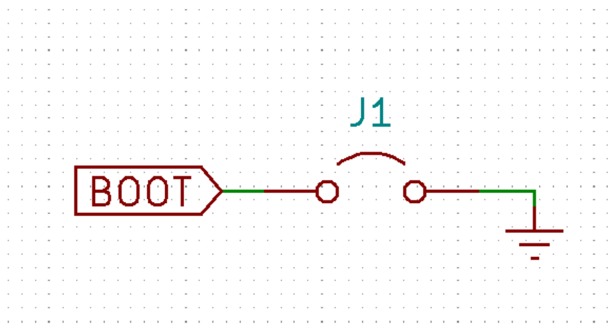

Figure 4.9. Boot Setting Jumper Schematic

5. SOLENOID ACTUATION:

The solenoids used in the design of the propellant feed system are listed in Table 5.1. The power specifications are listed along with the functional purpose of each solenoid. See the plumbing and instrumentation diagram for more information.

Table 5.1 Solenoid Specifications

Solenoid No.	Function	Power Supply	Power Requirement	Current Draw (Calculated)
1	LOX Pressurization (Normally Closed)	120V AC (RMS) 50-60 Hz	10W	83 mA (RMS)
2	Kerosene Pressurization (Normally Closed)	120V AC (RMS) 50-60 Hz	10W	83 mA (RMS)
3	LOX Venting (Normally Open)	120V AC (RMS) 50-60 Hz	10.1W	83 mA (RMS)
4	Kerosene Venting (Normally Open)	120V AC (RMS) 50-60 Hz	10.1W	83 mA (RMS)
5	LOX Purge	120V AC (RMS)	10.1W	83 mA (RMS)

	(Normally Open)	50-60 Hz		
6	Kerosene Purge (Normally Open)	120V AC (RMS) 50-60 Hz	10.1W	83 mA (RMS)

Solid State Relays:

The controller drives the 120V AC loads using 3.3V DC signals from the MCU using solid state relays (SSR). The SSR chosen for the design provides optical isolation between the MCU control signal and the AC load to protect the controller electronics from inductive electrical surges occurring during solenoid actuation. The relevant electrical characteristics of the AQH0223AX (SSR) are given in Table 5.2.

Table 5.2 AQH0223AX Electrical Characteristics

Characteristic	Type	Value
AC Load Current	Maximum	300 mA (RMS)
OFF-State Voltage	Maximum	600V (Peak)
Input LED Dropout voltage	Typical	1.21V
Input LED Forward Current	Recommended	15-25 mA
Turn on time	Maximum	100 us
Critical Rate of Rise of OFF-State Voltage	Minimum	200V/us

From the datasheet recommendations, the SSR input LED is configured to draw 20 mA of forward current when the 3.3V control signal is asserted by the MCU. With a 100Ω current limiting resistor, the LED forward current is 21mA assuming an LED forward voltage of 1.2V. The absolute maximum supply current the MCU can provide is 87 mA (datasheet pg. 57), so this supply current should not be problematic. The power dissipated by the resistor is 44.1 mW, and therefore a ⅛ W chip resistor will be capable of handling the input load. The total MCU current for solenoid actuation is therefore 126 mA, assuming all solenoid signals are asserted. This is the state when the propellant is pressurized prior to ignition.

SSR Pinout Considerations:

The pinout of the AQH0223AX obtained from the datasheet (pg. 1) is shown in Fig. 5.1. The input LED is shown on the left and the output driver on the right.

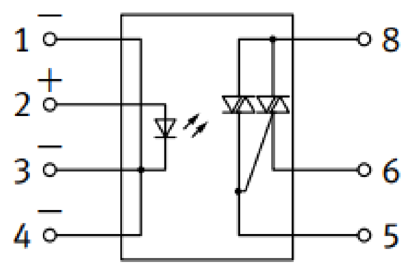

Figure 5.1 Solid State Relay Pinout

The datasheet (pg. 5, unused terminals section) strongly advises against shorting pins 5 and 6: “The No. 5 terminal is connected to the gate. Do not directly connect No. 5 and 6 terminals.”

Inductive Load Considerations:

The datasheet advises that a “snubber circuit” be used when driving inductive loads. A large rate of change in the voltage across the SSR output terminals may cause the SSR to trigger. From the datasheet (pg. 2), the critical rate is 200 V/us. The snubber is designed to keep the rate of change of the output voltage well below this rate.

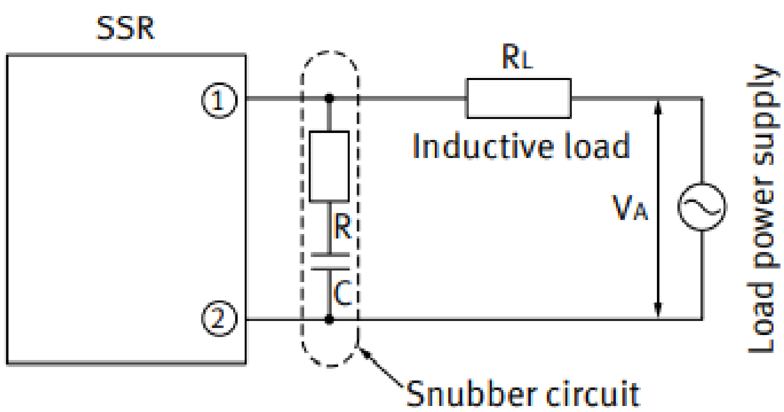

Figure 5.2 Inductive Load Snubber Circuit Configuration

The solenoid coil resistance is unknown, and therefore will be assumed to be zero for a conservative analysis. The datasheet advises that a capacitor of 0.1uF and a resistor of 20-100Ω be used for general applications. The L0005 design uses a 100Ω resistor in order to use the same part for the snubber and LED current limiter. This limits the rate of change of the off-state output voltage to the following (datasheet pg. 10):

$$\left(\frac{dv}{dt}\right)_{max} = \frac{0.632V_A}{C(R_L + R)}$$

$$\left(\frac{dv}{dt}\right)_{max} = \frac{0.632(120\,\mathrm{V})}{0.1\,\mu\mathrm{F}(100\Omega)} = 7.58\,\frac{\mathrm{V}}{\mu\mathrm{s}}$$

This is well below the 200V/us critical rate and therefore should work well for this application. The power dissipation in the resistor is the following:

$$P = \frac{1}{2}CV_A^2 f$$

$$P = \frac{1}{2}(0.1\,\mu\mathrm{F})(120\mathrm{V})^2(60\,\mathrm{Hz}) = 43\,\mathrm{mW}$$

Therefore a 1/8W or 1/10W resistor will suffice. Additionally, the steady state AC current in the snubber should be considered to ensure that the snubber current is insufficient to trigger the solenoid. The solenoid impedance is the following:

$$Z_L = \frac{V}{I} = \frac{120\,\mathrm{V}}{0.083\,\mathrm{A}} = 1.446\,\mathrm{k}\Omega$$

And the inductance assuming zero resistance is

$$L = \frac{|Z_L|}{\omega} = \frac{1.446\,\mathrm{k}\Omega}{2\pi(60\,\mathrm{Hz})} = 3.84\,\mathrm{H}$$

The RLC transfer function from AC supply to SSR off-state current is the following:

$$\frac{I(s)}{V(s)} = \frac{s/L}{s^2 + \left(\frac{R}{L}\right)s + \frac{1}{LC}}$$

$$\frac{I(s)}{V(s)} = \frac{0.261}{s^2 + 26.042s + 2.6 \times 10^6}$$

From this transfer function, the steady state snubber current for a 120V AC supply at 60Hz is 4.79 mA RMS. This is sufficiently smaller than the solenoid 83 mA RMS rating that the snubber circuit should not actuate the solenoid when the SSR is in the off state.

The Bode plot for this transfer function is shown in Fig. 5.3.

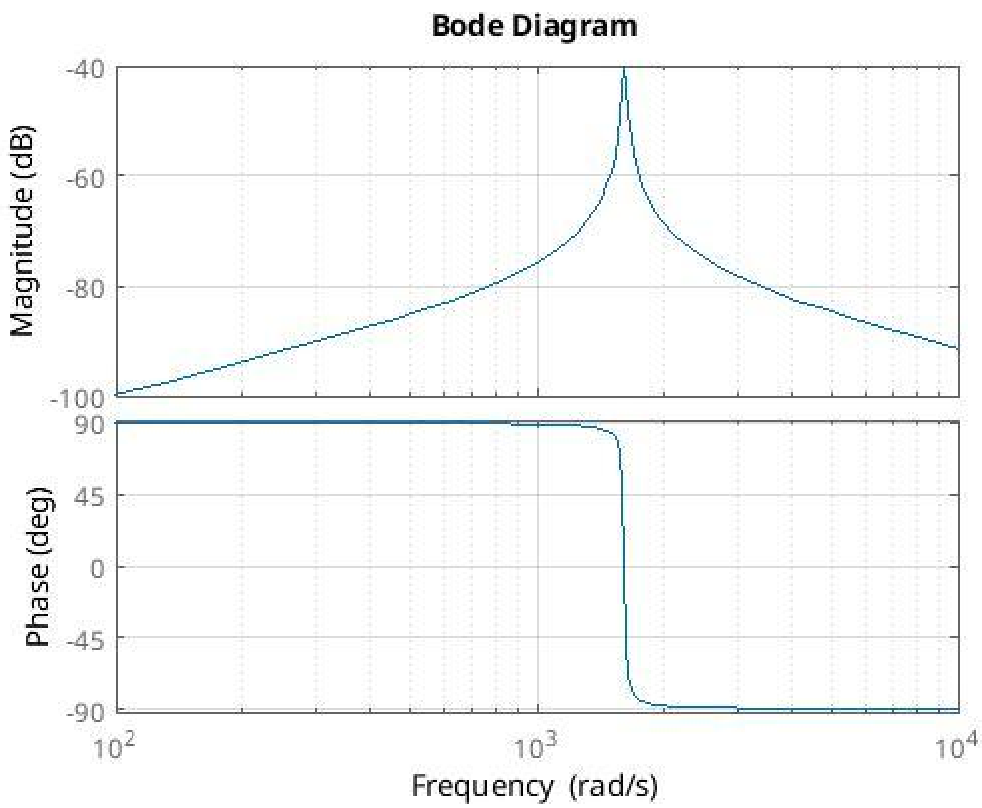

Figure 5.3 Snubber Circuit Bode Plot

From the bode plot, there is a sharp resonance peak at 258 Hz where the snubber impedance is 40.9 dB or 110.9Ω. The resultant steady state current while the SSR is in the off-state is 1.08 A for a 120V source. However, this is unlikely to be of importance as the AC supply should not generate a voltage with a frequency near the resonance frequency.

In order to clamp large transient voltage spikes, a varistor is connected across the SSR output terminals. For a 120V RMS supply, the datasheet recommends the following varistor rating:

$$V_{max} = (120\sqrt{2})(1.1)^3 = 225 \text{ V}$$

The chosen varistor has a maximum AC voltage of 275V RMS, and typical clamping voltage of 430V. Since the SSR tolerates a maximum of 600V (datasheet pg. 2), this varistor should prevent damage to the SSR due to inductive spikes caused by solenoid actuation.

The solenoid driver schematic design is shown in Fig. 5.4. The other five solenoid drivers are identical to that shown in the figure.

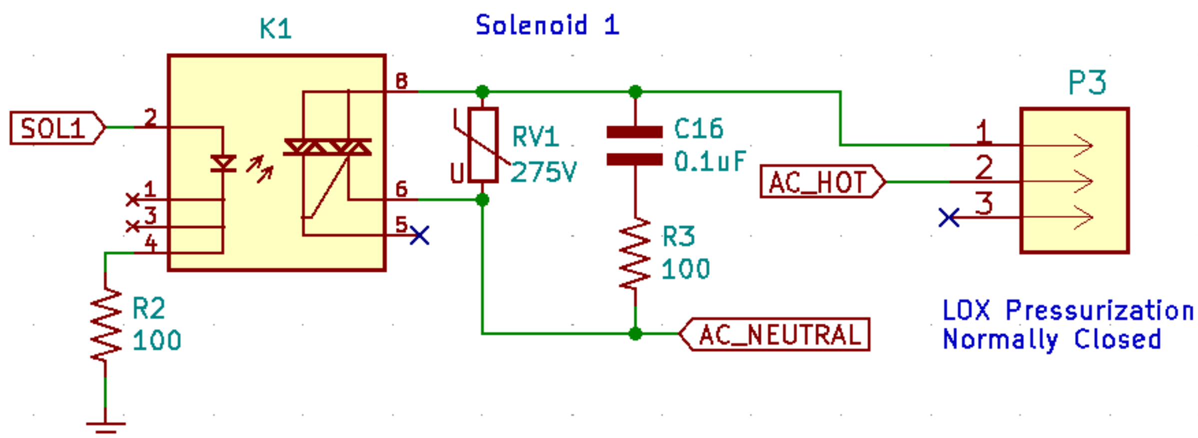

Figure 5.4. Solenoid Driver Schematic

6. AC POWER SUPPLY MONITORING:

In the event of solenoid power supply failure, it is critical for the MCU to be capable of detecting the failure so that the solenoid states (open/closed) are known at all times and the liquid engine controller (L0002) can respond appropriately. For this reason, an optically-isolated AC power supply monitoring circuit is used. The schematic is shown in Fig. 6.1. The AC power is first converted to DC using an external power supply that produces a 50-60V DC supply using the AC power. The DC supply connects to a two-terminal connector on L0005, which powers an optocoupler to communicate to the MCU when AC power is connected. The signal

(VAC_MON), read by the MCU at the emitter of the optocoupler phototransistor, is pulled to ground with a pull-down resistor such that a HIGH signal indicates that AC power is available for solenoid actuation. Additionally, an LED is connected in series with the optocoupler LED in order to provide visual indication that AC power is present.

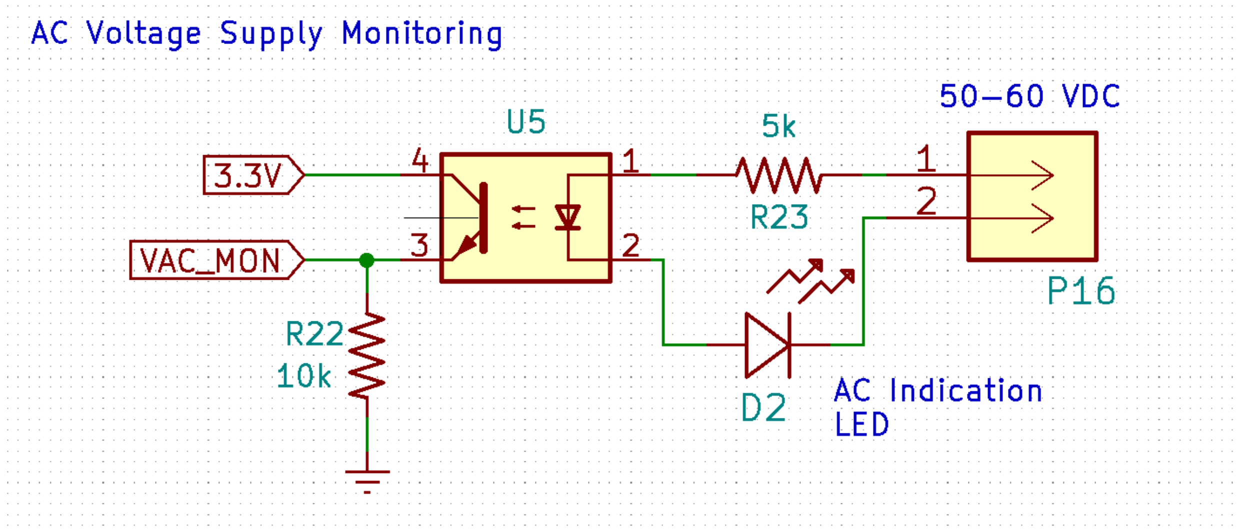

Figure 6.1. Optically-Isolated AC Power Supply Monitoring Schematic

From the optocoupler datasheet (pg. 2), the typical forward voltage drop of the LED is 1.24V with a current of 10mA. For the indication LED, the typical forward voltage drop is 2.2V at 20mA. With the 5kOhm current limiting resistor, the average current for the 50-60V supply range is 10.3mA with a range of 9.3-11.3mA. The maximum LED forward current specified by the optocoupler datasheet (pg. 2) is 60mA, which is appreciably greater than the target current even in the extreme case where the indication LED (D2) behaves like a short circuit with a 60V supply attached.

With a 10kOhm pull down resistor, the phototransistor current must be less than 330uA which is well below the maximum of 60mA and well above the dark current of 100nA. This will ensure that the VAC_MON signal is sufficiently low when power is applied and sufficiently high when power is removed.

Additionally, a 250VAC and 10A fuse is added to the AC supply line in order to prevent excessive voltage or current from damaging the board. The AC supply and fuse schematic is shown in Fig. 6.2.

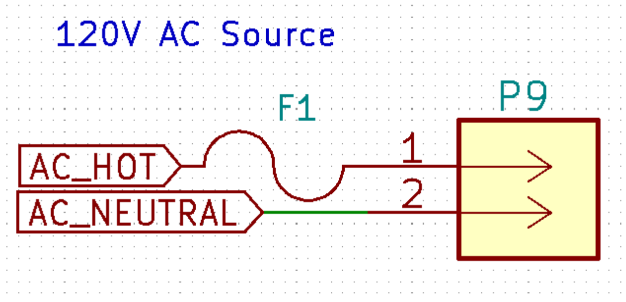

Figure 6.2. AC Supply and Fuse Schematic

7. BALL VALVE ACTUATION:

Stepper Motor Driver:

The liquid engine propellant feed system uses a servo-actuated ball valve for remote control of the engine's main propellant valves. To actuate the valves, a stepper motor is used with the MA860H stepper motor driver. The valve controller communicates with the driver with three control signals that enable the driver, control the motor's direction of rotation, and send pulses to rotate the motor. All three control signals use 5V logic, as shown in Fig. 7.1 (MA860H datasheet, pg. 4)

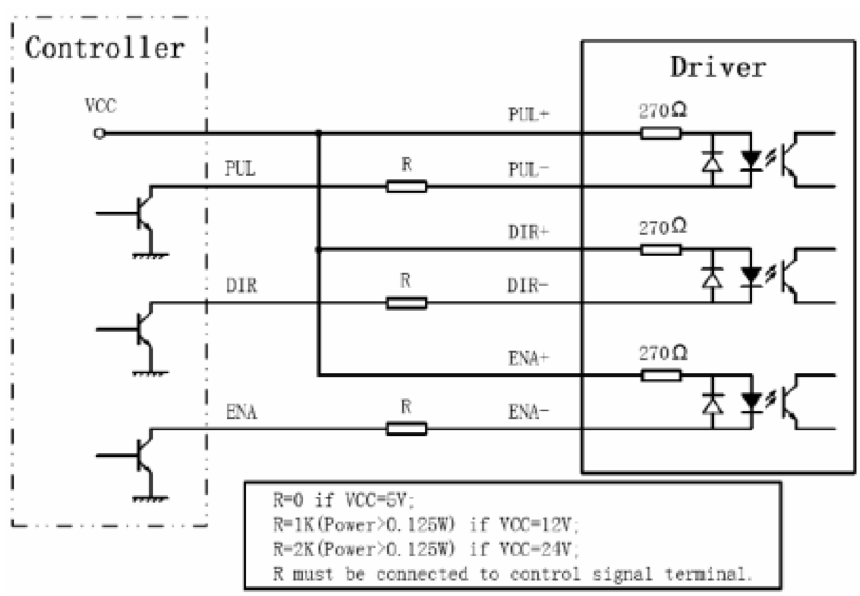

Figure 7.1. Stepper Motor Driver Wiring (MA860H Datasheet pg. 4)

Since the MCU operates on 3.3V logic, intermediate circuitry is required to allow the MCU to communicate with the stepper motor driver. For the low-speed enable and direction control signals, an n-channel MOSFET is used in an open-drain configuration. For the high-speed pulse signal, a level shifter is used.

Since the logic power supply is 5V, no current limiting resistor is needed as indicated in Fig. 6.1. In order to choose an appropriate MOSFET for the control signals, the driver diode forward voltage drops were characterized by applying a voltage of 5V to the control input terminals and recording the resultant current. The results of the experiment are given in Table 7.1.

Table 7.1. Motor Driver Control Input Currents at 5V

Input Signal	Current	LED forward voltage
PUL	13.54 mA	1.34V
DIR	13.46mA	1.37V
ENA	14.17mA	1.17V

From the results given in Table 7.1, the driver LED forward voltage is approximately 1.3V on average. The MA860H datasheet (pg. 2) specifies that the range of acceptable logic currents is 8-16mA, so the open-drain n-channel MOSFETs were chosen to produce a current in this range. The MOSFET characteristics of interest are the threshold voltage (Vth) and the transconductance parameter (kn). The threshold voltage provided by the datasheet is 1V, and the transconductance parameter is derived from the current-voltage relations provided on page 4 of the MOSFET datasheet and shown in Fig. 7.2.

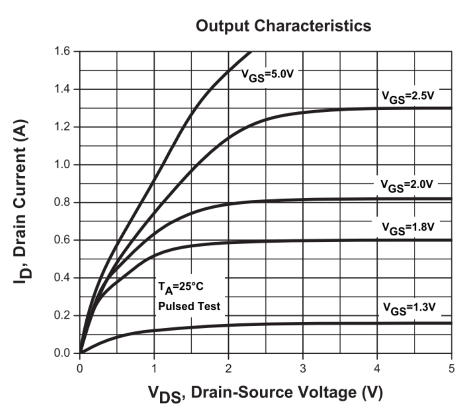

Figure 7.2. N-Channel MOSFET Current-Voltage Characteristics

Using the 1.8V gate to source (VGS) characteristic,

$$k_n = \frac{2i_D}{V_{ov}^2} = \frac{2(600)}{(1.8-1)^2} = 1875\,\mathrm{mA/V^2}$$

The MOSFET drain voltage is then,

$$V_D = V_{DD} - V_f - i_L R$$

$$i_L = k_n \left(V_{ov} V_D - \frac{1}{2} V_D^2 \right)$$

$$\frac{1}{2} k_n R V_D^2 - (1 + k_n V_{ov} R) V_D + V_{DD} - V_f = 0$$

$$253.125 V_D^2 - 1165.375 V_D + 3.7 = 0$$

$$V_D = 3.2\,\mathrm{mV}$$

Finally, the logic current is

$$i_L = \frac{V_{DD} - V_f - V_D}{R}$$

$$i_L = \frac{5 - 1.3 - 0.0032}{0.27} = 13.7\,\mathrm{mA}$$

This current is within the allowable range of 8-16mA, and therefore this choice of MOSFET should suffice.

To ensure the MOSFETs do not slow the pulse signal down at high frequencies, a level shifter is used instead of a MOSFET. This is the only 5V signal not in open-drain configuration due to the simplicity in which the level shifter is set up with push-pull IO. As recommended by the level-shifter datasheet, the 3.3V and 5V supply pins are decoupled using 0.1uF ceramic capacitors placed close to the level shifter chip in the PCB layout. The schematic of the stepper motor control signals and level shifter is shown in Fig. 7.3.

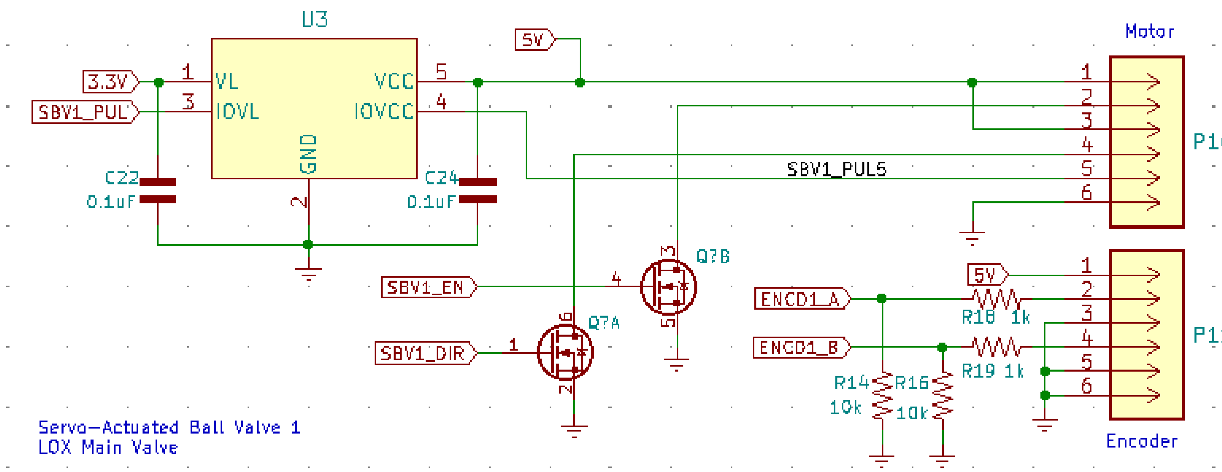

Figure 7.3. Stepper Motor Driver 5V Logic Control And Encoder Interface.

Quadrature Encoders:

The valve controller obtains feedback on the shaft angle of the stepper motors using an incremental quadrature encoder which is built into the motor itself. The encoder produces two pulse signals that are received by the MCU for feedback on the motor speed, shaft angle, and direction of rotation. The relative phase between the two signals indicates the motor direction. The encoder is powered directly from the 5V supply, resulting in pulse signals with an amplitude of 3.6V. A simple resistor divider is used to reduce the voltage on the MCU pin to approximately 3.3V by attenuating the signal by a factor of 10/11. This ratio was chosen due to the availability of 1k, 10k, and 100kOhm resistors. Through experimentation, the encoder power consumption was found to be 31mA when pulsing and 17mA when inactive. The encoder schematic is shown in Fig. 7.3 along with the stepper motor driver control signal circuitry.

Photogates:

Although the quadrature encoders provide the necessary feedback for the valve controller to make corrections due to missteps of the stepper motor, the incremental output of the encoders only allows the valve controller to know the motor shaft angle relative to its position upon controller reset. To allow the controller to calibrate the initial position of the shaft at startup, a "photogate" optical sensor is used (L0004), which was designed and developed by the SDR avionics team. See the L0004 documentation for reference. When the motor shaft reaches the closed position of the ball valve, the sensor's optical path becomes obstructed and the sensor voltage drops significantly. The photogate interfaces with the valve controller through a three terminal friction-lock connector which powers the sensor and connects the sensor output to an MCU pin. The MCU pins assigned to the sensor outputs were chosen in order to allow the analog voltage to be read by the MCU using the ADC. With this configuration, the firmware developer has maximal flexibility in programming the calibration sequence. The photogate connector schematic is shown in Fig. 7.4.

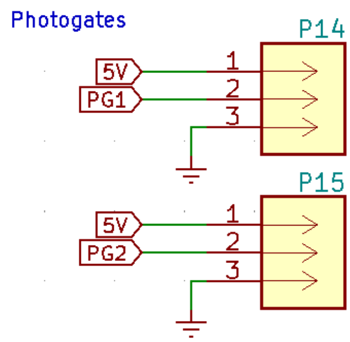

Figure 7.4. Photogate Connectors Schematic

8. UART INTERFACE:

The valve controller communicates with the liquid engine control with a bidirectional UART serial interface. The serial lines are connected to L0002 via a four terminal connector, which also serves as the power connector supplying the 5V rail used by the entire board. The UART schematic is shown in Fig. 7.1

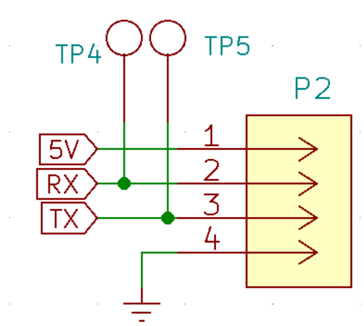

Figure 8.1. UART Interface Schematic

As mentioned in section 4, the RX and TX signals in the schematic refer to their connection to the MCU UART pins. That is, RX is connected to the MCU RX pin, and TX is connected to the MCU TX pin. On the liquid engine controller board, the connections are the opposite. The RX node connects to the engine controller TX pin, and the TX node connects to the engine controller RX pin.

9. POWER CONSUMPTION:

L0002 and L0005 are designed to be battery powered such that the onboard MCUs may make decisions in the absence of the high power sources used for valve actuation. The power consumption of L0005 is classified into static and dynamic consumption. Static consumption refers to the board's power consumption while mainly inactive. That is, when the MCU is not asserting signals that will draw power for a limited time. Dynamic consumption refers to the temporary consumption when the MCU draws powers to illuminate LEDs, record encoder readings, initiate solenoid actuation, etc.

Static Power:

The static power consumption of each component in L0005 is listed in Table 9.1.

Table 9.1. L0005 Component Static Power Consumption

Component	Conditions	Quantity	Current Draw	Power (Calc. P = VI)	Source
MCU	CortexM0+ in sleep Flash code execution 96 MHz clock speed Peripherals: Core + GPIO0 + GPIO1 + ADC0 + PWM + USART0	1	9.9 mA + 0.054 mA+ 0.062 mA + 0.160 mA + 0.388 mA + 0.115 mA = 10.7 mA (3.3V)	35.2 mW	Datasheet pg. 52-56
Regulator	Quiescent current, with Vin less than 15V.	1	5 mA (5V)	25 mW	Datasheet section 6.5 pg. 4
Power LED	-	1	4.58 mA (3.3V)	15.1 mW	Calculated
Optocoupler	Dark Current	1	100 nA (3.3V)	0.33 uW	Datasheet pg. 2
Photogate	-	2	30 mA (5V)	150 mW	Measured
Level-Shifter		2	75 uA (3.3 and	0.367 mW	Datasheet

			5V)		pg. 2
Encoder	Motor shaft stationary	2	17 mA (5V)	85 mW	Measured
Total			**114.4 mA** **15.3 mA (3.3V)** **99.14 mA (5V)**	**546 mW**	Calculated

The components on L0005 need to be capable of bearing the loads listed in Table 9.1 for extended periods of time. Therefore, the L0002 5V supply should be functional without the 114.4 mA consumed by the valve controller when connected. From the total current figures, the linear regulator dissipates 26 mW of energy assuming the regulator input current is the same as the output current. The maximum power dissipation of the regulator is calculated using the following relation provided on pg. 3 of the datasheet.

$$P_{D,MAX} = \frac{T_{J,MAX} - T_A}{R_{\theta JA}}$$

Where TJMAX refers to the maximum junction temperature provided by the datasheet, TA is the ambient temperature, and RJA is the junction-to-ambient thermal resistance which is also provided by the datasheet. The most extreme ambient temperature would be no greater than 100°F or 37.8°F. Using the formula, this amounts to a maximum power dissipation of 1.8W which is well above what is needed for static power.

Dynamic Power:

The dynamic power consumption of the components on L0005 is provided in Table 9.2.

Table 9.2. L0005 Component Dynamic Power Consumption

Component	Conditions/Duration	Quantity	Current Draw	Power (Calc. P = VI)	Source
Optocoupler	AC Power Connected Duration: indefinite	1	< 330 uA (3.3V)	< 1.1 mW	Calculated
Firmware LEDs	Status and/or exception Duration: indefinite	2	5 mA (3.3V)	16.5 mW	Calculated
Solenoid Driver	Solenoid Actuation Duration: max 15s	6	21 mA (3.3V)	69.3 mW	SSR Datasheet pg. 2

Pulse Signal Level-Shifter	Duration: max 5s at 50% duty cycle	2	13.7 mA (5V)	68.6 mW	Measured
Stepper Driver Control Input	Duration: indefinite	4	13.7 mA (5V)	68.6 mW	Calculated See section 7
Encoder	Motor Shaft Rotating Duration: Max 5s	2	31 mA (5V)	155 mW	Measured
Total			**280.5 mA** **136.3 mA (3.3V)** **144.2 mA (5V)**	**1.17 W**	

Absolute Maximum Power Consumption:

The data presented in Tables 9.1 and 9.2 can be compiled to estimate the absolute maximum power consumption the board will require. This will occur during the ignition sequence when all valves are actuated, AC power is present, all LEDs are illuminated, and all control signals are active. This condition must only be maintained for a few seconds during the ignition sequence. All relevant parameters are listed in Table 9.3.

Table 9.3. Absolute Maximum Power Consumption

Value	Quantity
3.3V Current	152.0 mA
5V Current	209.2 mA
Total Current	361.2 mA
Total Power	1.547 W

From the results in Table 9.3, the maximum power dissipation of the regulator is 258.4 mW which is still significantly lower than the device maximum of 1.8W. The total current draw of the board is 361.2 mA maximum, which the 5V buck converter on L0002 should be capable of supplying.

10. LAYOUT CONSIDERATIONS:

11. TEST RESULTS:

12. REVISION HISTORY: