January 20, 2014

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: Design Specification - Solar Powered Battery Unit for an Offshore Hydrophone

Dear Dr. Rawicz*,*

The following document contains the design specifications for AquaSol Solutions' solar powered battery unit for offshore applications.

The solar-powered charger will be installed on an offshore buoy to power a hydrophone and a wireless transmission unit. A solar panel, placed on the buoy, will harvest solar energy and store it in a lithium polymer battery bank underwater. In our specifications we describe the solar panels and the battery configurations. With safety and reliability being our company's top priorities, we also describe the hardware and software safeguards that we will put in place.

The specifications apply primarily to the proof-of-concept version of our product; however, we also briefly describe design considerations for the final product.

Sincerely,

AquaSol Solutions

Bharat Advani
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Michael Lew
David Stevens

Solar Powered Battery Charger for Offshore Applications

Design Specification

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EXECUTIVE SUMMARY

This document outlines the design specifications of AquaSol Solutions' proof-of-concept battery charging and monitoring system, with an accompanying desktop application. The document includes a detailed explanation of all the components within the system from a hardware and software standpoint.

The hardware proof-of-concept consists of five subsystems: charging module, battery pack, central module, external devices (hydrophone and Industrial, Scientific, and Medical band (ISM) transmitter), and remote desktop application. The charging module and ISM transmitter will sit atop a navigational buoy. The charging module will provide power to the remainder of the system while the ISM transmitter will wirelessly transmit information to a base station. The power generated by the charging module will be sent down a cable to the central module that will sit on a customized pad resting on the ocean floor. The central module will serve as the distribution hub for both power and data lines. The data from the hydrophone and monitoring system will then be sent back to the base station via the ISM transmitter.

Given that the product is meant to operate autonomously in remote locations for extended periods of time, reliability is a key focus in the design. All components, with the exception of the solar panel, will be housed in watertight enclosures; all connections between enclosures will be made with specialized military-grade marine connectors and cables. Additionally, the central module has been designed with several levels of fail-safes in case of unexpected failures.

The final section of this report will outline test plans that will ensure that this proof-of-concept meets the laid out functional and design specifications and the required reliability.

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GLOSSARY

BMS	Battery Management System
CEC	Canadian Electric Code
CSA	Canadian Standards Association
DC	Direct Current; DC loads require a constant voltage to power them
DFO	Department of Fisheries and Oceans
GPIO	General Purpose Input/Output
GSM	Global System for Mobile Communications
IC	Integrated Circuit
IO	Input/Output
ISM	Industrial, Scientific, and Medical – usually refers to the 2.4-2.5 GHz frequency band for transmitting information
MCU	Microcontroller Unit
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
OCP	Over Current Protection
OCPD	Over Current Protection Device
PCB	Printed Circuit Board
PMU	Power Management System
RH	Relative Humidity
SOC	State of Charge
STC	Standard Test Conditions

1. INTRODUCTION

The Department of Fisheries and Oceans (DFO) is interested in monitoring killer whale migration patterns off the coast of British Columbia. To do this, they have placed buoys equipped with hydrophones to record killer whale calls. However, these hydrophones are wired to land-based stations for power and data communication, and are thus limited in their range. The DFO has therefore asked AquaSol Solutions to design a solar-powered charger to provide power to buoys in remote locations.

The hydrophone recordings will be transmitted via an Industrial, Scientific, and Medical (ISM) band transmitter to the closest base station. The charging module will provide power to both the hydrophone and ISM transmitter via a battery pack. Since the system will be expected to function autonomously for up to two weeks at a time, it includes a battery control system in the central module. The control system implements hardware and software safeguards in case of battery/circuit failure, and transmits monitoring data via the ISM transmitter. The monitoring data can be viewed via a desktop application at the land-based station.

Figure 1 illustrates the buoy and the components attached to it. The buoy is anchored to a ground pad on the seafloor. The battery control system and the battery pack are enclosed in waterproof housing units. The hydrophone is attached to a rod on the ground pad. Not pictured in Figure 1 are the charge controller and the ISM transmitter. These will be placed in waterproof housing on top of the buoy. This document describes the technical details of each major subsystem of the solar-powered charger: the charging module, battery pack, central module, and desktop application. The external devices serve as peripherals to the system and are provided by a third party. Therefore, they are not a part of AquaSol Solutions' design specifications.

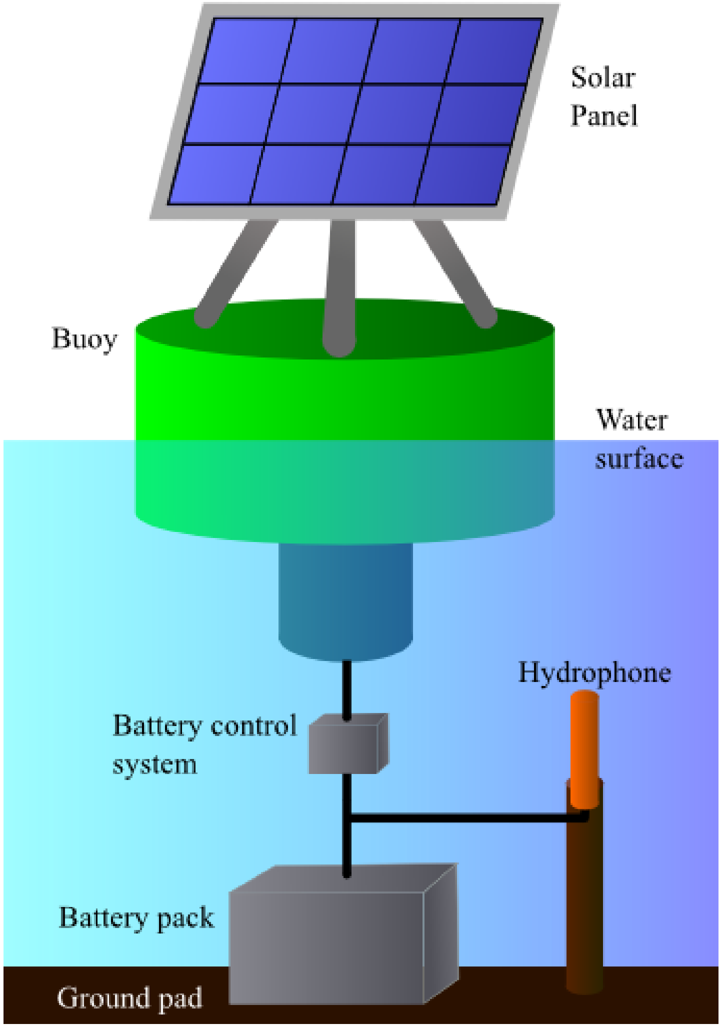


Figure 1: The buoy and various components attached to it

1.1 SCOPE

This document describes the design details of each major subsystem of the solar-powered charger. Where applicable, each design choice is justified by referring to the corresponding functional requirements described in the functional specifications [1]. The design details herein apply primarily to the proof-of-concept version. The corresponding functional requirements are those marked [Rn-A], where n is the requirement number and the letter following it indicates the production version, as described in the functional specifications. However, some design considerations for the final product are also presented. The main body of the document includes only high-level design details; low-level design details are relegated to appendices.

1.2. INTENDED AUDIENCE

This design specification is meant for use by members of AquaSol Solutions. Information within this document will serve as guidelines for implementation of the proof-of-concept, as well as guidelines for verifying the proof-of-concept functionality.

This document will also be useful to DFO, as well as future engineers and engineering co-op students commissioned by the DFO to take this project beyond the proof-of-concept stage.

2. SYSTEM SPECIFICATIONS

The overall system is composed of 5 main subsystems: a charging module, battery pack, central module, external devices, and a remote desktop application. The external devices include the ISM transmitter and hydrophone unit, which are off-the-shelf components from OceanSonics. The base station has already been installed and is currently in use with the existing hydrophone systems. AquaSol Solutions is responsible for the design and integration of the solar powered battery system and remote desktop application. Figure 2 shows a basic overview of the overall system.

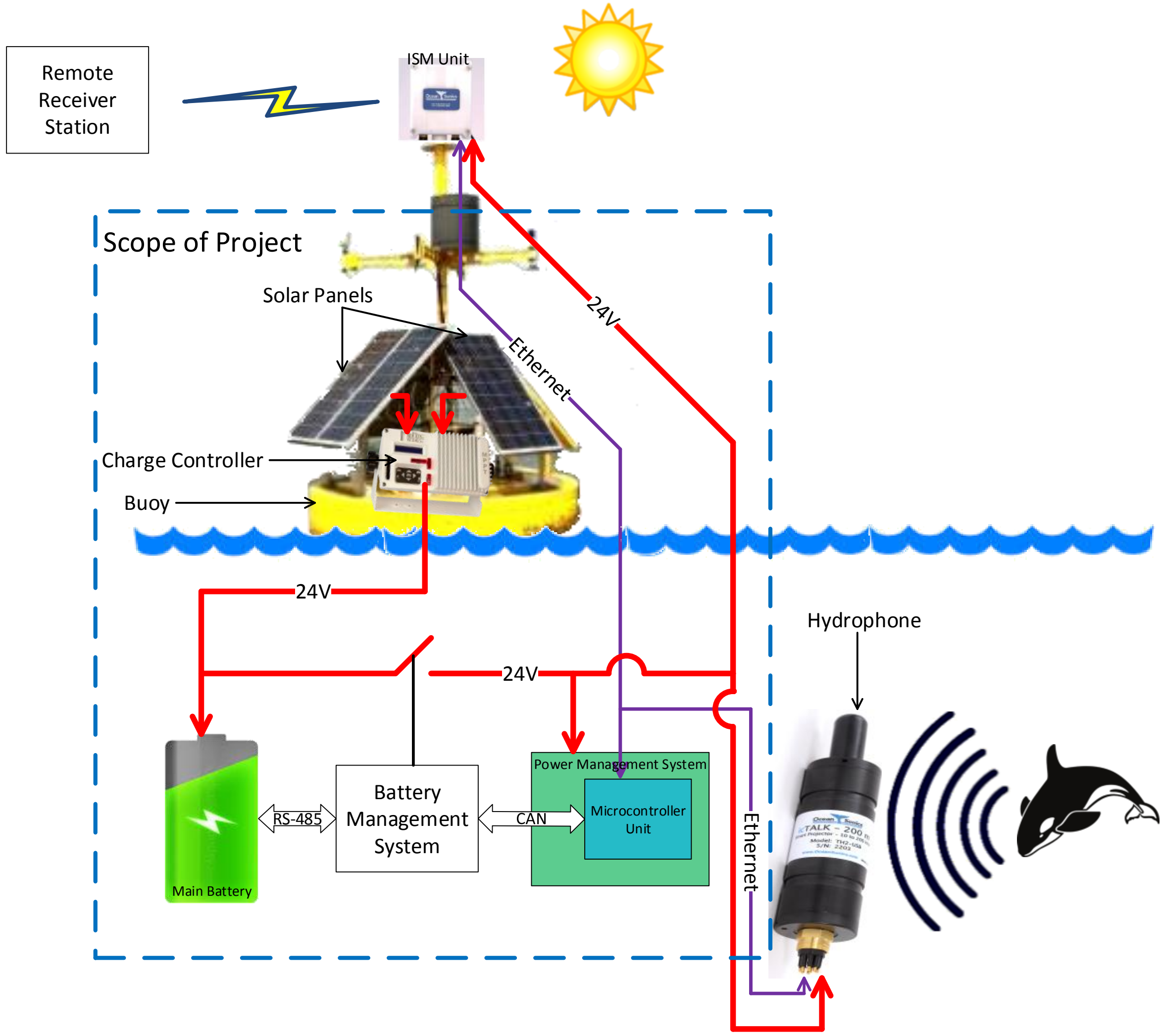


Figure 2: System overview

3. OVERALL SYSTEM DESIGN

This section provides a general description of the product and its parts. The high-level system design will outline all the major components and their interactions, while the mechanical design section summarizes the hardware enclosures and physical placement of the batteries, charging module, and central control module. Finally, the interface design describes the wiring and connections between the various components.

3.1. HIGH-LEVEL SYSTEM DESIGN

The off-shore solar-powered battery system will be comprised of the charging module, battery pack, the central module, external devices, and the remote application. A high-level overview is shown in Figure 3.

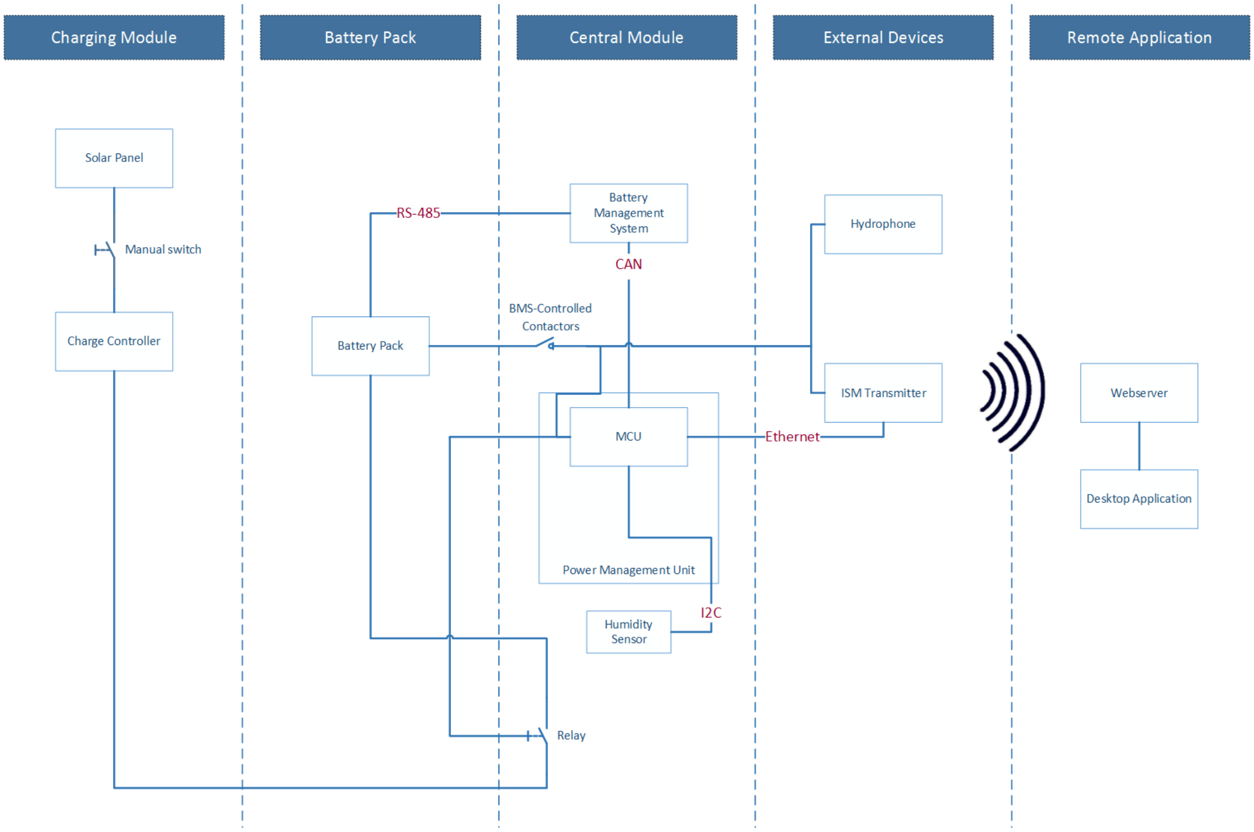


Figure 3: High-level overview of components and their connections

The charging module consists of the solar panel and charge controller, which will be placed on top of a buoy. The solar panel is connected to the charge controller with a circuit breaker, which can be used to interrupt current flow into the system during maintenance or part replacement. The charge controller directs power to the battery pack as a pulse-width modulated (PWM) wave, controlling the amount of current that goes into the battery.

The central module includes the main controls of the system, including a battery management system (BMS) specifically built for the battery pack and a power management unit (PMU). The PMU monitors the battery through the BMS, senses humidity of the central module, communicates with the ISM transmitter, and provides additional safety functions.

Finally, the remote application consists of a webserver and desktop application that displays battery status information, including the current state of charge (SOC), temperature, and charging history. It also displays any emergency warnings related to battery overheating, sub-zero temperatures, or excess humidity.

3.2. STRUCTURAL DESIGN

This subsection describes some structural considerations for various parts of the system.

3.2.1 SOLAR PANEL

The power output of the solar panel depends on the amount of its effective surface area available to harvest sunlight. In particular, bird defecation on the panel shields it and reduces its effective surface area. To deter birds from landing on the panel and soiling it, and in conformance with [R19-C] and [R40-C], spikes will be placed along the edges of the solar panel. Figure 4 illustrates the solar panel with the spikes. To avoid cluttering the image, only the spikes along the width of the panel are shown. In practice, spikes will be placed throughout the perimeter of the panel.

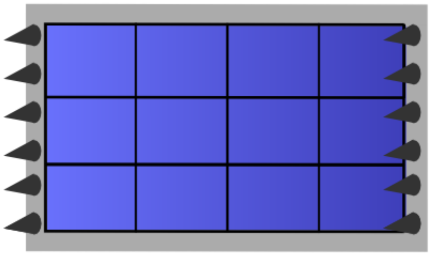
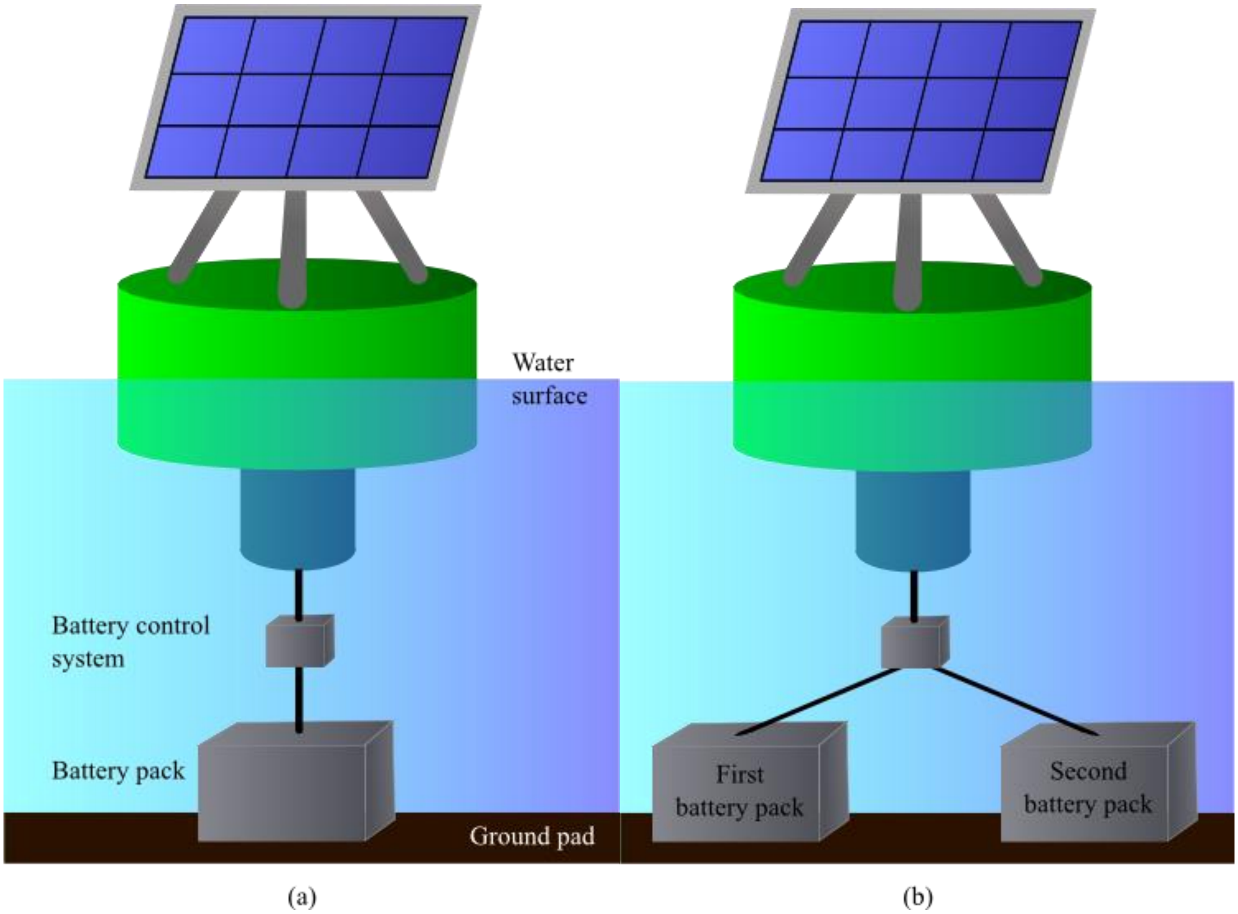


Figure 4: Solar panel with bird-deterring spikes

3.2.2 ENCLOSURES AND WEIGHT-BALANCING

Each battery pack and the central module will have their own enclosures. If more battery packs are added, then a new enclosure does not need to be designed. This ensures scalability in the number of battery packs. In compliance with [R6-B], this design also makes it easier to ensure the weight on the ground pad is balanced. Since the ground pad anchors the buoy, an unbalanced weight distribution on the pad may destabilize the buoy. Figures 5(a) and 5(b) illustrate balancing weight on the pad below the buoy with one and two battery packs, respectively. The pole and hydrophone on the pad are not shown in the figures.



(a) (b)

Figure 5: Weight distribution on the ground pad with (a) one battery pack, and (b) two battery packs

3.2.3 ROBUSTNESS AGAINST UNDERWATER CURRENTS

The circuit components within the battery control unit enclosure must stay in place against underwater currents. Therefore, in accordance with [R13-B], suitable consideration must be given to the stability and robustness of the physical intercomponent connections. Given that the physical connections are affected by the electrical connections, this issue is further discussed in section 3.3.2.

3.3. INTERFACE DESIGN

The primary purpose of the interface design is to provide robust and reliable mechanical and electrical connections between the different subsystems. The interfacing has been designed to allow the different subsystems to be compartmentalized into different watertight enclosures for the reasons provided in 3.2.2. These enclosures are connected together using marine rated SubConn connectors, which satisfy the functional specification [R30-A]. The battery pack terminals will be mated directly with the SubConn connectors. The overall interfacing of the power and data signals is handled within the central module. In the central module, standardized Molex connectors will be used to mate the SubConn signal wires with the individual components' connectors. The data interfacing between the hydrophone, ISM transmitter, and PMU will be facilitated through the use of a custom built passive hub. Detailed information on the various connectors can be found in Appendix A.

3.3.1 WIRING LAYOUT

The diagram in Appendix B illustrates the general wiring layout within the central module. However, the actual placement of the individual components is not represented in the diagram.

3.3.2 CONNECTORS

Battery Pack

Within the battery pack, the AMP Superseal 1.5mm 282107-1 connector from the battery will be directly mated with the SubConn connector, which connects the RS-485 communication lines to the BMS, as seen in Figure 13 and Figure 14. In addition, the power connectors on the batteries will use lug terminal connectors that will directly attach to wires of the SubConn connector.

Central Module

Within the central module, additional interconnectors are required to interface between the ISM transmitter, hydrophone, batteries, BMS, and PMU. All power and communication wires between modules will be connected via standardized SubConn connectors.

1. Battery connector: The power wires will be connected directly to positive and negative nodes using lug terminals. The wires for the RS-485 will be mated with a Molex 070107002 male housing connector.
2. ISM transmitter connector: The power wires will be connected directly to positive and negative nodes using lug terminals. The wires for the COM and SYNC signals will be mated with a Molex 0050579202 male housing connector. The Ethernet communication wires will be mated with a Keystone RJ45 jack.
3. Hydrophone connector: The power wires will be connected directly to positive and negative nodes using lug terminals. The wires for the COM and SYNC will be mated with a Molex 0050579202 male housing connector. The Ethernet communication wires will be mated with a Keystone RJ45 jack.
4. Charging module connector: The power wires will be connected directly to positive and negative nodes using lug terminals.
5. BMS connector: The BMS uses a pair of AMP Superseal 1.0mm 1473712-1 connectors. These connectors will be mated with Molex 070107002 male housing connectors for the connections for RS-485 and CAN. The positive, negative, and signal wires for the load contactor switch will be directly mated with the BMS connector.
6. PMU connector: The power connector on the PMU will be a Molex 874370243 male housing connector. This will attach to wires that are connected to the positive and negative nodes fitted with the matching female Molex 874390200 connector.
7. Wire interconnectors: Wires for RS-485 and CAN communications will be fitted with their respective matching female Molex 15-38-8030 connectors. The COM/SYNC communication wires will be fitted with their respective matching female Molex 070107001 connectors to allow connection to the male housing connectors. The

exception is with the Ethernet wires, which will be standard Ethernet wires with RJ45 connectors.

3.3.3 PASSIVE HUB

The passive hub will be built using a series connected diode array to allow the communication between the hydrophone, ISM transmitter, and PMU using standard Ethernet, and the circuit diagram can be found in Appendix C, Figure 24. This method of connecting devices is only possible with a half-duplex wiring configuration that limits total transmission speed to 10 - 100 Mbits/s. A passive hub was chosen for the system because it does not require power to operate and it can easily be integrated into the PMU circuitry.

4. CHARGING MODULE

4.1. SOLAR PANELS

After reviewing the functional specifications, the DFO requested a smaller (180 W) photovoltaic string due to the size constraints of mounting it on the buoy. Because of the new constraints, requirement [R32-A] is no longer applicable. Two 90W panels [2] in series will be used, with the tradeoff being that the loads may only be run at a 50% duty cycle during the winter period (October-March). During the summer period (April-September), the loads will be run at 100% duty cycle.

The output of a solar panel is maximized when rays of sun are normally incident upon its surface [3]. Because the sun is lower in the sky during the winter, the solar industry recommends orienting the solar panel due south, at a tilt angle (with respect to the ground) of latitude + 15° to maximize output during winter months [4]:

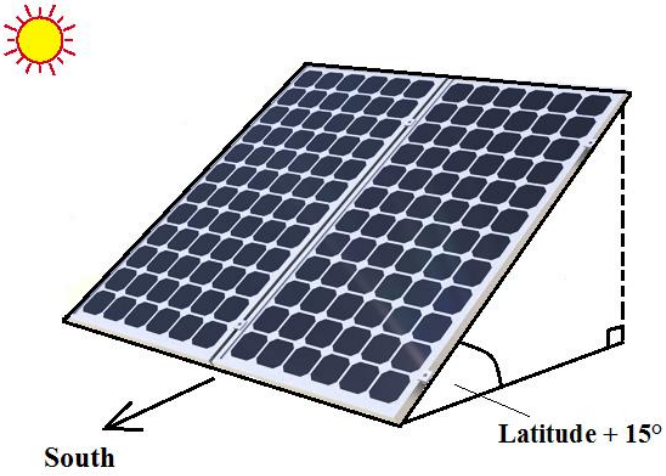


Figure 6: Solar panel orientation for maximizing winter output (northern hemisphere)

The loads must operate year round, so the solar panels will be mounted at latitude + 15° tilt angle.

Oriented due south at a latitude + 15° tilt angle, a solar panel in Seattle, WA (47.45° N, 122.30° W) receives an average 1.4 peak sun hours in December (lowest solar resource during the winter period) [5]. In the summer month with lowest solar resource (April),a solar panel at the same latitude and orientation receives 3.9 peak sun hours[5]. Seattle's latitude and longitude are very close to that of Vancouver (49.25° N, 123.10° W), so 1.4 and 3.9 peak sun hours per day will be the assumed solar resource during the winter and summer periods, respectively.

The system supplies power to two 24V DC loads (a 2 W hydrophone and an 8W ISM transmitter) with a combined power consumption of 10 W, which need to run 24 hours a day (100% duty cycle in summer, 50% duty cycle in the winter). The system also powers a microcontroller (MCU), humidity sensor, and electronic switches to ensure safe and reliable operation. This additional control circuitry will consume 1 W (see Section 6.2.1.6 for full power calculations), while operating for 24 hours per day. There are also several additional losses in the system:

- Lithium battery charging efficiencies are typically 97-99% [6].
- Charge controllers have typical efficiencies of 93-97% [7].

- The maximum power point tracking (MPPT) charge controller harvests 94-97% of the solar panels maximum output [8].
- An extra 20% loss in performance from: shading from bird soiling or crystallized sea salt on the panel, degradation of the semiconductor over time, and internal semiconductor temperatures higher than 25°C.

Taking into account the losses in the system, the available solar resource, and the power consumption of the loads, the minimum solar panel wattage was calculated for both the winter and summer periods:

Winter (0.50 duty cycle, 1.4 peak sun hours)

$$(11\ W)x\left(\frac{24\ hrs}{day}\right)x(0.50) \div (0.97) \div (0.93) \div \left(\frac{1.4\ sun\ hrs}{day}\right) \div (0.80) \div (0.94) = 137\ W.$$

Summer (1.00 duty cycle, 3.9 peak sun hours)

$$(11\ W)x\left(\frac{24\ hrs}{day}\right)x(1.00) \div (0.97) \div (0.93) \div \left(\frac{3.9\ sun\ hrs}{day}\right) \div (0.80) \div (0.94) = 98\ W.$$

Under the specified operating conditions, a 180 W photovoltaic string will be sufficient to power the system for both the winter and summer periods.

4.2. CHARGE CONTROLLER

The system requires a charge controller with an MPPT algorithm to maximize solar panel output. The system also requires a charge controller designed especially for harsh marine environments. The Midnite Solar KID meets both of these requirements, as well as having input and output voltages that are compatible with the solar panels and batteries [9]. This charge controller is also one of few on the market designed for integration with lithium batteries.

4.3. CIRCUIT BREAKER

Although the batteries already have over current protection (OCP), a backup over current protection device (OCPD) was included in the design. A circuit breaker also provides a convenient method of manually disconnecting the system for maintenance purposes by the end user [R39-A].

The short circuit current of the two series connected 90 W solar panels is 5.28 A [2]. Section 8 of the Canadian Electric Code (CEC) requires that current carrying wires be upsized for continuous operation by a factor of 1.25 [10]. Section 50 of the CEC also requires that current carrying wires from a photovoltaic array be upsized for increased solar irradiance by another factor of 1.25 [11]. The circuit breaker must therefore be rated to trip at a minimum current given by

$$(5.28\ A)x(1.25)x(1.25) = 8.23\ A.$$

The minimum circuit breaker size is 8.23 A. The next size up that is commercially available is a 9 A breaker. This is compatible with the manufacturer's specifications of the solar panels, which says that the maximum recommended circuit breaker size is 10 A [2]. The 9 A breaker used for the system is the MNEPV9 from Midnite Solar [12].

5. BATTERIES

5.1. BATTERY PACK FOR SUPPLYING POWER TO THE DC LOADS

The battery pack was designed to meet the power consumption requirements of the DC loads and system monitoring circuitry (11 W in total). The system will run 24 hours per day. It has also been designed for five days of autonomous operation in the summer (duty cycle of 1.00) and ten days of autonomous operation in the winter (duty cycle of 0.50). To extend the life of the batteries, the system was designed to discharge the batteries to at most 70% of their capacity, as opposed to a full discharge. The batteries will be contained in an underwater enclosure at a constant temperature of 4°C. The manufacturer advertises the battery capacity at 23°C, and looking at the voltage versus capacity at various temperatures of the product, the capacity was increased by a factor of 1.2 to take into account the lower operating temperature [13]. The minimum battery capacity was calculated for both the winter and summer periods:

Winter (0.50 duty cycle, 10 days of autonomy)

$$(11\ W)x\left(\frac{24\ hrs}{day}\right) \div (24\ V)x(1.2)x(0.50)x(10\ days\ autonomy) \div (0.70\ DOD) = 94\ Ah.$$

Summer (1.00 duty cycle, 5 days of autonomy)

$$(11\ W)x\left(\frac{24\ hrs}{day}\right) \div (24\ V)x(1.2)x(1.00)x(5\ days\ autonomy) \div (0.70\ DOD) = 94\ Ah.$$

Therefore, two 12 V batteries with a capacity of 110 Ah will be series-connected to meet the power consumption requirements of the system. The total weight of the battery pack will be 31.6 kg.

5.2. BACKUP BATTERY FOR MCU

For dangerous situations where the BMS or PMU disconnect the batteries from the system, a backup power source for the PMU is required. Because 5 V batteries are not commercially available, two small series connected 3.7 V lithium batteries (with a 2,200 mAh capacity) will be stepped down in voltage by a buck converter to power the 5 V rail of the PMU.

The buck converter has an efficiency of 80% [14]. The PMU will consume 1 W. To extend the life of the battery, the backup battery discharge level will be restricted to 50%. Therefore, the amount of time the backup battery can supply power to the PMU can be calculated as:

$$(7.4\ V)x(2.2\ Ah)x(0.80)x(0.50) \div (1\ W) = 6.51\ h.$$

The backup battery can supply power to the PMU for at least six hours without being recharged by the solar panels, satisfying requirement [R71-B].

6. BATTERY CONTROL

6.1. BATTERY MANAGEMENT SYSTEM

The off-the-shelf battery management system (BMS) comes equipped with the ability to monitor the batteries and detect abnormal conditions such as: over current, over voltage, under voltage and excessive temperatures. When the BMS senses an abnormal condition it has the ability to disconnect the batteries from the loads through the contactors.

6.2. POWER MANAGEMENT UNIT

The PMU serves the purpose of interfacing between the BMS through CAN and transmitting battery status information to the remote application through the ISM transmitter via Ethernet. It also performs safety functions in addition to the BMS safeguards, such as disconnecting the battery from the solar charging module and measuring humidity levels within the central module. It is composed of two parts: the electronics (PCB board) and the software on the MCU.

6.2.1. ELECTRONICS

The TIVA C series MCU was selected because it is capable of supporting CAN and Ethernet communication, interfacing between the BMS and the ISM transmitter, respectively. In contrast to the 24 V DC loads, the evaluation board for the TIVA C runs on 5 V, so a step-down converter is required. The figure below demonstrates the relationship between the custom PCB and the microcontroller evaluation board.

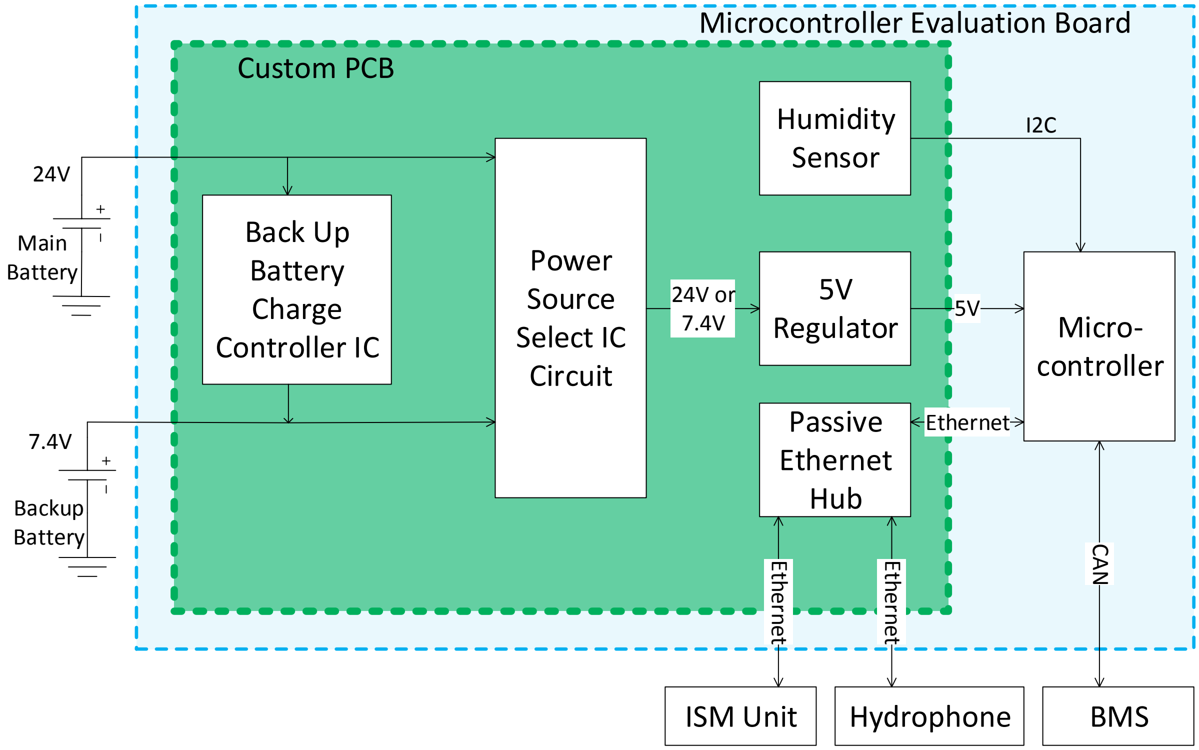


Figure 7: High level block diagram of PMU and MCU evaluation board

For a prototype, the MCU and PMU circuit would ideally be implemented on the same PCB (to save space, lower cost, improve signal integrity). However, the proof-of-concept will be composed of a PMU (custom PCB) attached to the MCU evaluation board through connectors [R55-C]. For the proof-of-concept, it is advantageous to have specialized circuits on separate PCBs in order to verify individual circuit functionality before trying to integrate the complete circuit onto a single PCB.

6.2.1.1. 5 V REGULATOR

The most vital hardware component on the PMU is the 5 V regulator. The step down voltage regulator is required to handle an input voltage of 5.5 V to 29.2 V. The lowest voltage the backup battery can reach is 5.5 V [15]. The 29.2 V maximum is the highest voltage the main battery pack can reach when they are fully charged [13]. With these requirements in mind, the Texas Instruments TPS5420 step down converter was chosen to fulfill the role of regulating the voltage to 5 V. It is capable of taking an input range of 5.5 V to 36 V and providing up to 2 A of output current [14]. Therefore, the 5 V regulator adequately satisfies the 5 V MCU load requirements.

6.2.1.2. BACKUP BATTERY

To fulfill [R64-C], the MCU also has the responsibility of sending warning or error messages to the ISM transmitter should the main battery fail. The MCU (which normally runs off of the 24 V main battery pack) would be rendered useless if the main battery shuts off. Thus, a backup battery was introduced in the design so that the MCU would operate long enough to receive an error message from the BMS and relay that message to the ISM transmitter. The backup battery specification has been mentioned in section 5.2.

6.2.1.3. POWER SOURCE SELECT IC

Since the backup battery was deemed necessary, a power source select became a necessity, since the backup battery would not have the same 24 V rating as the main battery pack [R57-B]. The backup battery chosen has a nominal rating of 7.2 V [15], as mentioned in section 5.2. The LTC 4414 was chosen to serve as a power source select as it can support an input voltage range of 3.5 V to 36 V [17]. A schematic of the source select can be viewed in Appendix D.

The LTC4414 automatically chooses the power source with a higher voltage. If the main battery were to shutoff, the LTC4414 will seamlessly select the backup battery, thus preventing the MCU from momentarily shutting off. The switches in the source select are Si4401 P-channel power MOSFETS, which were chosen to have low drain to source resistance (0.018 Ω) in order to prevent high voltage drops across them [18]. The chosen P-channel power MOSFETs have also been selected to handle 8.7 A loads [18], but as previously calculated, this ability surpasses the load requirement of the MCU and PMU. The LTC4414 is also a highly reliable component [19], which is necessary for the solar application, as the system is expected to run autonomously for months at a time.

6.2.1.4. BACKUP BATTERY CHARGE CONTROLLER IC

There exists a possibility in which the main battery may shut off due to high temperatures. Once this occurs, the backup battery will power the PMU and MCU; however, when the main battery reaches a safe temperature, it will reactivate and resume its role as the main power source [R65-C]. Once the MCU is running off the main battery, the backup battery will be recharged. This feature prevents the need for frequent replacements of the backup battery. The LT3652backup battery charge controller was chosen for this purpose. This IC is capable of providing a constant current charge state and constant voltage charge state, necessary for the backup lithium ion battery [20]. The LT3652 IC was chosen because of its reliability [21].

6.2.1.5. HUMIDITY SENSOR

The humidity sensor, being used to help comply with requirements [R11-A] and [R63-B], is a Honeywell HIH6030-021. All sensor specifications for the Honeywell HIH6030-021 described here are found in the Datasheet [22].

The sensor has an operating temperature range between -40° C and 100° C, complying with [R12-A], and an operating humidity range between 0 and 100%, complying with [R11-A]. Operating at 50% relative humidity (RH) for 5 years, the sensor has a typical accuracy of ±4.5%, with a deviation increase of up to ±1.2%. Thus, it is reasonable to assume that the sensor will remain stable over 10 years, partially complying with [R82-B]. The sensor is also RoHS compliant, fulfilling [R83-B].

The sensor outputs a digital relative humidity reading via I2C and will be directly connected to the I2C ports of the MCU. The PMU must consider the typical sensor accuracy of±4.5% RH when deciding if an emergency alert is to be sent.

6.2.1.6. POWER CONSUMPTION OF THE PMU

The datasheets for each component provided the following current consumption estimates. Current consumption will be verified once the entire system has been built.

Table 1: Power consumption calculations

Component	Max Current Consumption (mA)	Max Voltage Rail (V)	Max Power Consumption (mW)
LTC4414	0.761	24	18.264
LT3652[1]	23.5	24	564
TP5420	4.4	24	105.6
HIH6030-021	0.750	5	3.75
TIVA C[2]	84	3.3	277.2
Max Total Power Consumption			**968.814 mW ~ 1,000 mW**

1. The LT3652 is normally rated to consume 3.5 mA; however, the worst case was considered, in which the boost functionality would activate and add an additional 20 mA of current consumption.
2. The TIVA C current consumption was estimated using:

$$Current\ estimation = (\#\ of\ I/O\ pins) * (\max current\ of\ \ I/O\ \ pin)$$

The number of I/O pins used is 7 (2 for CAN bus, 2 for I2C, 3 for GPIOs) and the max current of an I/O pin is 12 mA.

6.2.2 MICROCONTROLLER SOFTWARE

The MCU within the PMU serves as a communication and control hub within the central module. The MCU will be a Texas Instruments TM4C129xNCZAD processor with CAN and Ethernet capabilities. This fulfills the communication requirements [R67-A] and safety monitoring requirements [R49-A], which will be accomplished through monitoring temperature readings from the BMS. If the battery temperature exceeds safe levels, the PMU will send a command to the BMS to disconnect the contactors. The PMU MCU will also control the relay between the charge controller and battery pack, in order to prevent charging while battery temperature is outside a safe operating range [R52-A].

FreeRTOS, a real-time operating system (RTOS), will run on the MCU in order to allow for effective task management. An RTOS will allow for effective periodic task management with varying priorities and execution rates. The RTOS will run tasks defined in the Application Layer and interface with the various drivers for the hardware peripherals. A figure of the layers and drivers can be seen in Figure 8.

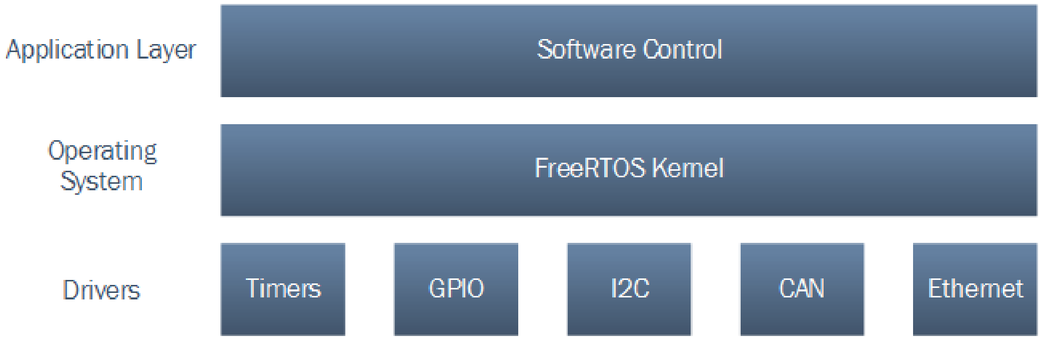


Figure 8: Firmware layers of PMU

The Application Layer will run several independent tasks, each with its own execution period. Diagrams of the logical run-path of several primary tasks can be found in Appendix F.

Communication with the BMS through CAN will operate every 500 ms, which will allow for fine-grain monitoring of battery temperature and state, but will still be slow enough to avoid consuming significant power. The logic flow is seen in Appendix F. If an issue is detected, such as temperature above safe operating range, the PMU will send an

Ethernet message and isolate the battery pack from charging or discharging, and automatically switch power sources in order to continue operating independently for a short time [R21-A, R22-A]. If the temperature is below 0°C, the PMU will disconnect the charge controller from the battery to prevent charging, but will allow the battery to power the load as normal.

The I2C connection to the humidity controller will also be updated every 500 ms (as seen in Appendix F). If the humidity goes above 98%, a shutdown protocol will be initiated in order to prevent damage to the circuitry within the system. Prior to shutting down operation, the MCU will transmit an emergency signal through Ethernet, posting an alert to the webserver that the system is no longer operating. If the humidity is above 85%, the MCU will send an Ethernet warning message to notify the user.

The Ethernet communication task will transmit messages every 5 seconds, except in emergency situations [R68-A]. The task will compile a message structure from the data provided by the BMS and humidity sensor, and transmit it to the ISM transmitter (Appendix F). The transmission Ethernet message structure can be seen below in Table 2.

Table 2: Ethernet transmission messages and possible values

Ethernet Message	Possible Values
Monitoring status	"Normal"
	"Over-temp"
	"Under-temp"
	"Moisture warning"
	"Moisture shutdown"
State of charge	<int>%
Temperature (C)	<float>
Voltage	<float>
Current	<float>

Humidity	<float – 0-100>%
Backup battery status	“Active”
	“Off”
Backup battery charge	<int>%
Command confirmation	“None”
	“Battery disconnected”
	“Battery connected”
	“Duty cycle = <int, int>”

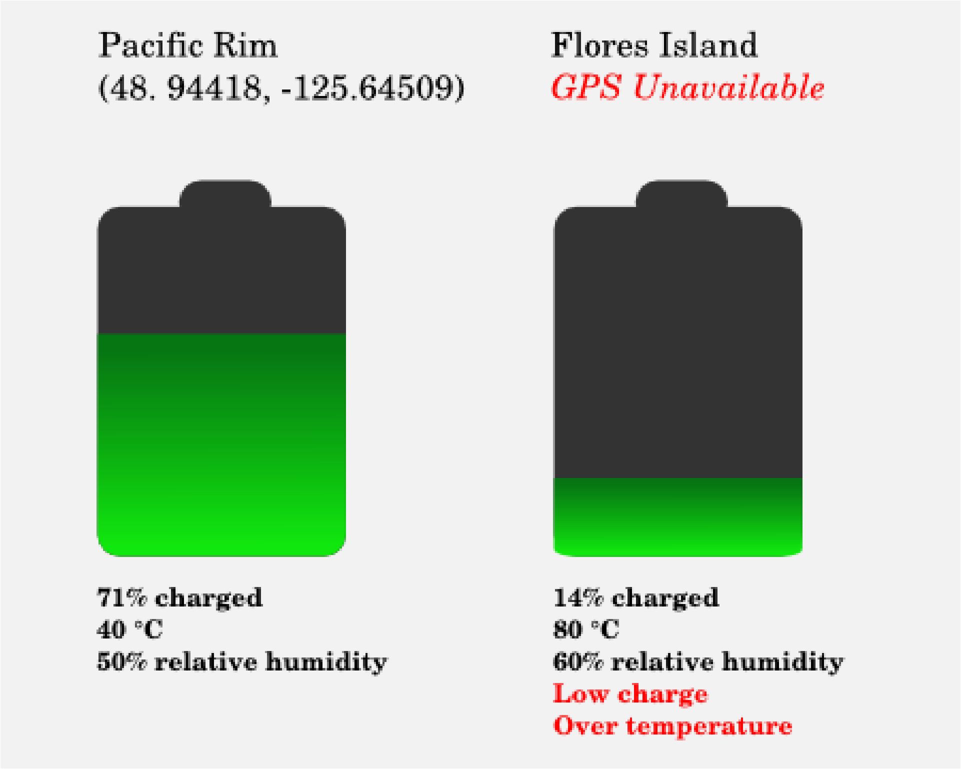
During periods of reduced solar resources, the user can modify the operating duty cycle such that the battery only supplies power for a specified number of minutes, and shuts off for a specified time. The software flow is outlined in Appendix F, Figure 31. The software runs normally until it receives an Ethernet notification telling it to modify the duty cycle. It then sets a shut-off timer for the number of “on” minutes specified, and continues to run as normal. Once the timer expires, the system sets a wake-up timer for the number of “off” minutes specified, sets the peripherals into low-power or shut-off mode, and then the MCU enters low-power mode. Once the wake-up timer goes off, the system enters normal operating mode and restarts the peripherals to normal functionality. The operating system ensures that all tasks execute at the same specified rates as usual. The MCU will receive an Ethernet message of the structure outlined in Table 3.

Table 3: Ethernet receive message for configuring battery

Ethernet Message	Possible Values
Command	"Disconnect battery"
	"Reconnect battery"
	"Set duty cycle"
Duty cycle:	<Minutes on, Minutes off>
Minutes on	<int>
Minutes off	<int>
	RESET = <0, 0>

7. DESKTOP APPLICATION

The desktop application allows the user to monitor the state of the batteries in remote locations and to be notified of any emergency states of unsafe conditions occurring within the battery packs. This is done via a web server which will be able to receive battery updates from various IP addresses [R73-A, R77-B]. Figure 9 shows the main window of the desktop application which displays the monitored information and emergency states of the battery packs at various locations.



Pacific Rim
(48. 94418, -125.64509)

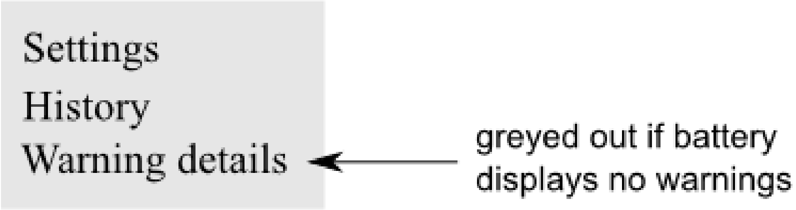
71% charged
40 °C
50% relative humidity

Flores Island
GPS Unavailable

14% charged
80 °C
60% relative humidity
Low charge
Over temperature

Figure 9: Main window showing battery statuses at various locations

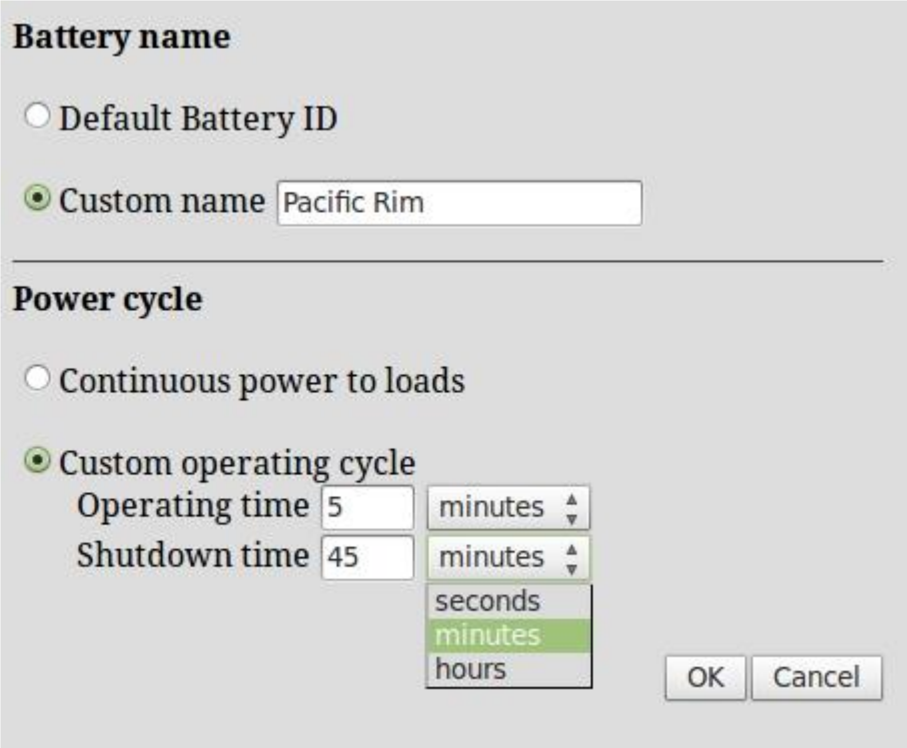
Clicking on a battery icon will bring up a menu as shown in Figure 10.



greyed out if battery displays no warnings

Figure 10: Menu for each battery pack

The settings menu item brings up a window as seen in Figure 11. The default battery ID will be the IP address of the associated hydrophone, but the user can also give it a custom name. The settings window also allows the user to remotely modify the battery operating duty cycle [R2-A].



Battery name

○ Default Battery ID

● Custom name: Pacific Rim

Power cycle

○ Continuous power to loads

● Custom operating cycle

Operating time: 5 minutes

Shutdown time: 45 minutes

Figure 11: Main window showing battery statuses at various locations

The history menu item from Figure 10 brings up the window shown in Figure 12. A database will be developed to store and retrieve historical battery monitoring data. This allows the user to monitor the charging and discharging of the batteries in varying locations over a period of time [R79-C].

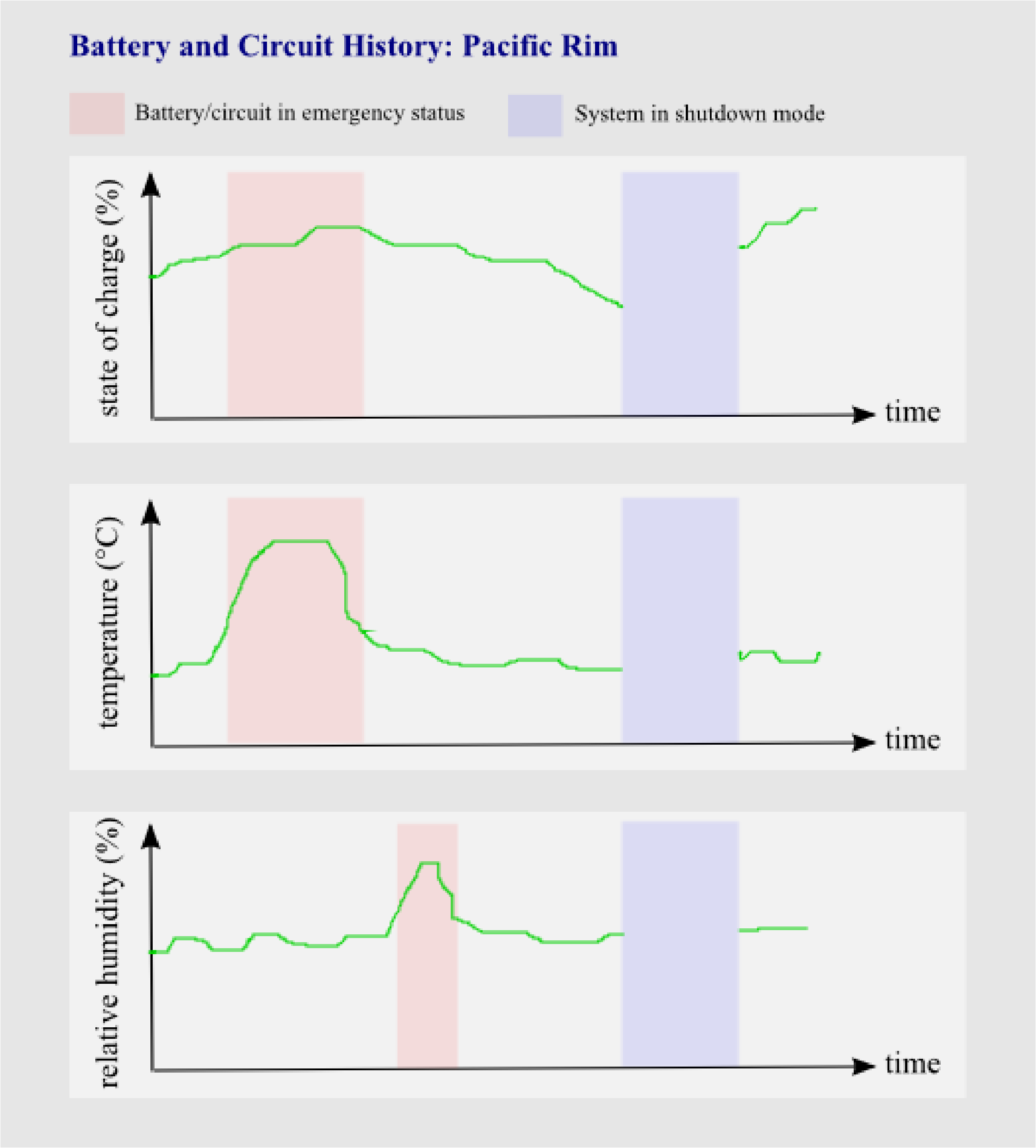


Figure 12: Main window showing battery statuses at various locations

8. SYSTEM TEST PLAN

8.1. CHARGING MODULE FUNCTIONALITY

Under normal operating conditions, the solar panels should not output a current large enough to trip the OCPD (9 A circuit breaker). Successful operation of the OCPD between the solar panels and the battery pack will be verified by replacing the solar panels and using a power supply to source 9 A of current through the OCPD. The tester will observe whether or not the circuit breaker has successfully tripped.

The solar panels will be connected in series and the open circuit voltage will be verified with a voltmeter. The voltmeter should read close to 44.6 V, since the open circuit voltage of one module is 22.3 V [2]. The short circuit current will also be verified with an ammeter. The ammeter should read close to 5.28 A – the short circuit current of each solar panels.

8.2. HARDWARE/ELECTRONICS

The PMU electronics will be connected as shown in Figure 7. The backup batteries will first be connected to a dummy load resistor for ten minutes to drain some of their capacity, and then reconnected to the PMU electronics. An ammeter will be connected in series between the backup battery charge controller IC and the backup battery pack, and a voltmeter will be connected across the backup battery terminals. The ammeter should read a current under 2 A (Appendix D), indicating that the backup battery charge controller IC is indeed charging the backup batteries. The voltmeter should read under 8.2 V, indicating that the backup batteries have not yet reached 100% SOC. When the backup battery pack voltage reaches close to 8.2 V, the backup battery charge controller IC should stop charging: the tester should now verify that the ammeter reading is zero amps.

A voltmeter will be connected in parallel to the input of the 5 V regulator. Under normal operating conditions, the voltmeter should read between 20-29.2 V – the output voltage of the main battery pack. This means that the power source select circuit has chosen to use the main battery pack as the power source for the PMU. The tester will then disconnect the main battery pack from the source select circuit (simulating a BMS contactor disconnect in the event of over-temperature, over-voltage, or over-current), and verify that the voltmeter now reads between 7-8.2 V – the output voltage of the backup batteries. This means that the power source select circuit has chosen the backup batteries as the power source for the PMU electronics.

8.3. MICROCONTROLLER POWER CONTROL

8.3.1. BATTERY MONITORING AND COMMUNICATION

Battery monitoring will be tested through successful display on a desktop system. The tester must ensure that the battery is properly connected to the BMS through the RS-485 port. The PMU must be securely connected to the BMS via a CAN network with a terminating resistor. The PMU must be connected to the humidity sensor via two wires for I2C communication. The tester can monitor the communications between the BMS and PMU or the humidity sensor and PMU via a logic analyzer. The tester must observe:

- A remote CAN frame transmitted from the PMU to the BMS to obtain SOC, temperature, voltage, and current readouts for all connected battery modules.
- A CAN data frame is transmitted by the BMS in response to the request, containing the required data.
- An I2C start condition and data request to the humidity sensor being initiated by the PMU. After roughly 50ms, the PMU will send a read request to the sensor. This is followed by a reply from the sensor of 2 bytes in length before the PMU acknowledges the reply and terminates communication.

8.3.2. BATTERY SAFETY SHUTOFF

The PMU must be able to quickly respond to changes in the environment that result in unsafe operating conditions. The moisture levels can be simulated by holding the sensor above a vapor source (such as boiling water), though it would be difficult to ensure that the measured moisture is at the exact threshold level. It may also be difficult to simulate battery overcharge conditions, but the expected behaviors are listed below:

- If the battery indicates a temperature over 45° C, the PMU sends a CAN data frame to disconnect the contactors. The PMU also disconnects the relay connecting the charge controller to the battery.
- If the battery indicates a temperature below 0° C, the PMU does not send a CAN frame to the BMS, but it disconnects the relay to the charge controller.
- If the battery detects a moisture level above 98%, it sends an immediate Ethernet message to the ISM transmitter, indicating that the system will shut down. The system then shuts down the peripherals and CPU.

8.3.3. ISM TRANSMITTER COMMUNICATION

The device must transmit standard battery status updates every 5 seconds to the ISM transmitter. This can be tested by connecting the PMU board via Ethernet to any standard computer with a packet sniffer installed. The packet sniffer must detect the messages coming from the MCU's IP address, with the proper format specified in Table 1. Note, not all values will be displayed on the desktop application, but they will be transmitted in order to assist with remote debugging. The Ethernet transmit message structure must reflect the structure outlined in Table 2, and the receive message must reflect the structure in Table 3.

8.4. DESKTOP APPLICATION

The desktop application will be tested for the quality of its user interface, ability to receive the battery information, and to configure the duty cycle. A tester will perform the operations required to access the application and view the battery information. In particular, the batteries that are within range should be automatically detected and displayed in the main window of the application.

The tester will then attempt to view the history of the battery charge. For the demo, the system will be connected for a limited time, so the application is permitted to display a graph of the last hour. Finally, the tester should be able to set a duty cycle for the battery system, and the PMU should configure the settings and respond with a confirmation message.

9. CONCLUSION

AquaSol Solutions is committed to designing safe and reliable solar charging systems that can withstand the harsh marine environments of coastal British Columbia. The design considerations for an offshore solar charging system that are necessary to build a successful project proof-of-concept have been presented.

The solar panels, batteries, and circuit breakers were designed based on DC load and monitoring system power consumption. Special considerations for the months with the lowest solar resource were taken into account to avoid depleting the battery pack, while providing enough solar energy throughout the day to keep the system running.

Interface design and wiring layout designed to ensure reliable connections and robust communication between the subsystems were presented. Dependable interconnections between the subsystems are crucial for the successful operation of a system in a harsh marine environment.

Backup batteries and charge controlling circuitry have been designed to provide backup power to the PMU in case the BMS disconnects the main 24 V battery pack due to an over-temperature, over-voltage, or over-current condition. In such an event, the backup batteries will provide power for a sufficient amount of time so that the PMU fault information can be transmitted to a base station.

The MCU was designed to meet the communication and safety monitoring requirements of the system. A real-time operating system will run on the MCU to facilitate task management. A desktop application was also designed to receive MCU monitoring information via the ISM transmitter, and to display the information in a user-friendly environment.

The functional specifications have served as a guideline for the design considerations presented in this document. Assembly of the system, based on these design specifications, has already commenced.

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APPENDIX A: CONNECTORS

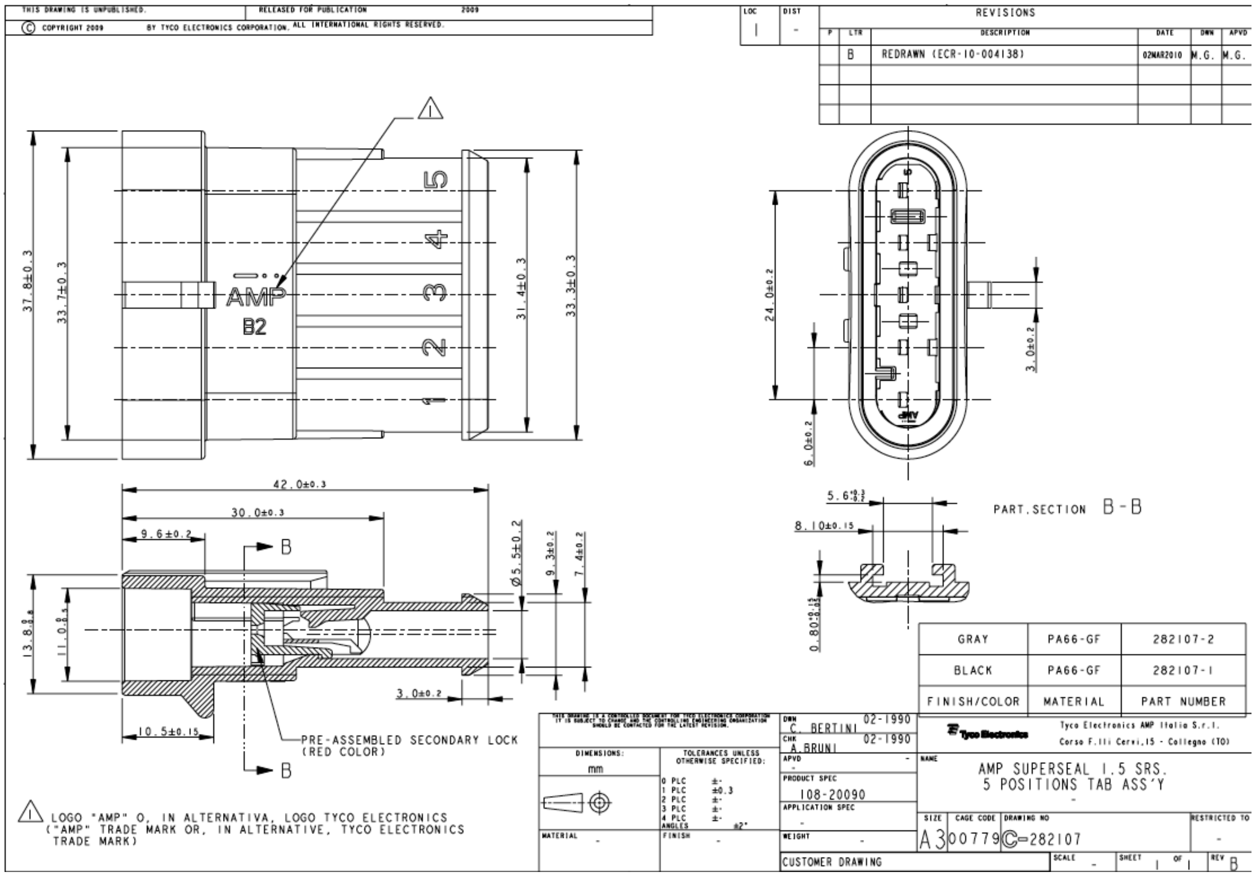
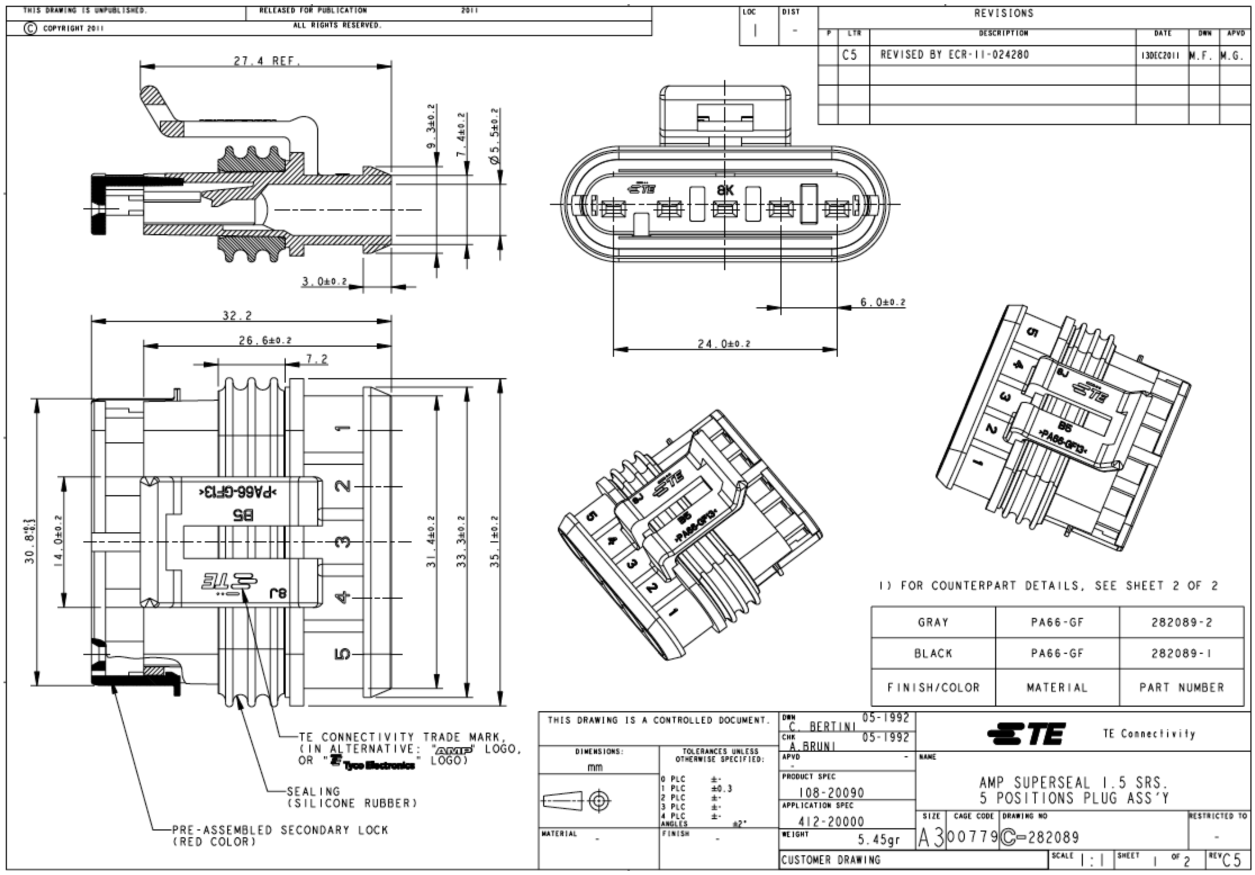


Figure 13: Amp Superseal 1.5mm 5pin female connector



GRAY	PA66-GF	282089-2
BLACK	PA66-GF	282089-1
FINISH/COLOR	MATERIAL	PART NUMBER

Figure 14: Amp Superseal 1.5mm 5pin male connector

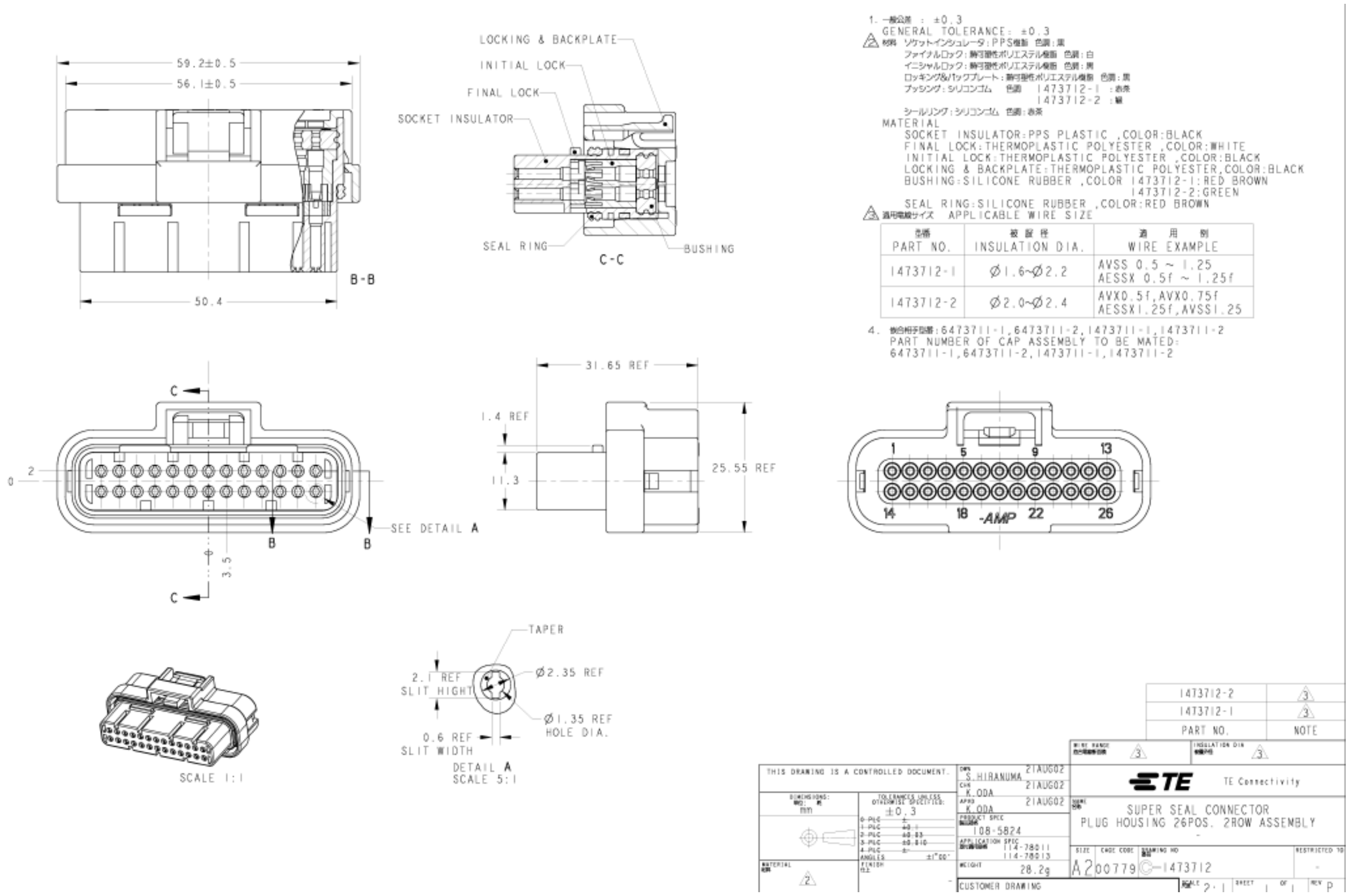
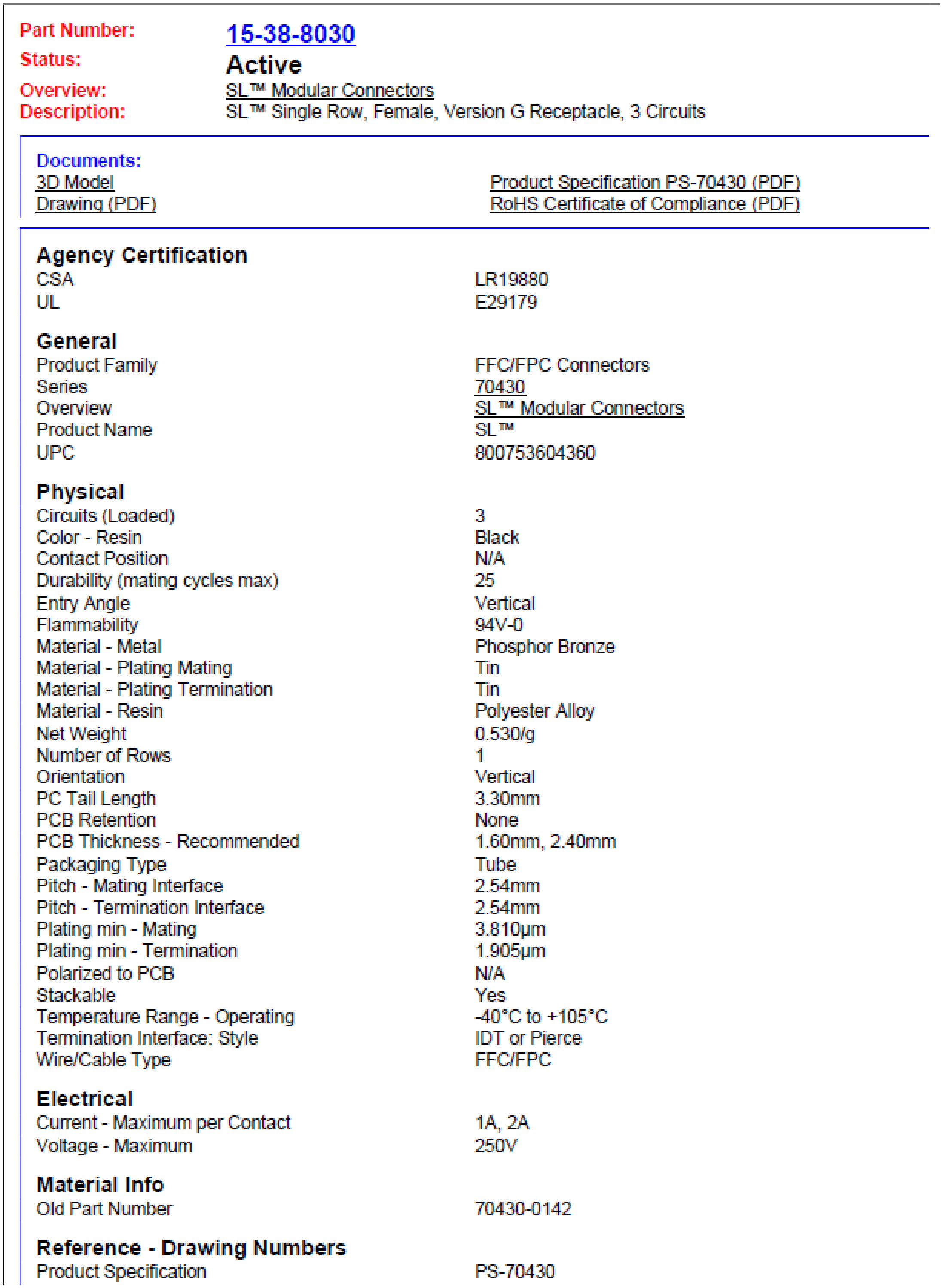


Figure 15: Amp Superseal 1.0mm 26pin male connector



Part Number:	15-38-8030
Status:	Active
Overview:	SL™ Modular Connectors
Description:	SL™ Single Row, Female, Version G Receptacle, 3 Circuits

Documents:

3D Model	Product Specification PS-70430 (PDF)
Drawing (PDF)	RoHS Certificate of Compliance (PDF)

Agency Certification

CSA	LR19880
UL	E29179

General

Product Family	FFC/FPC Connectors
Series	70430
Overview	SL™ Modular Connectors
Product Name	SL™
UPC	800753604360

Physical

Circuits (Loaded)	3
Color - Resin	Black
Contact Position	N/A
Durability (mating cycles max)	25
Entry Angle	Vertical
Flammability	94V-0
Material - Metal	Phosphor Bronze
Material - Plating Mating	Tin
Material - Plating Termination	Tin
Material - Resin	Polyester Alloy
Net Weight	0.530/g
Number of Rows	1
Orientation	Vertical
PC Tail Length	3.30mm
PCB Retention	None
PCB Thickness - Recommended	1.60mm, 2.40mm
Packaging Type	Tube
Pitch - Mating Interface	2.54mm
Pitch - Termination Interface	2.54mm
Plating min - Mating	3.810µm
Plating min - Termination	1.905µm
Polarized to PCB	N/A
Stackable	Yes
Temperature Range - Operating	-40°C to +105°C
Termination Interface: Style	IDT or Pierce
Wire/Cable Type	FFC/FPC

Electrical

Current - Maximum per Contact	1A, 2A
Voltage - Maximum	250V

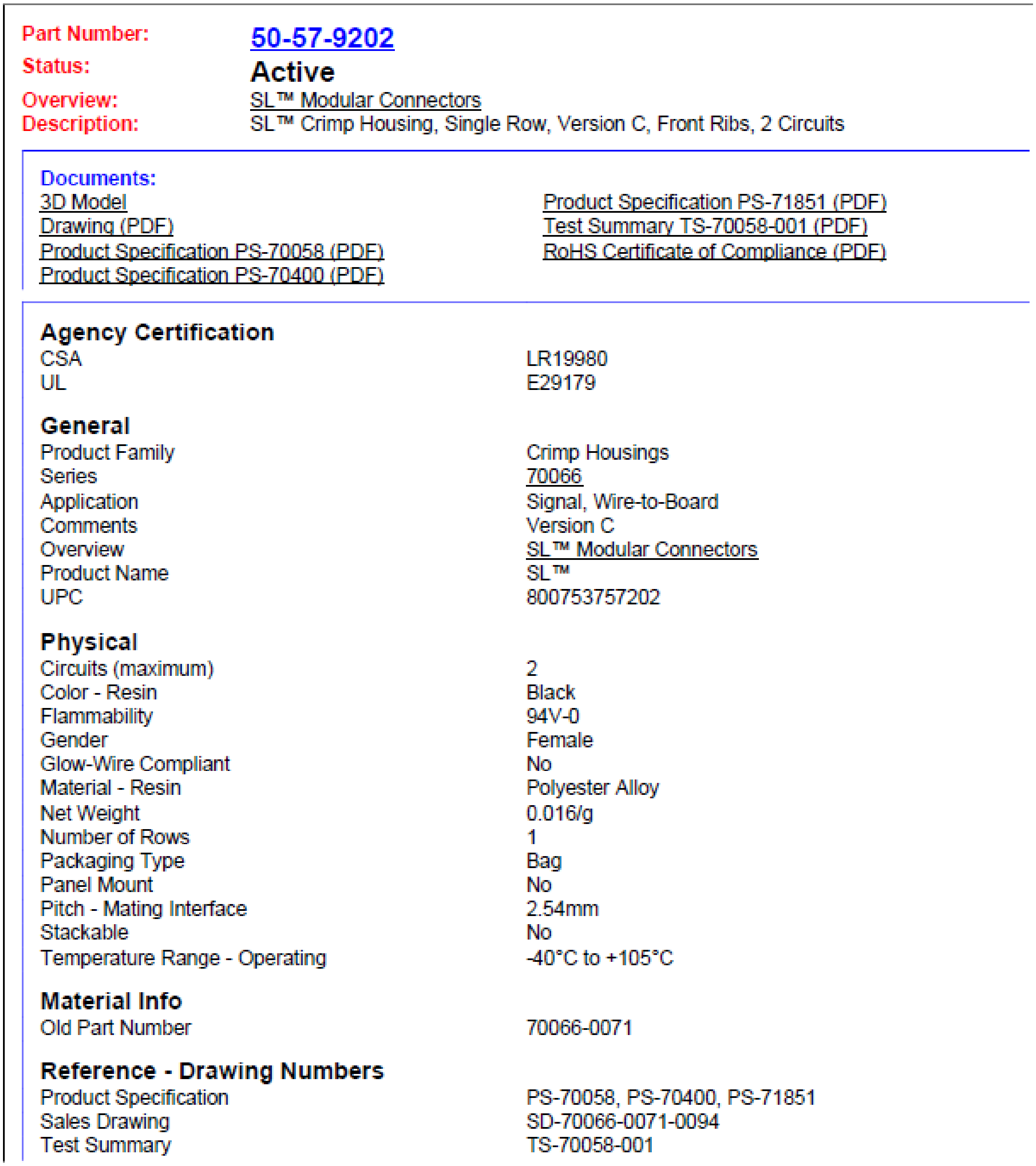
Material Info

Old Part Number	70430-0142

Reference - Drawing Numbers

Product Specification	PS-70430

Figure 16: Molex 15388030 connector



Part Number:	**50-57-9202**
Status:	**Active**
Overview:	SL™ Modular Connectors
Description:	SL™ Crimp Housing, Single Row, Version C, Front Ribs, 2 Circuits

Documents:

- 3D Model
- Drawing (PDF)
- Product Specification PS-70058 (PDF)
- Product Specification PS-70400 (PDF)
- Product Specification PS-71851 (PDF)
- Test Summary TS-70058-001 (PDF)
- RoHS Certificate of Compliance (PDF)

Agency Certification

CSA	LR19980
UL	E29179

General

Product Family	Crimp Housings
Series	70066
Application	Signal, Wire-to-Board
Comments	Version C
Overview	SL™ Modular Connectors
Product Name	SL™
UPC	800753757202

Physical

Circuits (maximum)	2
Color - Resin	Black
Flammability	94V-0
Gender	Female
Glow-Wire Compliant	No
Material - Resin	Polyester Alloy
Net Weight	0.016/g
Number of Rows	1
Packaging Type	Bag
Panel Mount	No
Pitch - Mating Interface	2.54mm
Stackable	No
Temperature Range - Operating	-40°C to +105°C

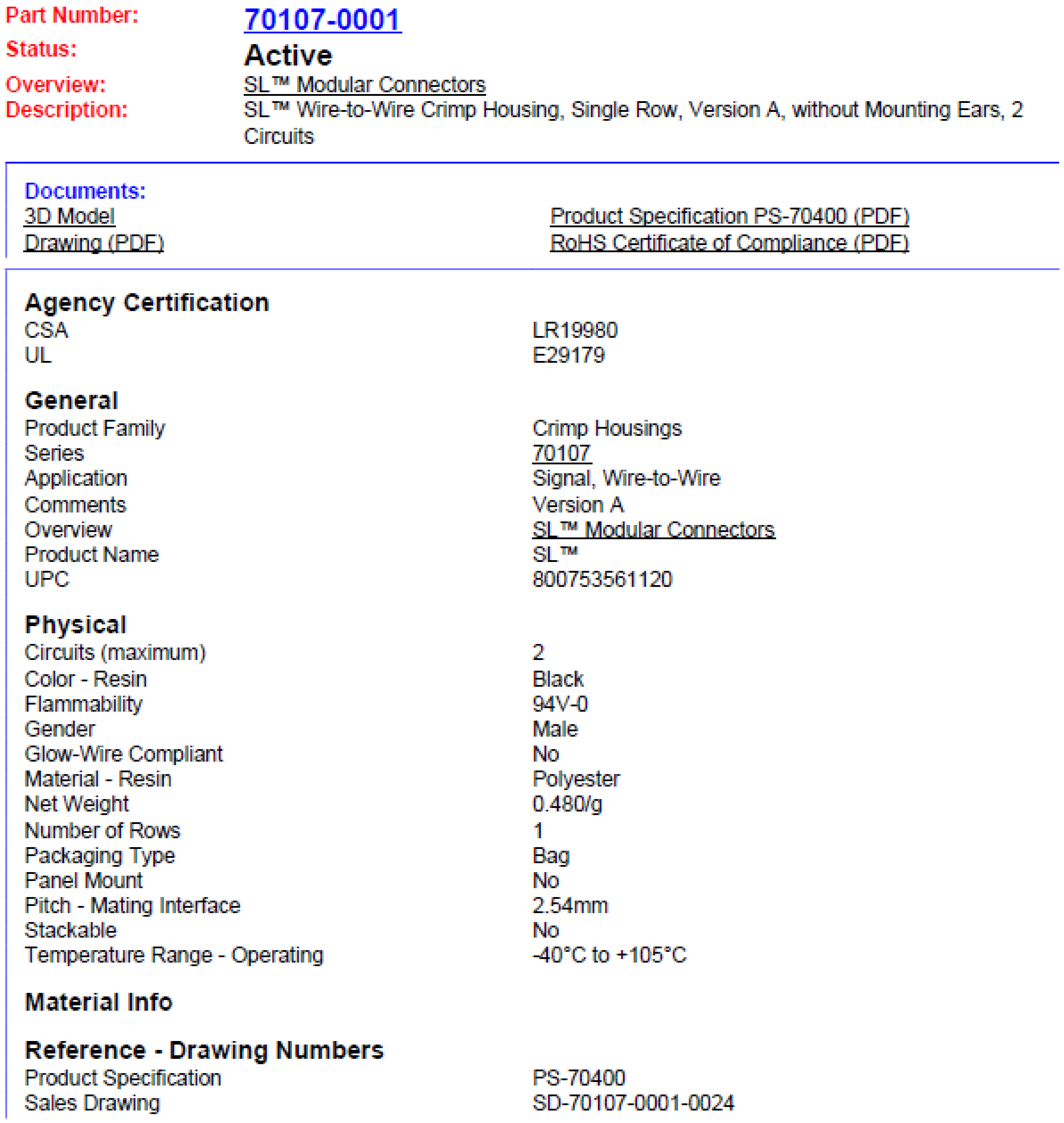
Material Info

Old Part Number	70066-0071

Reference - Drawing Numbers

Product Specification	PS-70058, PS-70400, PS-71851
Sales Drawing	SD-70066-0071-0094
Test Summary	TS-70058-001

Figure 17: Molex 50579202 connector



Part Number:	70107-0001
Status:	**Active**
Overview:	SL™ Modular Connectors
Description:	SL™ Wire-to-Wire Crimp Housing, Single Row, Version A, without Mounting Ears, 2 Circuits

Documents:

3D Model	Product Specification PS-70400 (PDF)
Drawing (PDF)	RoHS Certificate of Compliance (PDF)

Agency Certification

CSA	LR19980
UL	E29179

General

Product Family	Crimp Housings
Series	70107
Application	Signal, Wire-to-Wire
Comments	Version A
Overview	SL™ Modular Connectors
Product Name	SL™
UPC	800753561120

Physical

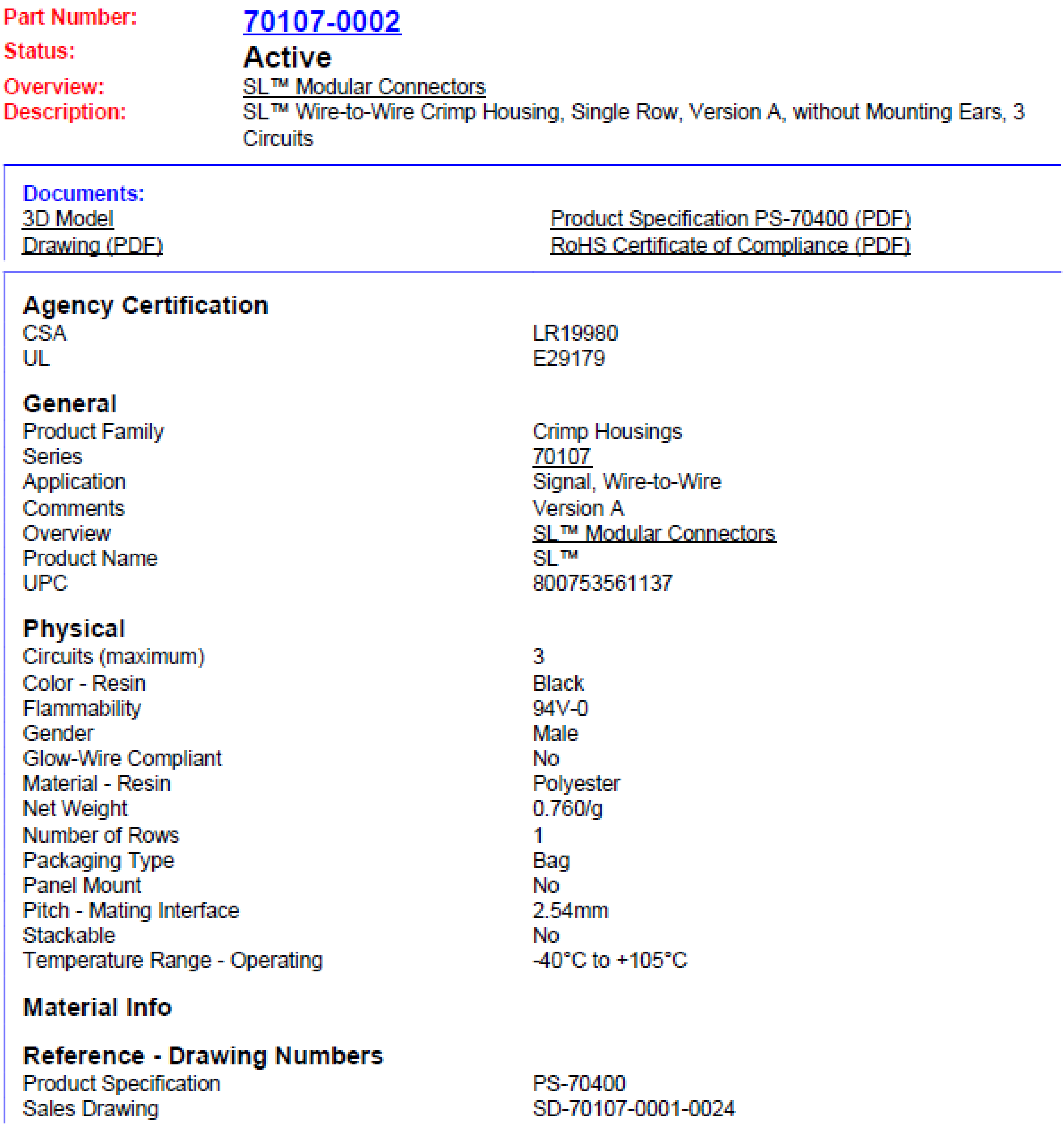
Circuits (maximum)	2
Color - Resin	Black
Flammability	94V-0
Gender	Male
Glow-Wire Compliant	No
Material - Resin	Polyester
Net Weight	0.480/g
Number of Rows	1
Packaging Type	Bag
Panel Mount	No
Pitch - Mating Interface	2.54mm
Stackable	No
Temperature Range - Operating	-40°C to +105°C

Material Info

Reference - Drawing Numbers

Product Specification	PS-70400
Sales Drawing	SD-70107-0001-0024

Figure 18: Molex 701070001 connector



Part Number:	70107-0002
Status:	Active
Overview:	SL™ Modular Connectors
Description:	SL™ Wire-to-Wire Crimp Housing, Single Row, Version A, without Mounting Ears, 3 Circuits

Documents:

3D Model	Product Specification PS-70400 (PDF)
Drawing (PDF)	RoHS Certificate of Compliance (PDF)

Agency Certification

CSA	LR19980
UL	E29179

General

Product Family	Crimp Housings
Series	70107
Application	Signal, Wire-to-Wire
Comments	Version A
Overview	SL™ Modular Connectors
Product Name	SL™
UPC	800753561137

Physical

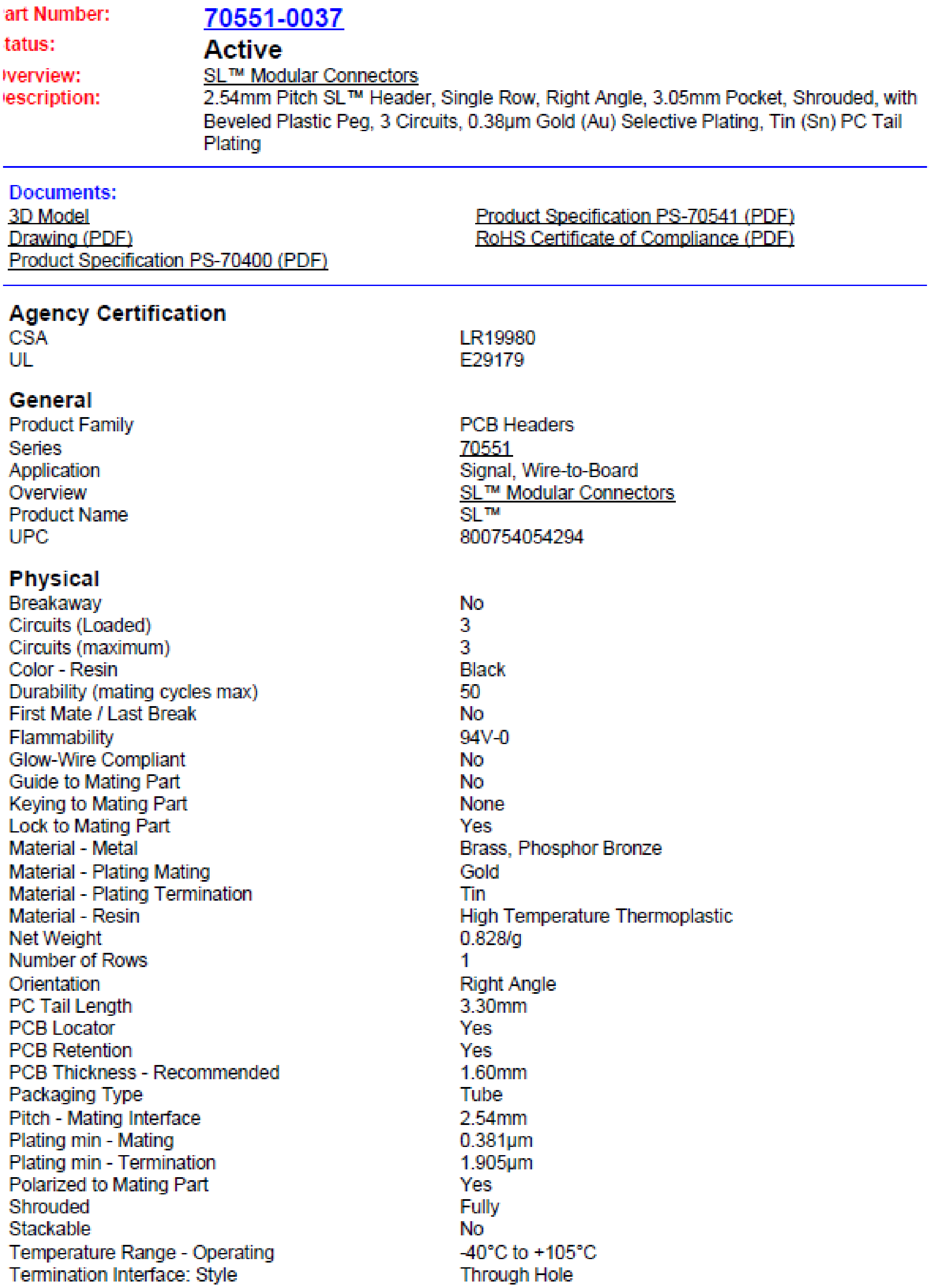
Circuits (maximum)	3
Color - Resin	Black
Flammability	94V-0
Gender	Male
Glow-Wire Compliant	No
Material - Resin	Polyester
Net Weight	0.760/g
Number of Rows	1
Packaging Type	Bag
Panel Mount	No
Pitch - Mating Interface	2.54mm
Stackable	No
Temperature Range - Operating	-40°C to +105°C

Material Info

Reference - Drawing Numbers

Product Specification	PS-70400
Sales Drawing	SD-70107-0001-0024

Figure 19: Molex 701070002 connector



art Number:	70551-0037
tatus:	Active
verview:	SL™ Modular Connectors
escription:	2.54mm Pitch SL™ Header, Single Row, Right Angle, 3.05mm Pocket, Shrouded, with Beveled Plastic Peg, 3 Circuits, 0.38µm Gold (Au) Selective Plating, Tin (Sn) PC Tail Plating

Documents:

- 3D Model
- Drawing (PDF)
- Product Specification PS-70400 (PDF)
- Product Specification PS-70541 (PDF)
- RoHS Certificate of Compliance (PDF)

Agency Certification

CSA	LR19980
UL	E29179

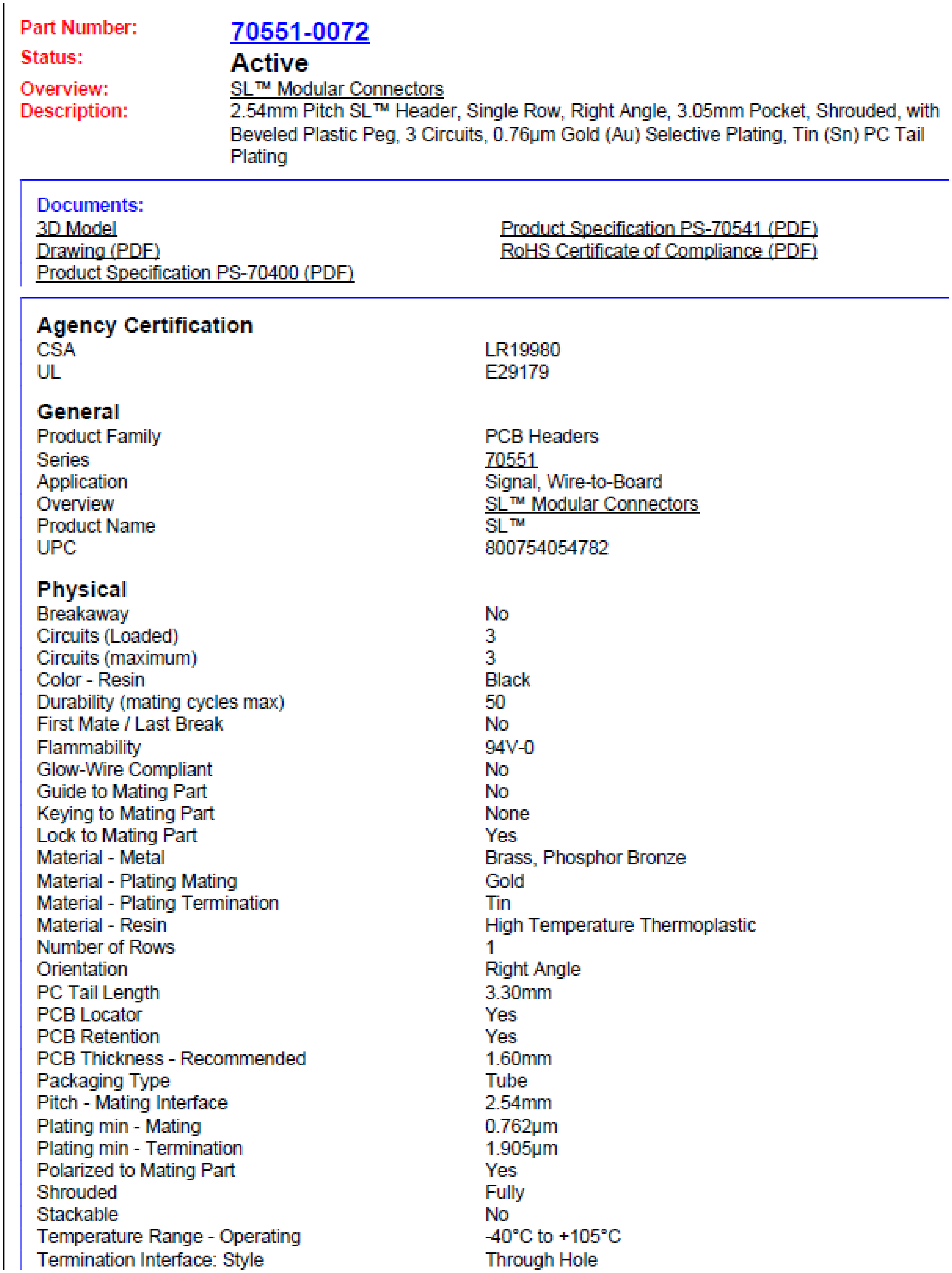
General

Product Family	PCB Headers
Series	70551
Application	Signal, Wire-to-Board
Overview	SL™ Modular Connectors
Product Name	SL™
UPC	800754054294

Physical

Breakaway	No
Circuits (Loaded)	3
Circuits (maximum)	3
Color - Resin	Black
Durability (mating cycles max)	50
First Mate / Last Break	No
Flammability	94V-0
Glow-Wire Compliant	No
Guide to Mating Part	No
Keying to Mating Part	None
Lock to Mating Part	Yes
Material - Metal	Brass, Phosphor Bronze
Material - Plating Mating	Gold
Material - Plating Termination	Tin
Material - Resin	High Temperature Thermoplastic
Net Weight	0.828/g
Number of Rows	1
Orientation	Right Angle
PC Tail Length	3.30mm
PCB Locator	Yes
PCB Retention	Yes
PCB Thickness - Recommended	1.60mm
Packaging Type	Tube
Pitch - Mating Interface	2.54mm
Plating min - Mating	0.381µm
Plating min - Termination	1.905µm
Polarized to Mating Part	Yes
Shrouded	Fully
Stackable	No
Temperature Range - Operating	-40°C to +105°C
Termination Interface: Style	Through Hole

Figure 20: Molex 705510037 connector



Part Number:	**70551-0072**
Status:	**Active**
Overview:	SL™ Modular Connectors
Description:	2.54mm Pitch SL™ Header, Single Row, Right Angle, 3.05mm Pocket, Shrouded, with Beveled Plastic Peg, 3 Circuits, 0.76µm Gold (Au) Selective Plating, Tin (Sn) PC Tail Plating

Documents:

3D Model	Product Specification PS-70541 (PDF)
Drawing (PDF)	RoHS Certificate of Compliance (PDF)
Product Specification PS-70400 (PDF)	

Agency Certification

CSA	LR19980
UL	E29179

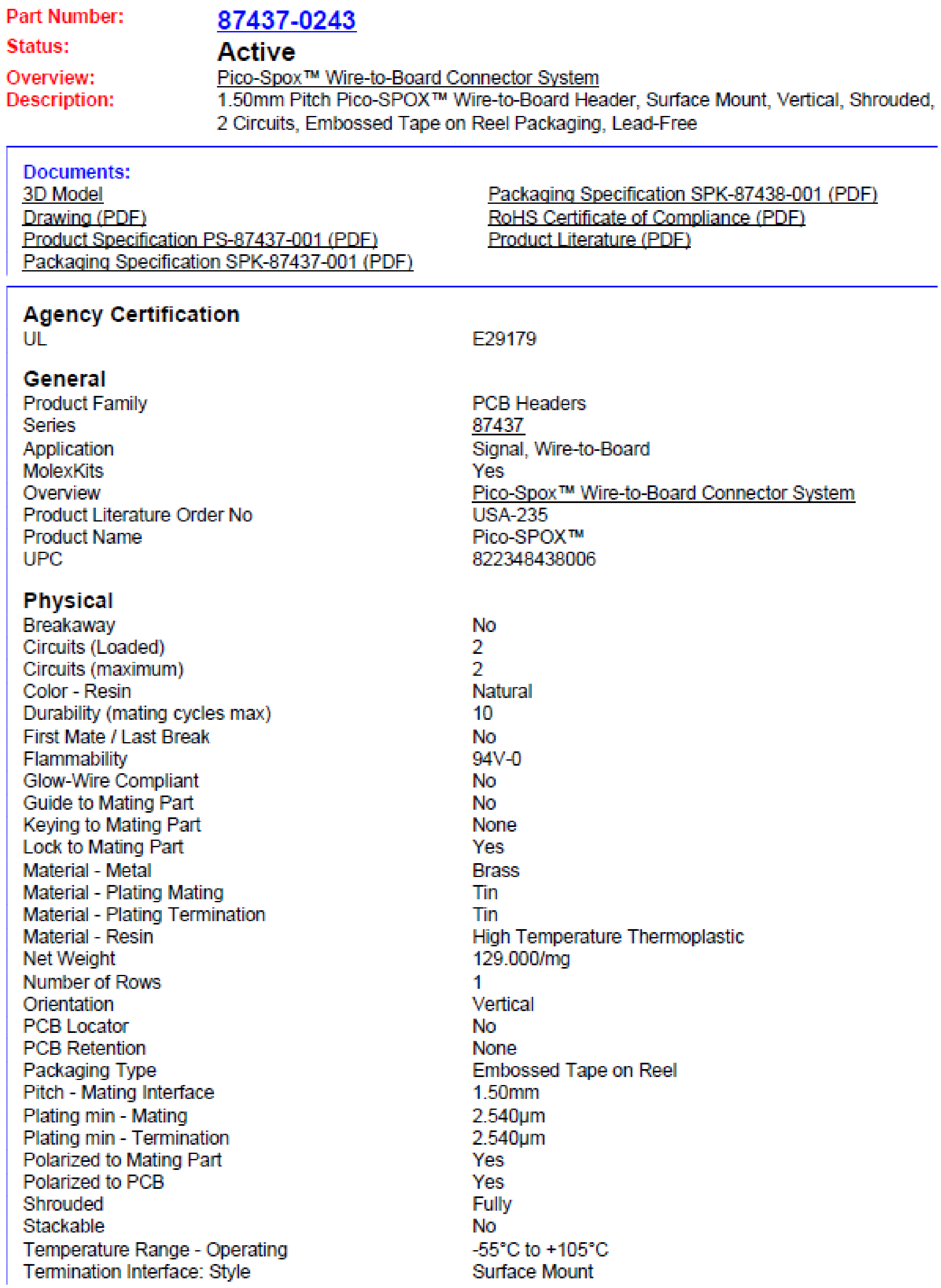
General

Product Family	PCB Headers
Series	70551
Application	Signal, Wire-to-Board
Overview	SL™ Modular Connectors
Product Name	SL™
UPC	800754054782

Physical

Breakaway	No
Circuits (Loaded)	3
Circuits (maximum)	3
Color - Resin	Black
Durability (mating cycles max)	50
First Mate / Last Break	No
Flammability	94V-0
Glow-Wire Compliant	No
Guide to Mating Part	No
Keying to Mating Part	None
Lock to Mating Part	Yes
Material - Metal	Brass, Phosphor Bronze
Material - Plating Mating	Gold
Material - Plating Termination	Tin
Material - Resin	High Temperature Thermoplastic
Number of Rows	1
Orientation	Right Angle
PC Tail Length	3.30mm
PCB Locator	Yes
PCB Retention	Yes
PCB Thickness - Recommended	1.60mm
Packaging Type	Tube
Pitch - Mating Interface	2.54mm
Plating min - Mating	0.762µm
Plating min - Termination	1.905µm
Polarized to Mating Part	Yes
Shrouded	Fully
Stackable	No
Temperature Range - Operating	-40°C to +105°C
Termination Interface: Style	Through Hole

Figure 21: Molex 705510072 connector



Part Number:	87437-0243
Status:	**Active**
Overview:	Pico-Spox™ Wire-to-Board Connector System
Description:	1.50mm Pitch Pico-SPOX™ Wire-to-Board Header, Surface Mount, Vertical, Shrouded, 2 Circuits, Embossed Tape on Reel Packaging, Lead-Free

Documents:

- 3D Model
- Drawing (PDF)
- Product Specification PS-87437-001 (PDF)
- Packaging Specification SPK-87437-001 (PDF)
- Packaging Specification SPK-87438-001 (PDF)
- RoHS Certificate of Compliance (PDF)
- Product Literature (PDF)

Agency Certification

UL	E29179

General

Product Family	PCB Headers
Series	87437
Application	Signal, Wire-to-Board
MolexKits	Yes
Overview	Pico-Spox™ Wire-to-Board Connector System
Product Literature Order No	USA-235
Product Name	Pico-SPOX™
UPC	822348438006

Physical

Breakaway	No
Circuits (Loaded)	2
Circuits (maximum)	2
Color - Resin	Natural
Durability (mating cycles max)	10
First Mate / Last Break	No
Flammability	94V-0
Glow-Wire Compliant	No
Guide to Mating Part	No
Keying to Mating Part	None
Lock to Mating Part	Yes
Material - Metal	Brass
Material - Plating Mating	Tin
Material - Plating Termination	Tin
Material - Resin	High Temperature Thermoplastic
Net Weight	129.000/mg
Number of Rows	1
Orientation	Vertical
PCB Locator	No
PCB Retention	None
Packaging Type	Embossed Tape on Reel
Pitch - Mating Interface	1.50mm
Plating min - Mating	2.540µm
Plating min - Termination	2.540µm
Polarized to Mating Part	Yes
Polarized to PCB	Yes
Shrouded	Fully
Stackable	No
Temperature Range - Operating	-55°C to +105°C
Termination Interface: Style	Surface Mount

Figure 22: Molex 874370243 connector

APPENDIX B: WIRING LAYOUT

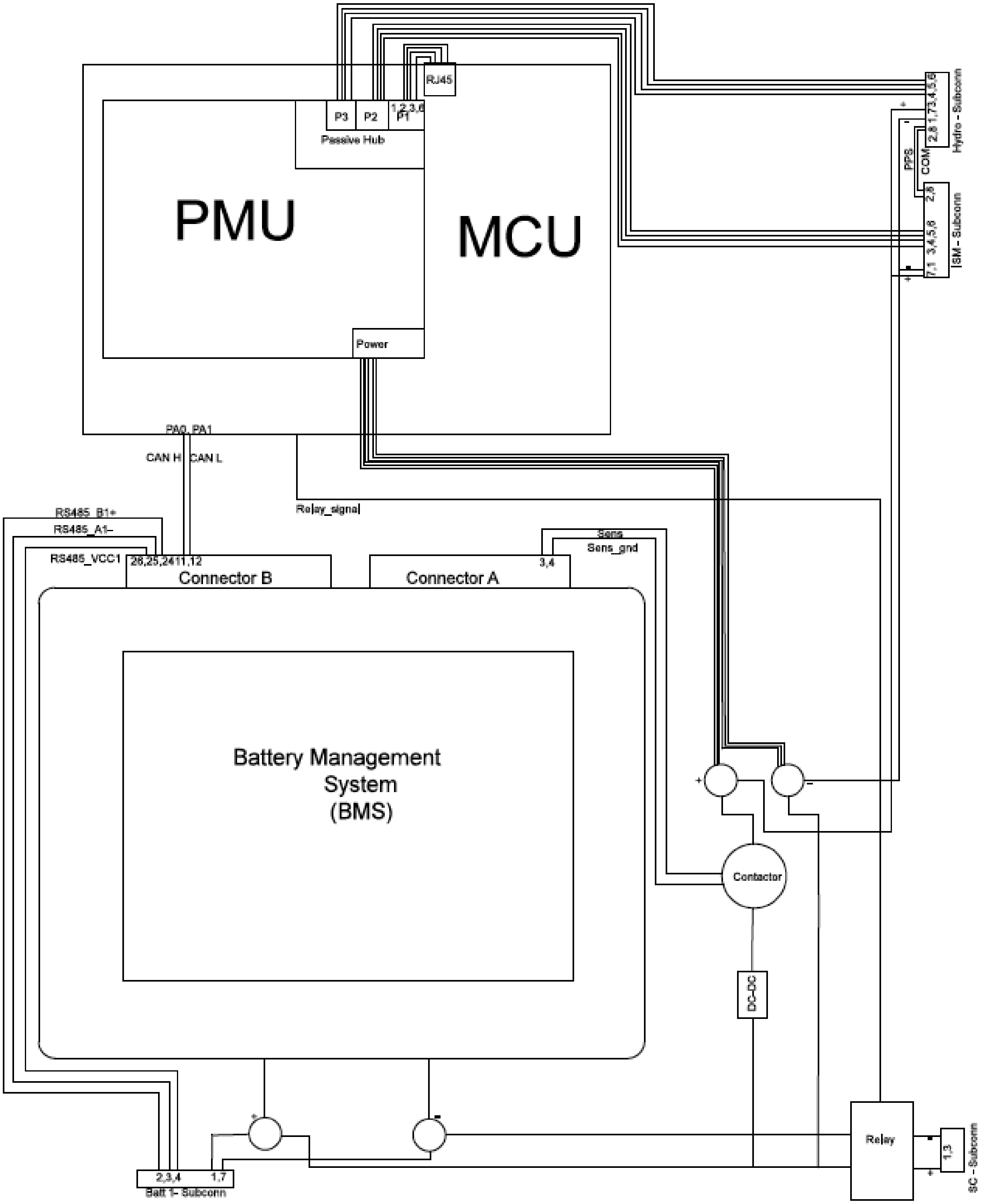


Figure 23: Wiring layout

APPENDIX C: PASSIVE HUB CIRCUIT DIAGRAM

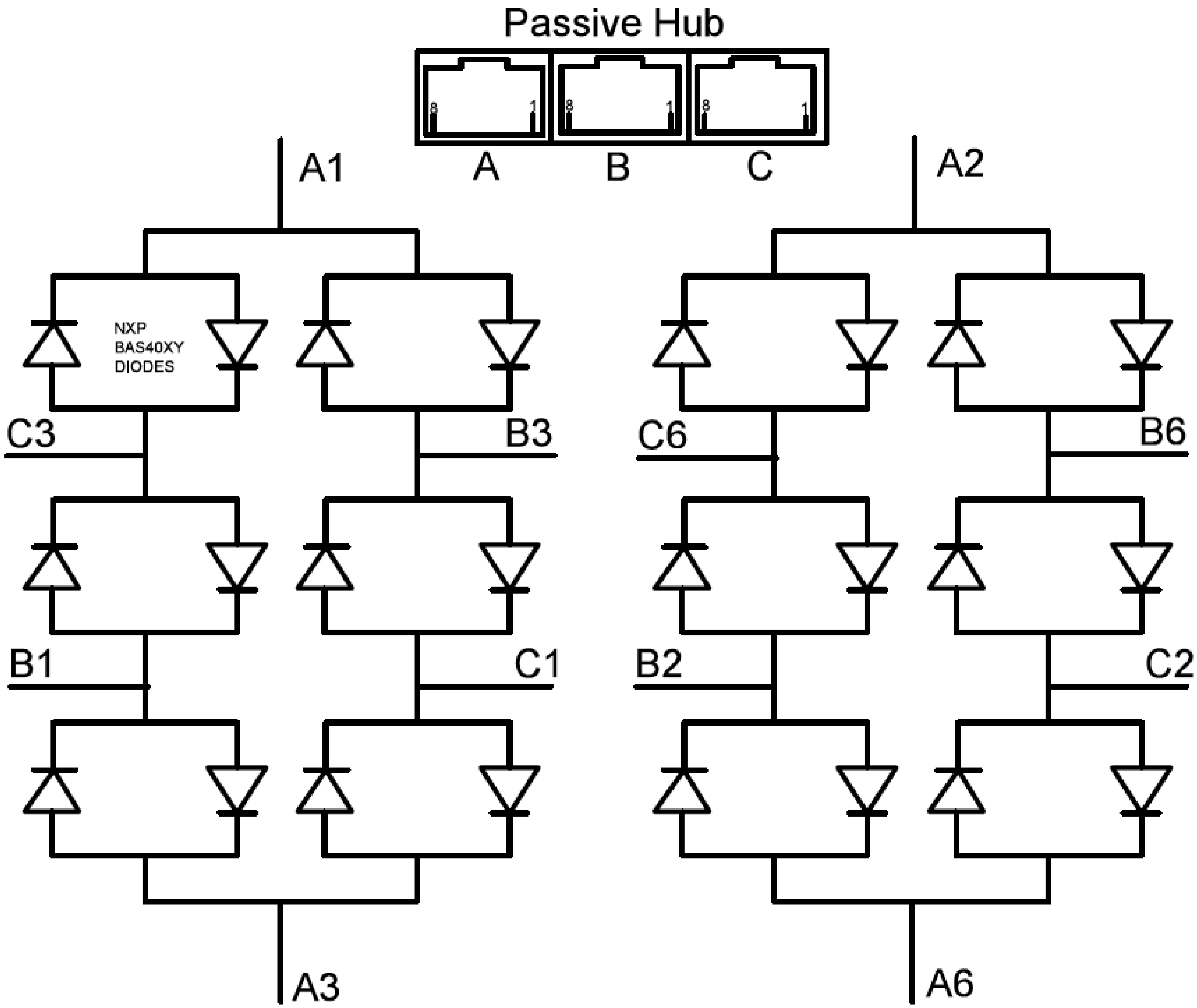
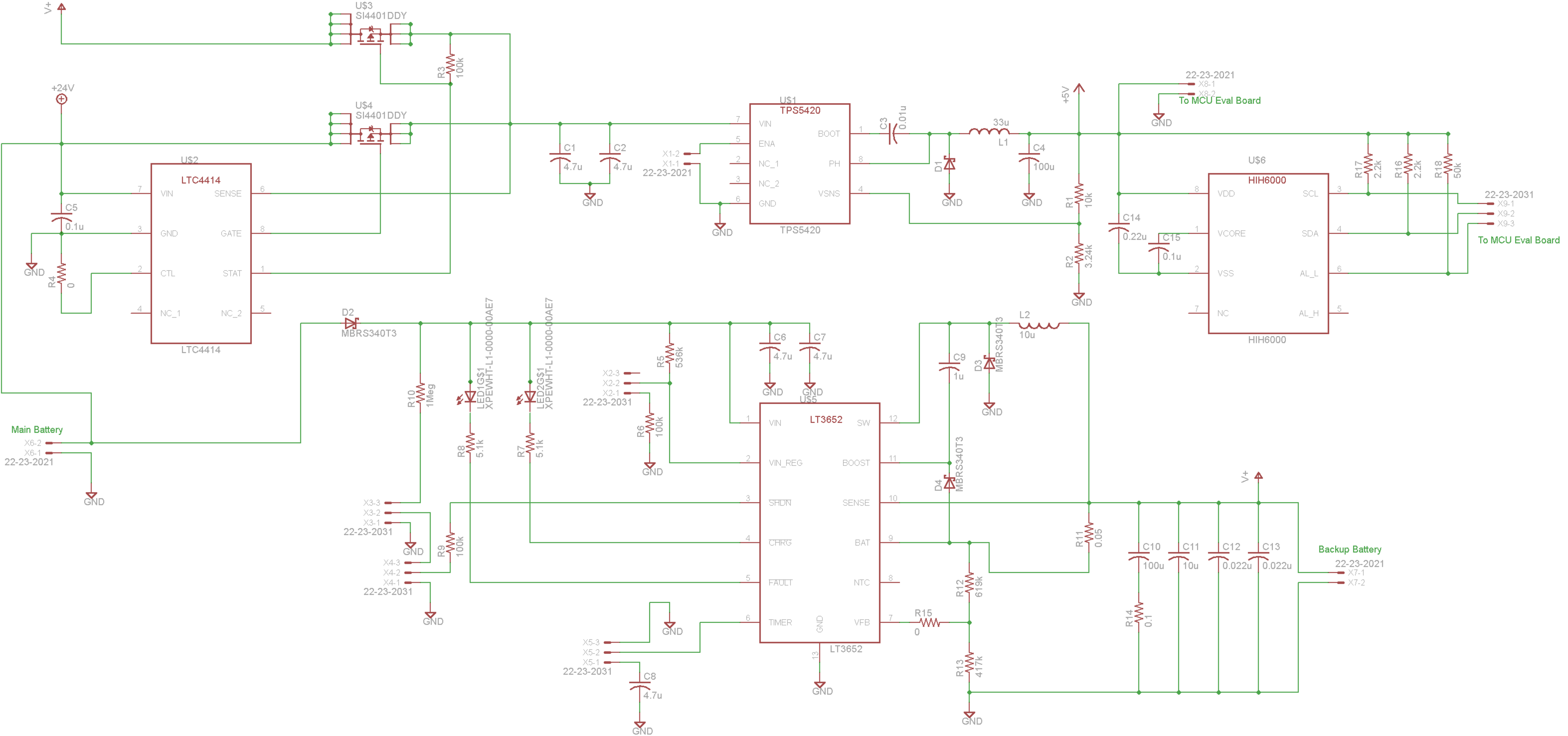


Figure 24: Passive hub circuit diagram

APPENDIX D: PCB SCHEMATIC

Figure 25: EaglePCB schematic capture of custom PCB circuit


V+
U$3
SI4401DDY
R3
100k
+24V
U$4
SI4401DDY
U$2
LTC4414
VIN
SENSE
GND
GATE
CTL
STAT
NC_1
NC_2
C5
0.1u
GND
R4
0
C1
4.7u
C2
4.7u
GND
U$1
TPS5420
VIN
ENA
NC_1
NC_2
GND
BOOT
PH
VSNS
X1-2
X1-1
22-23-2021
GND
C3
0.01u
33u
L1
D1
GND
C4
100u
GND
+5V
R1
10k
R2
3.24k
GND
22-23-2021
X8-1
X8-2
To MCU Eval Board
GND
U$6
HIH6000
VDD
VCORE
VSS
NC
SCL
SDA
AL_L
AL_H
C14
0.22u
C15
0.1u
R17
2.2k
R16
2.2k
R18
50k
22-23-2031
X9-1
X9-2
X9-3
To MCU Eval Board
D2
MBRS340T3
LED1G$1
XPEWHT-L1-0000-00AE7
LED2G$1
XPEWHT-L1-0000-00AE7
R10
1Meg
R8
5.1k
R7
5.1k
R5
536k
X2-3
X2-2
X2-1
22-23-2031
R6
100k
GND
C6
4.7u
C7
4.7u
GND
GND
U$5
LT3652
VIN
VIN_REG
SHDN
CHRG
FAULT
TIMER
GND
SW
BOOST
SENSE
BAT
NTC
VFB
L2
10u
C9
1u
D3
MBRS340T3
GND
D4
MBRS340T3
Main Battery
X6-2
X6-1
22-23-2021
GND
X3-3
X3-2
X3-1
22-23-2031
GND
R9
100k
X4-3
X4-2
X4-1
22-23-2031
GND
GND
X5-3
X5-2
X5-1
22-23-2031
C8
4.7u
GND
GND
R11
0.05
R12
619k
R15
0
R13
417k
GND
V+
C10
100u
C11
10u
C12
0.022u
C13
0.022u
R14
0.1
Backup Battery
22-23-2021
X7-1
X7-2

APPENDIX E: LTSPICE SIMULATIONS

Figure 26: LTSpice schematic capture of LT3652 and LTC4414

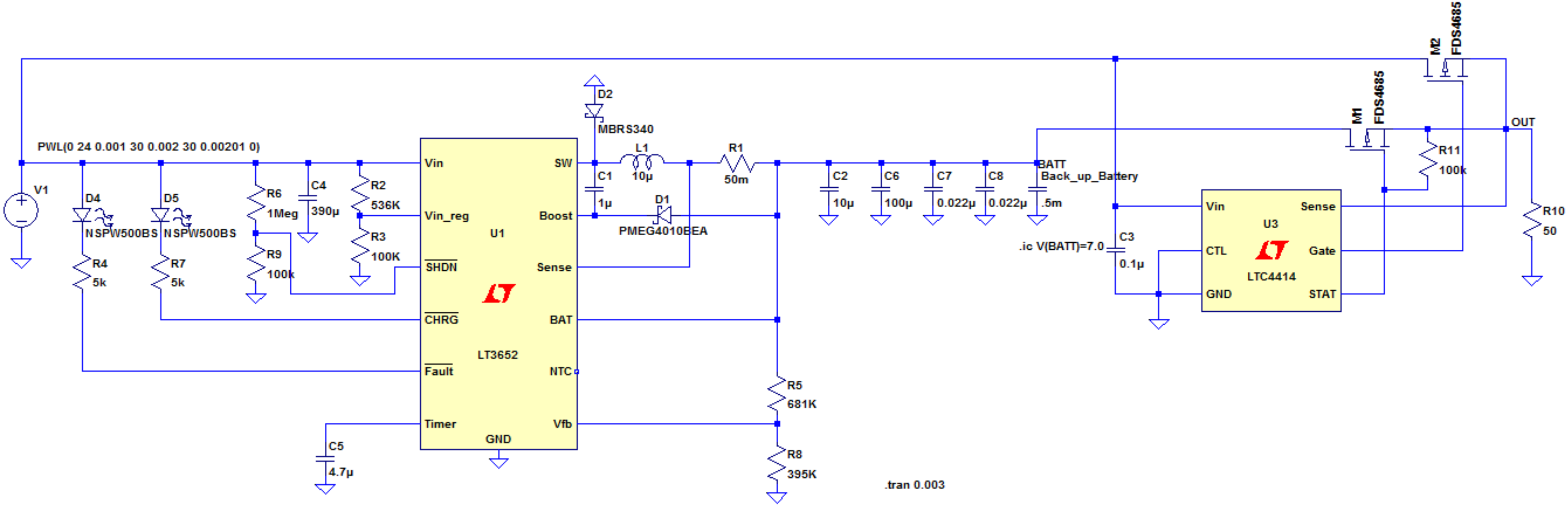
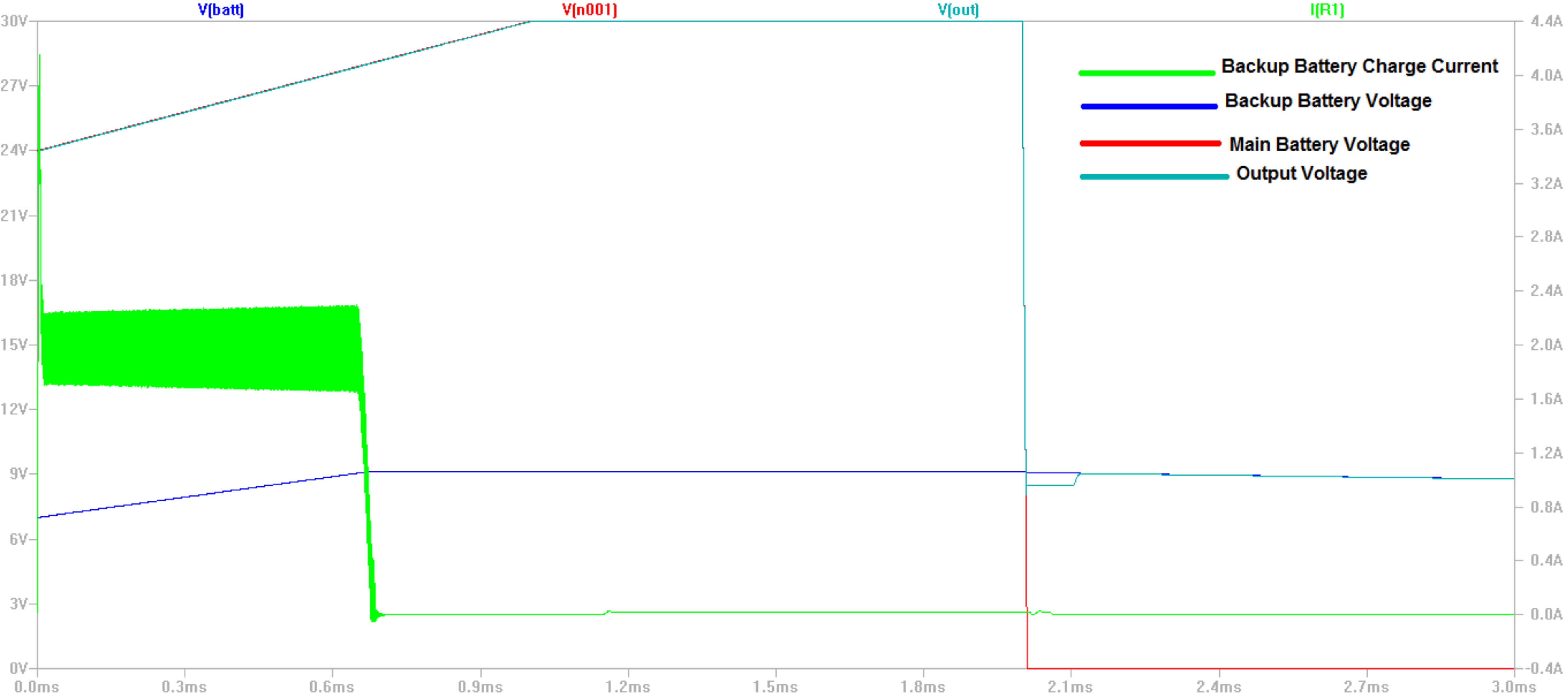

M2
FDS4685
M1
FDS4685
OUT
D2
MBRS340
PWL(0 24 0.001 30 0.002 30 0.00201 0)
L1
10µ
R1
50m
BATT
Back_up_Battery
R11
100k
V1
D4
NSPW500BS
D5
NSPW500BS
R6
1Meg
C4
390µ
R2
536K
Vin
Vin_reg
SHDN
CHRG
Fault
Timer
U1
LT3652
GND
SW
Boost
Sense
BAT
NTC
Vfb
C1
1µ
D1
PMEG4010BEA
C2
10µ
C6
100µ
C7
0.022µ
C8
0.022µ
.5m
R3
100K
R9
100k
R4
5k
R7
5k
.ic V(BATT)=7.0
C3
0.1µ
U3
LTC4414
Vin
CTL
GND
Sense
Gate
STAT
R10
50
R5
681K
R8
395K
C5
4.7µ
.tran 0.003

Figure 27: LTSpice Simulation of LT3652 and LTC4414

The simulation demonstrates several circuit features:

- The input voltage from the main battery ramps up from 20 to 29.2V (which is the range the valence batteries have) – and the system works across the whole voltage range
- The output voltage follows the input voltage with only a small voltage drop
- The output voltage switches to the backup battery when the main battery turns off (note how the output)
- The backup battery is charged with a constant 2 A initially


V(batt)
V(n001)
V(out)
I(R1)
Backup Battery Charge Current
Backup Battery Voltage
Main Battery Voltage
Output Voltage
30V
27V
24V
21V
18V
15V
12V
9V
6V
3V
0V
4.4A
4.0A
3.6A
3.2A
2.8A
2.4A
2.0A
1.6A
1.2A
0.8A
0.4A
0.0A
-0.4A
0.0ms
0.3ms
0.6ms
0.9ms
1.2ms
1.5ms
1.8ms
2.1ms
2.4ms
2.7ms
3.0ms

APPENDIX F: SOFTWARE LOGIC FLOW DIAGRAMS

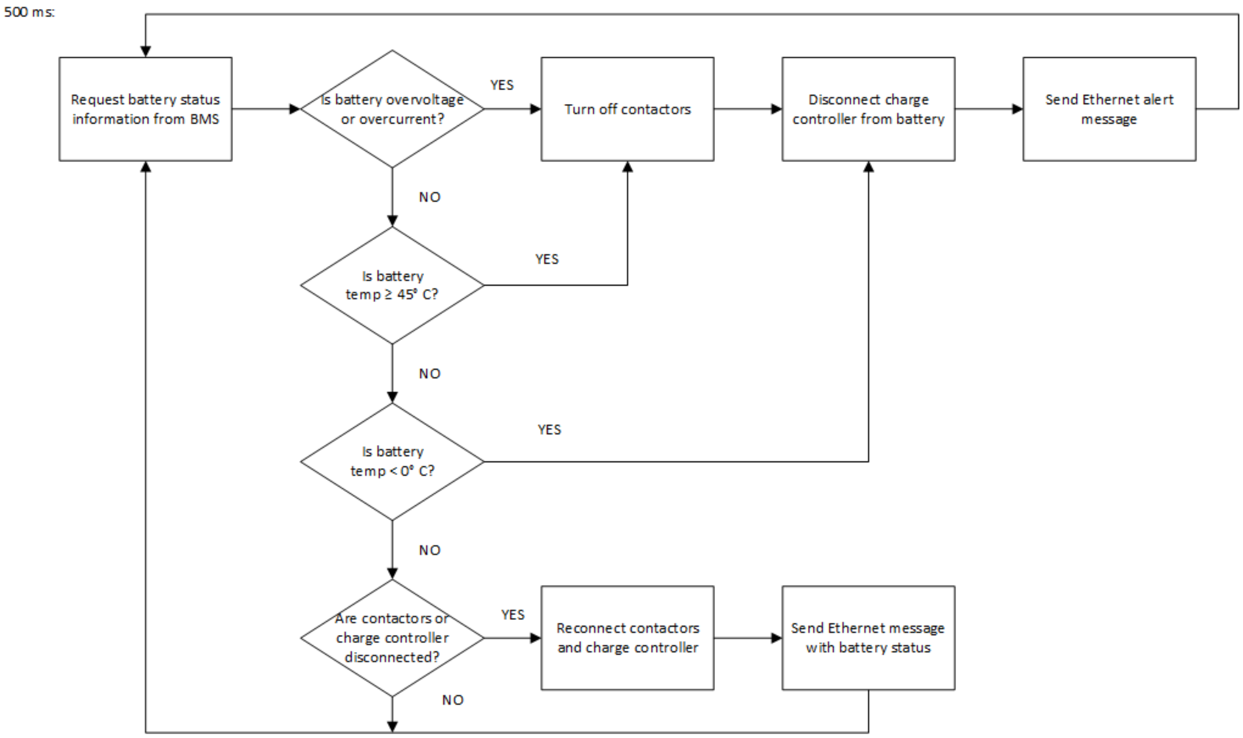


Figure 28: 500ms CAN communication task

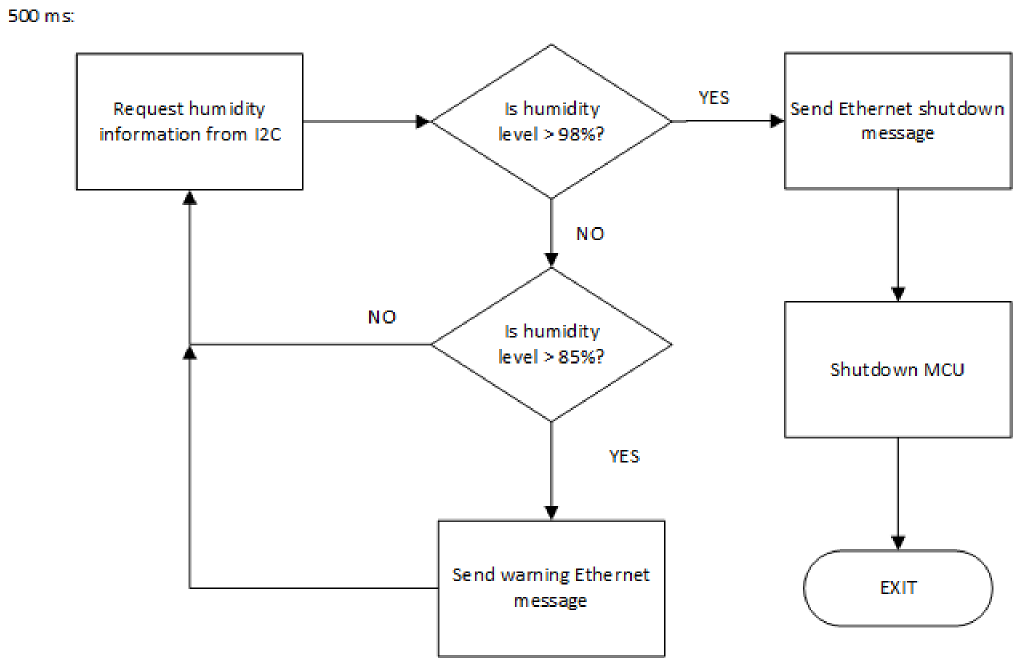


Figure 29: 500ms I2C communication task

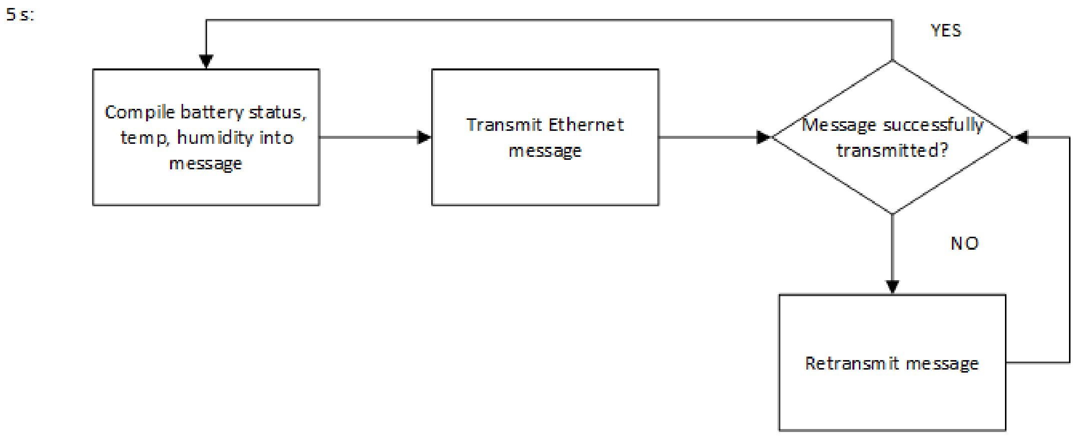


Figure 30: 5 second Ethernet transmission task

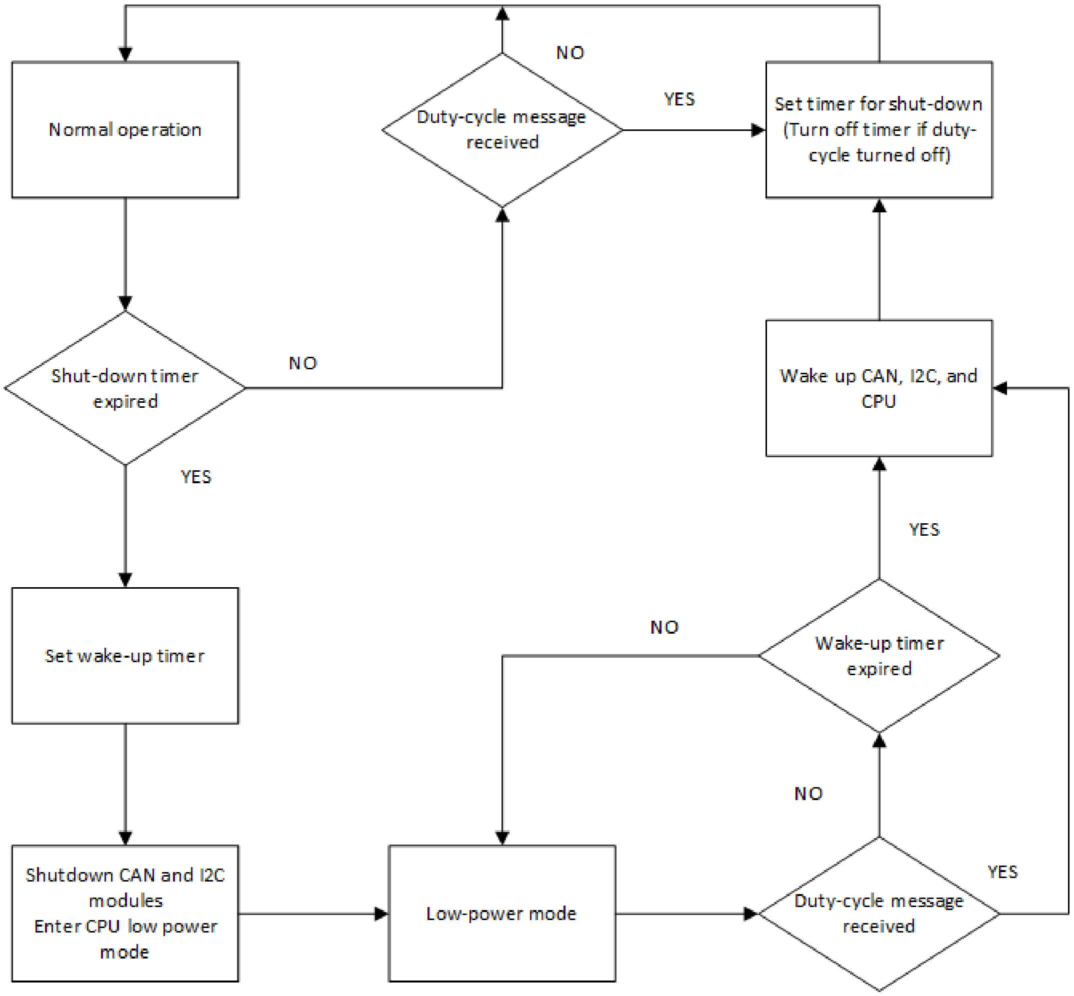


Figure 31: Low power mode logic flow