



Final Technical Report

NASA WIRELESS SMART PLUG Experimental Control Logic Laboratory (XCLL)

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Dear Dr. Joseph A. Morgan, D.E., P.E.,

Experimental Control Logic Laboratory (XCLL) is pleased to present the Final Technical Report for the NASA Wireless Smart Plug (NWSP). The NWSP project is sponsored by NASA through the 2013 eXploration Habitat (X-Hab) Academic Innovation Challenge. XCLL is a Capstone based team, consisting of four undergraduate seniors from the Electronics Engineering Technology program.

XCLL's faculty Technical Advisor is Dr. Jay Porter, and the team members are:

- Akeem Whitehead – Project Manager
- Derek Garsee – Software Engineer
- Jeffrey Jordan – Hardware Engineer
- Christian Carmichael – Systems Integration Engineer

The NWSP is a current monitoring and control device that enables users to identify and respond to situations when an end-device being used on NASA's mock-up Deep Space Habitat (DSH) is exceeding optimal current draw. Given the DSH will require strict consideration of power consumption, the ability to manually load shed between end-devices of various priorities will provide users with the ability to continue operating end-devices that are critical to the mission objective. By equipping the NWSP with a disconnect feature, load shedding is made possible remotely from the user's computer station running a LabVIEW based executable. NASA requires the NWSP to monitor and control current between 0 to 5 amperes on either or both a 28V-DC and 120V-DC load line, at increments of 100 milliamperes, and to update the LabVIEW executable in 1 second intervals. The user will be prompted when an end-device's current exceeds a threshold, and the option to manually disconnect from the DSH will reside with the user. Five NWSP units are to be delivered to NASA and work in parallel, thus the LabVIEW executable will be able to monitor and control multiple devices simultaneously.

The NWSP was scheduled to begin on January, 17, 2013. XCLL is to deliver five fully functioning NWSPs to NASA by May 20, 2013. After delivery, the project will be transferred to the Texas A&M University Mobile Integrated Solutions Lab (MISL) for final testing and delivery on-site at NASA Johnson Space Center (JSC). XCLL has completed the production of five NWSPs for NASA's DSH as described in this proposal on time, over budget, and with requisite quality. All ownership of intellectual property in the development of the NWSP will belong to NASA.

Regards,

Akeem P. Whitehead
Project Manager, XCLL



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1.0 Introduction

1.1 General

NASA is currently developing the Deep Space Habitat (DSH) to explore planets, asteroids, and moons beyond low earth orbit. Developing the DSH will allow a crew of four to live and work in space for up to a year. The DSH consists of a propulsion stage, Destiny-derived lab module, and an airlock. However, deep space missions present unique challenges. NASA has given universities the opportunity to participate in the eXploration Habitat (X-Hab) Academic Innovation Challenge, which will allow student teams to address specific technical challenges with innovative ideas and solutions. Experimental Control Logic Laboratory (XCLL), a team of undergraduates from Texas A&M University, has been selected to engineer and construct the NASA Wireless Smart Plug (NWSP).

1.2 Background

Power is a vital and limited resource on deep space missions. With crews spending up to a year in space, efficient use of the limited power on the DSH is critical. Presently, there is no way to monitor the current draw of specific end-devices connected to the DSH power system. If an end-device is drawing more current than expected, NASA needs to be able to detect and disconnect that specific end-device. The NWSP will be a small device that will plug into an outlet on the DSH. The user's end-device will be plugged into the NWSP. The NWSP will monitor the current draw of that end-device and wirelessly transmit the amperage to a Master Control Unit (MCU).

1.3 Justification

The NWSP will allow NASA to monitor the current draw of end-devices plugged into the DSH. Current measurements from each NWSP will be transmitted to the MCU, which will place all current readings in a table. The table will allow NASA to quickly see the current draw of each end-device plugged into each NWSP. The NWSP will have the capability to disconnect an end-device from the DSH power system. This will allow NASA to perform manual-defined load shedding to maximize the duration of the available power. NASA will receive five NWSP from XCLL. Each NWSP will be ready to use and connected to the MCU. XCLL will provide all source code to NASA, which will allow NASA engineers to modify the NWSP embedded logic or the MCU software. Once XCLL has completed creating the five NWSP units, Mobile Integrated Solutions Laboratory (MISL) will install the NWSP into the DSH mock-up.



2.0 Problem Statement & Scope

The five NWSPs delivered to NASA will be proof of concept prototypes intended to extend the mock-up version of the Deep Space Habitat's (DSH) capabilities to monitor and control power usage while still on Earth. The NWSPs will be used for testing and mock-up evaluation purposes only, and, therefore, are to be removed before flight or actual implementation in space.

2.1 Functional Requirements

As specified in the original contract solicitation, several key functional requirements have been outlined for the NASA Wireless Smart Plug. These requirements have been set to fully define the scope of the NWSP project.

2.1.1 Power Control

- **Support for 120VDC and/or 28VDC**
The NWSP will be able to operate from either or both a 120VDC and/or 28VDC input.
- **Near Real-Time Monitoring and Control**
The NWSP will be able to provide the capability to monitor and control the end-device's current related information to inform the user in near real-time.
- **Fail Safe**
The NWSP will be able to fail safely in the event of failure. Safely has been defined as failing open, whereby, the end-device ceases to operate as if disconnected from the DSH.
- **Windows Based Master Control Unit (MCU)**
The NWSP will send and receive data through the Master Control Unit configured on a Windows based platform running a LabVIEW executable.

2.1.2 Communications

- **Wireless Monitoring, Configuration and Control**
The NWSP unit will transmit its measurements data wirelessly to the MCU. The settings to configure and control the NWSP will be initiated at the MCU and wirelessly transmitted to the NWSP.
- **Data Rate**
The NWSP embedded software will be able to sample the current at least once per second to report this data to the Master Control Unit.
- **Use of a Nivis VersaNode210 (VN210) Radio**
The NWSP will use a Nivis VN210 radio as its wireless radio peripheral to integrate with the DSH.
- **Support Nivis VersaRouter900 (VR900) Standards**
The NWSP will be able to communicate with the Master Control Unit through the Nivis VR900 router via SPI and ISA 100.11a standards.



2.1.3 Form Factor & Fit

- **Cannon-Type Connector**
The NWSP will have a 5 (or more) pin Cannon-type connector available for both its input and output from the DSH and to the end-device respectively.
- **Integration with DSH**
The NWSP system will be able to integrate and operate within the DSH system.
- **Deliver Five NWSP Units for Evaluation**
Five operational NWSP units will be delivered for installation and evaluation on the DSH mockup.



3.0 Design Implementation Strategy and Overview

When the DSH receives more demand for electrical power than its available capacity can deliver, the habitat must resort to rationing the available electricity to its higher priority end-devices. This process is called load shedding. Given that XCLL is responsible for delivering five NWSP units, five end devices will be monitored and controlled, each of which can be configured and assigned a priority level by the user. This would enable the ability for an autonomous load shedding capability, such that when any one of the five devices is not supplied enough power or exceeding power based on the current sense measurements, the NWSP will disconnect the power supply from the lowest priority device. The autonomous disconnect ability is not required for the NWSP prototype and has been omitted from design due to the undesired possibility of autonomously disconnecting an end-device that the user would otherwise have needed to continue to operate. Alternatively, a manual feature will be the primary mode of operation such that the human user has all control over connect and disconnect capabilities of the NWSP. By manually prompting the user through the National Instrument's (NI) LabVIEW Graphic User Interface (GUI) executable that the current measurements are being read lower or higher than the set operating or optimal values, disconnecting the end-device in question will reside upon user's discretion.

3.1 Hardware

Based on the description of the X-Hab Challenge Solicitation, the NWSP shall use a Nivis VersaNode 210 radio and a Texas Instruments (TI) MSP430F5438A microcontroller to interface to the present DSH wireless mesh network through a Nivis VersaRouter 900 gateway.

3.1.1 Microcontroller

The MSP430 microcontroller is equipped with both Serial Peripheral Interface (SPI) and Universal Asynchronous Receiver/Transmitter (UART) standard capabilities to communicate with the Nivis VersaNode 210 radio; however, only one may be utilized. NASA prefers the use of SPI communication due to the faster data speeds. In order to translate the output data from the current sense and voltage sense components, Analog-to-Digital Converter (ADC) ported pins are utilized with 12-bit precision for 4096 steps of 0.8mV LSB increments when using a 3.3V reference. Given NASA's requirement of monitoring current at maximum of 100mA increments, 51 steps of precision are required. This precision can be accounted for using a 6-bit or greater ADC at 51.6mV LSB increments or smaller. I/O pins are used as the driving sources for the solid-state switching relay and other potential enable signals. The clock rate is required to update the LabVIEW GUI at 1 sample per second. Multiple measurements, current calculations, and data transmission must occur within this limit.

3.1.2 Nivis VersaNode 210

Nivis has recently upgraded their hardware and software release to version 2.7. However, to interface with the present DSH wireless mesh network, NASA does not require an update for NWSP project purposes. Instead, the Nivis VersaNode210 will be required to operate with



firmware version 4.3.14 (Upg_VN210_FullAPI_SpeedupSPI_ExtWakeup_v04_03_14), while the Nivis VersaRouter 900 will operate on development release version 2.6.39 for intended and NASA proven compatibility. The Nivis VersaNode can communicate with the MSP430 using SPI or UART; however, the VN210 firmware is designed for SPI communication. Therefore, SPI will be the primary standard of operation. The UART interface is mandatory, however, in the case that the VN210 must be upgraded or operated in debug mode.

3.2 Software

Though the X-Hab Challenge Solicitation does not specify a GUI software executable requirement, the NWSP must be monitored and controlled by a MCU running on Windows Operating System (Windows XP or later). Due to XCLL's experience and knowledge of National Instrument's LabVIEW, this program was selected and approved as the MCU's front end GUI. The GUI will display numeric indicators for measured current and voltage values, controls to manually disconnect or connect end-devices, and controls to add or remove NWSPs from the GUI. NASA did not specify a GUI software requirement because they intend to port the data received by the DSH's VR900 from the NWSP into their proprietary application. When using the SPI standard, select parameters must be configured for the serial line input. These parameters include COM port, baud rate, data bits, stop bits, parity, and flow control. These universal parameter settings allow the NWSP's data to be used on interchangeable platforms.

3.3 Integration

MISL will deliver the five NWSPs to NASA JSC to be integrated into the mock-up DSH. Three integration tactics will be required for complete confirmation. The first tactic will require the use of XCLL's hardware platform, a laptop, brought by MISL. By connecting the DSH's VR900 to the laptop, the test matrix can be executed to ensure the NWSPs and GUI executable are compatible with interchangeable VR900s. The second tactic will require the GUI executable to run on NASA's hardware platform to ensure compatibility among varying hardware platforms and Windows Operating Systems. The third tactic will require configuration of NASA's proprietary application to interface with NWSP's parameters.



4.0 System Requirements

The NWSP is a current monitoring and control device that enables users to identify and respond to situations when an end-device being used on NASA's mock-up Deep Space Habitat (DSH) is exceeding optimal current draw. This section discusses the requirements requested by NASA, as well as the approved features appended by XCLL to enable demonstration and integration on the mock-up DSH. The Conceptual Block Diagram in Figure 1 illustrates an overview of both NWSP operation and integration to the DSH and MCU.

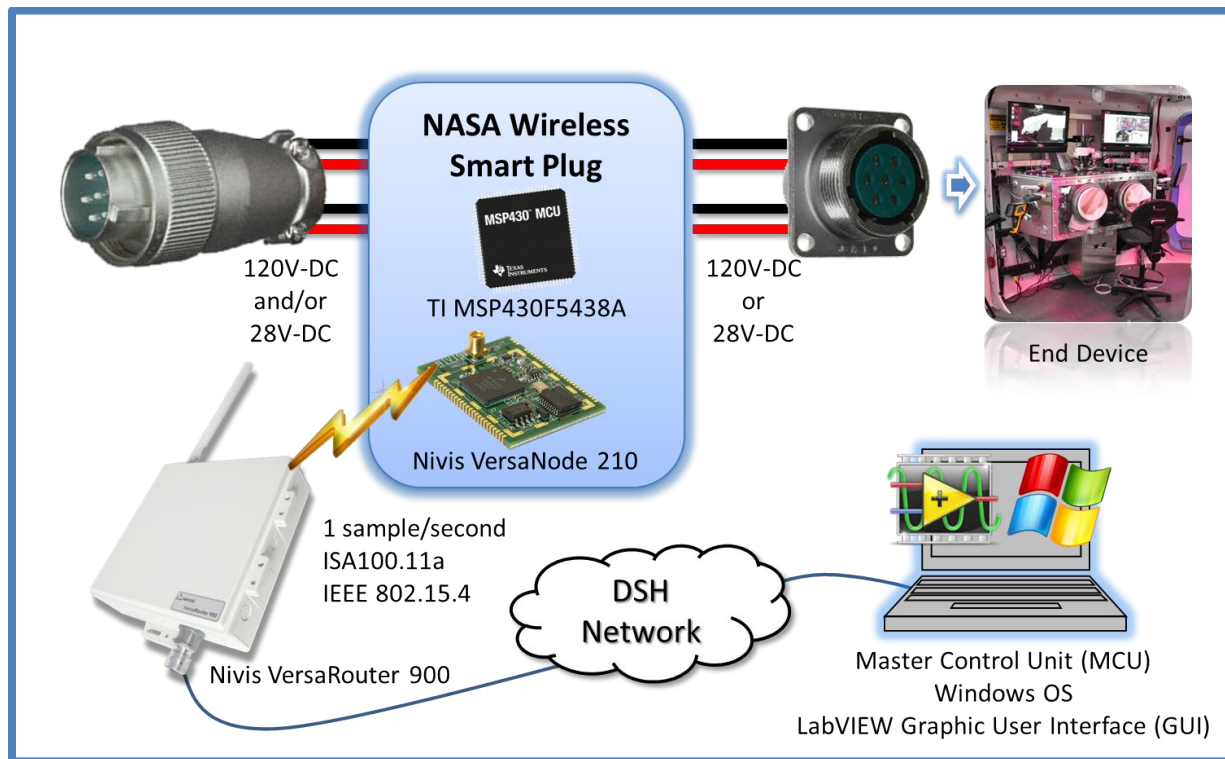


Figure 1: Conceptual Block Diagram

4.1 Hardware

The DSH will be able to output either or both 120VDC and 28VDC from the onboard outlets. The NWSP is expected to be able to power its internal circuitry using one of the two available voltages, given the NWSP is not a battery operated device. Two components specified by NASA are expected to be used as part of the NWSP solution: the Texas Instruments MSP430F5438A microcontroller and Nivis VersaNode 210 radio module. Both of these components will require 3.3V to operate, thus 28VDC or 120VDC must be efficiently regulated to 3.3V. To enable integration onto the DSH, 5 (or more) pin cannon-type connectors were requested by NASA. Though only for evaluation purposes, these connectors will simulate the actual connector type NASA may ultimately use for the actual re-designed for space qualification NWSP solution. The components comprising of the NWSP circuitry are to be low-power profiled. NASA does not want the NWSP to noticeably impact the end-devices operation in the case near maximum allowable output from the DSH is necessary for an end-device to operate.



4.2 Software

4.2.1 Embedded Intelligence Software

The primary purpose of the NWSP is to measure the current draw of an attached end-device (load). The Texas Instruments MSP430F5438A microcontroller has 12-bit ADC pins available for the required conversion process. NASA has requested the monitoring of current update on the MCU at a rate 1 sample per second, with precision of +/- 3% full scale (150mA) up to 5 amperes. However, the Texas A&M University stakeholders have requested precision of +/- 100mA. The microcontroller must be able to control whether an end-device is allowed power in the event the user configured current threshold has been exceeded. The DC solid-state relays used require a control voltage of at least 2.7V to close the relay to complete the circuit of the end-device.

4.2.2 Graphic User Interface Software

NASA did not request that a graphic user interface be made available for the NWSP project; however, in order for XCLL to demonstrate that all functional requirements are met, a custom graphic user interface is required. XCLL has developed a LabVIEW executable to operate on a Windows based operating system specifically for the purposes of demonstration. NASA will have the option of modifying the LabVIEW executable to fit their needs, or discard the LabVIEW executable to use their proprietary software instead. The LabVIEW GUI was designed according to the required use of the Nivis ISA100.11a standard with an SPI protocol.

4.3 Enclosure

Based on the X-Hab solicitation, NASA has required the NWSP sensor shall have a small form factor slightly larger than the size of an AC power plug that contains an AC to DC converter. NASA did not specify the dimensions for performance specification purposes, and ultimately adjusted the requirement such that XCLL be able to make the enclosure as small as possible when using the four layer PCB Bravo solution. The enclosure is to enable a panel mounted female connector as the output to the end-device, while using a pigtail extended male connector to connect to the DSH output. XCLL has appended local LED indicator slots on the NWSP enclosure for local analysis.

4.4 Performance Specifications

- **Voltage Source**
The NWSP will be able to connect to a 28 VDC and/or 120 VDC source. If both sources are present, the NWSP will default to the 28 VDC for internal power usage.
- **Monitor Current**
The NWSP will be able to monitor current up to 5 A with an accuracy of at least $\pm 3\%$ of full scale.
- **Control Power**



The NWSP will be able to set and control current from 0 to 5 A in 0.1 A increments. If the current flowing through the NWSP ever exceeds the set point, the user will be prompted to disconnect the NWSP from the end-device.

- **Data Collection and Response**

To allow for near real-time monitoring, the NWSP will be able to transmit at least 1 sample per second. Furthermore, loads exceeding the set current limit will be prompted for disconnect from power within 3 seconds of continual over-current.

- **User Interface**

NWSP configuration and monitoring will be done remotely using a LabVIEW GUI. This standalone GUI will run on a Windows XP based master computer and allow users to monitor NWSPs and set control routines. The ability to add or remove multiple NWSP units from the GUI will be made available through front end controls.

- **Networking and Communications**

In order to integrate into the current DSH wireless mesh network, the NWSP will use the Nivis VersaNode 210 wireless radio to communicate with the Master Control Unit through the Nivis VersaRouter 900 gateway located onboard the DSH. This requires that the NWSP implement the ISA100.11a standard.

- **Size**

The NWSP will be no larger than a typical AC to DC converter.

- **Failure Recovery**

In the event of failure, the NWSP must maintain safety. This safety measure is also taken if the NWSP loses its connection with the master control for prolonged periods of time.

- **Power Consumption**

The NWSP will act as a low power node when integrated into the DHS network. The Texas Instruments MSP430F5438 microcontroller will be used as its central control intelligence in order to minimize power requirements.

- **Deliverables**

There will be at least 5 NWSP units delivered and installed for testing and demonstration on the NASA DSH.



5.0 System Analysis

The MCU must be able to display the current draw of an end-device; therefore, understanding the process of digitizing and sensing current is critical to the operation of the NWSP. Due to the wireless communication that exists between the NWSP and the MCU, understanding the packet structure is required for appropriate conversion to port into the LabVIEW executable GUI. These two processes will be the primary operations analyzed at the NWSP's.

5.1 Current Sense Conversion

The current sensor must be accurate to within 100mA. The ACS714 hall-effect linear current sensor can accomplish this without loading down the power line due to the low internal conductor resistance of 1.2m Ω . Figure 2 shows the current range of which the ACS714 can output an equivalent voltage for when the supply voltage is 5V.

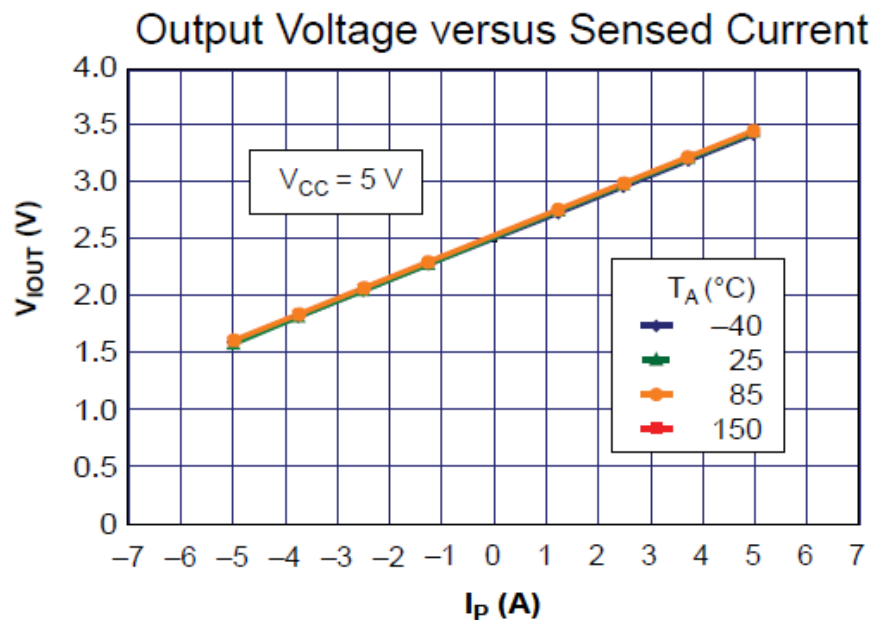


Figure 2: Current Sensor Characterization Graphed

This sensor uses the hall-effect to detect fluctuation in the magnetic field as the current changes. The sensor will output a linear voltage proportional to the current with an offset of +2.5V. The output voltage will change at a rate of 185mV/A. The output of the ACS714 will ultimately be connected to an ADC pin on the MSP430 post signal conditioning.

5.1.1 Signal Conditioning

To apply an offset and gain to the voltage output proportional to current sensed, an operation amplifier must be used to amplify the difference between two voltages. This will result in an operational amplifier circuit equivalent to a subtractor. This type of operational amplifier circuit is commonly known as a Differential Amplifier configuration as shown in Figure 3.

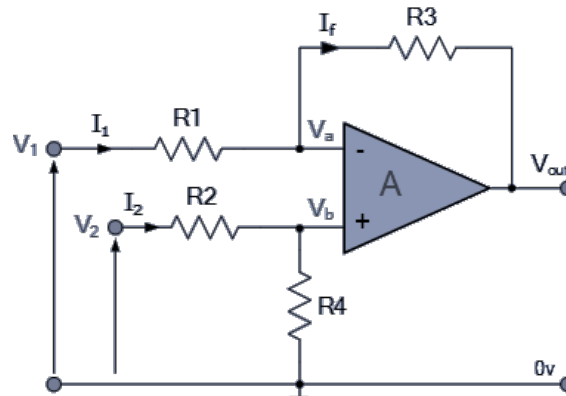


Figure 3: Differential Amplifier Configuration

By connecting each input to ground, and solving for the output voltage, the transfer function for a Differential Amplifier circuit is given as:

$$V_{out} = -V_1 * \left(\frac{R_3}{R_1}\right) - V_2 * \left(\frac{R_4}{R_2+R_4}\right) * \left(\frac{R_1+R_3}{R_1}\right)$$

If input V1 is higher than input V2 the output voltage sum will be negative, and if V2 is higher than V1, the output voltage sum will be positive. By adding more resistors in parallel with the input resistors R1 and R3, the resultant circuit can be made to either "Add" or "Subtract" the voltages applied to their respective inputs.

5.1.2 Analog to Digital Conversion

The resolution of the converter indicates the number of discrete values it can produce over the range of analog values. The values are usually stored electronically in binary form, so the resolution is usually expressed in bits. In consequence, the number of discrete values available, or "levels", is a power of two. For the purposes of the NWSP, an ADC with a resolution of 12 bits can encode an analog input to one in 4096 different levels, since $2^{12} = 4096$. The values can represent the ranges from 0 to 4095 (i.e. unsigned integer) or from -2048 to 2047 (i.e. signed integer), depending on the application.

Resolution can also be defined electrically, and expressed in volts. The minimum change in voltage required to guarantee a change in the output code level is called the least significant bit (LSB) voltage. The resolution Q of the ADC is equal to the LSB voltage. The voltage resolution of an ADC is equal to its overall voltage measurement range divided by the number of discrete values:

$$Q = \frac{E_{FSR}}{2^M - 1}$$

where M is the ADC's resolution in bits and EFSR is the full scale voltage range (also called 'span'). EFSR is given by:

$$E_{FSR} = V_{RefHi} - V_{RefLow}$$

where V_{RefHi} and V_{RefLow} are the upper and lower extremes, respectively, of the voltages that can be coded.



Normally, the number of voltage intervals is given by

$$N = 2^M - 1$$

where M is the ADC's resolution in bits.

That is, one voltage interval is assigned in between two consecutive code levels.

Using the known equations, XCLL has calculated the resolution of the NWSP as follows:

- Full scale measurement range = 0 to 3.3 volts
- ADC resolution is 12 bits: $2^{12} - 1 = 4096 - 1 = 4095$ quantization levels (codes)
- ADC voltage resolution, $Q = (3.3 \text{ V} - 0 \text{ V}) / 4095 = 3.3 \text{ V} / 4095 \approx 806 \text{ uV}$.

5.2 ISA-100.11a Wireless Standard

This standard uses the OSI layer description methodology to define protocol suite specifications, in addition to specifications for the functions of security, management, gateway, and provisioning for an industrial wireless network. The protocol layers supported are the physical layer (PhL), data link layer (DL), network layer (NL), transport layer (TL), and application layer (AL) as show in the reference model of Figure 4.

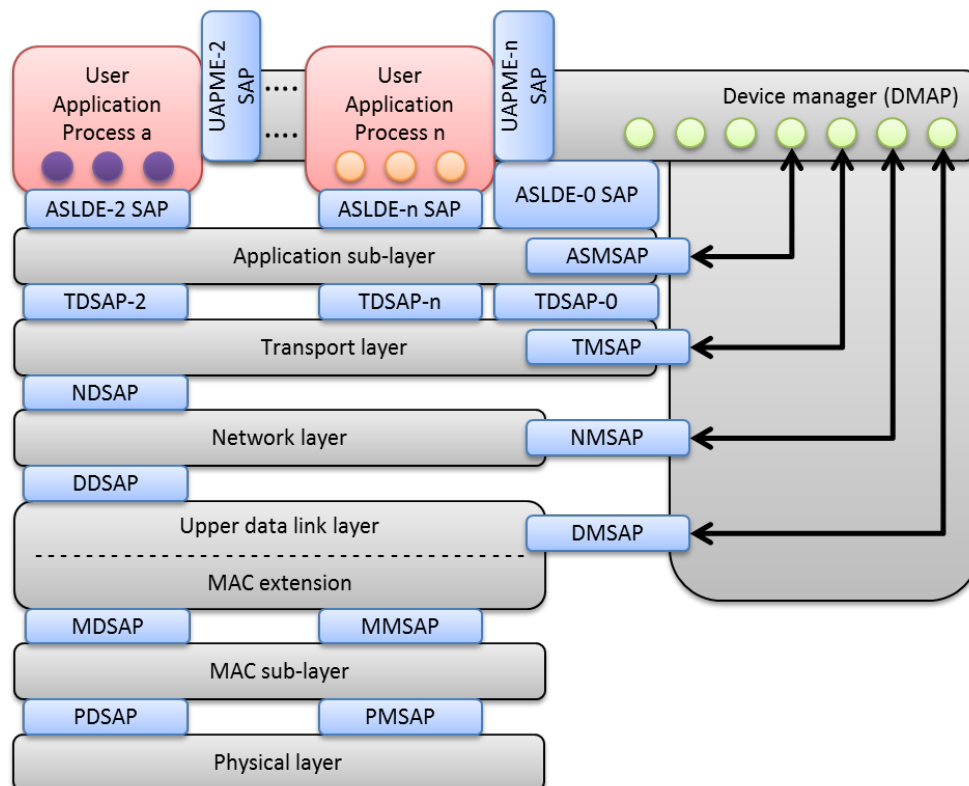


Figure 4: ISA-100.11a Reference Model

Each layer provides a service access point (SAP). The services of a layer are defined as the functions and capabilities of that layer that are exposed through the SAP to the surrounding layers. The services provided by a layer are defined by the data flowing through the SAP and, in



some cases, the states that a layer provides and the state transitions that are driven that perform the management function. Note that the device manager has a dedicated path to several of the lower layer protocol layers within a device. This is to provide direct control over the operation of these layers, as well as provide direct access to diagnostics and status information. All devices compliant to this standard are considered managed devices. All devices shall implement each SAP used by the DMAP for every protocol layer they implement. A protocol layer typically encapsulates its payload, hereafter referred to as a service data unit (SDU), with a header and footer in a single protocol data unit (PDU) as show in Figure 5. The header and footer are often referred to as overhead, with the amount of overhead depending upon how much information is necessary for the protocol to function properly. Since one of the goals of this standard is to keep PDUs short, minimizing the amount of overhead is a key attribute. A complete description of each header and footer will be found in the appropriate protocol layer clause. A full PDU includes all headers and footers as shown in Figure 6. The amount of data (measured in octets) of an application PDU that can be sent in a single transmission is determined by the difference between the maximum PhL payload and the overhead of all headers and footers.

Header	SDU	Footer
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Figure 5: Single Protocol Data Unit

PhL header	DL header	NL header	TL header	Application PDU	TL footer	NL footer	DL footer
------------	-----------	-----------	-----------	-----------------	-----------	-----------	-----------

Figure 6: Full Protocol Data Unit

5.3 Serial Peripheral Interface

The SPI bus can operate with a single master device and with one or more slave devices. If a single slave device is used, the SS pin may be fixed to logic low if the slave permits it. Some slaves require the falling edge (high to low transition) of the chip select to initiate an action, which starts conversion on said transition. With multiple slave devices, an independent SS signal is required from the master for each slave device. Most slave devices have tri-state outputs so their MISO signal becomes high impedance (disconnected) when the device is not selected. Devices without tri-state outputs can't share SPI bus segments with other devices; only one such slave could talk to the master, and only its chip select could be activated.



6.0 Hardware Design

6.1 Functional Block Diagram

The Conceptual Block Diagram in Figure 1 provides an illustrative representation of the NWSP operation and interface methodology to the DSH and MCU. To explore these processes in more detail, the outline of specific hardware and signal types internal to the NWSP are represented in the Functional Block Diagram Overview in Figure 7. Each block representing a major internal process is color coded according to their block breakdowns in the following sections.

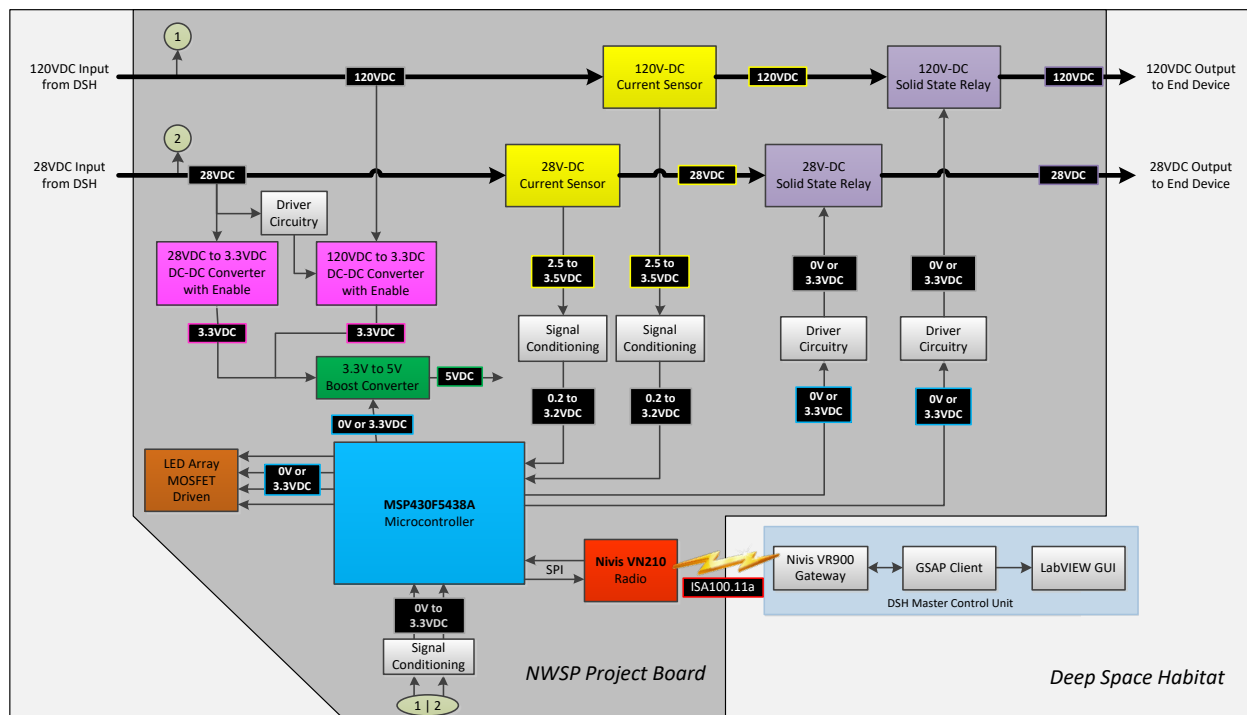


Figure 7: Functional Block Diagram Overview

The DSH will be sourcing either or both 28V-DC and 120VDC. Due to the possibility that both voltage sources will be available, the NWSP must only utilize a single supply voltage to power internal NWSP circuitry. The 120V-DC step-down converter is to be disabled in the case that both voltage sources are available. As compared to the 28V-DC power line, the 120VDC DC-DC converter is disabled given that more power is dissipated through the step down regulation process to power subsequent internal NWSP circuitry.



6.1.1 Microcontroller Interfaced with Radio Design

To achieve communication between the MSP430 microcontroller and Nivis VN210 radio, the ability to communicate by SPI or UART is made available to the user. SPI mode has been selected for the NWSP application based on the versioning and development release required by NASA. Figure 8 illustrates the connection scheme of the SPI interface format.

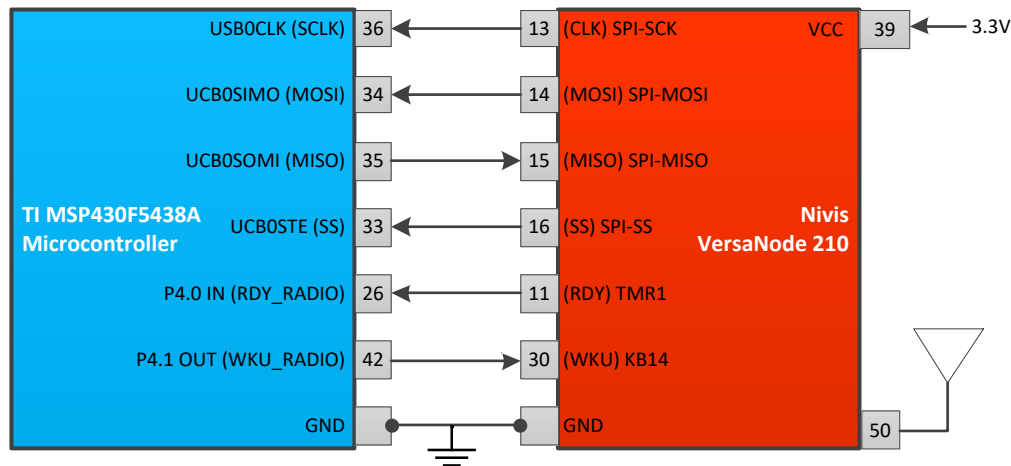


Figure 8: Microcontroller Interfaced with Radio Block Diagram

The Nivis VN210 has the option of utilizing the onboard SMT antenna connector for wireless communication, or, alternatively, using a custom or external antenna through pin contact 50. To initiate communication, the bus master (VN210) first configures the clock, using a frequency less than or equal to the maximum frequency the slave (MSP430 microcontroller) device supports. The master then transmits the appropriate chip select bit for the desired chip to a logic level 0 (chip select line is active low). If a waiting period is required, the master must wait for at least that period of time before starting to issue clock cycles. During each SPI clock cycle, a full duplex data transmission occurs. The master sends a bit on the MOSI line, and the slave reads it from that same line, while the slave sends a bit on the MISO line, and the master reads it from that same line.

6.1.2 Voltage Regulation and Ground Isolation for Internal Circuitry Design

To efficiently power the internal circuitry of the NWSP, the load line voltages must be utilized without significantly impacting the power available to the end-device. Given the power budget of the NWSP components, using highly efficient DC-DC converters will prevent potential impactful losses. Figure 9 shows the Voltage Regulation Block Diagram focused section of the Functional Block Diagram.

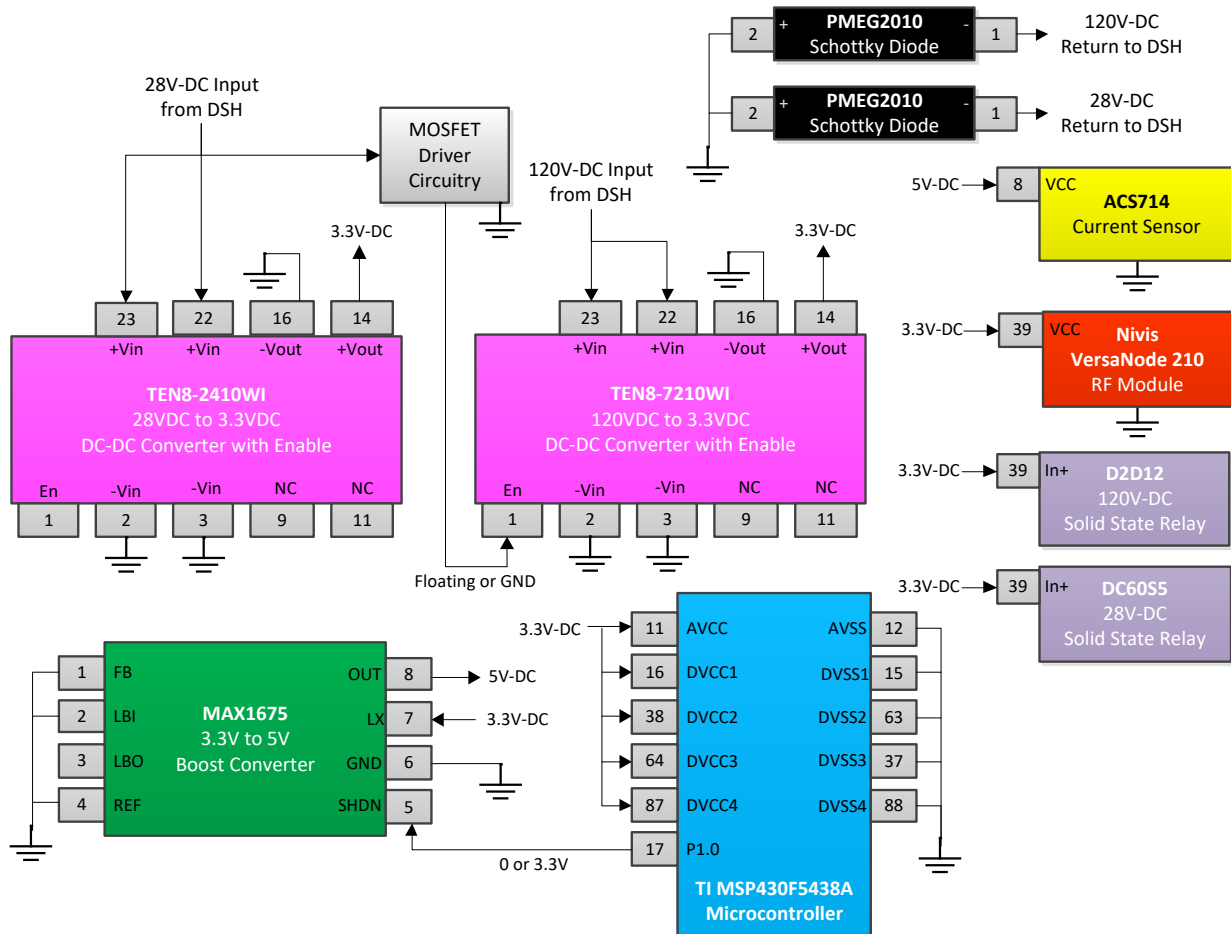


Figure 9: Voltage Regulation and Ground Isolation Block Diagram

Major components to be powered include the TI MSP430 microcontroller, the Nivis VN210, two current sense modules, and two DC solid state relays. The TEN8-2410WI and TEN8-7210WI both supply 3.3V-DC for the internal circuitry's components, whereby, the DSH's output of 28VDC and 120VDC are regulated respectively. The solution for the 120VDC to 28VDC regulation must include an enable low option, such that when the 28VDC source is present, the 120VDC regulation is disabled. A boost converter is used to step-up 3.3V to 5V in order to power the current sensors and the operational amplifiers used in the signal conditioning and driver circuits. The NWSP is not to act as the common ground of the 28VDC and 120VDC DSH supplies, thus a Schottky diode is used to isolate the NWSPs from the returns of both DSH voltage supplies. The DSH voltage supplies are only common at the solar panel array power source.

6.1.3 Current Sense and Conversion Design

In order to prompt the user to disconnect in the case of out of range current measurement detection, the TI MSP430 microcontroller must be able to precisely convert the analog output of the ACS714 current sense module to a digitally interpretable value. Figure 10 shows the connection scheme of the Current Sense and Conversion Design.

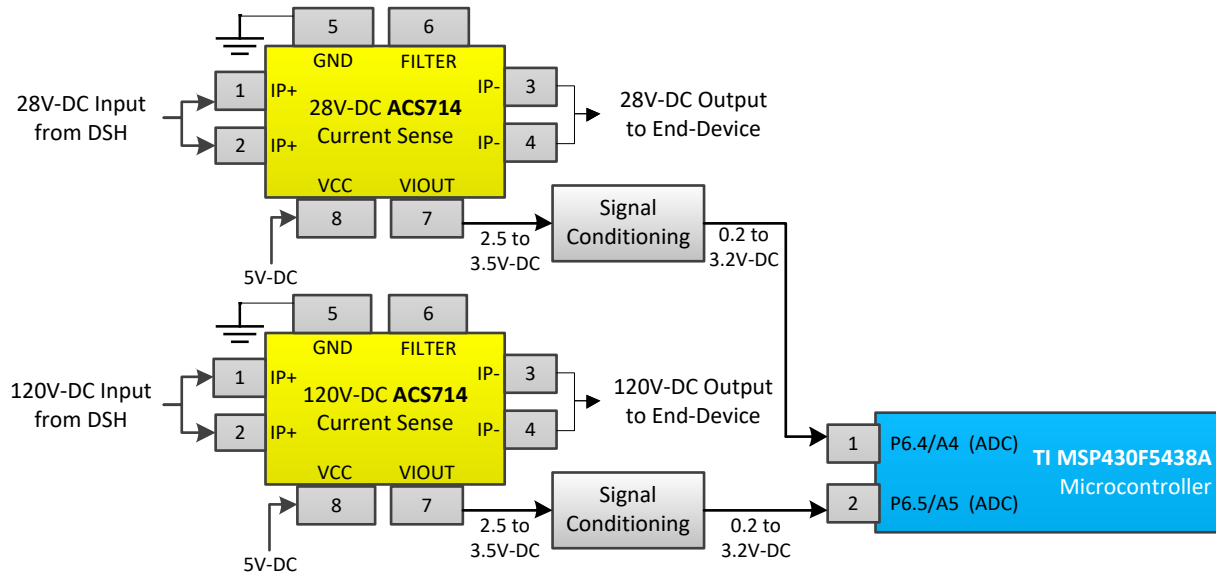


Figure 10: Current Sense and Conversion Block Diagram

Two independent current sense modules for each input voltage will require the same signal conditioning between the output voltage paths and the microcontrollers ADC inputs. The typical ADC signal conditioning process consists of an offset, gain, and low pass filtering of the raw analog voltage. Given the 0 to 10A current range of interest on the ACS714 module equates to a 2.5V to 3.5V range output, the raw analog signal must be offset by 2.3V, applied a gain of 3.2V, and low pass filtered through a differential amplifier and current sensor's FILTER pin.

6.1.4 Relay Control Design

The DC solid state relays are used to connect and disconnect the output from the DSH to the end-device. When the user is prompted to disconnect the end-device due to the current threshold being exceeded, the relays must be configured appropriately as a part of the command message at the MCU. Figure 11 shows the connection scheme of the Relay Control Design.

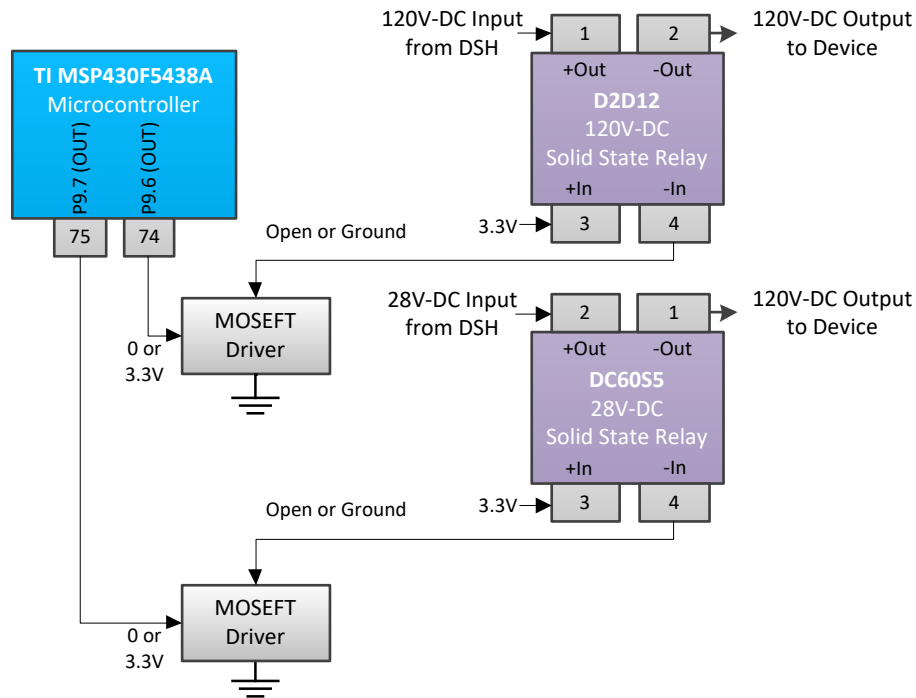


Figure 11: Relay Control Block Diagram

The driver circuit for the DC solid state relay will consist of an n-channel enhancement mode MOSFET circuit gated on or off by the MSP430. The MOSFET's gate will be connected to output of the relay's control terminal, such that when the MOSFET is gated off, the relay is opened, and the end-device does not receive power. When the MOSFET is gated on, the output of the relay's control terminal is shorted to ground, completing the circuit, and closes the relay to enable power to the end-device.

6.1.5 Voltage Measurement Design

In addition to measuring the current draw of the end-device, the NWSP will be equipped with the ability to detect the voltage at the input of the NWSP. Figure 12 depicts the connection scheme of the Voltage Detection Design.

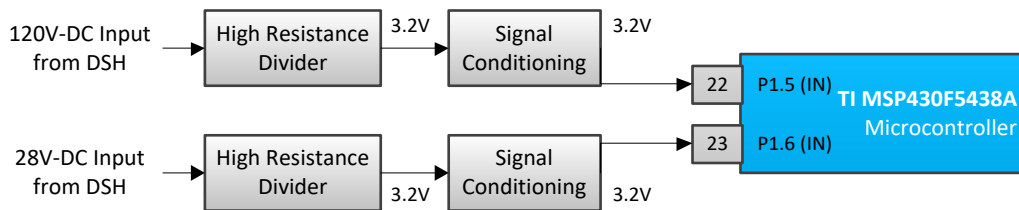


Figure 12: Voltage Measurement Block Diagram



To ensure the end-device is receiving either 120V-DC or 28V-DC, this monitoring feature is to be used as a multi-purpose indicator. Indications as to whether the DSH is actually sourcing 120V-DC and/or 28V-DC or if the solid-state relay controlling these power lines are open or closed. The voltage divider circuit will be drawing power continuously, thus, the resistors selected must be of high magnitude in value (i.e. mega ohms or greater) to reduce current draw. The power consumed must be negligible to the power profile of the NWSP's internal circuitry. The unity gain buffer's high input resistance ensures the voltage transferred from the voltage divider circuit is reduced to a low input impedance level for the MSP430's digital I/O pin.

6.1.6 Light Emitting Diode Indicator Design

To locally indicate the status of the NWSP, an array of light emitting diodes (LEDs) are used to indicate specific connection states and warnings. This local indication will enable the user to visually identify immediate information without having to reference the graphic user interface. Figure 13 depicts the connection scheme of the LED indicator design.

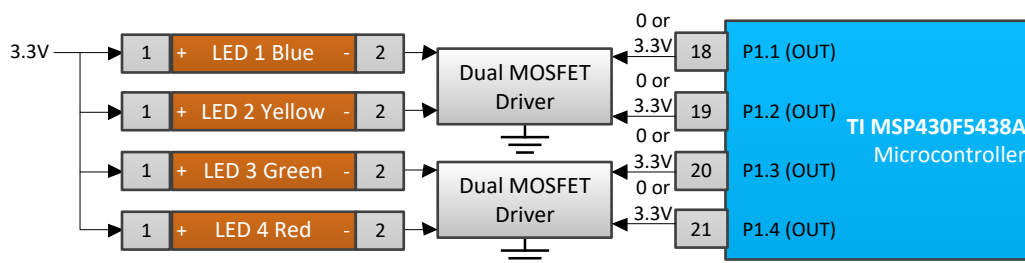


Figure 13: Light Emitting Diode Indicator Block Diagram

The LEDs' cathodes can be held in two states, floating or shorted to ground. By default, the LEDs will be floating, and thus remain in the off state while the microcontroller is sourcing a low, 0V signal. When the microcontroller outputs a high, 3.3V signal to the gate of the MOSFET, the LED's cathode, connected to drain, will short to ground through the MOSFET's source connected to ground. The blue LED is only on, and flashes at an on/off rate of 1 second when the NWSP is connected to the DSH network and transmitting. The yellow LED will be the first LED to turn on when attempting to initialize and is disconnected from the DSH network. The yellow LED will remain solid until the NWSP is connected to the DSH network. The green LED indicates the NWSP is connected to the network, but not transmitting. The red LED indicates that the current threshold configured on the NWSP has been exceeded, thus prompting that the user must decide whether to disconnect the NWSP from the end-device.

6.2 Schematic

The schematic of the NWSP has been divided into multiple schematics using global connectors to indicator interconnectivity. Each schematic represents a sub-circuit of a specific operation of



the NWSP, similar to the format of the Functional Block Diagram. The schematics will be explained on a component level to describe functionality.

6.2.1 Microcontroller Schematic

The detailed microcontroller schematic is shown in Figure 14. The power provided to the microcontroller is 3.3V from the output of the DC-DC converter. A decoupling capacitor is used to decouple one part of this electrical circuit from the remainder of the NWSP. Noise caused by other circuit elements is shunted through the capacitor, reducing the effect they have on the rest of the circuit. The capacitor cannot provide DC power because it stores only a small amount of energy but this energy can respond very quickly to changing current demands. The capacitors effectively maintain power-supply voltage at frequencies from hundreds of kHz to hundreds of MHz (in the milliseconds to nanoseconds range). A 4.7uF, 0.1uF, and 1nF capacitor have been selected for the microcontroller's analog supply pin, while only 0.1uF are used on the digital supply pins.

The ADC12_A module supports fast 12-bit analog-to-digital conversions. The module implements a 12-bit SAR core, sample select control, and a 16-word conversion-and-control buffer. The conversion-and-control buffer allows up to 16 independent analog-to-digital converter (ADC) samples to be converted and stored without any CPU intervention. Only three of the ADC pins must be used for the NWSP: current sensing of the 28V based end-device, current sensing of the 120V based end-device, and the digitization of 5V from the boost converter for calibration purposes. To interface to the VN210, the microcontroller is enabled to use both SPI and UART protocols. In synchronous mode, the USCI connects the device to an external system via three or four pins: UCxSIMO, UCxSOMI, UCxCLK, and UCxSTE. SPI mode is selected when the UCSYNC bit is set, and SPI mode (3-pin or 4-pin) is selected with the UCMODEx bits. In asynchronous mode, the USCI_Ax modules connect the device to an external system via two external pins, UCAxRXD and UCAxTXD. UART mode is selected when the UCSYNC bit is cleared.

To drive LEDs low or high, detect the presence of voltage, and open or close relays, digital I/O pins are used as drivers and indicators. To enable onboard flash programming and debugging of the microcontroller, a 4-wire JTAG programming communication configuration has been designed.

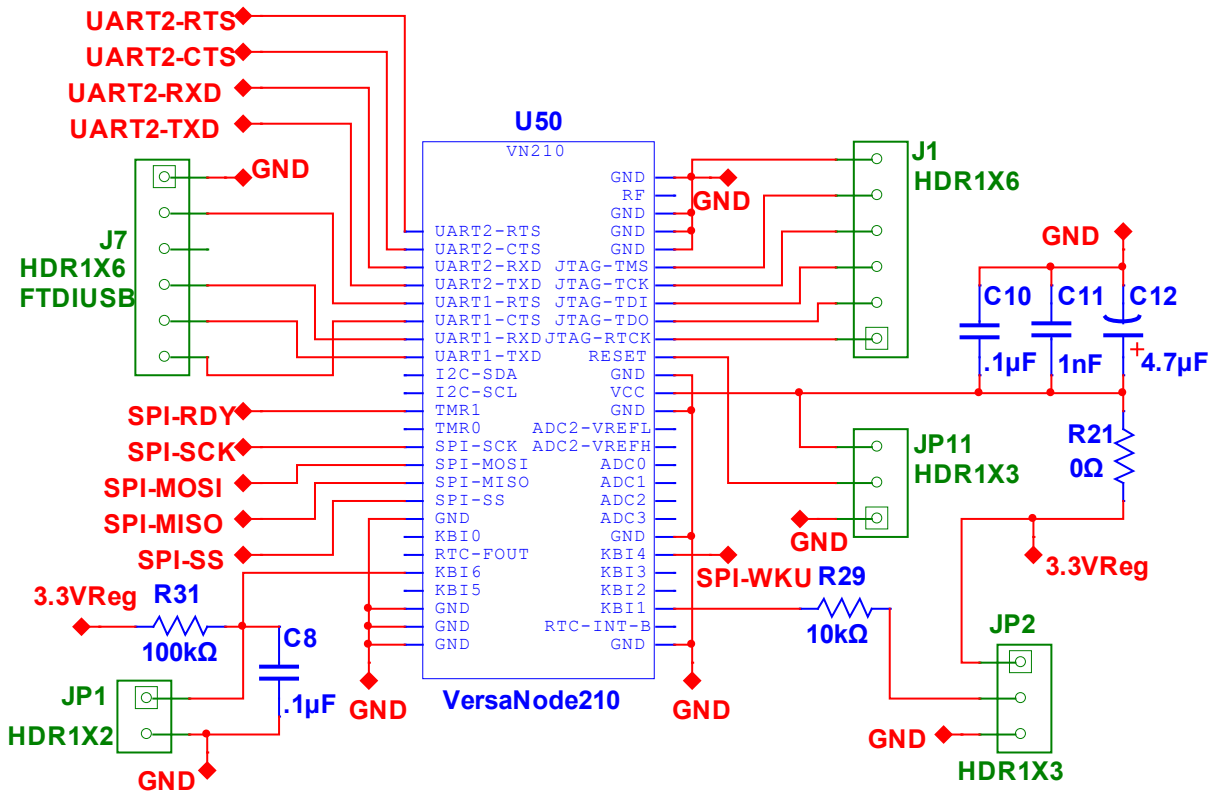


Figure 15: Radio Module Schematic

6.2.3 Power Schematic

The detailed power schematic is shown in Figure 16. The TEN8-2410WI steps-down input voltages ranging from 9V to 36V down to 3.3V. The TEN8-7210WI steps-down input voltages ranging from 43V to 160V down to 3.3V. TEN8-2410WI will always be enabled to convert the expected input voltage of 28V, given the Remote On/Off pin is floating. As long as this pin remains floating, the TEN8-2410WI is in the on-state. However, the TEN8-7210WI can be disabled when 28VDC drives the gate of the CDS18531Q5A MOSFET high, resulting in the TEN8-7210WI Remote On/Off pin shorting to ground. When 3.3V is present, the MAX1675 boost converter activates. Though the boost converter has a SHDN' pin controlled by a digital high or low from the microcontroller, the boost converter is to remain high during the entire operation of the NWSP.

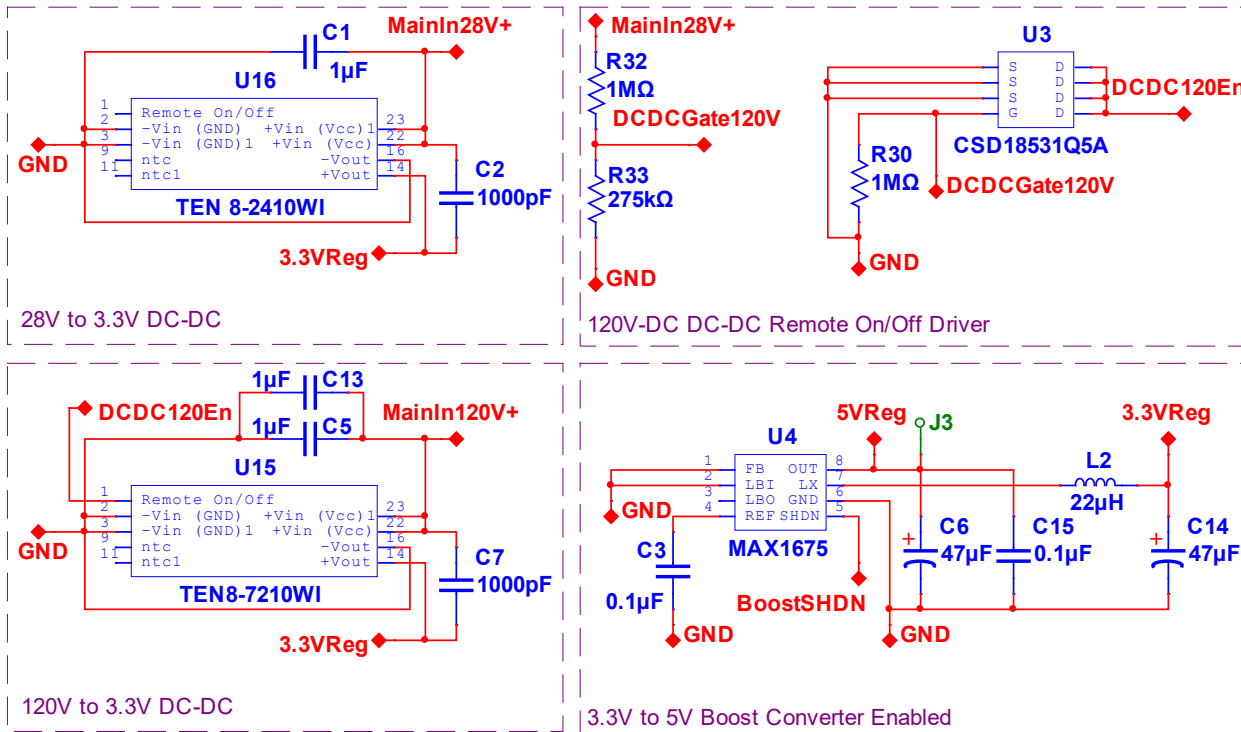


Figure 16: Power Schematic

6.2.4 Current Sensing Conversion and Calibration Schematic

The detailed current sensing conversion and calibration schematic is shown in Figure 17. The design of the current sense circuitry is based on the output of the current sensor. The current sensor has a FILTER pin. In low-frequency sensing applications, adding an RC filter to the output of the device improves the signal-to-noise ratio, and therefore the resolution, of the device output signal. The LM7301 rail-to-rail input-output operational amplifier has a minimum output swing of 112mV, thus the resistor configuration is designed such that the minimum output the signal conditioning circuitry is 200mV. Considering 5V exceeds the microcontroller's external reference voltage of 3.3V, a resistive voltage divider is used to reduce the voltage applied to the ADC pin to 2.5V. This voltage enables boost converter output offset in both the positive and negative direction to avoid saturation of the digitized signal.

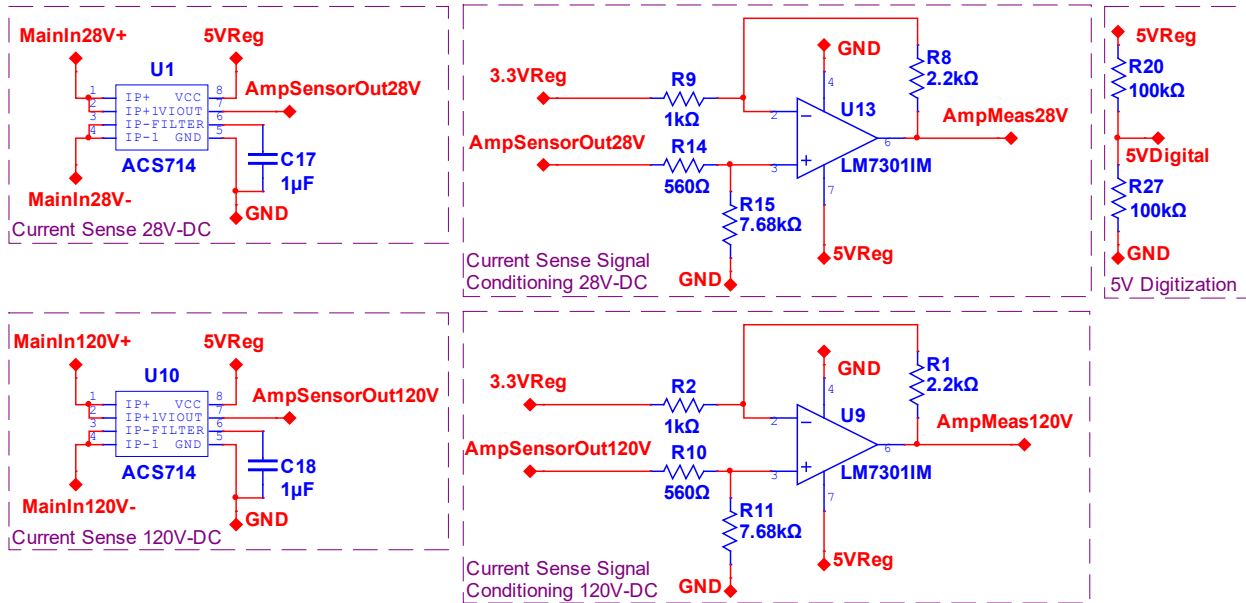


Figure 17: Current Sensing Conversion and Calibration Schematic

6.2.5 Voltage Detection Schematic

The detailed voltage detection schematic is shown in Figure 18. Considering that voltage is only detected, and the exact value is not measured, a digital high or low is ultimately necessary to indicate whether the expected 28VDC and 120VDC supplies are present at the NWSPs input. To reduce the power dissipated by the resistive dividers, high resistive values are used to reduce both voltages to 3.2V. The subsequent LM7301 is used as a buffer amplifier to transfer a voltage from a first circuit (resistive divider), having a high output impedance level, to a second circuit (MSP430 digital I/O) with a low input impedance level. The interposed buffer amplifier prevents the second circuit from loading the first circuit unacceptably and interfering with its desired operation. In the ideal voltage buffer in the diagram, the input resistance is infinite, the output resistance zero (impedance of an ideal voltage source is zero).

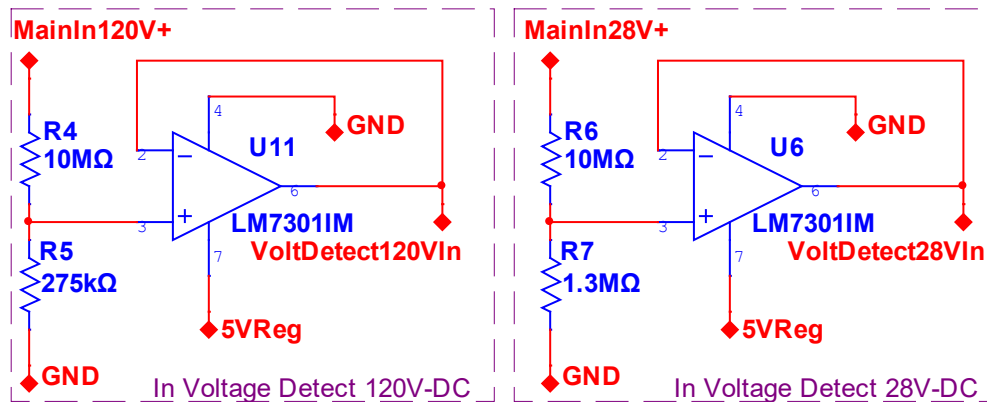


Figure 18: Voltage Detection Schematic



6.2.6 LED Indicators Schematic

The detailed LED indicators schematic is shown in Figure 19. Each LED receives 3.3V from the output of the DC-DC converts. The voltage drop of each LED was considered, whereby the red LED has the lowest voltage drop of 1.8V, while the blue LED has the largest voltage drop of 3V. The current supplied to each LED is limited by a 1kΩ resistor. Each LED is turned on or off based on the input to the MOSFET's gate voltage. If the microcontroller is outputting a low signal, the LED will be off given the cathode will remain floating at the drain of the MOSFET. The 1MΩ pull-down resistor ensures the gate will not be floating in the case the microcontroller's digital output is misconfigured or floating. When the gate of the MOSFET is high, drain shorts through the source to ground, thus completing the circuit of the LED.

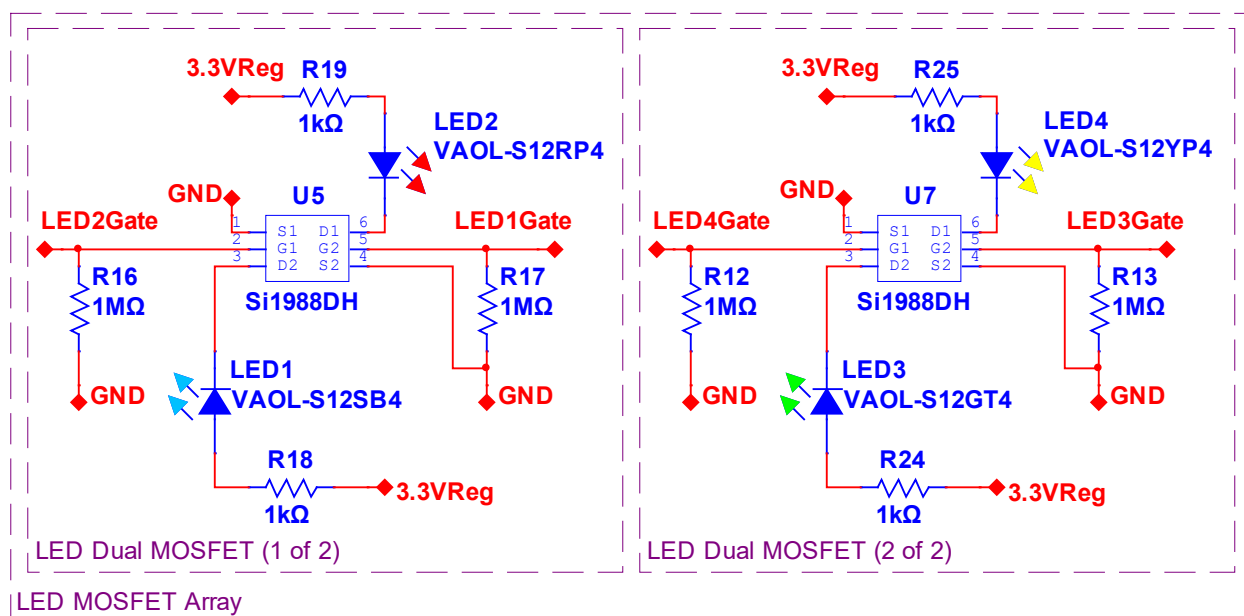


Figure 19: LED Indicators Schematic

6.2.7 Relay Control Schematic

The detailed relay control schematic is shown in Figure 20. The relays require a minimum of 2.7V at the control input in order to close the load side. 3.3V is supplied to the input of the control terminal of the relays. Similar to the LED control, when the gate of the MOSFET receives a low signal from the microcontroller's digital output, the relay will remain in open state given the control signal will be floating. When the gate of the MOSFET is supplied a high signal for the microcontroller's digital output, the relay control signal can complete its circuit by grounding through the drain-source of the MOSFET. In the case the microcontroller's digital output is floating, a 1MΩ resistor is used as a pull-down resistor to set the gate in a low state.

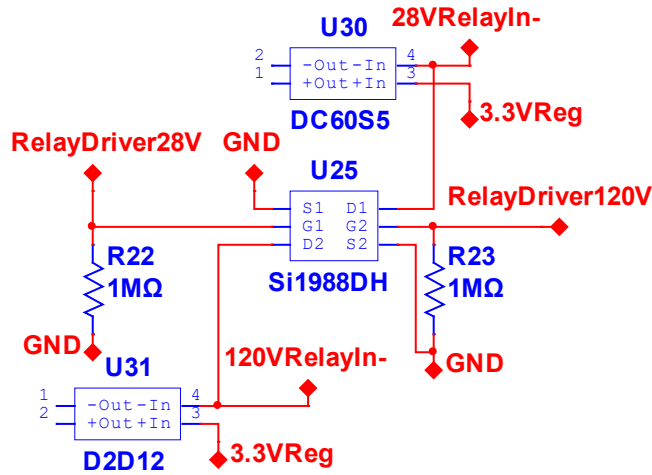


Figure 20: Relay Control Schematic

6.2.8 Connector and Ground Isolation Schematic

The detailed connector and ground isolation schematic is shown in Figure 21. The 12-pin terminal block is used to interface the NWSP to the connectors of DSH and end-device. 16 gauge wire is used for all terminals pertaining to the input and output of the NWSP, while 20 gauge wire is used for the relay control terminals. The Schottky diodes share a common ground on the anode side, but are separated independently at the returns of the DSH voltage supplies, whereby one diode connects to the 28V return and the other diode connects to the 120V return.

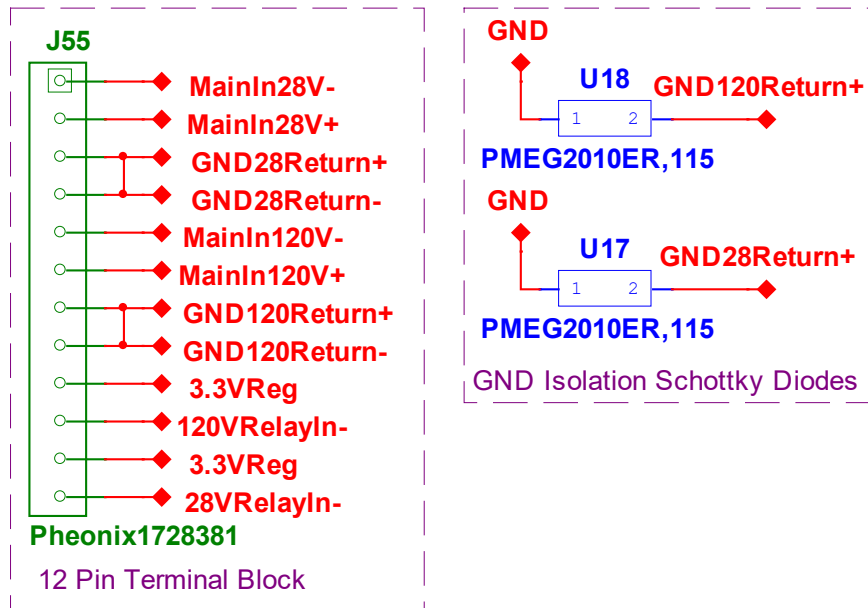


Figure 21: Connector and Ground Isolation Schematic



6.3 PCB Layout

The final PCB layout for NWSP is referred to as the Bravo Board Layout. The NWSP's PCB measures 3.88" by 3.41" as a four layer board. The overall thickness of the board measures 62 mils. All trace widths on the Bravo Board measure 10 mils with the exception of power and ground. The power traces on the Bravo Board measure at least 25 mils, while any ground traces measure at least 30 mils. This increase in width is to accommodate the larger amount of current that may be drawn when the NWSP's VN210 is transmitting or the DC-DC converter is using more internal resources to step-down a specific voltage to 3.3V.



6.3.1 Copper Top

Figure 22 shows the top copper layer of the Bravo Board PCB for the NWSP. The top copper layer stores all the components of the device, as well as the majority of signal traces. The top copper layer was designed with specific groupings of components. On the left side is located the 12-pin terminal block, where the high voltage inputs access the board. The current sensors were located closest to the pins of the terminal block that would carry the voltage and current to be supplied to the end-device. The DC-DC converters and voltage detection resistor configurations were located closest with a secondary priority to the same pins considering these two applications do not carry high currents on their respective traces. The center of the board comprises of the circuitry related to current sensing and signal conditioning. The right side of the board pertains to the digital processing and wireless communications. To avoid interference potentially caused by the presence of high voltages and currents as expected on the left, the microcontroller specifically was located on the right-most side of the PCB, followed by the radio module.

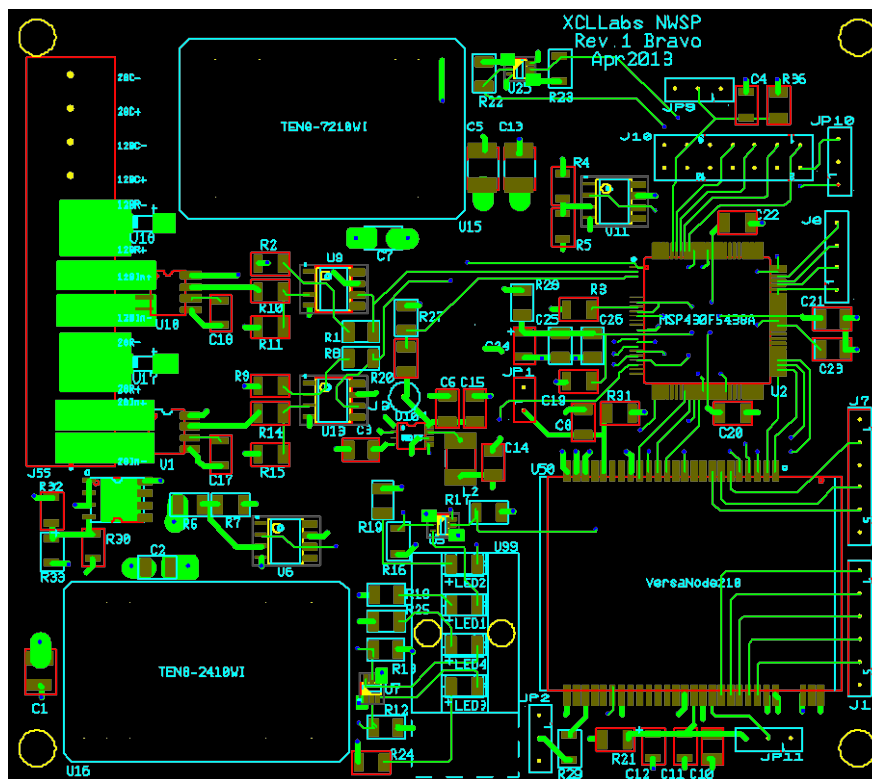


Figure 22: PCB Copper Top



6.3.2 Copper Inner Layer 1

Figure 23 shows the copper inner layer 1 of the Bravo Board PCB for the NWSP. This layer is strictly reserved for the purpose of internal analog and digital ground. No power or signal traces are shared on this plane.

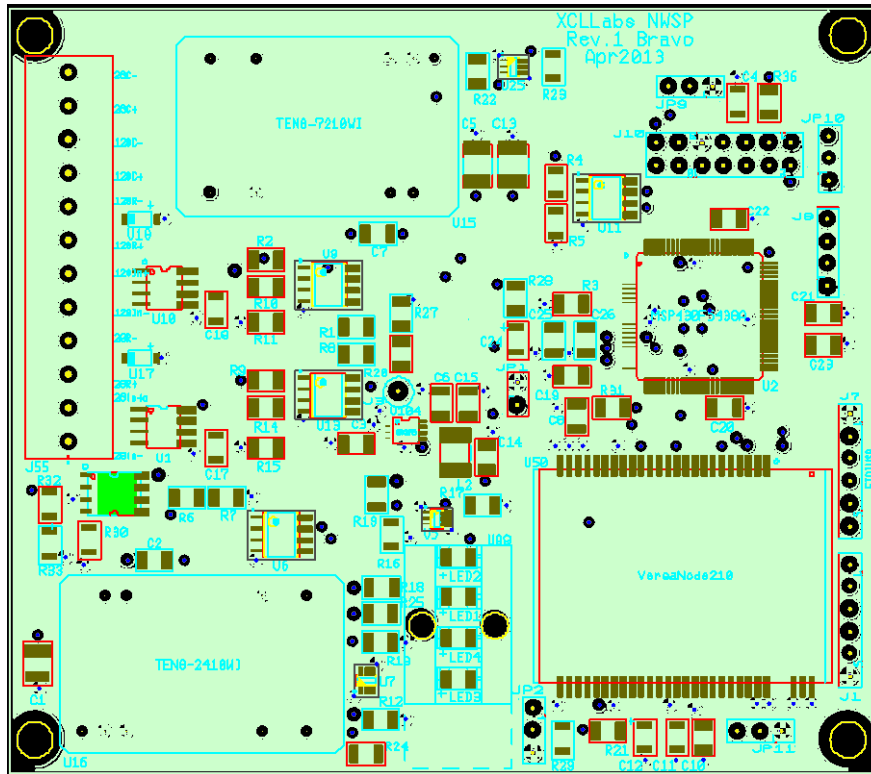


Figure 23: PCB Copper Inner Layer 1



6.3.3 Copper Inner Layer 2

Figure 24 shows the copper inner layer 1 of the Bravo Board PCB for the NWSP. This layer is strictly reserved as a power plane. The majority of the layer is compensated by the 3.3V polygon. The second largest polygon is used for 5V applications. 28VDC and 120VDC are routed to their respective DC-DC converter and voltage detection resistor configuration. Due to the concern of 120VDC arcing to the adjacent 3.3V layer, a clearance of 50 mils has been provided. Likewise, for the 28VDC trace, a signal trace of 30 mils has been provided. Both 28VDC and 120VDC traces were designed to be as short as possible to avoid spanning underneath or near components and signal traces requiring high precision and minimal interference.

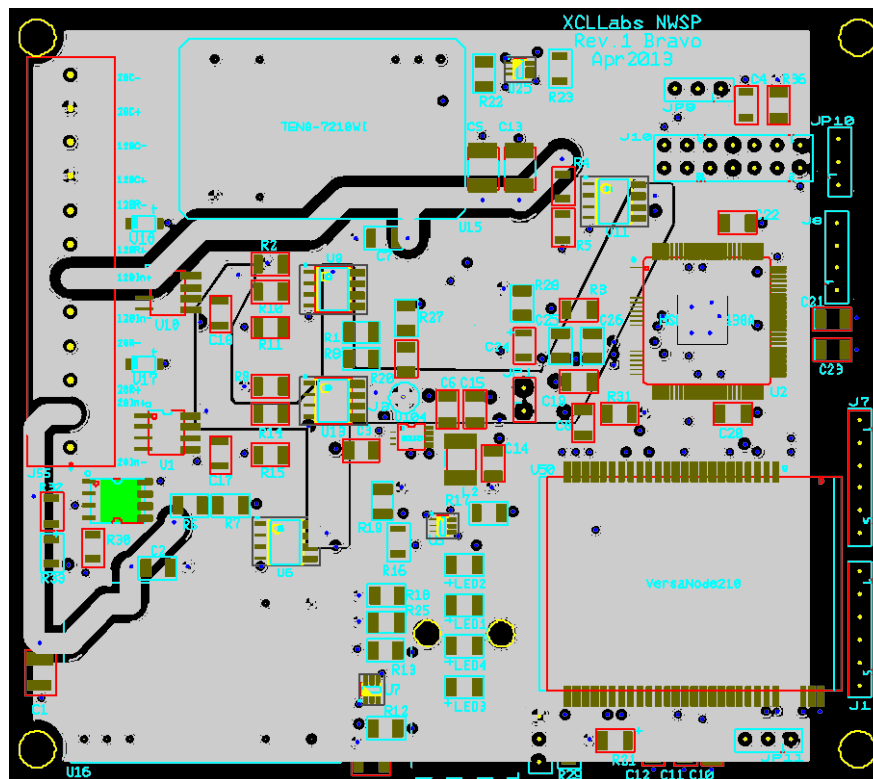


Figure 24: PCB Copper Inner Layer 2



6.3.3 Copper Bottom Layer

Figure 25 shows the copper bottom layer of the Bravo Board PCB for the NWSP. This layer has been used as the reserve layer for signal traces that would otherwise overlap on the top layer. Considering this layer is closer to the adjacent power plane layer, the signal traces that would usually directly route to their destination using the shortest path have been rerouted to avoid placement adjacent to high voltage traces.

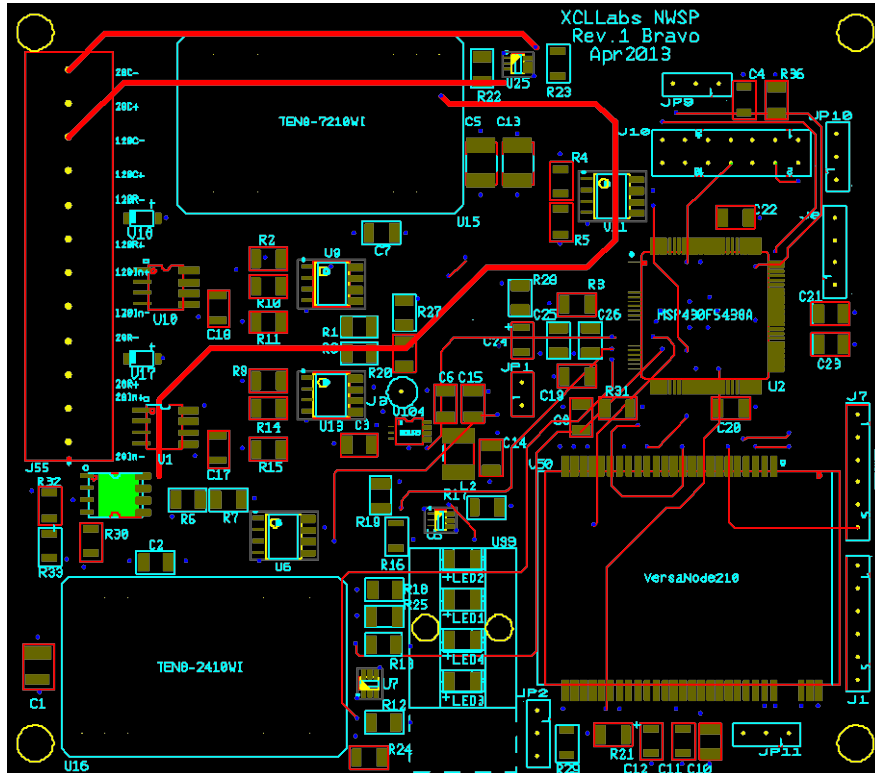


Figure 25: PCB Copper Bottom



6.4 Enclosure

An enclosure was designed and created to house and protect the NWSP. The enclosure was designed in SolidWorks 2013 and printed using the uPrint SE rapid prototyping system. The printing medium is ABSplus plastic. The enclosure was meant to provide secure housing for the NWSP PCB and two relays. The enclosure should be as small as possible while providing enough distance between components to maintain a safe environment inside the enclosure. The PCB is secured to the enclosure using four quarter inch #4-40 ANSI screws. Figure 26 shows the enclosure mockup designed in SolidWorks 2013.

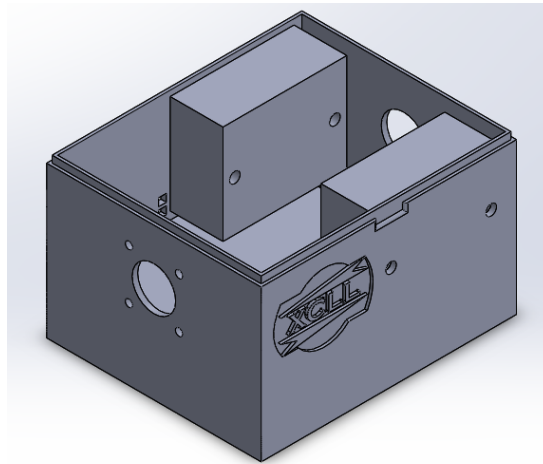


Figure 26: Complete Enclosure

The enclosure is 4.64x3.90x2.75 inches. The front of the enclosure has a hole 0.5 inches in diameter for the female panel mount connector. This connector is screwed in using four quarter inch #4-40 ANSI screw. On the opposite end, a hole 0.5 inches in diameter for the grommet which secures the pigtail to the back of the enclosure. Figure 27 shows the complete enclosure.

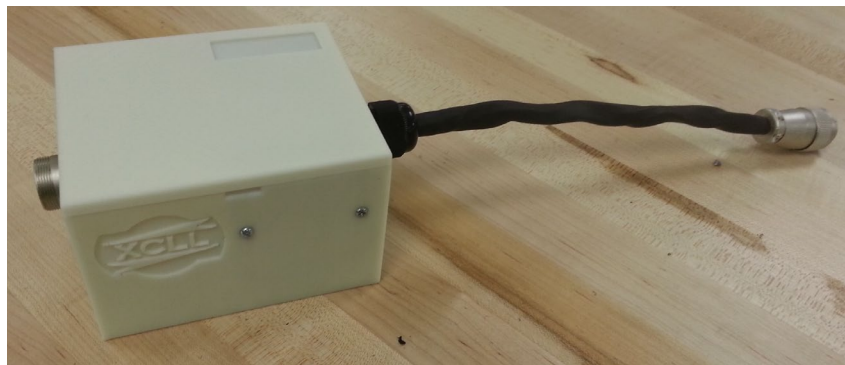


Figure 27: Complete Enclosure



The rectangular depression on the top of the enclosure is sized for label on which the MAC address of the VN210 radio can be written. A small rectangular depression on the side of the enclosure is designed to allow the user to remove the lid with ease.

6.5 Connectors

A requirement for the NWSP is to use cannon-type circular connectors. The NWSP uses two connectors, a female SRCN2A16-7S socket and male SRCN6A16-7P plug. Figure 28 shows both connectors as viewed from the NWSP.

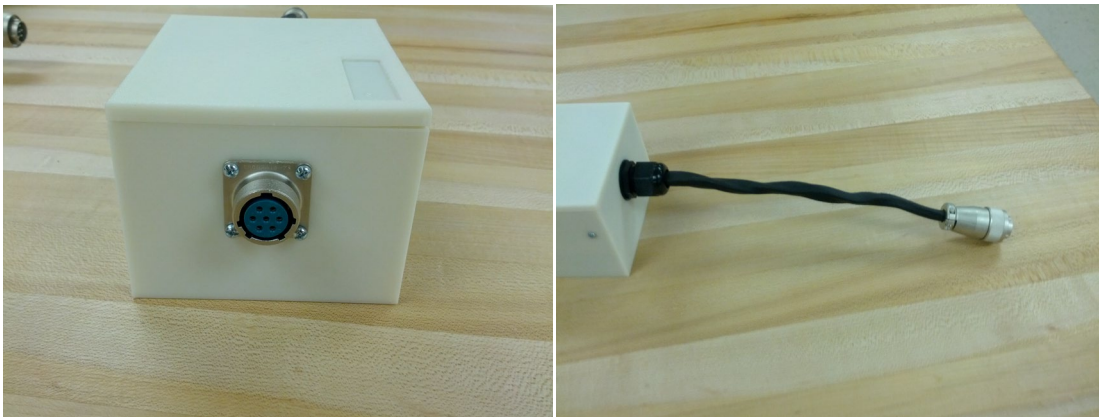


Figure 28: Input and Output Connectors of NWSP

6.5.1 SCRN2A16-7S Socket

A female SCRN2A16-7S socket is found on the front of the NWSP. This is where the end device will plug into the NWSP. The SCRN2A16-7S is a box mount, cannon-type, circular socket. This socket can support a 10A max current draw at a 300VDC max input voltage.

6.5.2 SCRN6A16-7P Plug

A male SCRN6A16-7S plug is found on a pig tail attached to the back of the NWSP. This is where the NWSP will plug into the DSH Mockup. The SCRN6A16-7P is a cable mount, cannon-type, circular plug. This plug can support a 10A max current draw at a 300VDC max input voltage.

6.6 Cost Data

To develop a fully functioning prototype, XCLL developed two revisions of the NWSP. The cost associated with the NWSP is divided into each revision.

6.6.1 Alpha NWSP

The alpha revision of the NWSP was XCLL's first attempt at designing a fully functioning NWSP. XCLL purchased two alpha revision boards. Everything worked with the exception of the boost converter and VN210. The boost converter was in a very small package, which proved difficult to solder and test. The VN210 did not have the proper pins brought to the MSP430I, and the



pins needed to provision the radio and flash firmware were not brought to headers. The costs associated with the alpha revision are in Table 1.

Table 1: Alpha Board Costs

Date	Vendor	Cost
3/5/2013	Mouser	
3/5/2013	AdvancedCircuits	
3/25/2013	Digikey	
	<i>Total</i>	

6.6.2 Bravo NWSP

The bravo revision of the NWSP is the last revision made by XCLL. XCLL purchased five boards. Everything worked as expected with the exception of two pins from the MSP430 routed to the wrong pins on the VN210. XCLL was able to correct the board by cutting the traces and using 30 AWG blue wire to swap the pins. The bravo board was smaller than the alpha board. The costs associated with the final bravo revision can be found in Table 2.

Table 2: Bravo Board Costs

Date	Vendor	Cost
4/9/2013	AdvancedCircuits	
4/9/2013	Mouser	
4/9/2013	Powergate	
4/9/2013	Digikey	
4/17/2013	Mouser	
4/23/2013	Mouser	
4/24/2013	Digikey	
	<i>Total</i>	

6.6.3 Final Costs

The final cost to produce one NWSP is \$. When quantities of 100 are ordered, the final cost is \$ for all 100 or \$ for one. This includes the cost of outsourcing enclosures, professional population, and putting together the final NWSP. For a complete listing of prices associated with the NWSP, please refer to the Bill of Material found in Appendix B.



7.0 Software Design

7.1 Implementation Strategy

The embedded code on the NWSP was an addition of plug capabilities to software provided by NASA. The software operates on an interrupt with polling solution based mainly around the Nivis VN210 radio communications. There are three states of communications between the MSP430 and the VN210: initialization, data transmission, and idle. The initialization state takes place on radio reset and initial startup. It provides the initial conditions of the platform. Once the initialization has been completed, transmission between the NWSP unit and the MCU will begin. After a packet has been received from the VN210 radio, the MSP430 will interpret the communications and transmit the appropriate response. The NWSP will transmit the settings and status of the plug to the MCU to be interpreted and displayed by the LabVIEW GUI.

During the idle communications state between the MSP430 and the VN210, the NWSP will measure current, identify the state of the relays, voltage presence, and current status. The data is transmitted from the MSP430 to the VN210 when a timer sets an interrupt and the “appflag” is raised to 1. This flag notifies when the MSP430 should send data. This is used to define the time between each update and is configurable by the user through the GSAP client. The NWSP will transmit relay conditions (open/closed), measured current, voltage presence, user defined threshold current, and current status (under/over threshold current) using a polling method.

While the MSP430 is not in a low power mode, all fields are constantly updated. If there are no impending communications from the VN210 and the appflag has not been raised, the MSP430 will enter a low power mode to reduce power consumption. The MSP430 will stay in this mode until the VN210 requests communications or the interrupt timer fires.

7.2 Hierarchy Chart

A hierarchy chart is used to aide in software planning and shows the calling hierarchy of each function. Figure 29 shows the Hierarchy Chart for the NWSP embedded software.

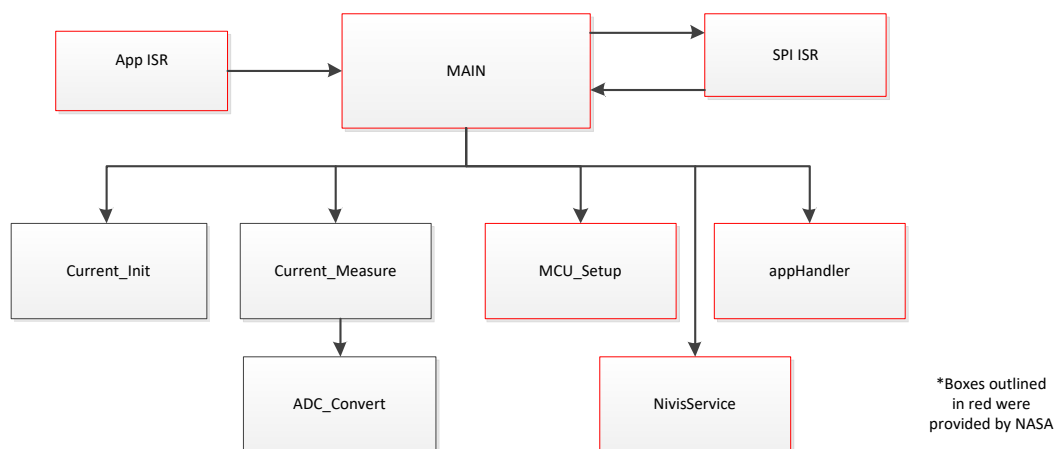


Figure 29: Hierarchy Chart



Boxes outlined in red were provided in the ISA100ThroughputTest program. Functions created for the NWSP include Current_Init, Current_Measure, ADC_Convert, Parse_Message, and Toggle_Relay. The Parse_Message and Toggle_Relay functions interact through the SPI interrupt service routine (ISR) while the Current_Measure function is called on each iteration of the main loop.

7.2.1 Current_Init

The Current_Init function initializes the ADC pins and measurements used to measure the current. The ADC channels are configured for a sequence of consecutive measurements. This means when the measurements are triggered, the channels will be measured in a sequence until the end channel is completed.

7.2.2 Current_Measure

Current_Measure has an input of the NWSP message buffer. The ADC channels are measured 512 times, then averaged. An offset is computed by measuring a 2.5v line and subtracting a measured value from the ideal 2.5v ADC value. This offset provides the base number to be subtracted. A static number is subtracted from the resulting offset value to increase accuracy. After the offset has been applied, the new ADC value is sent to the ADC_Convert function which computes the current equivalent. After the ADC value has been converted, the 120v or 28v current value is selected based on the active relay and stored in the message buffer.

7.2.3 ADC_Convert

The ADC_Convert function uses the ADC value found in the Current_Measure function and applies a simple equation to convert the ADC value to the current equivalent. Current_Measure passes the ADC value to ADC_Convert in the form of a pointer. This allows the equation to be applied to the value at the address directly.

7.2.4 Parse_Message

The Parse_Message function is called after the SPI interrupt completes. The received message is passed to the function and each byte is interpreted and the commands are applied to the NWSP.

7.2.5 Toggle_Relay

The Toggle_Relay function takes the third byte of the message as an input and turns on or off the specified relay. A hex 0x01 activates the 28v relay and deactivates the 120v relay, a hex 0x02 deactivates the 28v relay and activates the 120v relay. Any other value will deactivate both relays.

7.3 Flow Diagrams



7.3.1 High Level Diagram

Flow diagrams are used to plan the logical flow of the software. Flow diagrams allow the programmer to see how each aspect of the program interacts with each other. Figure 30 shows the flow diagram for the high level functionality.

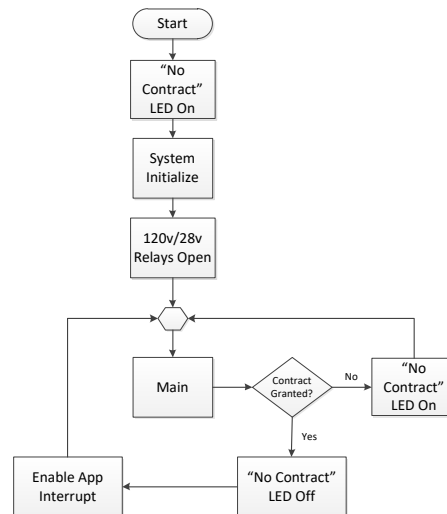


Figure 30: High Level Flow Diagram

The high level flow diagram shows the initialization and high level loop of the program. The main function checks the status of the contract and turns on and off an LED to indicate the contract status. Once a contract has been granted, the application interrupt is enabled. The application interrupt is a timer interrupt which tells the program when data from the MSP430 should be sent to the VN210.

7.3.2 Main Loop Diagram

The main loop executes after initialization and is the center of the program. Figure 31 shows the flow diagram for the main loop.

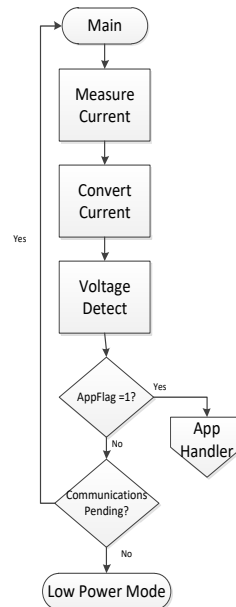


Figure 31: Main Loop Diagram

The main loop is where current measurements are made, the current is converted from an ADC measurement to the current equivalent, the voltage is detected, and the data is sent to the VN210 if the application flag is high. If there are no pending communications, meaning the application flag is not high and the VN210 has not signaled pending SPI communications, the MSP430 will enter into a low power mode. If the processor is in a low power mode, interrupts will return the processor to the normal mode of operation.

7.3.3 Application Flow Diagram

The application flow diagram shows how the message is created and triggered to be sent. Figure 32 shows the application flow diagram.

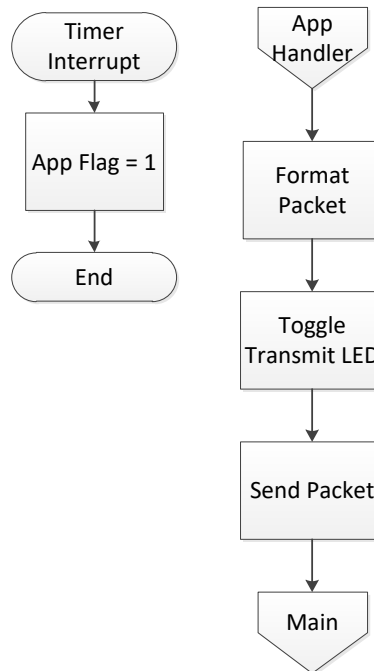


Figure 32: Application Flow Diagram

The timer interrupt is fired when the internal counter of the MSP430 reaches the user defined value. The interrupt sets the application flag high which signals the processor it is time to send the data packet to the MCU. The application handler then moves all information from the temporary NWSPmsg buffer to the outgoing message buffer. An LED is then toggled to show active communications and the message is sent from the MSP430 to the VN210 via SPI.

7.3.4 Message Parse Flow Diagram

In order to dynamically configure the NWSP, the smart plug must be able to receive commands from the MCU. It does this by relaying information from the VN210 to the MSP430 via SPI.

Figure 33 shows the flow diagram for the message parsing algorithm.

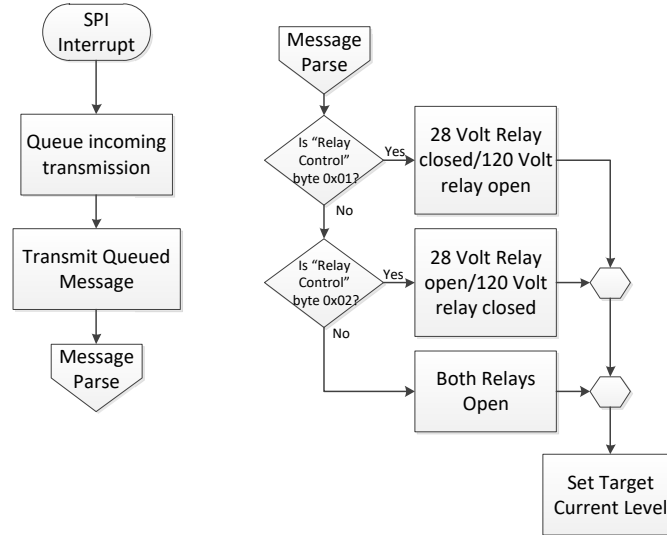


Figure 33: Message Parse Flow Diagram

The MSP430 handles communications using an SPI interrupt which stores incoming information on a queue while sending information. If the queued information is a command for the NWSP, the software will enter into the message parse function. In this function, the relays are configured according to the user input and the target current level is stored into a global variable.

7.4 Code Description

When power is first provided to the NWSP, the microcontroller begins initialization. All digital input/output pins and communications ports are configured and the relays are initialized open. After the initialization, the software enters into a loop which executes continuously. This loop measures current, detects the input voltage sends requests and responses to the VN210 radio.

7.4.1 Current Measurement

The main function of the NWSP is to measure current on either the 28v or 120v line. Both lines are measured during each measurement cycle and the channel is chosen based on the connected relay. This was accomplished using a sequence of measurements for the 28v channel, 120v channel, and ADC offset channel.

The boost converter will ideally provide exactly 5V; however, there is a small offset which impacts the current sensors' voltage range. To compensate, the ADC Offset channel utilizes a voltage divider to divide the boost convert's 5v output by 2.5V. This voltage will be input to the ADC channel, which is referencing a 3.3 volt line. Measuring this line allows dynamic calibration during measurement. The ideal 2.5v ADC measurement is subtracted by the measured value to find the offset which is subsequently subtracted from the 28v and 120v channels. To increase the accuracy, a second offset is added to the measured offset.



Each channel is measured 512 times in order to increase accuracy and decrease the impact of short spikes in current draw. Once the measurements have been made, the offset is subtracted from each channel and the resultant is compared to the current threshold limit. After this comparison has been made, the ADC value of the 28v and 120v line are passed to the ADC convert function.

7.4.2 ADC Conversion

A simple linear equation was used to convert the measured ADC value to its respective current value. The input voltage from the current sensor signal conditioning is between .2v and 3.2v, which is offset from the referenced 0v and 3.3v. To compensate, the offset will be subtracted from the converted ADC value. The conversion equation looks as follows:

$$(((ADC_VALUE*10)/4096)-(248/4096*10))*1.1$$
 This equation converts the ADC value and the Offset to the respective current values and subtracts them to compensate for the offset. This equation makes it possible to accurately convert between the ADC values measured from the current sensors to the respective current measurement.

7.5 Graphic User Interface

The Master Control Unit uses a LabVIEW Graphic User Interface running on a Microsoft Windows Operating System. The GSAP client interacts with the VR900 gateway through TCP/IP. If a wireless router is used, IEEE 802.3 or 802.11 can be used. The LabVIEW GUI reads data from a log file generated by the GSAP client. The GUI will generate the byte-stream that user will enter into the transmit window of the GSAP client to control the plug.

7.5.1 Receive Data

Most of the work done by the GUI involves reading the log file from the GSAP client. The GSAP client will append the last update to the end of the log file. As seen in Figure 34, the receive function of the GUI is completed by using the timeout case of an event structure. The GUI will open the log file and feed in fifteen lines from the bottom of the log file. The GUI will flip the array, so that the most recent data is on top. Next the array is searched using the MAC Addresses in the Networking table. The parsed data is then placed in an array. The GUI will interpret the parsed data and populate the Table and Configuration tabs of the GUI.



7.5.2 Transmit Data

The GUI will read the settings in the Configuration tab. From these settings, it will inform the user of the byte-stream that needs to be keyed into the “Transmit Window” field of the Device Command tab in the GSAP client. The configuration tab can be seen in Figure 36. The Voltage Available LEDs will display which voltage is available at the input to the NWSP. The user must select enable and then the correct voltage to supply to the end device. The value entered into threshold will be converted into hex. Once the user hits the Update button, the GUI will generate the byte-stream. A dialog box will pop up, which informs the user of the byte-stream that needs to be entered.

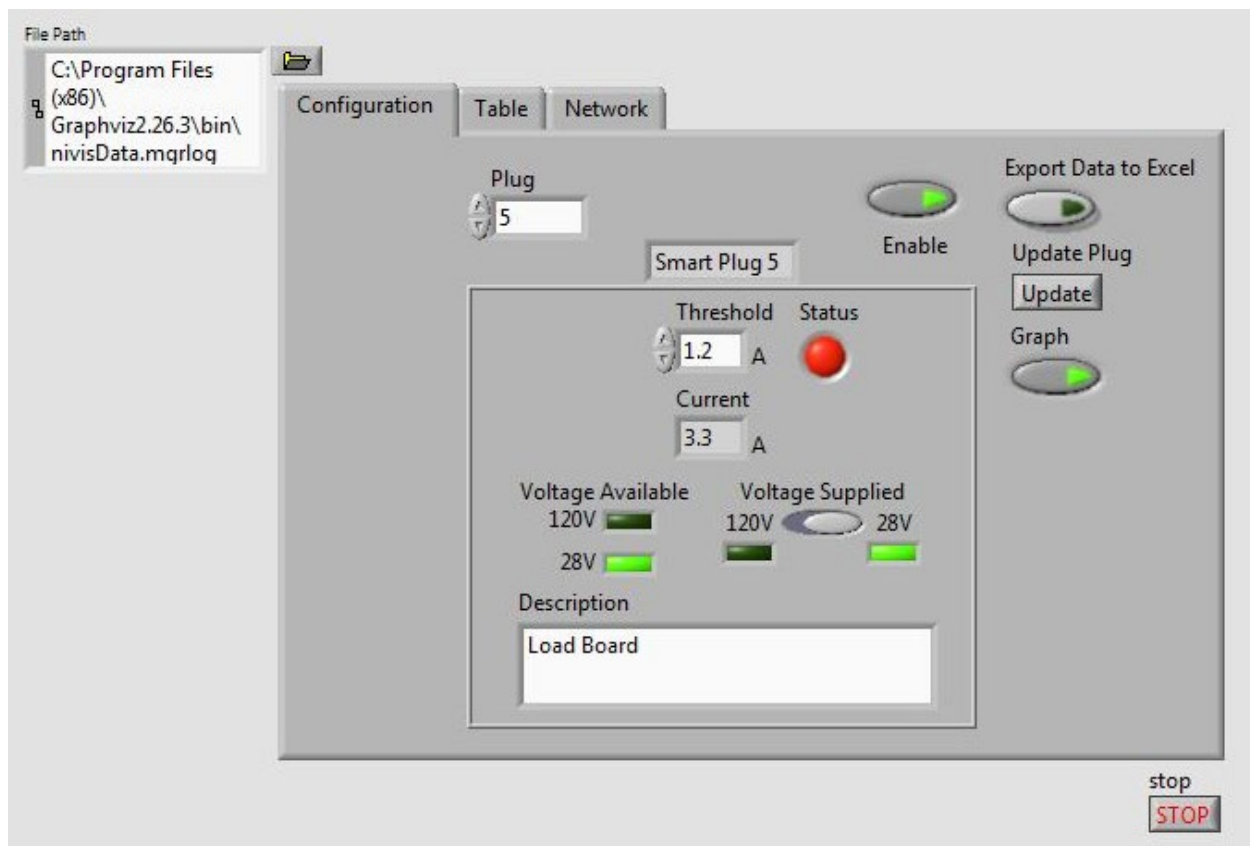


Figure 36: LabVIEW GUI Configuration View



7.5.3 Features

XCLL has added two features to the GUI. The first feature is graphing, which is displayed in Figure 37. Once the user has hit the Graph button, the GUI will display a real-time graph of the current being read by the plug selected in the Configuration tab. If the user hits the Graph button again, the graph will no longer be displayed. The second feature is the ability to export to Microsoft Excel. The data of the plug selected in the Configuration tab will be exported to a comma separated value file, which can be read by Excel.

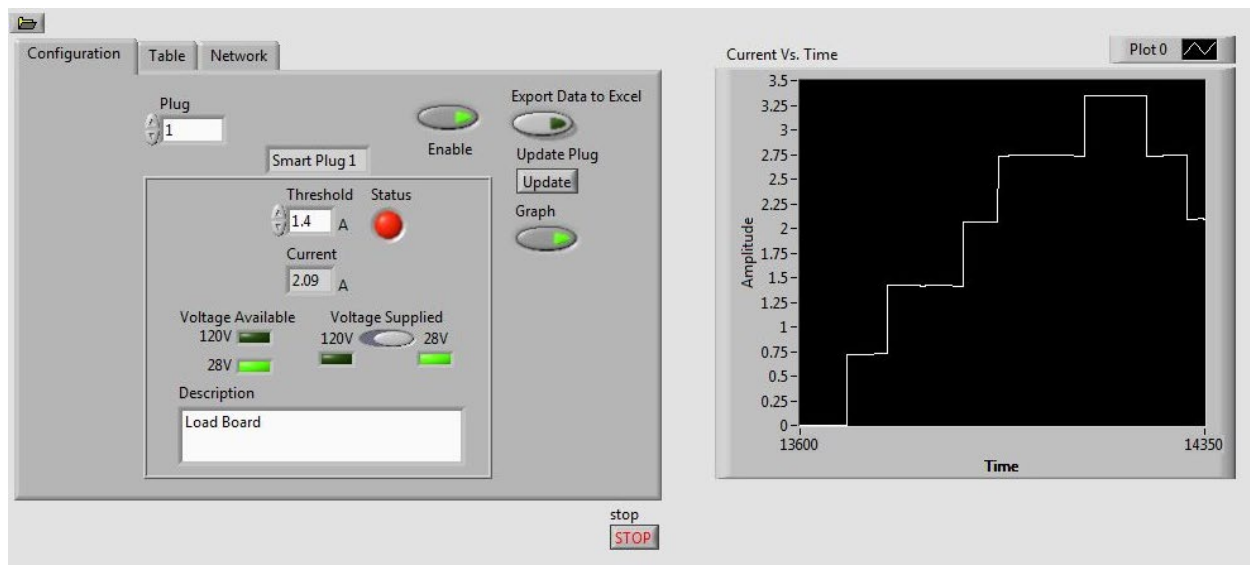


Figure 37: LabVIEW GUI Graphing Feature

7.6 Wireless Communication

The NWSP communicates to the MCU via the VN210 radio. The MSP430 communicates to the VN210 radio through four wire SPI communications. The VN210 is the master and provides the clock rate to the MSP430. The VN210 pulses the “Ready” line on the MSP430 to signal impending communications. The MSP430 responds with a short pulse on the “Wake Up” line to signal the VN210 the processor is ready for communications to proceed. An SPI interrupt handles the receipt and transmittal of data between the MSP430 and the VN210.

The NWSP sends data to the MCU once per second. A timer interrupt is used to maintain this frequency and enter a low power state when communications is not necessary. The timer interrupt fires when an internal counter of the MSP430 reaches a user defined value. This value can be configured by the user using the GSAP interface, but is initialized to 1 Hz. When the interrupt fires, the application flag is set to 1. The main loop polls the application flag. When the application flag is set to 1, the application handler is called and a data packet is sent to the VN210 to be wirelessly transmitted to the MCU.



8.0 Testing

8.1 Test Matrix

XCLL has created a Test Matrix (Table 3) to ensure that crucial tests are performed on the NWSP in order to validate all of its functionality. The row on the top of the Test Matrix (x-axis) describes all the functional requirements that the NWSP must implement as a final product. The column on the left (y-axis) contains all the test cases to be performed on the NWSP in order to validate its functionality. We marked with an “X” the test cases that validate one or more of the functional requirements.

Table 3: Test Matrix

Test	Support for 120V/28V	Real-Time Monitoring	Data Rate	Master Control Unit	Wireless Configuration	Five NWSP Unit Func.
Verification of Sensor Readings (28V)	X	X	X	X	X	
Verification of Sensor Readings (120V)	X	X	X	X	X	
Variable Load Test (28V)	X	X	X	X	X	
Variable Load Test (120V)	X	X	X	X	X	
Verification of Command and Control		X	X	X	X	
Load Test (all 5 devices)						X

8.2 Test Plan

8.2.1 Verification of Sensor Readings (28V)

Description: The NWSP will be tested to make sure we can monitor data in real time and to verify the accuracy of the sensor readings reported to the Master Control Unit.

Procedure:

- Apply 28V or 120V to the input of the NWSP
- Apply a 5A load
- Command the NWSP to turn on
- Wait until the blue LED is flashing
- Using external equipment, measure the current into the unit and voltage drop across the unit
- Collect the current/voltage readings from the MCU



- Verify that the independent current measurement matches the displayed measurement
- Repeat the above steps for the following range: 20-32V or 110-136V
- Command the NWSP off
- Disconnect the input power supply

Pass	Fail
<ul style="list-style-type: none">• Voltage indicated• Current readings match to within .1A• Voltage drop < 1V	<ul style="list-style-type: none">• Voltage not indicated• Current readings are off by more than .1A• Voltage drop > 1V

Results: Passed

8.2.2 Verification of Sensor Readings (120V)

Description: The NWSP will be tested to make sure we can monitor data in real time and to verify the accuracy of the sensor readings reported to the Master Control Unit.

Procedure:

- Apply 28V or 120V to the input of the NWSP
- Apply a 5A load
- Command the NWSP to turn on
- Wait until the blue LED is flashing
- Using external equipment, measure the current into the unit and voltage drop across the unit
- Collect the current/voltage readings from the MCU
- Verify that the independent current measurement matches the displayed measurement
- Repeat the above steps for the following range: 20-32V or 110-136V
- Command the NWSP off
- Disconnect the input power supply

Pass	Fail
<ul style="list-style-type: none">• Voltage indicated• Current readings match to within .1A• Voltage drop < 1V	<ul style="list-style-type: none">• Voltage not indicated• Current readings are off by more than .1A• Voltage drop > 1V

Results: Passed

8.2.3 Variable Load Test (28V)



Description: The NWSP will be tested to monitor its behavior under a varying load. Different loads will be connected to the NWSP while the current and voltage drop are measured directly and monitored through the MCU.

Procedure:

- Apply 28V/120V to the NWSP input
- Apply a .5A load to the NWSP output
- Command the NWSP to turn on
- Wait until the blue LED flashes
- Using external equipment, measure the current into the unit and voltage drop across the unit
- Collect the current/voltage readings from the MCU
- Verify that the independent current measurement matches the displayed measurement
- Repeat the previous steps incrementing the load by .5 A until 5A
- Command the NWSP off
- Disconnect the input power supply

Pass	Fail
<ul style="list-style-type: none">• Current readings match to within .1A• Voltage drop < 1V	<ul style="list-style-type: none">• Current readings do not match to within .1A• Voltage drop > 1V

Results: Passed

8.2.4 Variable Load Test (120V)

Description: The NWSP will be tested to monitor its behavior under a varying load. Different loads will be connected to the NWSP while the current and voltage drop are measured directly and monitored through the MCU.

Procedure:

- Apply 28V/120V to the NWSP input
- Apply a .5A load to the NWSP output
- Command the NWSP to turn on
- Wait until the blue LED flashes
- Using external equipment, measure the current into the unit and voltage drop across the unit
- Collect the current/voltage readings from the MCU
- Verify that the independent current measurement matches the displayed measurement
- Repeat the previous steps incrementing the load by .5 A until 5A
- Command the NWSP off



- Disconnect the input power supply

Pass	Fail
<ul style="list-style-type: none">• Current readings match to within .1A• Voltage drop < 1V	<ul style="list-style-type: none">• Current readings do not match to within .1A• Voltage drop > 1V

Results: Passed

8.2.5 Verification of Command and Control

Description: The command and control functions of the NWSP will be tested.

Procedure:

- Apply 28V to the NWSP input
- Attach a load to the NWSP
- Command the NWSP to turn on
- Wait until the blue LED flashes
- Verify the current and voltage readings on the MCU
- Command the NWSP to turn off
- Verify that the NWSP is off via the current/voltage readings on the MCU
- On the MCU, update the maximum current setting to 3A
- Command the NWSP to turn on
- Apply a load that is less than 3A for a time, then increase the load to 4A and verify that the MCU registers an overcurrent situation.
- On the MCU, disconnect power to the load device
- Remove the load from the NWSP
- Command the NWSP to turn power back on

Pass	Fail
<ul style="list-style-type: none">• Behavior and response of NWSP corresponds to commands	<ul style="list-style-type: none">• Behavior and response of NWSP corresponds to commands

Results: Passed

8.2.6 Five Device Load Test

Description: This test will verify that five NWSP units can operate on the same network and communicate with the MCU. This test will also verify that the MCU can control five NWSP units.



Procedure:

- Apply 28V to the input of five NWSP units
- Attach a load to each NWSP unit
- Command each Smart Plug to turn on
- Wait until the blue LED flashes on all units
- Verify the current and voltage readings on the MCU for all five units
- Command each NWSP to turn off sequentially, verifying the command was executed each time.
- Remove the loads from each NWSP

Pass	Fail
<ul style="list-style-type: none">• All units respond as expected.• MCU properly displays readings for all units	<ul style="list-style-type: none">• All units do not respond as expected.• MCU does not properly displays readings for all units

Results: Passed



9.0 Problems & Solutions

9.1 Technical

9.1.1 Current Sensor Conversion Error

When testing the actual input versus output characteristics of our Alpha design's current sensor conversion, two problems were noted. The expected versus actual current measurements were not identical as our theoretical design was otherwise able to produce. The results of the Alpha design current sense testing are shown in a graphical format in Figure 38.

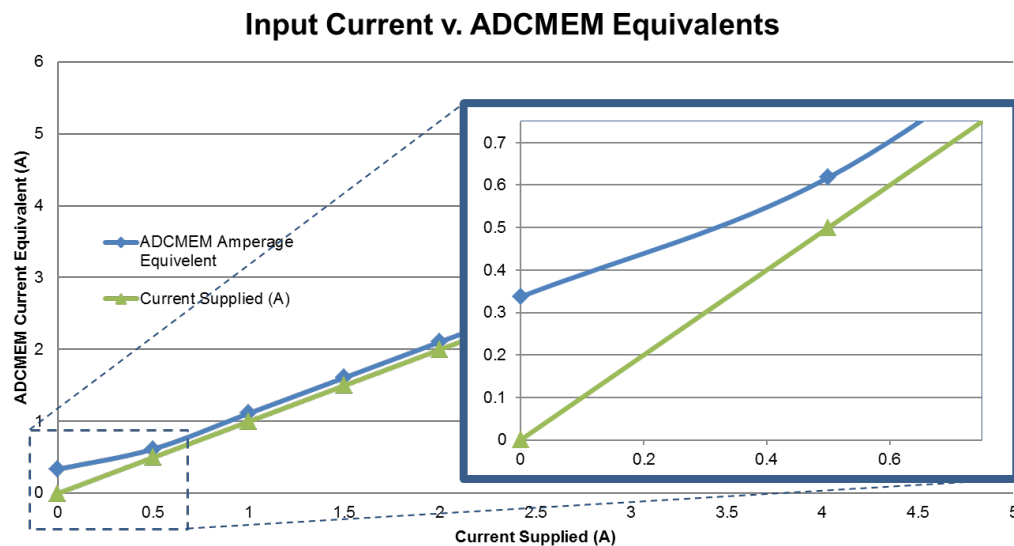


Figure 38: Alpha Design Results of Current Sensor Conversion

A consistent average difference of 0.08A was noted throughout the 0.5A to 5A range of measurements, with a larger difference was noted from the 0 to 0.4A range of measurements. After troubleshooting the problem, two sources of the problem were identified. The first problem is that the current sensor is sensitive to changes in the voltage supply reference. Ideally, the voltage supplied to Vcc of the current sensor is 5V; however, the boost converter that is powering the current sensor does not produce an exact output of 5V. Instead the boost converter produces an output larger than 5V, such as 5.038V. When the boost converter output is 5.038V, this results in a consistent offset equating to 0.25A at the output of the current sensor. The solution to the first problem is to dynamically calibrate the ADC pin capturing the current sensed converted data such that a reverse offset can be applied to the captured data to negate the offset caused by the difference in the boost converter's output of 5V. Figure 39 shows an example of the consistent offset equivalent captured at the output of the current sensor in isolation.

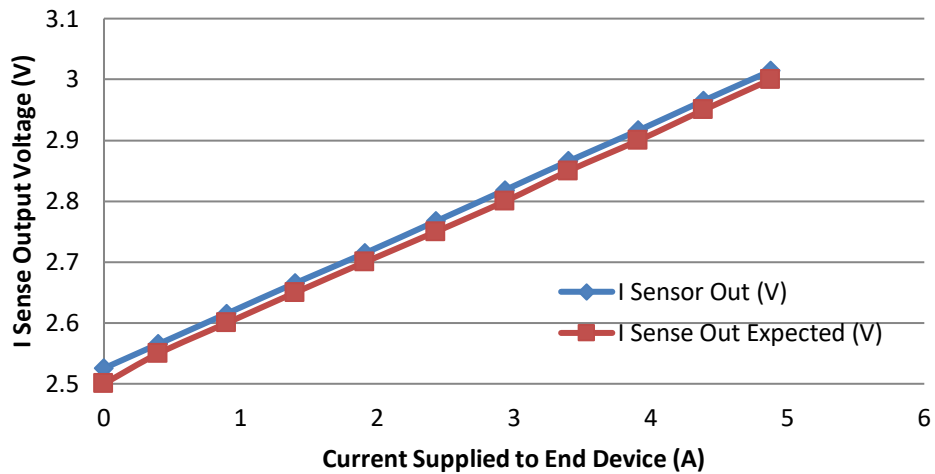


Figure 39: Current Sensor Output Offset Equivalent Results

The second problem was a result of lacking understanding of the LM7301 operation amplifier’s limitations. The datasheet of this operational amplifier indicates a minimum voltage output swing of 112mV. As a result of this output swing, the signal conditioning would never be able to output the current equivalent of any measurements below 0.33A. Considering that the output range of the differential amplifier is user defined, the output range required modification of 0V to 3.3V to a range within the minimum and maximum reference or reference voltages. Both the low and high end of potential achieved current equivalent values resulted in the Bravo solution of a signal conditioned output of 0.2V to 3.2V. The Bravo solution resulted in an average difference of 9mA from the expected current value. Figure 40 shows the Bravo solution’s signal conditioning results in isolation from the remainder of the circuit.

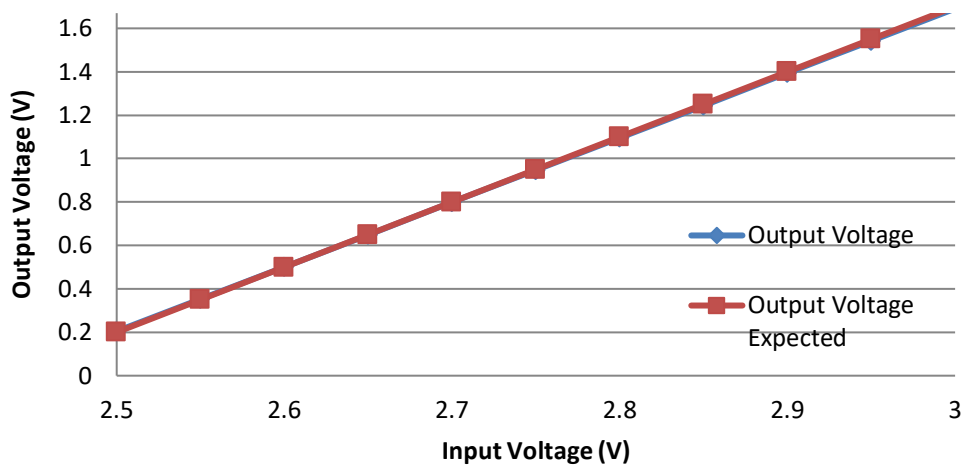


Figure 40: Bravo Design Signal Conditioning Solution Results



9.1.2 Wireless Communication Overhead

Originally, XCLL thought that the LabVIEW GUI running on the MCU would be able to directly communicate with a NWSP unit through the VR900 gateway. However, this is not the case. To communicate with the VR900, the MCU must use the GSAP client. The GSAP client will generate a log file, which contains all the information sent from every NWSP. The LabVIEW GUI will read the log file from the bottom to get updated information from the NWSP. In order to transmit data, the user must use the GSAP client. XCLL communicated with NASA and came up with a solution to transmitting data to the NWSP. The user will configure the plug, then hit the Update button in the GUI. The user is then directed to the Transmit Window of the GSAP client. The user will enter in the byte-stream into the transmit window of the GSAP client. This will send the command to the NWSP and update the settings of the NWSP.



10.0 Conclusions

The NASA Wireless Smart Plug was an exciting and interesting project for XCLL to cut its teeth on. We had a number of obstacles that covered the gamut of issues typically encountered by a small company and this allowed us to challenge ourselves in various ways and discover each other's strength. We began by creating a project plan for the design and implementation of the NWSP and proposing it to NASA. Upon its acceptance, we followed it from board layout through two revisions into testing and, finally, to delivery.

We had planned for three hardware revisions but, in the end, through long and intense planning on the first revision, we were able to forego the final revision. We experienced several challenges in the implementation of the hardware, some of which were already covered in more detail in this document. Bringing the board down to as small a size as possible was an interesting endeavor that kept us on the drawing board a long time and encouraged us to think outside the box and research parts and ideas we would never have before. Implementing the Nivis radio on to our board posed an entirely different problem that was no less challenging. The Nivis implementation was a challenge due to a lack of resources and a difficulty in getting help from the manufacturer. In the end, Dr. Ray Wagner at NASA was able to connect us to the resources Nivis gave them and this was crucial in fast tracking our implementation and finalization of our last revision.

Though the NWSP was challenging, we met all functional and performance requirements. This was due in no small part to the fantastic people we had behind us. Dr. Joseph Morgan and Dr. Jay Porter guided us deftly through the hazards of project management and board design. Dr. Ray Wagner and Dr. Kristina Rojdev at NASA were instrumental in clarifying some of the specifics of the project and were always quick to respond to our questions. Finally, Dr. Scott Howe of NASA, our sponsor, ably guided us through NASA's milestones and checkpoints throughout the entire project. With their collective guidance, XCLL has learned much about project management, product innovation, and bringing a product from concept to prototype and this knowledge will aid us in future projects.



Appendices

Appendix A: System Design Process



SYSTEM DESIGN PROCESS

NASA WIRELESS SMART PLUG (NWSP) *Experimental Control Logic Laboratory (XCLL)*

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National Aeronautics and Space Administration (NASA)



Problem Statement

High-Level Problem Statement

The National Aeronautics and Space Administration (NASA) requires the control and monitoring of DC power distribution and utilization of applicable systems for deep space exploration on NASA's Deep Space Habitat (DSH).

Background

Deep space missions will be characterized by continually changing demands on the power systems of a habitat's environment. Automated monitoring and manual control of the load on the power system must be possible to offload the astronauts from excessive power management overhead, yet still provide an overriding capability to sense and regulate power consumption throughout the habitat. The ability to disconnect any device which exceeds its expected load consumption automatically or to shed load based on a prioritized process is crucial to managing the habitat's power system over extended periods of time needed for deep space missions. Having the ability to database and control all power consumption from anywhere within the habitat via a wireless mesh network will provide adaptability for the crew. Currently, no system exists that can meet these demanding needs set forth by the Advanced Exploration Systems (AES) Habitation Systems Deep Space Habitat project. This lack of technology has been addressed by the eXploration Habitat (X-Hab) 2013 Academic Innovation Challenge. In this solicitation, the ASE has identified various technological capabilities that it envisions for the DSH, but has not yet developed.

Solution

The solution will be the development of the NASA Wireless Smart Plug (NWSP).

Concept of Operation

The NASA Wireless Smart Plug (NWSP) delivered by the Texas A&M University Electronics Engineering Technology Capstone and Mobile Integrated Solutions Laboratory (MISL) is a proof of concept prototype that will extend the mock-up version of the Deep Space Habitat's capabilities to monitor and control power usage while on Earth. This version of the NWSP will be used for testing and mock-up evaluation purposes only, and is to be removed before flight and actual implementation in space.



Functional Requirements

As specified in the original contract solicitation, several key functional requirements have been outlined for the NASA Wireless Smart Plug. These requirements have been set to fully define the scope of the NWSP project.

Power Control

- Support for 120V/28V DC
The NWSP will be able to run on 120V and/or 28V DC input whether one or both are present.
- Near real-time monitoring/control
The NWSP will be able to provide as near real-time as possible control and monitoring of current and voltage.
- Fail safe
The NWSP will be able to fail safely in the event of failure. Safely is currently understood as failing open, whereby, the end-device ceases to operate as if disconnected from the DSH.
- Windows based master control unit
The NWSP will provide data to a Windows-based GUI for user interactivity and monitoring.

Communications

- Wireless configuration, control, monitoring and reporting
The NWSP system will be controlled and monitored wirelessly via the master control unit.
- Data rate: 1 sample/second
The NWSP embedded software will be able to sample the current at least once per second and send this data to the master control unit.
- Use a Nivis VN210 radio
The NWSP will use a Nivis VN210 radio as its wireless radio peripheral to integrate with other NASA systems.
- Support a Nivis VR900 router Standards: UART, ISA 100.11a
The NWSP will be able to communicate with the master control unit through the Nivis VR900 router via SPI and ISA 100.11a standards.

Form Factor & Fit

- Small form factor
The NWSP will fit into the smallest practical package to limit its stowage footprint.
- Cannon-type connector
The NWSP will be able to input and output via 5-pin Cannon-type connectors.
- Integration with DSH
The NWSP system will be able to integrate and operate within the DSH system.
- Deliver five NWSP units for evaluation
Five operational test units will be delivered for installation and evaluation on the DSH mockup.



Conceptual Block Diagram

The NWSP will be a physical unit and require the execution of a companion GUI. A five-pin connector will serve as the input and output terminal configuration of the NWSP, whereby 120V-DC and/or 28V-DC will be expected on the input terminal, and only 120V-DC or 28V-DC will be available on the output terminal. The monitoring and control of measurements and parameters will be wirelessly managed through the interaction of a Nivis VersaNode 210 radio and Nivis VersaRouter 900 gateway using the ISA100.11a standard. The IEEE 802.15.4 standard is the physical layer and media access control for low-rate wireless personal area networks (LR-WPANS). *Because the monitoring and control is critical to an end device's condition and health, a minimum of 1 sample per second data rate must be maintained between the NWSP and the client software. The client software is a LabVIEW executable running on a Windows operating system (Win XP OS or beyond), and must be configurable to monitor and control multiple NWSP devices simultaneously.

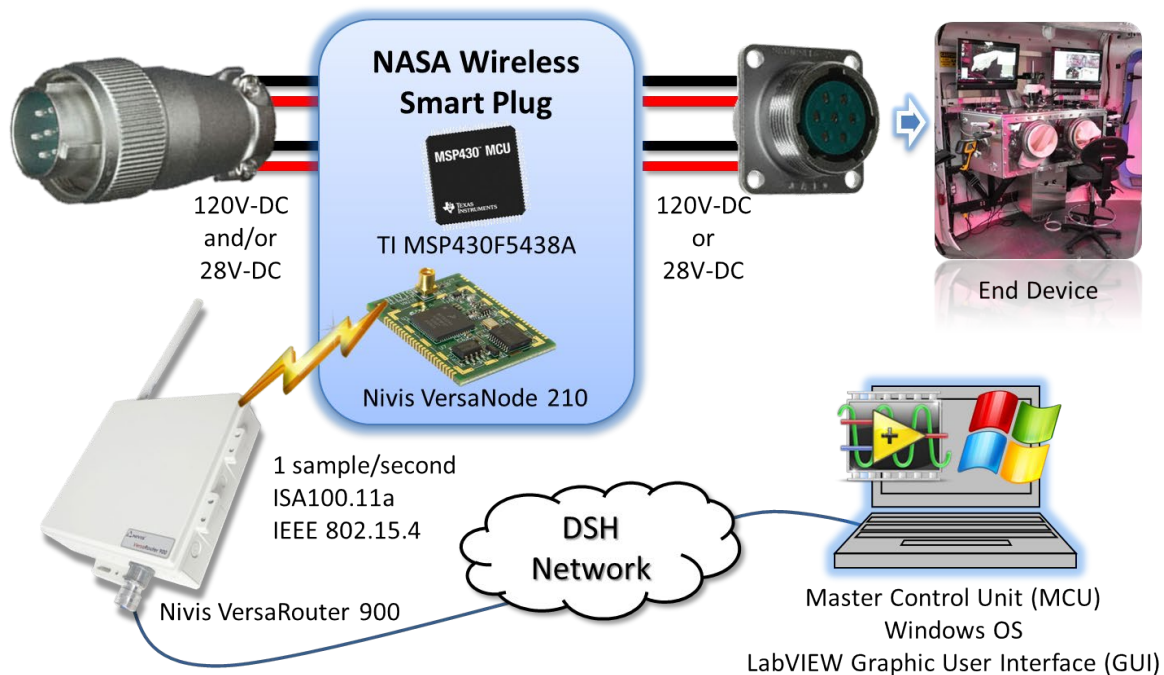


Figure 1. System Architecture in Pictorial Diagram Format



Performance Specifications

Voltage Source

The NWSP will be able to connect to a 28 VDC and/or 120 VDC source. If both sources are present, the NWSP will default to the 28 VDC for internal power consumption.

Monitor Current

The NWSP will be able to monitor current up to 5 A with an accuracy of at least $\pm 3\%$ of full scale.

Control Power

The NWSP will be able to set and control current from 0 to 5 A in 0.1 A increments. If the current flowing through the NWSP ever exceeds the set point, the load will be disconnected.

Data Collection and Response

To allow for near real-time monitoring, the NWSP will be able to transmit at least 1 sample per second. Furthermore, loads exceeding the set current limit will be disconnected from power within 3 seconds of continual over-current.

User Interface

NWSP configuration and monitoring will be done remotely using a LabVIEW GUI. This standalone GUI will run on a Windows XP based master computer and allow users to monitor NWSPs and set control routines. The ability to add or remove multiple NWSP units from the GUI will be made available through front end controls.

Networking and Communications

In order to integrate into the current DSH wireless mesh network, the NWSP will use the Nivis VersaNode 210 wireless radio to communicate with the master control unit through the Nivis VersaRouter 900 gateway located onboard the DSH. This requires that the NWSP implement the ISA100.11a standard.

Size

The NWSP will be no larger than a typical AC to DC converter.

Failure Recovery

In the event of failure, the NWSP must maintain safety. This safety measure is also taken if the NWSP loses its connection with the master control for prolonged periods of time.

Power Consumption

The NWSP will act as a low power node when integrated into the DHS network. The Texas Instruments MSP430F5438 microcontroller will be used as its central control intelligence in order to minimize power requirements.

Deliverables

There will be at least 5 NWSP units delivered and installed for testing and validation in the NASA DSH.



Technology Survey Assessment

The technical survey assessments are used when considering components for the NWSP. These are for critical used components that must be researched to find the most appropriate manufacturer and model suited for the functionality needed in this device.

Current Sensor

The ACS714 hall-effect linear current sensor was selected due to its low power requirements and it will not load down our circuit. It has the ability to with stand the 5A required by the Deep Space Habitat and is in a very small package.

Table 1: Technical Survey – Current Sensor

Device	Type	Pros	Cons	Cost
*ACS714	Hall Effect	Small package Negligible power dissipation Single 5V supply 40A Range	Requires offset, gain, and low pass filter	
CMS2015	Magneto Resistive Current Sensor	Electrical Isolation 15A Range Small package	Bipolar 15V supply Relatively expensive	
VCS1625	High Precision Shunt Resistor	Very small package Non inductive, non-capacitive No ringing	Power Dissipation Heat	

Note: * denotes preferred solution component



28V to 3.3V Step-Down

The NWSP must be able to operate when either 120 V-DC or 28 V-DC is present at the wall. The 28V will be stepped down to 3.3V which will supply the NWSP's internal circuitry. A TEN8-2410WI DC-DC converter will be used to step down the 28V to 3.3V. This voltage regulator has a fixed output and will operate with the 28V source from the Deep Space Habitat.

Table 3: Technical Survey – DC-DC Converter

Device	Type	Pros	Cons	Cost
667-ERA-8AHD300V	Voltage Divider	Inexpensive Small package	Power dissipation Heat Fluctuations in output	
MC33363B	High Voltage Switching Regulator	Small Package Inexpensive Negligible heat	Noisy Large current draw of >1A Requires 40V supply	
*TEN8-2410WI	DC-DC Converter	Efficiency of 80%+	Package size Expensive	



DC Solid State Relay

The NASA Wireless Smart Plug must not only sense current, but autonomously disconnect power. The Crydom D2D12 solid-state relay will accomplish this task. This relay can operate within the 28 V-DC or 120V-DC required by the Deep Space Habitat. It can be controlled from a pin on the MSP430 to disconnect the load from the source. This relay is much more expensive than other solutions, but offers isolation and a much longer life span than a mechanical relay.

Table 4: Technical Survey – DC Solid State Relay

Device	Type	Pros	Cons	Cost
Micropac 53238	Optocoupled Power Mosfet	Small package Operates up to 125V Can handle 5A continuous Radiation tolerant Can be controlled with pin from MSP430	Heat Power dissipation Long lead time	
AV3712613	Relay	Can be controlled with pin from MSP430 Inexpensive	Mechanical Power dissipation	
*D2D12	High Power DC Solid-State Relay	Can handle up to 20A continuous Low control voltage of 3.5V Can be controlled with pin from MSP430	Large package Expensive	



Physical Connector

The Deep Space Habitat has a requirement for a 5 (or more) pin quarter turn Cannon-type connector. The smart plug must be compatible with NASA’s existing standard. The SRCN2A16-7S can operate at 120V and with stand the 5A current from the DSH.

Table 5: Technical Survey – Physical Connector

Device	Manufacturer	Pros	Cons	Cost
HBL2513	Hubbell	Operates up to 208V Can handle 20A continuous Fits NASA requirement Available locally Locking	Not quarter turn	
Veam GRH	Cannon	Operates up to 250V Can handle 15A continuous Quarter turn locking High shock and vibration resistance	Not available locally	
*SRCN2A16-7S	JAE Electronics	Operates up to 350V Can handle 10A continuous	Solder cup termination	



Microcontroller

The microcontroller for this project must have a Serial Peripheral Interface (SPI) and/or Universal Asynchronous Receiver/Transmitter (UART) to communicate with the Nivis VersaNode 210 radios. The microcontroller must have I/O pins available for the current sensors, voltage sensors, and switch enables. Precision at or beyond 0.1A increments for a 0 to 5A range must be available for precision calculations of measured values. The clock rate must be 1 sample per second requirement such that a measurement, calculation, and transmission of data occur within this limit. Table 6.6 shows the microcontrollers we considered for the NWSP.

Table 6: Technical Survey – Microcontroller

Manufacturer	Microcontroller	Pros	Cons	Price per Unit
*Texas Instruments	MSP430F5438A	Large memory size of 256KB Low operating voltage (1.8 ~ 3.6V)	High cost	
Microchip	PIC24FJ128GA110	Cost	Less precise A/D convertor of 10 bits	
Freescale	MC56F8257VLH	Fast processing speed of 60MHz	No UART communication Higher supply voltage necessary	



Functional Block Diagram

The Conceptual Block Diagram in Figure 1 provides an illustrative representation of the NWSP operation and interface methodology to the DSH and MCU. To explore these processes in more detail, the outline of specific hardware and signal types internal to the NWSP are represented in the Functional Block Diagram Overview in Figure 2. Each block representing a major internal process is color coded according to their block breakdowns in the following sections.

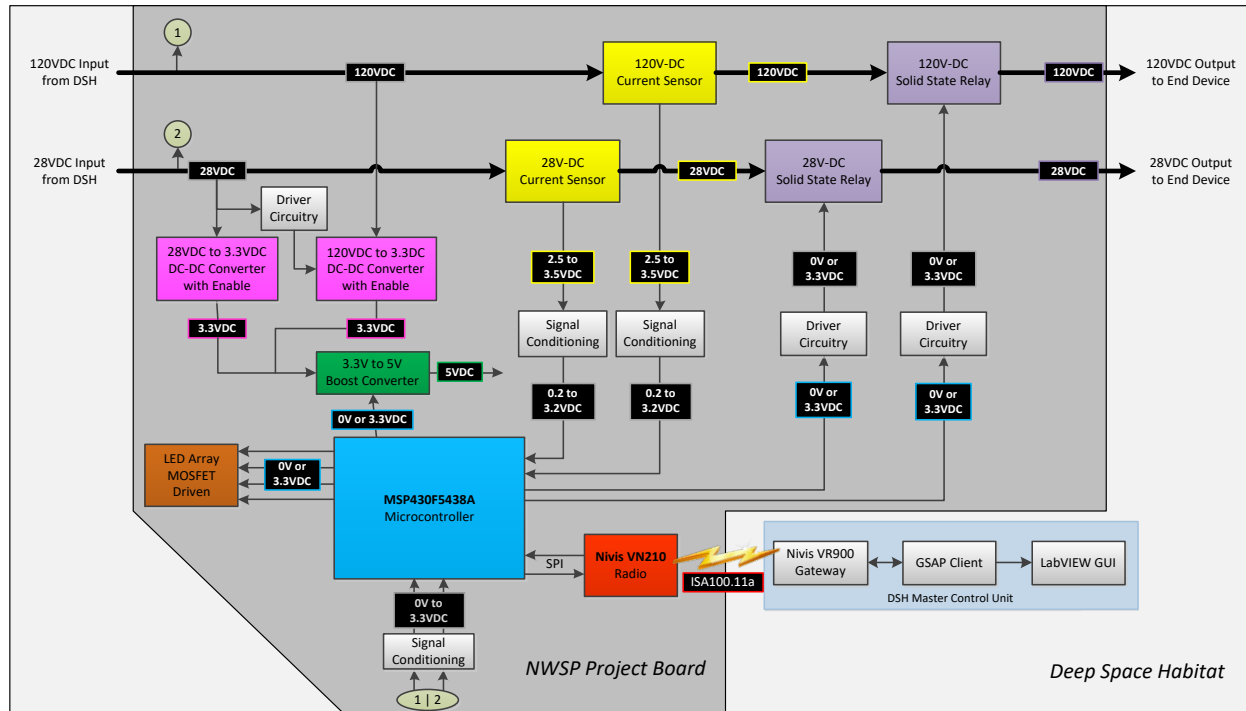


Figure 2: Functional Block Diagram Overview

The DSH will be sourcing either or both 28V-DC and 120V-DC. Due to the possibility that both voltage sources will be available, the NWSP must only utilize a single supply voltage to power internal NWSP circuitry. The 120V-DC step-down converter is to be disabled in the case that both voltage sources are available. As compared to the 28V-DC power line, the 120V-DC DC-DC converter is disabled given that more power is dissipated through step down regulation process to power subsequent internal NWSP circuitry.



Microcontroller Interfaced with Radio Design

To achieve communication between the MSP430 microcontroller and Nivis VN210 radio, the ability to communicate by SPI or UART is made available to the user. SPI mode has been selected for the NWSP application based on the versioning and development release required by NASA. Figure 3 illustrates the connection scheme of the SPI interface format.

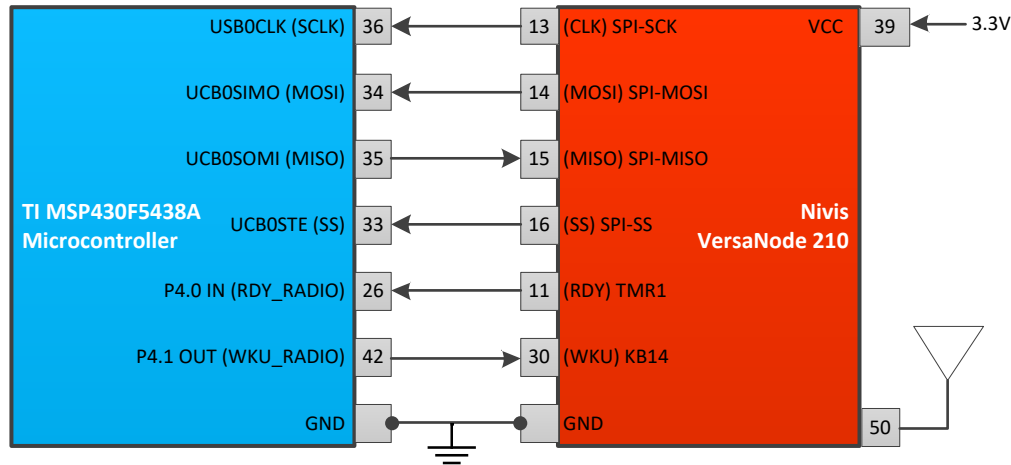


Figure 3: Microcontroller Interfaced with Radio Block Diagram

The Nivis VN210 has the option of utilizing the onboard SMT antenna connector for wireless communication, or, alternatively, using a custom or external antenna through pin contact 50. To initiate communication, the bus master (VN210) first configures the clock, using a frequency less than or equal to the maximum frequency the slave (MSP430 microcontroller) device supports. The master then transmits the appropriate chip select bit for the desired chip to a logic level 0 (chip select line is active low). If a waiting period is required, the master must wait for at least that period of time before starting to issue clock cycles. During each SPI clock cycle, a full duplex data transmission occurs. The master sends a bit on the MOSI line, and the slave reads it from that same line, while the slave sends a bit on the MISO line, and the master reads it from that same line.

Voltage Regulation and Ground Isolation for Internal Circuitry Design

To efficiently power the internal circuitry of the NWSP, the load line voltages must be utilized without significantly impacting the power available to the end-device. Given the power budget of the NWSP components, using highly efficient DC-DC converters will prevent potential impactful losses. Figure 4 shows the Voltage Regulation Block Diagram focused section of the Functional Block Diagram.

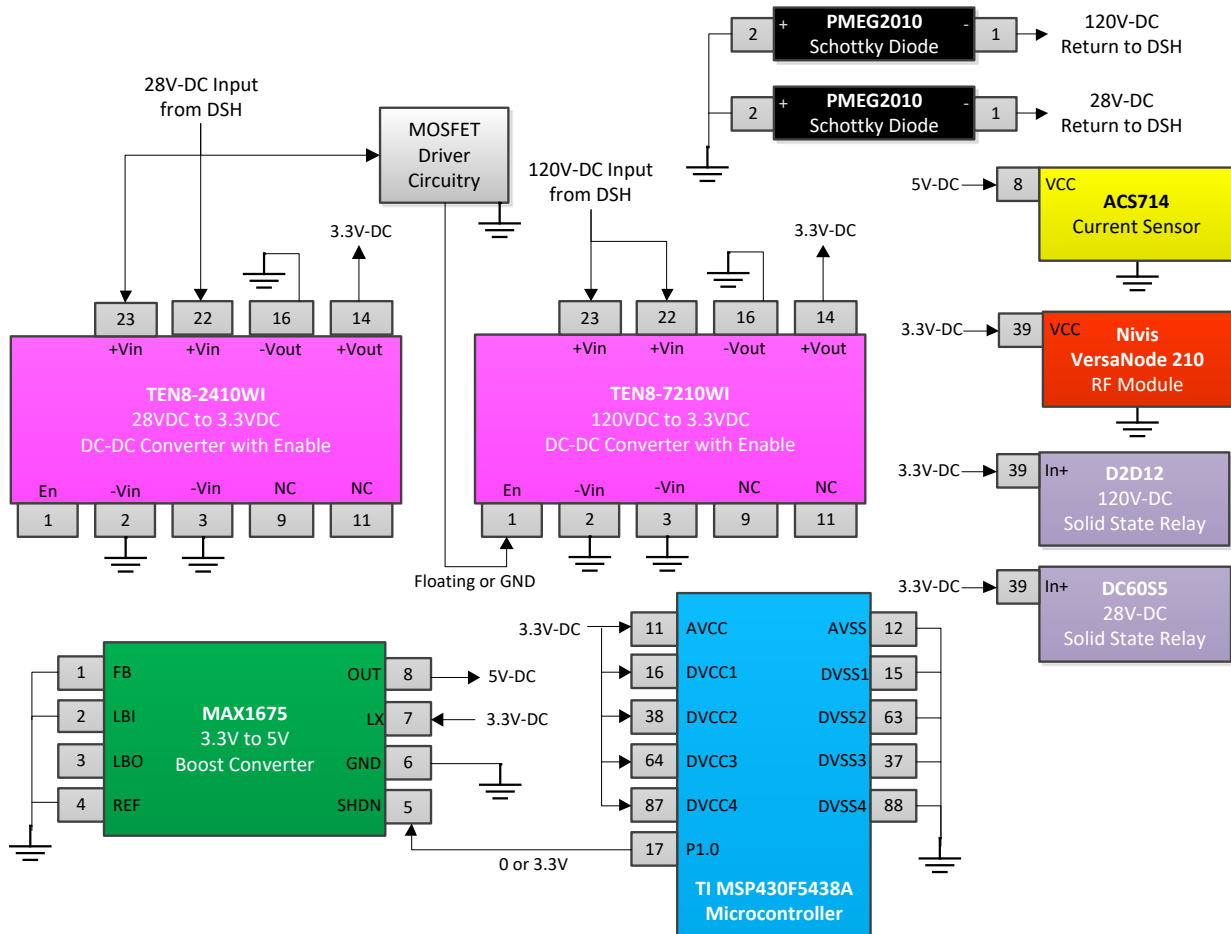


Figure 4: Voltage Regulation and Ground Isolation Block Diagram

Major components to be powered include the TI MSP430 microcontroller, the Nivis VN210, two current sense modules, and two DC solid state relays. The TEN8-2410WI and TEN8-7210WI both supply 3.3V-DC for the internal circuitry's components, whereby, the DSH's output of 28VDC and 120VDC are regulated respectively. The solution for the 120VDC to 28VDC regulation must include an enable low option, such that when the 28VDC source is present, the 120VDC regulation is disabled. A boost converter is used to step-up 3.3V to 5V in order to power the current sensors and the operational amplifiers used in the signal conditioning and driver circuits. The NWSP is not to act as the common ground of the 28VDC and 120VDC DSH supplies, thus a Schottky diode is used to isolate the NWSPs from the returns of both DSH voltage supplies. The DSH voltage supplies are only common at the solar panel array power source.

Current Sense and Conversion Design

In order to prompt the user to disconnect in the case of out of range current measurement detection, the TI MSP430 microcontroller must be able to precisely convert the analog output of the ACS714 current sense module to a digitally interpretable value. Figure 5 shows the connection scheme of the Current Sense and Conversion Design.

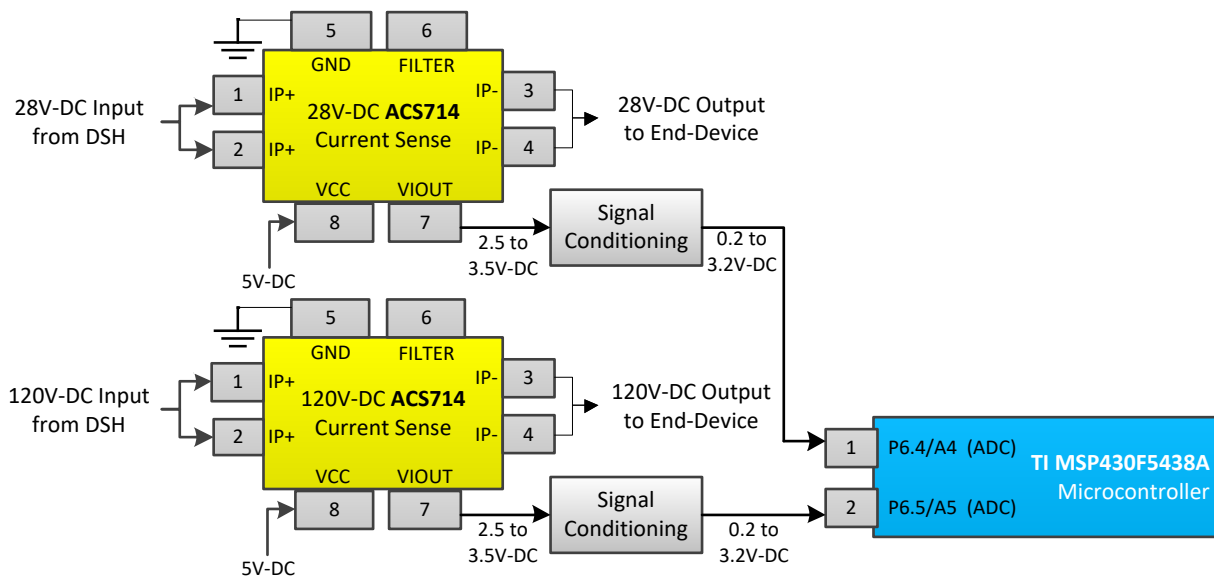


Figure 5: Current Sense and Conversion Block Diagram

Two independent current sense modules for each input voltage will require the same signal conditioning between the output voltage paths and the microcontrollers ADC inputs. The typical ADC signal conditioning process consists of an offset, gain, and anti-aliased filtering of the raw analog voltage. Given the 0 to 10A current range of interest on the ACS714 module equates to a 2.5V to 3.5V range output, the raw analog signal must be offset by 2.3V, applied a gain of 3.2V, and low pass filtered through a differential amplifier and current sensor's filter pin.

Relay Control Design

The DC solid state relays are used to connect and disconnect the output from the DSH to the end-device. When the user is prompted to disconnect the end-device due to the current threshold being exceeded, the relays must be configured appropriately as a part of the command message at the MCU. Figure 6 shows the connection scheme of the Relay Control Design.

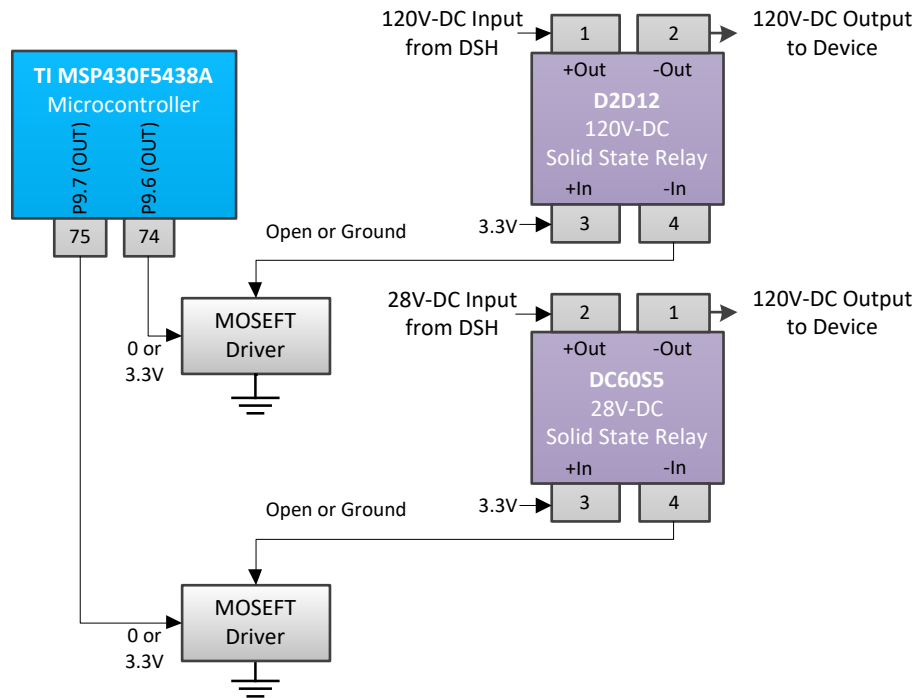


Figure 6: Relay Control Block Diagram

The driver circuit for the DC solid state relay will consist of an n-channel enhancement mode MOSFET circuit gated on or off by the MSP430. The MOSFET's gate will be connected to output of the relay's control terminal, such that when the MOSFET is gated off, the relay is opened, and the end-device does not receive power. When the MOSFET is gated on, the output of the relay's control terminal is shorted to ground, completing the circuit, and closes the relay to enable power to the end-device.

Voltage Measurement Design

In addition to measuring the current draw of the end-device, the NWSP will be equipped with the ability to detect the voltage at the input of the NWSP. Figure 7 depicts the connection scheme of the Voltage Detection Design.

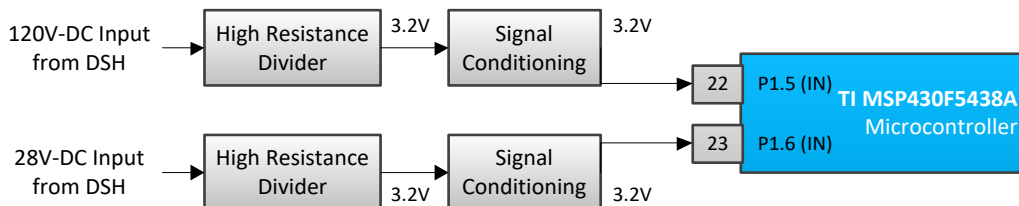


Figure 7: Voltage Measurement Block Diagram



To ensure the end-device is receiving either 120V-DC or 28V-DC, this monitoring feature is to be used as a multi-purpose indicator. Indications as to whether the DSH is actually sourcing 120V-DC and/or 28V-DC or if the solid-state relay controlling these power lines are open or closed. The voltage divider circuit will be drawing power continuously, thus, the resistors selected must be of high magnitude in value (i.e. mega ohms or greater) to reduce current draw. The power consumed must be negligible to the power profile of the NWSP's internal circuitry. The unity gain buffer's high input resistance ensures the voltage transferred from the voltage divider circuit is reduced to a low input impedance level for the MSP430's digital I/O pin.

Light Emitting Diode Indicator Design

To locally indicate the status of the NWSP, an array of light emitting diodes (LEDs) are used to indicate specific connection states and warnings. This local indication will enable the user to visually identify immediate information without having to reference the graphic user interface. Figure 8 depicts the connection scheme of the LED indicator design.

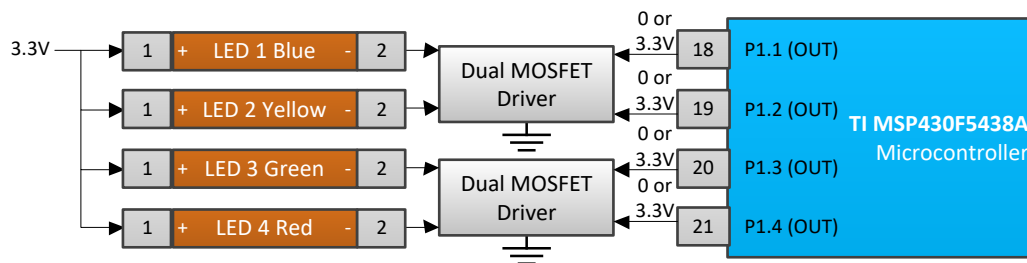


Figure 8: Light Emitting Diode Indicator Block Diagram

The LEDs' cathodes can be held in two states, floating or shorted to ground. By default, the LEDs will be floating, and thus remain in the off state while the microcontroller is sourcing a low, 0V signal. When the microcontroller outputs a high, 3.3V signal to the gate of the MOSFET, the LED's cathode, connected to drain, will short to ground through the MOSFET's source connected to ground. The blue LED is only on, and flashes at an on/off rate of 1 second when the NWSP is connected to the DSH network and transmitting. The yellow LED will be the first LED to turn on when attempting to initialize and is disconnected from the DSH network. The yellow LED will remain solid until the NWSP is connected to the DSH network. The green LED indicates the NWSP is connected to the network, but not transmitting. The red LED indicates that the current threshold configured on the NWSP has been exceeded, thus prompting that the user must decide whether to disconnect the NWSP from the end-device.



Sensor Characterization

The MCU must be able to display the current draw of an end-device; therefore, understanding the process of digitizing and sensing current is critical to the operation of the NWSP. Due to the wireless communications that exist between the NWSP and the MCU, understanding the packet structure is required for appropriate conversion to port into the LabVIEW executable GUI. These two processes will be the primary operations analyzed at the NWSP's.

Current Sense Conversion

The current sensor must be accurate to within 100mA. The ACS714 hall-effect linear current sensor can accomplish this without loading down our power line due to the low internal conductor resistance of 1.2m Ω . Figure 9 shows the current range of which the ACS714 can output an equivalent voltage for when the supply voltage is 5V.

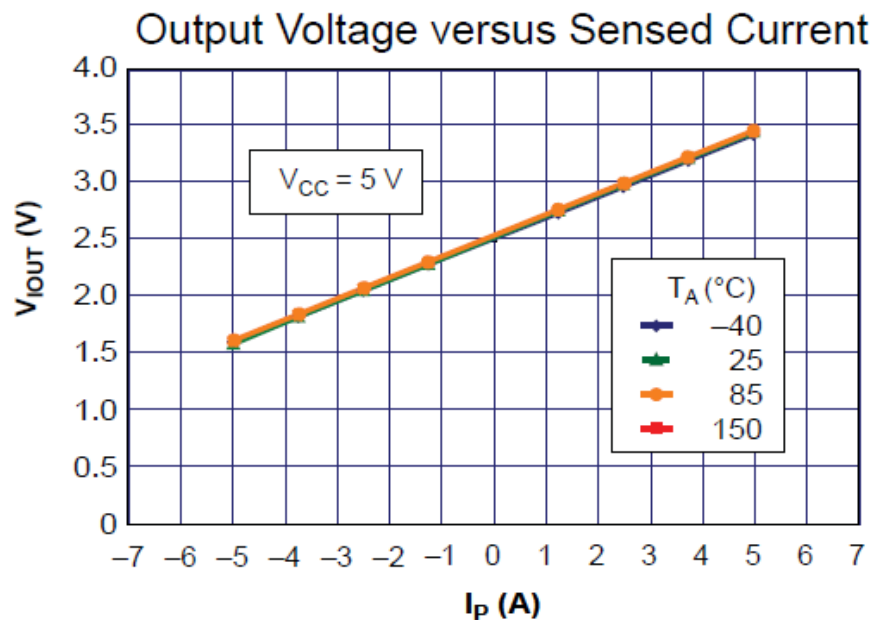


Figure 9: Current Sensor Characterization Graphed

This sensor uses the hall-effect to detect fluctuation in the magnetic field as the current changes. The sensor will output a linear voltage proportional to the current with an offset of +2.5V. The output voltage will change at a rate of 185mV/A. The output of the ACS714 will ultimately be connected to an ADC pin on the MSP430 post signal conditioning.

Signal Conditioning

To apply an offset and gain to the voltage output proportional to current sensed, an operational amplifier must be used to amplify the difference between two voltages. This will result in an operational amplifier circuit equivalent to a subtractor. This type of operational amplifier circuit is commonly known as a Differential Amplifier configuration as shown in Figure 10.

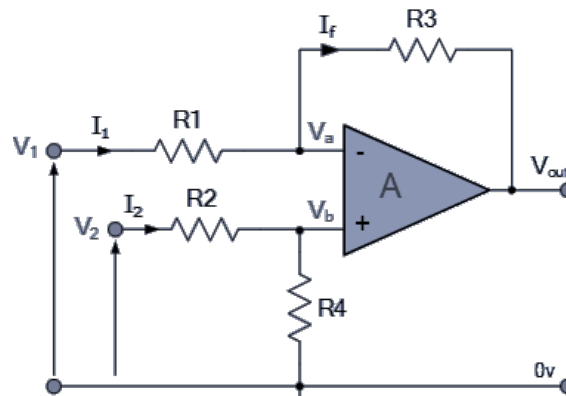


Figure 10. Differential Amplifier Configuration

By connecting each input to ground, and solving for the output voltage, the transfer function for a Differential Amplifier circuit is given as:

$$V_{out} = -V_1 * \left(\frac{R_3}{R_1}\right) - V_2 * \left(\frac{R_4}{R_2+R_4}\right) * \left(\frac{R_1+R_3}{R_1}\right)$$

If input V1 is higher than input V2 the output voltage sum will be negative, and if V2 is higher than V1, the output voltage sum will be positive. By adding more resistors in parallel with the input resistors R1 and R3, the resultant circuit can be made to either "Add" or "Subtract" the voltages applied to their respective inputs.

Analog to Digital Conversion

The resolution of the converter indicates the number of discrete values it can produce over the range of analog values. The values are usually stored electronically in binary form, so the resolution is usually expressed in bits. In consequence, the number of discrete values available, or "levels", is a power of two. For example, an ADC with a resolution of 12 bits can encode an analog input to one in 4096 different levels, since $2^{12} = 4096$. The values can represent the ranges from 0 to 4095 (i.e. unsigned integer) or from -2048 to 2047 (i.e. signed integer), depending on the application.

Resolution can also be defined electrically, and expressed in volts. The minimum change in voltage required to guarantee a change in the output code level is called the least significant bit (LSB) voltage. The resolution Q of the ADC is equal to the LSB voltage. The voltage resolution of an ADC is equal to its overall voltage measurement range divided by the number of discrete values:

$$Q = \frac{E_{FSR}}{2^M - 1}$$

where M is the ADC's resolution in bits and EFSR is the full scale voltage range (also called 'span'). EFSR is given by:

$$E_{FSR} = V_{RefHi} - V_{RefLow}$$

where V_{RefHi} and V_{RefLow} are the upper and lower extremes, respectively, of the voltages that can be coded.



Normally, the number of voltage intervals is given by

$$N = 2^M - 1$$

where M is the ADC's resolution in bits.

That is, one voltage interval is assigned in between two consecutive code levels.

Using the known equations, XCLL has calculated the resolution of the NWSP as follows:

- Full scale measurement range = 0 to 3.3 volts
- ADC resolution is 12 bits: $2^{12} - 1 = 4096 - 1 = 4095$ quantization levels (codes)
- ADC voltage resolution, $Q = (3.3 \text{ V} - 0 \text{ V}) / 4095 = 3.3 \text{ V} / 4095 \approx 806 \text{ uV}$.

ISA-100.11a Wireless Standard

This standard uses the OSI layer description methodology to define protocol suite specifications, in addition to specification for the functions of security, management, gateway, and provisioning for an industrial wireless network. The protocol layers supported are the physical layer (PhL), data link layer (DL), network layer (NL), transport layer (TL), and application layer (AL) as show in the reference model of Figure 11.

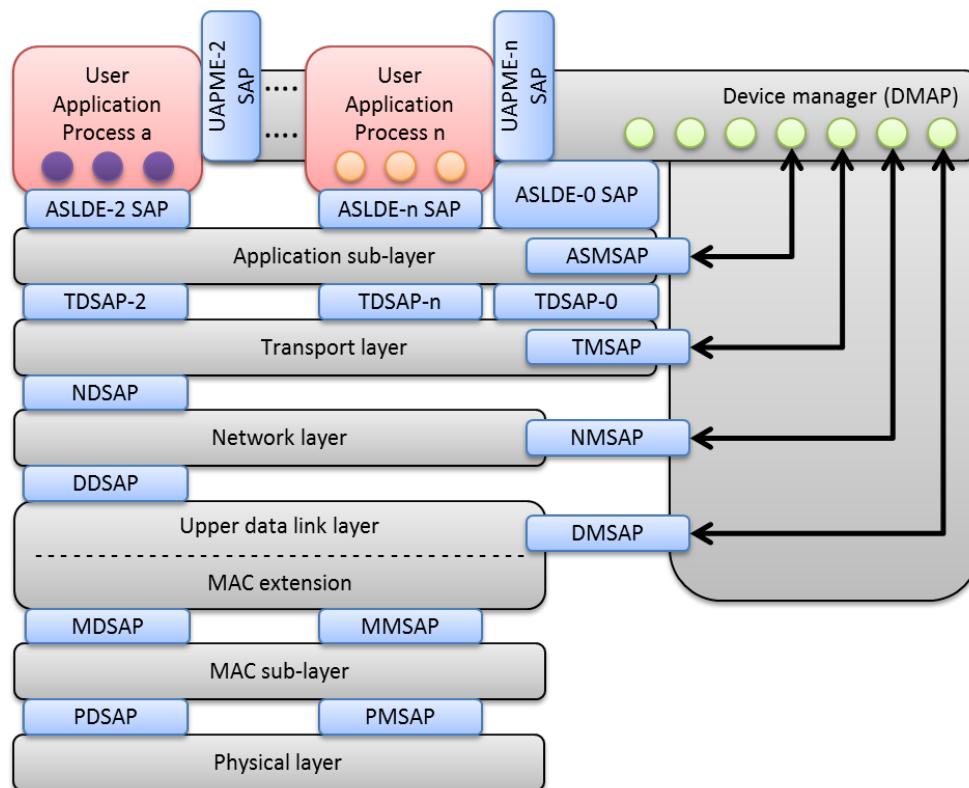


Figure 11. ISA-100.11a Reference Model

Each layer provides a service access point (SAP). The services of a layer are defined as the functions and capabilities of that layer that are exposed through the SAP to the surrounding layers. The services provided by a layer are defined by the data flowing through the SAP and, in



some cases, the states that a layer provides and the state transitions that are driven that perform the management function. Note that the device manager has a dedicated path to several of the lower layer protocol layers within a device. This is to provide direct control over the operation of these layers, as well as provide direct access to diagnostics and status information. All devices compliant to this standard are considered managed devices. All devices shall implement each SAP used by the DMAP for every protocol layer they implement. A protocol layer typically encapsulates its payload, hereafter referred to as a service data unit (SDU), with a header and footer in a single protocol data unit (PDU) as show in Figure 12. The header and footer are often referred to as overhead, with the amount of overhead depending upon how much information is necessary for the protocol to function properly. Since one of the goals of this standard is to keep PDUs short, minimizing the amount of overhead is a key attribute. A complete description of each header and footer will be found in the appropriate protocol layer clause. A full PDU includes all headers and footers as shown in Figure 13. The amount of data (measured in octets) of an application PDU that can be sent in a single transmission is determined by the difference between the maximum PhL payload and the overhead of all headers and footers.

Header	SDU	Footer
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Figure 12. Single Protocol Data Unit

PhL header	DL header	NL header	TL header	Application PDU	TL footer	NL footer	DL footer
------------	-----------	-----------	-----------	-----------------	-----------	-----------	-----------

Figure 13. Full Protocol Data Unit

Serial Peripheral Interface

The SPI bus can operate with a single master device and with one or more slave devices. If a single slave device is used, the SS pin may be fixed to logic low if the slave permits it. Some slaves require the falling edge (high to low transition) of the chip select to initiate an action, which starts conversion on said transition. With multiple slave devices, an independent SS signal is required from the master for each slave device. Most slave devices have tri-state outputs so their MISO signal becomes high impedance (disconnected) when the device is not selected. Devices without tri-state outputs can't share SPI bus segments with other devices; only one such slave could talk to the master, and only its chip select could be activated.



Deliverables

Table enumerates the deliverables XCLL will provide to the stakeholders of the NASA Wireless Smart Plug (NWSP). The due date and responsible individual for each deliverable are shown alongside.

Table 7: Enumerated Deliverables

Deliverable	Date	Responsibility
Rev. 0 Software Hierarchy Chart	21-Jan-13	CC
Rev. 0 Software Flow Chart	21-Jan-13	CC
Rev. 0 Schematic	25-Jan-13	AW
Rev. 0 Layout	6-Feb-13	AW
Rev. 1 Schematic	15-Feb-13	JJ
Rev. 1 Layout	25-Feb-13	JJ
Rev. 2 Schematic	4-Mar-13	JJ
Rev. 2 Layout	7-Mar-13	JJ
Quick Start Guide	15-Apr-13	DG
Detailed Instruction	19-Apr-13	DG
Maintenance	21-Apr-13	DG
Test Matrix	22-Apr-13	CC
Final Prototypes	27-Apr-13	AW
Test Plan	29-Apr-13	CC
Final Presentation	2-May-13	AW
Final Documentation	7-May-13	AW

Legend: AW = Akeem Whitehead
 CC = Christian Carmichael
 DG = Derek Garsse
 JJ = Jeffrey Jordan



Deliverables Timeline

The name and due date for each deliverable are shown on the project timeline in Figure 14.

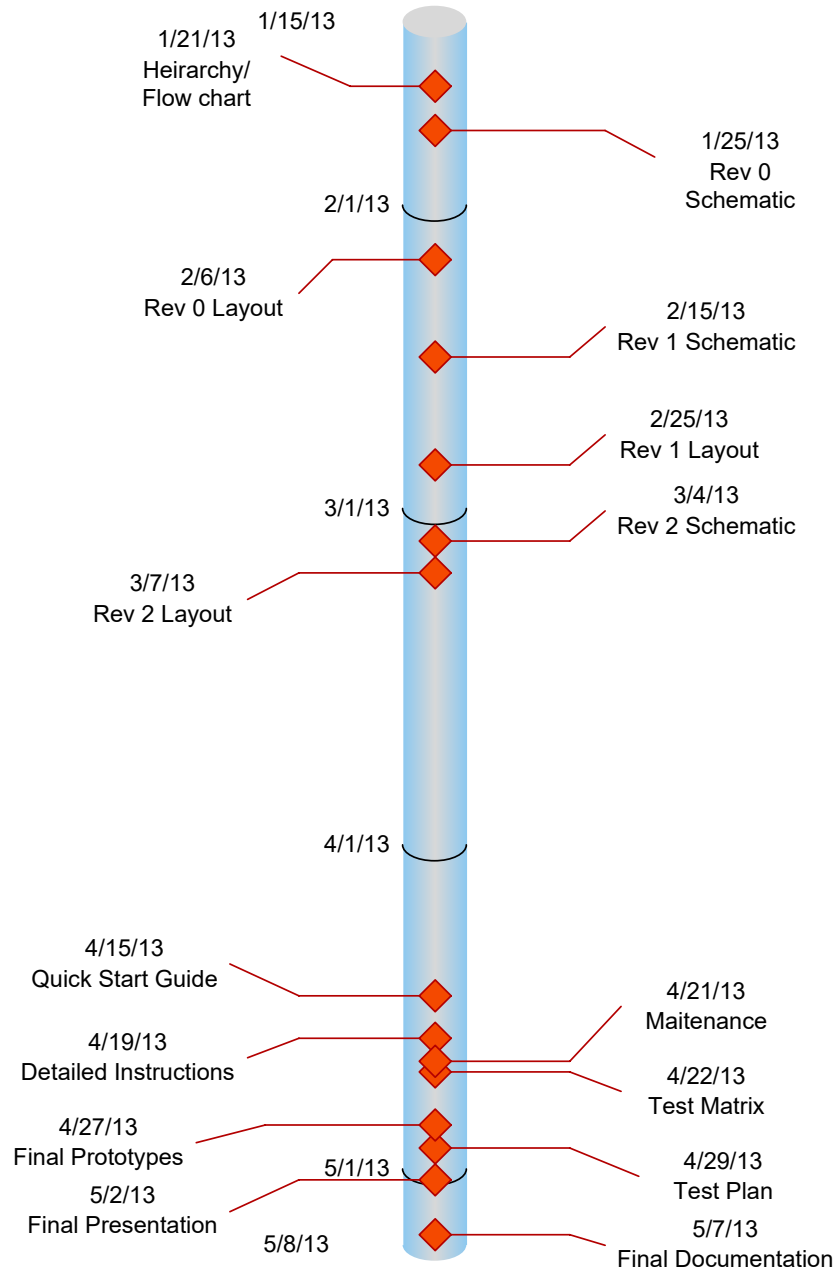


Figure 14: Project Timeline



Deliverable Descriptions

Rev. 0 Schematic

We will develop a first revision hardware schematic to enhance the understanding of the stakeholders regarding our implementation of the NWSP. The first revision hardware schematic will detail each component and the circuitry for the NWSP. We will use National Instrument's Multisim 2012 to create the first revision hardware schematic. This first revision hardware schematic will be delivered via the Progress Checkpoint #1 presentation. A softcopy will also be delivered via e-mail to stakeholders as a PDF.

Rev. 0 Board Layout

The first revision board layout will be constructed once the alpha hardware schematic is completed. The first revision board layout will be created with National Instrument's Ultiboard 2012. The first revision board layout will be delivered via the Progress Checkpoint #1 presentation. A softcopy will also be delivered via e-mail to stakeholders as a PDF.

Rev. 0 Software Hierarchy Charts

Hierarchy charts will be created for both the embedded software and the master control client software. The first revision software hierarchy charts will be delivered via the Progress Checkpoint #1 presentation. A softcopy will also be delivered via e-mail to stakeholders as a PDF.

Rev. 0 Software Flow Charts

Flow charts will be created for both the embedded software and the master control client software. The first revision software flow charts will be delivered via the Progress Checkpoint #1 presentation. A softcopy will also be delivered via e-mail to stakeholders as a PDF.

Test Matrix

We will construct a test matrix to test the overall functionality of our device. The test matrix will be presented in a spreadsheet and will map tests to be performed to the function requirements to be tested. The test matrix will be delivered via the Progress Checkpoint #1 presentation. A softcopy will also be delivered via e-mail to stakeholders as a Microsoft Word document.

Progress Checkpoint #1

Progress Checkpoint #1 (PC1) is a presentation to our stakeholders at the request of our NASA stakeholders. During PC1, we will present our first revision schematic, our first revision board layout, our software hierarchical charts, and our test matrix for approval by our stakeholders. There will also be a general progress update. This presentation will take place on February 13, 2013 and all stakeholders will be invited to attend. The presentation will be given via PowerPoint over WebEx and via teleconference. A follow-up memorandum covering the main points and any topics raised by the stakeholders will be e-mailed following the presentation. The presentation itself, including all deliverables mentioned, will also be e-mailed out ahead of time to all attending stakeholders.



Final Design Review

We will present our final design concepts during our FDR for stakeholder approval. The presentation will include final mockups for the graphical user interface on the Master Control Client, the final enclosure design, and the final functional and conceptual designs of the NWSP. This presentation will take place on March 3, 2013 and all stakeholders will be invited to attend. The presentation will be given via PowerPoint over WebEx and via teleconference. A follow-up memorandum covering the main points and any topics raised by the stakeholders will be e-mailed following the presentation. The presentation itself will also be e-mailed out ahead of time to all attending stakeholders.

Final Schematics

We will develop our final hardware schematic from the lessons learned from and testing done on our first and second revision boards. This schematic will further enhance the understanding of the stakeholders regarding our implementation of the NWSP. The final hardware schematic will detail each component and the circuitry for the NWSP. We will use National Instrument's Multisim 2012 to create the final hardware schematic. The final hardware schematic will be delivered via the Progress Checkpoint #2 presentation. A softcopy will also be delivered via e-mail to stakeholders in PDF format.

Final Board Layout

The final board layout will be constructed once the final hardware schematic is completed. The final board layout will be created with National Instrument's Ultiboard 2012. The final revision board layout will be delivered via the Progress Checkpoint #2 presentation. A softcopy will also be delivered via e-mail to stakeholders in PDF format.

Final Software Flow Charts

We will create software flow charts describing the functionality of both our embedded software and our master control client software. The flow chart will be color coded and laid out in a user-friendly fashion. All functions we create will be included but library functions, if any, will be excluded for clarity. We will use Visio to create our software flow charts. The software flow charts will be delivered via the Progress Checkpoint #2 presentation. A softcopy will also be delivered via e-mail to stakeholders in PDF format.

Test Plan

We will design a test plan to ensure the overall functionality of the NWSP. This test plan will be the culmination of our earlier test matrix with much greater detail added. Within our test plan we will describe what tests are to be performed, how the test will be setup, what results we expect, and what determines a failing or passing test. The test plan will be delivered via the Progress Checkpoint #2 presentation. A softcopy will also be delivered via e-mail to stakeholders in a Microsoft Word document.

Progress Checkpoint #2



Progress Checkpoint #2 (PC2) is a presentation to our stakeholders at the request of our NASA stakeholders. During PC2, we will present our final schematic, our final board layout, our software flow charts, and our test plan for approval by our stakeholders. There will also be a general progress update. This presentation will take place on April 3, 2013 and all stakeholders will be invited to attend. The presentation will be given via PowerPoint over WebEx and via teleconference. A follow-up memorandum covering the main points and any topics raised by the stakeholders will be e-mailed following the presentation. The presentation itself, including all deliverables mentioned, will also be e-mailed out ahead of time to all attending stakeholders.

User Documentation

We will create a user manual to aid the stakeholders and end users in the use and installation of the NWSP. The user manual will consist of three main sections: a maintenance and troubleshooting guide, a quick start guide and a detailed user guide. The maintenance and troubleshooting section will consist of tips, hazards and advice to aid a layman end user who may be experiencing a problem operating the device. The quick start guide will be a very simple, brief set of illustrated instructions to get the NWSP installed and operational as quickly as possible. Finally, the detailed user guide will be the bulk of the documentation as it will be an exhaustive explanation and instruction set on all the features in the hardware and software. The user documentation will be delivered via bound color hardcopy. A softcopy will also be delivered via e-mail to stakeholders in a Microsoft Word document and will be included in the final CD.

Final Prototypes

We will deliver five prototype NWSP devices. These devices will be ready for testing in the DSH mockup. We will demonstrate the devices during our Progress Checkpoint #3 and we will hand over all five devices to the MISL team during the close out of our project. Final testing and delivery of the prototypes to the stakeholders will be the responsibility of the MISL team from that point forward.

Progress Checkpoint #3/Final Demonstration

Progress Checkpoint #3 (PC3) is our final presentation to our NASA stakeholders. During PC3, we will demonstrate the final prototype NWSP devices and present the user documentation to all attending stakeholders. This presentation will take place on May 15, 2013 and all stakeholders will be invited to attend. The presentation will be given via PowerPoint over WebEx and via teleconference. A follow-up memorandum covering the main points and any topics raised by the stakeholders will be e-mailed following the presentation. The presentation itself will also be e-mailed out ahead of time to all attending stakeholders.

Final Report

The final report is the culmination of two semesters within the Capstone program and is the final documentation to our Capstone stakeholders. An additional copy will be provided to our



NASA stakeholders to complete all documentation requirements. The final report will include the System Design Process (SDP), hardware schematics, board layouts, gerber files, all source code, hierarchical charts, flow charts, enclosure schematics, user documentation, a bill of materials (BOM), and any other documentation generated during the life of the project. A color, bound hardcopy will be provided in addition to a softcopy in a Microsoft Word document delivered via CD. All hardware and software deliverables will be included on the CD in their respective formats, as well.

Final Presentation

The final presentation is the last presentation we will give for our Capstone program. The final presentation will be delivered partially via PowerPoint and partially via live demonstration. During the final presentation we will demonstrate the functionality of our device for verification and technically explain our NWSP prototype devices from start to finish. The final presentation will be recorded and the video and PowerPoint slides will be delivered with the softcopy of our final report on CD.



Milestones

Milestones here are defines as major events, such as a demonstration of a critical portion of hardware or software, that clearly demarcate the progression of our project. Figure 15 is a timeline of the major milestones for our project. Each milestone is a demonstration of phase of progress for our hardware or software.

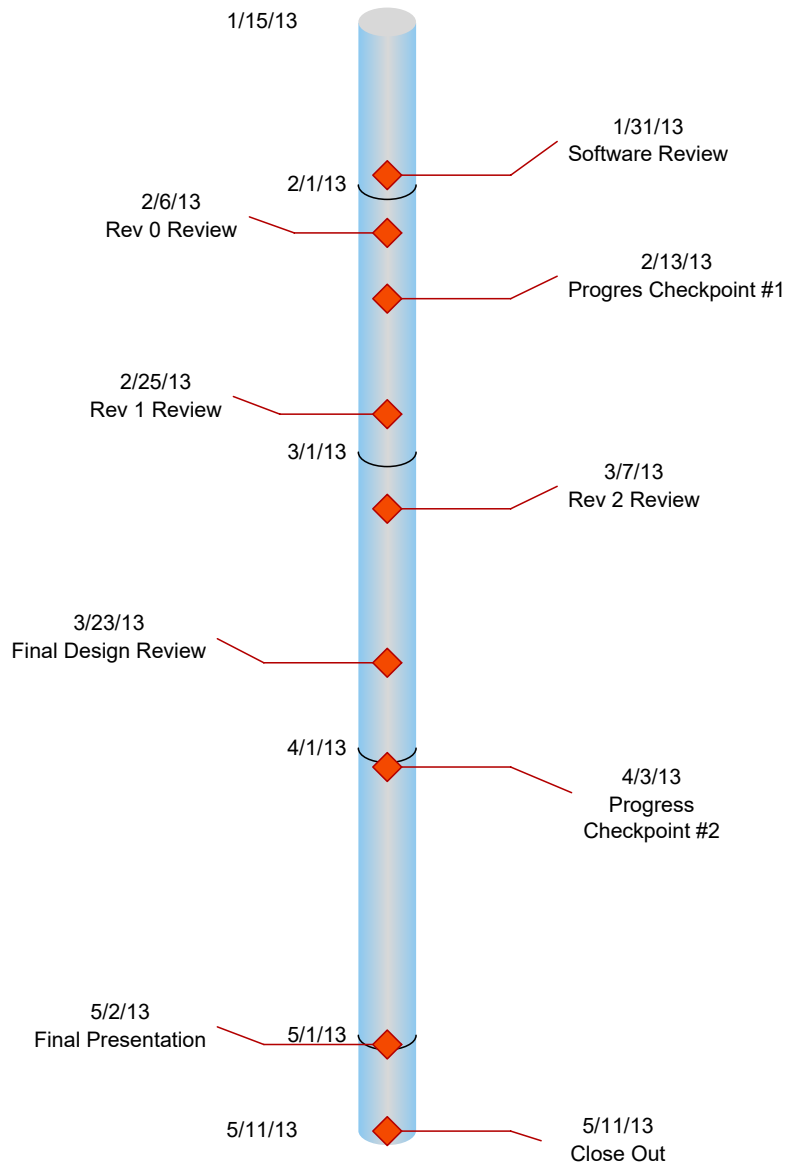


Figure 15: Milestones Timeline



Progress Checkpoint #1

Progress Checkpoint #1 (PC1) is a presentation to our stakeholders at the request of our NASA stakeholders. During PC1, we will present our first revision schematic, our first revision board layout, our software hierarchical charts, and our test matrix for approval by our stakeholders. There will also be a general progress update. This presentation will take place on February 13, 2013 and all stakeholders will be invited to attend.

Final Design Review

We will present our final design concepts during our Final Design Review (FDR) for stakeholder approval. The presentation will include final mockups for the graphical user interface on the Master Control Client, the final enclosure design, and the final functional and conceptual designs of the NWSP. This presentation will take place on March 3, 2013 and all stakeholders will be invited to attend.

Progress Checkpoint #2

Progress Checkpoint #2 (PC2) is a presentation to our stakeholders at the request of our NASA stakeholders. During PC2, we will present our final schematic, our final board layout, our software flow charts, and our test plan for approval by our stakeholders. There will also be a general progress update. This presentation will take place on April 3, 2013 and all stakeholders will be invited to attend.

Progress Checkpoint #3/Final Demonstration

Progress Checkpoint #3 (PC3) is our final presentation to our NASA stakeholders. During PC3, we will demonstrate the final prototype NWSP devices and present the user documentation to all attending stakeholders. This presentation will take place on May 15, 2013 and all stakeholders will be invited to attend.

Final Presentation

The final presentation is the last presentation we will give for our Capstone program. The final presentation will be delivered partially via PowerPoint and partially via live demonstration. During the final presentation we will demonstrate the functionality of our device for verification and technically explain our NWSP prototype devices from start to finish.



Gantt Chart

The project has been divided into seven phases: Research, Design, Simulation, Implementation, Testing, Documentation, and Close-out. The duration of these seven phases is outlined in the Gantt chart. Research is the first phase, followed by the Design phase. The third phase is Simulation followed by Implementation and Testing. Each of these phases has overlap to allow for a parallel approach to the project. The Documentation phase will start in the middle of the Research phase and continue till the end of the project. Close-out will be the final phase in the project and will end with the completion of the project.

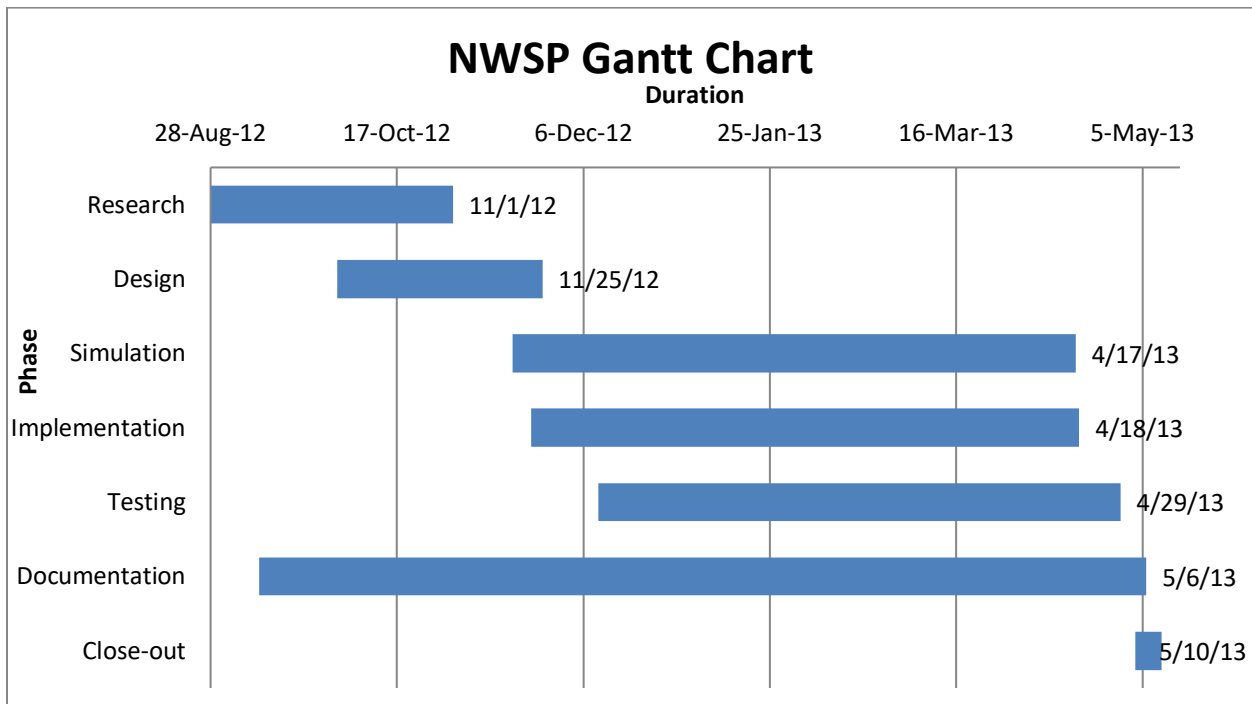


Figure 16. Overall Project Gantt Chart



Test Matrix

XCLL has created a Test Matrix (below) to ensure that crucial tests are performed on the NWSP in order to validate all of its functionality. On the top of our Test Matrix (x-axis) we can find all the functional requirements that the NWSP must implement as a final product. The column on the left (y-axis) contains all the test cases to be performed on the NWSP in order to validate its functionality. We marked with an “X” the test cases that validate one or more of the functional requirements.

Test	Support for 120V/28V	Real-Time Monitoring	Data Rate	Master Control Unit	Wireless Configuration	Five NWSP Unit Func.
Verification of Sensor Readings (28V)	X	X	X	X	X	
Verification of Sensor Readings (120V)	X	X	X	X	X	
Variable Load Test (28V)	X	X	X	X	X	
Variable Load Test (120V)	X	X	X	X	X	
Verification of Command and Control		X	X	X	X	
Load Test (all 5 devices)						X

Figure 17: Test Matrix

- **Sensor Readings(28V)**

The NWSP will be tested to make sure we can monitor data in real time and to verify the accuracy of the sensor readings reported to the Master Control Unit.

- **Sensor Readings(120V)**

The NWSP will be tested to make sure we can monitor data in real time and to verify the accuracy of the sensor readings reported to the Master Control Unit.

- **Variable Load (28V)**

Different loads will be connected to the NWSP while the current and voltage drop are measured directly and monitored through the MCU.

- **Variable Load (120V)**

Different loads will be connected to the NWSP while the current and voltage drop are measured directly and monitored through the MCU.

- **Command and Control**



Verify the command and control functionality of the NWSP.

- **Five Unit Load**

To verify that five NWSP units can operate on the same network and communicate with the MCU. This test will also verify that the the MCU can control five NWSP units.

Technical Merit

XCLL uses a technical merit matrix during project selection to weigh certain aspects of a given project being considered. For a project to be selected and approved for credit, a technical merit greater than 1.0 must be achieved. For the NWSP, the summation of each technical merit category results in a value of 1.5, thus satisfying our 1.0 minimum requirement. Table 8 lists each technical merit factor, and justification for assessing value of each factor is provided below.

Table 8: Technical Merit

#	Technical Merit Factors	Weight
1	Contains a clearly described and completely understood technical challenge	0.1 / 0.1
2	Contains a requirement for system integration	0.2 / 0.2
3	Contains a requirement for system testing	0.2 / 0.2
4	Contains a requirement for theoretical analysis and simulation	0.0 / 0.2
5	Contains hardware design, development and test	0.3 / 0.3
6	Contains software design, development and test	0.3 / 0.3
7	Contains an enclosure design/fabrication requirement	0.2 / 0.2
8	Contains a requirement for documentation other than the project related	0.2 / 0.2
9	Contains a requirement for intellectual property protection	0.0 / 0.1
10	Contains requirement beyond Capstone	0.0 / 0.1
Total		1.5 / 1.9

1. Contains a clearly described and completely understood technical challenge

The use of both 120V-DC and 28V-DC are high voltage signals that have not been handled previously given their near exclusive use in space applications. The ISA100.11a is an industry standard not learned in the TAMU EET course load.

2. Contains a requirement for system integration

The NWSP devices are to be utilized in NASA's Deep Space Habitat for monitoring and control of targeted application devices. Either a Smart Plug GUI will be provided as independent software to be run on NASA's computers, or data transmitted from the Smart Plug will be formatted for NASA's proprietary software.

3. Contains a requirement for system testing



NWSP will require system testing to ensure that all performance and functional requirements are met, especially due to the lack of technical support or exchangeability when actual implementation is achieved outside of Earth in a deep space habitat.

4. Contains a requirement for theoretical analysis and simulation

Before proceeding with physical construction and microcontroller programming, the functionality of the NWSP will be simulated on National Instrument's Multisim to simulate and extract theoretical values at designated test points. Failures and emergency scenarios will also be simulated for non-ideal conditions. LabVIEW may be used as alternative software.

5. Contains hardware design, development and test

Multisim schematics and Ultiboard PCB layouts will be provided, as well as component population for a board of at least 2 layers. Test points will be populated on the final board for testing purposes in the case that NASA astronauts must troubleshoot.

6. Contains software design, development and test

NASA requires that the NWSP use a TI MSP430F5438 microcontroller to handle all operations, both manual and autonomous. In-Circuit Debugging pins will be provided for NASA astronauts to debug or re-program the onboard microcontroller. A LabVIEW based Graphic User Interface (GUI) will be developed as an executable on a Windows based operating system.

7. Contains an enclosure design/fabrication requirement

A custom enclosure will be provided to enclose the input/output receptacles, custom PCB, Nivis radio, and potentially an external button and LCD configuration for local non-GUI monitoring.

8. Contains a requirement for documentation other than the project related

Presentations for Industrial Advisory Committee and TAMU Engineering Showcase.
Documentation for Texas Instruments Analog Design Contest.

9. Contains a requirement for intellectual property protection

The NWSP will be protected under the intellectual property law, with the intention of selling NASA or the competing private-sector based Space X (Space Exploration Technologies Corporation) the IP rights.

10. Contains requirement beyond Capstone

This section is not applicable to the NWSP project.



Appendix B: Parts Lists with Unit and 100 Quantity Pricing



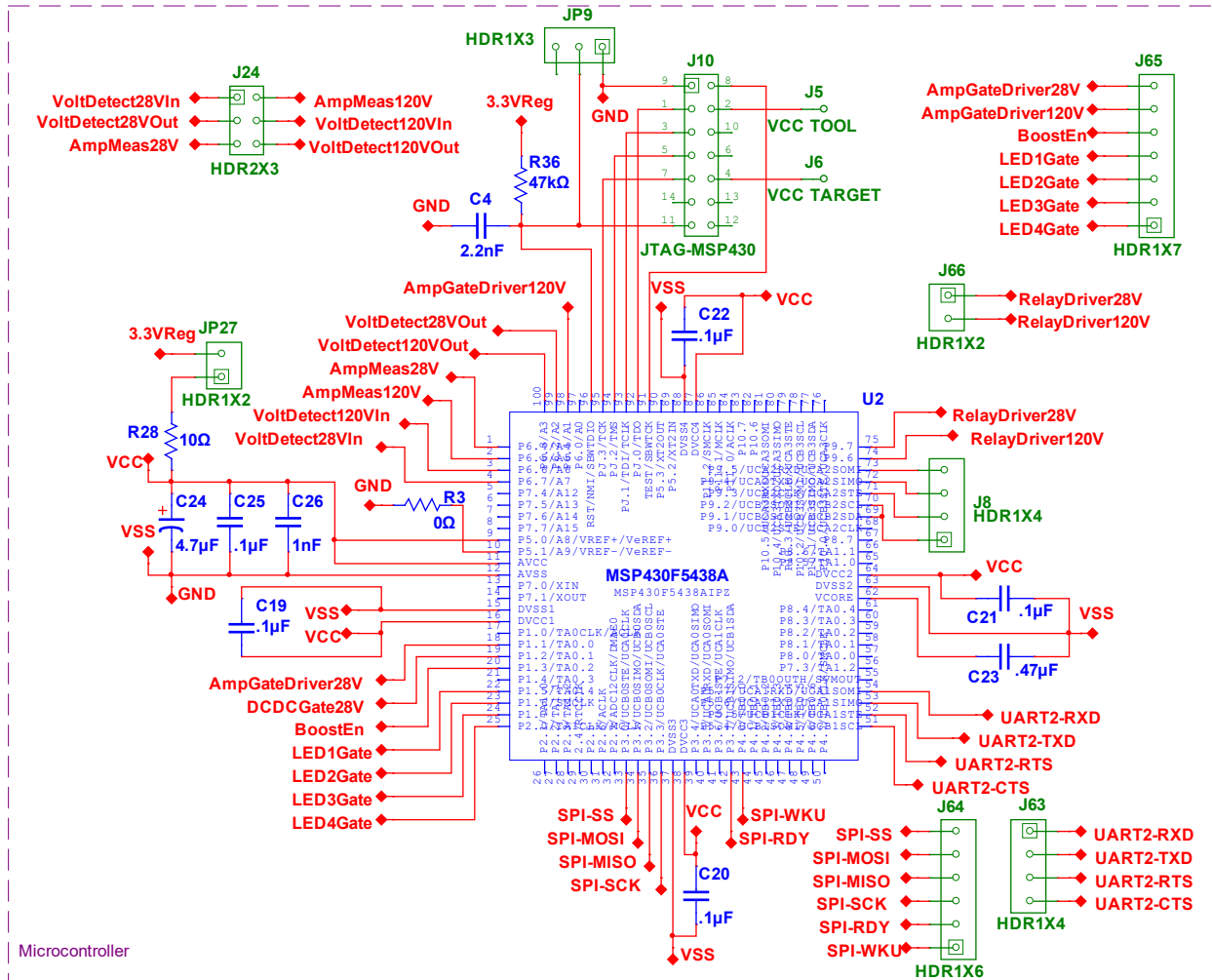
Part Description	Part Number	Amount per NWSP	Price at 1	1 NWSP Unit	5 NWSP Units	Price at 100	100 NWSP Units
LED Light Pipes Quad	696-LPF-S014331S	1					
Red LED 624nm	593-VAOL-S12RP4	1					
Yellow LED 589nm	593-VAOL-S12YP4	1					
Yellow Green LED 573nm	593-VAOL-S12GT4	1					
Blue LED 486nm	593-VAOL-S12SB4	1					
1M ohm Resistor	660-SG73P2BTDD1004F	8					
Mosfet Dual N-CH 20V	781-SI1988DH-T1-E3	3					
1K ohm Resistor	603-RT1206FRE071KL	6					
0.01 ohm Resistor	71-WSL1206R0100FEA	3					
4.7 uF Tantalum Capacitor	74-293D475X9010A2TE3	2					
0.1 uF 1206 Capacitor	810-C3216X7R2E104KST	9					
1000 pF Capacitor 1000V	810-C3216X7S3A102K	2					
0.47 uF Capacitor	810-C3216X7R2A474KST	1					
2200 pF Capacitor	810-C3225X7S3D222K	1					
47K ohm Resistor	71-CRCW1206-47K-E3	1					
Headers 1x21	538-22-28-4215	2					
100K ohm Resistor	71-CRCW1206-100K-E3	3					
10K OHM Resistor	652-CRT1206BY1002ELF	1					
2.4 GHz Antenna	960-FXP73090100A	1					
1uF Capacitor 1206	963-UMK325B7105KH-T	1					
1000pF Capacitor 2000V	767-1206B102K202NT	2					
1uF Capacitor 1812	810-C4532X7T2E105KST	2					
274K ohm Resistor	660-RK73H2BTDD2743F	2					
Mosfet 60V N-CH	595-CSD18531Q5A	1					
DC/DC Switching Boost Converter	700-MAX1675EUA	1					
47uF Tantalum Capacitor	74-TR3A476K6R3C0800	2					
22uH Inductor	81-LQH43CN220K03L	1					
Traco Power 28 to 3.3V DC/DC Converter	TEN8-2410WI	1					
Traco Power 120 to 3.3V	TEN8-7210WI	1					

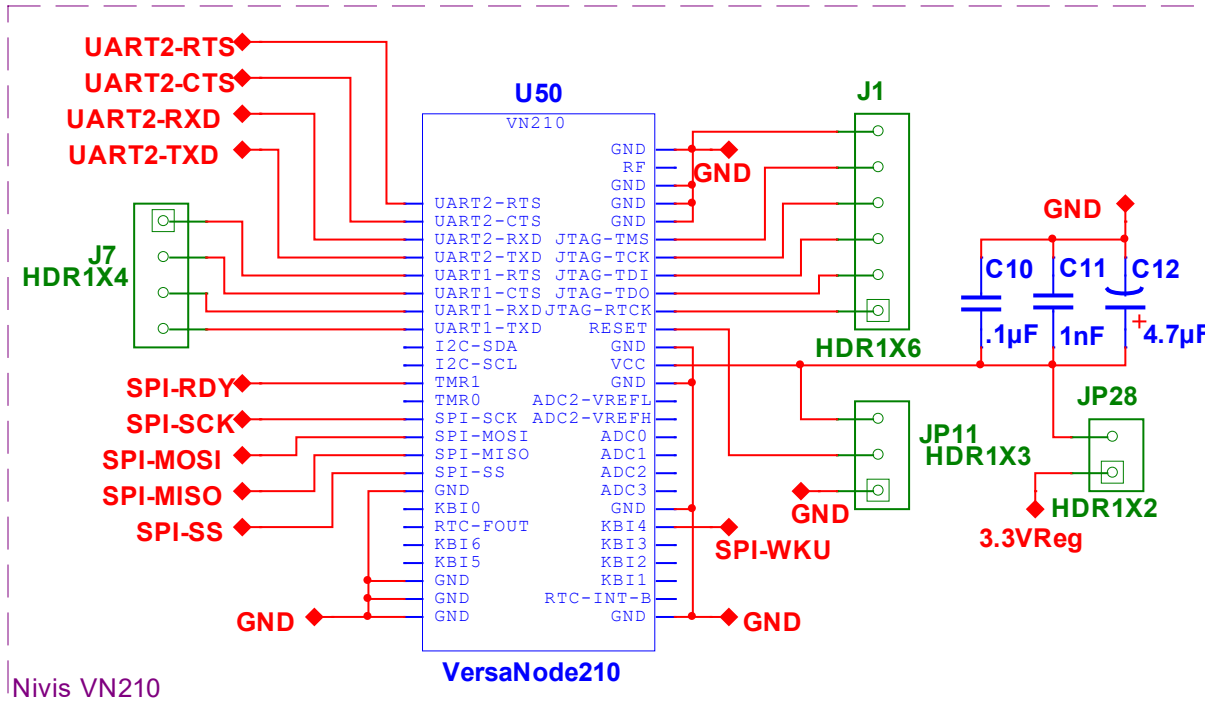


DC/DC Converter							
ACS714 20A Current Sensor	620-1226-1-ND	2					
1.0 uF 100V Capacitor	810-C3216X7R2A105KST	2					
7.68K ohm Resistor	71-CRCW1206-7.68K-E3	2					
560 ohm Resistor	71-CRCW1206-560-E3	2					
2.2K ohm Resistor	71-CRCW1206-2.2K-E3	2					
LM7301 Dual Op Amp	926-LM7301IM/NOPB	4					
10M ohm Resistor	66-WCR1206LF1005FPLT	2					
1.3M ohm Resistor	603-RV1206FR-071M3L	1					
Solid State Relay 60VDC	558-DC60S5	1					
Solid State Relay 120VDC	558-D2D12	1					
Phoenix 1/12 Terminal Block	651-1728381	1					
Schottky Diodes	771-PMEG2010ER115	2					
7 Pin Circular Connector Male	SRCN6A16-7P	1					
7 Pin Circular Connector Female	SRCN2A16-7S	1					
MSP430 processor	595-MSP430F5438AIPZ	1					
VN210 radio module	VN210	1					
Boards		1					
Enclosures		1					
Professional Population		1					
Building NWSP		1					
Total		92					



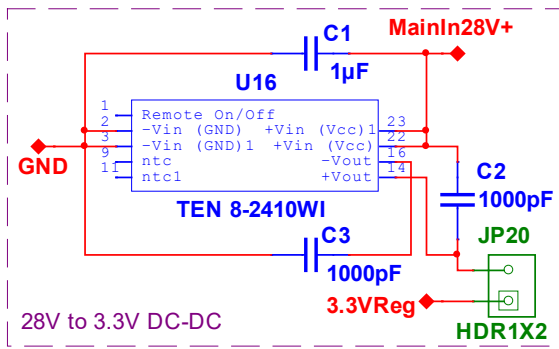
Appendix C: Complete Alpha Schematics



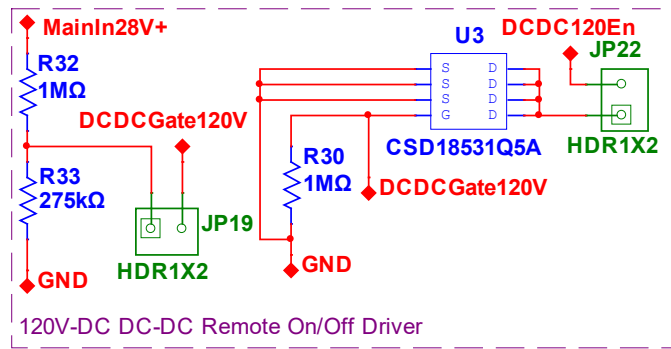


Nivis VN210

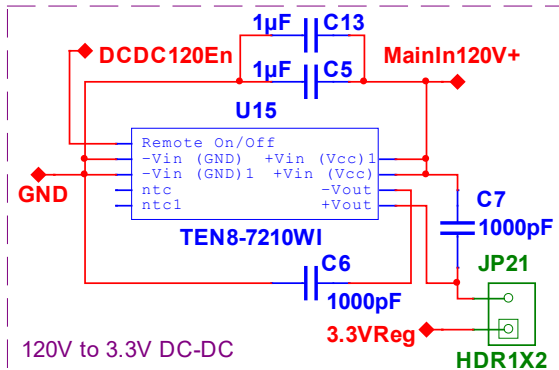
VersaNode210



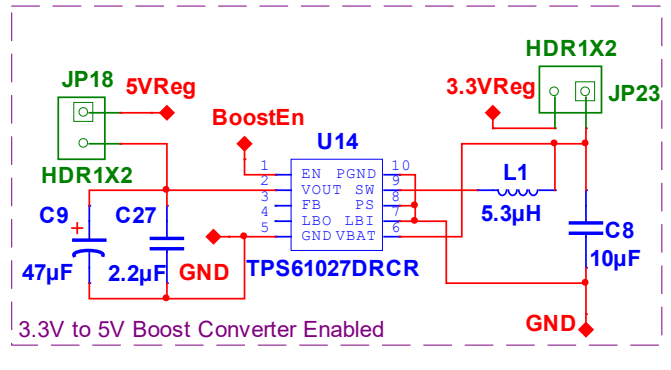
28V to 3.3V DC-DC



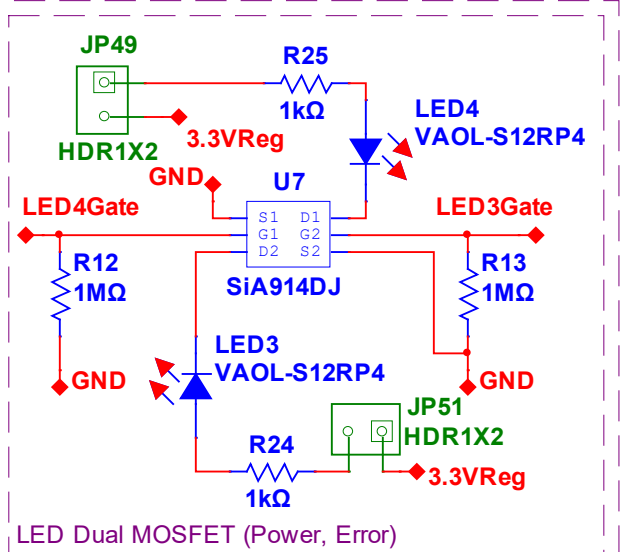
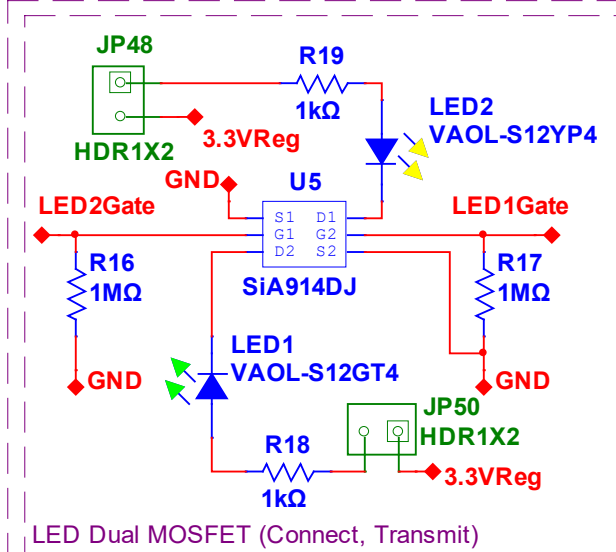
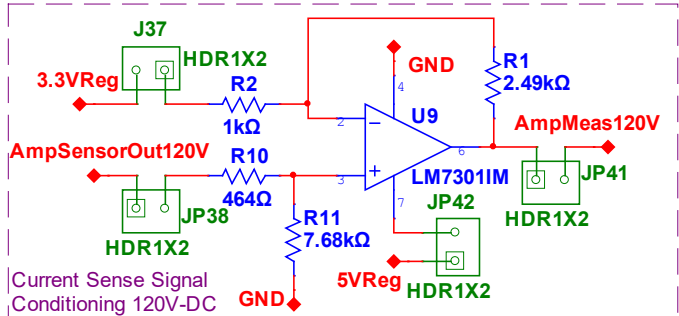
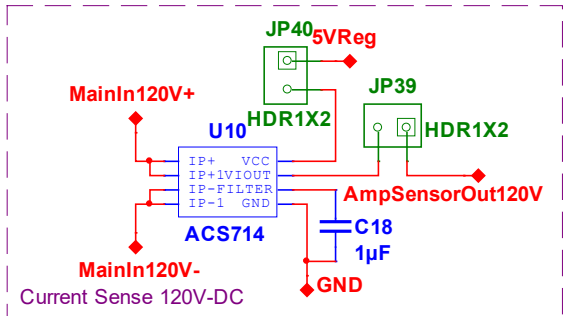
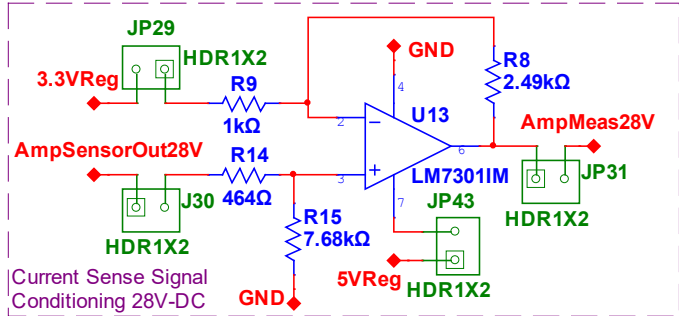
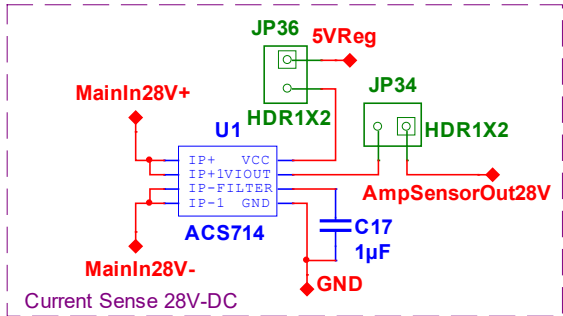
120V-DC DC-DC Remote On/Off Driver



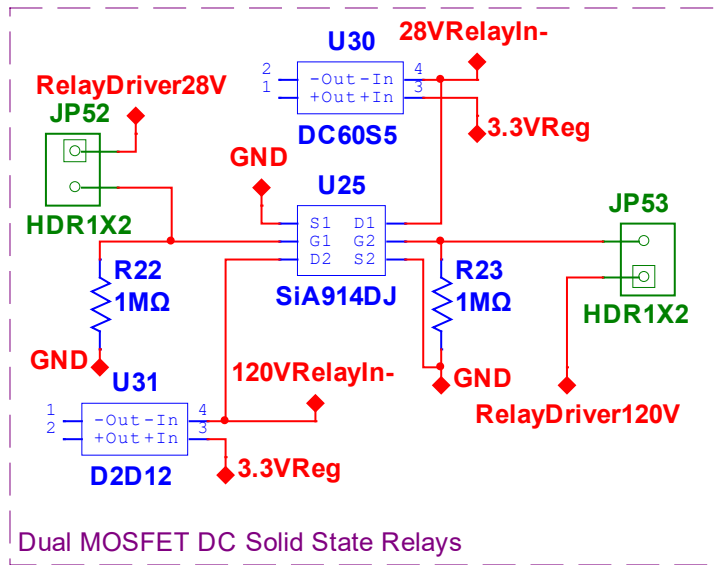
120V to 3.3V DC-DC

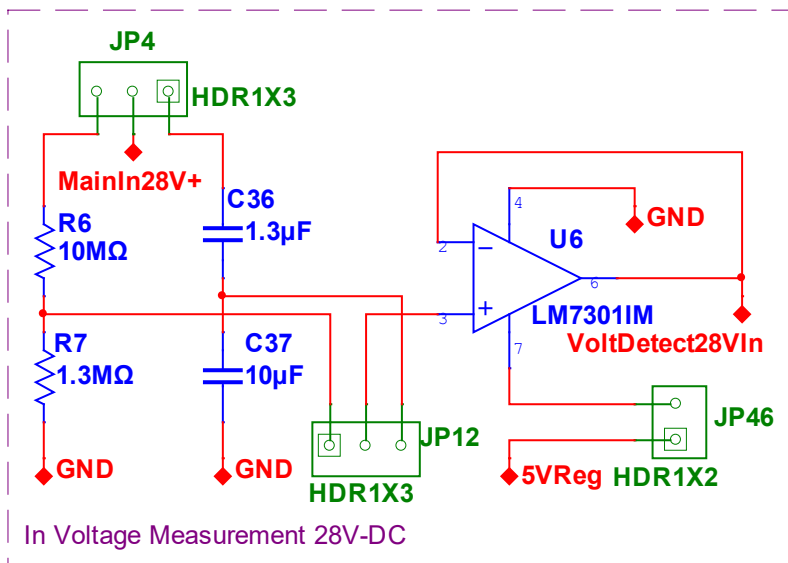
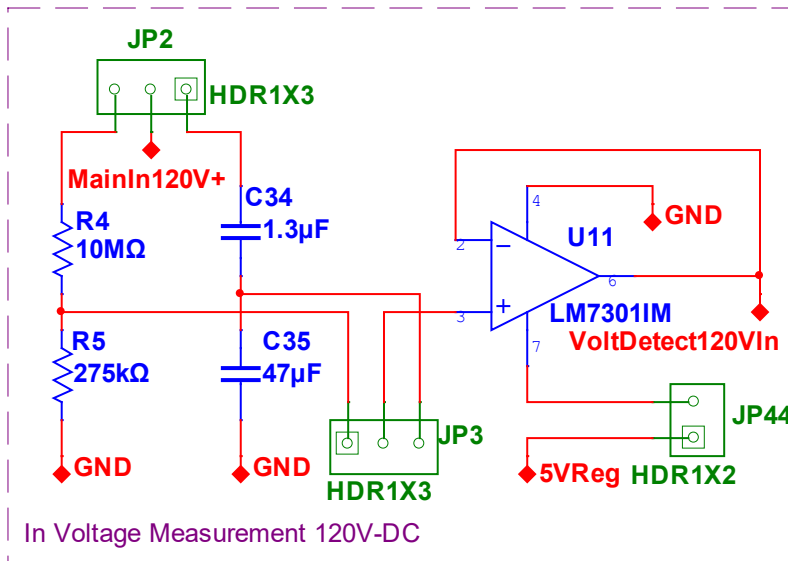


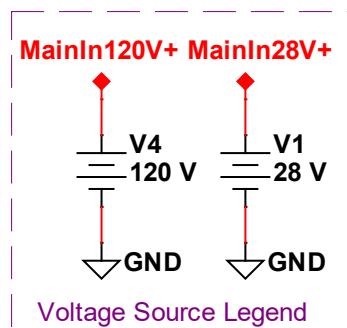
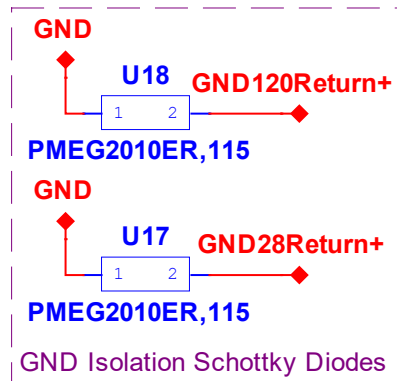
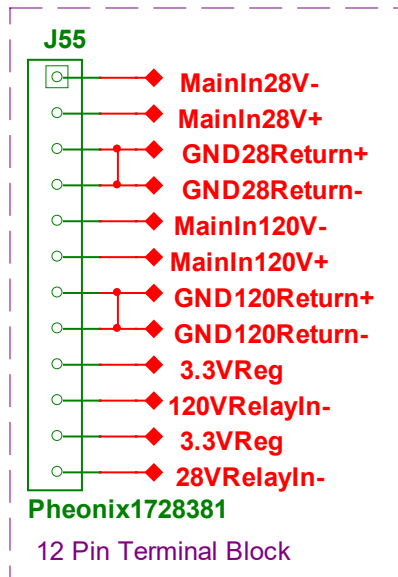
3.3V to 5V Boost Converter Enabled



LED MOSFET Array

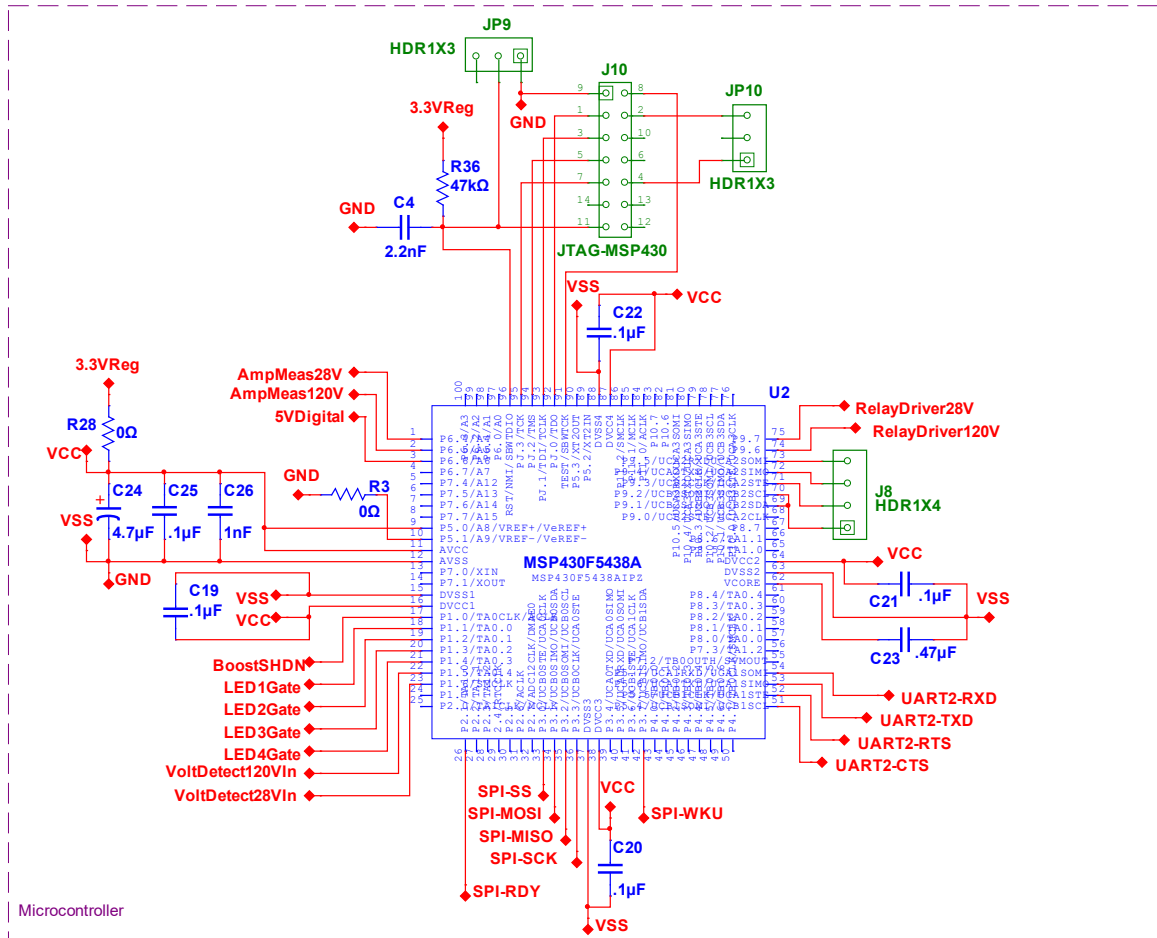


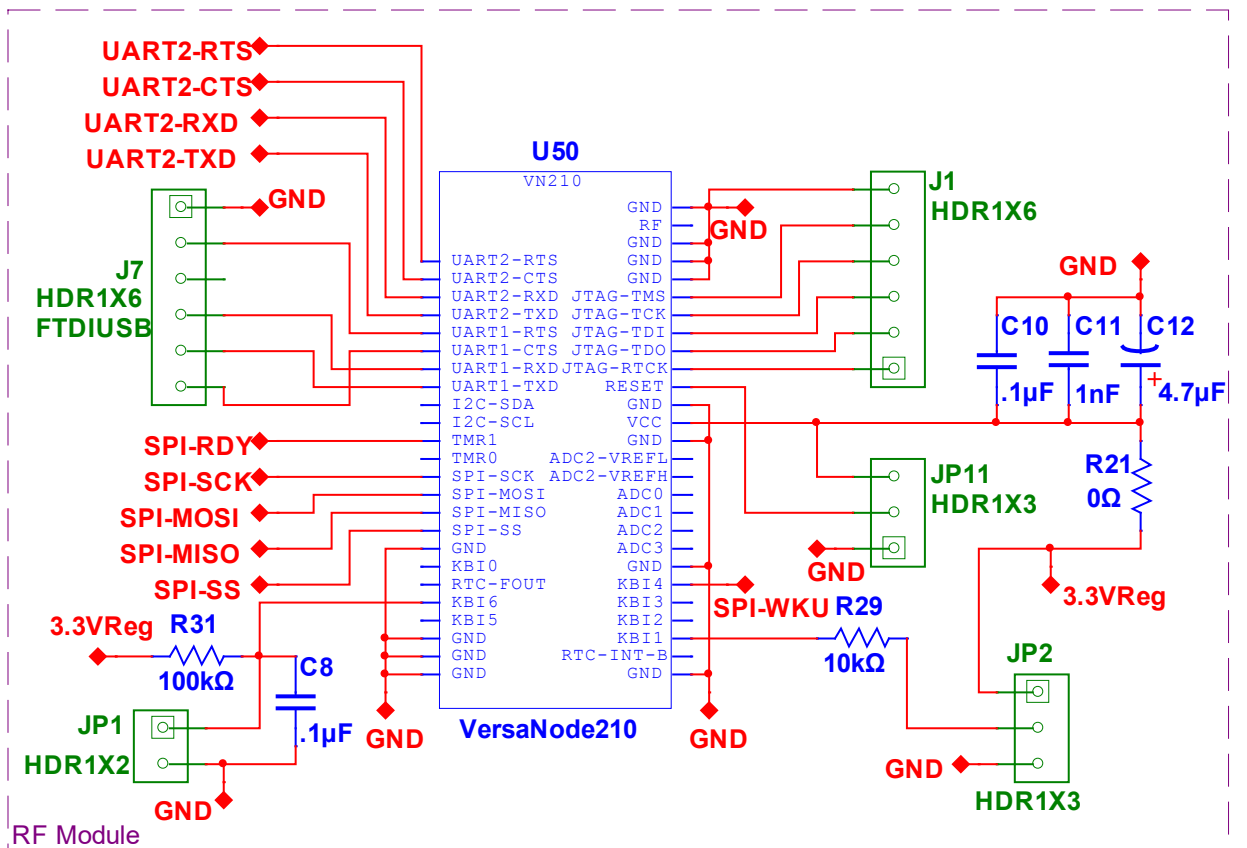
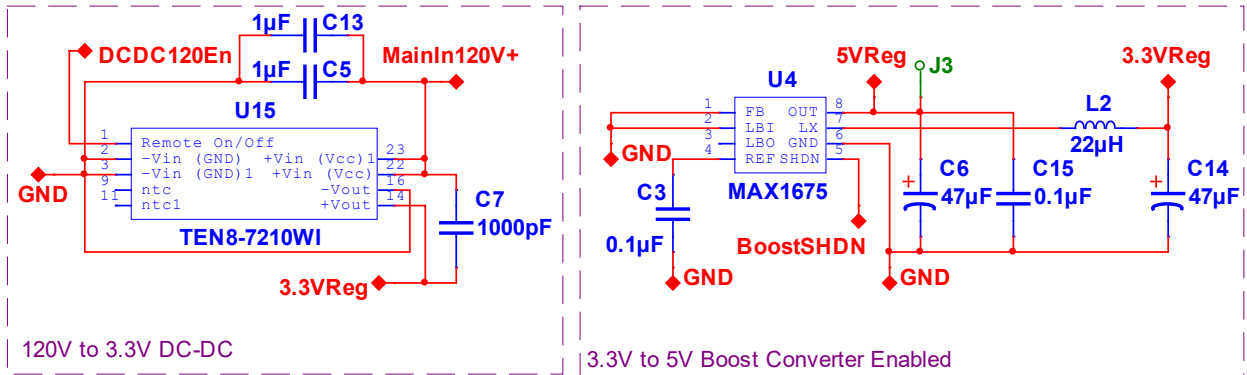
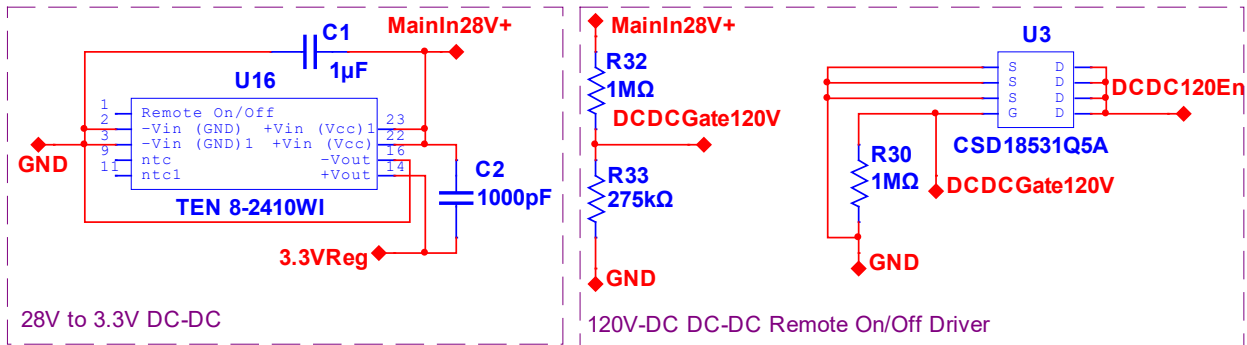


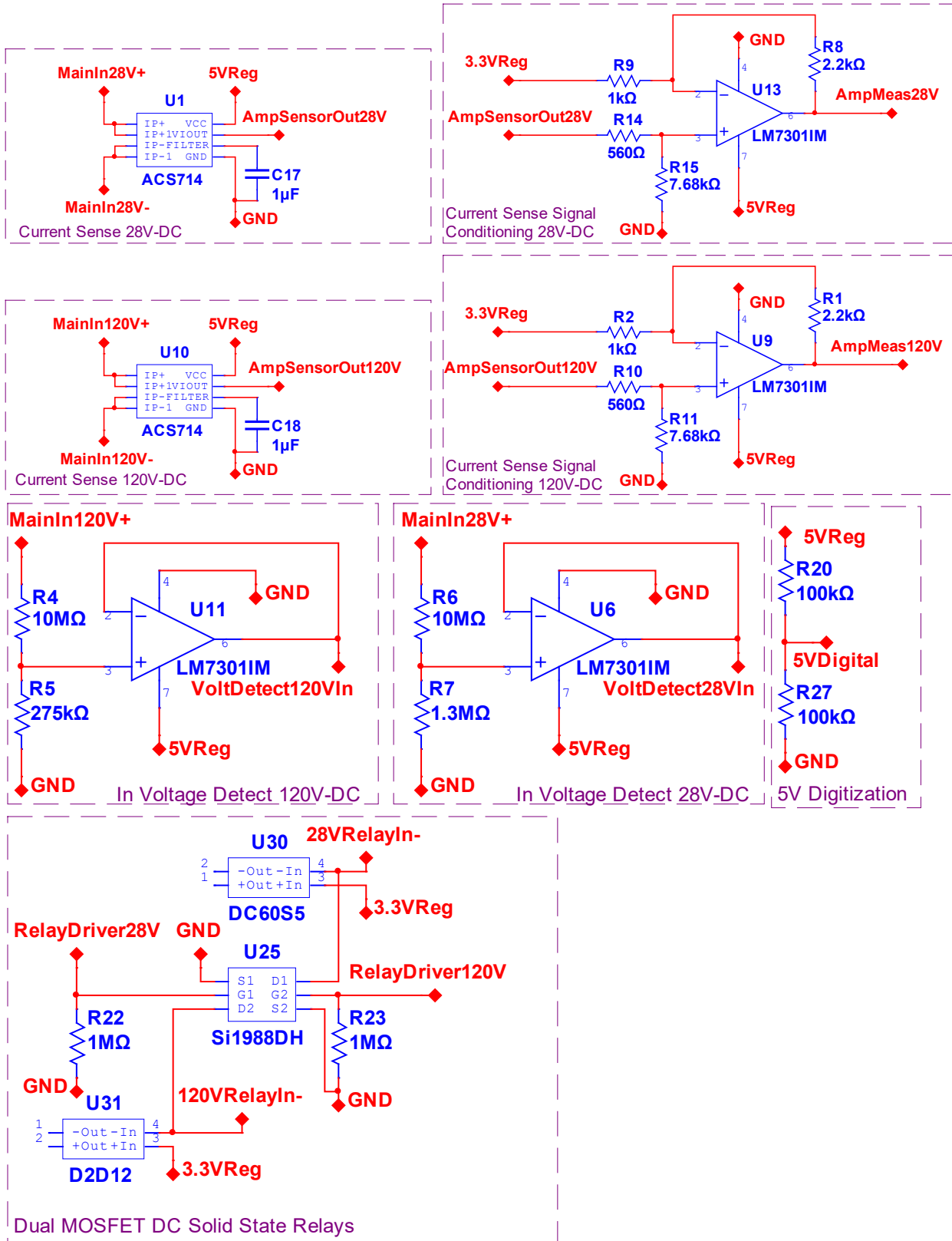


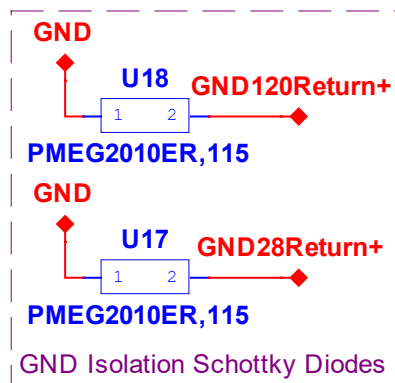
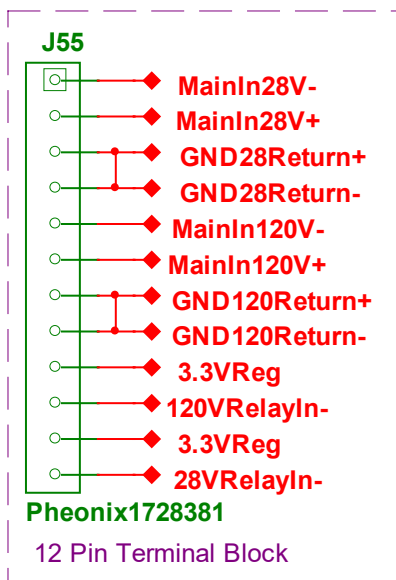
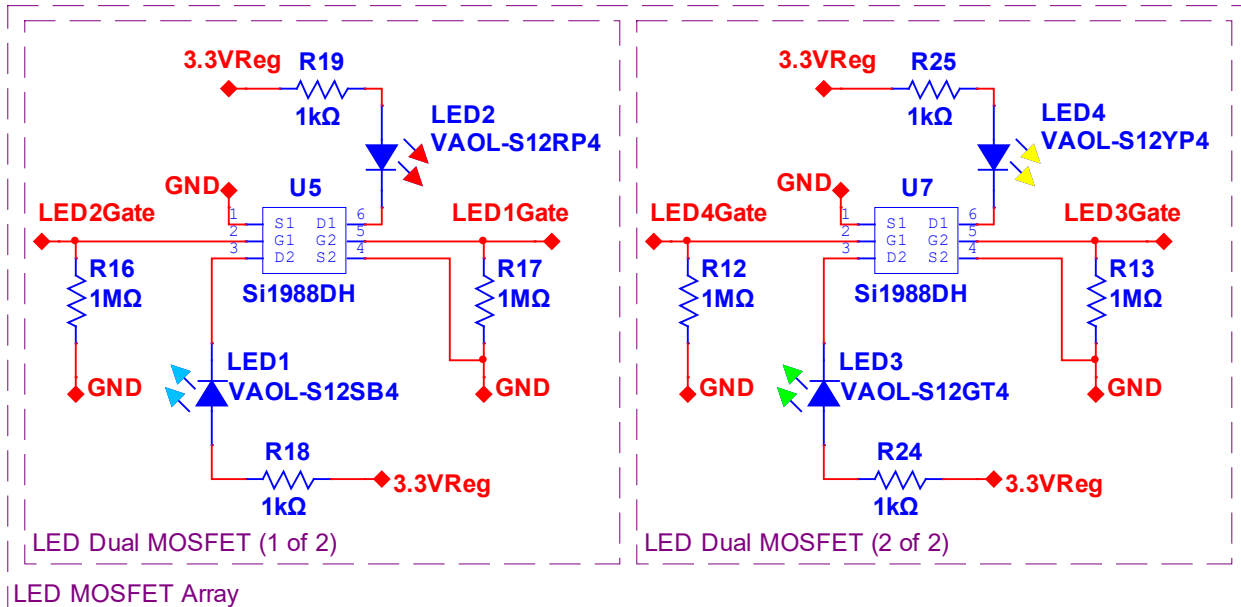


Appendix D: Complete Bravo Schematics



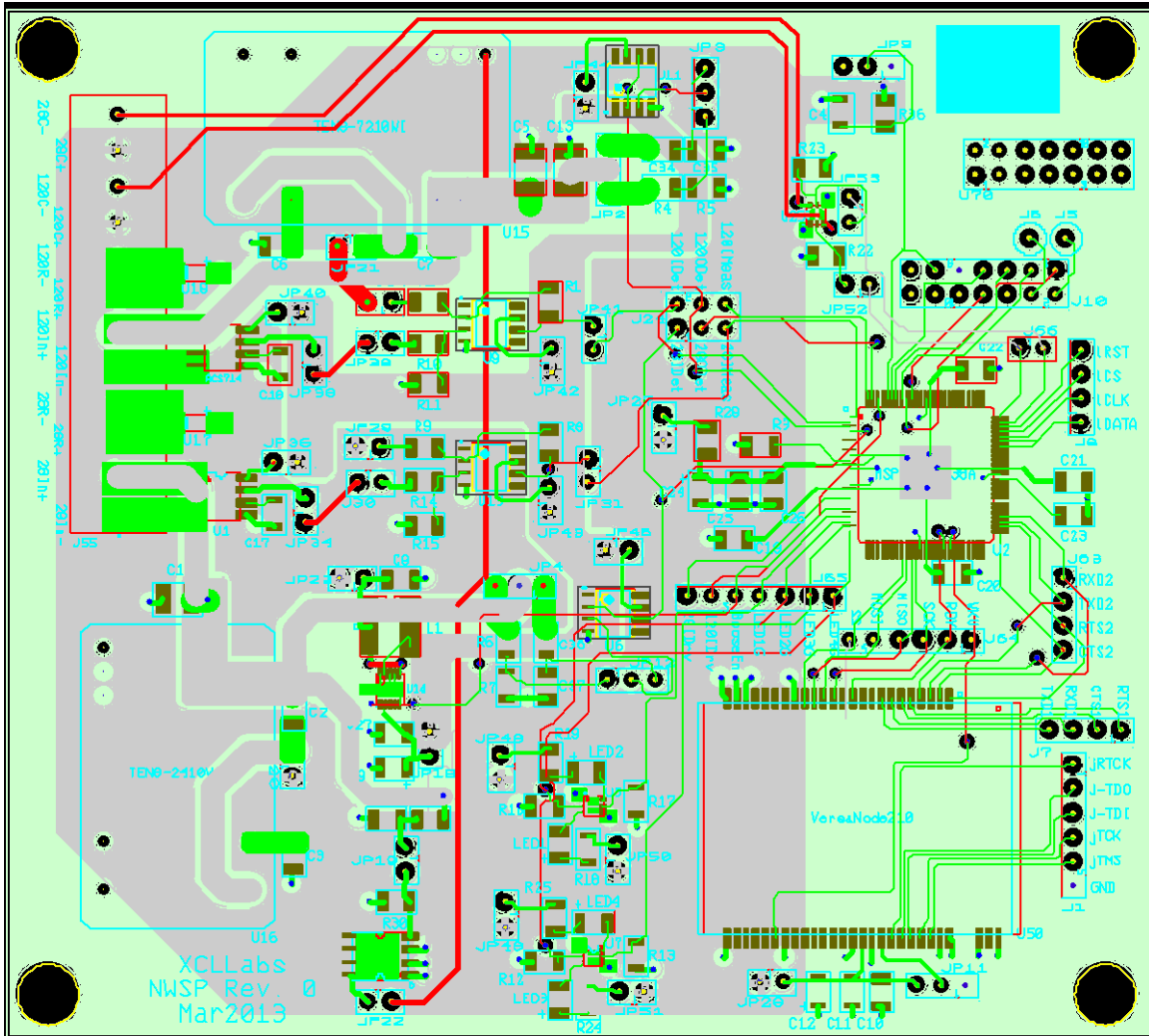




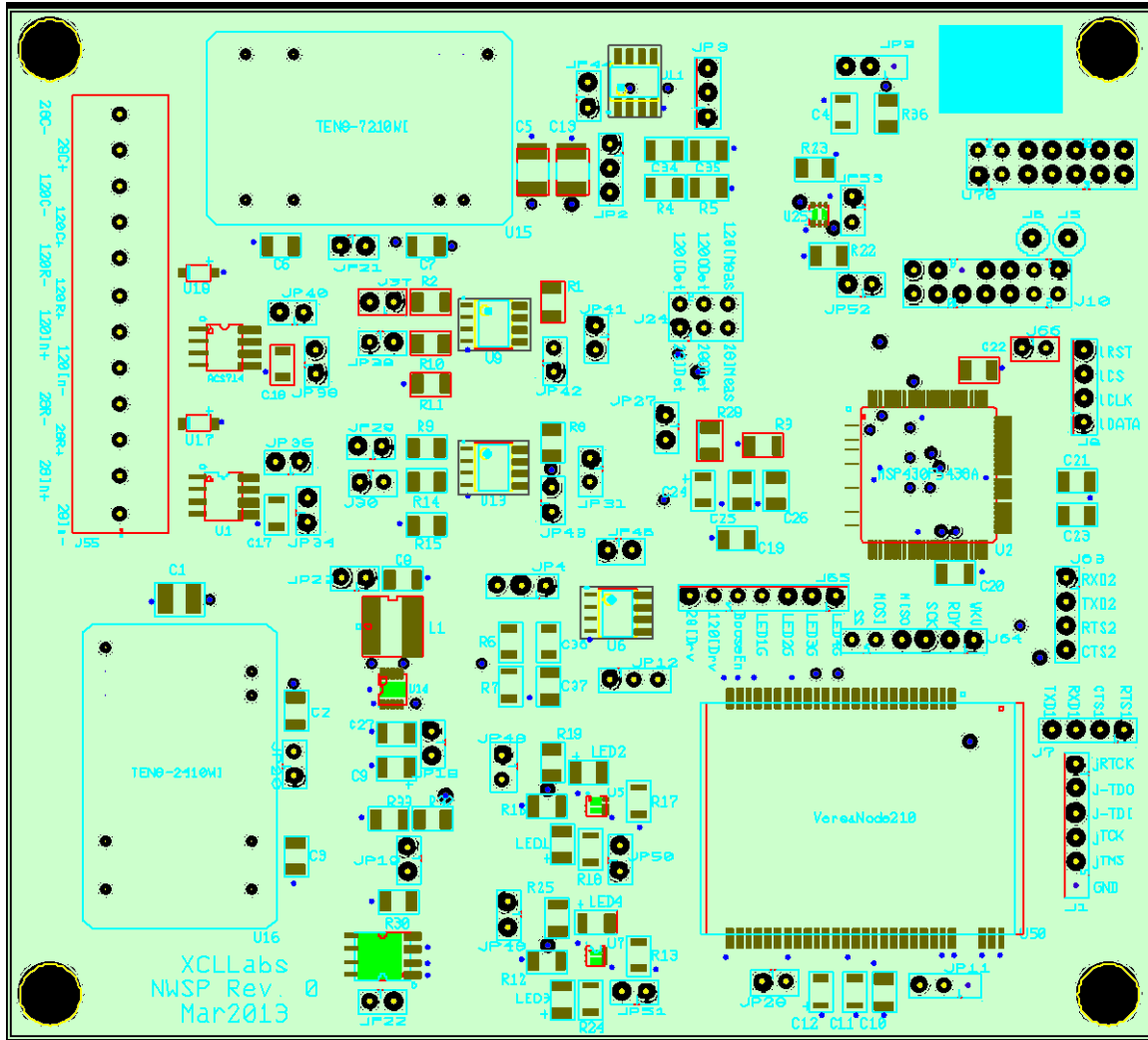




Appendix E: Alpha PCB Layout

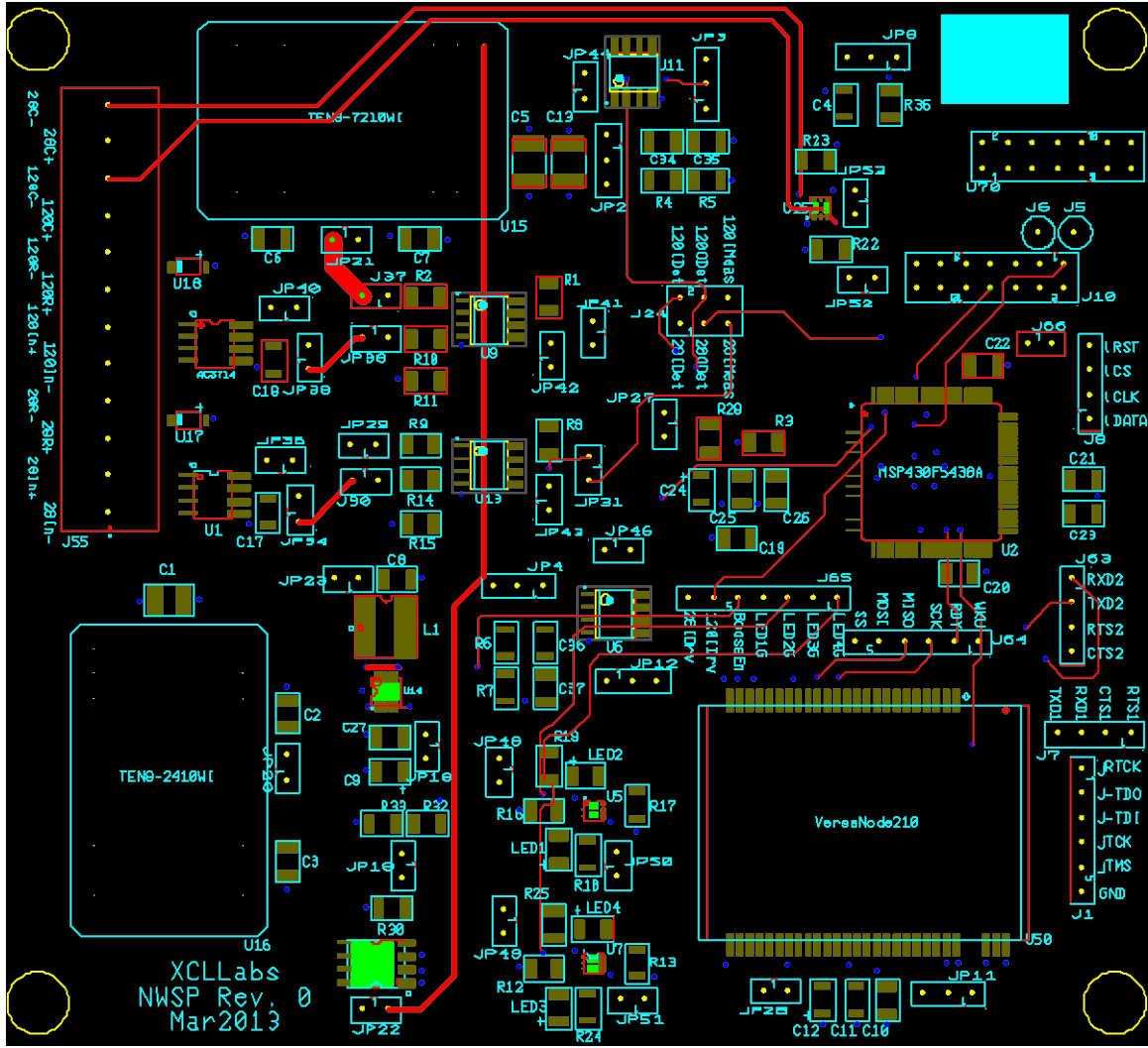


Alpha PCB Overview



Alpha

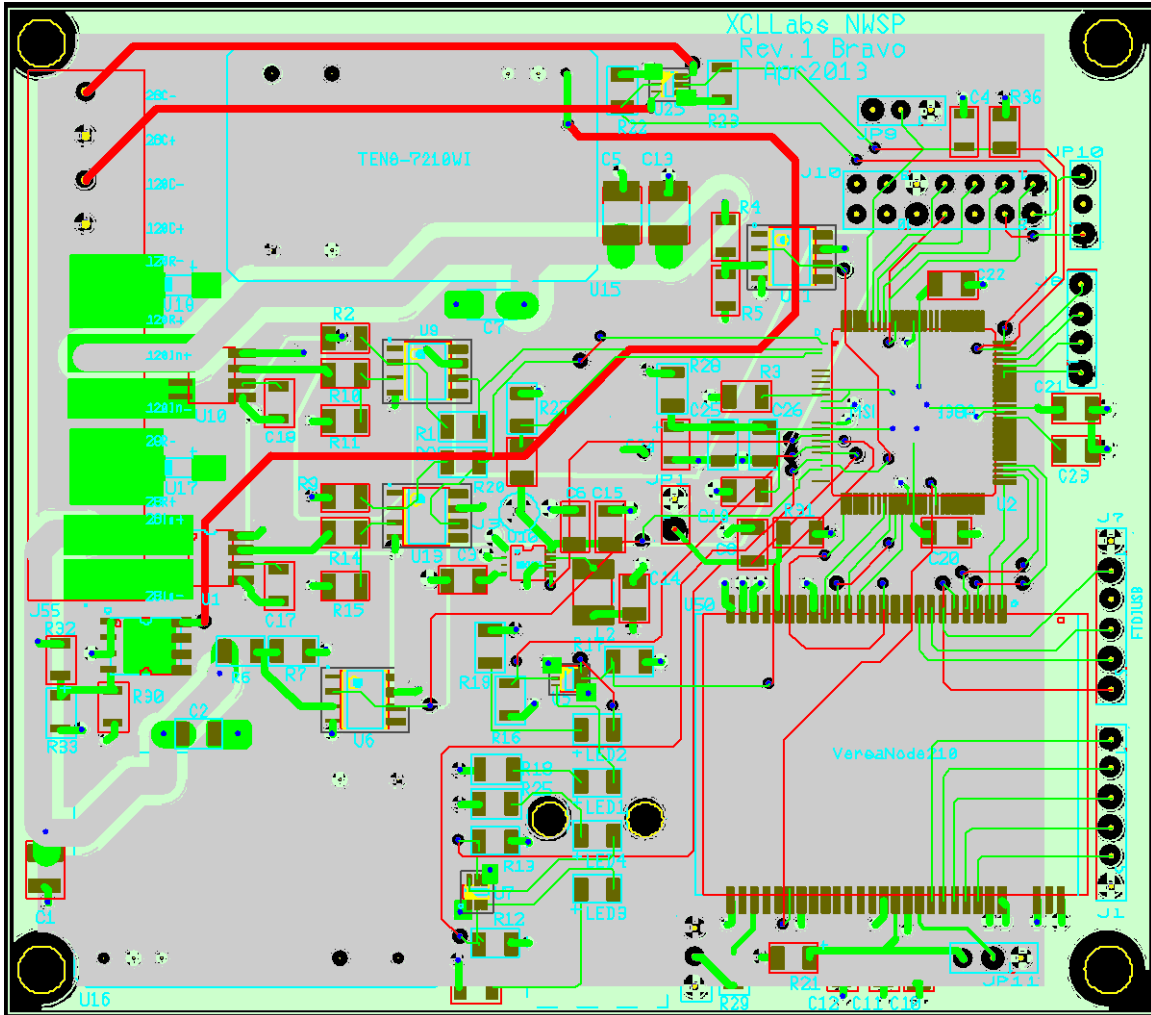
Alpha Copper Inner Layer 1



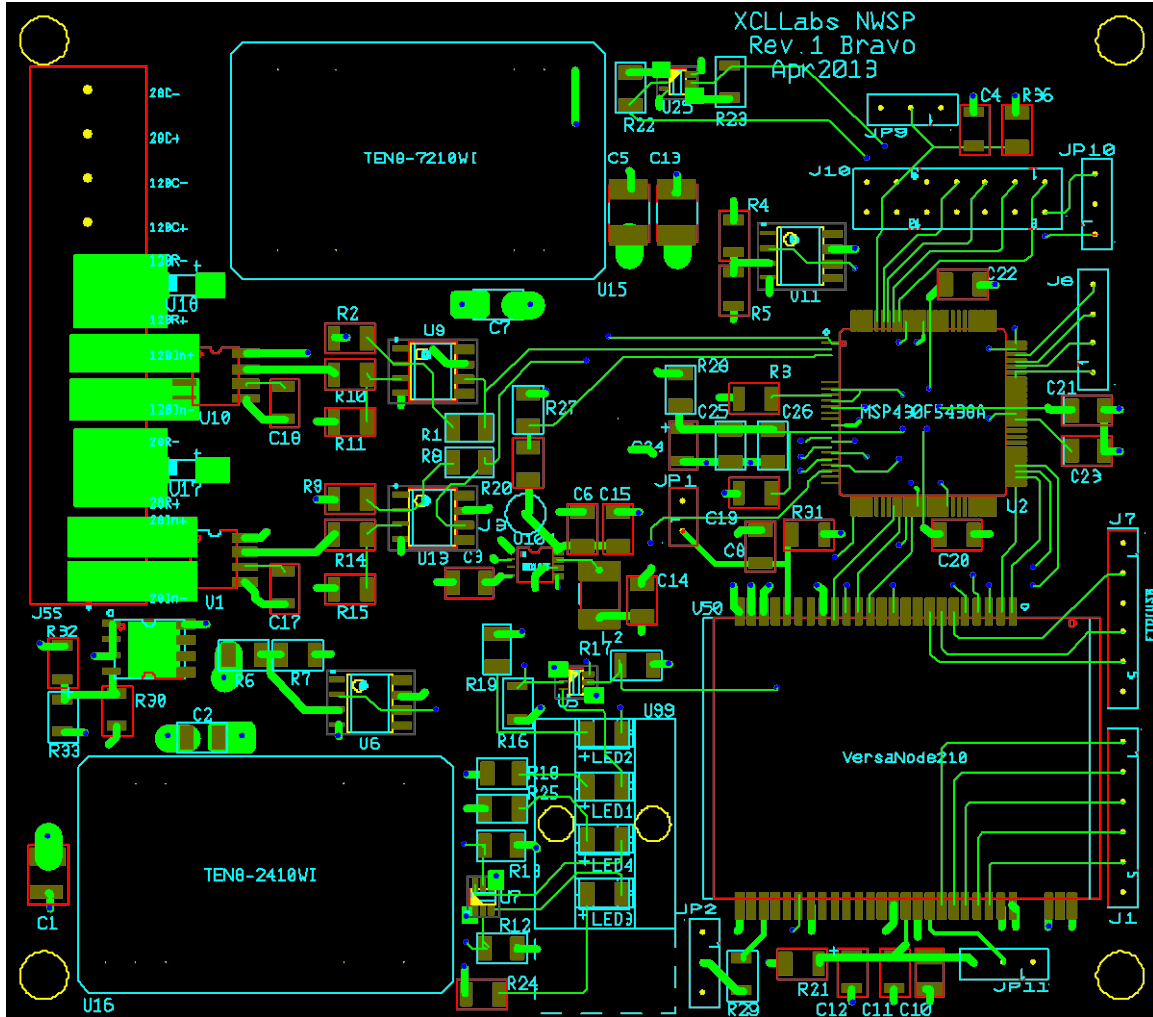
Alpha Copper Bottom



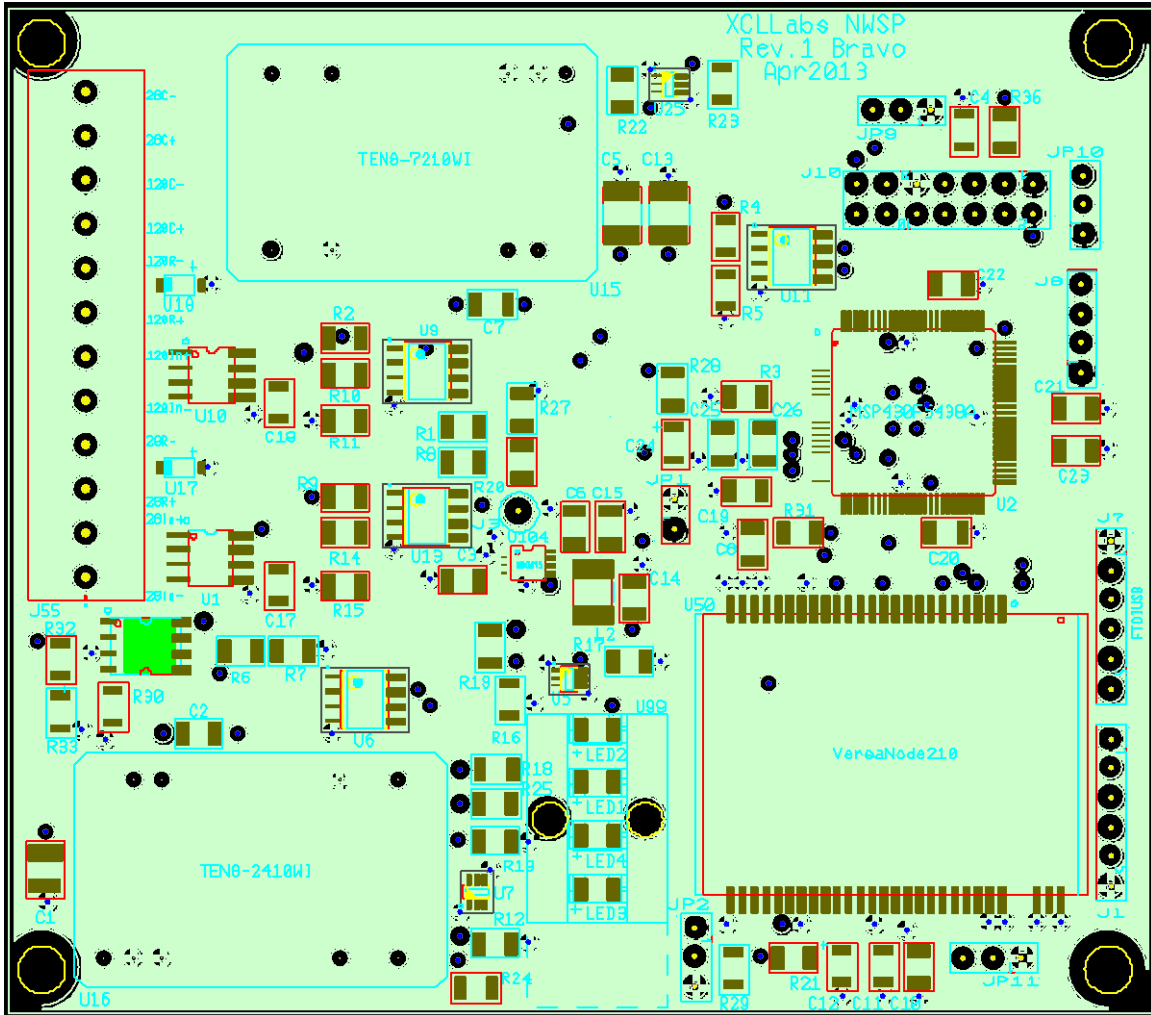
Appendix F: Bravo PCB Layout



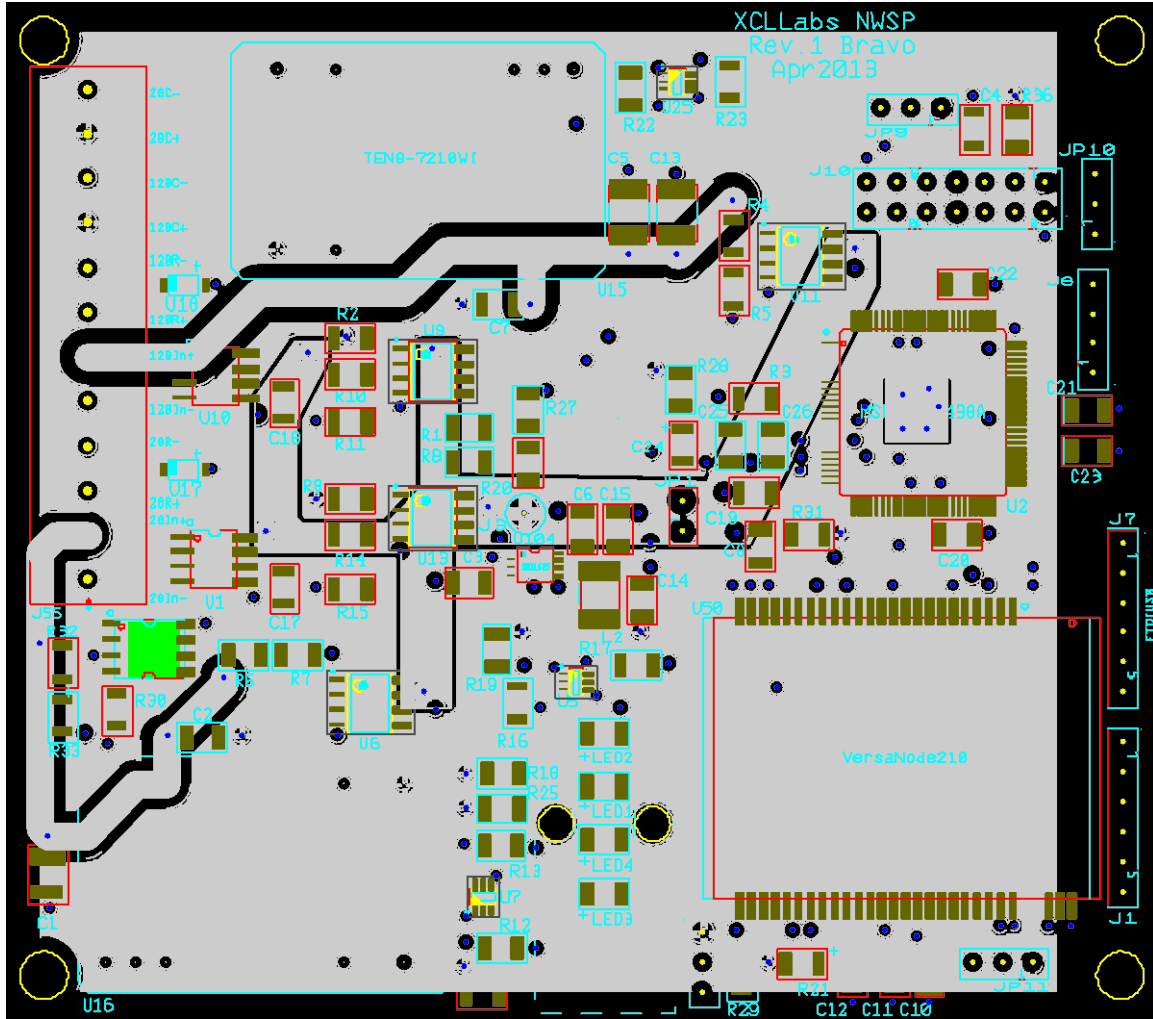
Bravo PCB Overview



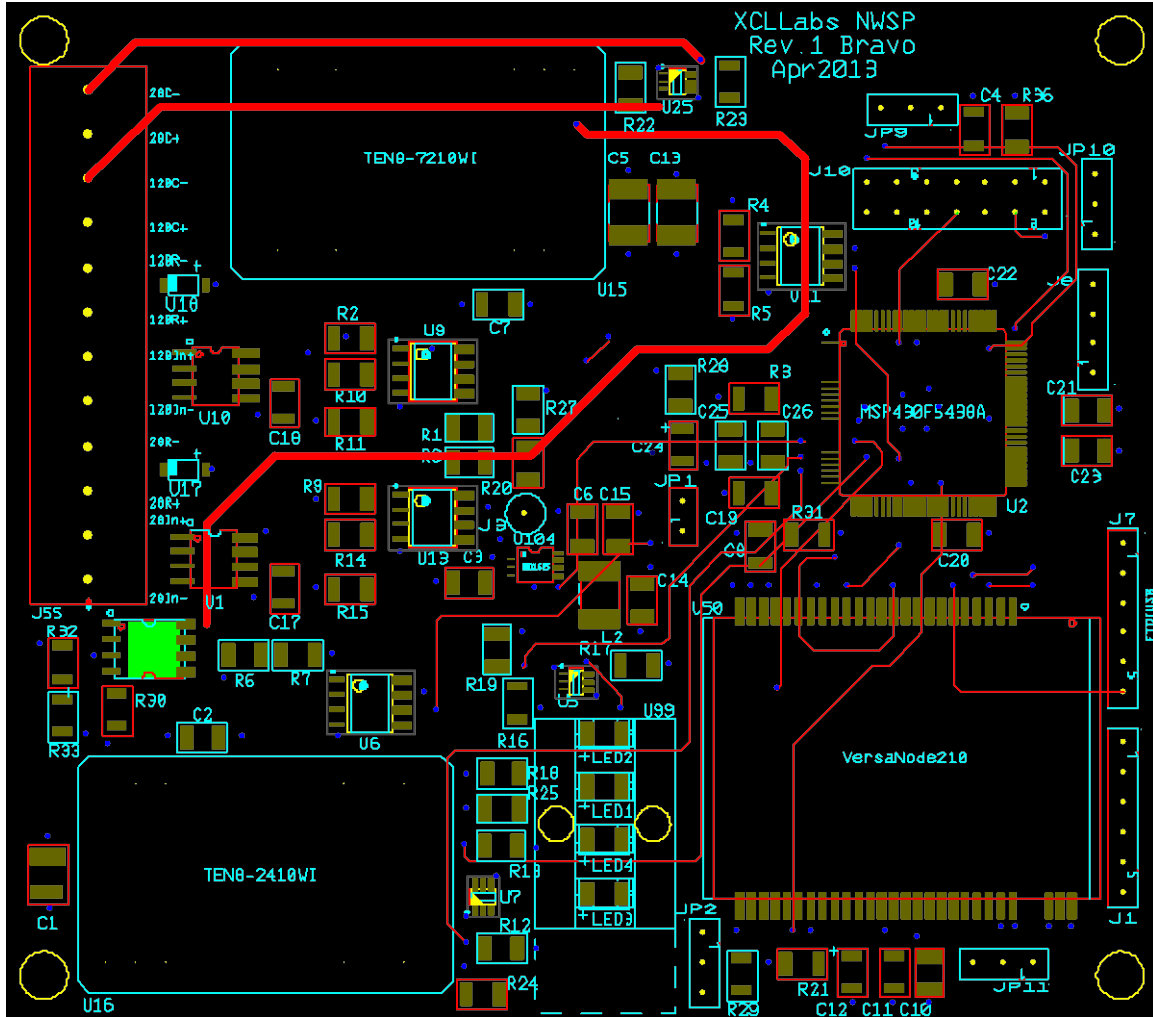
Bravo Copper Top



Bravo Copper Inner Layer 1



Bravo Copper Inner Layer 2



Bravo Copper Bottom



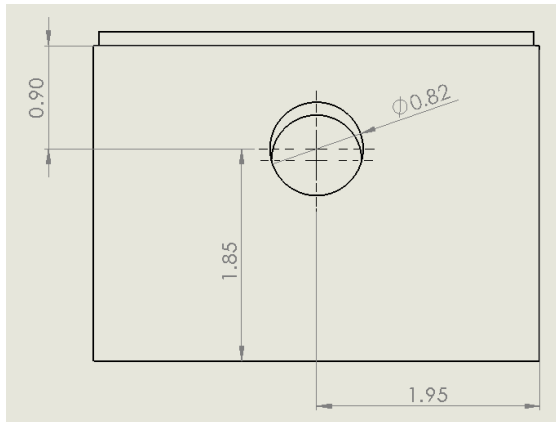
Appendix G: Code Listing



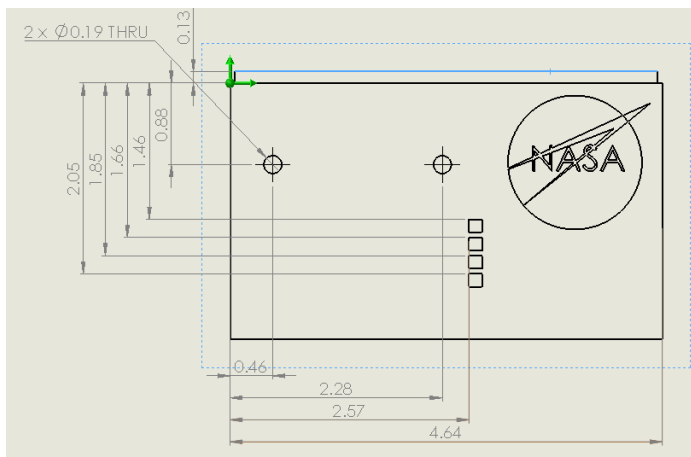
Appendix H: Mechanical Drawings



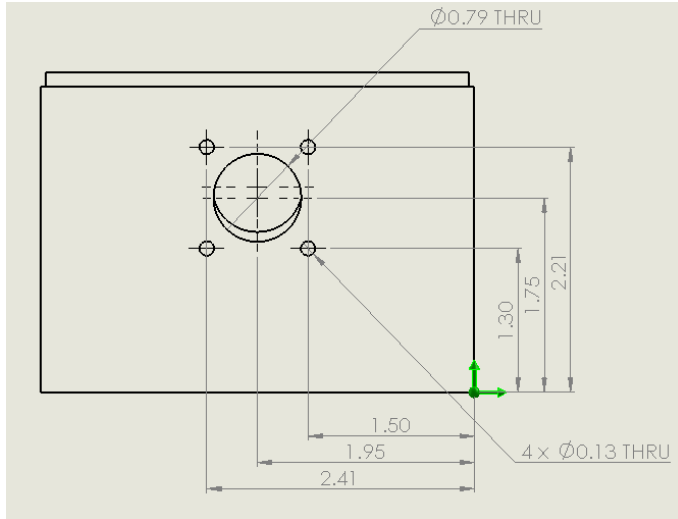
Back



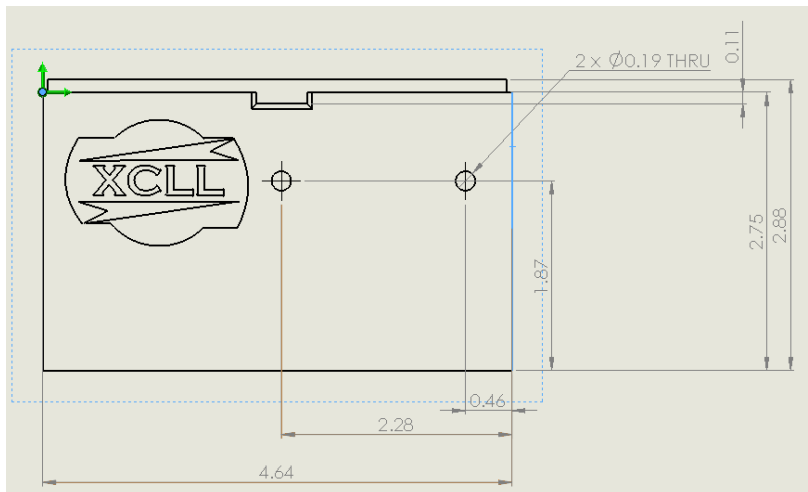
Left



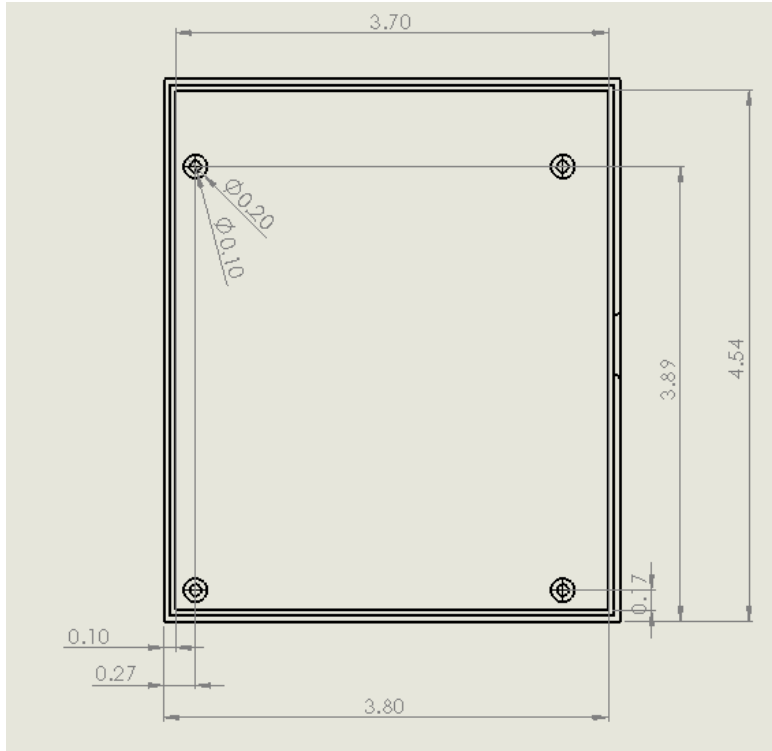
Front



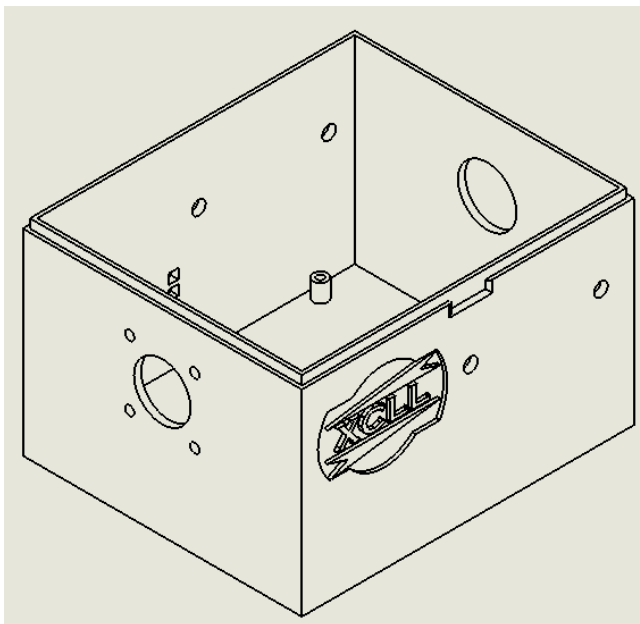
Right



Top

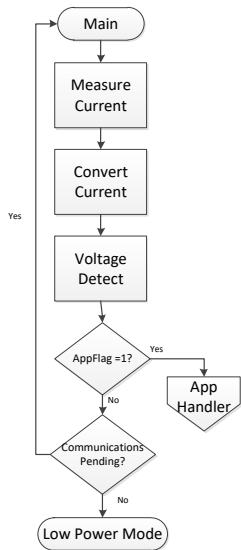
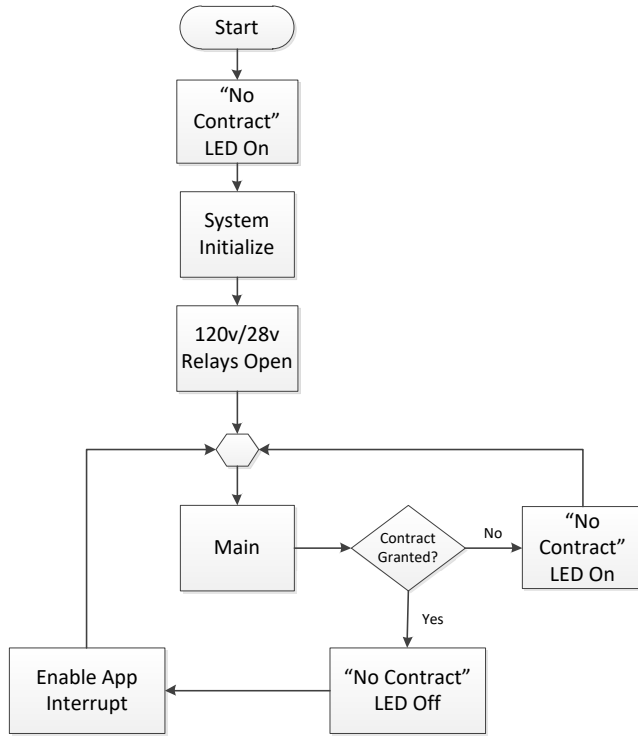


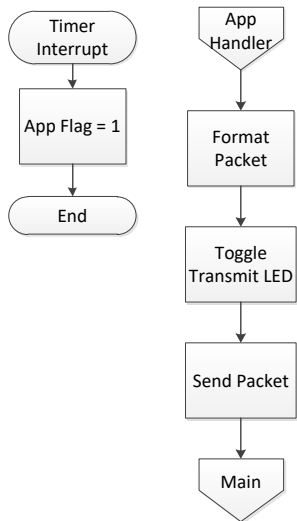
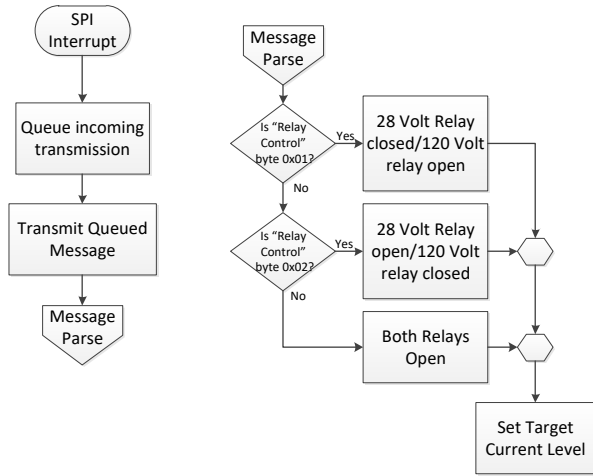
Isometric





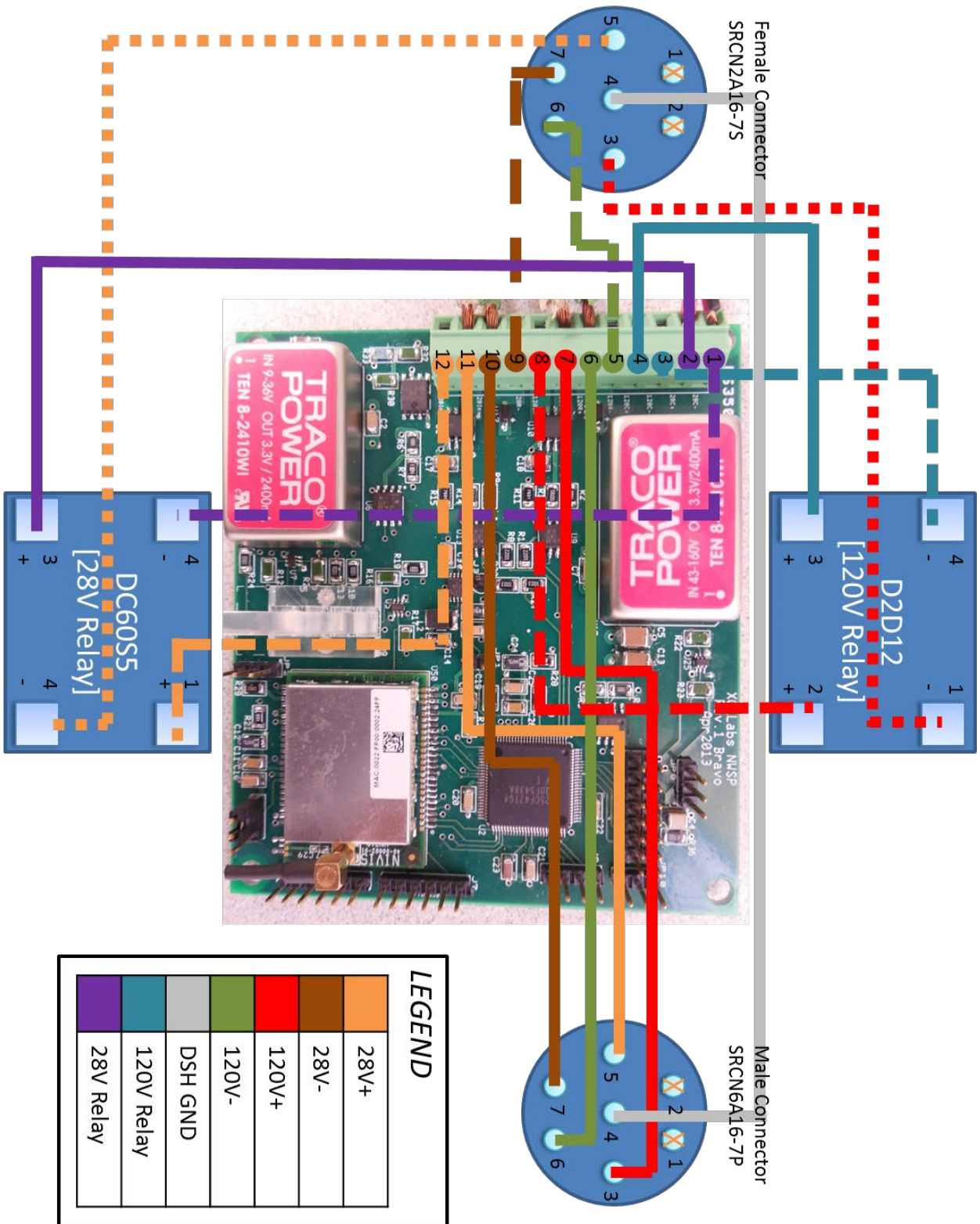
Appendix I: Flow Charts







Appendix J: NWSP to DSH and End-Device Connection Diagram





Appendix K: Resumes