UNIVERSITY OF VICTORIA

Department of Electrical and Computer Engineering
ECE 499 - Design Project II
Summer, 2020

Final Report

July 31, 2020

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Acknowledgement

We would like to thank our project supervisor, Dr. Ilamparithi Thirumarai Chelvan, for his guidance and support throughout this project. Also, we would like to thank AUVIC for providing us with specifications and allowing us to complete this project on their behalf. Finally, we would like to thank our fellow fourth-year students for providing an inspirational and supportive work environment.

Executive Summary

AUVIC is building a new AUV for the 2021 competition season and requires a new power management board. Several new features including battery cell monitoring, improving power distribution efficiency, CAN bus connectivity, and a leakage detection sensor were to be included in the final design. Each additional feature was researched and incorporated into the design. These designs were thoroughly simulated and tested in LTspice to ensure functionality. The integrated system was also simulated to test the interconnectivity between subsystems. Finally, detailed schematics for the entire power management board were created in Altium. These schematics achieved all the provided design objectives and thus the project was completed successfully.

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Glossary

ADC	Analog-to-Digital Convertor
AUV	Autonomous Underwater Vehicle
AUVIC	Autonomous Underwater Vehicle Interdisciplinary Club
CAN	Controller Area Network
DC	Direct Current
DVL	Doppler Velocity Log
EEM	Environmental Effect Monitoring
emf	Electromotive Force
IC	Integrated Circuit
IMU	Inertial Measurement Unit
I2C	Inter-Integrated Circuit
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LiPo	Lithium Polymer
MOSFET	Metal Oxide Silicon Field Effect Transistor
PCB	Printed Circuit Board
PMB	Power Management Board
SoC	State of Charge
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus

1 Introduction

The Autonomous Underwater Vehicle Interdisciplinary Club (AUVIC) competes in an annual international competition where teams build Autonomous Underwater Vehicles (AUVs) to complete an underwater obstacle course. AUVIC is building a new AUV for the 2021 competition and needs a new power and battery management board to meet the new requirements.

There is a wide range of applications for AUVs, mostly for research and some industry purposes. AUVs are useful for acquiring data from hard to reach areas, for example beneath ice sheets [1]. They can also be used for geohazard assessment and seafloor mapping or monitoring [1]. For industry purposes, AUVs can be used for Environmental Effect Monitoring (EEM), which evaluates the environmental risk from offshore petroleum operations [2]. This can minimize the damage done to marine life and the ocean by identifying any pollutants in the water earlier so action can be taken.

The potential user base for this specific project would be the AUVIC student club, which is currently building and using the AUV for the RoboSub competition held annually. In general, the user base for AUVs is primarily marine researchers and industries, for the reasons stated above.

The AUV developed by AUVIC currently uses a power management board (PMB) created in 2018. This board is divided into four subsections and the current functionality of each subsection is outlined below.

1.1 Battery Management

The battery management portion of the PMB involves all of the control circuits to and from the main battery packs, including all protection and bridging circuits required to provide power to other subsections. Fig. 1 and 2 below are high level block diagrams of the existing functionality.

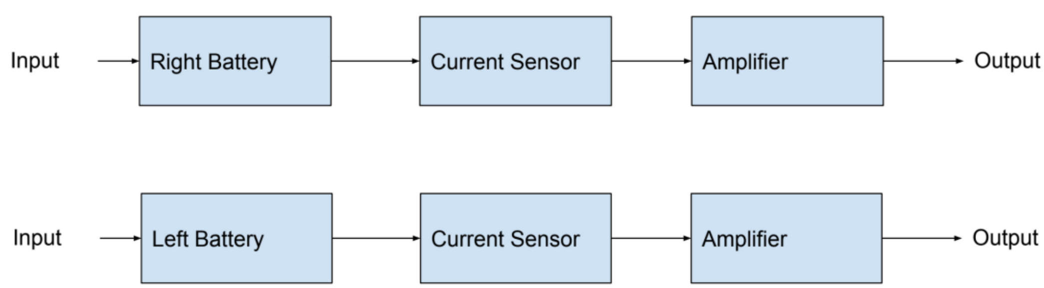

Fig. 1: Flow charts for each battery on the existing power board.

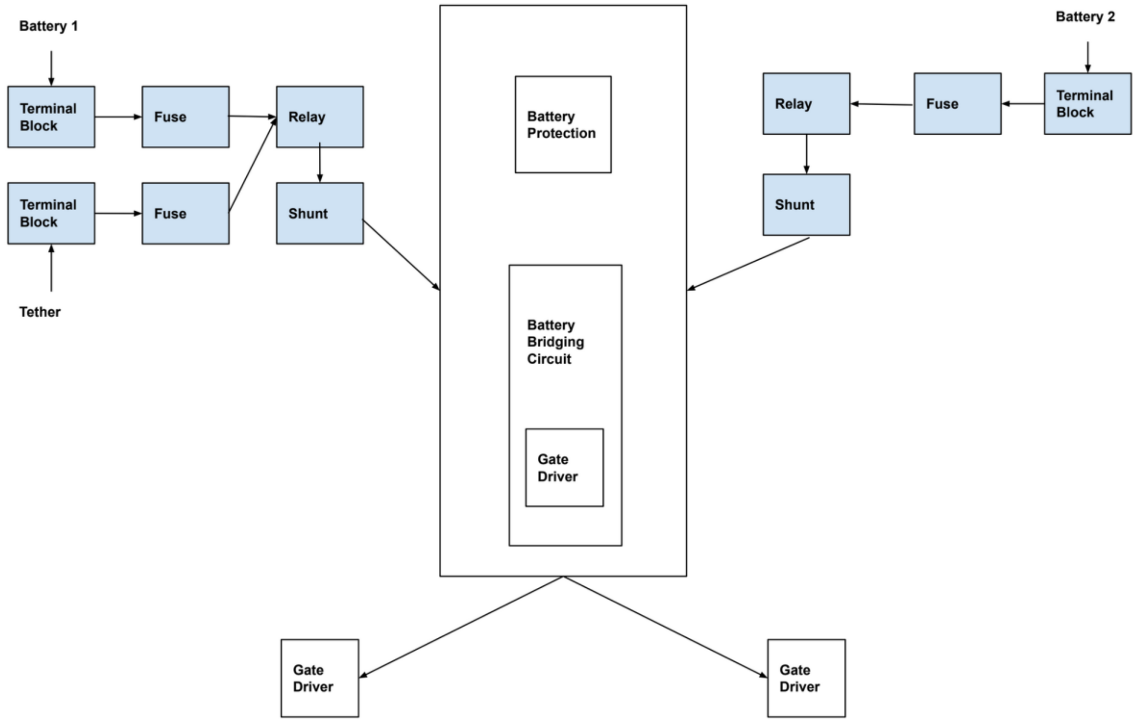

Fig. 2: High level diagram of the existing circuitry for battery management.

The battery circuit for the existing PMB contains motor and system enable lines to control power for the other subsections. Additionally, the circuit controls and monitors current draw from the batteries using sensors and external circuits. Fuses are used as protection devices throughout the circuit. The left and right side of the circuit is dedicated for Battery 1 and Battery 2 respectively. The current setup can switch to using external power automatically when an external source is connected. The board can run the two batteries in parallel to discharge the batteries evenly. Lastly, gate drivers have been used to drive MOSFETs and ultimately control the enable lines.

1.2 Power Management

The power management subsystem is responsible for distributing and monitoring the different power rails to external systems. The power rails include 12V at 500mA, 9V at 500mA (shared with 12V), 5V at 500mA and 2 VBatt outputs at 60A and 5A. All external power rails are switched on or off by the microcontroller. This allows the power to faulted systems to be shut off or run in a lower power mode to preserve battery life. Fig. 3 below shows a high-level diagram of the power management subsystem.

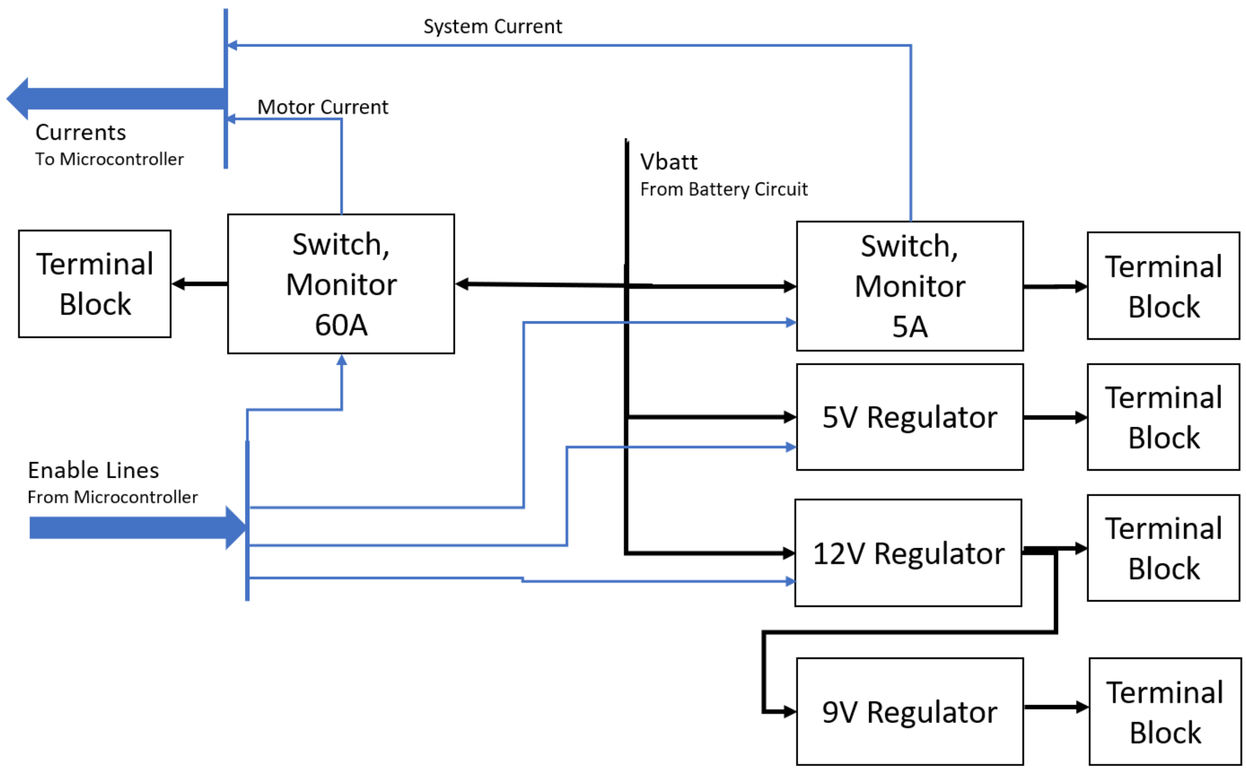

Fig. 3: Existing power management subsystem flow chart.

1.3 Microcontroller & Communication

The microcontroller and communication portions of the power board control the flow of information between all the input and output signals from the other sections. The current microcontroller is an STM32F09 board powered by the internal 3.3V sources to the VBAT pin. This ensures the STM can be running even if the AUV is not completely powered on. The STM board has SDA (data line) and SCL (clock line) pins connected through I2C protocol to the internal pressure sensors and the temperature/humidity sensors. The external pressure and water sensors also have inputs and outputs connected to the analog-to-digital (ADC) pins of the STM board. The three reed switch inputs are outputted from the STM board and the reed switch detection is an input to the microcontroller.

From the battery and power sections, there are currently four inputs to the STM board, all from current sensors. The current sensors are for both the left and right batteries, the motor, and the system current. There are also two inputs with the voltage from both the left and right batteries. Three enable outputs from the STM board are the parallel power enable, the motor power enables, and the system power enable. There is also a 5V and 12V enable output to the voltage converters. All the pins from the battery sections are on the ADC pins of the STM board.

In terms of communication, the current PMB uses UART to USB to communicate with the on-board computer of the AUV. This is done by first using a UART isolator to ground the signal from the STM board separately, preventing any damage from extra current to the on-board computer. From the isolator, the signal is fed into a UART-USB converter and then into a mini USB port. Finally, there are two LEDs, blue and green, used for firmware debugging.

Fig. 4 below outlines the flow of information to and from the microcontroller between all the other subsystems.

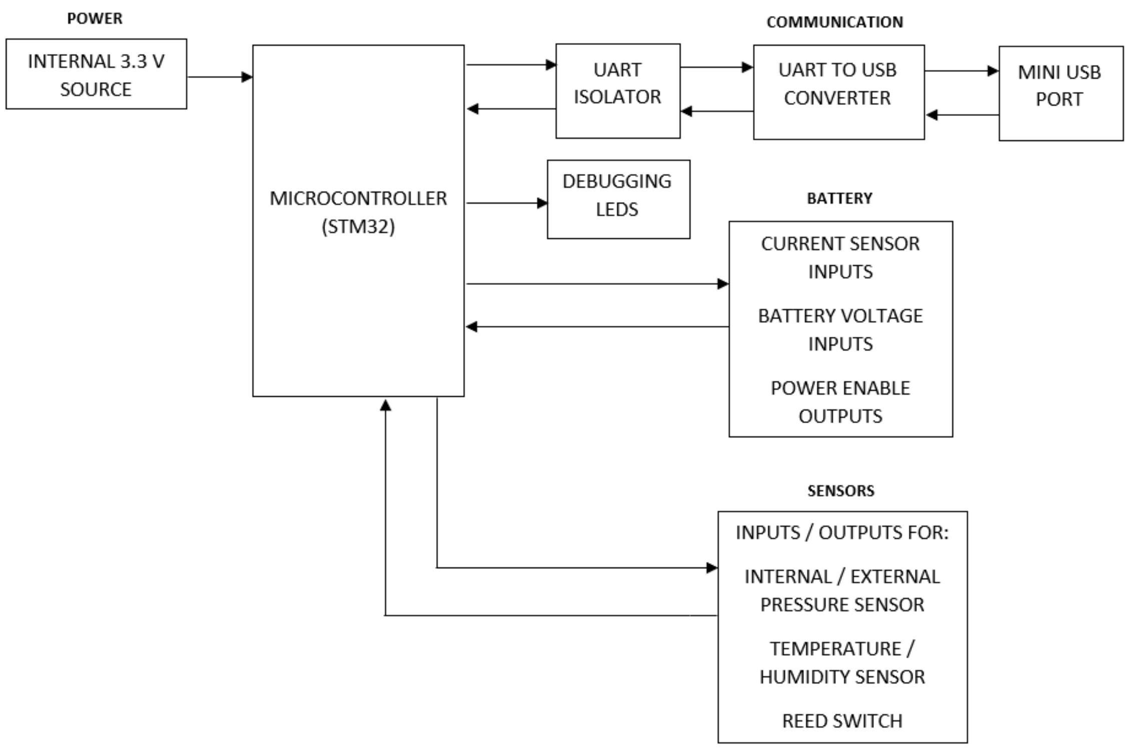

Fig. 4: Existing flow chart for the microcontroller and communication subsystems.

1.4 Sensors

The existing AUV currently uses three environmental sensors. The internal pressure sensor uses I2C protocol to measure internal pressure of the sub and feeds it back to the microcontroller through SDA and SCL pins. The external pressure sensor takes readings of the external pressure and feeds it to the STM through the ADC-Input-Pressure port. A buffer is used to ensure the voltage does not exceed 3.3V. The temperature and humidity sensor measures internal temperature and humidity and feeds back to the STM board through SCL and SDA ports. A reed switch is used to start the internal power line through a change in magnetic flux from an externally applied magnet. The output supplies the step-down converter that provides power to the rest of the system. Fig. 5 below shows a high-level diagram of the sensor connections to various other components of the power board.

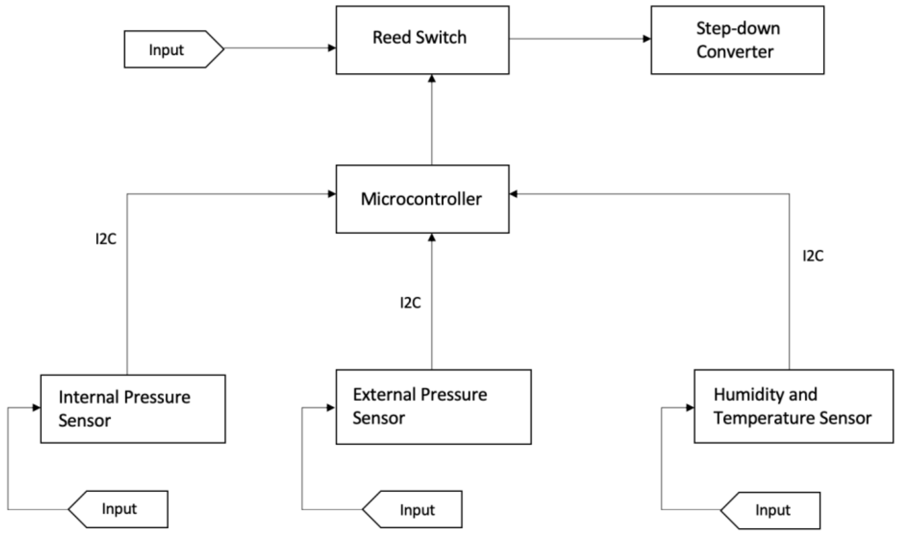

Fig. 5: Existing flow chart for sensors subsystem.

2 Project Goal

The new AUV needs a solution to distribute and monitor power to the various components in the AUV, monitor the batteries, monitor the internal and external environment, and communicate with other components in the AUV. This solution is a newly designed PMB including the additional features required by AUVIC.

3 Design Objectives

The new PMB is divided into four subsections. The requirements for each subsection are outlined in the following sections.

3.1 Battery Management

The following specifications were established by AUVIC for the battery management section of the power board:

1. Should have an input voltage range of 18V to 28V.
2. Should use two 6 cell LiPo batteries as its power source.
3. Should have the ability to run the two batteries in parallel.
4. Each battery should have fuses. Regular sized automotive fuses are recommended.
5. Should have LEDs to indicate if the battery is connected.
6. Should have the ability to monitor battery pack voltage, individual cell voltage and pack current.

3.2 Power Distribution

The following specifications were provided by AUVIC for the power distribution section of the PMB:

1. Should have the following power outputs for external systems:
   1.1. 5V at 8A.
      1.1.1. LCD board - 4A*
      1.1.2. Inertial Measurement Unit (IMU) - 500mA
      1.1.3. Hydrophones - 250mA*
      1.1.4. Torpedo 5V electronics - 250mA*
      1.1.5. Motor controller 5V electronics - 250mA*
      1.1.6. Buffer for unplanned boards - 2.75A
   1.2. 12V at 8A.
      1.2.1. Doppler Velocity Log (DVL) - 3A
      1.2.2. Ball dropper and grabber arm - 3A*
      1.2.3. Buffer for unplanned boards - 2A
   1.3. 16V at 3A.
      1.3.1. Nvidia Jetson TX2 and peripherals - 3A
   1.4. VBatt (22.2V nominal) at 60A continuous.
      1.4.1. Motor controller - 60A peak
      1.4.2. Torpedo launcher - 30A for < 1s
2. Should be able to switch on/off all external power using the microcontroller.
3. Should have the ability to monitor current for each external power output.
4. Should have LEDs at each output to indicate if the output is on or off.
5. Should have fuses at each output. Regular sized automotive fuses are recommended.

* Estimated values.

3.3 Microcontroller & Communication

The following specifications were provided by AUVIC for the microcontroller and communication section of the power board:

1. Should use a STM32F413 microcontroller.
2. Should have a RS232 transceiver to communicate with an IMU.
3. Should have LEDs connected to the microcontroller for debugging and to show system status.
4. Should use a Controller Area Network (CAN) bus to communicate to external systems.

3.4 Sensors

From AUVIC, the following requirements were given for the sensors section of the power board:

1. Should connect to a reed switch to power on/off the AUV.
2. Should connect to a water sensor to detect leaks in the vehicle’s housing.

3. Should measure internal pressure, temperature, and humidity.
4. Should connect to an external water pressure sensor used to determine the AUV's depth in the water.

4 Literature Survey

The literature survey included researching methods and different solutions for meeting the design objectives and ultimately the project goal. These solutions were for the new features to be added to the existing design and were examined in the following sections.

4.1 Battery Management

The current nominal battery voltage is 22.2V however it can get as low as 18V. The upper 28V threshold from the specifications allows AUVIC to use the existing power supplies with the board. It is recommended from AUVIC to use two 6 cell lithium polymer (LiPo) batteries. The current board uses a MultiStar12000mAh 6S 10C Lipo Pack XT90 and as AUVIC has these batteries in stock ready for use, it is ideal to use this model as well. Furthermore, the batteries should have the ability to run in parallel. This is essential to ensure that we can achieve peak battery performance. Running the batteries in parallel ensues that the batteries are depleted evenly utilizing the full capacity of both batteries. Battery fuses must be implemented as a safety feature since they prevent excessive current from entering various parts of the board's circuitry. Regular sized automotive fuses are recommended because they can be easily sourced and are already in use by the current AUV. LED indicators are included and used to monitor battery status and allow for easier troubleshooting.

The last specification states that the board should have the ability to monitor battery pack voltage, individual cell voltage and pack current. The current board is only capable of monitoring battery pack voltage. The two different methods that were researched to monitor the state of charge for LiPo batteries are terminal voltage method and coulomb counting. The terminal voltage method uses the electromotive force (emf) and terminal voltage proportional relationship to estimate the state of charge (SoC). Although this method is relatively simple to implement, it can be quite inaccurate especially during the end of battery discharge [3]. The second approach to monitor SoC is coulomb counting. The method essentially monitors the discharging current and integrates with respect to time. This method is ideal for lithium battery compositions due to their high coulombic efficiency [4]. Lastly, the method can be further enhanced by using alternate approaches such as modified coulomb counting for more accurate readings [3].

4.2 Power Distribution

The first requirement of the design objectives comes from the power requirements of the other components in the AUV. The existing PMB has an external 16V regulator for the main computer. The new PMB will integrate the 16V regulator onto the main printed circuit board

(PCB). 16V at 3A is used by the existing system and works sufficiently. The 5V and 12V are general purpose designed to be used by all other components in the AUV. The current board also has a 5V and 12V output however the current rating is to be increased from 500mA to 8A for the new PMB. VBatt is to be used by the motor controller and other electromechanical components on the AUV which can require up to 60A to operate. Although the sum of all peak currents of the components is higher than the rated current of 60A, the components will not consume that current simultaneously and the total current at any one time is expected to stay below 60A. Additionally, the AUV must be able to switch off power in event of a water leakage in the main housing to protect the electronics.

Being able to monitor current is beneficial for future development as this data can be used to determine if the current rating requirements need to be improved in future designs. It can also be used as a method to detect fault by comparing the measured current to the expected current. LEDs at the output are a useful debugging tool as it can show the state of the outputs without having to use a multimeter. Fuses are used as the last step in protecting the electronics in the event of a short circuit.

The two common methods for DC-DC step down converters are linear regulators and switching regulators also known as buck converters. Due to the high current requirements of this PMB, the usage of linear regulators for stepping down external power outputs is not being considered as linear regulators are very inefficient. Comparison of only switching regulators will be explored for this project. More specifically, comparison between switching regulators with integrated components versus external components will be executed.

A switching regulator with integrated components, commonly referred to as just a switching regulator, has the MOSFET switches, diode and sometimes the inductor inside the same package. A regulator with external components, also referred to as a switching controller, has external MOSFET switches, inductor, and diode if necessary [5]. In general, designs with integrated components consume less board space and are less complex in terms of design and bill of materials [6]. Integrated components may also cost less, but this depends mainly on the specific part being used. However, since components that carry the full output current through them are integrated in a small package, switching regulators are not efficient at handling large currents. This is the main advantage of switching controllers. Switching controllers can be scaled easily to handle much larger currents and can operate more efficiently at those currents. The amount of current a switching regulator can handle and its efficiency at that current depends on the specific part. However, in general switching controllers are primarily used when currents are higher than 10A [7]. Since the AUV is battery operated, improving efficiency is very important. Minimizing board space is not a large concern for this project. Therefore, the power distribution in this board could benefit from using switching controllers for its 5V and 12V outputs.

4.3 Microcontroller & Communication

The first specification from Section 3.3 refers to the main microcontroller to handle all the inputs and outputs of the various sensors around the power board. The STM32F413 microcontroller is what AUVIC uses for all other systems, thus conforming to this will allow code to be shared between those controllers and expedite the firmware development process. The RS232 transceiver is required to communicate with a pre-existing IMU used in the AUV. Lastly, LEDs are required for debugging the firmware during development as the LEDs can indicate if the signal is coming from the pin or not.

The last specification is a design change from the previously used PMB. The past board used UART to USB as its main communication line to the on-board computer of the AUV. However, there are disadvantages to UART and USB. UART data frames are limited to 9 bits, and UART is low speed, so the data transfer from the microcontroller to the on-board computer will be slower [8]. The selected microcontroller has inputs and output pins for CAN bus protocol, meaning a CAN bus communication line could replace the UART to USB line. CAN bus is a simple and low-cost system that is very resistant to electric disturbances and electromagnetic radiation [9]. This makes it ideal for safety critical application and extreme environments. In this case, low-speed, fault tolerant CAN protocol will be preferred as opposed to high-speed CAN because the AUV was operating with UART previously and thus it does not require much more speed to operate.

4.4 Sensors

According to the first design objective for this subsection, the purpose of the reed switch is to be able to turn on or turn off the AUV remotely while underwater as it provides an easy access kill switch in case of emergency. It is also important to have a remote turn on method as the AUV is in a watertight container that is pressurized to prevent changes in the internal environment as well as opening and closing of watertight closures. Therefore, a remote switch provides the safest start method. Leaks in the AUV can cause major damage to the electrical components in the AUV and therefore it is important a water sensor is implemented to prevent flooding or damage to the electrical system. To further assist with environmental control, it is important that the internal pressure, temperature, and humidity are measured to monitor any changes to the internal environment, including assisting with the detection of leaks. To monitor the external environment, an external pressure sensor is needed to determine the depth of the AUV at any given time. This allows the controller to know the location of the vehicle as well as whether it is under normal operating conditions.

In previous models of the PMB there were no functioning water sensors that could accurately determine leaks, leading to significant electrical failures from the internal computer. There are various types of water leak sensors with the most common type sensors being a transistor-based sensor detection. This sensor utilizes either NPN or PNP bipolar junction transistor (BJT) connected to various probes placed near watertight closures. For a PNP BJT the circuit is set up in a common emitter configuration with the probes connected to the base of the BJT, shown in Fig. 6.

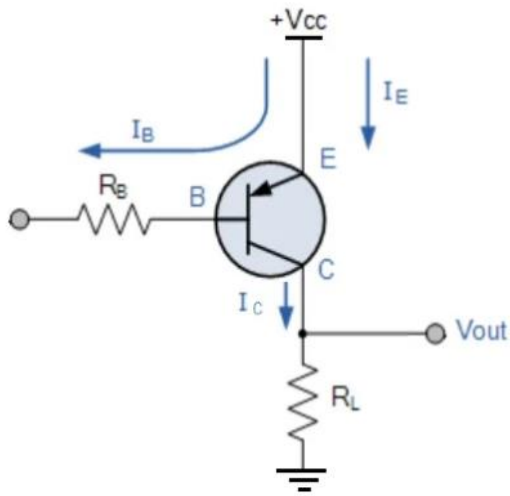

Fig. 6: BJT common emitter configuration.

When a leak is detected, the signal from the base will pull VCC high which will trigger an LED to light up to signal leak [10]. The advantages of this system are it is relatively easy to implement and simulate using any analog simulation software like LTspice and it is relatively inexpensive as transistors are readily available. One disadvantage to this solution is that the probes commonly used are topped with sponge tips and therefore once the tips are in contact with water, it must fully dry out before reuse, which significantly decreases efficiency during testing. Another type is a fibre optic leak sensor which utilizes a light emitting sensor that contains a light emitter and receiver. When water is detected, the light receiver will not receive a signal from the emitter triggering a LED to signal leak detection [11]. The benefit of this system is that early leak detection can be achieved as the distance between the emitter and receiver is relatively small, however the drawback is due to the sensitivity of the sensor. If internal humidity increases, condensation could trigger the sensor leading to false leak detection. Therefore, due to the easy application, implementation, and relatively cheap composition, the transistor-based solution would be more suited to this system.

5 Team Duties & Project Planning

Table 1 below outlines the team duties for each section of the PMB:

Table 1: Team duties per member and section.

TEAM MEMBER	SECTION	DUTIES
Gurdeep	Battery Management	● Literature review on different methods to monitor state of charge of LiPo batteries. ● Schematic design for battery management section of the PMB ● Simulations for SoC monitoring circuit
Poorna	Power Distribution	● Literature review on voltage regulation methods. ● Schematic design for power distribution section of the board ● Simulations of circuits
Stefanie	Microcontroller & Communication	● Literature review for new CAN bus communication line ● Schematic design for microcontroller and communication circuits ● Simulation of CAN bus communication line
Jessica	Sensors	● Literature review for various types of water leak sensors ● Schematic design for water sensors ● Simulations of analog water sensor and reed switch in LTspice.

There are various constraints to this project as many tasks depend on each other. Since the schematics for the power board will contain various new components, a factor that will cause delay will be if one of the proposed solutions cannot be implemented or requires changes. This would cause the schedule of our schematic design to be delayed. Strategies to mitigate this risk would be to simulate the components to ensure they satisfy the specification before developing the schematic.

As outlined in Table 1, deliverables for each team member included a literature review, simulation of new features, and a completed circuit schematic for their respective subsystem. These deliverables were all completed by the end of the project.

6 Design Methodology & Analysis

The design methodology and analysis were done through theoretical calculations and then validated in simulation software. Various software packages such as Simulink, Keil MDK, WEBENCH and LTSpice were explored to validate the newly designed circuits. The main two simulation software that were further explored in depth were WEBENCH and LTSpice. WEBENCH Power Designer is a free software package provided by Texas Instruments. WEBENCH is convenient when it comes to testing individual subsystems or ICs that are manufactured by Texas Instruments as supporting components are automatically generated to construct a working circuit. The primary issue with WEBENCH is its integration abilities, it is not possible to test multiple ICs or subsystems at once. This makes it very difficult to validate the overall proposed power board since testing multiple subsystems in conjunction is critical to validate the overall design. Majority of the subsystems were validated using LTSpice, as well as the entire integrated model. Test results and validation can be found in Section 8.

6.1 Battery Management

The two main design implementations made were an individual cell monitoring circuit and battery bridging circuit. The battery currently being used by AUVIC is the Multistar 12000mAh 6S 10C LiPo pack. The battery is equipped with a 7-pin JST-XH connector which can be used to read the individual cell voltages.
The two options explored to implement the connector were:

1. Use an IC chip capable of stepping down the cell voltages and completing all ADC calculations internally, along with any necessary filtering.
2. Step down the individual cell voltage to 3.3V for each pin using a basic voltage divider circuit.

Various cell monitoring integrated circuits (ICs) for lithium batteries were explored, the primary issue with using an IC was the ability to validate its functionality. Unfortunately, Texas Instruments WEBENCH simulation tool has a limited selection of IC’s that can be imported into the testing software. Therefore, it was convenient to choose the second option that uses a basic voltage divider circuit as shown in Fig. 7 below.

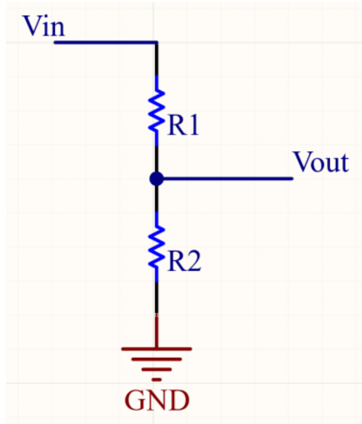

Fig. 7: Voltage divider circuit

Equation 1 was used to calculate the required resistor value for R1:

$$V_{OUT}=\frac{R_2}{R_2+R_1}V_{IN} \qquad (1)$$

$$V_{OUT}(R_2+R_1)= R_2V_{IN}$$

$$V_{OUT}R_2+V_{OUT}R_1= V_{IN}R_2$$

$$R_2= \frac{R_2(V_{IN}-\boldsymbol{V_{OUT}})}{V_{OUT}}= R_2(\frac{V_{IN}}{V_{OUT}}\text{-}1)$$

$$R_1 = R_2(\frac{V_{IN}}{V_{OUT}}\text{- }1)$$

R_2= 10kΩ, V_{OUT}= 3.3V, V_{IN}= 0V (cell #1), 4.2V (cell #2), 8.4V(cell #3), etc.

$$R_1\text{= 10k}\Omega\ (\frac{4.2V}{3.3V}\text{-}1)$$

$$= 2.737\text{k}\Omega$$

Selected resistor value: 3kΩ ± 1%

$$V_{OUT,min}=\frac{R_2}{R_2+R_1}V_{IN}$$

$$= \frac{10k\Omega}{10k\Omega+(3k\Omega+1\%)}(4.2\text{V})$$

$$= 3.223\text{ V}$$

$$V_{OUT,max}=\frac{R_2}{R_2+R_1}V_{IN}$$

$$= \frac{10k\Omega}{10k\Omega+(3k\Omega-1\%)}(4.2\text{V})$$

$$= 3.238\text{ V}$$

These calculations provide the component values for the proposed voltage divider circuit. This voltage divider circuit was analyzed in LTspice, as stated above. The results and test procedure can be found in Section 8.1.

6.2 Power Distribution

The overall proposed power board design requires 5V, 12V, and 16V power supplies for external systems. The output voltage must remain within ±0.1V for the 5V supply, ±0.5V for 12V supply and ±2V for 16V supply. As the ripple voltage should not exceed 1%, the minimum and maximum output voltages were calculated to account for the resistor tolerances. The following three sections provide the analysis done to calculate the required feedback resistor values and verification for the three output voltages.

6.2.1 5V Output Voltage

$$R_{FB2} = R_{FB1}\left(\frac{V_{out}}{V_{FB}} - 1\right) \qquad (2)$$

First iteration: R_{FB1}= 10kΩ, V_{FB}= 0.6V

$$R_{FB2} = 10\text{k}\Omega\left(\frac{5V}{0.6} - 1\right)$$
$$= 73.333\text{k}\Omega$$

Closest 1% resistor: 73.2kΩ

$$V_{OUT} = \left(\frac{R_{FB2}}{R_{FB1}} + 1\right)V_{FB} \qquad (3)$$

$$V_{OUT} = \left(\frac{73.2k\Omega}{10.0k\Omega} + 1\right)0.6V$$
$$= 4.99\text{V}$$

$$V_{OUT,min} = \left(\frac{73.2k\Omega - (73.2k\Omega)(1\%)}{10.0k\Omega + 10.0k\Omega(1\%)} + 1\right)0.6V$$
$$= 4.91\text{V}$$

$$V_{OUT,max} = \left(\frac{73.2k\Omega + (73.2k\Omega)(1\%)}{10.0k\Omega - 10.0k\Omega(1\%)} + 1\right)0.6V$$
$$= 5.08\text{V}$$

6.2.2 12V Output Voltage

$$R_{FB2} = R_{FB1}\left(\frac{V_{out}}{V_{FB}} - 1\right) \qquad (2)$$

First iteration: R_{FB1}= 10kΩ, V_{FB}= 0.6V

$$R_{FB2} = 10\text{k}\Omega\left(\frac{12V}{0.6} - 1\right)$$
$$= 190\text{k}\Omega$$

Closest 1% resistor: 191kΩ

$$V_{OUT} = \left(\frac{R_{FB2}}{R_{FB1}} + 1\right) V_{FB} \qquad (3)$$

$$V_{OUT} = \left(\frac{191k\Omega}{10.0k\Omega} + 1\right) 0.6V$$

= 12.06V

$$V_{OUT,min} = \left(\frac{191k\Omega - (191k\Omega)(1\%)}{10.0k\Omega + 10.0k\Omega(1\%)} + 1\right) 0.6V$$

= 11.83V

$$V_{OUT,max} = \left(\frac{73.2k\Omega + (73.2k\Omega)(1\%)}{10.0k\Omega - 10.0k\Omega(1\%)} + 1\right) 0.6V$$

= 12.29V

6.2.3 16V Output Voltage

$$R_{FBB} = \frac{R_{FBT}}{\left(\frac{V_{out}}{V_{FB}} - 1\right)} \qquad (4)$$

Starting with: R_{FBT}= 100kΩ, V_{REF}= 1V,V_{OUT}= 16V

$$R_{FBB} = \frac{100k\Omega}{\left(\frac{16V}{1V} - 1\right)}$$

= 6.667kΩ

Closest 1% resistor: 6.65kΩ

$$V_{OUT} = \left(\frac{R_{FBT}}{R_{FBB}} + 1\right) V_{REF} \qquad (5)$$

$$V_{OUT} = \left(\frac{100k\Omega}{6.65k\Omega} + 1\right) 1V$$

= 16.04V

$$V_{OUT,min} = \left(\frac{100k\Omega - (100k\Omega)(0.01)}{6.65k\Omega + 6.65k\Omega(0.01)} + 1\right) 1V$$

= 15.74V

$$V_{OUT,max} = \left(\frac{100k\Omega + (100k\Omega)(0.01)}{6.65k\Omega - 6.65k\Omega(0.01)} + 1\right) 1V$$

= 16.34V

The feedback resistor values were found from these calculations and the output voltages were confirmed to be as intended in the design objectives.

In this case, it was convenient to validate the functionality of the LM3150 buck converter using WEBENCH. WEBENCH uses the exact IC and it automatically generates a surrounding circuit with all necessary components. Additionally, WEBENCH provides an in-depth analysis in the form of graphs for the overall circuit design.

6.3 Communication

The initial attempt to validate the communication portion was to use Keil MDK. However, Keil requires a license to access required functionality to validate a CAN transceiver. Additionally, the Keil software is primarily useful for simulating the firmware functionality of a CAN bus connected to a STM microcontroller. As firmware was not part of the scope of this project, a hardware-based simulation was more useful. To do a hardware simulation and analysis, LTspice was used as it contained a built-in CAN transceiver part. This allowed the proposed CAN transceiver circuit to be simulated and analyzed, as described in Section 8.4.

6.4 Sensors

It was necessary to implement a water detection circuit for the newly designed power board. The following analysis was done for the implementation of a water detection system and analysis was done for with water and without water cases. Fig. 8 shows the water sensor circuit with no water present with V_{in} representing the open probe to detect water leakage.

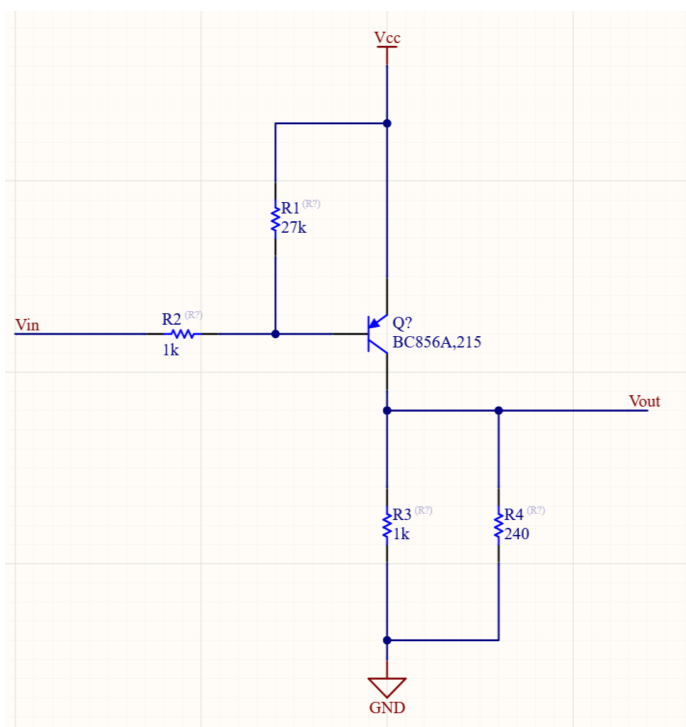

Fig. 8: Water detection circuit with no water present.

$R_B = \infty$

$i_B = \frac{V_{CC}-V_{BE}}{R_B} = 0 \text{ , } i_C = 0$ (6)

$V_{BC} = 3.3V$

$V_{OUT} = V_{CC} - V_{EC}$

$= 0V$

These calculations form the expected results from the simulation, because if there is no water present in the housing, V_{out} should be equal to 0V. This means no signal will be sent to the microcontroller and no alarm will be triggered indicating a leak.

Fig. 9 below shows the proposed water sensor circuit with water present, represented by the V_{in} probe connecting to ground. This allows current to flow through the base resistor, indicating that water is present.

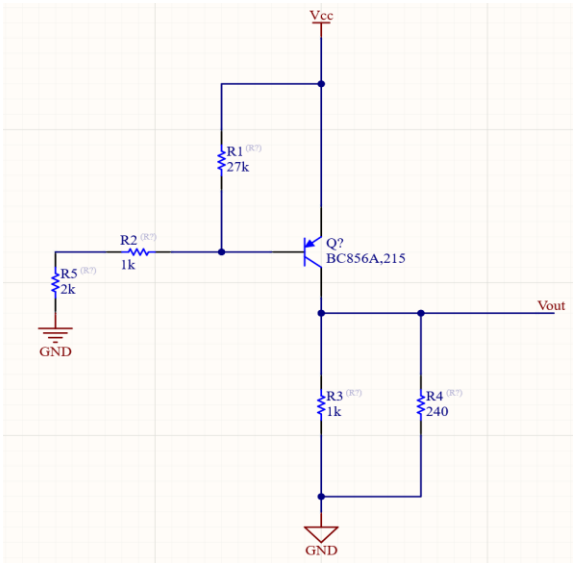

Fig. 9: Water detection circuit with water present.

$\text{Max } i_C = \frac{3.3V}{R_C} = \frac{3.3V}{1k\Omega||240\Omega} = 0.01705A \text{ or } 17.05mA$

$i_B = \frac{V_{CC}-V_{BE}}{R_B}$ (6)

$= \frac{3.3-0.7}{3\cdot 10^3}$

$= 0.0008667A$

$i_C = \beta i_B > \frac{3.3V}{R_C} \rightarrow i_{C,limit} = 0.01705A \text{ or } 17.05mA$

$V_{CE} = V_{CC} - i_C R_C = 0V$ (7)

$\therefore V_{OUT} = 3.3V$

These calculations form the expected results for the simulations because if V_{out} is equal to 3.3V, this indicates there is water in the main housing.

Once again, LTspice was used to validate the functionality of the water detection system. The circuit uses basic components such as a PNP transistor and various resistors. WEBENCH was not considered since the focus was not to validate a certain IC or component. It was easier to use LTSpice for a common circuit setup as such, as it allows us to easily validate the circuit logic by probing the output.

7 Final Design Details

The completed master schematic can be seen in Fig. 10. The final design achieves all objectives stated in Section 3. Full schematics of each subsystem can be found in Appendix A. Connection between input and output ports from each subsection is shown in Fig. 10. The final PMB includes a battery monitoring module to monitor individual cell battery voltage, a power distribution module with five output voltages for other areas of the AUV, a microcontroller module to facilitate all communication between various modules of the PMB, and a sensor module to monitor the external and internal environment of the AUV.

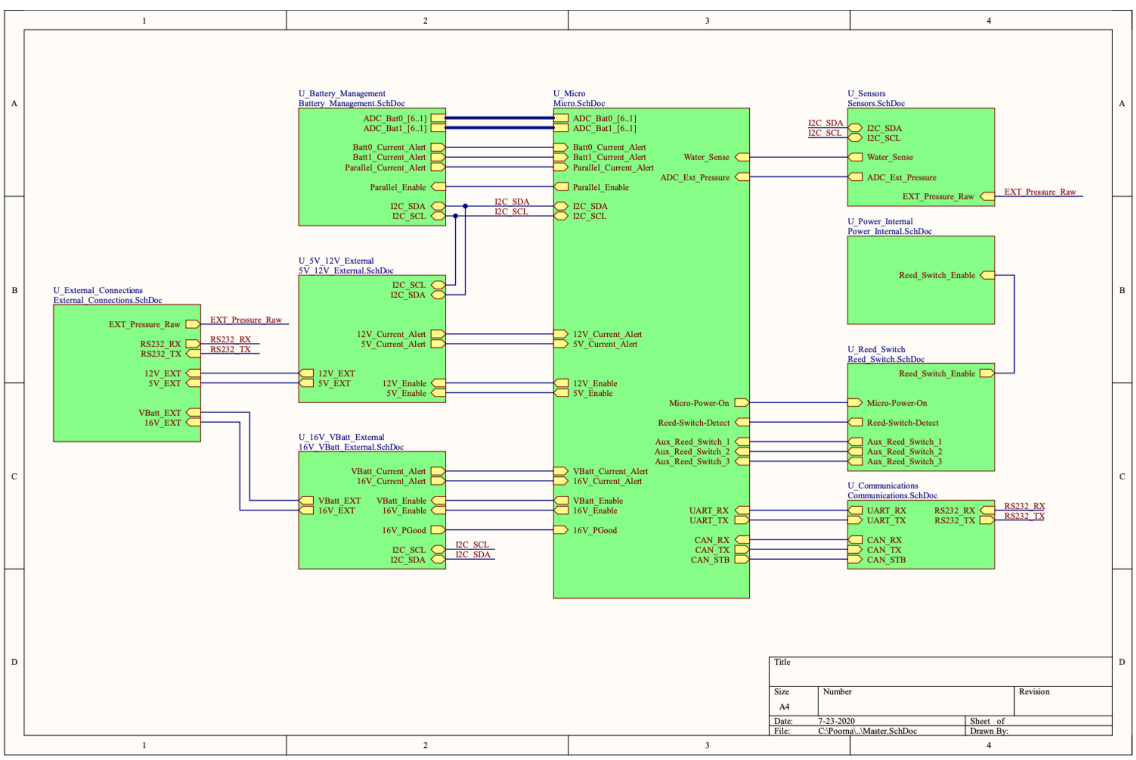

Fig. 10: Final master schematic sheet

7.1 Battery Management

From the requirements stated in Section 3.1, the input voltage required is between 18V and 28V. The input voltage requirement was determined by the constraints of the battery and this was met by selecting components to match the input voltage range including gate driver, MOSFETs, and buck converters. As shown in the detailed battery management schematics from Appendix A, the battery current monitor takes two battery inputs, Battery0 and Battery1. The main batteries used are two Multistar 12000mAh 6S 10C LiPo packs. This satisfies the battery requirement set by AUVIC, as each battery pack includes six cells. To satisfy the power requirements for the AUV the batteries are required to run in parallel. It can be observed that the two battery inputs are connected in parallel using a battery bridge circuit with a gate driver shown in Fig. 11. Fuses and LED's are included in the battery input terminal and bridge circuit also shown in Fig. 11.

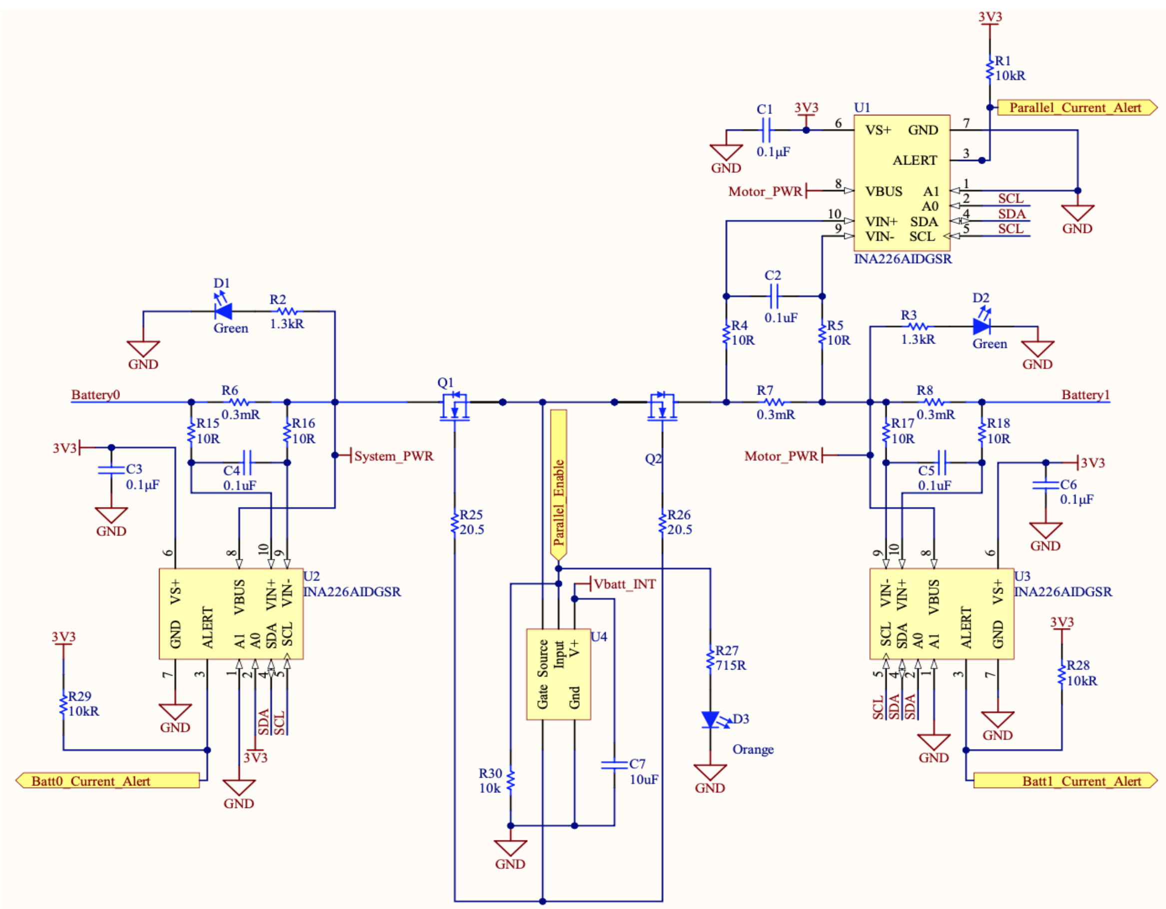

Fig. 11: Battery bridging circuit.

The battery management module uses a voltage divider circuit to monitor individual cell voltage as outlined in Section 6.1. Each individual cell voltage output is combined into a bus connected to the ADC pins on the microcontroller as shown in Fig. 12. Each pack current is monitored using an INA226A current shunt and power monitor chip and sent as feedback to the microcontroller as shown in the full schematics in Appendix A.

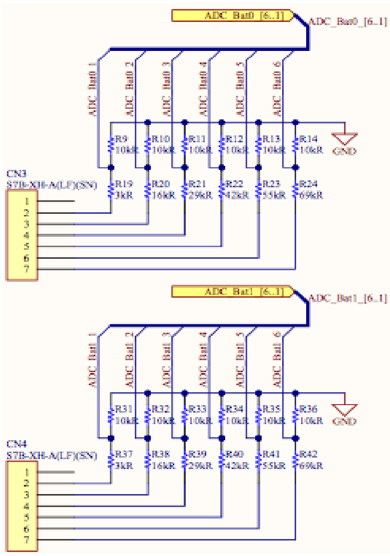

Fig. 12: Battery cell monitoring circuit.

7.2 Power Distribution

The power distribution module contains four external supply outputs: 5V, 12V, 16V, and V_battery (22.2V nominal). Detailed schematics for each external supply are provided in Appendix A. Sample detailed schematic for 12V external supply is shown in Fig. 13. Current monitoring is accomplished through the INA226A current shunt and power monitoring chip. The sample current output port for 12V external supply provides an alert to the microcontroller as shown in the lower right of Fig. 13. LEDs and fuses are connected to supply output in the sample schematic shown in Fig. 13.

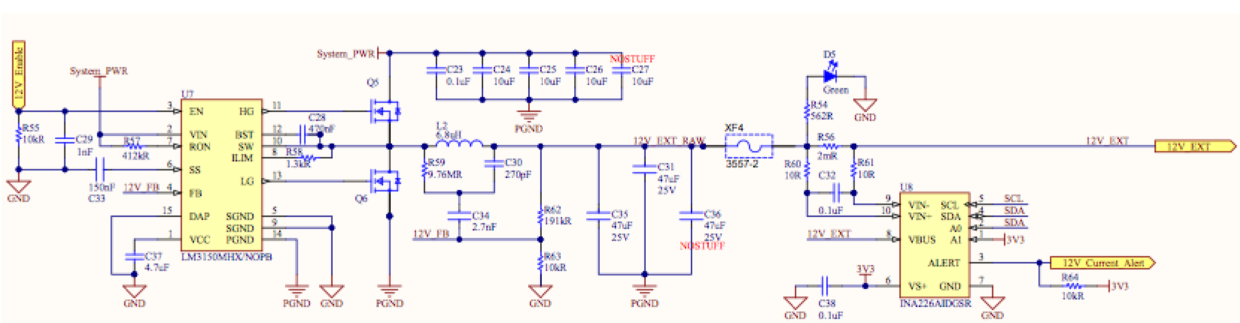

Fig. 13: Detailed schematic for 12V external supply.

A power reed switch circuit was implemented to remotely activate power to the microcontroller. The detailed schematic is shown in Fig. 14. When an external magnet is attached to the reed switch, VBatt_INT connects to the reed switch line, which sends a signal through Micro-Power-On to power on the microcontroller.

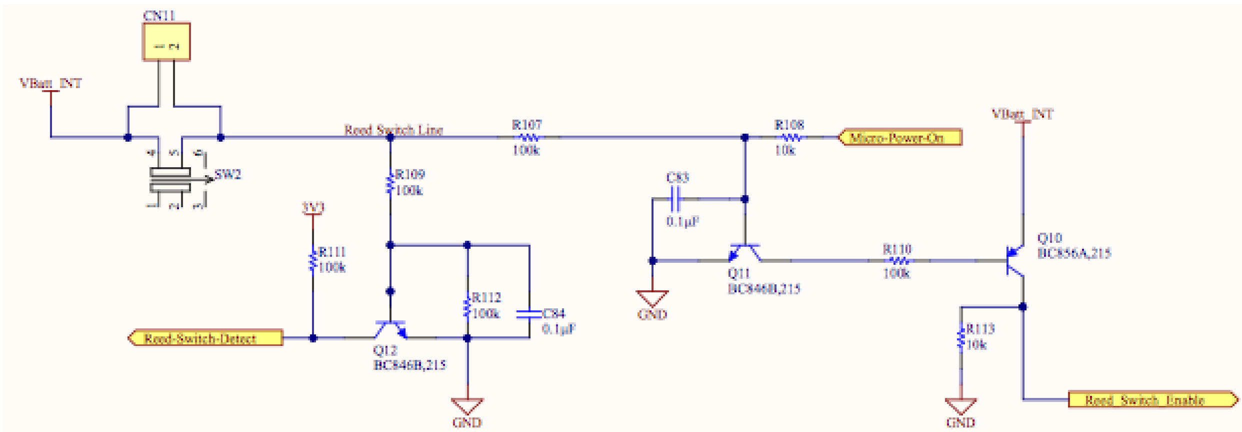

Fig. 14: Power reed switch circuit.

7.3 Microcontroller & Communication

The microcontroller used was a STM32F413 microcontroller which meets the objectives stated in Section 3.3. An RS232 transceiver circuit uses a ST232BTR transceiver chip that outputs two RS232 signals, RS232_TX and RS232_RX to the IMU shown in Fig. 15. Three debugging LEDs are implemented at ports 3, 4, 54 on the microcontroller shown in Appendix A.

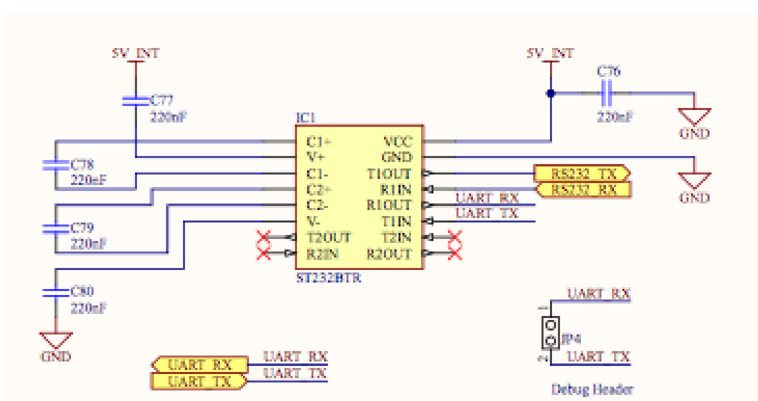

Fig. 15: RS232 transceiver circuit.

A CAN transceiver circuit is implemented to communicate with external systems. It uses a TJA104T/3 high speed CAN transceiver chip which takes input from the CAN_TXD on the microcontroller and outputs the received signal from CAN_RXD back to the microcontroller.

Outputs CAN_P and CAN_N connect to the CAN bus. Fig. 16 outlines the detailed schematic for the CAN transceiver.

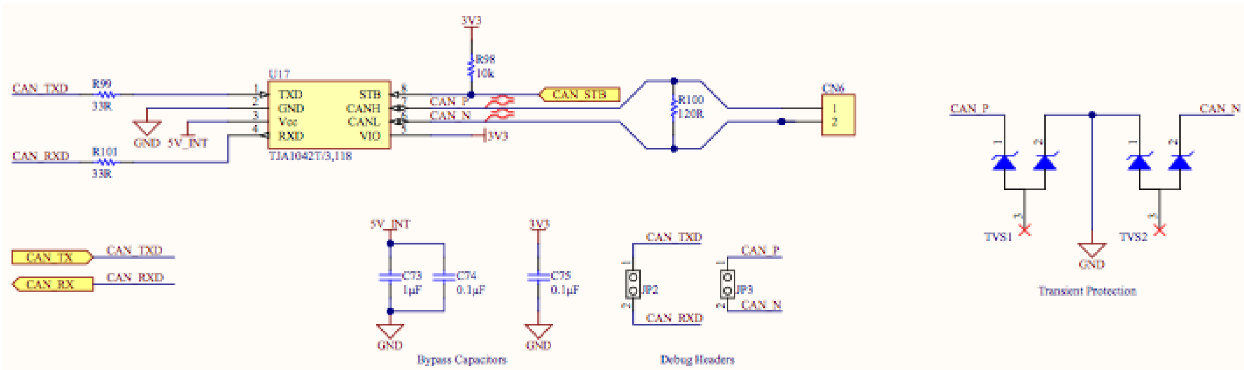

Fig. 16: CAN transceiver circuit.

7.4 Sensors

An auxiliary reed switch circuit was implemented to provide external inputs for software. The water sensor uses a BC856A PNP BJT in common emitter configuration to detect leaks within the main housing. This meets the specifications outlined in Section 3.4. Output from the water sensor feedback to the microcontroller and the accompanying LED provides easy visibility from outside the AUV. Fig. 17 shows the detailed water sensor schematic.

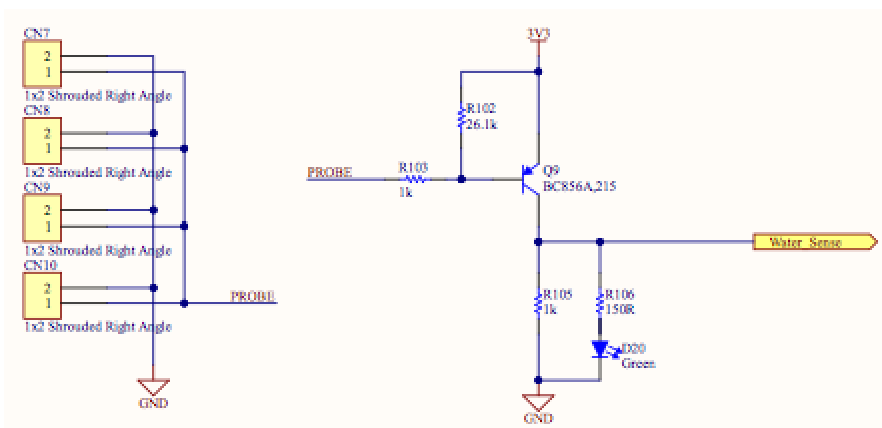

Fig. 17: Completed water sensor schematic.

From the completed sensor schematics provided in Appendix A, various environmental sensors were implemented including internal/external pressure, humidity, and temperature. This meets the objectives stated in Section 3.4.

8 Testing & Validation

Testing was divided into two steps. Subsystem level tests were conducted first using LTspice and WEBENCH. Once successfully completed, system level integration tests were conducted using LTspice.

8.1 Battery Management Subsystem Test

The first function of the battery management subsystem is to safely bridge the two lithium polymer batteries and ensure the two batteries do not interfere with each other when operating independently. The second function is to monitor cell voltages. Fig. 18 and 19 show the circuit diagram used to simulate this functionality.

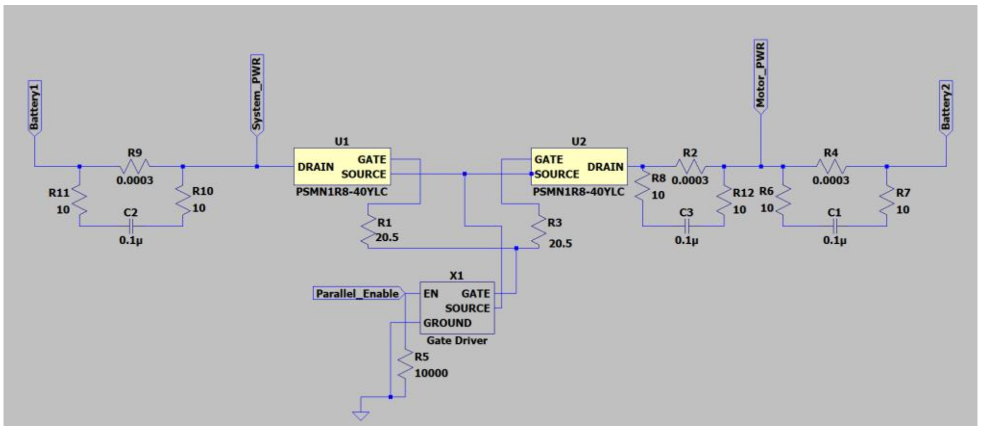

Fig. 18: Test setup in LTspice for the battery bridging circuit.

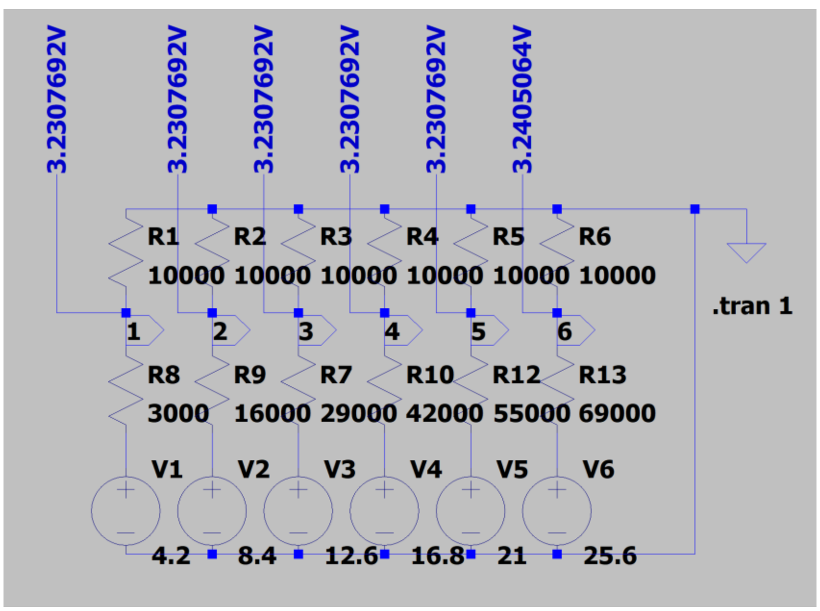

Fig. 19: Test setup in LTSpice for the cell voltage monitor circuit.

The following test procedure was run using LTspice. Plots showing the results for each test case can be found in Appendix B.

1. Set Battery1 to 21.7V, Battery2 to 22.2V, Parallel_Enable to 0V
2. Verify that no current flows through the parallel branch
   Result: Current through R2 is 0A
3. Set Battery1 to 21.7V, Battery2 to 22.2V, Parallel_Enable to 3.3V
4. Verify that current flows from Battery2 to Battery1 through the parallel branch
   Result: 65A flows from Battery2 to Battery1
5. Set Battery2 to 22.2V, Parallel_Enable to 0V, and open circuit Battery1
6. Verify that Battery2 is 22.2V and Battery1 is 0V.
   Result: Battery2 voltage is at 22.2V and Battery1 voltage is at 0V
7. Set Battery2 to 22.2V, Parallel_Enable to 3.3V, and open circuit Battery1
8. Verify that Battery2 and Battery1 voltage is 22.2V
   Result: Battery2 voltage is 22.2V and Battery1 voltage is 22.2V
9. In the cell monitoring circuit, set V1 to 4.2V, V2 to 8.4V, V3 to 12.6V, V4 to 16.8V, V5 to 21.0V and V6 to 25.6V
10. Verify that none of the outputs are above 3.3V.
    Result: All outputs are below 3.3V. The maximum output voltage is 3.24V.

These results show the proposed circuit design will function as intended and provide the functionality required of this subsystem.

8.2 Power Distribution Subsystem Test

Subsystem level tests were conducted on the 5V, 12V, 16V and VBatt power supply circuits. WEBENCH was used for simulating the 5V, 12, and 16V switch mode power supply circuits. Since VBatt did not require a switch mode power supply and only required a MOSFET and gate driver, this circuit was simulated using LTspice.

8.2.1 5V External

The 5V external supply output should not be lower than 4.9V and should not be higher than 5.1V. The ripple voltage must not be higher than 1% or the peak to peak ripple voltage should not be higher than 142mV. This prevents damage to the other electrical components in the circuit. Fig. 20 below shows the test setup in WEBENCH for the 5V supply circuit. A voltage source is placed at the input and a current source is placed at the output to simulate a load.

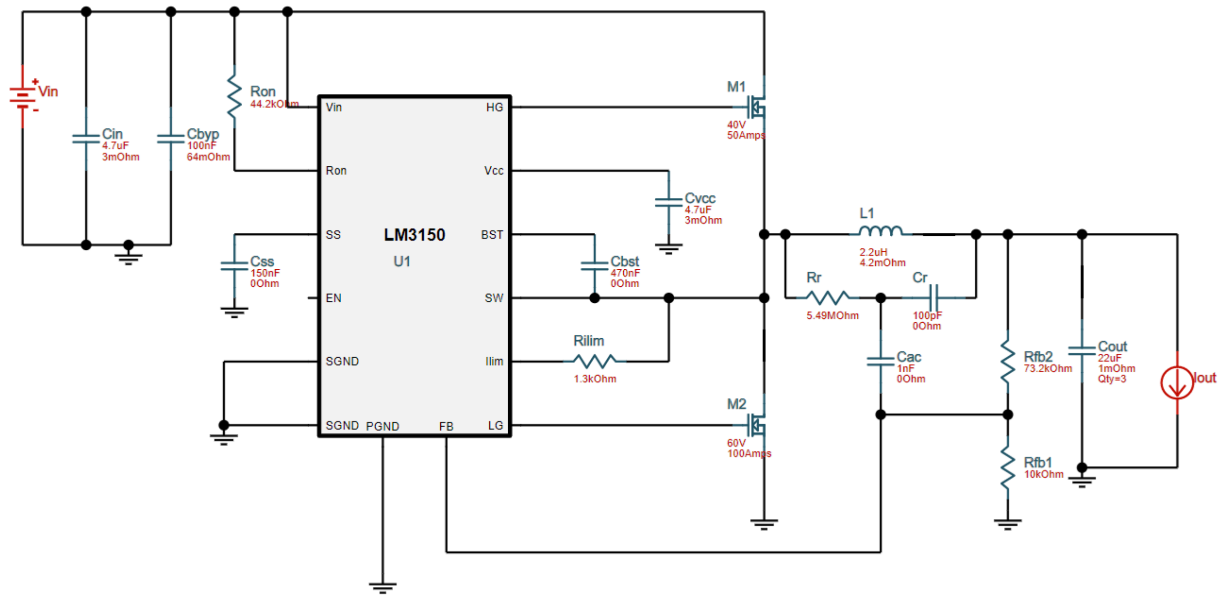

Fig. 20: Test setup in WEBENCH for the 5V supply.

The following test procedure was used to test the circuit. Fig. 21 shows the simulated plot for the nominal use case and from which the test result was extracted. Plots corresponding to the remaining test cases can be found in Appendix B.

1. Set V_{in} to 23V, I_{out} to 0.01A.
2. Verify that the output voltage is between 4.9V to 5.1V and the peak to peak voltage ripple is under 142mV.
   Result: Output voltage reaches a maximum of 5.1003V and peak to peak voltage is 0.4mV
3. Set V_{in} to 23V and I_{out} to 5.25A. This is the nominal use case.
4. Verify that the output voltage is between 4.9V to 5.1V and the peak to peak voltage ripple is under 142mV.
   Result: Output voltage is 5.0123V and the peak to peak voltage ripple is 4.5mV
5. Set V_{in} to 23V and I_{out} to 8A.
6. Verify that the output voltage is between 4.9V to 5.1V and the peak to peak voltage ripple is under 142mV.
   Result: Output voltage is 5.009V and peak to peak voltage ripple is 4.5mV
7. Set V_{in} to 28V and I_{out} to 5.25A.
8. Verify that the output voltage is between 4.9V to 5.1V and the peak to peak voltage ripple is under 142mV.
   Result: Output voltage is 5.0225V and peak to peak ripple voltage is 5mV
9. Set V_{in} to 18V and I_{out} to 5.25A.

10. Verify that the output voltage is between 4.9V to 5.1V and the peak to peak voltage ripple is under 142mV.
   Results: Output voltage is 4.9985V and peak to peak ripple voltage is 4mV

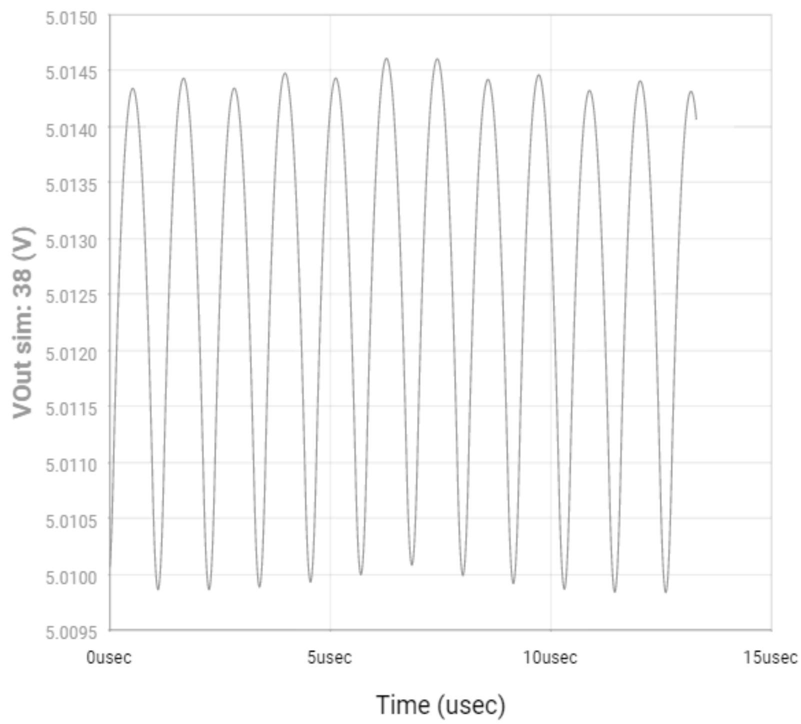

Fig. 21: 5V supply output at V_{in} = 23V and I_{out} = 5.25A; nominal use case.

The output voltage with V_{in} set to 23V and I_{out} set to 0.01A caused the output voltage to reach a maximum of 5.1003V. Since this is 0.3mV above the specification, the result is acceptable. All other test results meet the specification. Therefore, the 5V external supply circuit has passed the testing.

8.2.2 12V External

For optimal functionality, the 12V external supply output should not be lower than 11.5V and should not be higher than 12.5V. The ripple voltage must not be higher than 1% or the peak to peak ripple voltage should not be higher than 340mV. Fig. 22 below shows the test setup in WEBENCH for the 12V supply circuit. A voltage source is placed at the input and a current source is placed at the output to simulate a load.

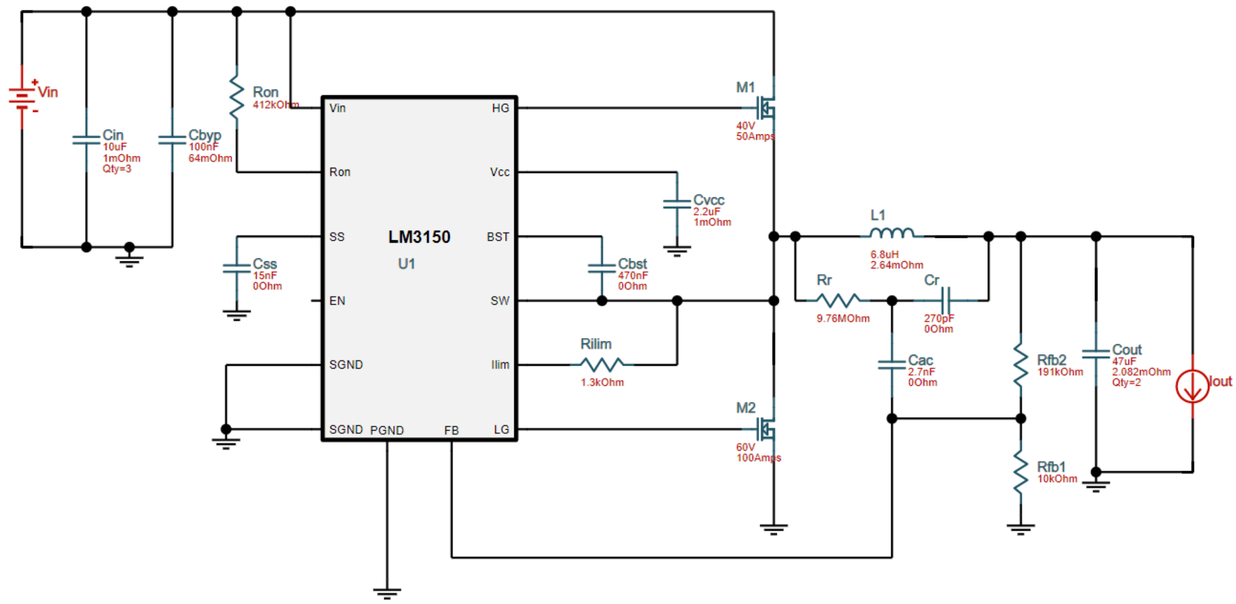

Fig. 22: Test setup in WEBENCH for the 12V supply

The following test procedure was used to test the circuit. Fig. 23 shows the simulated plot for the nominal use case and from which the test result was extracted. Plots corresponding to the remaining test cases can be found in Appendix B.

1. Set V_{in} to 23V, I_{out} to 0.01A.
2. Verify that the output voltage is between 11.5V to 12.5V and the peak to peak voltage ripple is under 340mV.
   Result: Output voltage ranges from 12.16V to 12.155V with a peak to peak voltage ripple of 0.5mV.
3. Set V_{in} to 23V and I_{out} to 6A. This is the nominal use case.
4. Verify that the output voltage is between 11.5V to 12.5V and the peak to peak voltage ripple is under 340mV.
   Result: Output voltage is 11.988V with a peak to peak voltage ripple of 16mV.
5. Set V_{in} to 23V and I_{out} to 3A.
6. Verify that the output voltage is between 11.5V to 12.5V and the peak to peak voltage ripple is under 340mV.
   Result: Output voltage is 11.948V with a peak to peak voltage ripple of 16mV.
7. Set V_{in} to 28V and I_{out} to 6A.
8. Verify that the output voltage is between 11.5V to 12.5V and the peak to peak voltage ripple is under 340mV.
   Result: Output voltage is 12.107V with a peak to peak voltage ripple of 18mV.
9. Set V_{in} to 18V and I_{out} to 6A.

10. Verify that the output voltage is between 11.5V to 12.5V and the peak to peak voltage ripple is under 340mV.
Result: Output voltage is 11.813V with a peak to peak voltage ripple of 12mV.

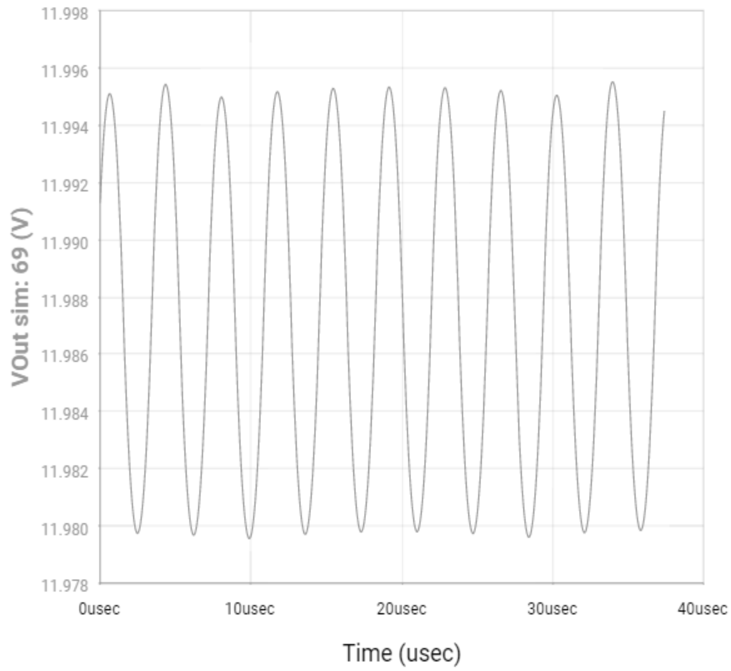

Fig. 23: 12V supply output at V_{in} = 23V and I_{out} = 6A; nominal use case.

8.2.3 *16V External*

The 16V external supply output should not be lower than 14V and should not be higher than 18V. The wide voltage range on this supply is acceptable because the device using this voltage has an input voltage range of 5V to 19.5V. The ripple voltage must not be higher than 1% or the peak to peak ripple voltage should not be higher than 450mV to prevent damage to the other components in the circuit. Fig. 24 below shows the test setup in WEBENCH for the 16V supply circuit. A voltage source is placed at the input and a current source is placed at the output to simulate a load.

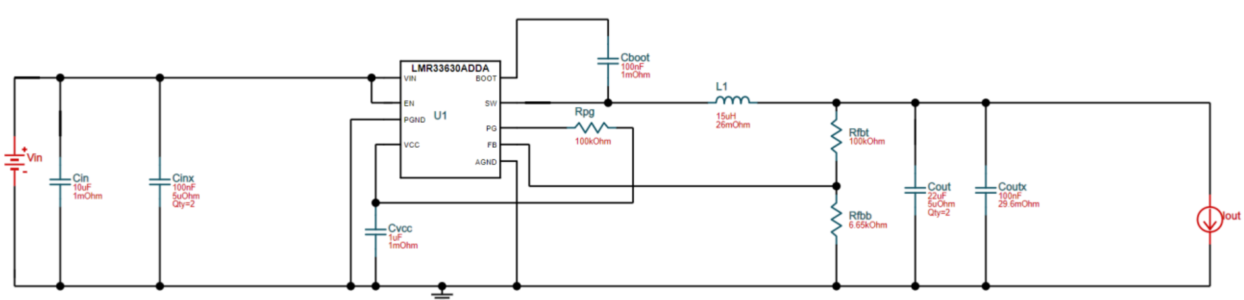

Fig. 24: Test setup in WEBENCH for the 16V supply.

The following test procedure was used to test the circuit. Fig. 25 shows the simulated plot for the nominal use case and from which the test result was extracted. Plots corresponding to the remaining test cases can be found in Appendix B.

1. Set V_{in} to 23V, I_{out} to 0.01A.
2. Verify that the output voltage is between 14V to 18V and the peak to peak voltage ripple is under 450mV.
   Result: Output voltage ranges from 16.088 to 16.096V with a peak to peak voltage ripple of less than 0.1mV.
3. Set V_{in} to 23V and I_{out} to 0.7A. This is the nominal use case.
4. Verify that the output voltage is between 14V to 18V and the peak to peak voltage ripple is under 450mV.
   Result: Output voltage is 16.040V with a peak to peak ripple voltage of 8mV
5. Set V_{in} to 23V and I_{out} to 3A.
6. Verify that the output voltage is between 14V to 18V and the peak to peak voltage ripple is under 450mV.
   Result: Output voltage is 16.040V with a peak to peak voltage ripple of 8mV
7. Set V_{in} to 28V and I_{out} to 0.7A.
8. Verify that the output voltage is between 14V to 18V and the peak to peak voltage ripple is under 450mV.
   Result: Output voltage is 16.035V with a peak to peak voltage ripple of 8mV
9. Set V_{in} to 18V and I_{out} to 0.7A.
11. Verify that the output voltage is between 14V to 18V and the peak to peak voltage ripple is under 450mV.
   Result: Output voltage is 16.0V with a peak to peak voltage ripple of 13mV

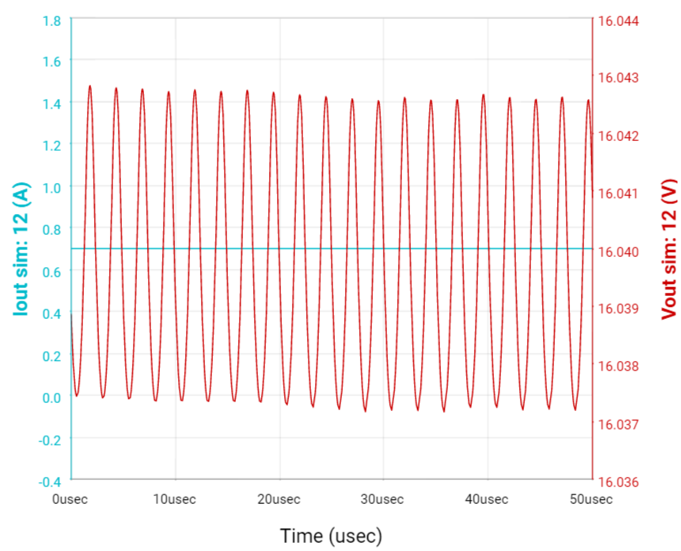

Fig. 25:16V supply output at Vin = 23V and Iout = 0.7A.

8.2.4 *VBatt External*

The VBatt external supply can range from 18V to 28V and must be capable of delivering 60A. Fig. 26 below shows the test setup in LTspice. A current source is placed at the output to simulate a load. The input power is supplied by a DC voltage source in series with a AC voltage source to simulate noise on the voltage rail. Another DC power source is connected to the enable pin to simulate the microcontroller.

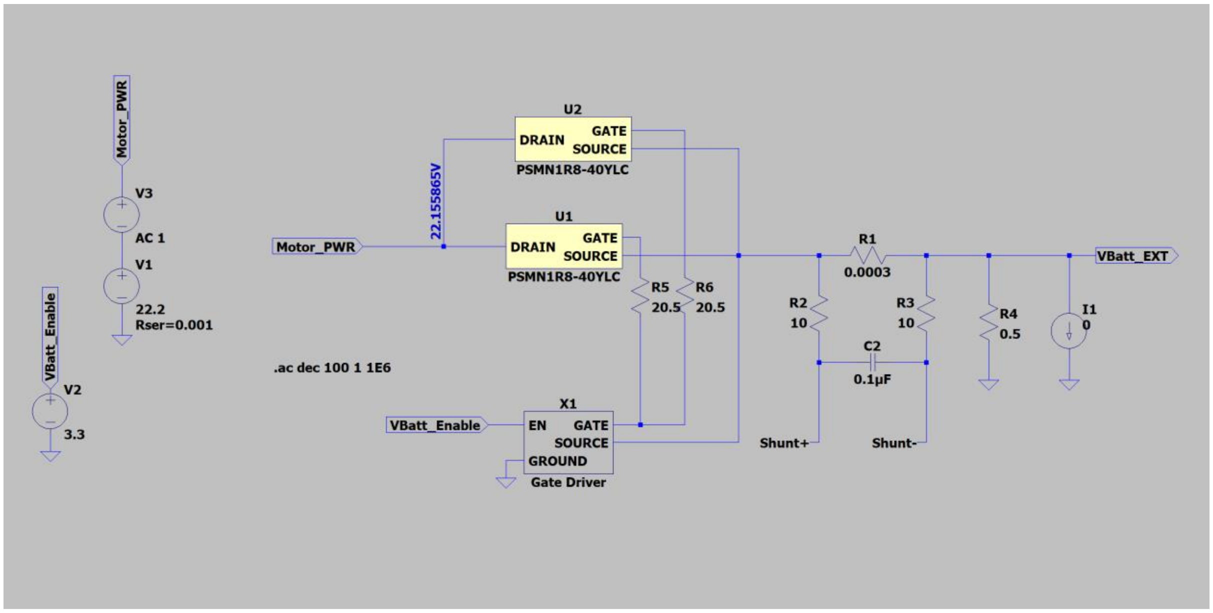

Fig. 26: Test setup in LTspice for the V_{Batt} supply circuit.

The following test procedure was used to test the circuit. Plots corresponding to the test cases can be found in Appendix B.

1. Set Motor_PWR to 22.2V, VBatt_Enable to 0V, and I_{load} to 0A.
2. Verify that the output voltage, VBatt_EXT, is 0V.
   Results: Output voltage is equal to 0V.
3. Set Motor_PWR to 22.2V, VBatt_Enable to 3.3V, and I_{load} to 0A.
4. Verify that the output voltage is 22.2V or slightly under 22.2V.
   Results: Output voltage is equal to 22.2V.
5. Set Motor_PWR to 22.2V, VBatt_Enable to 3.3V, and I_{load} to 0A.
6. Verify that the shunt voltage is less than 2.5uV(1 LSB for INA 226 sensor).
   Results: Shunt voltage is equal to 0V.
7. Set Motor_PWR to 22.2V, VBatt_Enable to 3.3V, and I_{load} to 30A.
8. Verify that the shunt voltage is equal to 9mV +/- 2.5uV.
   Results: Shunt voltage is equal to 9mV.
9. Set Motor_PWR to 22.2V, VBatt_Enable to 3.3V, and I_{load} to 60A.
10. Verify that the shunt voltage is equal to 18mV +/- 2.5uV.

Results: Shunt voltage is equal to 18mV.

11. Set Motor_PWR to 22.2V, VBatt_Enable to 3.3V, I_{load} to 0A, and connect a 0.5Ω load resistor to VBatt_EXT. Run an AC analysis sweep from 1Hz to 1MHz using V3 as the AC source.
12. Verify that the cutoff frequency is above 50kHz (minimum sampling frequency required by application) and below 500kHz (ADC sampling frequency).
    Results: Cutoff frequency is equal to 77.76kHz.

The test results described above show the VBatt external power subsystem will function as intended.

8.3 Communication Subsystem Test

The CAN transceiver is the interface between the microcontroller and the CAN bus. It must assert the CAN bus when requested by the microcontroller and read the CAN bus state. Fig. 27 and 28 shows the test setup in LTspice for the CAN transceiver circuit. A voltage source is used where a microcontroller would be connected. The receive pin, CANH, and CANL are probed to read its state.

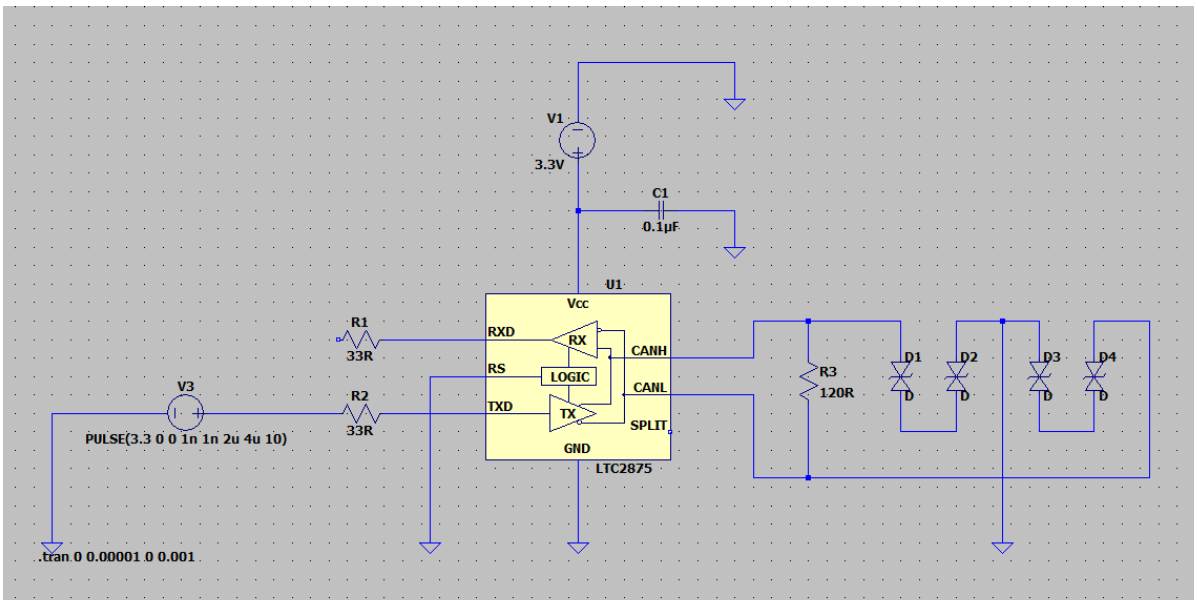

Fig. 27: Test setup in LTspice for the CAN transceiver circuit.

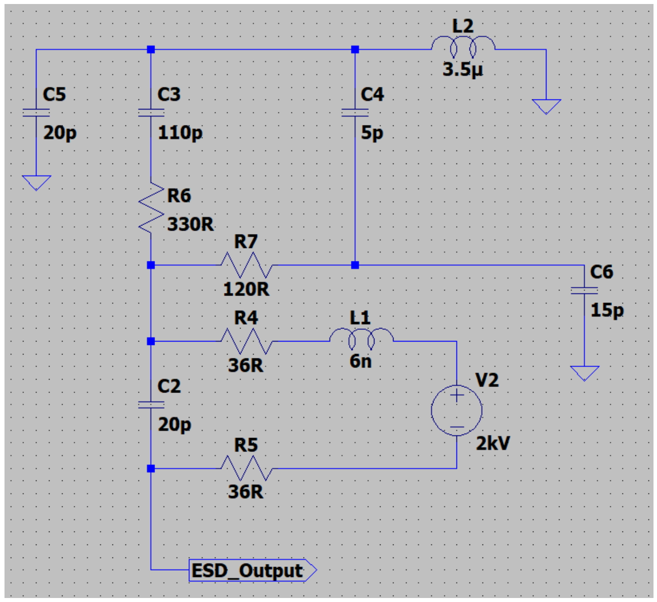

Fig. 28: ESD generator for inducing ESD on CAN bus.

The following test procedure was used to test the circuit. Plots showing the results for each test case can be found in Appendix B.

1. Set TX pin to 3.3V.
2. Verify that the CAN bus is in the recessive state (CANH - CANL < 0.5V).
   Results: CANH - CANL is equal to 0V.
3. Send a 2µs pulse with V_{on} equal to 0V on the TX pin.
4. Verify that the CAN bus is in the dominant state (CANH - CANL >= 2V). Verify that the RX pin reflects the state of the CAN bus.
   Results: CANH - CANL is equal to 2.2V. RX pin is pulled low when the CAN bus is transmitting a 0V and is pulled up to 3.3V when the CAN bus is transmitting a 1.
5. Send a square wave with a period of 4us on the TX pin. Turn on the ESD generator.
6. Verify that the operation of the CAN bus is unaffected.
   Results: CAN bus state reflects the state of the TX pin correctly same as in previous tests.

These results indicate the CAN transceiver will be able to successfully connect the microcontroller to the CAN bus and the external systems of the AUV.

8.4 Sensor Subsystem Test

The sensor subsystem is responsible for monitoring the internal pressure, temperate, humidity and water leaks in the housing. Since the internal pressure, temperature, and humidity sensors were copied from the old power board without modification, those circuits are not tested in the simulations. Fig. 29 shows the test circuit in LTspice for the water sensor. R5 is the equivalent circuit for the water probe. When the sensor detects water, the resistance across its leads will be close to 2kΩ.

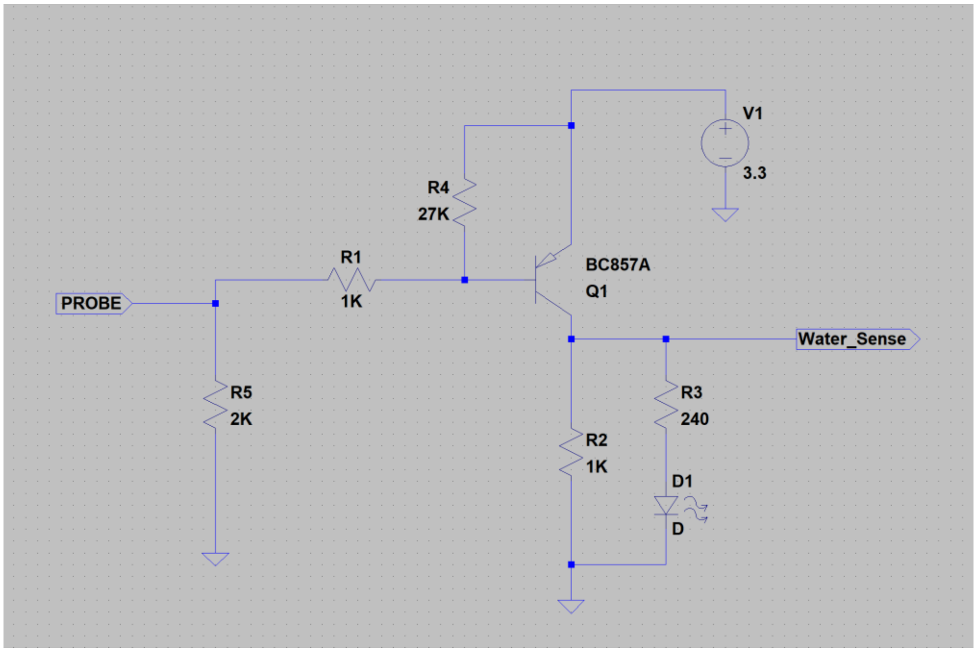

Fig. 29: Test setup in LTSpice for the water sensor circuit.

The following test procedure was used to test the circuit. Plots corresponding to the test cases can be found in Appendix B.

1. Set R5 to 500kohm
2. Verify that Water_Sense is equal to 0V
   Result: Water_Sense is equal to 11.7448nV
3. Set R5 to 2kohm
4. Verify that Water_Sense is equal to 3.3V
   Result: Water_Sense is equal to 3.247V

These results above demonstrate the water sensor circuit will be able to detect a water leak in the main housing and signal to the microcontroller.

8.5 Reed Switch Subsystem Test

The reed switch subsection encompasses the power reed switch used for powering on the AUV and auxiliary reed switches. Fig. 30 shows the test setup in LTspice for the power reed switch circuit. System_PWR is supplied by the battery which can range from 18V to 28V. V1 is used to simulate the reed switch being connected or disconnected. Reed_Switch_Enable is an output that controls the enable for the internal 5V and 3.3V power supplies. Micro-Power-On is an input to the circuit to hold the state of Reed_Switch_Enable high. Reed_Switch_Detect is an output to the microcontroller and is an active low signal that reflects the presence of a reed switch regardless of the state of Reed_Switch_Enable and Micro-Power-On.

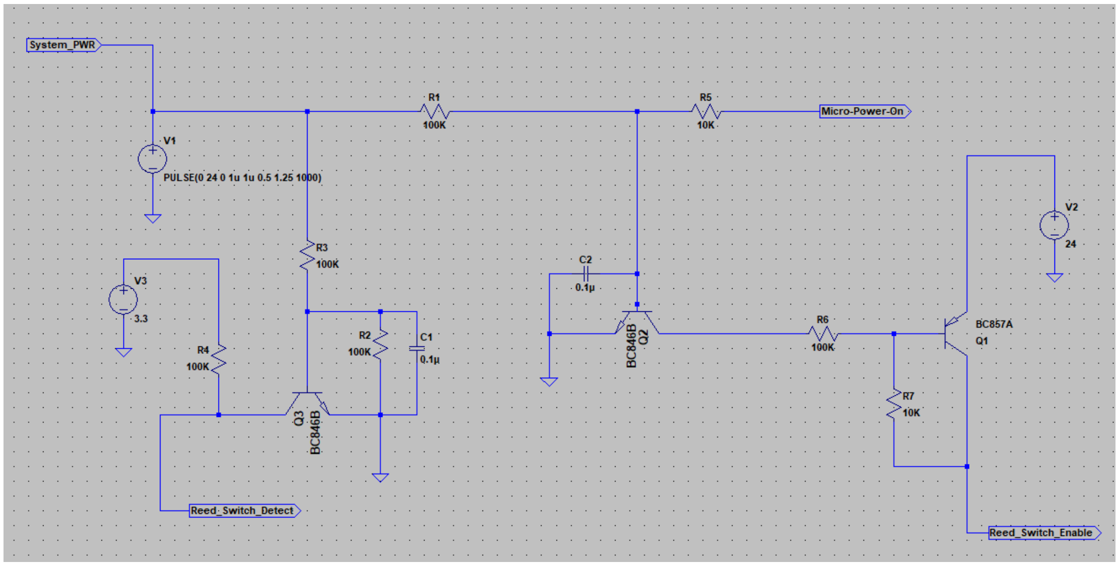

Fig. 30: Test setup in LTspice for the power reed switch.

Fig. 31 shows the test setup in LTspice for the auxiliary reed switch. V1 is used to simulate the reed switch being connected or disconnected. Aux_Reed_Switch_1 is the input into the microcontroller and is an active low signal.

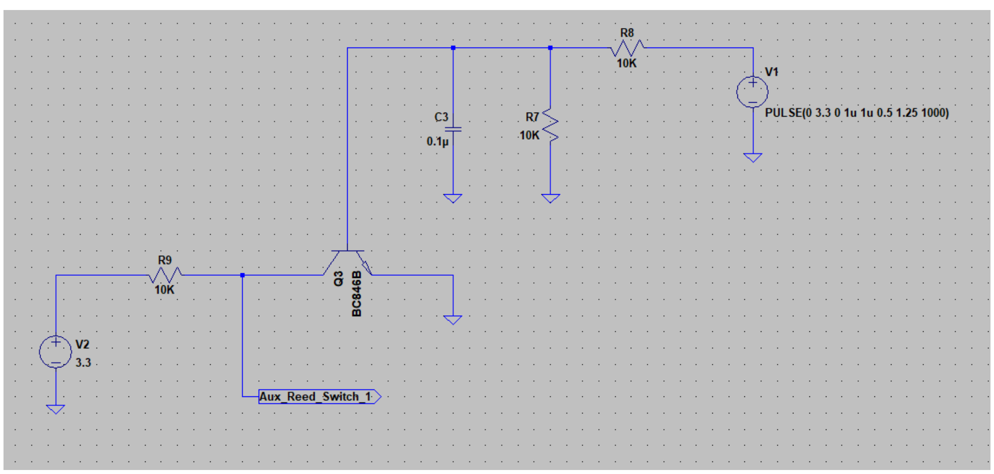

Figure 31: Test setup in LTspice for the auxiliary reed switch.

More through testing on the reed switch circuit was conducted at the system level through the integration tests. Therefore, results from the integration tests were used to verify the functionality. See the section below for the test procedure used on this circuit.

8.6 Integration Test

Once subsystem level tests were completed on the individual circuits, the circuits were combined to test interoperability. The circuits in the figures above were converted into a schematic symbol in LTspice with only the inputs and output exposed. For circuits tested using WEBENCH, an equivalent circuit was created in LTspice.

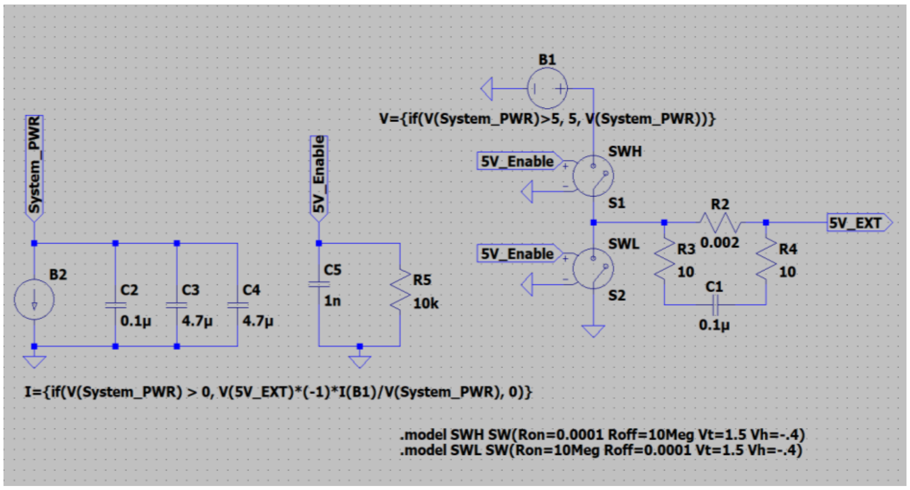

Fig. 32: Equivalent model in LTSpice for the 5V external supply circuit.

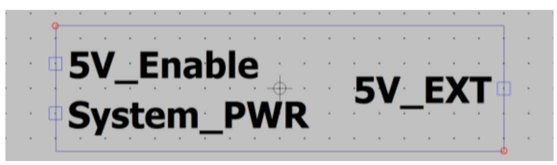

Fig. 33: Schematic symbol for 5V external supply equivalent circuit.

Fig. 32 shows an example of the equivalent circuit for the 5V external supply and fig. 33 shows its corresponding schematic symbol used in the interoperability simulation. A current source was connected to the input, System_PWR, that has a current value proportional to the output current to represent the average current draw of the block for a given load. The output, 5V_EXT, was connected to a voltage source that will regulate to 5V given that the input power is above 5V. 5V_Enable switches the output on or off. These inputs and outputs were exposed in the schematic symbol.

Fig. 34 shows the master simulation sheet in LTspice with the interconnects between the schematic symbols generated from the above circuit. The 6cell LiPo battery used by the AUV was modeled as six series capacitors each with a capacitance of 10kF. The reed switch inputs into the board were modeled using a voltage controlled switch. The switch was closed when the voltage was 3.3V and open when the voltage was 0V. The water sensor was modeled as a voltage controlled switch with a series 2kΩ resistor.

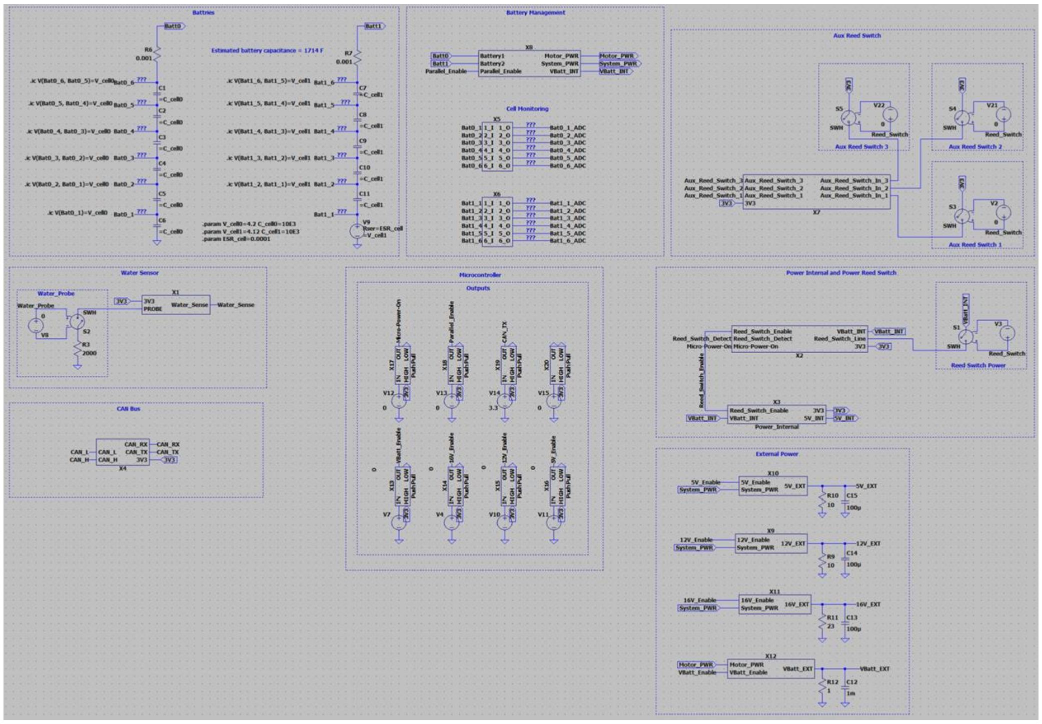

Fig. 34: Master simulation sheet in LTspice.

The following test procedure was used to test the circuit. Plots corresponding to the test cases can be found in Appendix B.

8.6.1 Power Reed Switch Test

1. Set Batt0 and Batt1 to 22.2V
2. Turn the power reed switch off and set Micro-Power-On to 0V
3. Verify that 5V_INT and 3V3 are equal to 0V

   Result: 5V_INT is equal to 0V and 3V3 is equal to 0V
4. Turn the power reed switch on and set Micro-Power-On to 0V
5. Verify that 5V_INT is equal to 5V, 3V3 is equal to 3.3V and Reed_Switch_Detect is equal to 0V

   Result: 5V_INT is equal to 5V, 3V3 is equal to 3.3V, Reed_Switch_Detect is equal to 0V
6. Set Micro-Power-On to 3.3V
7. Turn the power reed switch off
8. Verify that 5V_INT is equal to 5V, 3V3 is equal to 3.3V, Reed_Switch_Detect is equal to 3.3V

   Result: 5V_INT is equal to 5V, 3V3 is equal to 3.3V, Reed_Switch_Detect is equal to 3.3V
9. Set Micro-Power-On to 0V

10. Verify that 5V_INT is equal to 0V and 3V3 is equal to 0V
Result: 5V_INT and 3V3 are equal to 0V

8.6.2 *Auxiliary Reed Switch*

1. Set Batt0 and Batt1 to 22.2V.
2. Turn the power reed switch on and turn off all auxiliary reed switches.
3. Verify that all auxiliary reed switch signals are 3.3V.
Result: Aux_Reed_Switch_1 is equal to 3.3V, Aux_Reed_Switch_3 is equal to 3.3V, and Aux_Reed_Switch_3 is equal to 3.3V.
4. Turn on all auxiliary reed switches.
5. Verify that all auxiliary reed switch signals are 0V.
Result: Aux_Reed_Switch_1 is equal to 0V, Aux_Reed_Switch_3 is equal to 0V, and Aux_Reed_Switch_3 is equal to 0V.

8.6.3 *Battery Bridge*

1. Set Batt0 to 25.2V and Batt1 to 24.72V.
2. Turn on the power reed switch.
3. Verify that there are no negative currents through either battery.
Result: Batt0 current is greater than 0A, Batt1 current is greater than 0A.
4. Enable the parallel battery branch.
5. Verify that Batt0 starts to charge Batt1.
Result: A negative current of 45A can be seen through Batt1.
6. Verify that Batt0 voltage and Batt1 voltage start to converge.
Result: Batt0 - Batt1 reaches under 50mV 30s after the parallel branch is enabled.

8.6.4 *External Power Supply*

1. Set Batt0 to 25.2V and Batt1 to 25.2V.
2. Turn on the power reed switch.
3. Verify that the VBatt_EXT, 16V_EXT, 12V_EXT, and 5V_EXT rails are equal to 0V.
Result: VBatt_EXT, 16V_EXT, 12V_EXT, and 5V_EXT rails are equal to 0V.
4. Set VBatt_Enable to 3.3V.
5. Verify that VBatt_EXT is equal to Batt1 voltage.
Result: VBatt_Enable is equal to 25.2V.
6. Set 16V_Enable to 3.3V.
7. Verify that 16V_EXT is within the acceptable range for the 16V rail.
Result: 16V_EXT is equal to 16V.
8. Set 12V_Enable to 3.3V.

9. Verify that 12V_EXT is within the acceptable range for the 12V rail. **Result:** 12V_EXT is equal to 12V.
10. Set 5V_Enable to 3.3V.
11. Verify that 5V_EXT is within the acceptable range for the 5V rail.
    Result: 5V_EXT is equal to 5V.

The results outlined in the subsections above show the interoperability of the system will function as intended and the subsystems will work together as predicted.

9 Discussion & Recommendations

From the testing completed in section 8, all test results obtained were as expected when compared with theoretical values obtained in section 3. From the results obtained from battery management subsystem test, it can be observed that the output voltage from voltage monitoring circuits are below 3.3V, which matches the theoretical results calculated. Power distribution subsystem conducted 5V, 12V, 16V, and VBatt external power supply tests and the output results are detailed in section 8.2. From the values obtained, each external power supply produced output voltages that complies with the design objectives and theoretical results. The 5V external supply test reached a maximum output of 5.1003 V. This is 0.3 mV above the specification which is acceptable and does not affect the results of other subsystems. For the communication test, the CAN transceiver input was sent a square wave which was observed at the output therefore verifying the design of the transceiver. Outputs from the reed switch and water sensors also matched with theoretical results obtained. Water sensor outputs 3.3V when the water is present (probes are shorted) and the power reed switch circuit powered on the internal 5V and 3.3V when the switch is turned on. Integration tests were completed once each subsystem tests were passed. Results show that the interoperability of the system functions as intended and works together as expected.

Due to the time constraint of this project and the restricted access to lab and manufacturing equipment, only a schematic design was completed. For future work, a PCB layout and Gerber files should be created and the manufacturing and assembly of the PMB should be completed. Additional testing and validation of manufactured prototype should be conducted. Firmware and integration with other systems of the AUV should also be completed once the manufactured prototype is finished.

10 Conclusion

To conclude, the project goals and design objectives stated in the beginning of this report were accomplished for the various four sections. The battery management section proposes a successful model to monitor individual cell voltages and pack voltage. The model makes use of the existing

JST-XH connector on the current LiPo battery. A battery bridging circuit that allows two batteries to run in parallel was also designed and validated. The power distribution section meets all required specifications, circuitry for all external power rails was successfully designed and validated using WEBENCH. Furthermore, a CAN transceiver circuit was analyzed and validated using LTSpice. Lastly, the sensors section provides a functional model to detect water, the circuit's functionality was validated using LTSpice. The probe was modelled as a resistor and testing was done for with and without water cases, in either case the circuit performed as expected.

11 References

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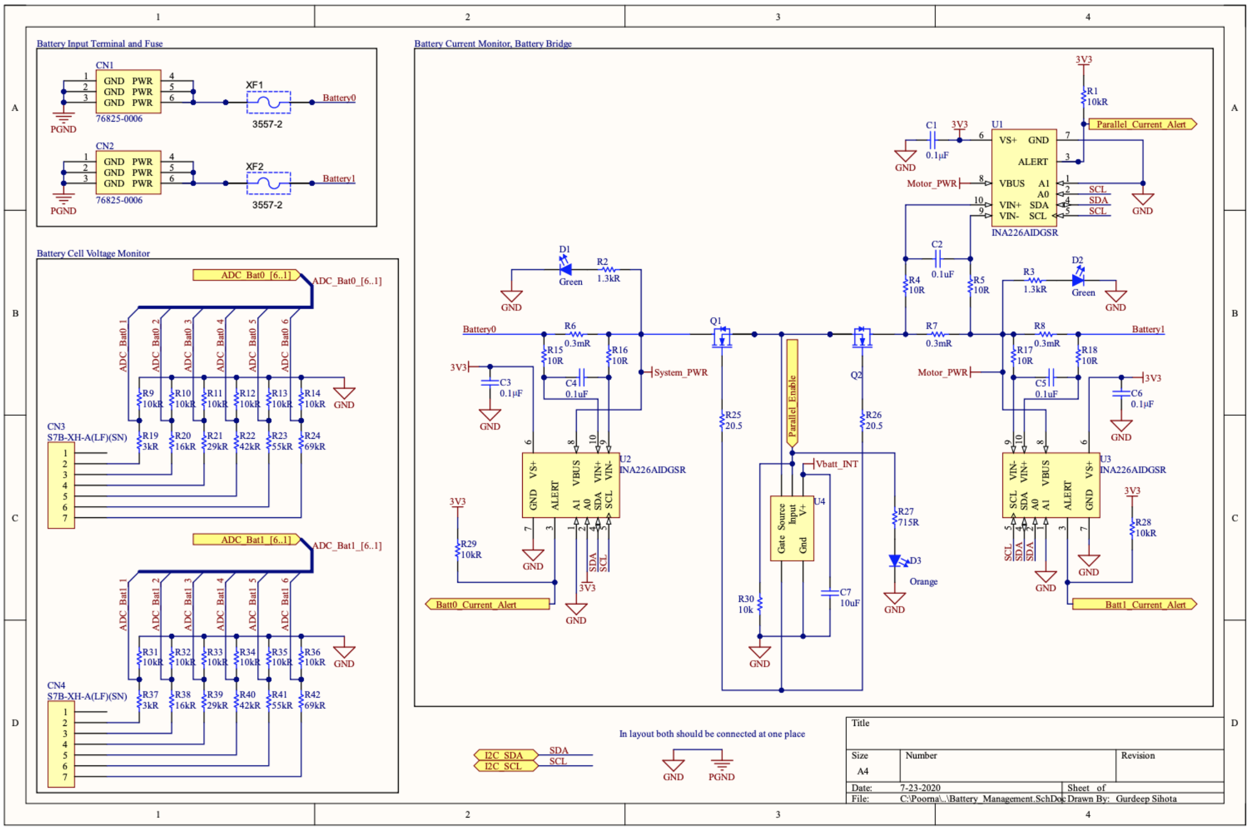
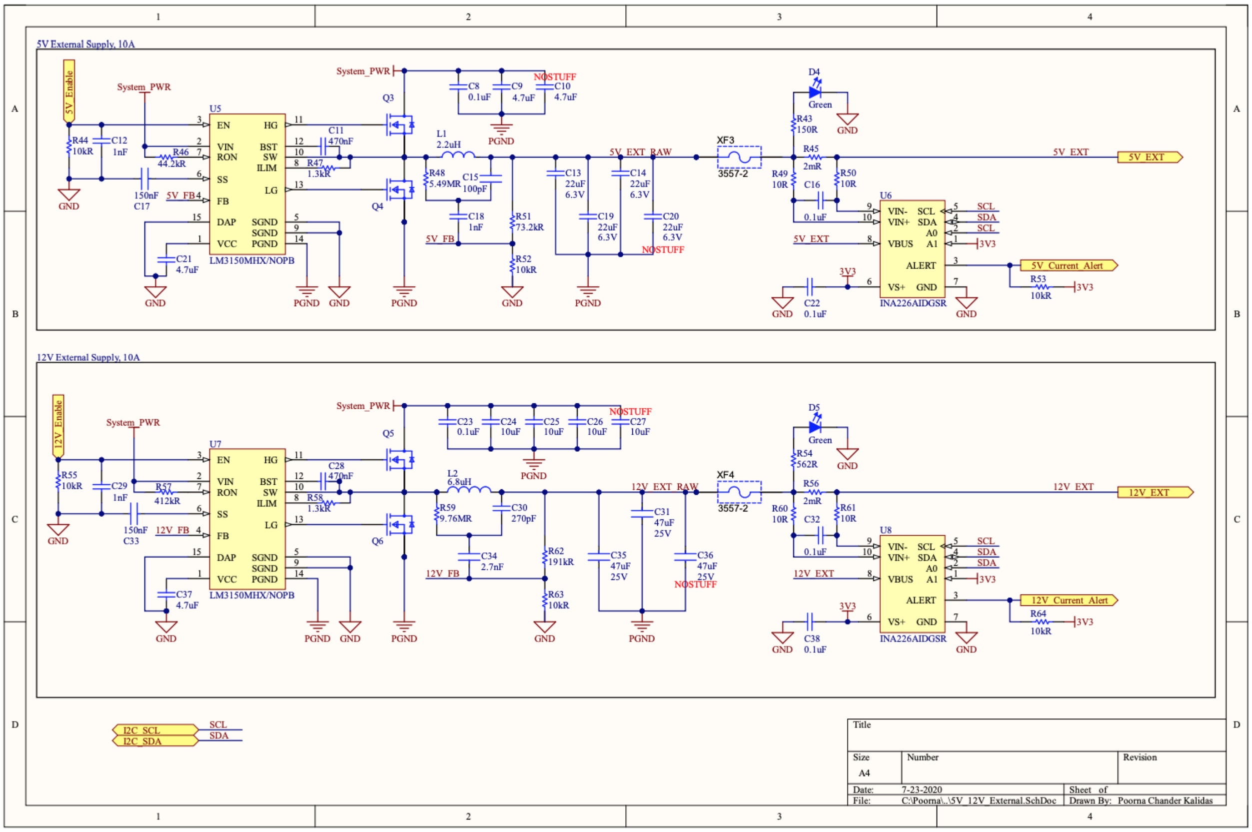
[11] “Compact Liquid Leak Sensor”. NetMotion. [Online]. Available: http://www.netmotion.com/htm_files/fh_leak.htm

Appendix A: Final Schematics

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5V_Enable
System_PWR
U5
EN
VIN
RON
SS
FB
DAP
VCC
HG
BST
SW
ILIM
LG
SGND
SGND
PGND
LM3150MHX/NOPB
R44 10kR
C12 1nF
R46 44.2kR
C17 150nF
5V_FB
C21 4.7uF
C11 470nF
R47 1.3kR
Q3
Q4
C8 0.1uF
C9 4.7uF
C10 4.7uF
NOSTUFF
L1 2.2uH
R48 5.49MR
C15 100pF
C18 1nF
R51 73.2kR
R52 10kR
C13 22uF 6.3V
C14 22uF 6.3V
C19 22uF 6.3V
C20 22uF 6.3V
5V_EXT_RAW
XF3
3557-2
D4
Green
R43 150R
R45 2mR
R49 10R
R50 10R
C16 0.1uF
U6
VIN-
VIN+
VBUS
ALERT
VS+
SCL
SDA
A0
A1
GND
INA226AIDGSR
5V_EXT
5V_Current_Alert
R53 10kR
3V3
C22 0.1uF
GND
PGND
12V External Supply, 10A
12V_Enable
U7
R55 10kR
C29 1nF
R57 412kR
C33 150nF
12V_FB
C37 4.7uF
C28 470nF
R58 1.3kR
Q5
Q6
C23 0.1uF
C24 10uF
C25 10uF
C26 10uF
C27 10uF
L2 6.8uH
R59 9.76MR
C30 270pF
C34 2.7nF
R62 191kR
R63 10kR
C35 47uF 25V
C31 47uF 25V
C36 47uF 25V
12V_EXT_RAW
XF4
D5
R54 562R
R56 2mR
R60 10R
R61 10R
C32 0.1uF
U8
12V_EXT
12V_Current_Alert
R64 10kR
C38 0.1uF
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I2C_SDA
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SDA
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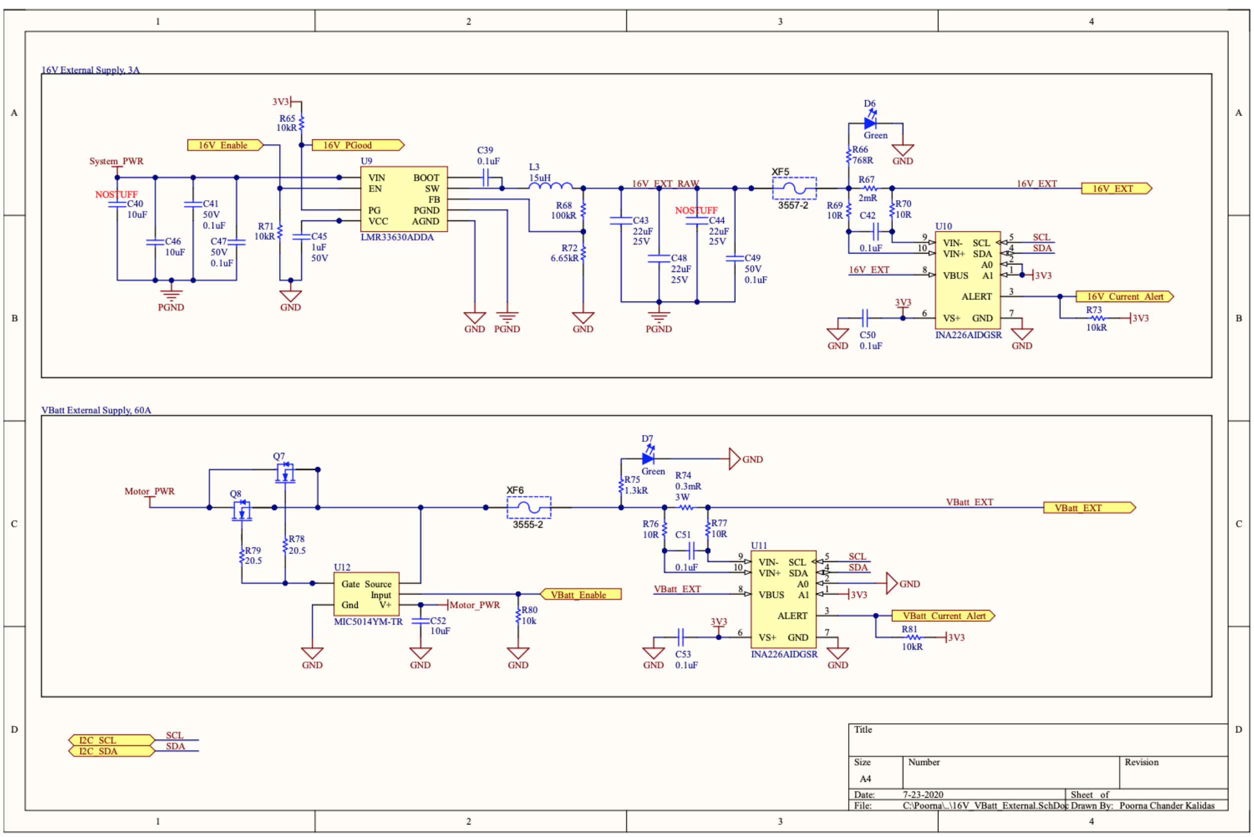
Drawn By: Poorna Chander Kalidas


16V External Supply, 3A
3V3
R65 10kR
16V_Enable
16V_PGood
System_PWR
NOSTUFF
C40 10uF
C41 50V 0.1uF
C46 10uF
C47 50V 0.1uF
R71 10kR
C45 1uF 50V
U9
VIN
EN
PG
VCC
BOOT
SW
FB
PGND
AGND
LMR33630ADDA
C39 0.1uF
L3 15uH
R68 100kR
R72 6.65kR
16V_EXT_RAW
C43 22uF 25V
C44 22uF 25V
C48 22uF 25V
C49 50V 0.1uF
XF5
3557-2
D6
Green
R66 768R
R67 2mR
R69 10R
R70 10R
C42 0.1uF
U10
INA226AIDGSR
16V_EXT
16V_Current_Alert
R73 10kR
C50 0.1uF
VBatt External Supply, 60A
Motor_PWR
Q7
Q8
R79 20.5
R78 20.5
U12
Gate
Source
Input
Gnd
V+
MIC5014YM-TR
C52 10uF
R80 10k
VBatt_Enable
XF6
3555-2
D7
Green
R75 1.3kR
R74 0.3mR 3W
R76 10R
R77 10R
C51 0.1uF
U11
INA226AIDGSR
VBatt_EXT
VBatt_Current_Alert
R81 10kR
C53 0.1uF
GND
PGND
I2C_SCL
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SDA
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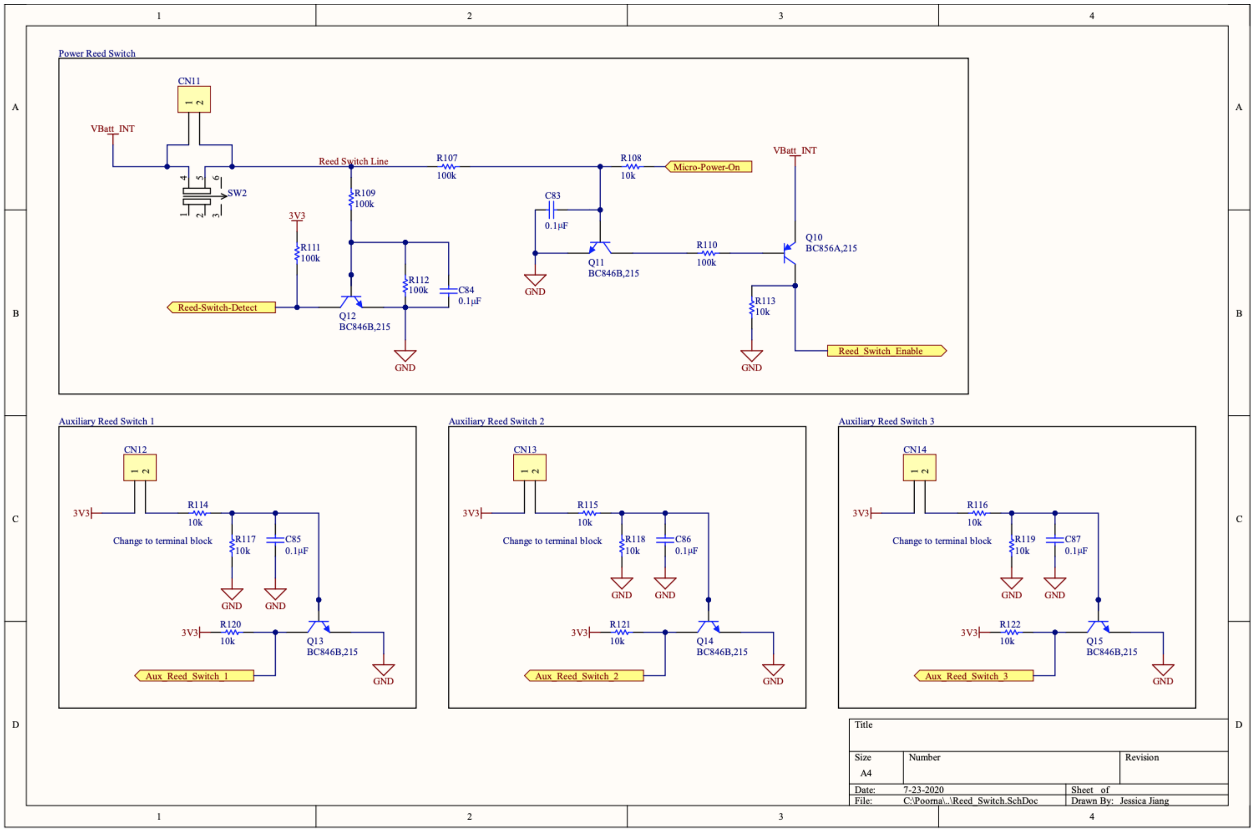
Power Reed Switch
CN11
VBatt_INT
SW2
Reed Switch Line
R107
100k
R108
10k
Micro-Power-On
VBatt_INT
R109
100k
3V3
R111
100k
C83
0.1µF
Q11
BC846B,215
R110
100k
Q10
BC856A,215
GND
R112
100k
C84
0.1µF
Reed-Switch-Detect
Q12
BC846B,215
R113
10k
Reed_Switch_Enable
GND
GND
Auxiliary Reed Switch 1
CN12
3V3
R114
10k
Change to terminal block
R117
10k
C85
0.1µF
GND
GND
3V3
R120
10k
Q13
BC846B,215
Aux_Reed_Switch_1
GND
Auxiliary Reed Switch 2
CN13
3V3
R115
10k
Change to terminal block
R118
10k
C86
0.1µF
GND
GND
3V3
R121
10k
Q14
BC846B,215
Aux_Reed_Switch_2
GND
Auxiliary Reed Switch 3
CN14
3V3
R116
10k
Change to terminal block
R119
10k
C87
0.1µF
GND
GND
3V3
R122
10k
Q15
BC846B,215
Aux_Reed_Switch_3
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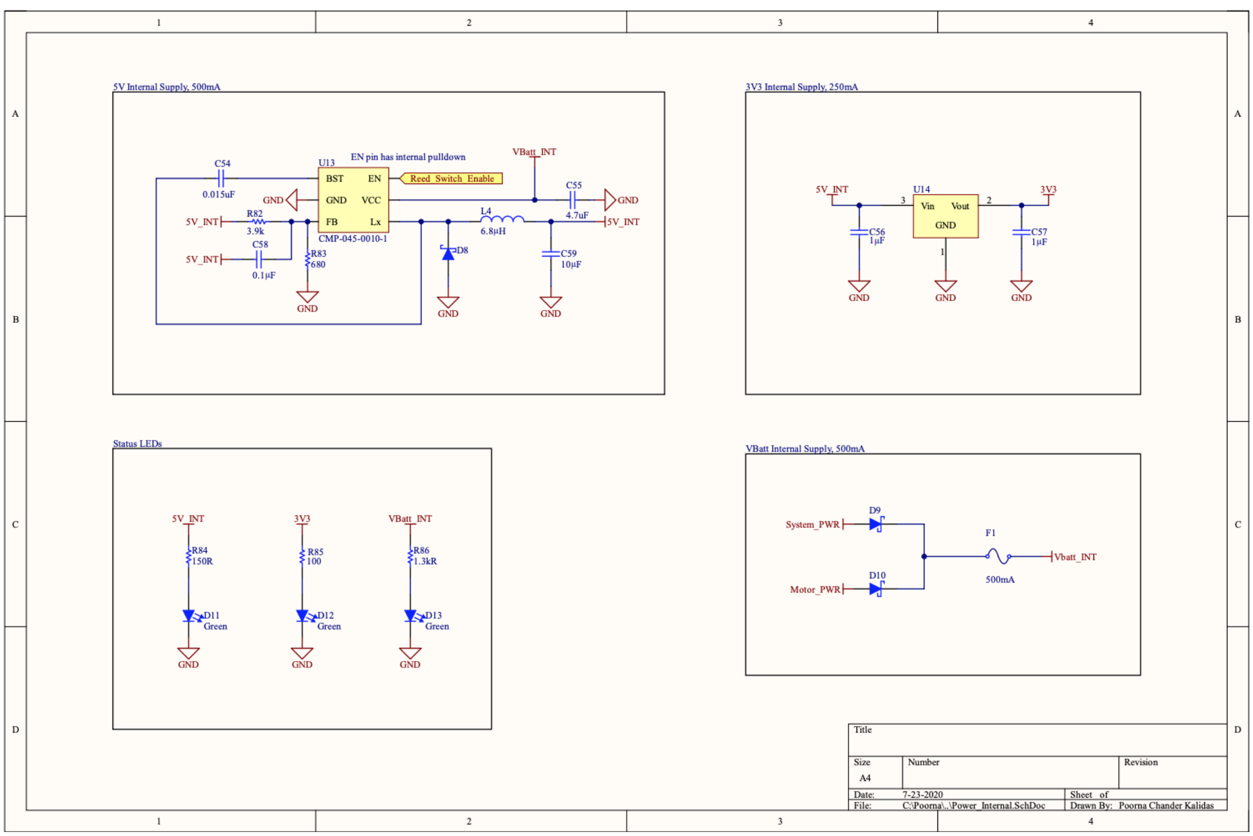
5V Internal Supply, 500mA
EN pin has internal pulldown
VBatt_INT
C54
0.015uF
U13
BST
EN
Reed_Switch_Enable
GND
GND
VCC
C55
4.7uF
GND
5V_INT
R82
3.9k
FB
Lx
L4
6.8µH
5V_INT
CMP-045-0010-1
5V_INT
C58
0.1µF
R83
680
D8
C59
10µF
GND
GND
GND
3V3 Internal Supply, 250mA
5V_INT
U14
3V3
Vin
Vout
GND
C56
1µF
C57
1µF
GND
GND
GND
Status LEDs
5V_INT
3V3
VBatt_INT
R84
150R
R85
100
R86
1.3kR
D11
Green
D12
Green
D13
Green
GND
GND
GND
VBatt Internal Supply, 500mA
D9
System_PWR
F1
Vbatt_INT
500mA
D10
Motor_PWR
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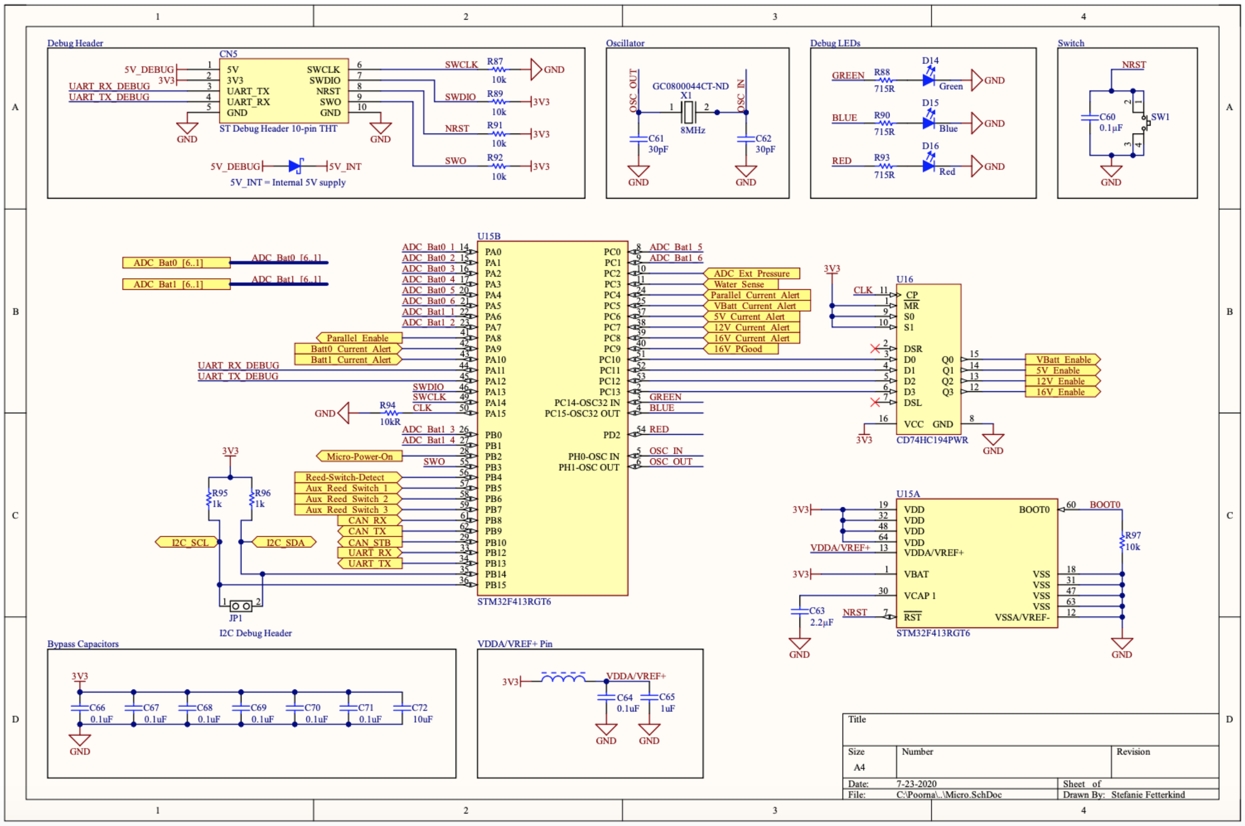
Debug Header
ST Debug Header 10-pin THT
5V_INT = Internal 5V supply
Oscillator
Debug LEDs
Switch
STM32F413RGT6
I2C Debug Header
Bypass Capacitors
VDDA/VREF+ Pin
CD74HC194PWR
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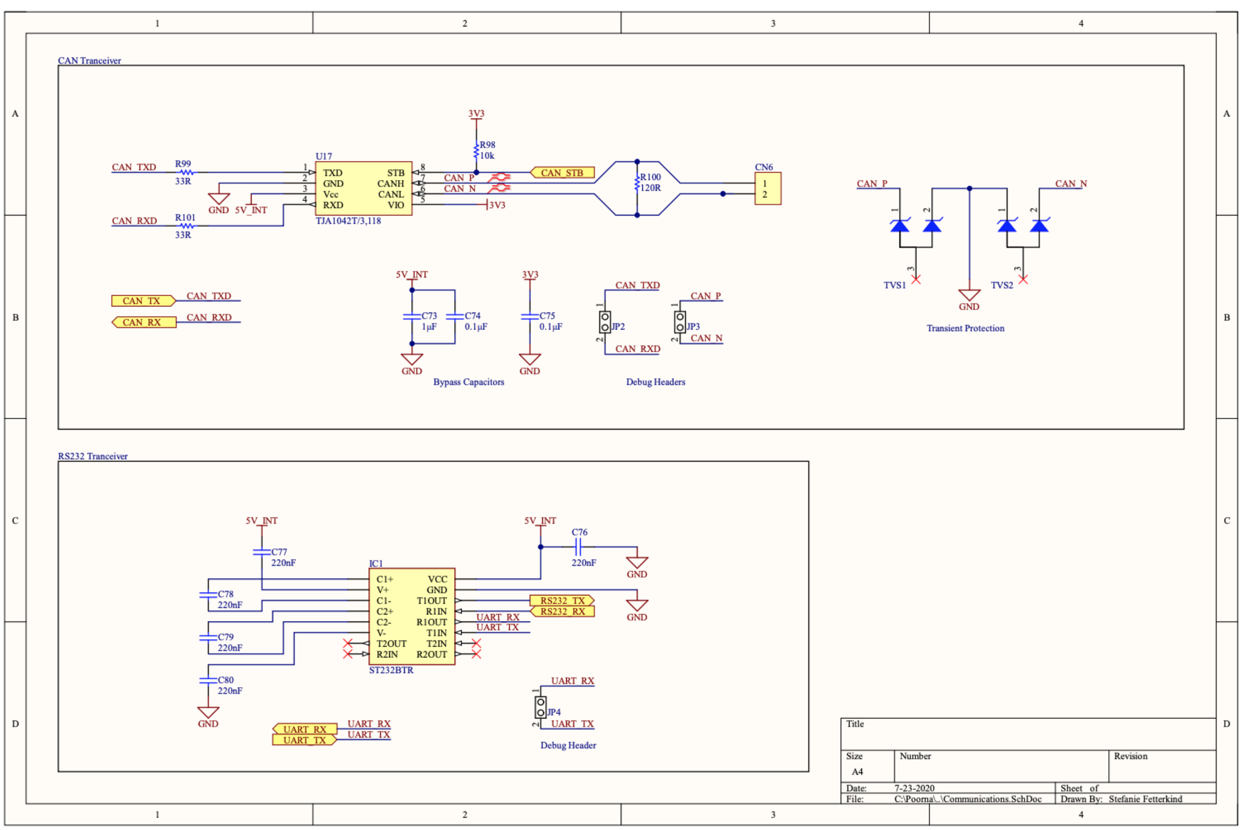
CAN Tranceiver
TJA1042T/3,118
Transient Protection
Bypass Capacitors
Debug Headers
RS232 Tranceiver
ST232BTR
Debug Header
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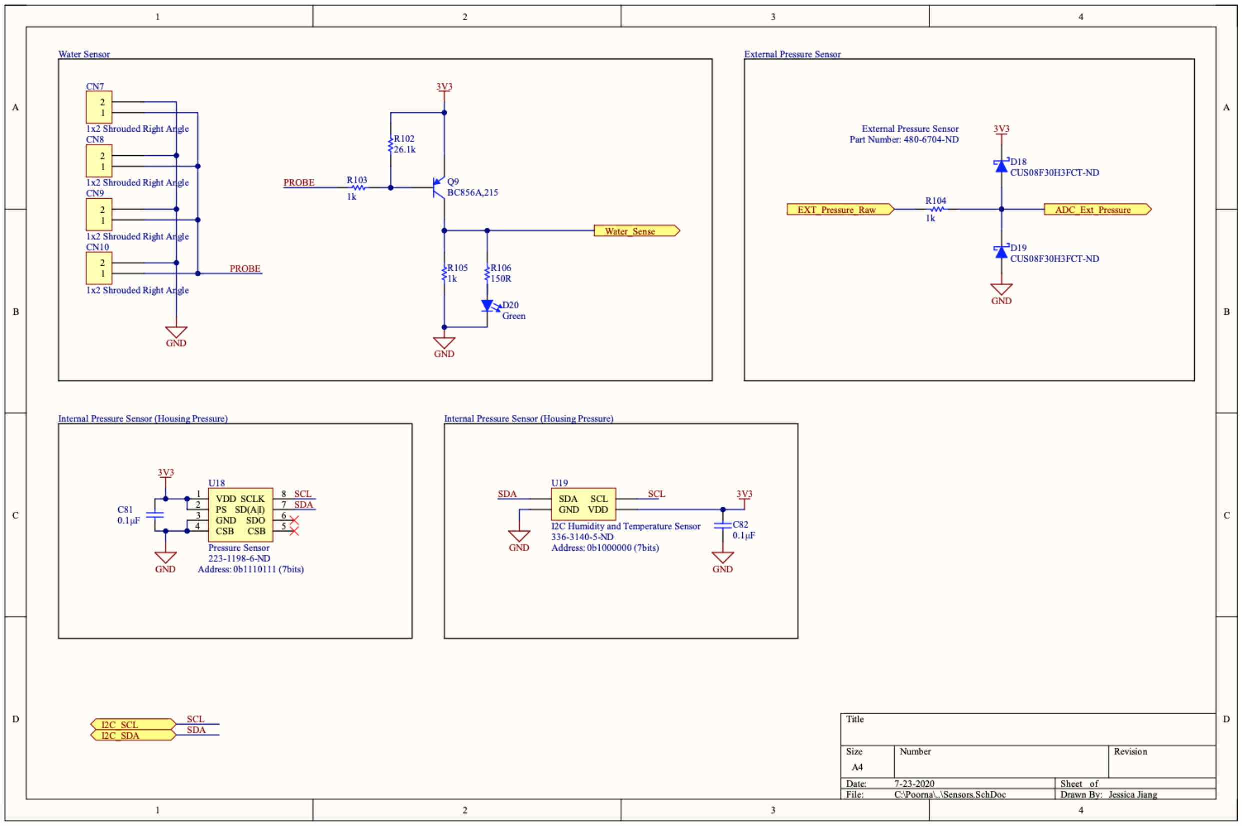

Water Sensor
CN7
CN8
CN9
CN10
1x2 Shrouded Right Angle
PROBE
GND
3V3
R102
26.1k
R103
1k
Q9
BC856A,215
Water_Sense
R105
1k
R106
150R
D20
Green
External Pressure Sensor
External Pressure Sensor
Part Number: 480-6704-ND
D18
CUS08F30H3FCT-ND
EXT_Pressure_Raw
R104
1k
ADC_Ext_Pressure
D19
CUS08F30H3FCT-ND
Internal Pressure Sensor (Housing Pressure)
U18
C81
0.1μF
VDD SCLK
PS SD(A/I)
GND SDO
CSB CSB
SCL
SDA
Pressure Sensor
223-1198-6-ND
Address: 0b1110111 (7bits)
Internal Pressure Sensor (Housing Pressure)
U19
SDA SCL
GND VDD
I2C Humidity and Temperature Sensor
336-3140-5-ND
Address: 0b1000000 (7bits)
C82
0.1μF
I2C_SCL
I2C_SDA
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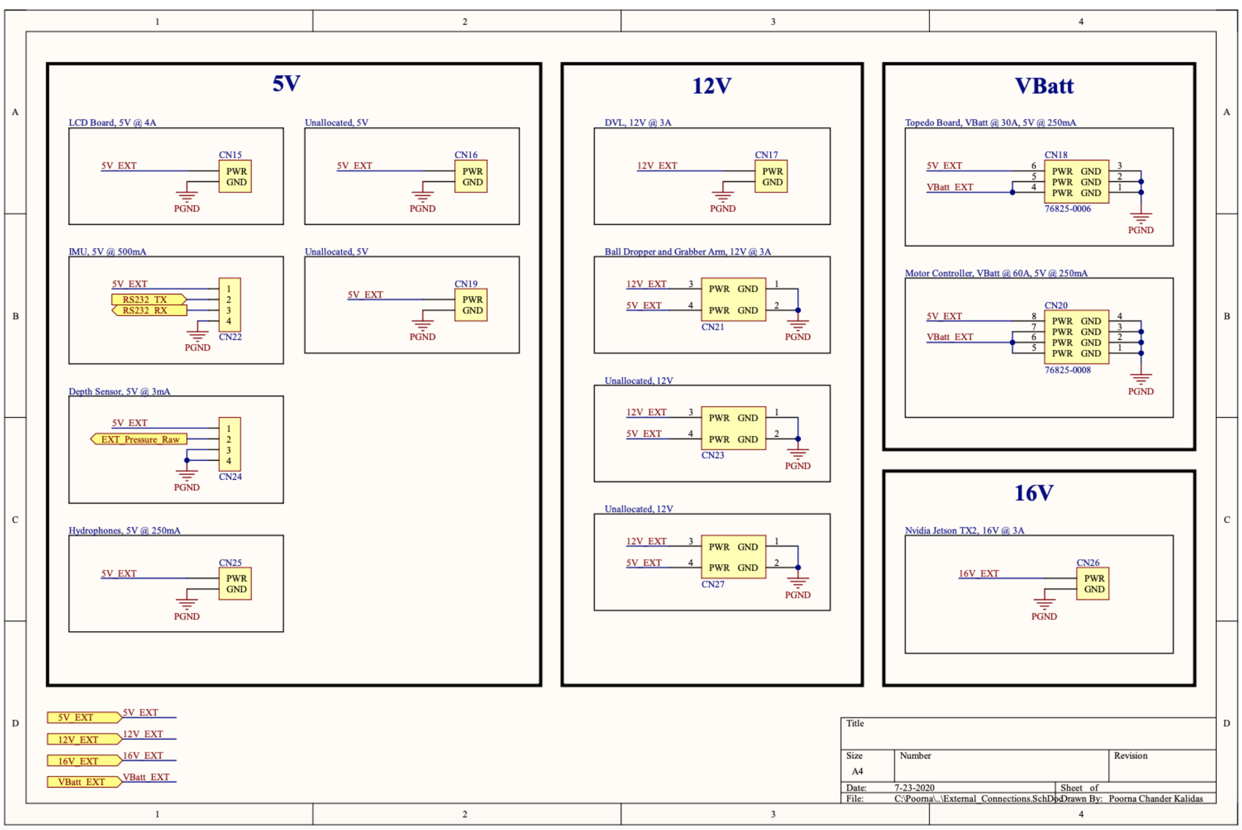

5V
LCD Board, 5V @ 4A
CN15
5V_EXT
PWR
GND
PGND
Unallocated, 5V
CN16
IMU, 5V @ 500mA
RS232_TX
RS232_RX
CN22
Unallocated, 5V
CN19
Depth Sensor, 5V @ 3mA
EXT_Pressure_Raw
CN24
Hydrophones, 5V @ 250mA
CN25
12V
DVL, 12V @ 3A
CN17
12V_EXT
Ball Dropper and Grabber Arm, 12V @ 3A
CN21
Unallocated, 12V
CN23
Unallocated, 12V
CN27
VBatt
Topedo Board, VBatt @ 30A, 5V @ 250mA
CN18
VBatt_EXT
76825-0006
Motor Controller, VBatt @ 60A, 5V @ 250mA
CN20
76825-0008
16V
Nvidia Jetson TX2, 16V @ 3A
CN26
16V_EXT
5V_EXT
12V_EXT
16V_EXT
VBatt_EXT
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Drawn By: Poorna Chander Kalidas

Appendix B: Test Results

B.1 Battery Bridging Subsystem Tests

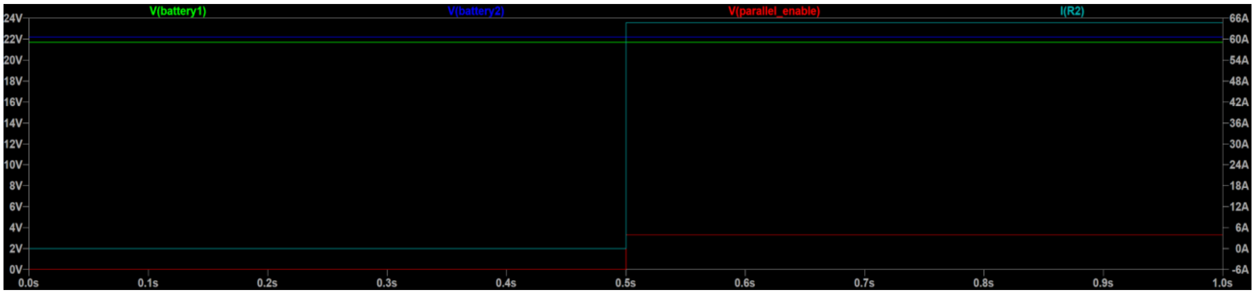

Fig. 35: Current flow through parallel current shunt when gate driver is on/off.

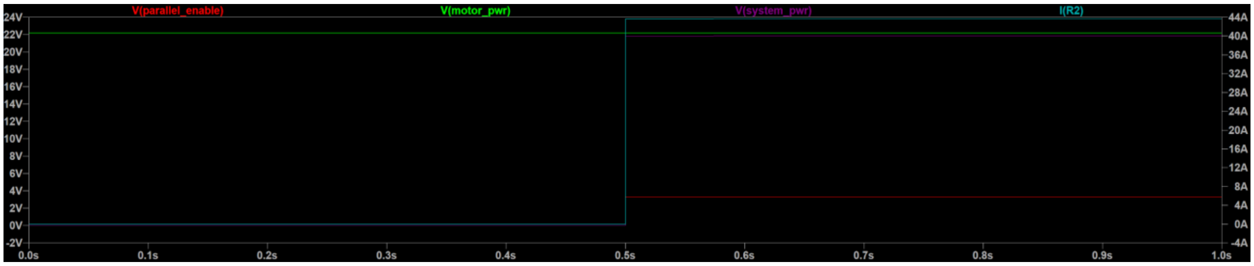

Fig. 36: Parallel circuit test with Battery1 disconnected.

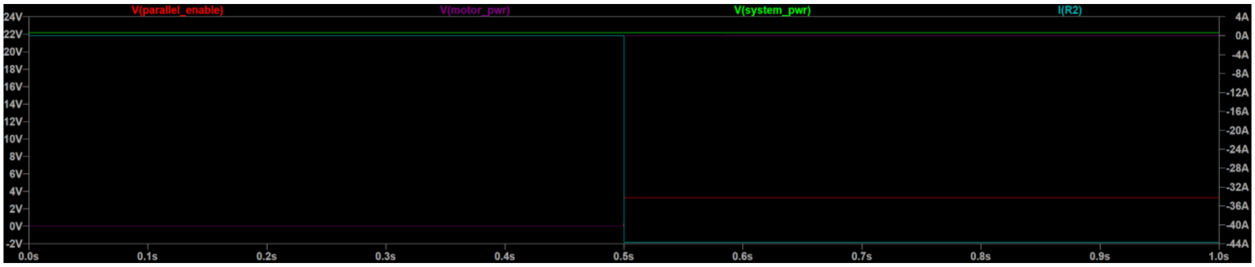

Fig. 37: Parallel circuit test with Battery2 disconnected.

B.2 Cell Monitor Subsystem Tests

```
        --- Operating Point ---

V(1):            3.23077        voltage
V(2):            3.23077        voltage
V(3):            3.23077        voltage
V(4):            3.23077        voltage
V(5):            3.23077        voltage
V(6):            3.24051        voltage
V(n001):         4.2            voltage
V(n002):         8.4            voltage
V(n005):         21             voltage
V(n006):         25.6           voltage
V(n003):         12.6           voltage
V(n004):         16.8           voltage
```

Fig. 38: Operating point test of maximum cell voltage

B.3 5V External Subsystem Tests

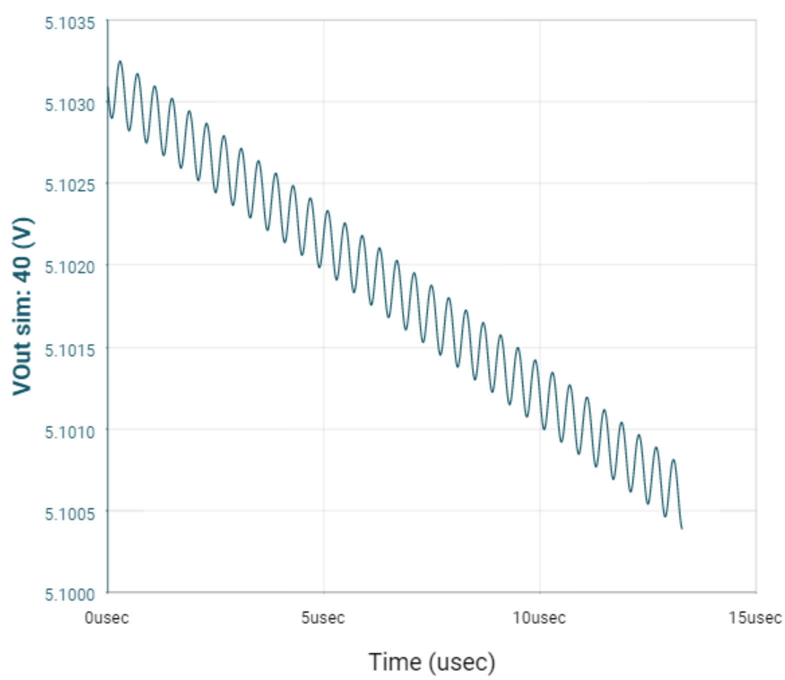

Fig. 39: 5V supply output at V_{in} = 23V and I_{out} = 0.01A.

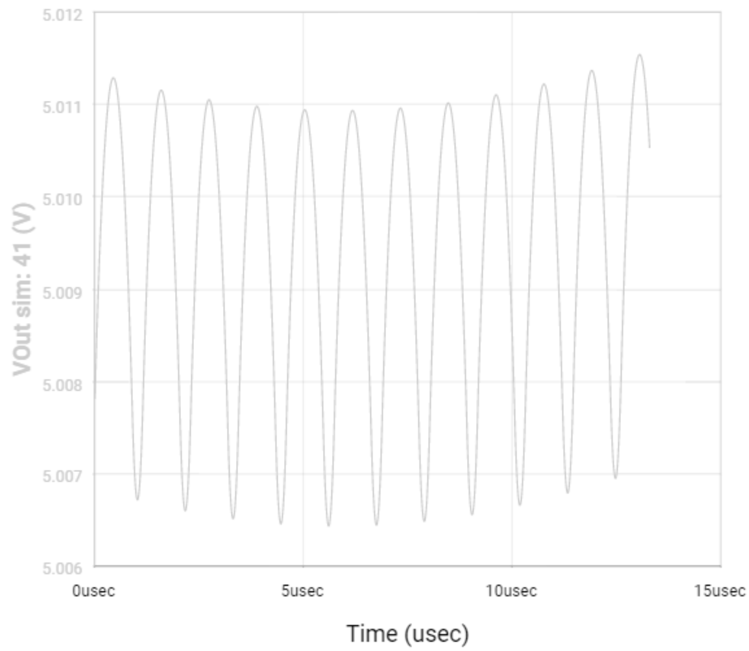

Fig. 40: 5V supply output at V_{in} = 23V and I_{out} = 8A.

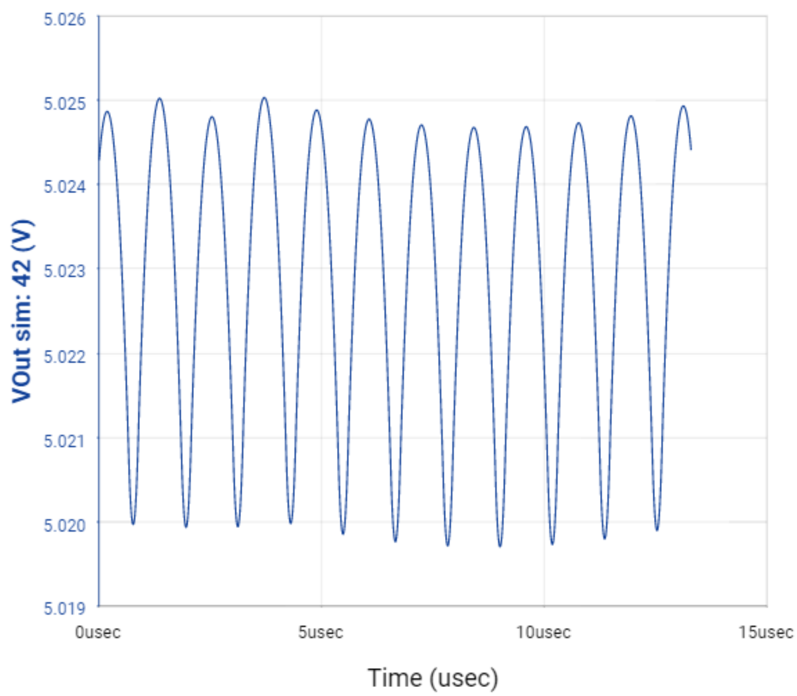

Fig. 41: 5V supply output at V_{in} = 28V and I_{out} = 5.25A.

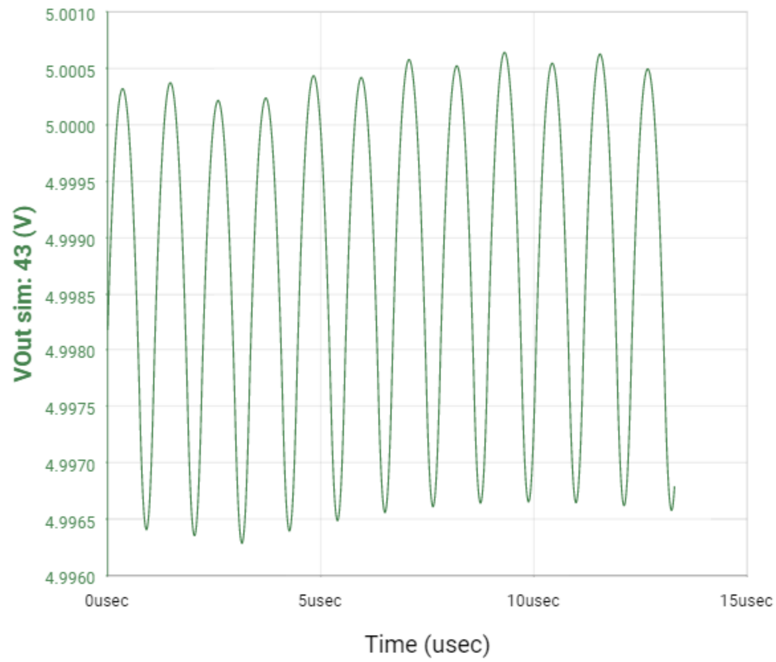

Fig. 42: 5V supply output at V_{in} = 18V and I_{out} = 5.25A.

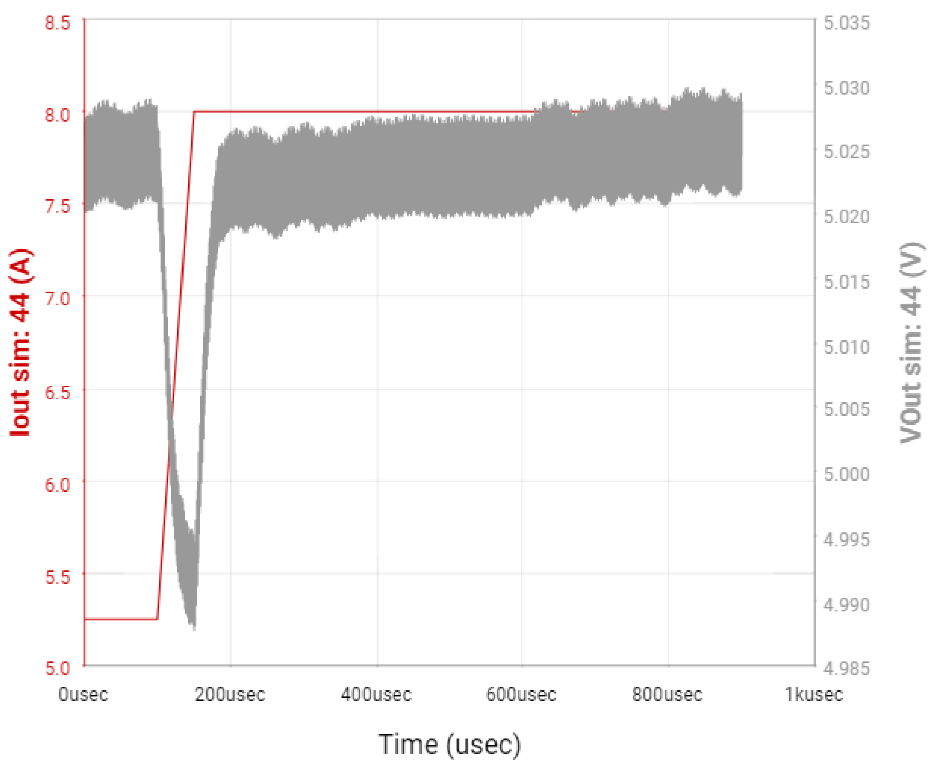

Fig. 43: 5V supply output at V_{in} = 23V and I_{out} step from 5.25A to 8A.

B.4 12V External Subsystem Tests

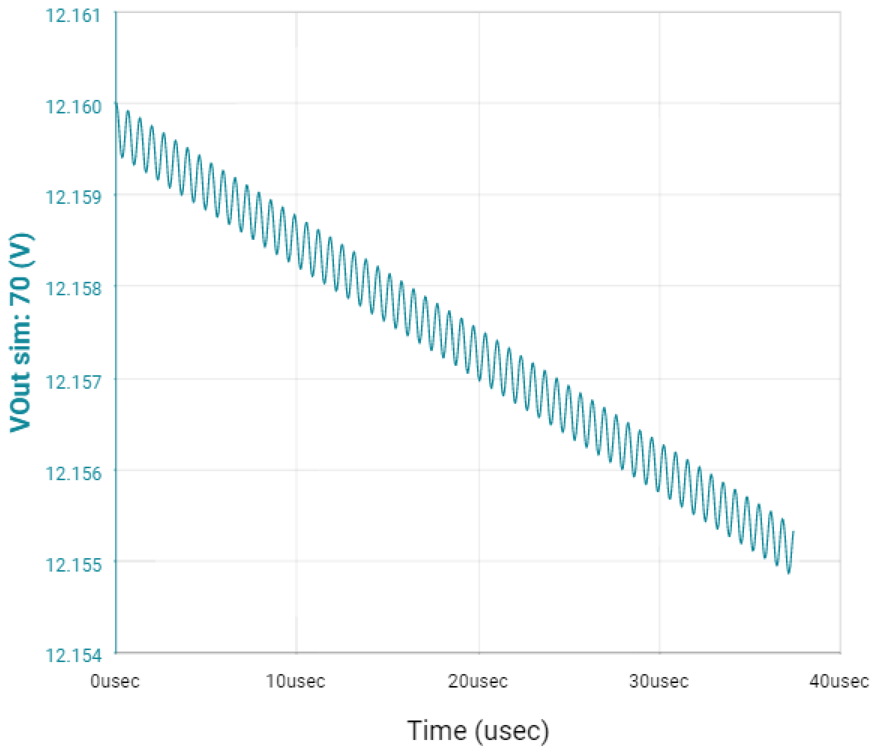

Fig. 44:12V supply output at V_{in} = 23V and I_{out} = 0.01A.

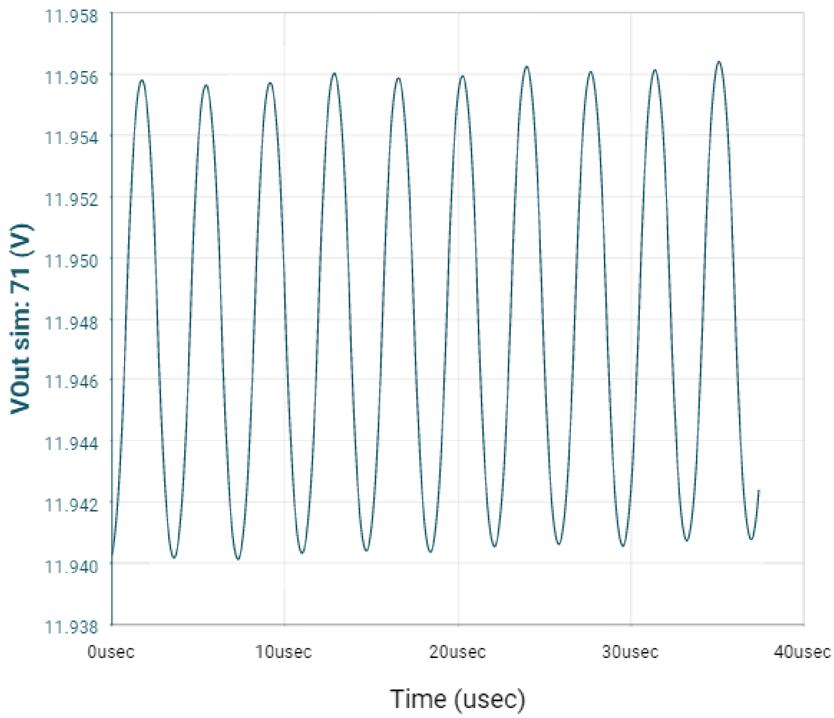

Fig. 45: 12V supply output at V_{in} = 23V and I_{out} = 8A.

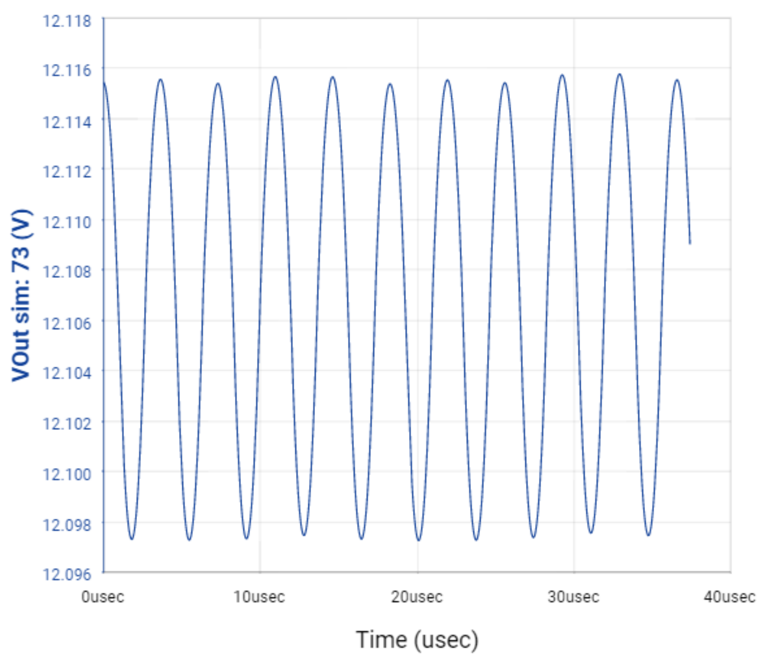

Fig. 46: 12V supply output at V_{in} = 28V and I_{out} = 6A.

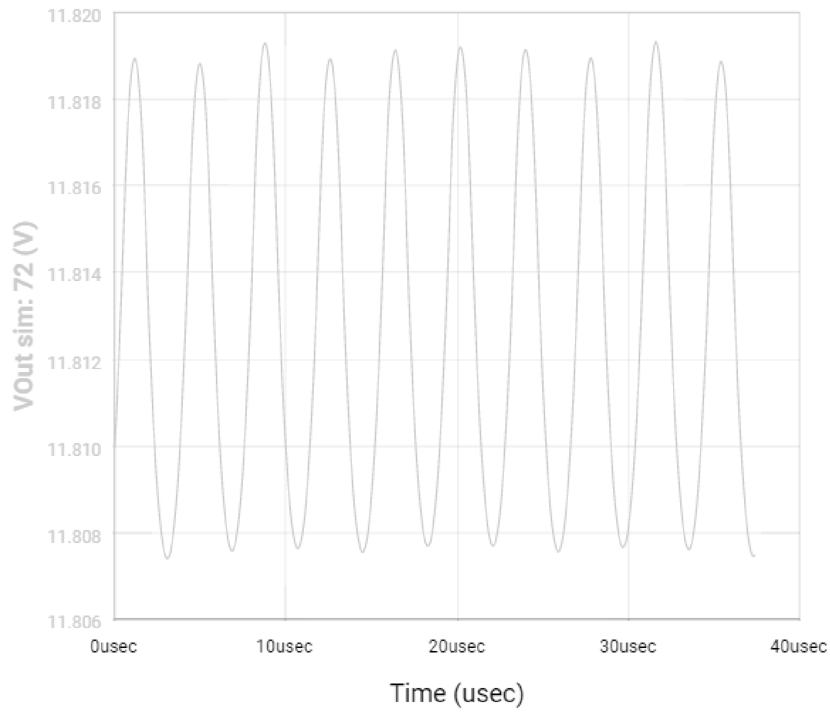

Fig. 47: 12V supply output at V_{in} = 18V and I_{out} = 6A.

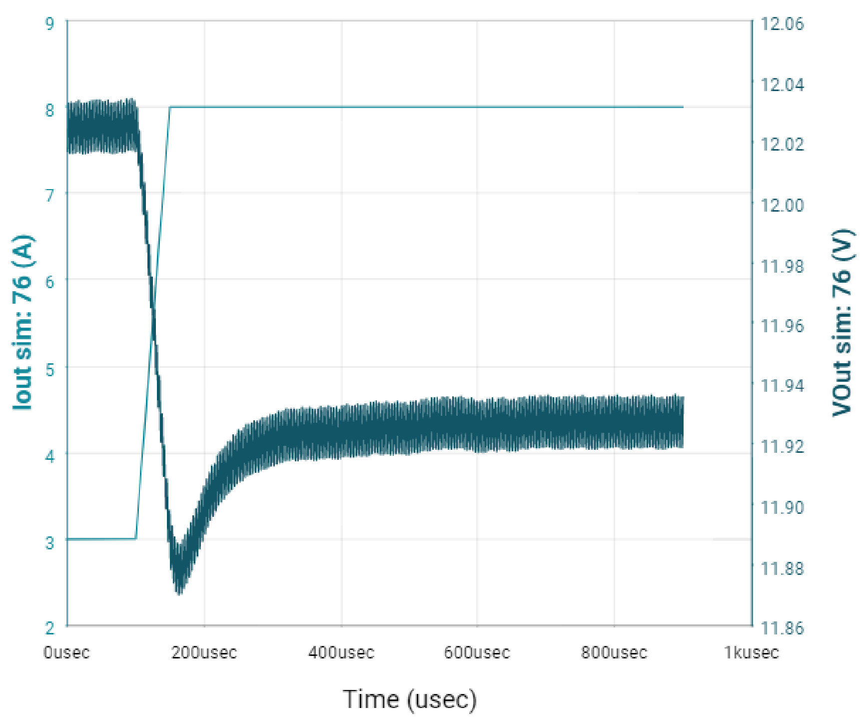

Fig. 48: 12V supply output at V_{in} = 23V and I_{out} step from 6A to 8A.

B.5 16V External Subsystem Tests

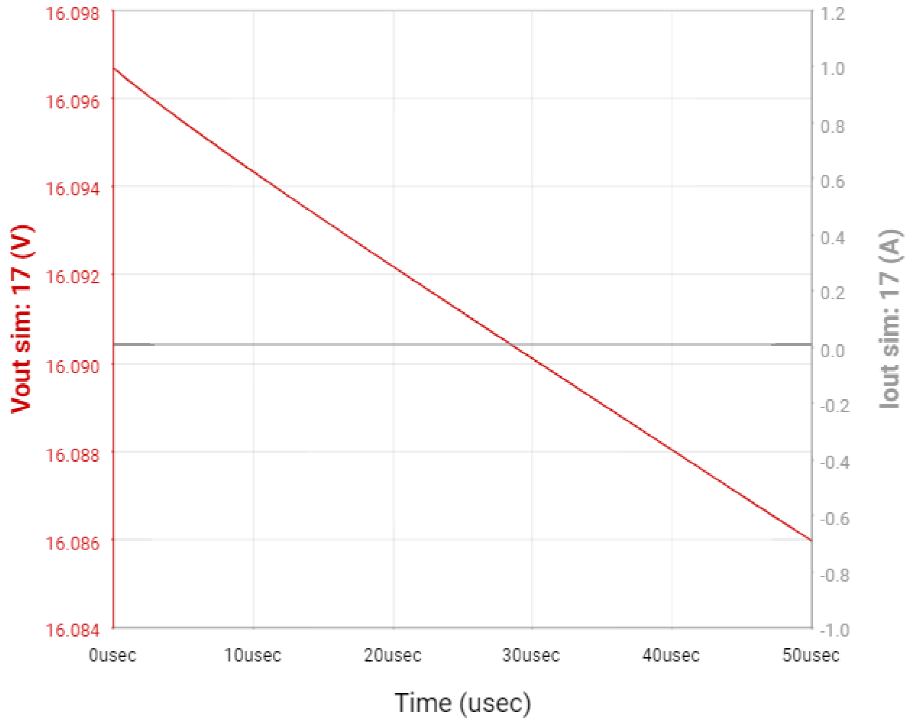

Fig. 49: 16V supply output at V_{in} = 23V and I_{out} = 0.01A.

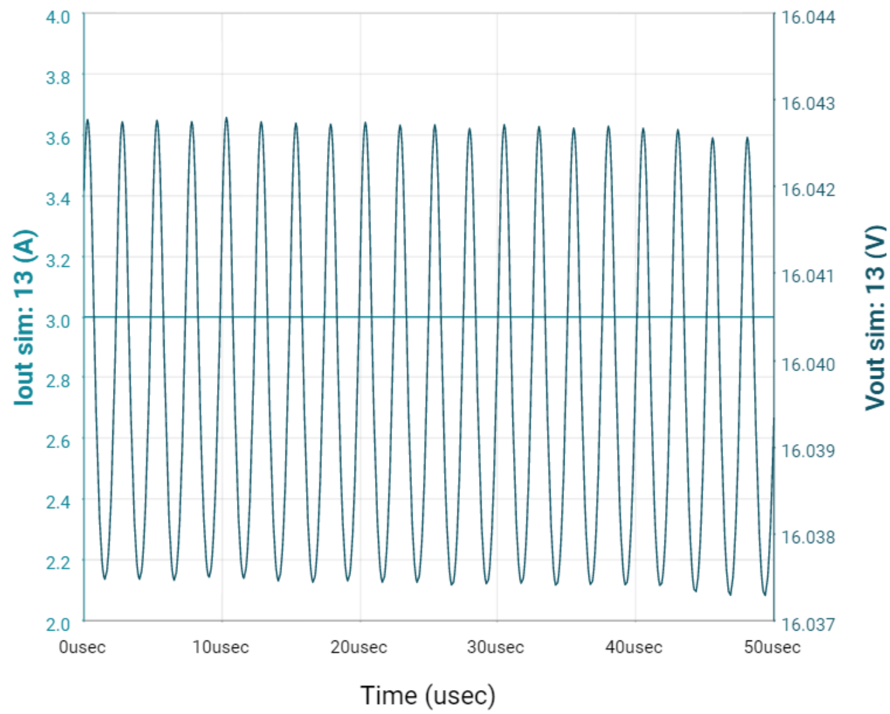

Fig. 50: 16V supply output at V_{in} = 23V and I_{out} = 3A.

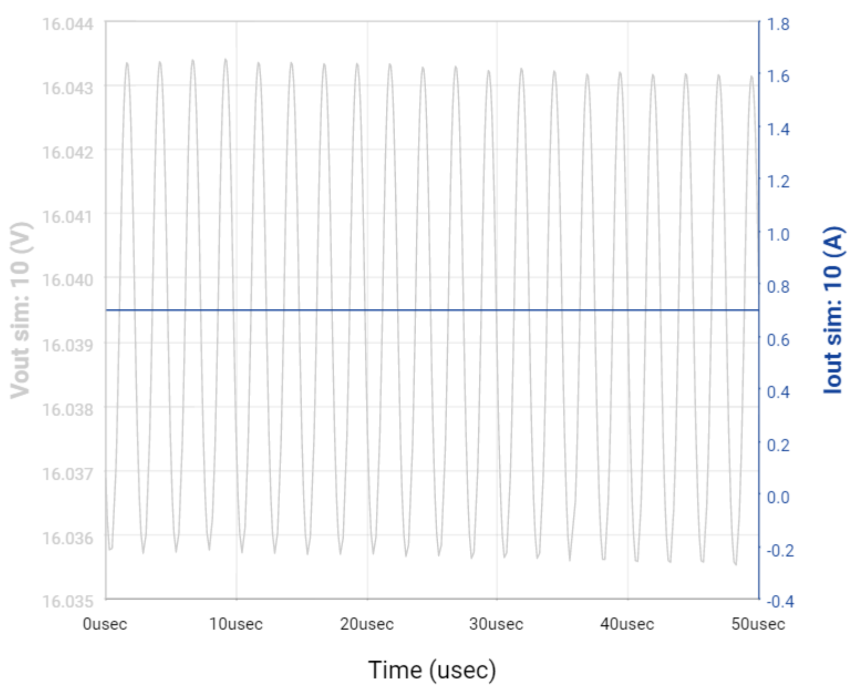

Fig. 51: 16V supply output at V_{in} = 28V and I_{out} = 0.7A.

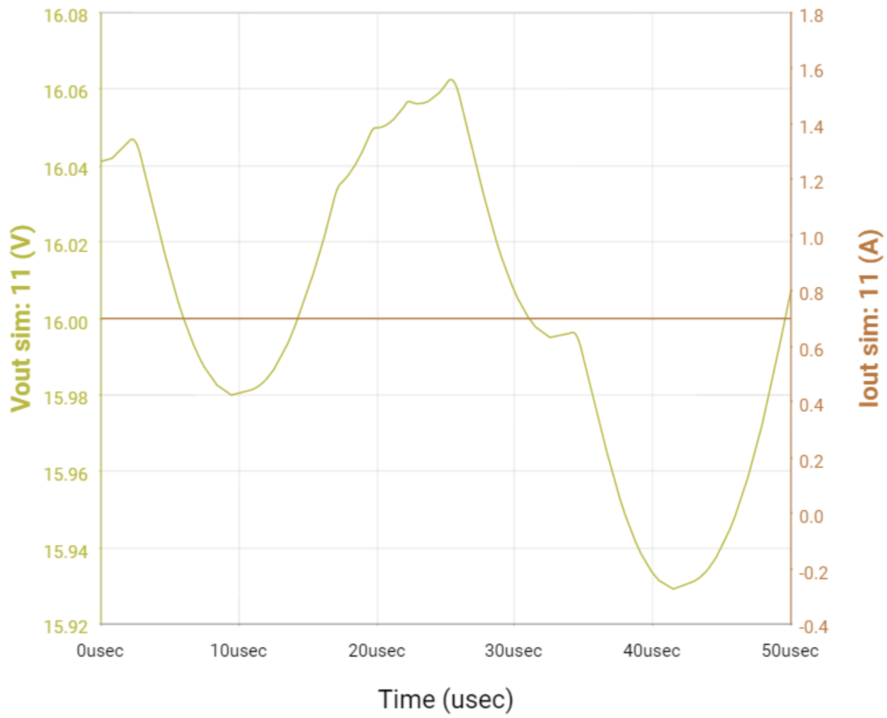

Fig. 52: 16V supply output at V_{in} = 18V and I_{out} = 0.7A.

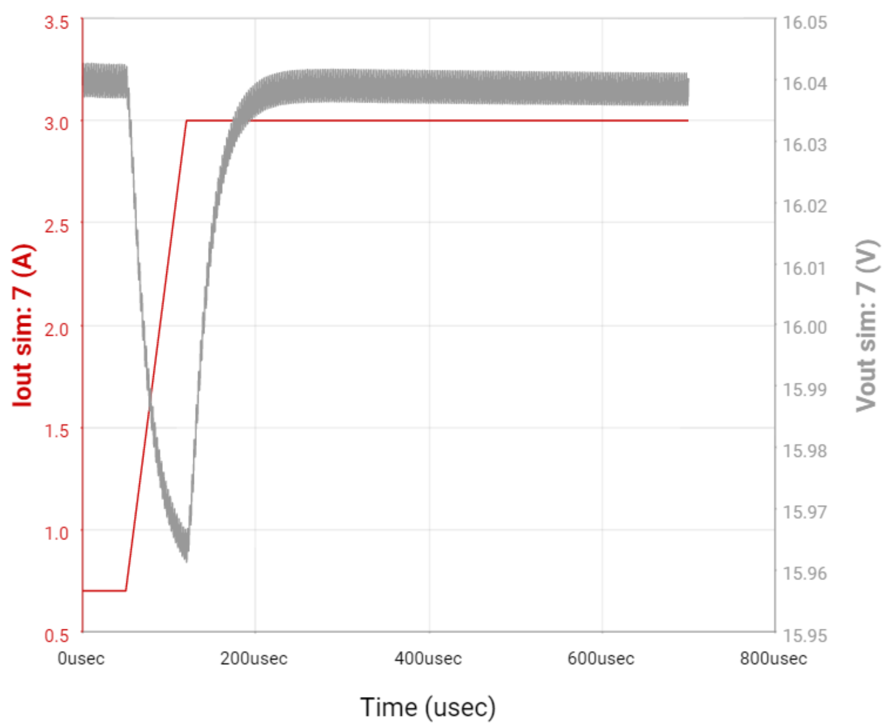

Fig. 53: 16V supply output at V_{in} = 23V and I_{out} step from 0.7A to 3A.

B.6 VBatt External Subsystem Tests

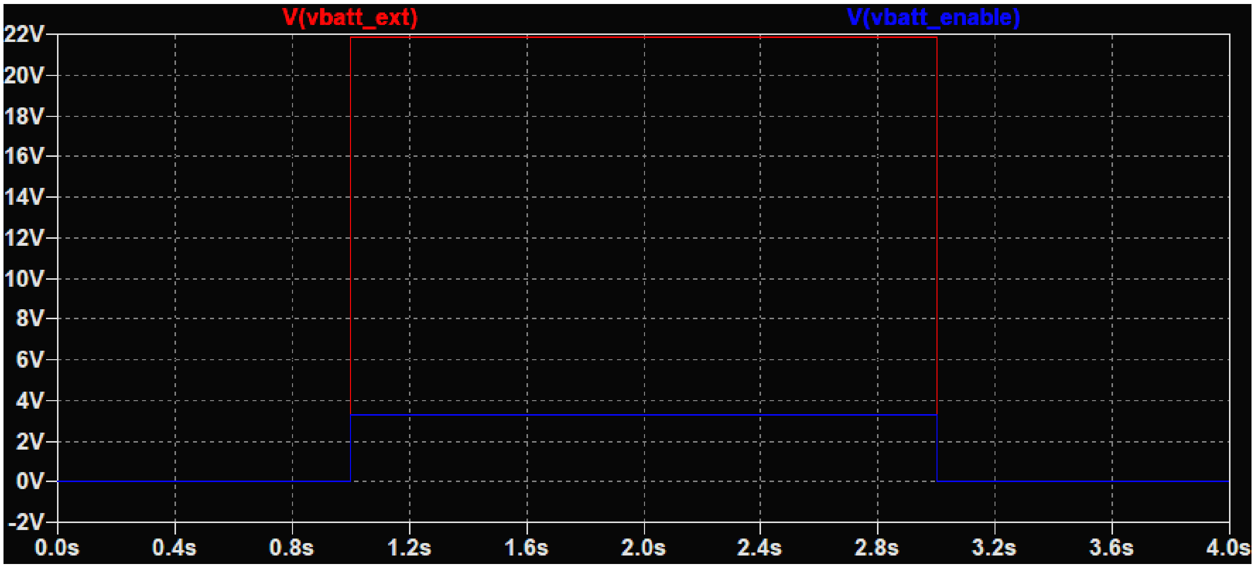

Fig. 54: VBatt enable and output test

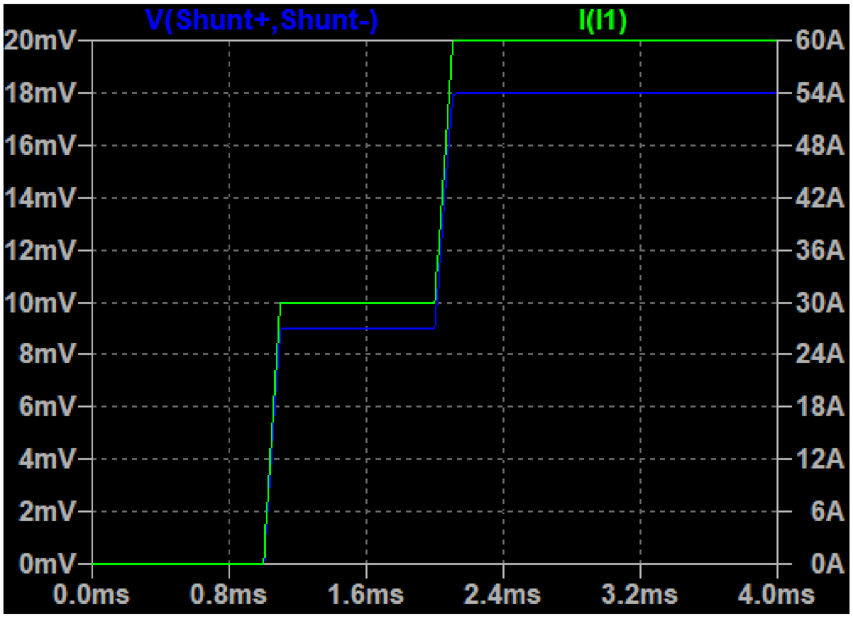

Fig. 55: VBatt current shunt voltage range test

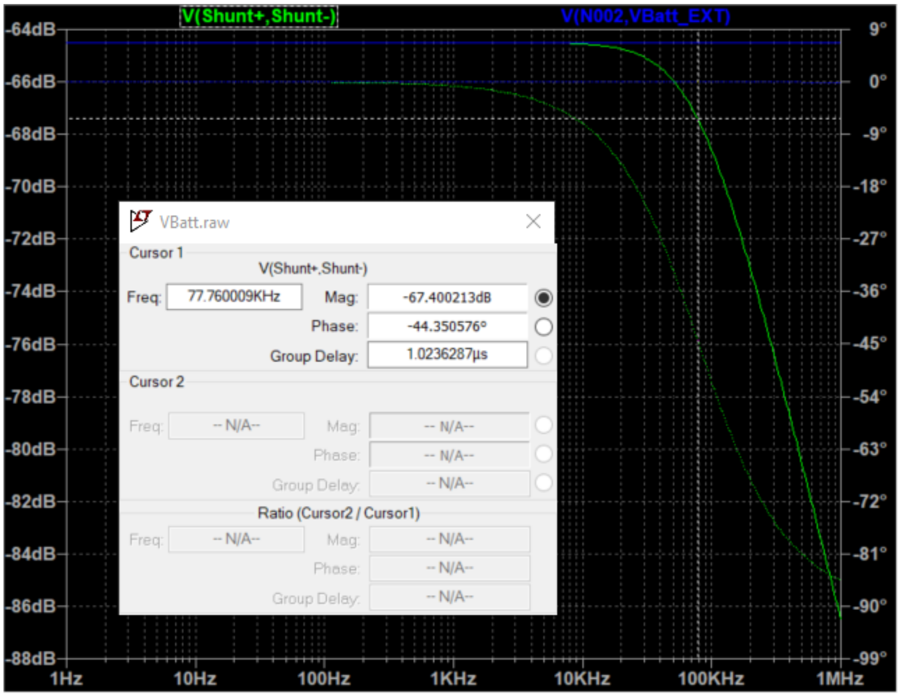

Fig. 56: VBatt current shunt filter frequency response

B.7 Communications Subsystem Tests

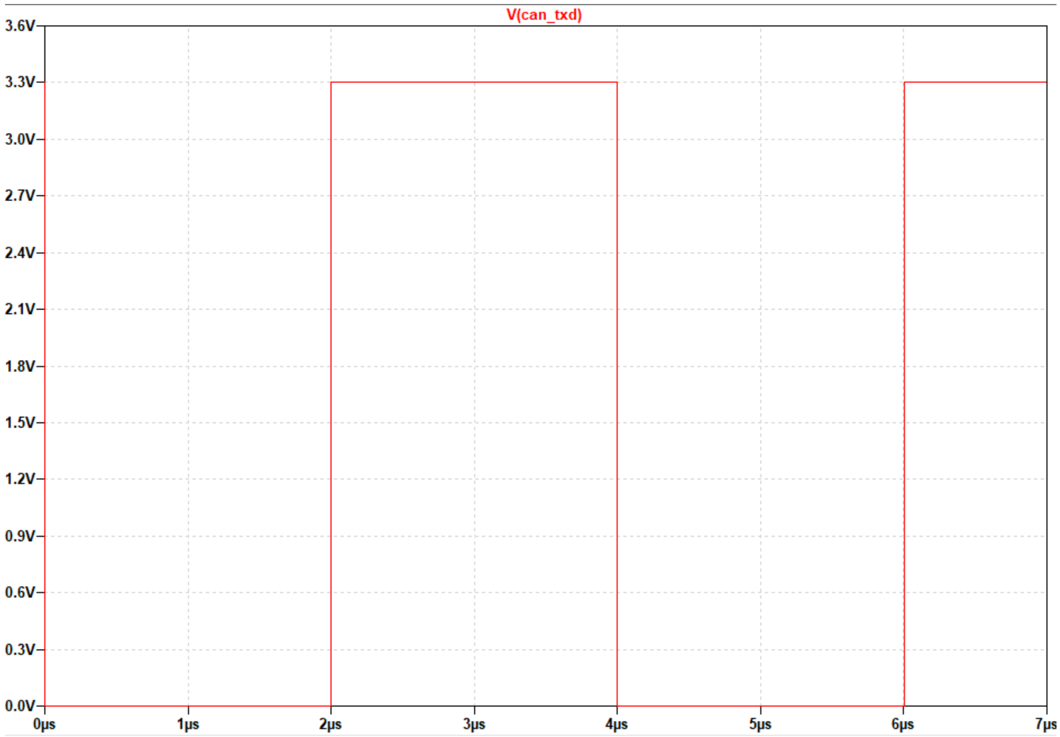

Fig. 57: TXD input for CAN transceiver test.

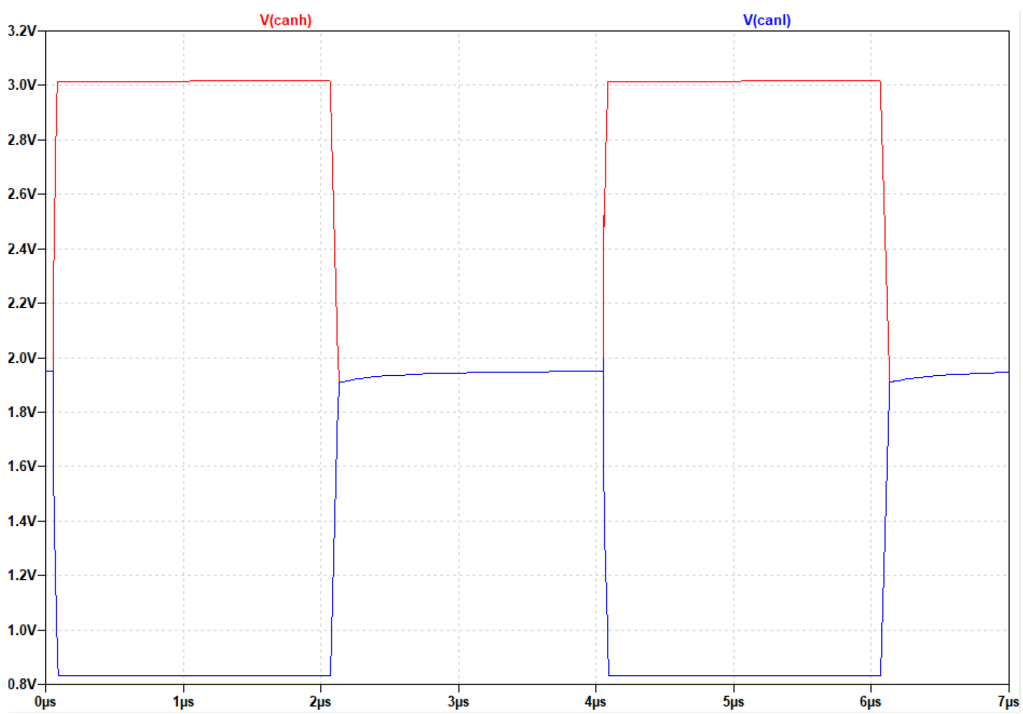

Fig. 58: CANH and CANL for a square wave input on TXD.

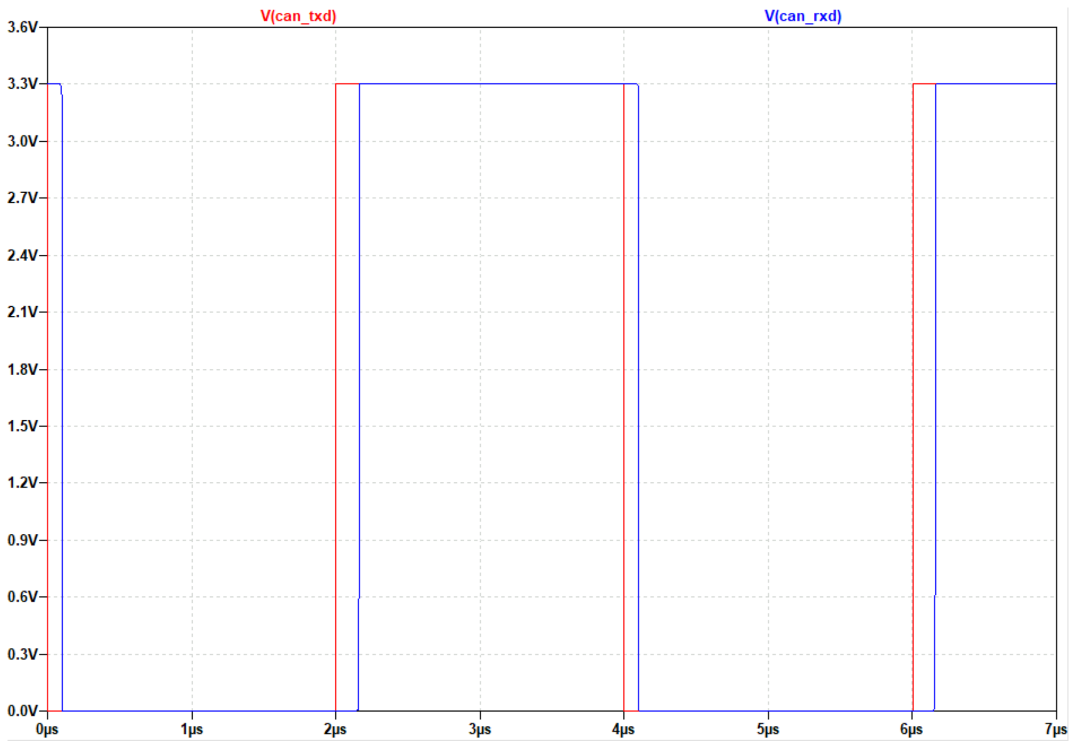

Fig. 59: RXD pin for a square wave input on TXD.

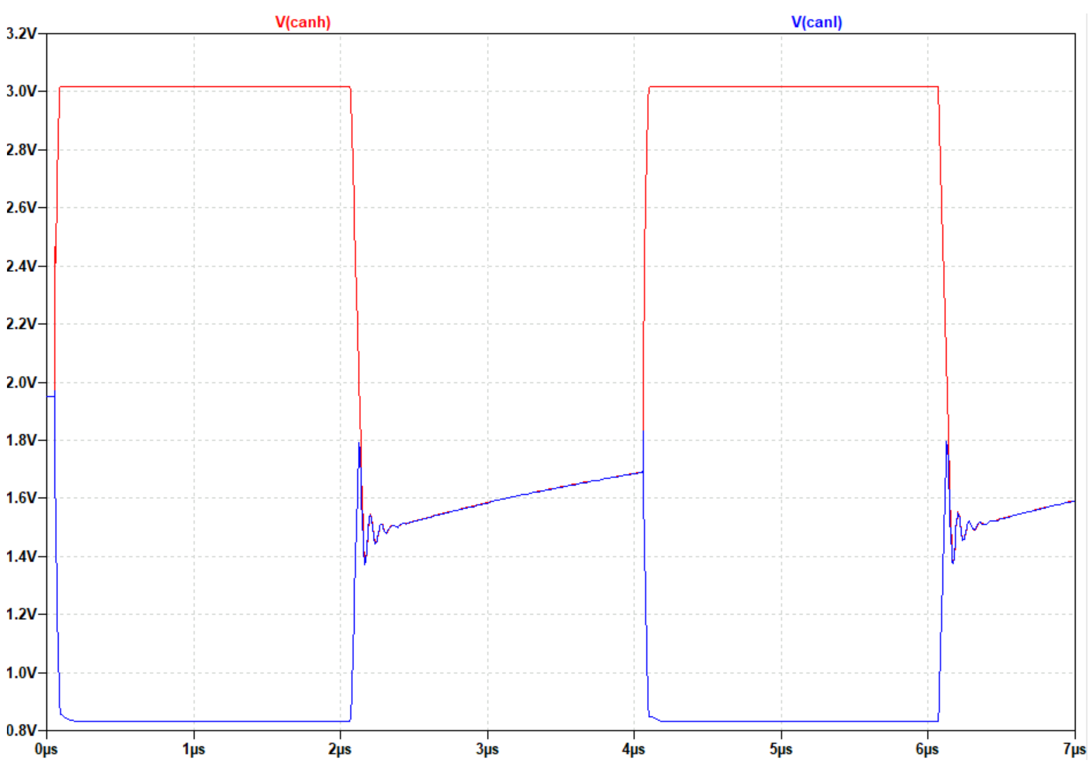

Fig. 60: CANH and CANL pins with ESD applied during operation.

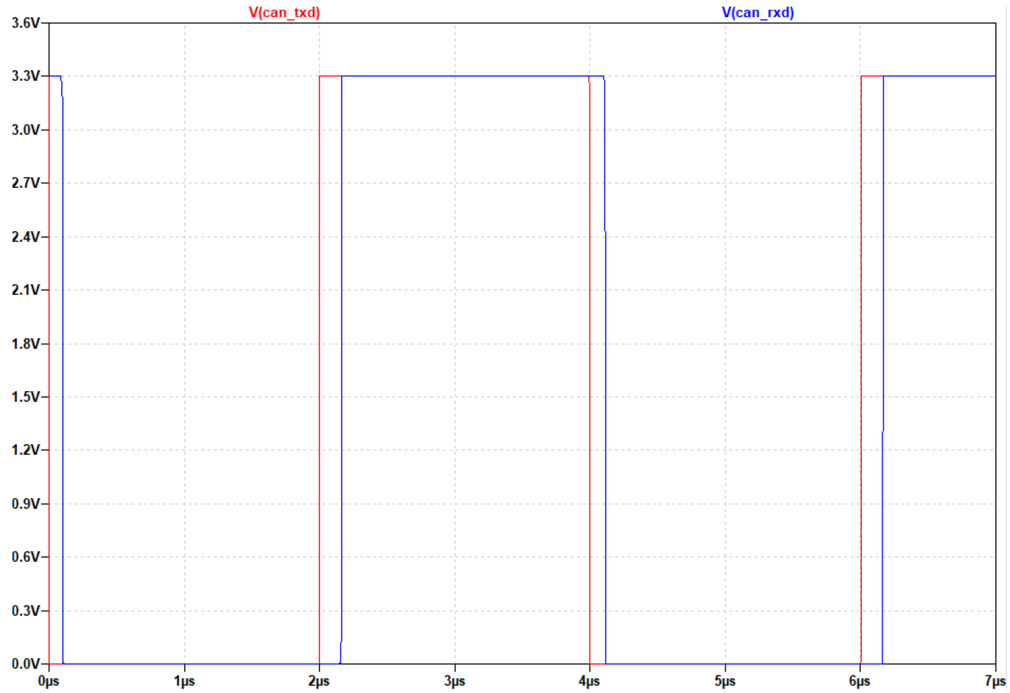

Fig. 61: RXD pin with ESD applied during operation.

B.8 Water Sensor Subsystem Tests

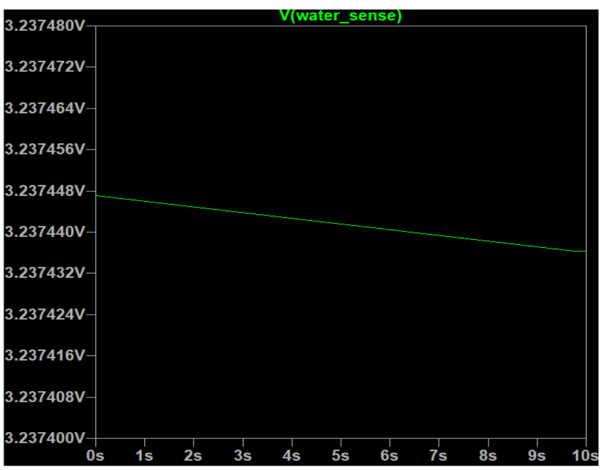

Fig. 62: Water sensor output when resistance of 2kΩ is seen at the water probe inputs.

B.9 Integration Tests

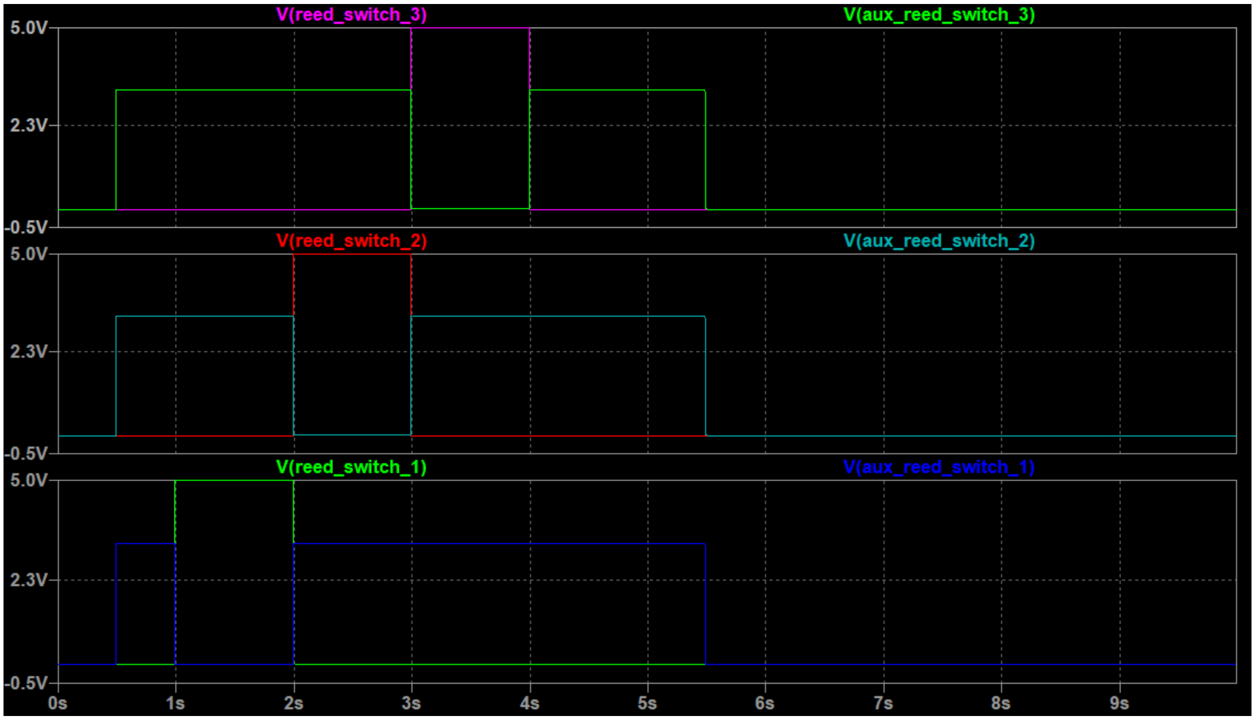

Fig. 63: Auxiliary reed switch integration test.

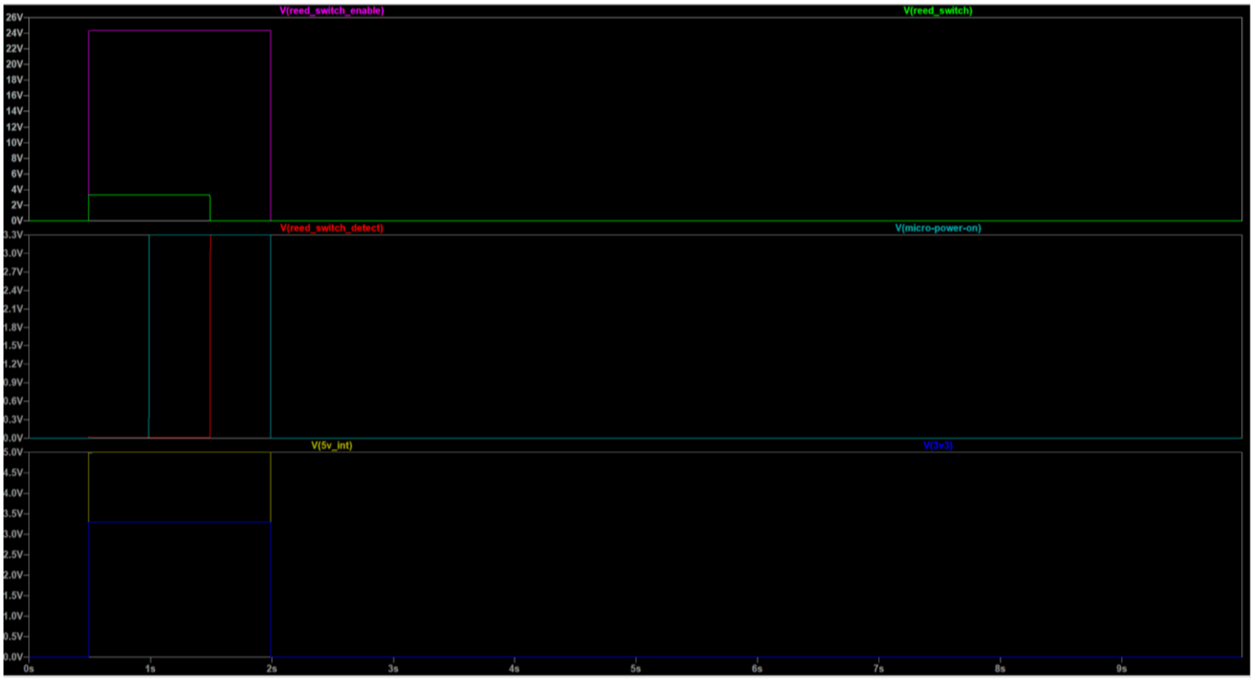

Fig. 64: Power reed switch integration test.

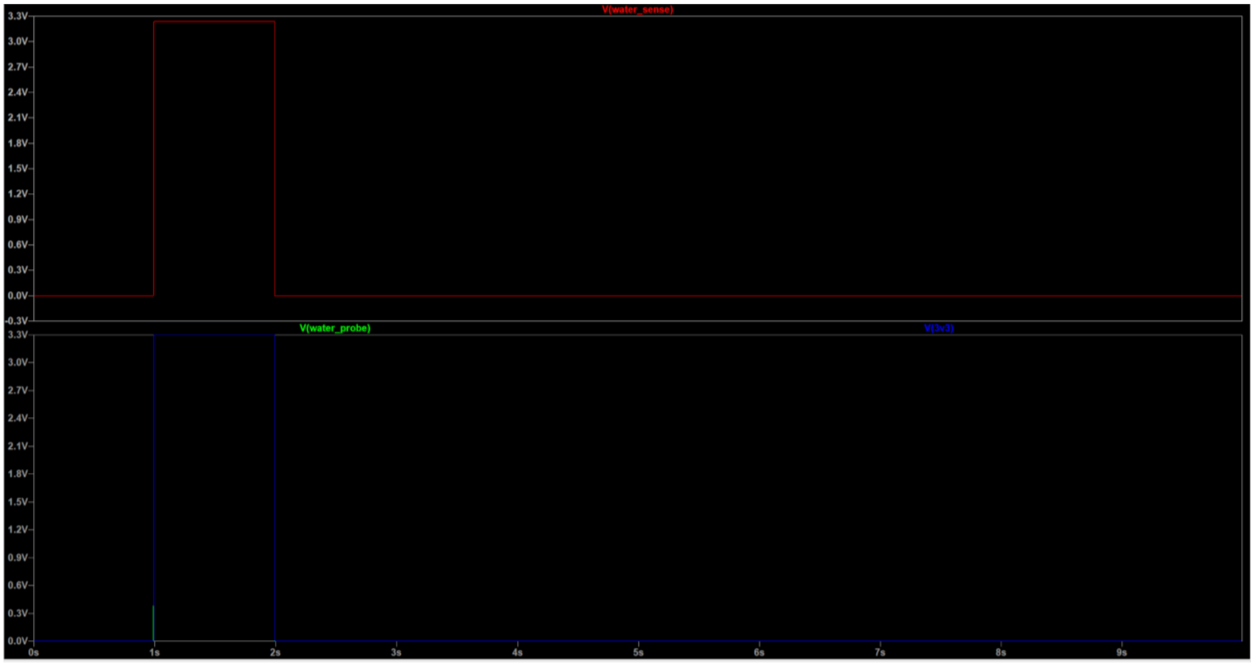

Fig. 65: Water sensor integration test.

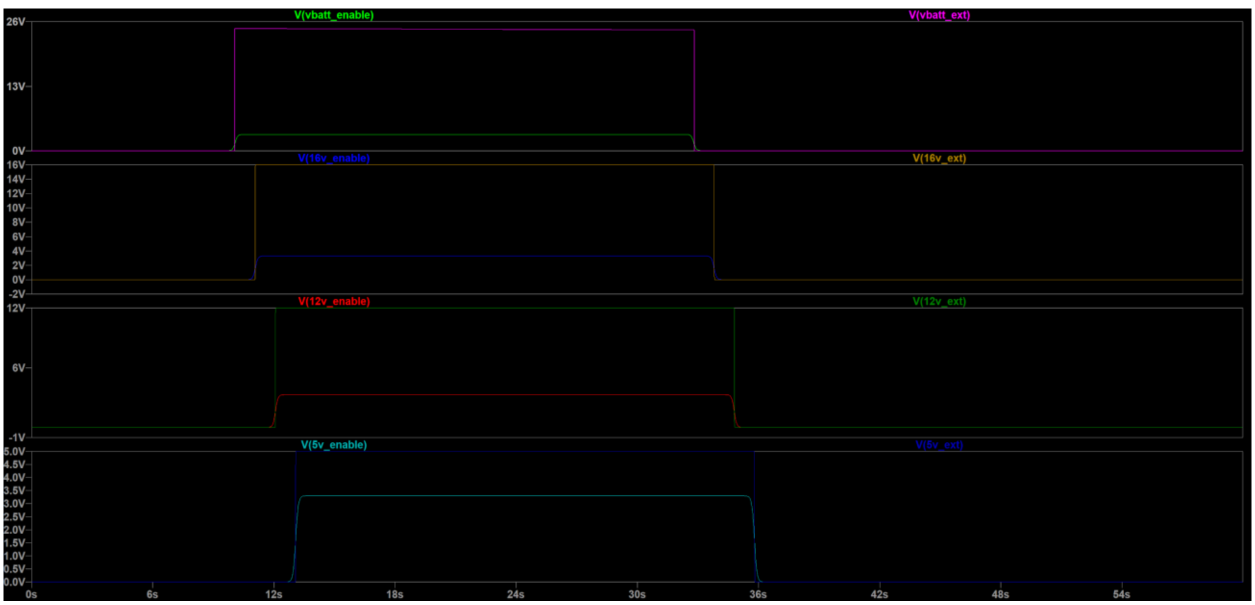

Fig. 66: External power supply integration test.

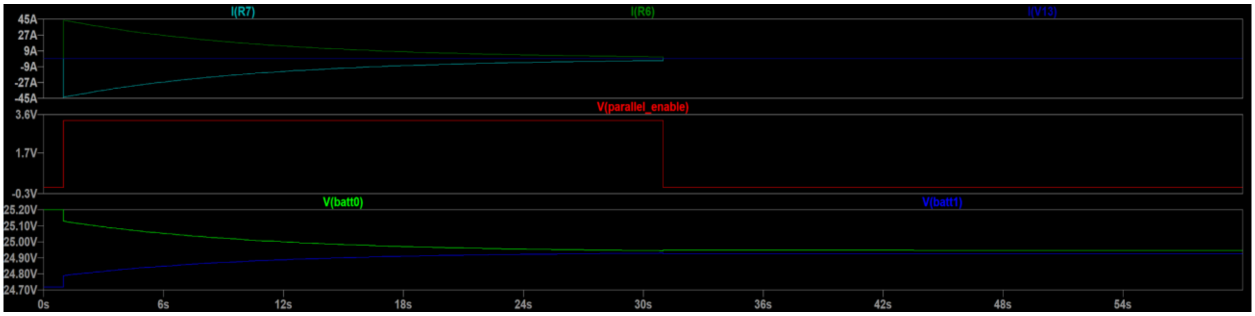

Fig. 67: Battery bridging integration test with no load.

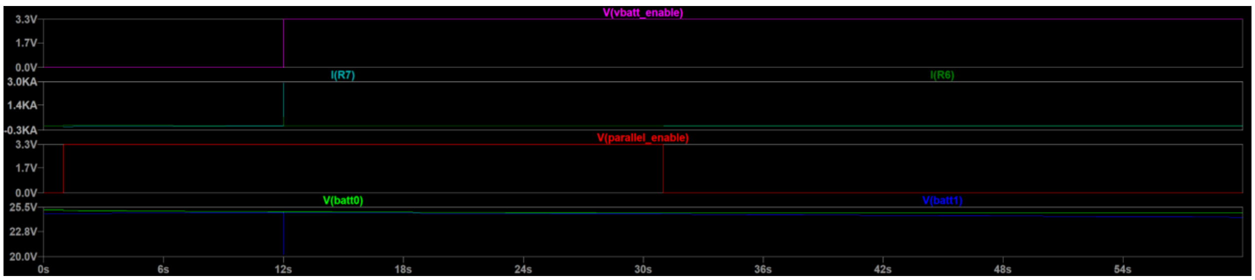

Fig. 68: Battery bridging integration test with load.

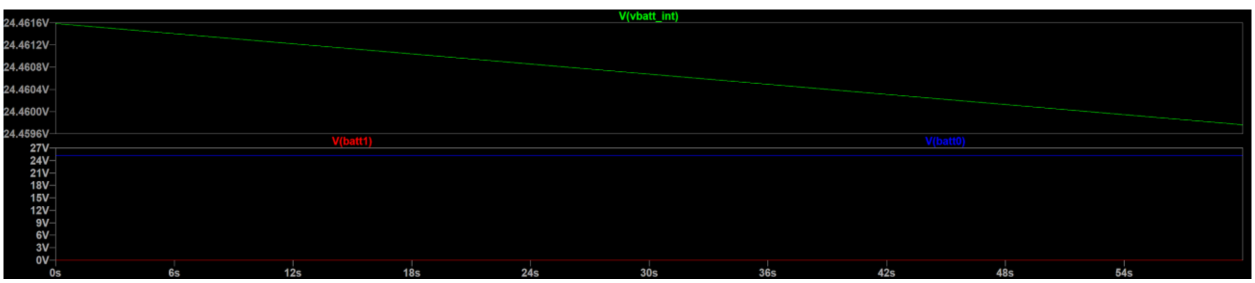

Fig. 69: Battery bridging integration test with only battery 1 connected.

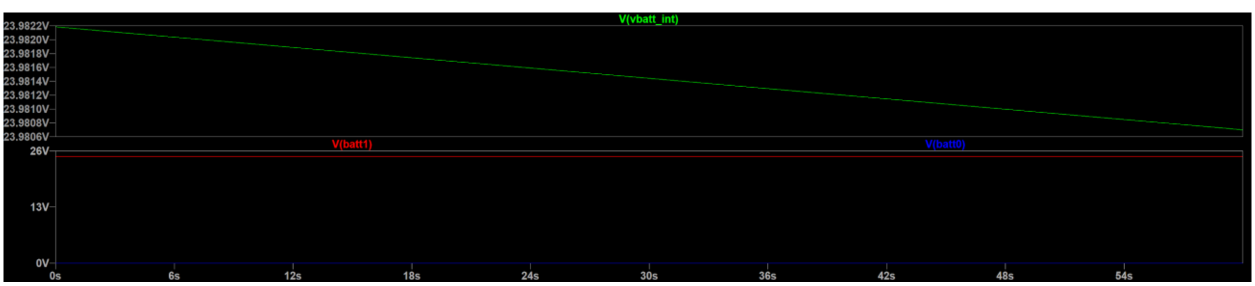

Fig. 70: Battery bridging integration test with only battery 0 connected.