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2 Revision History

Date	Revision	Description	Author
25 May 2020	A	First issue.	Andrew Li

3 Introduction

This technical documentation outlines the design considerations that were taken in the design of the Instrumentation Buoy Logic Board Version 2.

4 Power Supply

4.1 Power budget – consumption

Component	Current consumption	Effective average power consumption over 24hrs	Typ Value (mW)	Peak current (mA)	Power rail	Percentage
100PSI pressure sensor	1.6mA	$1.6\text{mA} * 3\text{V3} = 5.28\text{mW}$	5.28	1.6	3V3	6.7%
30PSI pressure sensor	1.6mA	$1.6\text{mA} * 3\text{V3} = 5.28\text{mW}$	5.28	1.6	3V3	6.7%
MCU	5.2mA typ (9mA max) @ 8MHz, active mode Power save (0.9uA)	$P_{\text{total}} = 9 * 3.3 = 29.7\text{mW}$	29.7	5.2	3V3	37.6%
HC-12 wireless	16mA during TX 80uA on idle	Average estimated usage = 5mins of TX once per week $P_{\text{avg}} = 16 * 3.3 * 5 / (60 * 24 * 7) = 0.026\text{mW}$ $P_{\text{idle}} = 0.08 * 3.3 = 0.264\text{mW}$ $P_{\text{total}} = 0.29\text{mW}$	0.29	16	3V3	0.4%
Accelerometer	140uA	$P_{\text{total}} = 0.140 * 3.3 = 0.462\text{mW}$	0.462	0.14	3V3	0.6%
microSD	100mA during read and write @ 25MHz standard mode 500uA sleep	5% of time is spent in write mode, 95% of time is spent in sleep mode: $P_{\text{total}} = (0.05 * 100 + 0.95 * 0.5) * 3.3 = 18.0675\text{mW}$	18.0675	100	3V3	22.8%

LED light	1.5W	Light is on 8 hours a day @ 5% duty (8/24) * 1500 / 20 = 20 mW	20	405	3V3	25.3%
Total			79.1	529.5		100.0%
Designed (plus 50% margin)			118.6	794.3		

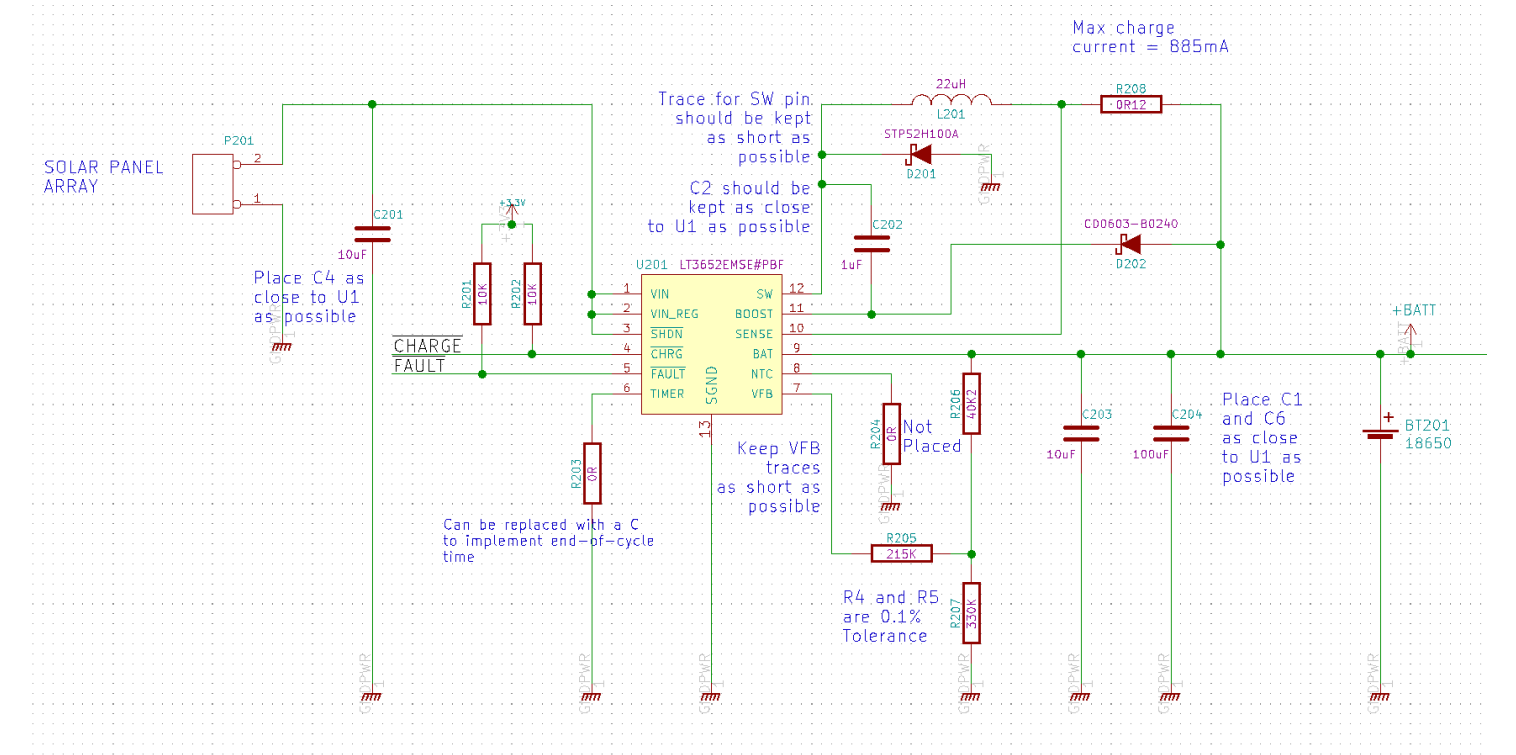
4.2 Power budget – generation

Avg daily energy requirement (J)	10248.7
Avg number of hours of sun	8.0
Minimum solar power output requirement (mW)	355.9
Designed solar power output requirement (added 2X margin) (mW)	711.7

Voltage OC of solar panels (V)	3
Current of solar panels (mA)	30
Number of solar panels	12
Total power (avg per day) (mW)	1080

4.3 Solar charging

Solar charging is provided by the LT3652 charge controller from Linear Technology. The LT3652 is a step-down battery charger that operates over a 4.95V to 32V input voltage range (40V absolute maximum).



4.3.1 Maximum charge current

The lithium ion cell used can charge at 1C (2.6A, 9.62W). Given that the maximum power provided the solar cell array is approximately 1W, the designed maximum charging current is calculated as below:

$$\begin{aligned} I_{(CHG(MAX))} &= \frac{1000}{2.8V} (mA) \\ &= 357 (mA) \end{aligned}$$

R208 is the R_{SENSE} resistor. It's value is calculated as follows:

$$\begin{aligned} R_{SENSE} = R208 &= \frac{0.1}{I_{CHG(MAX)}} \\ &= \frac{0.1}{0.357} (\Omega) \\ &= 280 (m\Omega) \end{aligned}$$

Selecting from E24 series resistor values, a 1% tolerance 270mOhm resistor is used for R208. The actual

$I_{CHG(MAX)} = \frac{100mV}{0.27\Omega} = 370mA$, however for simplicity, 357mA will be used for remaining calculations.

	Requirement	Solution
Resistance	270mΩ	270mΩ
Tolerance	1%	1%
Minimum current rating specification	370mA + 50% margin = 555mA	900mA

4.3.2 Input voltage supply decoupling capacitor

This is implemented using C201.

The manufacturer recommends using a high quality, low ESR decoupling capacitor at the input pin of LT3652. The decoupling capacitor is used to sink input ripple current. The input charging RMS ripple current $I_{CVIN(RMS)}$ is given by the equation below.

$$I_{CVIN(RMS)} \cong I_{CHG(MAX)} \cdot \frac{V_{BAT}}{V_{IN}} \sqrt{\frac{V_{IN}}{V_{BAT}} - 1} (A)$$

The above relation is maximum when $V_{IN} = 2 \cdot V_{BAT}$. We designed $I_{CHG(MAX)} = 0.357A$. Therefore:

$$\begin{aligned} I_{CVIN(RMS)} &= \frac{I_{CHG(MAX)}}{2} \\ &= \frac{0.357}{2} \\ &= 0.18 (A) \end{aligned}$$

Therefore, the maximum input charging RMS input current $I_{CVIN(RMS)}$ is 0.18A.

The minimum bulk capacitance required at the input is given by the below equation, where $\Delta V_{IN} = 100 mV$. This is the maximum acceptable ΔV_{IN} as specified by the manufacturer.

$$\begin{aligned} C_{IN(BULK)} &= I_{CHG(MAX)} \cdot \left(\frac{V_{BAT}}{V_{IN} \cdot \Delta V_{IN}} \right) (\mu F) \\ &= 0.18 \cdot \left(\frac{4.2}{9 \cdot 0.1} \right) (\mu F) \\ &= 0.84 (\mu F) \end{aligned}$$

The voltage rating of C201 needs to have voltage rating greater than 9V (three solar cells in series) as well as maintain sufficient capacitance at the operating voltage such that the input ripple voltage is maintained below 100mV.

The manufacturer recommends a value of 10uF for C201. The below solution has been chosen.

Solution MPN	Requirement	AVX, TPSD106K035R0125
Capacitance	10uF	10uF
Tolerance	10%	10%
ESR	Low	0.12mΩ
Voltage rating	9V + 50% margin = 13.5V	35V
Rated ripple current	0.18A + 50% margin = 0.27A	0.986A [at 85°C, 35V]

This solution will achieve an input charging RMS ripple voltage of:

$$\begin{aligned}
 \Delta V_{IN} &= I_{CHG(MAX)} \cdot \left(\frac{V_{BAT}}{V_{IN} \cdot C_{IN(BULK)}} \right) \\
 &= 0.357A \cdot \left(\frac{4.2V}{9 \cdot 10} \right) \\
 &= 17 \text{ mV} < 100 \text{ mV}
 \end{aligned}$$

4.3.3 Boost supply

The internal switch driver uses a bootstrapped power supply to drive the internal switch transistor. For correct start-up, the BOOST pin must be above 2V with respect to the SW pin (or VIN pin must be above 3.3V with respect to the SW pin). For correct operation, the VBOOST cannot exceed 8.5V with respect to the SW pin. C202 acts as the bootstrap capacitor. The value of 1uF is recommended by the manufacturer. The voltage rating of C202 must exceed the maximum BAT voltage of 4.2V.

A bootstrap diode D202 connected between the BAT pin and the BOOST pin is required to facilitate the bootstrapping mechanism. The manufacturer recommends using a diode with average current greater than 0.1A and a reverse voltage greater than $V_{IN(MAX)}$ of 9V.

Solution MPN	Requirement	Bourns, CD0603-B0240
Forward voltage	Low	0.55V (at $I_F = 0.2A$)
Reverse voltage	9V + 50% margin = 13.5V	40V
Average forward current	100mA + 50% margin = 150mA	200mA
Reverse leakage current	Low	10uA (at $V_R = 30V$)

There is the option of using a Zener diode to clamp the voltage between BOOST and SW pins to be below 8.5V. However, this is not required as only one Li-ion cell is used where the BAT pin voltage will not exceed 4.2V.

4.3.4 MPPT temperature compensation

Temperature compensated MPPT (maximum power point tracking) can be implemented using an LM234 3-terminal temperature sensor (U203) and resistor network R209, R210 and R203. The values for the resistors are calculated using the equations below.

$$\begin{aligned}
 R209 &= -R203 \cdot (TC \cdot 4405) \\
 R210 &= \left(\frac{R209}{\frac{V_{MP(25C)} + R209 \cdot \left(\frac{0.0674}{R203} \right)}{V_{IN(REG)}} - 1} \right)
 \end{aligned}$$

Where TC is the temperature coefficient (in $V/^{\circ}C$) of the solar panel array. $V_{MP(25C)}$ is the maximum power voltage at $25^{\circ}C$.

For our 12 solar cell array, the specifications are:

$$TC = 0.07 (V C^{-1})$$

$$V_{MP(25C)} = 9V$$

$$\text{Let } R203 = 1k\Omega$$

$$R209 = -1k\Omega \cdot (-0.078 \cdot 4405) = 344k\Omega$$

$$R210 = \left(\frac{\frac{344k\Omega}{9V + 344k \cdot \left(\frac{0.0674}{1k\Omega} \right)} - 1}{2.7V} \right) = 31.5k\Omega$$

1% tolerance resistors were used for the resistor in this network. Selecting from E96 component values:

Resistor	Calculated value	Implemented value
R203	1k Ω	1k Ω 1%
R209	344k Ω	340k Ω 1%
R210	31.5k Ω	31.6k Ω 1%

4.3.5 Output capacitor

Output decoupling capacitor C203 is required. The manufacturer's recommended value is 10uF. The same capacitor used for C201 has been used for C203 to save on BOM count.

4.3.6 Inductor design

The primary criterion for inductor value selection in an LT3652 charger is the ripple current created in that inductor. Once the inductance value is determined, an inductor must also have a saturation current equal to or exceeding the maximum peak current in the inductor. An inductor value (L), given the desired amount of ripple current (ΔI_{MAX}) can be approximated using the relation:

$$L = \left(10 \cdot \frac{R_{SENSE}}{\Delta I_{MAX}} \right) \cdot V_{BAT(FLT)} \cdot \left(1 - \frac{V_{BAT(FLT)}}{V_{IN(MAX)}} \right) (\mu H)$$

$$\text{where } R_{SENSE} = R208$$

$$V_{BAT(FLT)} = 4.2V$$

$$V_{IN(MAX)} = 9V$$

Where ΔI_{MAX} is the normalised inductor ripple current. The manufacturer recommends setting ΔI_{MAX} to between 25% and 35% of $I_{CHG(MAX)}$. We will set ΔI_{MAX} to 30%. Therefore:

$$\begin{aligned} L &= \left(10 \cdot \frac{0.28\Omega}{0.3} \right) \cdot 4.2V \cdot \left(1 - \frac{4.2V}{9V} \right) (\mu H) \\ &= 20.9 (\mu H) \end{aligned}$$

The inductor also needs to meet the minimum volt-second requirement as specified in the equation below:

$$\begin{aligned} \text{volt second} &= V_{BAT(FLT)} \cdot \left(1 - \frac{V_{BAT(FLT)}}{V_{IN(MAX)}} \right) (V \cdot \mu s) \\ &= 4.2V \cdot \left(1 - \frac{4.2V}{9V} \right) \\ &= 2.24 (V \cdot \mu s) \end{aligned}$$

Inductor maximum RMS and saturation current rations ($I_{MAX(RMS)}$ and I_{SAT} respectively) are calculated as follows:

$$\begin{aligned}
I_{SAT} &= \left(1 + \frac{\Delta I_{MAX}}{2}\right) \cdot I_{CHG(MAX)} \\
&= \left(1 + \frac{0.3}{2}\right) \cdot 0.357 \text{ (A)} \\
&= 0.41 \text{ (A)} \\
I_{MAX(RMS)} &> I_{CHG(MAX)} \\
&> 0.357 \text{ A}
\end{aligned}$$

	Requirement	Murata, 46223C	TDK, SLF6025T-220MR73-PF
Inductance at 1MHz operating frequency	22uH	22uH	22uH
Tolerance	20%	20%	20%
DC resistance	Low	120mΩ	122mΩ (typ) 146.4mΩ (max)
Rated DC saturation current specification	0.41A + 50% margin = 0.62A	1.8A (defined when inductance falls below 75% or when component temperature reaches 40°C from TA=25°C).	0.73A

4.3.7 Rectifier design

The rectifier diode from SW to GND, in a LT3652 battery charger provides a current path for the inductor current when the main power switch is disabled. The rectifier is selected based upon forward voltage, reverse voltage, and maximum current. A Schottky diode is required, as low forward voltage yields the lowest power loss and highest efficiency. The rectifier diode must be rated to withstand reverse voltages greater than the maximum VIN voltage. The minimum average diode current rating $I_{DIODE(MAX)}$ is calculated with maximum output current $I_{CHG(MAX)}$, maximum operational VIN, and output at the precondition threshold ($V_{BAT(PRE)}$, or $0.7 \cdot V_{BAT(FLT)}$):

$$\begin{aligned}
I_{DIODE(MAX)} &> I_{CHG(MAX)} \cdot \frac{V_{IN(MAX)} - V_{BAT(PRE)}}{V_{IN(MAX)}} \text{ (A)} \\
I_{DIODE(MAX)} &> 0.357 \text{ A} \cdot \frac{9\text{V} - 0.7 \cdot 4.2\text{V}}{9\text{V}} \text{ (A)} \\
I_{DIODE(MAX)} &> 0.24 \text{ (A)}
\end{aligned}$$

Solution MPN	Requirement	ST Microelectronics, STPS2H100A
Forward voltage	Low	0.6V typ. (at $I_F = 2\text{A}$)
Reverse voltage specification	9V + 50% margin = 13.5V	100V (peak repetitive)
Average forward current	0.24A + 50% margin = 0.36A	2A
Reverse leakage current	Low	1uA (at 25°C)

4.3.8 Battery float voltage programming

The float voltage of the battery is programmed using the resistor network R205, R206 and R207. $V_{BAT(FLT)}$ can be programmed up to 14.4V. Because the battery voltage is across the $V_{BAT(FLT)}$ programming resistor divider, this divider will draw a small amount of current from the battery at a rate of

$$I_{RFB} = \frac{3.3}{R207}$$

Values for R205, R206 and R207 are calculated as follows

$$\begin{aligned} \frac{R207}{R206} &= \frac{3.3}{V_{BAT(FLT)} - 3.3} \\ &= \frac{3.3}{4.2 - 3.3} \\ &= 3.67 \end{aligned}$$

Setting $I_{RFB} = 10\mu A$ yields:

$$\begin{aligned} R207 &= \frac{3.3}{10\mu A} \\ R207 &= 330k\Omega \end{aligned}$$

$$\begin{aligned} R206 &= \frac{330k\Omega}{3.67} \\ &= 90k\Omega \end{aligned}$$

The equivalent input resistance at the VFB pin needs to be 250kOhm to compensate for input bias current error. Therefore:

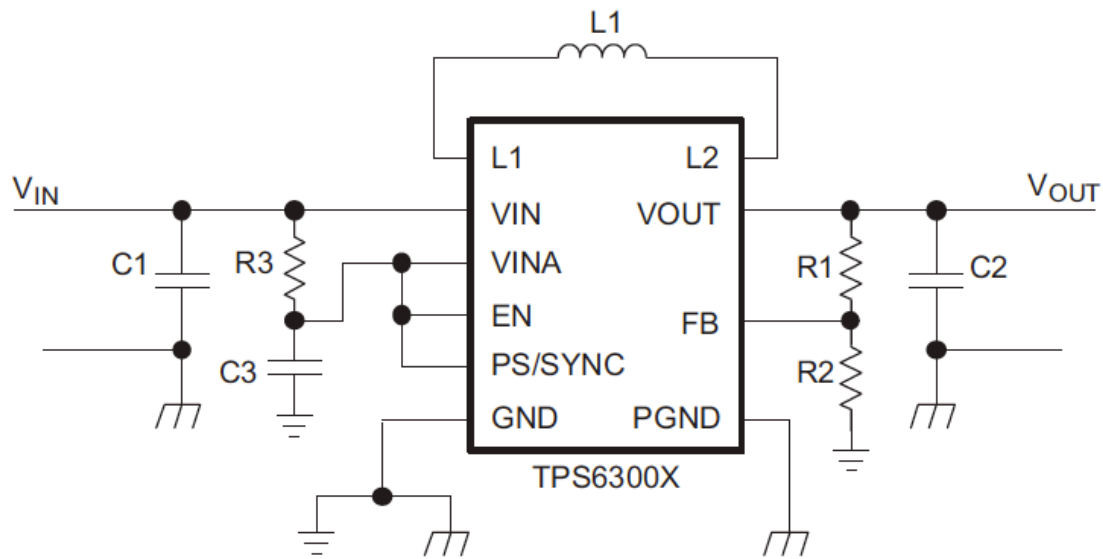
$$R205 = 250k\Omega - 90k\Omega = 160k\Omega$$

Resistor	Calculated value	Implemented value
R205	160k	160kΩ 1%
R206	90kΩ	90.9kΩ 1%
R207	330kΩ	330kΩ 1%

4.4 3V3 power supply

Power supply requirements

	Requirement	Solution
Minimum output current requirement	0.794A	1.6A (min, VIN = 3.6V, TA = 25°C)
Output voltage	3.3V +/- 10%	
Output voltage ripple	+/-300mV	
Input voltage range	2.8V to 4.2V	1.8V to 5.5V
Efficiency	> 80% at 0.794A	



The TPS63001 voltage regulator (U202) is to switch mode buck-boost converter to efficiently convert the output voltage of the battery to 3V3.

4.4.1 Input capacitors

TPS63001 requires at least 4.7uF of input capacitance to improve transient behaviour of the regulator and EMI behaviour of the total power supply circuit. The input capacitor for this design is required to have a voltage rating greater than 4.2V. The reference design provided by the manufacturer uses a GRM188R60J106KME84D, 10uF capacitor from Murata. This is used in the instrumentation buoy logic board.

4.4.2 Output capacitors

TPS63001 requires at least 15uF of output capacitance. The reference design for TPS63001 has two 10uF capacitors at its output. The capacitor is required to have a voltage rating greater than 3.3V. The manufacturer recommends the GRM188R60J106KME84D from Murata for both output capacitors. This is used in the instrumentation buoy logic board.

4.4.3 Inductor design

L202 is the inductor for the buck-boost mechanism. The peak inductor current is calculated using the equations below:

$$D = \frac{V_{OUT} - V_{IN}}{V_{OUT}}$$

$$I_{PEAK} = \frac{I_{OUT}}{\eta \times (1 - D)} + \frac{V_{IN} \times D}{2 \times f \times L}$$

Where:

V_{IN}	Minimum input voltage	2.8V
V_{OUT}	Output voltage	3.3V
η	Efficiency of the converter at worst case loading	80%
f	Converter operating frequency	1.25MHz to 1.8MHz
L	Inductance of inductor at operating frequency	2.2uH

$$D = \frac{3.3 - 2.8}{3.3}$$

$$= 0.15$$

$$I_{PEAK} = \frac{0.529}{0.8 \cdot (1 - 0.15)} + \frac{2.8 \cdot 0.15}{2 \cdot 1.25MHz \cdot 2.2\mu H}$$

$$= 0.85A$$

The datasheet recommends using a 2.2uH inductor. The solution is listed below.

Solution MPN	Requirement	TDK, VLS3015CX-2R2M-1
Inductance at 2.4MHz operating frequency	2.2uH	2.2uH
Tolerance	20%	20%
DC resistance	Low	64 mΩ(max)
Rated DC saturation current specification	0.85 + 50% margin = 1.28A	1.71A (30% drop in inductance)

4.4.4 Thermal design

The resistive heating P_R dissipated during operation at I_{PEAK} is calculated below:

$$P_R = I_{PEAK}^2 \cdot R_{DC}$$

$$= 0.85^2 \cdot 0.087$$

$$= 63 (mW)$$

Calculating the ΔT between the IC junction and ambient at peak power.

$$\Delta T_{JA} = 0.063 \cdot R_{\theta JA}$$

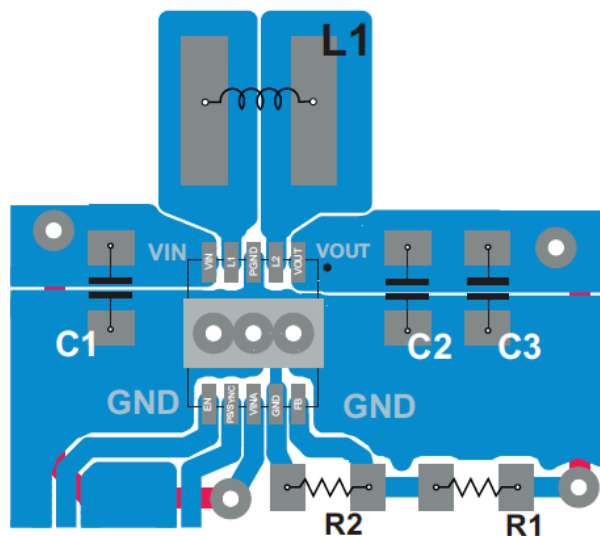
$$= 0.063W \cdot 48.6^{\circ}CW^{-1}$$

$$= 3.1^{\circ}C$$

At maximum ambient temperature of 30°C, the junction temperature will be 33.1°C. This is well below the maximum operating junction temperature of 125°C, therefore no heat sinking is required.

4.5 Layout considerations

The manufacturer recommends the below layout.



5 Microcontroller

5.1 RTC

The RTC is used to keep track of the time so that the data can be timestamped. Allowable drift of the RTC is 20mins per year.

The 32.768kHz crystal used was the CC4V-T1A 32.768KHZ +20PPM 9PF. The specifications for the crystal are listed below:

Load capacitance C_L	9.0pF
Frequency tolerance	30ppm
Drive power	1.0uW
Aging first year max.	3ppm
Frequency vs temperature	-0.035ppm/°C

A properly designed oscillator with this crystal will exhibit a theoretical maximum frequency drift of $30 + 3 + 0.7 = 33.7\text{ppm}$ after one year of operation. This equates to 18 mins per year.

Calculations of C309 and C310, the external capacitors for the crystal are as follows, assuming the stray capacitance between the crystal pins is 3pF.

$$\begin{aligned} C_{309} &= C_{310} = 2 \cdot (C_L - C_{STRAY}) \\ &= 2 \cdot (9.0\text{pF} - 3.0\text{pF}) \\ &= 12\text{pF} \end{aligned}$$

5.2 HC-12

The HC-12 is the wireless module that allows UART communication to occur wirelessly. The effective range is 1km, given an adequate antenna.

5.3 Battery voltage measurement

The battery voltage is measured using a resistor divider R301 and R302. The values were chosen such that the voltage at +BAT_AD is 3V when the +BATT net is 4.2V. Schottky diode D301 with $V_F < 200\text{mV}$ is used to clamp voltage at +BATT_AD to less than 3.5V to protect the MCU pin. The ADC reading this voltage is 10 bits. This gives a resolution of 3.2mV.

$$V_{+BATT} = 3.3\text{V} \cdot \frac{10\text{k}\Omega}{10\text{k}\Omega + 4.7\text{k}\Omega}$$

+BATT voltage	+BATT_AD voltage	ADC count (10 bits, 0 to 1023)
2.8V	1.90V	589
4.2V	2.86V	887

6 Sensing

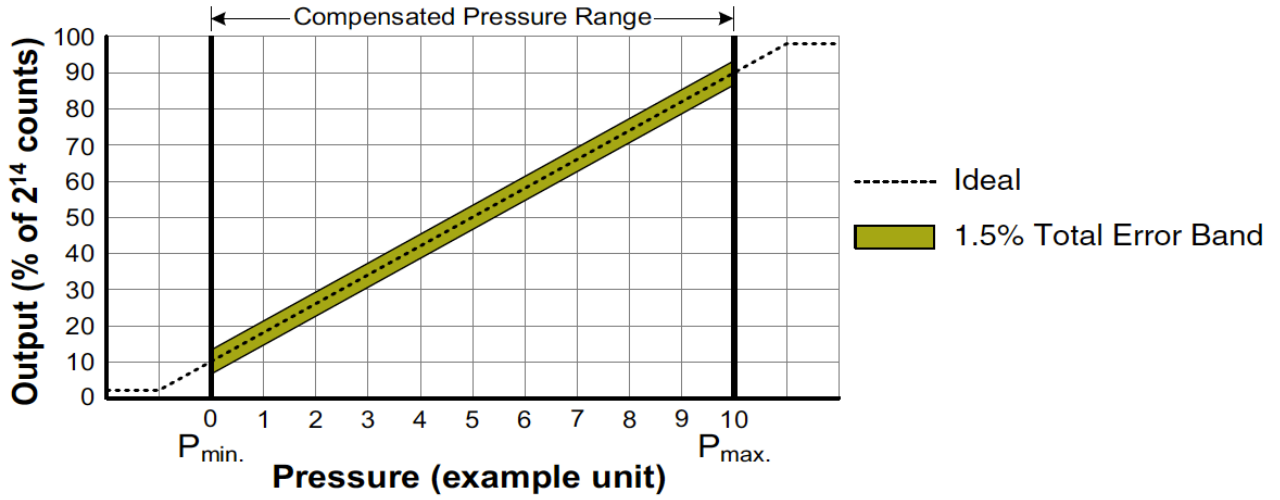
6.1 Accelerometer

The accelerometer used is the ADXL343. It is set to operate at the +/-2g range, 100Hz output data rate. The accelerometer requires a 1uF decoupling capacitor at the VS pin (C401) and a 100nF decoupling capacitor at the VDDIO pin (C402).

6.2 Pressure sensor

The pressure sensor ABPMANN005PG2D3 used is a digital pressure sensor with I2C interface. It is rated to 5 PSI, gauge pressure, DIP package with single axial barbed port.

The formula for translating counts to pressure is given below.



Where:

$$Output (\% \text{ of } 2^{14} \text{ counts}) = \frac{80\%}{P_{max} - P_{min}} \cdot (P_{applied} - P_{min}) + 10\%$$

where $P_{min} = 0 \text{ PSI}$, $P_{max} = 5 \text{ PSI}$

6.3 Depth measurement

The depth measurement apparatus is used to measure the depth that the buoy is submerged in the water as it floats in the ocean. It does this using an using two 800mm metal rods made from nichrome with a resistivity ρ_{rod} of $13.77\Omega/\text{m}$, strapped on the side of the buoy. A schematic of the apparatus is shown in Figure 1 where x is the water depth as measured from the top of the buoy. The resistance R_{DEPTH} measured between points a and b is given by the expression below. The resistivity of seawater $\rho_{seawater} = 0.2\Omega\text{m}^{-1}$.

$$\begin{aligned} R_{DEPTH} &= 2 \cdot \rho_{rod}x + \rho_{seawater} \cdot 0.314 \\ &= 27.54x + 0.0628 \Omega \end{aligned}$$

R_{DEPTH} is driven by a constant current source built around D401, R402, R404 and Q402. The design of the current source is outlined below.

6.3.1 Zener diode design

The current source will be designed to source 30mA of current. 30mA is a good trade-off between signal to noise ratio and power consumption.

A 1.8V Zener diode was selected as the voltage reference. To maintain a 1.8V Zener voltage, the Zener voltage needs to be around 600uA. This current is programmed using R402.

$$R402 = \frac{3.3V - 1.8}{0.6mA} = 2.5k\Omega$$

The implemented value for R402 is 2.4k Ω , selected from E24 values.

The transistor Q402, when switched on exhibits a V_{BE} of 0.70V. There the emitter current I_E and base current I_B of Q402 is

$$\begin{aligned} I_E &= \frac{1.8V - 0.7V}{R404} = \\ I_B &= \frac{I_E}{h_{FE} + 1} = \frac{1.8V - 0.7V}{R404 \cdot (h_{FE} + 1)} \end{aligned}$$

The current of the current source equals the collector current of Q402. Therefore, the current source current is calculate as follows:

$$I_C = \frac{I_E \cdot h_{FE}}{h_{FE} + 1} = \frac{(1.8V - 0.7V) \cdot h_{FE}}{R404 \cdot (h_{FE} + 1)}$$

$$R404 = \frac{(1.8V - 0.7V) \cdot h_{FE}}{I_C \cdot (h_{FE} + 1)} = 36\Omega$$

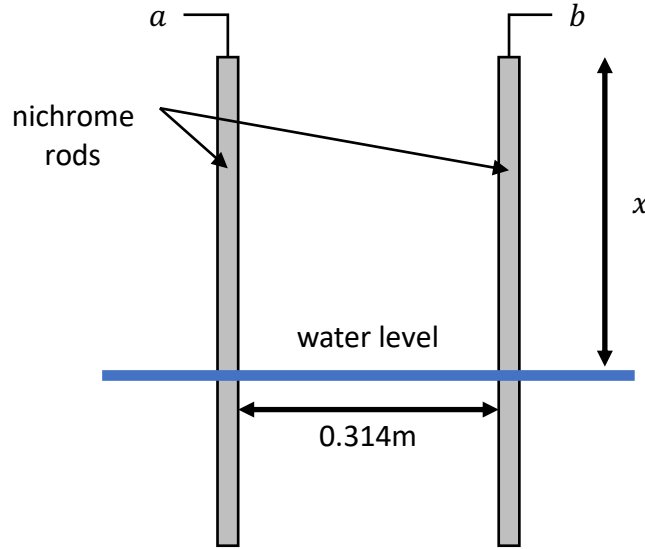


Figure 1

6.3.1 Instrumentation amplifier

We would like to resolve the depth to within 5mm over 800mm (0.6%). We calculate the minimum and maximum values of R_{DEPTH} .

$$R_{DEPTH(MIN)} = 27.54 \cdot 0 + 0.0628 \Omega$$

$$= 0.0628\Omega$$

$$R_{DEPTH(MAX)} = 27.54 \cdot 0.8 + 0.0628\Omega$$

$$= 22.1\Omega$$

The voltage across R_{DEPTH} is as follows

$$V_{DEPTH}(x) = (27.54 \cdot x + 0.0628) \cdot 0.03 (V)$$

$$V_{DEPTH(MIN)} = 0.0628 \cdot 30mA = 1.88mV$$

$$V_{DEPTH(MAX)} = 22.1 \cdot 30mA = 663mV$$

To amplifier the signals such that $V_{DEPTH(MAX)}$ is amplified to 3.0V, the gain of the instrumentation amplifier needs to be around 4.52. The gain of the instrumentation amplifier can be calculated as below.

$$G = \frac{V_{OUT}}{V_a - V_b} = 1 + \frac{R_1}{R_2} + \frac{2R_1}{R_G}$$

$$= 4.60$$

Where

$$R_1 = RN401A = RN401D = 56k\Omega$$

$$R_2 = RN401B = RN401C = 56k\Omega$$

$$R_G = R407 = 43k\Omega$$

The output voltage to the ADC is as follows

$$V_{ADC} = 4.60 \cdot (27.54 \cdot x + 0.0628) \cdot 0.03$$

$$= 0.138 \cdot (27.54 \cdot x + 0.0628)$$

The ADC count (10 bit ADC) is calculated as follows

$$\begin{aligned} COUNT_{ADC} &= 1023 \cdot \frac{V_{ADC}}{3.3} \\ &= 42.78 \cdot (27.54x + 0.068) \\ &= 1178x + 2.91 \end{aligned}$$

$$x = \frac{(COUNT_{ADC} - 2.91)}{1178} \text{ (m)}$$

Where x is the water depth as measured from the top of the buoy.

The signal is passed through a low pass filter implemented with R409 and C403 with a cut-off frequency of 1kHz to attenuate noise before being fed into the ADC of the microcontroller.

7 LED drive

7.1 Light detect

A photoresistor (connected to P502) in conjunction with a resistor R510 is used to detect night and day and automatically used to switch on the LED lights. The VT90N1 has a resistance between 6kΩ and 18kΩ at 10 lux and 200k at 0 lux. The signal is fed through a low pass filter before being fed into the ADC pin. The specifications for the light detect circuit is shown below.

	10 lux	0 lux
Min voltage / ADC count at LIGHT_DETECT_AD	2.50V / 755	0.72V / 223
Max voltage / ADC count at LIGHT_DETECT_AD	2.99V / 927	0.72V / 223

7.2 LED

The buoy uses six Cree Inc. CLA2A-WKW-CYBZ0343 white LED modules (LED501 to LED506). Each LED module contains two LEDs. The LEDs have the following specifications:

Colour temperature	5500K typ.
Luminous intensity (at $I_F = 2 \times 20\text{mA}$)	3550 to 5600 mcd
Forward current	2 x 25mA
Peak forward current	2 x 100mA (pulse width $\leq 0.1\text{s}$, duty ≤ 0.1)
Forward voltage (at $I_F = 20\text{mA}$)	3.2V typ., 4.0V max
Viewing angle	60 degrees (when relative luminous intensity drops by 50%)

The LEDs have been designed to operate at 20mA per diode which achieves a relative luminous intensity of 1. The buoy will shine with a luminous intensity between 21.3cd and 33.6cd per flash.

7.3 LED driver

The FAN5333A from ON Semiconductor (U501) was selected to drive the LED array. The specifications for FAN5333A are shown below:

	Requirement	Specification
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Input voltage range	2.8V to 4.2V	1.8V to 5.5V
Output voltage	Greater than 19.5V	From VIN to 30V
Output load current	Greater than 40mA	65mA min.

7.3.1 Maximum output voltage

The output voltage is calculated to ensure that the voltage is within the capabilities of the FAN5333A chip.

$$V_{OUT} = V_{FB} + V_D + 6 \cdot V_{LED}$$

$$= 0.11V + 0.18V + 6 \cdot 3.2V = 19.49V \cong 19.5V$$

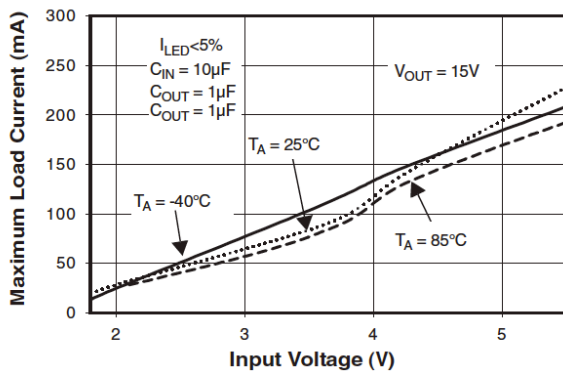
The calculated output voltage is within the maximum output voltage capability of the FAN5333A.

7.3.2 Setting output current

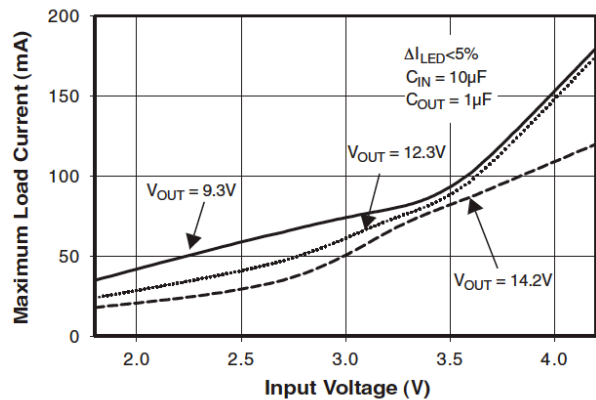
The output current is programmed by selecting the feedback resistor R512. For the FAN5333A, $V_{FB} = 0.11V$.

$$R_{512} = \frac{V_{FB}}{I_{LED}} = \frac{0.11V}{20mA} = 5.5\Omega$$

Maximum Load Current vs. Input Voltage



Maximum Load Current vs. Input Voltage



Examining the current and voltage curves of the FAN5333A, the required output current of 40mA can only be maintained if the battery voltage is above 3.0V. This is sufficient as the battery voltage will likely be high at the start of evening due to an entire day of charging under the sun. If the 40mA output current cannot be sourced, the LEDs will still be able to shine with sufficient brightness.

7.3.3 Inductor design

The manufacturer recommends using a 10uH inductor with saturation current greater than 1A and a DC resistance as low as possible to improve converter efficiency. The SLF6025T-100M1R0-PF from TDK was selected, which is also a part recommended by the manufacturer.

	Requirement	TDK, SLF6025T-100M1R0-PF
Inductance	10uH	10uH
DC resistance	Low	68.76mΩ (max)
Saturation current	Equal or greater than 1A	1A

7.3.4 Capacitor selection

The manufacturer recommends input and output capacitors of values 10uF and 1uF respectively. These are implemented by capacitors C505 and C501 respectively, X5R SMD ceramic capacitors.