MegaSat
Assembly Manual

December 2020

Electronics Development Group
Department of Physics and Astronomy
Louisiana State University
Baton Rouge, LA

Description

The MegaSat is a custom sensor interface shield which serves as the platform for learning to use and apply the Arduino Mega 2560 development board. It includes an accelerometer/gyroscope breakout board, internal and external temperature sensors, humidity and pressure sensors, and a real-time clock (RTC). Power is provided to the MegaSat’s sensors and circuits by a +12V supply. Voltage regulators are used to supply +3.3V and +5V. There is also a +5V reference onboard. The MegaSat includes a datalogger shield that provides GPS, micro-SD for storage, and a small prototyping area.

The MegaSat is a shield that interfaces with the Arduino Mega 2560 development board. It features a 16-channel, 10-bit analog-to-digital converter (ADC) with 16 analog input/output (I/O) pins. It has 54 digital I/O pins, 15 of which are designated for pulse width modulation (PWM) with 6 interrupts, and 4 are designated universal asynchronous receiver-transmitter (UART) hardware serial ports. It has a 16 MHz processor with 8 kB static random-access memory (SRAM), 256 kB of flash memory, and 4kB electrically erasable programmable read-only memory (EEPROM).

MegaSat can be used as a compact data acquisition system in the laboratory or integrated into a student-designed balloon payload where it can serve as the payload flight computer. MegaSat is programmed with the Arduino integrated development environment (IDE) using the Arduino programming language, which is a C/C++ variation. The IDE runs on a personal computer where programs (referred to as sketches) are written, edited, and then uploaded to the microcontroller. Several different versions of the Arduino Mega are available. The MegaSat uses the ATmega2560 Rev3.
The **MegaSat** evolved from the **BalloonSat**, which was an adaptation of the **CanSat**. **CanSat** was a project conceived by Professor Bob Twiggs at Stanford University’s Space Science Development Laboratory in the late 1990s. The original **CanSat** included an auxiliary EEPROM memory chip for data storage and a modem (modulator-demodulator) to allow connection to an external radio transmitter and receiver.

In the early 2000s, S.B Ellison and Jim Giammanco at Louisiana State University (LSU) Department of Physics and Astronomy designed the **BalloonSat** as an adaptation of **CanSat** for the Louisiana Aerospace Catalyst Experiences for Students (LaACES) program. **BalloonSat** eliminated the modem, but provided a number of enhancements including a 4-channel ADC, a voltage reference, temperature sensor and four on-board LED’s for use as visual indicators. It also provided pins for connecting external hardware. Furthermore, a prototyping area with ground and supply buses was provided to allow students to incorporate additional components or circuits into their payload.

The **MegaSat** modernizes the **BalloonSat** and provides more versatility. It moves away from traditional through-hole components and introduces students to surface mounts which are more commonly seen in today’s market. By replacing the Parallax BASIC Stamp with the Arduino Mega, the **MegaSat** can operate more sensors and devices. Students can utilize extra peripherals and take advantage of Arduino shields for advanced projects. The **MegaSat**’s basic build provides everything needed to monitor atmospheric conditions, payload kinematics and location during a balloon flight.

**Theory of Operation**

The **MegaSat** incorporates multiple printed circuit boards (PCB) connected using extended headers. These include the **MegaSat** sensor board, an Arduino Mega 2560 development board, and an Adafruit Ultimate GPS Logger shield. The Arduino functions as the central controller for the entire **MegaSat**.

![Figure 1: High-level block diagram for the MegaSat](image)
The major functional subsystems of the MegaSat are depicted in the high-level block diagram (figure 1). The mid-level diagram (figure 2) shows how each subsystem breaks down. All the components and electrical connections are shown in the full schematic (figure 64).

For power, the MegaSat will accept an external DC source between +9 VDC and +15 VDC. The circuit is protected by a Schottky diode, which prevents damage if the supply is accidentally connected backwards (reversing the polarity). A resettable fuse is connected between the cells of the power supply to prevent damage from short circuits. The sensors and integrated circuits require a clean, stable +5V or +3.3V power source under conditions of changing input voltage or amount of current required by the MegaSat. This is provided by voltage regulators V1 and V2, respectively.

Both temperature sensors (internal and external) and the humidity sensor require a reference voltage with higher precision than the voltage regulators can provide. Voltage reference V3 is used to maintain a constant +5V reference for these sensors. The power converters supply enough current for all of the MegaSat’s onboard components. The Arduino Mega and GPS shield also have their own internal voltage regulations.

The Arduino Mega 2560 development board is a microcontroller breakout board for the ATmega2560 microchip. Programs are written in the Arduino IDE and uploaded from a personal computer to the Arduino Mega using a USB cable. Once programmed, the Arduino Mega can be
disconnected from the personal computer and will execute the uploaded program every time it is powered on.

Figure 2 summarizes the I/O pins associated with each device. The Arduino Mega always serves as the master [sic] device in synchronous serial communication. The master [sic] initiates all operations and generates the required serial clock signal. Caution must be exercised not to apply negative voltages or voltages greater than +5V to any Arduino pin.

Various protocols have been established in the industry for synchronous serial I/O. Some common protocols are the Inter-Integrated Circuit (I²C) developed by Phillips Semiconductor, Microwire from National Semiconductor, Serial Peripheral Interface (SPI) created by Motorola, and the Dallas Semiconductor OneWire protocol. Component datasheets will usually describe the protocol used in sufficient detail for writing and debugging user programs. Example circuits and programs are often available from the chip manufacturer’s datasheets or websites.

The Arduino Mega contains onboard flash memory for storing the executable program (your sketch). Flash memory is nonvolatile, which means it retains the program even if the power is lost. There is a limited amount of SRAM to create and work with variables and data. The SRAM is volatile and will therefore lose data when the power is turned off.

EEPROM is also available onboard. This is nonvolatile memory that is similar to a hard drive in a computer. EEPROM can be erased and used again, but it does have a limited number of write cycles before it “wears out.” This is usually on the order of 50,000 writes. It is possible to “wear out” the EEPROM if a user program “runs away” and repeatedly writes to the EEPROM chip. Inadvertently placing a write routine in an endless loop is a common programming mistake.

The MegaSat has a dedicated RTC that continuously runs regardless of what other tasks the Arduino Mega microcontroller may be performing. It uses a Maxim Integrated DS3231 timekeeping chip with provisions for an external backup battery. The external battery can be connected to P3 on the MegaSat sensor board. The current requirements are so small that a backup battery will typically last its shelf life for this type of application.

For extreme environmental conditions, the choice of battery does require some care. Review the DS3231 datasheet for voltage and current requirements. Note that this backup battery only serves the RTC. The other systems of the MegaSat still require their respective supplies for proper operation.

The DS3231 uses a simple two-wire serial interface with an integrated temperature-compensated crystal oscillator and crystal which enhances long-term accuracy of the device. I/O pin D20 (SDA) is the bidirectional data line, and I/O pin D21 (SCL) is the serial clock. Together, these make up the I²C interface which allows multiple peripherals to share the same clock and data lines, yet operate independently of one another.

The Sparkfun MPU-6050 accelerometer/gyroscope breakout board shares the I²C bus with the RTC, where it also uses I/O pins D20 (SDA) for data and D21 (SCL) for the serial clock. In order for both components to operate independently of one another, they must have different slave [sic]
addresses. The RTC operates under a permanent address which is b1101000 and the MPU-6050 has a programmable address that is set to b1101001.

The breakout board incorporates the InvenSense MPU-6050 microchip which contains a 3-axis gyroscope, a 3-axis accelerometer, and a digital motion processor. It allows for precise tracking of both slow and fast motion by using a programmable accelerometer that can scale the range of ±2g, ±4g, ±8g, and ±16g. There are three onboard 16-bit ADCs for digitizing the accelerometer outputs.

To monitor the inertial reference, it has a gyroscope with a programmable full-scale range of ±250, ±500, ±1000, and ±2000 dps (degrees per second). For better customization, the sampling rate can be programmed from 3.9 to 8000 samples per second. It also has three on-board 16-bit ADCs for digitizing the gyroscope outputs.

Both the RTC and the MPU-6050 have logic levels of 3.3V. The Arduino Mega supports a 5V logic. To allow for easy communication between these devices, a voltage level shifter (U3) is used to step up the 3.3V logic to a 5V logic that the Arduino can process.

The temperature sensors use ordinary PN junction silicon diodes (S1 and S2) to measure the change in temperature. With a constant current applied, the voltage will decrease at a rate of approximately 1 to 2 mV/ºC. This change occurs in a near-linear fashion which makes it easy to correlate the change in voltage with the change in temperature. A constant current of 1 mA is provided by integrated circuits CS1 and CS2.

The internal temperature sensor produces a very small output voltage and requires amplification from op amp U5. Resistors R9, R10, R11, R12, R13 and R14 and are used to determine the voltage gain of this stage. Variable resistors R13 (offset) and R14 (gain) can be adjusted by a small screwdriver for fine tuning. The output from U5 is connected to analog channel 2 (A2) on the Arduino microcontroller.

The external temperature output is amplified by op amp U6. Resistors R15, R16, R17, R18, R19 and R20 determine the voltage gain of this stage. Variable resistors R19 (offset) and R20 (gain) can be adjusted by a small screwdriver for fine tuning. The output of U6 is connected to analog channel 1 (A1) on the Arduino microcontroller.

The HIH-4000 humidity sensor is designed to produce a near-linear voltage output that correlates to changes in relative humidity. It uses a thermoset polymer capacitive sensing element with integrated signal conditioning. Changes in sensor capacitance relate directly to changes in relative saturation. Relative saturation, when at ambient temperature, is the same as ambient relative humidity. Therefore, changes in the sensor capacitance can be used to measure changes in relative humidity. The sensor is sensitive to light and must remain shielded or it will produce inaccurate readings.

The humidity sensor is ratiometric with respect to its supply voltage, so a well-regulated +5V supply is required. This is provided by V3. The sensor output is amplified by op amp U4. Resistors R5, R6, R7 and R8 determine the voltage gain of this stage. Variable resistors R7 (offset)
and R8 (gain) can be adjusted by a small screwdriver for fine tuning. The output of U4 is connected to analog channel (A3) on the Arduino Mega microcontroller.

The TE Connectivity 1230 is a piezoresistive silicon pressure sensor that uses a Wheatstone bridge configuration as a stress gauge to monitor changes in voltage. Due to proprietary UltraStable technology, these changes have a near-linear relationship with respect to changes in pressure.

The pressure sensor requires a constant current of 1.5 mA which is provided by CS3. The output is amplified by op amps U8 and U9. Resistors R23, R24, R25, R26, R27, R28, R29 and R30 determine the voltage gain of this stage. Variable resistor R30 can be adjusted by a small screwdriver for fine tuning. The output of U8 connects to U9, and the output of U9 connects to analog channel (A0) on the Arduino Mega microcontroller.

The Adafruit Ultimate GPS Logger shield contains both a GPS chip and a microSD card reader. The GPS uses UART for asynchronous serial communication. It has a switch that toggles between software serial and direct serial. The Arduino Mega communicates through pins D18 (TX) and D19 (RX). At nearly any location on or near Earth’s surface, the GPS should be able to receive a signal from at least four GPS satellites. This information is used to trilaterate the signal and determine the location of the GPS receiver within 5 to 10 meters of accuracy in only a couple of seconds.

Data is received in a sentence which follows the format set by the National Marine Electronics Association (NMEA) 0183 protocol. The datasheet explains this information in detail, including how to customize what the information received based on the experiment’s specific needs.

The GPS has a sensitivity of -165 dBm (decibel-milliwatts), a 10 Hz refresh rate, and 66 channels. It includes built-in datalogging to flash memory. There is an onboard patch antenna and a connection provided for an external antenna. It has low power consumption compared to other GPS devices with only a 20 mA current draw.

The shield also offers a microSD card reader. The card reader uses the SPI protocol for synchronous serial communication. The designated pins are D10 for chip select (CS), D11 for master out slave in (MOSI), D12 for master in slave out (MISO), and D13 for serial clock (SCK).
# Inventory

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Part ID</th>
<th>Image</th>
<th>Description</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B0</td>
<td><img src="image1.png" alt="Image" /></td>
<td>MegaSat PCB</td>
<td>Loose in Envelope</td>
</tr>
<tr>
<td>1</td>
<td>B1</td>
<td><img src="image2.png" alt="Image" /></td>
<td>Arduino Mega ATmega2560 Rev3 Microcontroller</td>
<td>Not in Kit</td>
</tr>
<tr>
<td>1</td>
<td>B2</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Adafruit Ultimate GPS Logger Shield</td>
<td>Not in Kit</td>
</tr>
<tr>
<td>1</td>
<td>U1</td>
<td><img src="image4.png" alt="Image" /></td>
<td>Sparkfun Accelerometer/Gyroscope Breakout Board</td>
<td>Sensors Module</td>
</tr>
<tr>
<td>1</td>
<td>U7-B</td>
<td><img src="image5.png" alt="Image" /></td>
<td>ICS1230 Pressure Sensor DIP-8 0.6” Wide Package</td>
<td>Sensors Module</td>
</tr>
<tr>
<td>1</td>
<td>S3</td>
<td><img src="image6.png" alt="Image" /></td>
<td>IMPORTANT – The humidity sensor is packaged with a small slip of paper containing the manufacturer’s certification and test data. BE SURE TO RETAIN THIS ESSENTIAL INFORMATION</td>
<td>Sensors Module</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HIH-4000-003 Relative Humidity Sensor</td>
<td>Sensors Module</td>
</tr>
<tr>
<td>Quantity</td>
<td>Component</td>
<td>Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>D2, S1, S2</td>
<td>1N457 Silicon Small Signal Diode, Axial Leads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>U2</td>
<td>DS3231SN RTC Module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>U3</td>
<td>TCA9517DR Bidirectional Level Shifter Module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>U5, U6, U9</td>
<td>AD820 Single Op Amp Module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>U4, U8</td>
<td>AD822 Dual Op Amp Module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CS1, CS2, CS3</td>
<td>LM334M Current Source Module</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>V1</td>
<td>LM1117_5V Regulator Power Module</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>V2</td>
<td>LM1117_3.3V Regulator</td>
<td>Power Module</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>V3</td>
<td>REF02 5V Reference</td>
<td>Power Module</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>LED1</td>
<td>Red LED</td>
<td>Power Module</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>D1</td>
<td>1N5818 Schottky Diode</td>
<td>Power Module</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R13, R19</td>
<td>1 kΩ Potentiometer</td>
<td>Temperature Module</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R14, R20</td>
<td>100 kΩ Potentiometer</td>
<td>Temperature Module</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>R7, R8, R30</td>
<td>10 kΩ Potentiometer</td>
<td>Humidity Module Pressure Module</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.2 kΩ 1210 SMD Resistor</td>
<td>Power Module</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>--------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>2</td>
<td>R12, R18</td>
<td>68 Ω 1210 SMD Resistor</td>
<td>Temperature Module</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R9, R15</td>
<td>3.9 kΩ 1210 SMD Resistor</td>
<td>Temperature Module</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R11, R16</td>
<td>180 kΩ 1210 SMD Resistor</td>
<td>Temperature Module</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R10, R17</td>
<td>20 kΩ 1210 SMD Resistor</td>
<td>Temperature Module</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>R6</td>
<td>75 kΩ 1210 SMD Resistor</td>
<td>Humidity Module</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>R4</td>
<td>6.8 kΩ 1210 SMD Resistor</td>
<td>Humidity Module</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
</tbody>
</table>
| 3 | R2, R3, R5 | 10 kΩ 1210 SMD Resistor | RTC Module  
Humidity Module |
<p>| 1 | R21 | 910 Ω 1210 SMD Resistor | Pressure Module |
| 1 | R22 | 91 Ω 1210 SMD Resistor | Pressure Module |
| 1 | R23 | 3.3 kΩ 1210 SMD Resistor | Pressure Module |
| 2 | R24, R25 | 100 kΩ 1210 SMD Resistor, 0.1% tolerance | Pressure Module |
| 4 | R26, R27, R28, R29 | 10 kΩ 1210 SMD Resistor, 0.1% tolerance | Pressure Module |
| 15 | C1, C2, C3, C4, C6, C7, C8, C10, C11, C12, C14, C15, C16, C17, C18 | 1 μF 1210 SMD Ceramic Capacitor | Temperature, Pressure, &amp; Humidity Modules |</p>
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Component Details</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>C9, C13, C5, C19</td>
<td>10 μF Electrolytic Capacitor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temperature, Pressure, &amp; Humidity Modules</td>
</tr>
<tr>
<td>1</td>
<td>B1-B</td>
<td>CR1220 Coin Cell Battery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RTC Module</td>
</tr>
<tr>
<td>1</td>
<td>B1</td>
<td>Coin Cell Battery Holder</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RTC Module</td>
</tr>
<tr>
<td>1</td>
<td>P1</td>
<td>Terminal Block Plug 2 Position</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power Module</td>
</tr>
<tr>
<td>1</td>
<td>J1</td>
<td>Terminal Block Header 2 Pin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power Module</td>
</tr>
<tr>
<td>2</td>
<td>J3, J4, J5</td>
<td>Right-Angle Breakaway Header (2 pin)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temperature Module Arduino Hardware</td>
</tr>
<tr>
<td>1</td>
<td>J2</td>
<td>Right-Angle Breakaway Header (3 pin)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Humidity Module</td>
</tr>
<tr>
<td></td>
<td>Part Number</td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3</td>
<td>J3-B, J4-B, J5-B</td>
<td>Connection Housing 2 Position</td>
</tr>
<tr>
<td>1</td>
<td>J2_B</td>
<td>Connection Housing 2 Position</td>
</tr>
<tr>
<td>7</td>
<td>---</td>
<td>Connection Terminal Female 22-24 AWG Tin</td>
</tr>
<tr>
<td>1</td>
<td>U7</td>
<td>8-pin 0.6” spacing (may be cut down from 24-pin socket)</td>
</tr>
<tr>
<td>7</td>
<td>B0_H8</td>
<td>8-Pin Stackable Headers</td>
</tr>
<tr>
<td>2</td>
<td>B0_H10</td>
<td>10-Pin Stackable Headers</td>
</tr>
<tr>
<td>1</td>
<td>B0_H36</td>
<td>36-Pin Stackable Headers</td>
</tr>
<tr>
<td></td>
<td>B2_SD</td>
<td>MicroSD Card (minimum 8 GB class 10)</td>
</tr>
<tr>
<td>---</td>
<td>-------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
When soldering surface mounts, it may be helpful to begin by heating a small amount of solder onto one pad, then aligning the component properly on top. After which, heat can be applied to the pad with the solder. This helps keep the component in place allowing you to more easily solder the other pins to their corresponding pads.

It can be helpful to start soldering components inward and work your way out, soldering smaller components before larger ones. Allow yourself enough space to work in and avoid blocking access to areas or pads you may need to reach later on.

A via is a small hole drilled into the circuit board. If a via is near a solder pad you are working with, be mindful not to solder over it. This can create a short circuit and prevent the circuit from functioning properly.

There is a silkscreen outline of each component on the printed circuit board (PCB) that shows the part ID as well as orientation and alignment of the component to help guide you through proper installation.

A footprint is the arrangement of pads or drill holes where you solder the components to the PCB. These also help with orientation and proper placement for each component.

Refer to datasheets to identify the location and function for each pin of the components you are working with. This will help prevent accidentally soldering a component in backwards.

Check resistor values prior to installing (see the user’s manual for your multimeter to obtain detailed instructions on how to measure resistance).

The footprints for the potentiometers were designed to accommodate both linear and triangular pin configurations, so you will always have one unused hole regardless of which potentiometer you use. The triangular configuration is recommended due to the additional support it offers.

When soldering electronic components, verify if the component is polarized. Diodes, electrolytic capacitors, and many other electronics require a specific orientation for successful operation. There are indicators on the board and details in the instructions to identify the correct orientation of parts.

Staying organized while you work can help prevent mistakes. Use the check boxes provided to mark off the components once they have been installed. It is also helpful to highlight the schematic as each step is complete.

The MegaSat will be assembled in stages. For each stage, you will be provided module-specific information such as inventory, schematic, images of the PCB (both assembled and unassembled), and assembly instructions. This document is meant to be self-sustaining; however, you may find it useful to reference the accompanying lectures and activities for additional assistance. For component-specific information, always refer to the datasheet for that specific component.

At the end of each assembly module, you will find a checkpoint, troubleshooting steps and when applicable an exercise. It is recommended to complete all of these steps and record your findings in a lab notebook.
Sometimes, there is a need to create a custom circuit as part of MegaSat. This can be done without the time and expense of a separate circuit board by using the prototyping area on the GPS shield. This provides space for soldering components directly onto the circuit board. It is best to draw the desired circuit and layout a tentative component placement plan prior to soldering components to the MegaSat.

The stacking headers on the GPS shield connect directly to the MegaSat and can be used for expansions (be mindful not to use a port that is already in use by another component). Additional pads are provided on the sensor board for all of the Arduino Mega’s I/O pins, as well as I2C connections through the bidirectional level shifter.

If high current devices such as some incandescent lamps, motors, or relays are connected to MegaSat, a separate power source for high current loads is recommended.

If you incorporate expansions to your sensor board, it might be necessary to disable some of the MegaSat’s internal devices if they are not needed for a specific application. This will free I/O pins for use by external peripherals.

Caution must be exercised not to apply negative voltages or voltages greater than +5 VDC to any Arduino pin. Devices with +5 VDC logic can connect directly to the Arduino Mega. Devices with +3.3 VDC must go through the bidirectional logic level shifter and the address must be changed as to be different than the RTC and accelerometer/gyroscope.

Expanding the MegaSat
Checkpoints

Throughout the manual, there will be various checkpoints. The checkpoints help identify any potential issues. It is much easier to troubleshoot and debug problems as they occur rather than wait until the entire board has been complete.

It is recommended to use a bench supply for testing as opposed to a battery pack. If it is a current-limiting supply, set the current to no more than 200 mA. The current will rarely reach 200 mA and will stabilize around 160 mA with the MegaSat in full operation. Set the voltage between +9 VDC and +12 VDC. Do not exceed +15 VDC. This will damage the Arduino and the op amps.

It is helpful to become familiar with normal operating values for the circuit. Knowing how things should work can help you better determine what is not responding appropriately if you need to troubleshoot something later on. Note that values are approximate. See datasheets for specific tolerance ratings of individual components.

You will be provided a table stating the location of the test point along with the expected value. This will be accompanied by an empty column where you can document the measured value from your circuit.

Safety First!

- Remember to wear safety goggles!
- Solder can splash and clippings can fly.

- Soldering irons get hot...450 degrees Celsius to melt most solder…that’s approximately 842 degrees Fahrenheit!
- Don’t touch the solder tip while the unit is powered.
- Wait for the soldering iron to cool down before returning it to storage.
- Always keep your hair pulled back.
- Avoid loose, long-sleeve shirts or clothing that may come in contact with the iron.
- Never leave an iron unattended!

- Electrical components are sensitive to electrostatic discharge (ESD).
- When possible, it is recommended to use ESD-rated tools and mats.
Power for the MegaSat is provided by an external 12-volt battery pack comprised of two 2CR5 lithium batteries connected in series. A resettable fuse is installed between the two cells to prevent damage from short circuits. Power is provided through a block plug that connects the batteries to the PCB board using two multi-conductor cables. A Schottky-barrier diode, D1 (1N5818) protects the system from damage should the battery be accidently connected backwards, which would reverse the polarity.

Two linear voltage regulators are used to provide the necessary +5V and +3.3V needed for the components of the MegaSat to function. The voltage regulators are used to step the input supply down to +5V and +3.3V, provided by V1 (LM1117_5V) and V2 (LM1117_3.3), respectively.

The temperature and humidity sensors must have a precisely regulated reference voltage to ensure that measurements are stable and accurate. A precision, temperature-compensated voltage reference is provided by V3 (REF-02CESA).

Open your assembly kit and find and open the Power Module packet. Locate the following components. Check off each component after you have located each component.
Power Module Parts List

- V1: LM1117 5V Regulator
- V2: LM1117 3.3V Regulator
- V3: REF02-CESA 5V Reference
- D1: 1N5818 Schottky Diode
- LED1: Red LED
- R1: 1.2 kΩ Resistor
- J1: Two-Pin 5 mm Vertical Male Headers
- P1: Two-Pin Term Block Plug

Power Module Schematic

Figure 3: Schematic for power circuit

Power Module PCB Layout

Figure 4: Unassembled printed circuit board for power circuit
Power Module Assembly

Power Module Assembly Step 1
Locate the REF02-CESA chip. Align the chip on the pads at V3.

Tips for Success
Pay attention to the orientation of the chip! Pin 1 needs to be soldered to its assigned pad on the PCB board. There is a white dot on the board for Pad 1 that matches the dot on the chip for Pin 1.

Power Module Assembly Step 2
Press down on the IC gently with tweezers to hold it in place and solder one pin to the board. It may be useful to apply the solder to the pad first before attempting to attach the chip.
Power Module Assembly Step 3

Check to make sure all the other pins are aligned with their respective pads before soldering anymore pins. If the pins are not aligned, melt the solder and redo the previous step.

Power Module Assembly Step 4

Tin your soldering iron. Place the soldering wire on the pin you wish to solder. Where the pin and pad meet, apply the soldering iron gently to this area to solder the pin to the pad. Repeat this for all the pins. Do not let the iron “sit” on the pad/pin for too long as the heat can damage the board and the IC.
Power Module Assembly Step 5

Align the LM1117 3.3V Regulator (7AOR-N05B) with the pad at V2.

Power Module Assembly Step 6

Press down on the IC gently with tweezers to hold it in place and solder a pin of the chip onto the board. It may be useful to apply the solder to the pad first before attempting to attach the chip.

Tips for Success

Be careful not to install the 3.3V where the 5V goes, or vice versa. The 3.3V and 5V look almost identical so double-check what IC you are installing before soldering.

Power Module Assembly Step 7

Check to make sure all the other pins are aligned with their respective pads before soldering anymore pins. If the pins are not aligned, melt the solder tack and redo the previous step.
Power Module Assembly Step 8

Locate the LM1117 5V Regulator (83F4-N068). Align the chip with V1. Repeat steps 6 – 8 with the 5V regulator.

Power Module Assembly Step 9

The silkscreen on the printed circuit board has a white line marking that corresponds to the sliver line on the diode. Be sure to align the diode properly before soldering.
Power Module Assembly Step 10

Locate the 1N5818 Schottky diode. Bend the leads of the diode. Insert the leads into the holes of the PCB at D1. You may need to use needle nose pliers to gently pull the diode leads through the hole.

Power Module Assembly Step 11

Once the diode is flush with the board, bend the leads on the underside of the board to hold the diode in place while soldering.
Power Module Assembly Step 12

On the backside of the board, place the tip of the soldering iron to the metal ring, wait a second and bring the soldering wire to the where the ring and iron meet. The solder should melt and form a small “Hershey Kiss” on the joint. Trim the leads down to the solder joint.

Power Module Assembly Step 14

Locate the red SMD LED. Align the LED with the pad at LED1. There is a small black mark on the corner of the LED, this is the cathode marker. The silkscreen on the board has an arrow and that points in the direction of the cathode’s alignment and a white dot that aligns with the black dot on the LED.
Place the LED on top of both pads and press down on the LED gently with tweezers to hold it in place. Solder the LED onto the board. It may be useful to apply the solder to the pad first before attempting to attach the chip. Check that the LED is flush with the board, and that the other side of the LED is making contact its respective pad. If not, melt the solder and reposition the LED. When satisfied with the position, solder the other pad to the LED.

Locate the 1.2kΩ SMD resistor. Place the resistor on top of both pads at R1 and press down on it gently with tweezers to hold it in place. Solder one lead of the resistor onto the board. It may be useful to apply the solder to the pad first before attempting to solder the resistor.
Power Module Assembly Step 17

Check that the resistor is flush with the board, and that the other side of it is making contact its respective pad. If not, melt the solder tack and reposition the resistor. When satisfied with the position solder the other pad to the resistor.

Power Module Assembly Step 18

Insert the header into the board. Make sure the black plastic is flush with the board.
Power Module Assembly Step 19

One the back side of the board, place the tip of the soldering iron to the metal ring, wait a second, and bring the soldering wire to where the ring and iron meet. The solder should melt and form a small “Hershey Kiss” on the joint. Check that the male headers are still flush with the board and pointing 90° vertical from it as well. If not, use a solder wick or solder sucker to remove the solder applied in the previous step and reposition the headers.

![Image of soldering process](image1)

Power Module Assembly Step 20

Solder the other lead on the bottom side of the board.

![Image of soldering process](image2)
Using an external power supply, apply +12V to the input power of the MegaSat. Measure the voltage at the following points and record the voltage at the following points. Compare the voltage to the expected value.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Expected Value (V)</th>
<th>Measured Value (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+12V</td>
<td>Input Power</td>
<td>+12 V</td>
<td></td>
</tr>
<tr>
<td>+5V</td>
<td>5V Linear Regulator</td>
<td>+5 V</td>
<td></td>
</tr>
<tr>
<td>+3.3V</td>
<td>3.3V Linear Regulator</td>
<td>+3.3 V</td>
<td></td>
</tr>
<tr>
<td>+5V REF</td>
<td>5V Reference</td>
<td>+5 V</td>
<td></td>
</tr>
</tbody>
</table>
An ordinary PN junction diode can serve as an effective temperature sensor over a wide range of temperatures. The sensor remains fairly linear over a wide range of temperatures (50 – 400 Kelvin). When forward biased, the forward voltage drop exhibits a negative temperature coefficient of about -2.5 mV per kelvin. For example, the forward voltage with a 1 mA bias current at room temperature (300 K) is approximately 650 mV. It rises to approximately 900 mV at 200 K.

The circuit shown in figure 13 employs an FET-input operational amplifier (U5, AD820) as a summing amplifier to provide adjustable voltage gain and DC offset trimming. A LM334M constant current source (CS1) maintains a steady bias current of about 1 mA through the sensor diode (S1, 1N457).

Refer to the LM124/234/334 series product datasheet for details of the calculation of the current set resistor (R12).

\[ R_{12} = \frac{0.0681V}{I_{set}} = \frac{0.0681V}{1 mA} = 68\Omega \]

This bias current will have a small temperature dependence of about +3 μA/K. The internal temperature sensor is located inside the insulated payload enclosure and is not subject to extreme variations in temperature; however, the external temperature sensor seen in the next module will be exposed to extreme variations in temperature. If tighter control of the bias current is desired, a compensating circuit such as that seen later in this manual with the pressure sensor may be employed.

Since the PN junction forward voltage will vary over a range of about 240 to 300 mV with the temperatures encountered in flight (-80 to +30ºC, or about 200 to 300 K) a voltage gain of about 15 will be needed. In addition, a DC offset will have to be subtracted so that the signal presented to the Arduino Mega’s ADC is the required range of 0 to 5V with respect to ground. The gain, \( A_V \), of the amplifier is determined by

\[ A_V = 1 + \left( \frac{R_{16} + R_{20}}{R_{17}} \right) \]

For the values shown, the gain is adjustable between approximately 9 to 14. Should more or less gain be required, adjust the resistor values as needed.

The internal and external temperature signal conditioning circuits have similar circuits and use the same components. It is recommended that the internal temperature sensor be installed first as it is more centrally located on the board.

Locate and open one of the Temperature Module packets. Identify the following components. Check off each component after you have installed and inspected its solder connections.
Internal Temperature Module – Parts List

- CS1: LM334M Current Source
- U5: AD820ARZ Single Op Amp
- R9: 3.9 kΩ Resistor
- R10: 20 kΩ Resistor
- R11: 180 kΩ Resistor
- R12: 68 Ω Resistor
- R13: 1 kΩ Potentiometer
- R14: 100 kΩ Potentiometer
- C6-C8: 0.1 μF Ceramic Capacitors
- C9: 10 μF Electrolytic Capacitor
- J3: Right-Angle Breakaway Header (2-Pin)

Internal Temperature Modules – Schematic

Internal Temperature Modules – PCB Layout
External Temperature Module – Parts List

- CS2: LM334M Current Source
- U6: AD820ARZ Single Op Amp
- R15: 3.9 kΩ Resistor
- R16: 20 kΩ Resistor
- R17: 180 kΩ Resistor
- R18: 68 Ω Resistor
- R19: 1 kΩ Potentiometer
- R20: 100 kΩ Potentiometer
- C10-C12: 0.1 μF Ceramic Capacitors
- C13: 10 μF Electrolytic Capacitor
- J4: Right-Angle Breakaway Header (2-Pin)

External Temperature Module – Schematic

External Temperature Module – PCB Layout
Temperature Modules – Assembly

There are two temperature modules present on the MegaSat PCB. One is dedicated to external temperature and the other to internal. The circuits for both modules are identical. The instructions will guide you through assembling the internal temperature module. The process is similar for the external temperature module. Refer to the inventory list, schematic, and PCB layout for the external temperature module when assembling the module.

Temperature Module Assembly Step 1

Locate the LM334 chip. Align the chip with the pad at CS1. There is a dot on the silkscreen pattern that matches the dot marks pin 1 on the chip itself.

Temperature Module Assembly Step 2

While holding the IC in place with tweezers, solder one of the pins onto the board. Next, check to make sure all the other pins are aligned with their respective pads before soldering anymore pins. If not, melt the solder and realign the IC. It may be useful to apply the solder to the pad first before attempting to solder the pin.

Temperature Module Assembly Step 3

Solder all the pins on one side, then give the chip a break from the heat for ten seconds before soldering the pins on the other side. Do not let the iron “sit” on the pad/pin for too long as the heat can damage the board and the IC.
Tips for Success

Identifying SMD resistors can be a challenge to those who aren’t familiar with resistor codes. Each resistor is labeled with a three- or four-digit code. The first two or three digits identify the resistance. The last digit always identifies the magnitude of the resistance. R’s are sometimes added in the middle of the code to identify the component as a resistor. For example, a resistor labeled 68R0 is a $68 \times 10^0$ or $68 \ \Omega$; 3901 would be $390 \times 10^1$ or $3.9 k\Omega$; 203 would be $20 \times 10^3$ or $20 k\Omega$.

Temperature Module Assembly Step 4

Locate the 68Ω resistor. Place the resistor on top of both pad at R12 and press down on it gently with tweezers to hold it in place. Then solder one side of the resistor to the board. Inspect the resistor. If the resistor is flush with the board and aligned with the other pad, solder the other pad to the resistor.

Temperature Module Assembly Step 5

Locate the two-pin header and two-pin housing. This header will be used to connect the temperature sensor to the board. This sensor will be assembled later.
Temperature Module Assembly Step 6

Place the header into the board at J3. The header should clear the current source IC previously installed. Test the height by putting the 2-pin connector housing onto the connector. The housing should not touch the IC.

Temperature Module Assembly Step 7

Solder the header to the board on the bottom side just as you have with all through hole components before. Solder one pin, check the alignment, adjust if necessary, and then solder the other pin.

Tips for Success

The right-angle headers have straight leads and bent leads. The straight leads are used to connect to the housing to provide a secure fit during flight. The bent lead is soldered onto the board. The header should be installed such that the straight leads overhang the installed resistor and chip.
The LM334 chip is a constant current source designed to output 1 mA of current through the sensor. If the current is not held constant at 1 mA, the sensor may not function as designed.

Apply power to the MegaSat and measure the voltage at pin 4 of the LM334 chip using a multimeter. This is the input power for the chip. It should read approximately 12V when power is supplied to the MegaSat. Record the value on the table below.

Next, measure the current output the LM334. Set the multimeter to measure DC current. Connect the positive lead of the multimeter to the pin of the J3 connector with a ‘+’ sign next to it. Connect the negative lead to the opposite lead. The multimeter should read a value of 1 mA. Record the value on the table below.

<table>
<thead>
<tr>
<th>Test</th>
<th>Component</th>
<th>Expected Value</th>
<th>Measured Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Check</td>
<td>CS2 – Pin 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Check</td>
<td>J4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Temperature Module Assembly Step 8

Locate the AD820 chip. Align the chip with the pad U5. There is a dot on the silkscreen pattern that matches a dot on the chip itself. Solder one pin to the board. Adjust the alignment so that all pin are aligned with the pads before proceeding to the next step.

Temperature Module Assembly Step 9

Locate the 0.1uF SMD capacitors. These capacitors have a light brown casing with no label. Install the 0.1 uF ceramic capacitors to C6, C7, and C8. Solder one side of the capacitor to the pad. Adjust the alignment as needed before soldering the other pad.

Temperature Module Assembly Step 10

Locate the 180 kΩ resistor. Install the 180 kΩ resistor to R11. Solder one side of the resistor to the pad. Adjust the alignment as needed before soldering the other pad.
Temperature Module Assembly Step 11

Locate the 20kΩ resistor. Install the 20 kΩ resistor to R10. Solder one side of the resistor to the pad. Adjust the alignment as needed before soldering the other pad.

Temperature Module Assembly Step 12

Locate the 3.9kΩ resistor. Install the 3.9 kΩ resistor to R9. Solder one side of the resistor to the pad. Adjust the alignment as needed before soldering the other pad.

Temperature Module Assembly Step 13

Solder all the pins on one side, then give the chip a break from the heat for ten seconds before soldering the pins on the other side. Do not let the iron “sit” on the pad/pin for too long as the heat can damage the board and the IC.
Temperature Module Assembly Step 14

Locate the 10uF electrolytic capacitor. This component is polarized. There is a black line on top of the capacitor that designates the cathode (negative side), and the silkscreen on the board at C9 has the positive side marked.

Temperature Module Assembly Step 15

Place the capacitor on top of both pads at C9 and press down on it gently with tweezers to hold it in place. Solder one lead of the capacitor onto the board. It may be useful to apply the solder to the pad first before attempting to solder the capacitor. Inspect the capacitor. If the capacitor is flush with the board and aligned with the other pad, solder the capacitor to the other pad.
Tips for Success

In the next few steps, you will be installing potentiometers. The potentiometers have similar packages and are easily mixed up. The 1kΩ potentiometer is labeled W102. The 100kΩ potentiometer is labeled W104. The circuit may not function correctly if the components are installed incorrectly. Double check the part number before soldering to ensure you don’t accidentally install the wrong part in the wrong place!

Temperature Module Assembly Step 16

Locate the 100kΩ potentiometer. Insert the potentiometer to R14. Bend the leads outwards so that part remains secure on the board. Solder one pin and check that the potentiometer is flush with the board. If it is not, remove the solder and adjust the component. Then solder the other two pins.

Temperature Module Assembly Step 17

Flip the board over and trim the potentiometer leads using a wire clipper.

Temperature Module Assembly Step 18

Locate the 1kΩ potentiometer. Insert the potentiometer to R13. Bend the leads outwards so that part remains secure on the board. Solder one pin and check that the potentiometer is flush with the board. If it is not, remove the solder and adjust the component. Then solder the other two pins.
Temperature Module Assembly Step 19

Flip the board over and trim the potentiometer leads using a wire clipper.

Temperature Module Assembly Step 20

Locate the other Temperature Module Packet. Open the packet and repeat steps 1 – 19 for the external module. Refer to the inventory list, schematic, and PCB layout provided on page 32 as necessary.

Assembled Temperature Modules
The HIH-4000 relative humidity sensor utilizes a polymer plastic element that responds to changes in relative humidity by exhibiting a varying capacitance. Initial signal conditioning is integrated within the device in order to provide a temperature-compensated linear output voltage in the range of 0.8V to 3.3V for relative humidities ranging from 0% to about 75%. The output is ratiometric with respect to the supply voltage, so a well-regulated 5V supply is required. The REF02-CESA reference device provides a stable supply voltage. Only about 200 μA are required from the 5V supply, well within the limits of the REF02-CESA. The sensor needs a load resistance of 80 kΩ or greater, which is provided by R6.

Over the measurable range of relative humidity, the sensor output voltage span is less than 5V. Therefore, the final signal conditioning circuit must amplify the signal slightly, as well as subtract a DC offset to present a 0 to 5V signal to the Arduino Mega’s ADC.

Figure 24 shows an AD822 dual FET input operational amplifier (U4) operated as a summing amplifier with a voltage gain of approximately 2 (6 dB) for the signal presented to its noninverting input (pin 6). Voltage divider potentiometer R8 attenuates the output of the first amplifier stage before it is buffered by the second stage of U4, which is operated as a unity gain voltage follower. The amount of DC offset subtracted is controlled by voltage divider potentiometer R7.

The voltage gain is somewhat dependent upon the setting of R7. Therefore, the gain (R8) and offset (R7) adjustments interact with one another and must be adjusted alternately until the desired output span and base are achieved.

The humidity sensor is sensitive to light. If the active area is exposed to light, the output will become erratic and no longer correlated to humidity. Exposure to light does not damage the sensor. It is recommended to install a cover over the sensor to prevent light from hitting the active sensor area.

Install and solder the following components. Check off each component after you have installed and inspected its solder connections.
Humidity Module – Parts List

- U4: AD822ARZ Dual Op Amp
- R4: 6.8 kΩ Resistor
- R5: 10 kΩ Resistor
- R6: 75 kΩ Resistor
- R7-R8: 10 kΩ Potentiometer
- C1-C4: 0.1 μF Ceramic Capacitors
- C5: 10 μF Electrolytic Capacitor
- J2: Right-Angle Breakaway Header (3 pin)

Humidity Module – Schematic

Humidity Module – PCB Layout
Humidity Module – Assembly

Humidity Module Assembly Step 1

Locate the 0.1 uF capacitors. Align the capacitors with the pads C1, C2, C3, and C4. Solder each capacitor to the pad in turn. Check that the capacitor is flush with the board.

Humidity Module Assembly Step 2

Locate the 10 uF capacitor. This is a polarized capacitor. Align the capacitor with the pad C5. The black bar on the capacitor should face the negative terminal (the flat end of the silkscreen marking). Check that the capacitor is flush with the board.

Humidity Module Assembly Step 3

Locate the 75kΩ resistor. Align the resistor with the pad R6. Solder the resistor to the pad. Check that the resistor is flush with the board.
Humidity Module Assembly Step 4

Locate the 10kΩ resistor. Align the resistor with the pad R5. Solder the resistor to the pad. Check that the resistor is flush with the board.

Humidity Module Assembly Step 5

Locate the 6.8kΩ resistor. Align the resistor with the pad R4. Solder the resistor to the pad. Check that the resistor is flush with the board.
Humidity Module Assembly Step 6

Locate the AD822 chip. Align the chip with the pad U4. There is a dot on the silkscreen pattern that matches a dot on the chip itself.
Humidity Module Assembly Step 7

Locate the 10kΩ potentiometer. Insert the potentiometer to R19. Bend the leads outwards so that part remains secure on the board. Solder one pin and check that the potentiometer is flush with the board. If it is not, remove the solder and adjust the component. Then solder the other two pins.

Humidity Module Assembly Step 8

Locate the 10kΩ potentiometer. Insert the potentiometer to R20. Bend the leads outwards so that part remains secure on the board. Solder one pin and check that the potentiometer is flush with the board. If it is not, remove the solder and adjust the component. Then solder the other two pins.
Humidity Module Assembly Step 9

Locate the three-pin header. This header will be used to connect the humidity sensor to the board. This sensor will be assembled later. Place the header into the board at J2. Ensure there is enough clearance above the board for the sensor connector.

Assembled Humidity Module
The circuit shown in figure 31 provides a 0 to 5V signal, representing an absolute pressure of 0 to 1020 mb, to analog channel 0 (A0) of the Arduino Mega. Temperature compensation circuitry is included to preserve accuracy over a modest (-20 to +85 °C) range of operating temperatures.

PS1, the ICS1230 is an electromechanical hybrid device employing a piezoresistive strain gauge in a Wheatstone bridge configuration. Pressure changes applied to the internal strain gauge produce resistance changes that result in a differential output voltage of approximately 1 to 100 mV. The transducer includes internal temperature compensation and a factory-trimmed gain setting resistor ($R_{int}$).

The manufacturer recommends a constant current supply of approximately 1.5 mA for operation within nominal specifications. The 1.5 mA is provided by CS3, a LM334 current source. The network of R21, R22, and D2 compensate for temperature variations and help maintain a constant bias current for the transducer. D2 is selected to be a diode whose temperature-voltage characteristics are a close match to the temperature response of the LM334. The output current is programmed by selection of R21 and R22. Details leading to the calculation below can be found in the LM334 series product datasheet.

$$R_1 = \frac{0.134V}{1.5 mA} = 89.3\Omega$$

$$R_2 \approx 10R_1 = 893\Omega$$

In this case, the nearest standard resistor values (91 Ω and 910 Ω) have been selected.

A dual FET-input operational amplifier (U8) forms a difference amplifier with a voltage amplification ratio of approximately 30 (can also be expressed as 30 dB). It is important for circuit balance that R24 and R25 be closely matched, hence the choice of 0.1% tolerance precision resistors. The voltage gain is set by the ratio of the R24 (or R25) value to the equivalent resistance appearing between the inverting inputs of the two amplifier stages.

Under normal operating conditions, the manufacturer laser trims the value of $R_{int}$ to provide an output voltage of 0 to 3.12 V over a pressure range of 0 to 15 psi (1034.2 mb) when R24 and R25 are 100 kΩ. If this is acceptable, then R23 may be omitted ($R_{23} = \infty$) and R30 replaced by a shorting jumper ($R_{30} = 0$). If more precise control of the gain is desired, then R30 and/or R23 may be required. The equation below gives the voltage gain of the difference amplifier in terms of the circuit resistances.

$$R_{eff} = R_{30} + \frac{R_{int}R_{23}}{R_{int} + R_{23}} \text{ and } A_v = 2\left(\frac{R_{24}}{R_{eff}}\right) \text{ and } R_{24} = R_{25}$$

Note that $R_{eff}$ is the parallel combination of $R_{int}$ and R23, appearing in series with R30. If a gain smaller than about 30 is needed, R23 is omitted ($R_{23} = \infty$) and a variable resistor can be used at
R30 to reduce the gain to the desired value. Should a voltage gain larger than 30 be required, choose a value of R23 that, with R30 = 0, would yield a gain of about 20% or larger than the target, then use a variable resistor at R30 to bring the gain back down to the target value.

The final amplifier stage (U8, AD820) is another FET-input operational amplifier that forms a unity gain difference amplifier to provide an output voltage reference to ground suitable for the Arduino’s ADC. Again, for balance, it is essential that R26, R27, R28, and R29 be closely matched, so 0.1% tolerance parts are used once more.

Install and solder the following components. Check off each component after you have installed and inspected its solder connections.
Pressure Module – Parts List

- CS3: LM334M Current Source
- U8: AD822ARZ Dual Op Amp
- U9: AD820ARZ Single Op Amp
- R21: 910 Ω Resistor
- R22: 91 Ω Resistor
- R23: 3.3 kΩ Resistor
- R24, R25: 100 kΩ, 0.1% Tolerance Resistor
- R26-R29: 10 kΩ, 0.1% Tolerance Resistor
- R30: 10 kΩ Potentiometer
- C14-C18: 0.1 μF Ceramic Capacitors
- C19: 10 μF Electrolytic Capacitor
- D2: 1N457 Diode
- U7: 8-Pin Socket

Pressure Module - Schematic

Pressure Module – PCB Layout
Locate the 0.1μF capacitors. The capacitors are unlabeled. Align the capacitor with the pads C14, C15, C16, C17, and C18. Solder the capacitors to the pads in turn. Check that the capacitors are flush with the board.
Pressure Module Assembly Step 2

Locate the 10 uF capacitor. This is a polarized capacitor. Align the capacitor with the pad C19. The black bar on the capacitor should face the negative terminal (the flat end of the silkscreen marking). Check that the capacitor is flush with the board.

Pressure Module Assembly Step 3

Locate the 10kΩ 0.1% resistors. Align the resistor with the pads R26, R27, R28, and R29. Solder the resistors to the pads in turn. Check that the resistors are flush with the board.
Pressure Module Assembly Step 4

Locate the 100kΩ 0.1% resistors. Align the resistor with the pad R24 and R25. Solder the resistors to the pad in turn. Check that the resistors are flush with the board.

Pressure Module Assembly Step 5

Locate the 3.3kΩ resistor. Align the resistor with the pad R23. Note that this pad does not include a label indicating its resistance. Solder the resistor to the pad. Check that the resistor is flush with the board.
Pressure Module Assembly Step 6

Locate the 910Ω resistor. Be very careful to not confuse the 910Ω and 91Ω resistors. The resistor code for the 910Ω resistor is 911. Align the resistor with the pad R21. Solder the resistor to the pad. Check that the resistor is flush with the board.

Pressure Module Assembly Step 7

Locate the 91Ω resistor. Be very careful to not confuse the 910Ω and 91Ω resistors. The resistor code for the 91Ω resistor is 91R0. Align the resistor with the pad R22. Solder the resistor to the pad. Check that the resistor is flush with the board.
Pressure Module Assembly Step 8

Locate the 1N457 PN-junction diode. This component is polarized! The silkscreen on the printed circuit board has a white line marking that corresponds to the sliver line on the diode. Be sure to align the diode properly before soldering. Bend the leads of the diode and insert them into the holes of the PCB at D2. Check that the diode is flush with the board. Solder the leads then trim the excess with wire clippers.

Pressure Module Assembly Step 9

Locate the LM334M chip. Align the chip with the pad CS3. There is a dot on the silkscreen pattern that matches a dot on the chip itself.
Pressure Module Assembly Step 10

Locate the AD820 chip. Align the chip with the pad U9. There is a dot on the silkscreen pattern that matches a dot on the chip itself.

Pressure Module Assembly Step 11

Locate the AD822 chip. Align the chip with the pad U8. There is a dot on the silkscreen pattern that matches a dot on the chip itself.
Pressure Module Assembly Step 12

Locate the 8 pin IC-header. Insert the header to the pad U7. Make sure the header is flush with the board. Flip the board over and solder one pin. Check and adjust the header as needed before soldering the rest of the pins.

Pressure Module Assembly Step 13

Locate the 10kΩ potentiometer. Insert the potentiometer to R30. Bend the leads outwards so that part remains secure on the board. Solder one pin and check that the potentiometer is flush with the board. If it is not, remove the solder and adjust the component. Then solder the other two pins.
The DS3231SN real-time clock is a temperature-compensated integrated circuit with a backup battery that provides accurate timekeeping even when power is lost. It is able to maintain time in seconds, minutes, hours, and days. It can also maintain date, month, and year. It is able to compensate for months with fewer than 31 days, including leap years. It can be programmed to operate in a 12-hour format or a 24-hour format.

With datalogging, it can be important to have an accurate timestamp associated with your data. This allows you to correlate the data points with a specific moment in time and match the timestamp with multiple data points taken at the same time. You can also correlate your data with data from other systems or payloads, such as the main flight string, if both times are in sync with one another.

The Arduino Mega has its own built-in timekeeping system for tracking the length of time it has been powered on. This timestamp can be utilized in your code by using the millis() function. The value returned from this function resets after every power loss. This timestamp can be used to track power losses but should not be used as a timestamp without careful consideration for its limitations.

The MegaSat also incorporates a GPS module that has its own timekeeping system. The GPS Module has an accurate timestamp that is adjusted via satellite link. However, if the connection to satellite is unreliable or if the GPS loses power, the timestamp for all the saved data points would be off. To prevent this, the RTC and GPS act as redundancies for each other to ensure a timestamp is always saved.

The DS3231SN RTC utilizes I2C serial communication at 400 kHz with a unique, nonprogrammable address. Its logic operates at VCC, which can be set to either +3.3 V or +5 V. The RTC shares the I2C with the accelerometer/gyroscope chip. The accelerometer/gyroscope has a hardware address that can be changed. Details on how to change the I2C address are shown in Appendix E.

The Arduino communicates using +5V logic. In order to communicate with the RTC and accelerometer/gyroscope chip, a TCA9517DR bidirectional logic level shifter (U3) is used. This chip converts +5V logic into +3.3V logic and vice versa to allow communication between the devices.

Install and solder the following components. Check off each component after you have installed and inspected its solder connections.
RTC Module – Parts List

- U2: DS3231SN RTC
- U3: TCA9517DR Bidirectional Level Shifter
- R2-R3: 10 kΩ Resistor
- B1: 3000TR Coin Cell Battery Holder

RTC Module – Schematic

RTC Module – PCB Layout
RTC Module – Assembly

RTC Assembly Step 1

Locate the 10kΩ resistors. Align the resistor with the pad R2 and R3. Solder the resistors to the pads in turn. Check that the resistors are flush with the board.

RTC Module Assembly Step 2

Locate the TCA9517 chip. Align the chips with the pad U3. There is a dot on the silkscreen pattern that matches a dot on the chip itself. While holding the IC in place with tweezers, solder one of the pins onto the board. Next, check to make sure all the other pins are aligned with their respective pads before soldering anymore pins. If not, melt the solder and realign the IC. It may be useful to apply the solder to the pad first before attempting to solder the chip.
RTC Module Assembly Step 3

Locate the DS3231 chip. Align the chips with the pad U2. There is a dot on the silkscreen pattern that matches a dot on the chip itself. While holding the IC in place with tweezers, solder one of the pins onto the board. Next, check to make sure all the other pins are aligned with their respective pads before soldering anymore pins. If not, melt the solder and realign the IC. It may be useful to apply the solder to the pad first before attempting to solder the chip.

RTC Assembly Step 4

Locate the pad for the battery holder located at B1. Melt solder on the center pad and on one of the side pads. The solder on the center pad will ensure the battery is secured in-flight.
RTC Assembly Step 5

Locate the battery holder. Align the battery holder with the pads at B1. Solder one bracket to the board. Check the alignment of the other bracket. If it is aligned with the pad, solder the other bracket down. Otherwise, melt the solder and realign the battery holder.
The Sparkfun MPU-6050 Triple Axis Accelerometer and Gyroscope combines both components and their respective circuits onto one easy to use breakout board. InvenSense designed the MPU-60X0 series in 2012, which was the world’s first integrated 9-axis motion tracking device. They were the first company to deliver motion interface solutions that include fully integrated sensors and robust MotionFusion firmware algorithms.

The MPU-6050 communicates with the Arduino Mega via I2C protocol over pins D20 (SDA) and D21 (SCL). By default, the breakout board sets the address to b1101001, which is the same as the RTC. The address can be changed by breaking a connection on the board and reconnecting it to another pad. The process for doing so is detailed in Appendix E.

The gyroscope uses three micro-electro-mechanical system (MEMS) motion sensors that detect and measure rotation about the X (roll), Y (pitch), and Z (yaw) axes. These are referred to as the sense axes. This process relies on the Coriolis effect, which is the inertial force that appears to act perpendicular to the axis of rotation and direction of motion.

A capacitive pickoff circuit is used to measure the relative position between two vibrations. When the gyroscope rotates about the X, Y, or Z axis, this circuit detects the deflection of vibrations caused by the Coriolis effect. This signal goes through a signal conditioning circuit where it becomes amplified, demodulated, and filtered. This produces a voltage that is proportional to the angular velocity.

The accelerometer also uses three MEMS motion sensors to measure proper acceleration, which is the inertial or free-fall acceleration. It accomplishes this by using a predetermined mass as a reference. This mass is known as a proof mass. When movement occurs across a particular axis, it causes a displacement of the corresponding mass. The displacement causes strain which is measured by a piezoresistive strain gauge. This is coupled with a capacitive sensor that detects the differential displacement.

The device is factory calibrated to measure 0g for the X and Y axes and +1g for the Z axis when sitting on a flat surface. It includes an embedded temperature sensor with an onboard oscillator. This has a ±1% variation over the operating temperature range. The MPU-6050 has a 10 kg shock tolerance.

The breakout board also utilizes a FIFO (first in, first out) register. This stores data that arrives asynchronously, which allows it to incorporate data from other devices such as the GPS. FIFO also works with interrupt features such as high-G interrupt or gesture and/or motion recognition. These interrupts can be turned on using a command but are turned off by default. Refer to the datasheet for more information on how to activate these features.

Locate and open the Accelerometer / Gyroscope Module packet. You will install and solder the following components. Check off each component after you have installed and inspected its solder connections.
Accelerometer / Gyroscope Module – Parts List

- U10: Sparkfun Triple Axis Accelerometer/Gyroscope Breakout Board
- Vertical Breakaway Headers (10-pin)

Accelerometer / Gyroscope Module – Schematic

Level Shifter

Gyroscope/Accelerometer

Accelerometer / Gyroscope Module – PCB Layout
Accelerometer / Gyroscope Module – Assembly

Accelerometer / Gyroscope Assembly Step 1

Locate the Accelerometer / Gyroscope breakout board and the ten-pin header. Insert the header into the breakout board. Make sure the long pins go down through the board.

Accelerometer / Gyroscope Assembly Step 2

Solder one pin of the header to the breakout board. Adjust the header so that it is flush with the breakout board. Be careful not to apply too much heat to the header! It is very easy to melt the header’s plastic and ruin the header if you overheat the pins.

Accelerometer / Gyroscope Assembly Step 3

Solder the remaining pins to the breakout board.
The process for changing the I2C address on the accelerometer/gyroscope breakout board can be done before or after installation to the MegaSat. The address is defined by an external solder-jumper on the breakout board. The location of this jumper is identified in the picture below.

**Accelerometer / Gyroscope Assembly Step 4**

Insert the breakout board with soldered header into the pad U1. The VDD pin should go into pin 1, which is marked by a dot on the silkscreen. Ensure the breakout board remain flush with the PCB. It may be useful to secure the breakout board with tape or clamps.

**Accelerometer / Gyroscope Assembly Step 5**

Flip the PCB board over and solder one of the header pins to the PCB board. Verify that your pins are lined up correctly and that the breakout board is flush with the PCB board before soldering the remaining pins.

**Changing the Address for the Accelerometer / Gyroscope**

The process for changing the I2C address on the accelerometer/gyroscope breakout board can be done before or after installation to the MegaSat. The address is defined by an external solder-jumper on the breakout board. The location of this jumper is identified in the picture below.
This jumper changes the last bit address of the breakout board from a “0” to “1” or vice versa. This is accomplished by changing the voltage applied to pin from 0V (“0”) to +5V (“1”). The center pad connects to the accelerometer/gyroscope chip while the other two pads connect to +5V(left) and GND(right).

To change the address, remove solder from the jumper and solder a new jumper to the other pad. A small wire may be used to assist with the bridge. Before powering on the board, perform a continuity check with a multimeter between all three pin to ensure no shorts have occurred. A electrical short here may cause internal damage to the accelerometer/gyroscope chip or the +5V regulator.

The above image on the left shows the condition of the address jumper AD0 as in the condition it will be from the manufacturer. After removing the solder from center and ground connection and making the necessary solder bridge to connect the center pad to the +VDD pad the address jumper should look like the image on the right.
The Arduino Mega connects with the MegaSat PCB through stackable headers. There are seven stackable headers that act as the interface. It is important that the headers line up properly and remain straight. The Arduino Mega will slide into the header pins. If the headers are misaligned or crooked, the Arduino Mega may not fit properly.

Additional pins have been included on the MegaSat PCB to make it easier to expand the project. It is important to install the headers into the proper location on the board. The Arduino Mega will not fit if the headers are installed in these expansion pins. To prevent this, the appropriate locations are marked with a white silkscreen outline.

The expansions pins are used to interface with the GPS shield. A two-pin breakaway header is installed on the PCB and GPS board.

Locate the follow components from the Arduino Hardware packet. You will install and solder the following components. Check off each component after you have installed and inspected its solder connections.

- 8-Pin Stackable Headers x5
- 10-Pin Stackable Headers
- 36-Pin Stackable Headers
- Right-Angle Breakaway Headers (2-Pin)
Arduino Hardware – Assembly

Arduino Hardware Assembly Step 1
Locate the five 8-pin headers. Insert them into the board.

Arduino Hardware Assembly Step 2
Locate the 10-pin headers. Insert it into the board.

Arduino Hardware Assembly Step 3
Locate the 36-pin headers. Insert it into the board. Due to the large amount of pins, it may prove difficult to insert the header into the board.
**Arduino Hardware Assembly Step 4**

Ensure that the headers are all aligned correctly. The headers should be flush with the board with the leads exiting the holes. It is important to ensure the leads are all straight. You may accomplish this by using a grooved surface to hold the components, securing it with tape, or by hand. When the components are straight, solder two pins down to secure the header.

**Arduino Hardware Assembly Step 5**

Inspect the alignment of the headers and ensure they are flush with the board. If they are not, heat or remove the solder and adjust the alignment. When all the headers are flush and aligned, locate your Arduino Mega. Line up the leads of the installed headers with those of the Arduino. Adjust any headers that are misaligned.
Arduino Hardware Assembly Step 5

Solder the remaining pins to the board.

Arduino Hardware Assembly Step 6

Locate the 2-pin header. Insert the header into Pin 18 and 19 (RX1 and TX1). Solder the component to the board.
Assembled Arduino Hardware

Figure 5: Image of assembled Arduino mounts
It is now time to attach the sensors to the MegaSat. The orientation of each sensor is important. If the sensors are installed backwards, it may cause damage to the sensors and not function correctly.

The humidity and temperature sensors are not mounted directly on the MegaSat PCB. Instead, they are mounted to a length of cable that connects to the 2-pin and 3-pin headers that were installed in the Temperature and Humidity modules. The PCB board has silkscreen guidelines to assist with installing the cabled in the correct orientation.

The pressure sensor is mounted on the U7 socket installed in the Pressure Module. The orientation of the sensor is important. There are orientation guidelines on the board to assist with installation.

Locate and open the Sensors packet. You will install the following components. Check off each component after you have installed and inspected its connections.

**Sensors – Parts List**

- 1230-015A-3L Pressure Sensor
- 1N457 Diode
- HIH-4000-003 Humidity Sensor
- Right-Angle Breakaway Headers (2-Pin)
- 7x 22-24 AWG Female Crimps

**Sensors – Assembly**

**Sensors Assembly Step 1**

Find the Pressure Sensor. Align it with the socket installed at U7. Slowly insert the sensor into the socket until the sensor is secured. There is a circle on the board that marks where the cylindrical tube on top of the sensor goes.
Sensors Assembly Step 2

Locate the 1N457 diodes. Bend the lead of the diode in a 180 bend like in the figure below.

Sensors Assembly Step 3

Solder hookup wire to the leads of the diode. It is recommended to use red wire for the anode and black wire for the cathode to provide a visual cue to the polarity of the diode.

Sensors Assembly Step 4

Use wire strippers to trim the insulation off the hookup wire. Make sure the stripped wire is about 1 cm long.

Sensors Assembly Step 5

Insert the crimp over the stripped wire. Use the crimper to secure the crimp to the wire. The crimp should cover a small portion of the insulation to provide mechanical stability.

Sensors Assembly Step 6

Locate the two-pin housing from the Hardware packet. Insert the crimped wire in the two-pin housing.

Sensors Assembly Step 7

Repeat Steps 3 – 6 with the other 1N457 diode.

Sensors Assembly Step 8

Insert the assembled temperature sensors onto the 2 pin connectors installed at J2 and J3. Ensure that the polarity of the diode is correct.

Sensors Assembly Step 9

Locate the humidity sensor and its calibration sheet. Store the calibration sheet in a safe spot where it will not be lost. The calibration sheet is unique for each humidity sensor and cannot be replaced if lost. The humidity sensor has three pins: input power, output signal, and ground.
**Sensors Assembly Step 10**

Solder hookup wire to the three pins on the humidity sensor. It is recommended that you use color-coded wires to provide a visual cue to the polarity of the sensor wires.

**Sensors Assembly Step 11**

Use wire strippers to trim the insulation off the hookup wires. Make sure the stripped wire is about 1 cm long.

**Sensors Assembly Step 12**

Insert the crimp over the stripped wire. Use the crimper to secure the crimp to the wire. The crimp should cover a small portion of the insulation to provide mechanical stability.

**Sensors Assembly Step 13**

Insert the crimped wire in the three-pin housing. Make sure the polarity of the wires are correct!

**Sensors Assembly Step 14**

Insert the assembled temperature sensors onto the 2 pin connectors installed at J4. Ensure that the orientation of the connector is correct.
Installation of the Adafruit Ultimate GPS Logger Shield is the final step in the assembly process. It is designed to connect directly to the Arduino with very little assembly involved. The headers that were installed previously function as the interface between the shield, the MegaSat PCB, and the Arduino. Some modifications will need to be made to the GPS shield in order to communicate with the MegaSat. They are detailed below.

The Adafruit Ultimate GPS Logger Shield was not designed specifically for the Arduino Mega. It was designed for the Arduino Uno. The shield designates RX and TX to pins D7 and D8, which are the TX and RX for the Uno. However, the Mega designated D7 and D8 as digital I/O pins and does not have a hardware UART port on these pins. To interface with the Mega, a jumper must be installed between D7 and D8 to D18 and D19, respectively.

Locate the follow components from the Arduino Hardware packet. Check off each component after you have installed and inspected its solder connections.

**GPS Logger Shield – Parts List**

- Right-Angle Breakaway Headers (2-Pin)

**GPS Logger Shield – Assembly**

**GPS Logger Shield Assembly Step 1**

Locate the 2-pin header provided in the Hardware packet. Insert and solder the header into the GPS shield at the TX and RX pins shown in the figure below.
GPS Logger Shield Assembly Step 2

Measure and cut two lengths of hookup wire that can reach between the installed header and the header installed on the MegaSat board during the Hardware assembly.

GPS Logger Shield Assembly Step 3

Use wire strippers to trim the insulation on both ends of the hookup wires. The exposed wire should be 1 cm in length.

GPS Logger Shield Assembly Step 4

Insert the bare metal of one hookup wire into the crimp provide. Use the crimping tool to secure the crimp onto the wire. Repeat for the other ends of the wires.

GPS Logger Shield Assembly Step 5

Insert the crimps into the two-pin housings. There should be a small audible click when the crimp is secured within the housing.

GPS Logger Shield Assembly Step 6

Insert the two pin headers onto the 2-pin headers installed on the MegaSat and the GPS Logger shield.

GPS Logger Shield Assembly Step 7

Locate the software serial switch on the GPS Logger shield. Slide the switch to Software Serial.

Assembled GPS Logger Shield
List of Appendices

A. MegaSat Assembly Kit Bill of Materials
B. MegaSat Schematic
C. MegaSat Board Layout
D. MegaSat Pin Assignments
E. MegaSat Power Distribution Diagram
F. NMEA Strings
G. References
### Appendix A – MegaSat Assembly Kit Bill of Materials

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Designator</th>
<th>Power Module</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V1</td>
<td>LM1117 5V Regulator</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>V2</td>
<td>LM1117 3.3V Regulator</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>V3</td>
<td>REF02 5V Reference</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>D1</td>
<td>1N5818 Schottky Diode</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>R1</td>
<td>1.2kΩ SMD Resistor</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>J1</td>
<td>5mm 2 Pin Vertical Male Header</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>J1-B</td>
<td>5mm Term Block Plug</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>LED1</td>
<td>Red LED</td>
<td>Pressure Module</td>
</tr>
</tbody>
</table>

#### Temperature Module

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Designator</th>
<th>Power Module</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CS1, CS2</td>
<td>LM334M Current Source</td>
<td>Temp Module</td>
</tr>
<tr>
<td>1</td>
<td>U5, U6</td>
<td>AD820ARZ Single Op Amp</td>
<td>Temp Module</td>
</tr>
<tr>
<td>1</td>
<td>R9, R15</td>
<td>3.9kΩ SMD Resistor</td>
<td>Temp Module</td>
</tr>
<tr>
<td>1</td>
<td>R10, R17</td>
<td>20kΩ SMD Resistor</td>
<td>Temp Module</td>
</tr>
<tr>
<td>1</td>
<td>R11, R16</td>
<td>180kΩ Resistor</td>
<td>Temp Module</td>
</tr>
<tr>
<td>2</td>
<td>R12, R18</td>
<td>680Ω SMD Resistor</td>
<td>Temp Module</td>
</tr>
<tr>
<td>1</td>
<td>R13, R19</td>
<td>1k Potentiometer</td>
<td>Temp Module</td>
</tr>
<tr>
<td>1</td>
<td>R14, R20</td>
<td>100k Trimpot</td>
<td>Temp Module</td>
</tr>
<tr>
<td>3</td>
<td>C6, C7, C8, C10, C11, C12</td>
<td>0.1µF SMD Capacitor</td>
<td>Temp Module</td>
</tr>
<tr>
<td>1</td>
<td>C9, C13</td>
<td>10µF SMD Electrolytic Capacitor</td>
<td>Temp Module</td>
</tr>
<tr>
<td>2</td>
<td>J2, J3</td>
<td>Right Angle Breakaway Header (2 pin)</td>
<td>Temp Module</td>
</tr>
</tbody>
</table>

#### Humidity Module

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Designator</th>
<th>Power Module</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U4</td>
<td>AD822ARZ Dual Op Amp</td>
<td>Humidity Module</td>
</tr>
<tr>
<td>1</td>
<td>R4</td>
<td>6.8kΩ Resistor</td>
<td>Humidity Module</td>
</tr>
<tr>
<td>1</td>
<td>R5</td>
<td>10kΩ SMD Resistor</td>
<td>Humidity Module</td>
</tr>
<tr>
<td>1</td>
<td>R6</td>
<td>75kΩ SMD Resistor</td>
<td>Humidity Module</td>
</tr>
<tr>
<td>2</td>
<td>R7, R8</td>
<td>10k Trimpot</td>
<td>Humidity Module</td>
</tr>
<tr>
<td>4</td>
<td>C1, C2, C3, C4</td>
<td>0.1µF SMD Capacitor</td>
<td>Humidity Module</td>
</tr>
<tr>
<td>1</td>
<td>C5</td>
<td>10µF SMD Electrolytic Capacitor</td>
<td>Humidity Module</td>
</tr>
<tr>
<td>1</td>
<td>J2</td>
<td>Right Angle Breakaway Header (3 pin)</td>
<td>Humidity Module</td>
</tr>
</tbody>
</table>

#### Pressure Module

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Designator</th>
<th>Power Module</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CS3</td>
<td>LM334M Current Source</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>U8</td>
<td>AD822ARZ Dual Op Amp</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>U9</td>
<td>AD820ARZ Single Op Amp</td>
<td>Pressure Module</td>
</tr>
<tr>
<td>1</td>
<td>D2</td>
<td>1N457 PN Junction Diode</td>
<td>Pressure Module</td>
</tr>
<tr>
<td></td>
<td>Item</td>
<td>Description</td>
<td>Module</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>-------------------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>1</td>
<td>R21</td>
<td>91Ω SMD Resistor</td>
<td>Pressure</td>
</tr>
<tr>
<td>1</td>
<td>R22</td>
<td>910Ω SMD Resistor</td>
<td>Pressure</td>
</tr>
<tr>
<td>1</td>
<td>R23</td>
<td>3.3k Resistor</td>
<td>Pressure</td>
</tr>
<tr>
<td>2</td>
<td>R24, R25</td>
<td>10k Resistor (0.1% Tolerance)</td>
<td>Pressure</td>
</tr>
<tr>
<td>4</td>
<td>R26, R27, R28, R29</td>
<td>100kΩ SMD Resistor (0.1% Tolerance)</td>
<td>Pressure</td>
</tr>
<tr>
<td>5</td>
<td>C14, C15, C16, C17, C18</td>
<td>0.1µF SMD Capacitor</td>
<td>Pressure</td>
</tr>
<tr>
<td>1</td>
<td>C19</td>
<td>10µF SMD Electrolytic Capacitor</td>
<td>Pressure</td>
</tr>
<tr>
<td>1</td>
<td>U7</td>
<td>DIP-24 IC Socket (0.6” spacing)</td>
<td>Pressure</td>
</tr>
</tbody>
</table>

**RTC Module**

| 1  | U2   | DS3231 Real Time Clock                          | RTC          |
| 1  | U3   | TCA9517 Level Shifter                           | RTC          |
| 1  | B1   | Coin Cell Battery Holder                       | RTC          |
| 1  | B1-BAT | CR1220 Lithium coin cell, 3v, 12mm               | Envelope 8   |
| 2  | R2, R3 | 10kΩ SMD Resistor                               | RTC          |

**Hardware**

| 1  | PCB  | MegaSat Printed Circuit Board                   | Outer Envelope |
| 1  | SD-Card | Samsung 32GB SD Card                          | Outer Envelope |
| 5  |      | 8 Pin Stackable Header                          | Hardware      |
| 1  |      | 10 Pin Stackable Header                         | Hardware      |
| 1  |      | 36 Pin Stackable Header                         | Hardware      |
| 4  | J3, J4, J5, J6 | Right Angle Breakaway Header (2 pin) | Hardware      |
| 11 |      | 22-24AWG Female Crimp                           | Hardware      |
| 4  | J3-B, J4-B, J5-B, J6-B | 2-Pin Receptacle Housing                   | Hardware      |
| 1  | J2-B | 3 Pin Crimp Receptacle Housing                  | Hardware      |

**Sensors**

| 1  | S3   | Humidity Sensor                                 | Sensors      |
| 1  | U7   | Pressure Sensor                                 | Sensors      |
| 2  | S1, S2 | 1N457 General Purpose Diode                     | Sensors      |
| 1  | U1   | Sparkfun MPU 6050 Breakout Board                | Sensors      |
| 1  | U1   | 10-pin Right Angle Breakaway Header             | Hardware      |
Appendix B – MegaSat Full Schematic
## Appendix D – MegaSat Pin Assignments

### The MegaSat Pin Layout

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Pin #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>ADC</td>
<td>AD0</td>
</tr>
<tr>
<td>External Temperature</td>
<td>ADC</td>
<td>AD1</td>
</tr>
<tr>
<td>Internal Temperature</td>
<td>ADC</td>
<td>AD2</td>
</tr>
<tr>
<td>Humidity</td>
<td>ADC</td>
<td>AD3</td>
</tr>
<tr>
<td>RTC</td>
<td>Reset</td>
<td>D23</td>
</tr>
<tr>
<td></td>
<td>SDA</td>
<td>D20</td>
</tr>
<tr>
<td></td>
<td>SCL</td>
<td>D21</td>
</tr>
<tr>
<td>Gyroscope/Accelerometer</td>
<td>SDA</td>
<td>D20</td>
</tr>
<tr>
<td></td>
<td>SCL</td>
<td>D21</td>
</tr>
<tr>
<td>GPS</td>
<td>TX</td>
<td>D18</td>
</tr>
<tr>
<td></td>
<td>RX</td>
<td>D19</td>
</tr>
<tr>
<td>SD</td>
<td>CS</td>
<td>D10</td>
</tr>
<tr>
<td></td>
<td>MOSI</td>
<td>D11</td>
</tr>
<tr>
<td></td>
<td>MISO</td>
<td>D12</td>
</tr>
<tr>
<td></td>
<td>SCK</td>
<td>D13</td>
</tr>
</tbody>
</table>
NMEA stands for National Marine Electronics Association, a marine electronics organization. This organization sets the standard for communication between marine electronics. Their NMEA 0183 standard is used for GPS communication. This communication involves sending ASCII sentences containing the information requested; these are called NMEA sentences.

NMEA sentences have a three-letter prefix that defines the device using the sentence type. Since the MegaSat is using NMEA sentences for GPS communication, we will be receiving sentences that have the prefix “$GP.” Following the “$GP” prefix are three letters that define the sentence type. Some examples of these three letters are “RMC,” “GGA,” and “VTG.” At the end of NMEA sentence is a carriage return. Between the prefix letters and the carriage return is the GPS data. This data is separated by commas and can include things like longitude, latitude, altitude, speed, and number of satellites being tracked.

### Types of NMEA Sentences

Using the Adafruit Ultimate GPS Logger Shield, there are 6 different NMEA sentences that are available. These are the RMC, GGA, GGL, VTG, GAS, and GSV sentences. The rest of this section goes over the information contained in each of these NMEA sentences.

### RMC: Recommended Minimum

<table>
<thead>
<tr>
<th>Layout:</th>
<th>$GPRMC,hhmmss,A,lli.ll,a,yyyy.yy,a,x.x,x.x,ddmmyy,x.x,a,A*hh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position:</td>
<td>1 ,2, 3 ,4, 5 ,6, 7 ,8, 9 , 10,11,12,13</td>
</tr>
<tr>
<td>1: hhmmss</td>
<td>Time of fix hh:mm:ss UTC</td>
</tr>
<tr>
<td>3: llll.ll</td>
<td>Latitude: ll degrees 07.038 minutes</td>
</tr>
<tr>
<td>4: a</td>
<td>Direction. N = North. S = South.</td>
</tr>
<tr>
<td>5: yyyy.yy</td>
<td>Longitude: 11 degrees 31.000 minutes</td>
</tr>
<tr>
<td>7: x.x</td>
<td>Speed over ground, knots</td>
</tr>
<tr>
<td>8: x.x</td>
<td>Track angle (degrees, True)</td>
</tr>
<tr>
<td>9: ddmmyy</td>
<td>Date of fix</td>
</tr>
<tr>
<td>10: x.x</td>
<td>Magnetic variation 20.3 degrees</td>
</tr>
<tr>
<td>11: a</td>
<td>Magnetic variation direction</td>
</tr>
<tr>
<td>13: *4A</td>
<td>Checksum</td>
</tr>
</tbody>
</table>
GGA: Time, Position, and Fix Data

Layout: SGPGGA,hhmmss,llll.ll,a,yyyy.yy,a,x,xx,x.x,x.x,x,M,x.x,M,x.x,xxxx*hh

Position: 1 , 2 ,3 , 4 ,5,6, 7 , 8 , 9 ,10, 11,12,13, 14 ,15

1: hhmmss.ss Time of fix hh:mm:ss UTC
2: llll.ll Latitude: ll degrees 07.038 minutes
4: yyyy.yy Longitude: 11 degrees 31.000 minutes.
6: x Fix quality: 0 = no fix. 1 = GPS fix. 2 = Differential GPS fix.
   4 = Real-Time Kinematic (RTK) fixed integers. 5 = RTK float integers. 6 = Dead reckoning. 7 = Manual input mode.
   8 = Simulator. 9 = WAAS.
7: xx Number of satellites being tracked
8: x.x Horizontal dilution of position
9: x.x Altitude
10: M Meters (units for 10)
11: x.x Relationship between geoid and WGS84 ellipsoid
12: M Meters (units for 11)
13: x.x Time (seconds) since last DGPS update
14: xxxx DGPS station ID number
15: *hh Checksum

GLL: Geographic Latitude and Longitude

Layout: SGPGLL,llll.ll,a,yyyy.yy,a,hhmmss,A*hh

Position: 1 ,2 , 3 ,4 , 5 , 6 , 7

1: llll.ll Latitude: ll degrees ll.ll minutes
2: a Direction: N = North. S = South.
3: yyyy.yy Longitude: 11 degrees 31.000 minutes.
5: hhmmss.ss Time of fix hh:mm:ss UTC
7: *hh Checksum
### VTG: Track Made Good and Speed Over Ground

Layout: \$GPVTG,x,x,T,x,x,M,x,x,N,x,x,K,A*hh

Position: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

1: x.x  Track made good (degrees true)
2: T  T = track made good relative to true north
3: x.x  Track made good (degrees magnetic)
4: M  Magnetic
5: x.x  Ground speed (knots)
6: N  N = knots
7: x.x  Ground speed (km/hr)
8: K  K = kilometers/hr
10: *hh  Checksum

Track made good is the actual track of the GPS device, taking into account wind and other things that have influenced its track.

### GSA: GPS Dilution of Precision and Active Satellites

Layout: \$GPGSA,A,X,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,x,*hh

Position: 1, 2, 3, 4, …………., 13, 14, 15, 16, 18

2: X  Mode 2: 1 = no fix. 2 = 2D fix. 3 = 3D fix.
3-13: x  PRNs of satellites used for fix
14: x.x  PDOP (dilution of precision)
15: x.x  HDOP (horizontal dilution of precision)
16: x.x  VDOP (vertical dilution of precision)
17: *hh  Checksum
## GSV: Satellite Information

**Layout:** SGPGSV,T,a,a,x,xx,xxx,x,y,yy,yyy,y,z,zz,zzz,z,a,aa,aaa,a*hh

**Position:** 1,2,3,4, 5 , 6 ,7,8, ……,11,12,……,15,16,……,19,20

1:  T          Total number of sentences for full data
2:  a          Sentence number (a of T)
3:  a          Number of satellites in view
4:  x          Satellite PRN
5:  xx         Elevation (degrees) 90° max
6:  xxx        Azimuth (degrees from True North) 0° ≤ x ≤ 359°
7:  x          SNR (signal to noise ratio)
8-11:  y       Information about second satellite, same format as 4-7
12-15:  z      Information about third satellite, same format as 4-7
16-19:  a      Information about fourth satellite, same format as 4-7
20:  *hh       Checksum
NMEA Sentences Examples

**RMC: Recommended Minimum**

$GPRMC,213415.000,A,3024.7490,N,09110.7014,W,1.18,26.06,250719,,,A*4A

1: 213415.000 Time of fix 21:34:15 UTC
3: 3024.7490 Latitude: 30 degrees 24.7490 minutes
4: N North
5: 09110.7014 Longitude: 91 degrees 10.7014 minutes
6: W West
7: 1.18 Speed over ground, knots
8: 26.06 Track angle (degrees, True)
9: 250719 Date of fix: July 25, 2019
10: Magnetic variation
11: Magnetic variation direction
12: A Positioning system mode indicator. A = autonomous.
13: *4A Checksum

**GGA: Time, Position, and Fix Data**

$GPGGA,213918.000,3024.7495,N,09110.7011,W,1,04,1.83,160.6,M,-25.9,M,,*56

1: 213918.000 Time of fix 21:39:18 UTC
2: 3024.7495 Latitude: 30 degrees 24.7495 minutes
3: N North
4: 09110.7011 Longitude: 91 degrees 10.7011 minutes.
5: W West
6: 1 Fix quality: GPS fix
7: 04 Number of satellites being tracked
8: 1.83 Horizontal dilution of position
9: 160.6 Altitude
10: M Meters
11: -25.9 Height of geoid
12: M Meters
13: Time (seconds) since last DGPS update
14: DGPS station ID number
15: *56 Checksum
### GLL: Geographic Latitude and Longitude

$GPGLL,3024.7471,N,09110.7130,W,214559.000,A,A*49$

1: 3024.7471  Latitude: 30 degrees 24.7471 minutes
2:  N North
3: 09110.7130  Longitude: 91 degrees 10.7130 minutes.
4:  W West
5: 214559.000  Time of fix 21:45:59 UTC
6:  A Signal status: Active Signal
7:  *49 Checksum

### VTG: Track Made Good and Speed Over Ground

$GPVTG,93.85,T,,M,0.35,N,0.64,K,A*0E$

1: 93.85  Track made good (degrees true)
2:  T T = track made good relative to true north
3:  Track made good (degrees magnetic)
4:  M Magnetic
5: 0.35  Ground speed (knots)
6:  N N = knots
7: 0.64  Ground speed (km/hr)
8:  K K = kilometers/hr
9:  A Positioning system mode indicator. A = autonomous.
10: *0E Checksum

### GAS: GPS Dilution of Precision and Active Satellites

$GPGSA,A,3,15,05,29,13,,,,,,2.13,1.88,0.99*0B$

1:  A Mode 1: Automatic
2:  3 Mode 2: 3D fix
3:  15 PRN of satellite used for fix
4:  05 PRN of satellite used for fix
5:  29 PRN of satellite used for fix
6:  13 PRN of satellite used for fix
7-13: PRNs of satellites used for fix
14: 2.13 PDOP (dilution of precision)
15: 1.88 HDOP (horizontal dilution of precision)
16: 0.99 VDOP (vertical dilution of precision)
17: *0B Checksum
GSV: Satellite Information

S1: $GPGSV,3,1,11,29,73,300,28,13,50,104,24,15,50,168,25,05,39,040,22*7B
S2: $GPGSV,3,2,11,02,29,089,,21,20,303,,25,19,227,,20,12,250,*7F
S3: $GPGSV,3,3,11,12,07,191,15,26,04,311,,42,,,*75

S1:
1: 3 Total number of sentences for full data
2: 1 Sentence number (a of T)
3: 11 Number of satellites in view
4: 29 Satellite PRN
5: 73 Elevation (degrees) 90° max
6: 300 Azimuth (degrees from True North) 0° ≤ x ≤ 359°
7: 28 SNR (signal to noise ratio)
8: 13 Satellite PRN
9: 50 Elevation (degrees) 90° max
10: 104 Azimuth (degrees from True North) 0° ≤ x ≤ 359°
11: 24 SNR (signal to noise ratio)
12: 15 Satellite PRN
13: 50 Elevation (degrees) 90° max
14: 168 Azimuth (degrees from True North) 0° ≤ x ≤ 359°
15: 25 SNR (signal to noise ratio)
16: 05 Satellite PRN
17: 39 Azimuth (degrees from True North) 0° ≤ x ≤ 359°
18: 22 SNR (signal to noise ratio)
19: 040 Azimuth (degrees from True North) 0° ≤ x ≤ 359°
20: *7B Checksum

S2:
1: 3 Total number of sentences for full data
2: 2 Sentence number (a of T)
3: 11 Number of satellites in view
4: 02 Satellite PRN
5: 29 Elevation (degrees) 90° max
6: 089 Azimuth (degrees from True North) 0° ≤ x ≤ 359°
7: SNR (signal to noise ratio)
8: 21 Satellite PRN
9: 20 Elevation (degrees) 90° max
10: 303 Azimuth (degrees from True North) 0° ≤ x ≤ 359°
11: SNR (signal to noise ratio)
12: 25 Satellite PRN
13: 19 Elevation (degrees) 90° max
14: 227 Azimuth (degrees from True North) 0° ≤ x ≤ 359°
15: SNR (signal to noise ratio)
16: 20 Satellite PRN
17: 12  Azimuth (degrees from True North) $0^\circ \leq x \leq 359^\circ$
18: 250 Azimuth (degrees from True North) $0^\circ \leq x \leq 359^\circ$
19:     SNR (signal to noise ratio)
20: *7B Checksum

S3:
1:  3 Total number of sentences for full data
2:  3 Sentence number (a of T)
3: 11 Number of satellites in view
4: 12 Satellite PRN
5:  07 Elevation (degrees) 90° max
6: 191 Azimuth (degrees from True North) $0^\circ \leq x \leq 359^\circ$
7: 15 SNR (signal to noise ratio)
8:  26 Satellite PRN
9:  04 Elevation (degrees) 90° max
10: 311 Azimuth (degrees from True North) $0^\circ \leq x \leq 359^\circ$
11:  SNR (signal to noise ratio)
12:  42 Satellite PRN
13:  Elevation (degrees) 90° max
14:  Azimuth (degrees from True North) $0^\circ \leq x \leq 359^\circ$
15:  SNR (signal to noise ratio)
16: *7B Checksum
Appendix F - References

Images
R13, R19: https://www.mouser.com/ProductDetail/Bourns/3266W-1-104?qs=vB%252BfAIyCWO71CSciiTFOQ%3D%3D&gclid=EAIaIQobChMI16zy3b_N4gIVDNbACh0jkWfiEAYYASABgIRB_D_BwE
R14, R20: https://www.mouser.com/ProductDetail/Bourns/3266W-1-104?qs=vB%252BfAIyCWO71CSciiTFOQ%3D%3D&gclid=EAIaIQobChMI16zy3b_N4gIVDNbACh0jkWfiEAYYASABgIRB_D_BwE
R10, R17: https://www.mouser.com/ProductDetail/Vishay-Dale/CRCW20100000ZSTF?qs=LuV470vrCuX3ntWMqh%3D%3D&gclid=EAIaIQobChMI16zy3b_N4gIVv_iBx08AAAX7EAYYASABgIDIrD_BwE
22-24 AWG: https://www.amazon.com/Stranded-different-colored-spool-included/dp/B00B4ZQ3L0
6-Pin Stackable Headers: https://www.mouser.com/ProductDetail/SparkFun/PRT-09280?qs=sGAEpiMZZMwWq7rhECAKeFWyTi%252BCwWXXmWqO4%3D
8-Pin Stackable Headers: http://www.hobbytronics.co.uk/arduino-header-8pin
Checklist Clipart: http://clipart-library.com/clipart/2079774.htm
Troubleshooting Clipart: http://ruthbowers.com/growing-means-not-being-afraid-to-ask-tough-questions/
Safety Clipart https://dumielauxepices.net/wallpaper-1417154
MicroSD Card: https://www.mouser.com/ProductDetail/SanDisk/SDSDQAF3-008G-T_?qs=sGAEpiMZZMwvQiTeTDzAaCaoaAZe%252BhhGFadmv7QiS14vUZ3o86g%3D%3D

References
AccuBeat: Accurate Frequency & Time (http://www.accubeat.com/rubidium-atomic-clock-technology/)
GPS.gov: https://www.gps.gov/systems/gps/space/
Vejayan, VVR (2017): How atomic clocks can keep accurate time for billions of years (https://cosmosmagazine.com/technology/how-atomic-clocks-keep-perfect-time-for-billions-of-years)
Constantine, Friedman & Goldberg, LLP (https://webpages.uncc.edu/~jmconrad/ECGR6185-2006-01/notes/Accelerometer.pdf)
Sparkfun installation https://learn.sparkfun.com/tutorials/mma8452q-accelerometer-breakout-hookup-guide/all
NovAtel GPS Specific Information: https://docs.novatel.com/OEM7/Content/Logs/GPRMC.htm?NMEAPositioningSystemModeIndicator
NovAtel GNSS Logs: https://docs.novatel.com/OEM7/Content/Logs/Core_Logs.htm?tocpath=Logs%7CAll%20Logs%7CGNSS%20Logs%7CN

Datasheets