IoT Motion Switch

EE 4490 SPECIAL TOPICS INTRO TO ENGINEERING DESIGN TOOLS MIDTERM PROJECT.

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KSU ID: | 07/05/2021

I. Introduction

Since the inception of the transistor from bell laboratories in 1947 the electronic devices have had an exponential growth in computational power, inversely this development means devices become smaller, or denser and importantly power efficient. Which with the advent of cheap and reliable wireless chips the Internet of Things (IoTs) will become the new standard for not just consumer devices but for all fields that require any form of data collection, processing, and user interaction. Internet of Things are devices that employ technology that allows them to communicate as a network together or directly to the internet. Currently the IoT market is estimated to be 35 billion devices, and 75 billion by 2025. With the potential to be integrated into large portions of industrial, Commercial, and Consumer fields.

The IoT device focused on this report is a full three-dimensional accelerometer chip capable of precise X,Y,Z measurement for movement from Analog devices, is low powered and can operate with a decent voltage range. See Table 1 for details, also Figures 1 and 2 for device housing and functional block diagram.

Application Device			
Designation:	ADXL362		
Manufacture:	Analog Devices Inc.		
Product ID:	ADXL362BCCZ-RL7		
Description:	ACCELEROMETER X, Y, Z Axis		
	Minimal:	Nominal:	Maximum:
Current (µA):	1.8µA	2.4µA	3.3µA
Voltage (V):	1.6V	2.0V	3.5V
Power (µW):	2.88µW	4.8µW	11.6µW
Resistance (calc)	888 kΩ	833 kΩ	1.06MΩ
Vendor:	Digi-key	Link:	https://www.digikey.com/short/hphf2m53

Table 1. Application device chip specifications.

However, this chip alone would not be enough for a standalone device. On Analog Devices' data sheet details an application for an autonomous motion switch. See Table 2 for details. See Figures 3 and 4 for device appearance and simplified circuit.

Application Device			
Designation:	CN0274		
Manufacture:	Analog Devices Inc.		
Product ID:	EVAL-CN073-SDPZ Rev A		
Description:	Ultralow Power Standalone Motion Switch		
	Minimal:	Nominal:	Maximum:
Current:	300nA	<3µA	N/A
Voltage (V):	1.6V	2.0V	3.5V
Power (µW):	480nW	6 µW	N/A
Resistance (calc)	3.33 MΩ	333 kΩ	N/A
Vendor:	Mouser Electronics	Link:	https://www.mouser.com/ProductDetail/Analog-Devices/EVAL-CN0274-SDPZ?qs=WIvQP4zGaniRu7BFXA8C9w%3D%3D

Table 2 Application device Specifications.

Likewise, if wireless charging is not working for any amount of time, a battery that matches the same voltage as the device has been chosen to be able to deliver continuous power. See Table 3 for details.

Energy Storage Device			
Designation:		MS421R	
Manufacture:		Seiko Instruments	
Product ID:		MS421R-IV03E	
Description:		Coin Cell Battery RTC & SRAM Backup Reflowable Rechargeable Battery	
Rechargeable:		Yes	
	Nominal:	Maximum:	
Capacity (mAh):	1.5	N/A	
Voltage (V):	3	3.3	
Internal R (Ω)	600	N/A	
Vendor:	Mouser Electronics	Link:	https://www.mouser.com/ProductDetail/Seiko-Instruments/MS421R-IV03E?qs=DRkmTr78QARdKPbYOSfXog%3D%3D

Table 3. Energy storage device specifications.

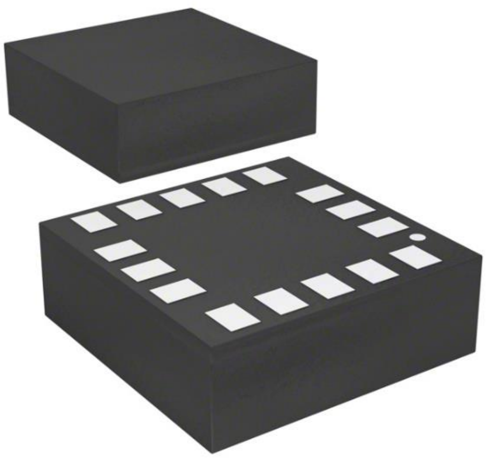

Figure 1. Rendering of ADXL362 Accelerometer

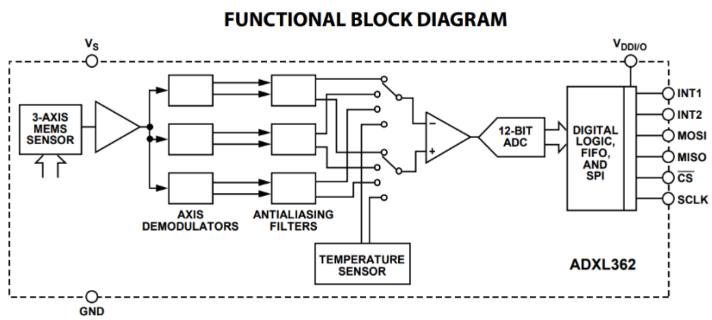

Figure 2. Functional block diagram of ADXL362.

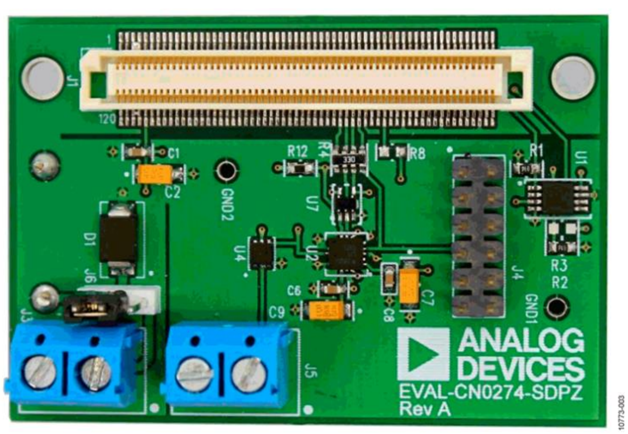

Figure 3. Device Appearance from manufacturer.

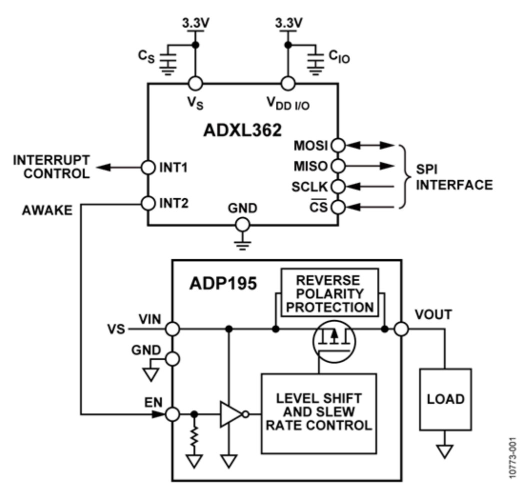

Figure 4. Device simplified circuit schematic.

This IoT motion sensor could be used in several ways, for wireless sensors, metering devices, home healthcare. One aspect could be security, as home and professional security systems become more integrated with IoT, the aspect of having expensive disposable batteries that often do not get recycled for every sensor could be problematic. One possible solution could be utilizing far field wireless power to keep sensors charged and/or prolong the lifetime on their batteries.

II. Wireless Power Transfer.

Wireless Power Transfer (WPT) can be classified in two main categories, Near-field WPT and Far-field WPT. While both are for the same overall goal, each operate on very separate principles and techniques. For near field power transfer the area is close to the dimension of the transmitting antenna, also the transmission is usually so close that use of capacitive coupling (electrostatic induction) between two electrodes or magnetic coupling (magnetic induction) between two coils are used to transmit power. One key aspect is since coupling is involved if there is no receiver power loss is minimal because there is no load. On the other end, for far field the area is farther from the dimension of the transmitter making induction coupling impractical so radiative methods are used like radio waves, microwaves and possibly visible light. Unlike before, the energy is radiated out so there is a "load" no matter if there is a receiver, combined with inverse-square law efficiency takes a nosedive. For a more definitive view on the differences between near and far field see table 4 and figure 5.

Reactive Near Field	Fresnel (Radiative) Near Field	Far Field
$Near\ Field\ Region < \frac{2D^2}{\lambda}$		$Far\ Field\ Region > \frac{2D^2}{\lambda}$
$Reactive\ Region < 0.62\sqrt{\frac{D^3}{\lambda}}$	$0.62x\sqrt{\frac{D^3}{\lambda}} < Radiative\ Region < \frac{2D^2}{\lambda}$	
Region closest to the original transmission location.	Between Reactive and Far Field, it is where the waves begin to become radiating fields, but still with some pattern variations.	Farthest field in spectrum; EM fields are predominantly radiating fields.
D = Maximum dimension of antenna λ = Wavelength		

Table 4. Breakdown of Near Field and Far Field.

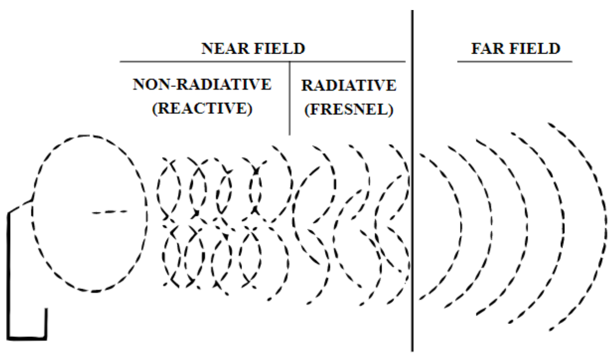

Figure 5. Graphical view of Near and Far field.

To determine what region a device is in or what parameters are needed to be in a particular region the Friis formula is used to determine the power at the receiving antenna. For the application of an IoT motion switch the key would be to pick an antenna's, operating frequency, Gain and Dimension to make sure the device receive adequate power.

For the Friis formula: $P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2}$

The calculation can be broken down on figure 6, where P_R = Power Received, P_T = Power Transmitted, G_R = Gain of receiving Antenna, G_T = Gain of Transmitting Antenna, λ = Wavelength, R = Range between Antennas.

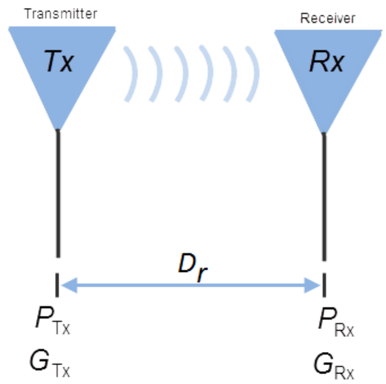

Figure 6. Friis Formula variables.

For the IoT motion switch, Frequency will be considered at 2.4GHz, with a high gain antenna of 22 dBi, and an antenna dimension of 17.5" (0.4445m), transmitting at 1W (legal limit). For simplicity, the same antenna will be used for both the transmitter and receiver. See table 5 for final calculation results and figure 7 for a diagram of how the flow of power works (not to scale).

Distances:		
Near Field: R ≤	0.838	m
Frenesel Reg. ≤	3.163	m
Far Field ≥	3.163	m
Power Needed:		Power at Receiver:
4.8E-6 W		4.78E-3W

Table 5. Calculated Near & Far field distance.

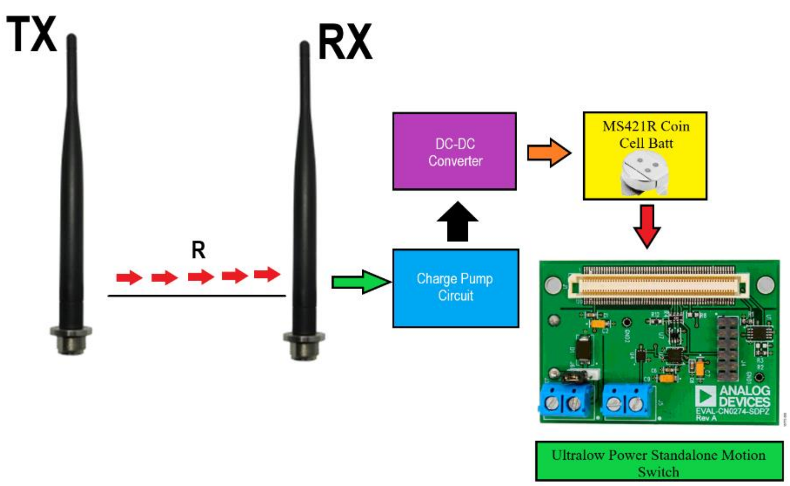

Figure 7. System Diagram of wireless power transfer to IoT.

III. DC-DC Buck Converter

A buck (or step-down) converter is a DC/DC switch mode power supply that is intended to buck (or lower) the input voltage of a DC supply to lower output voltage to the load. Switching mode converters are often preferred than traditional, linear regulators or transformers because they are more efficient (often higher than 90%) are light weight and can be manufactured inexpensively. Because of this Buck converters provide low-voltage on-board power in a variety of applications, such as microprocessors, communication equipment, microprocessors, control systems, etc. This includes applications that are involved with Wireless power Transfer for Near or Far Fields like IoT connected devices.

The converter functions in two states which is determined when the switch is open or closed. When the switch is in the on state (closed), it allows current to flow to the capacitor, allowing it to charge. Due to the inductor dampening the charge current and that the voltage across the capacitor cannot increase instantly, the voltage across the capacitor is limited and will not reach the full voltage of the original source voltage. When the switch is off (open), the current in the inductor cannot change instantaneously, so for a limited time, it holds a charge and creates a voltage. Then the capacitor discharges and powers the load. The diode acts like another switch to ensure current flows in the right direction. All the components result in maintaining current output when the switch is cycling. The circuit cycles continuously with the rate of switching which helps in maintaining the required voltage.

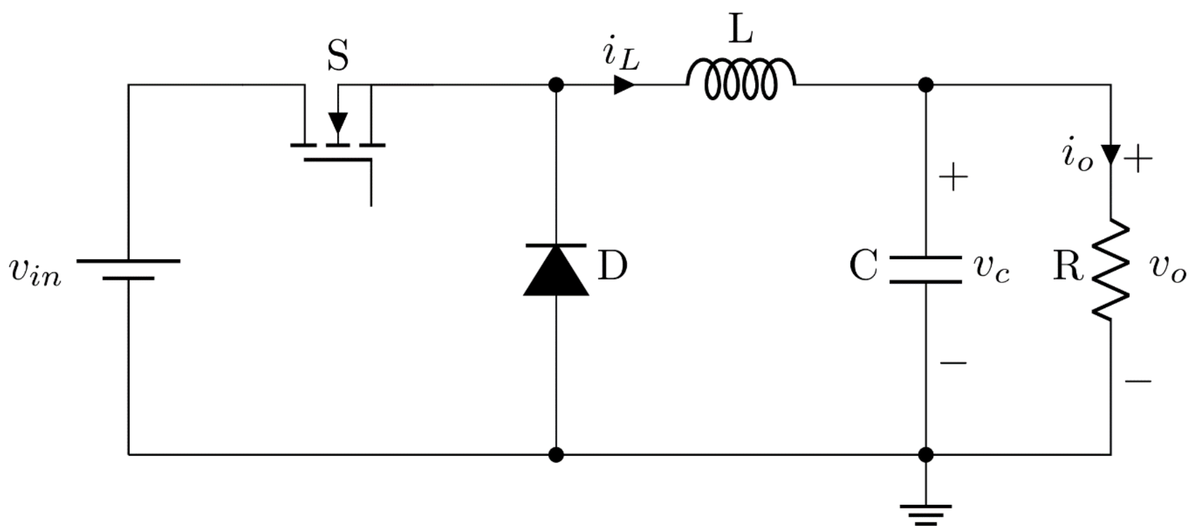

Figure 8. Theoretical schematic of a DC-DC Buck Converter.

For the IoT motion switch two volts DC is required so therefore, a buck converter will be designed to ensure proper continuous voltage within the device's operating voltage range. To achieve this, an idealized version of the buck converter is designed in ADS for simulation, this process took a while because several items can change how the value of the voltage at the load end behaves. Figure 9 shows the ADS schematic setup for a transient analysis for about 3.5 milliseconds and through trial and error the component values found in figure 9 produced a stable voltage at around 2V.

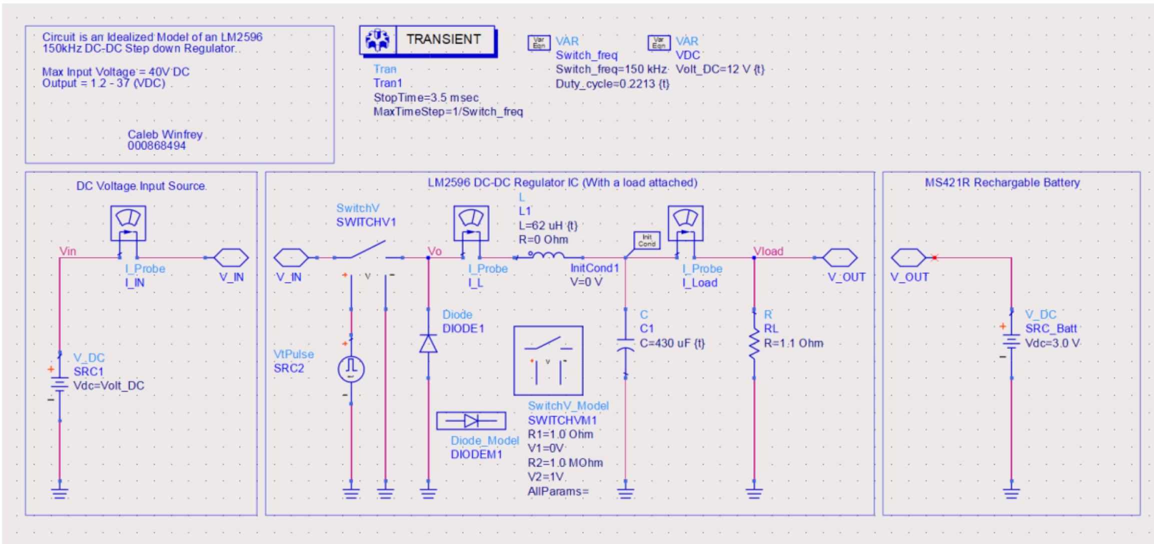

Figure 9. ADS Schematic for simulation.

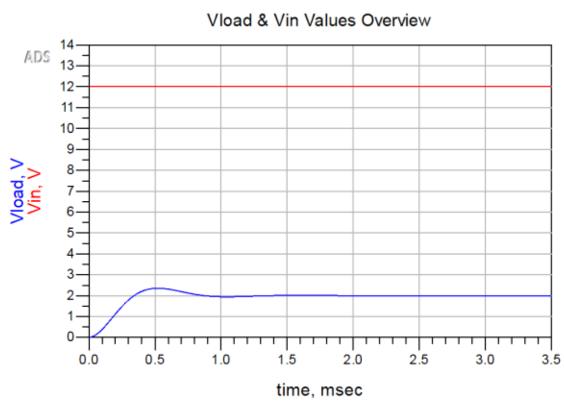

Figure 10. Transient Simulation plot overview.

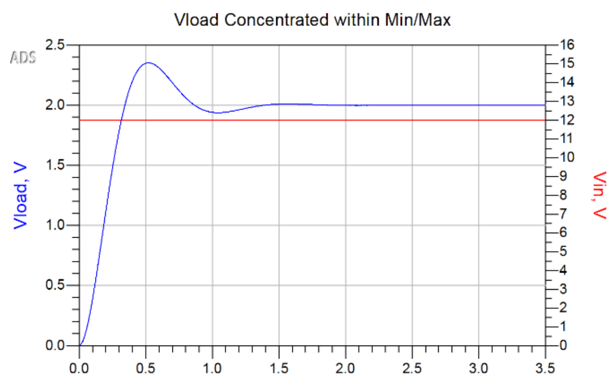

Figure 11. Transient Simulation within 0-2.5V for Vload.

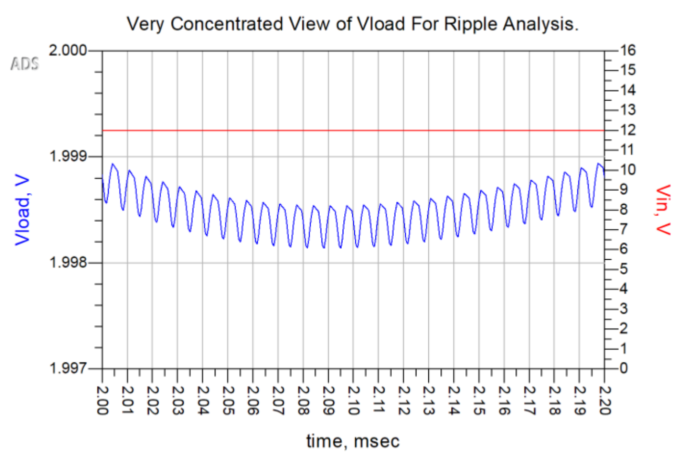

Figure 12. Concentrated Vload Voltage ripple.

Once, the circuit passed the ADS simulation, it was rebuilt in EagleCAD for PCB design, an aspect the circuit is a bit different with some added bypass capacitor since a commercially produced buck converter would have some to reduce any possible noise from the ground. A potentiometer was also placed for the purpose of in field tuning of the feedback loop if the real-world results do not match up with the simulation enough. Figures 13-14 will show the finished EagleCAD Schematic and Layout, while figures 15-16 are the vendor preview of the board.

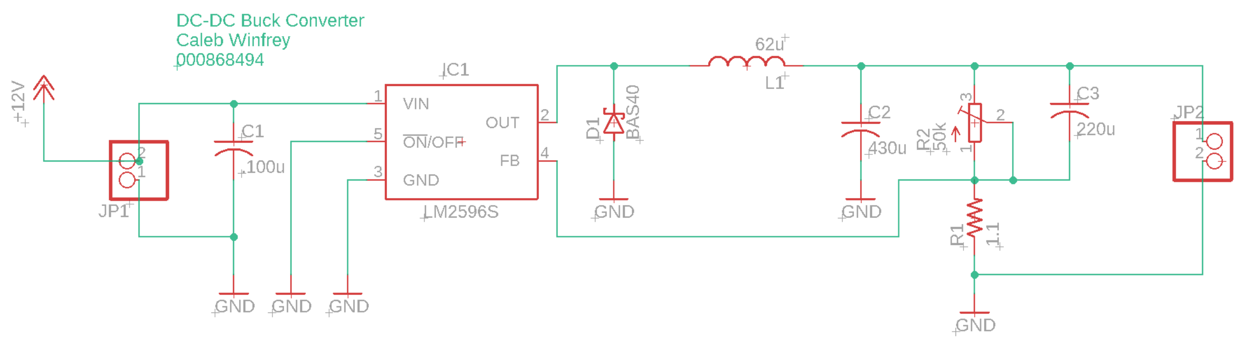

Figure 13. Eagle schematic for buck converter.

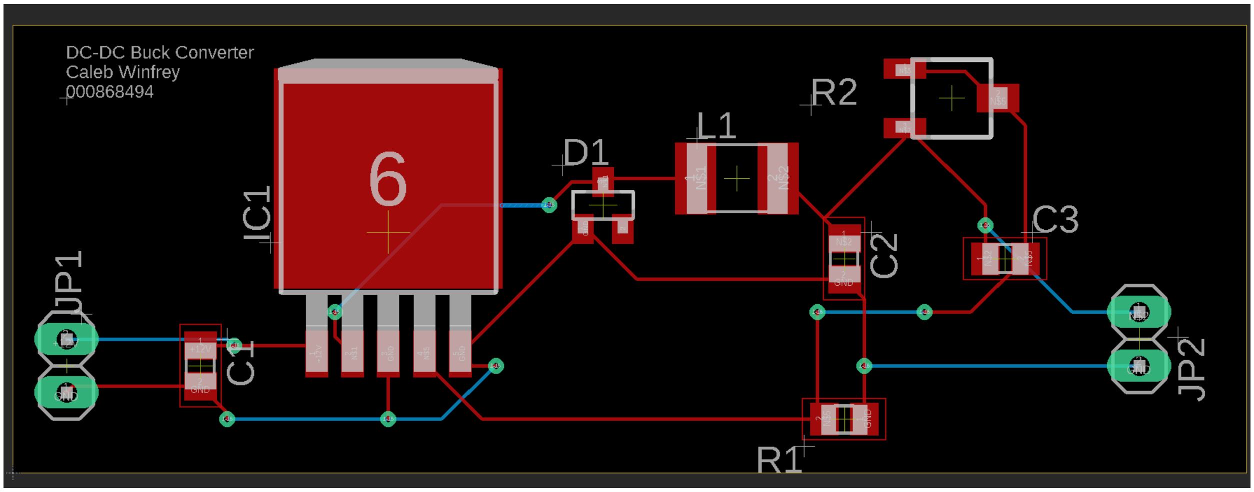

Figure 14. Eagle layout of buck converter.

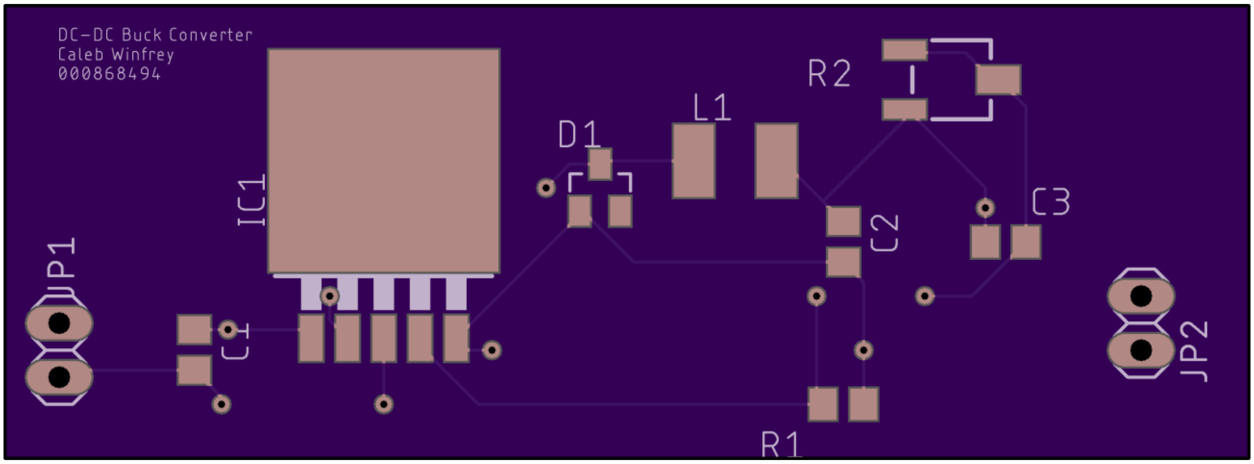

Figure 15. Manufacture preview of PCB by Oshpark. (top)

Figure 16. Manufacture preview of PCB by Oshpark. (Bottom)

IV) Conclusion

For the simulation Vin, and Vload were measured, while there is an initial “bump” in voltage to about 2.5V around .5 milliseconds it tapers off to the 2V range quickly. This is evidence that the basic DC-DC Buck converter design is stable and could work. However, since this is a switching mode power supply there was a ripple in the signal that was not immediately apparent. Some investigation of the Vload plot determined there is a ripple at the millivolt range (figure 12). This should not pose an issue for the IoT Motion Switch as its operating range is in volts so an oscillation at 1/1000th will not cause device stability issues. After the design, the PCB dimensions are approximately 58X21 mm. Some pros to this converter is it is relatively simple, and should be easy to construct, however it with some more work it could be more compact to save manufacturing costs. Since this is a wirelessly powered device, an improvement of adding a boost converter in case input voltage is too low. In this case, 12V input is assumed, but if it is too high or low some logic could be used to ensure normal operation while making it more compact on the layout would fit better for small IoT devices.

References:

ADXL362 Chip:

Render:
https://www.digikey.com/en/products/detail/ADXL362BCCZ-RL7/ADXL362BCCZ-RL7CT-ND/3758437

Block Diagram: (On spec sheet)
https://www.analog.com/media/en/technical-documentation/data-sheets/ADXL362.pdf

CN0274 Stand Alone Motion Switch (photo and schematic)
https://www.analog.com/en/design-center/reference-designs/circuits-from-the-lab/CN0274.html

Figure for Far and Near field:
https://en.wikipedia.org/wiki/Near_and_far_field

Figure for Friis Formula Variables:

https://www.pasternack.com/t-calculator-friis.aspx

Theoretical Schematic for Buck Converter:

https://latexdraw.com/dc-dc-buck-converter-latex-circuitikz/

Transistor History:
https://en.wikipedia.org/wiki/History_of_the_transistor

Internet of Things Outlook:

https://www.forbes.com/sites/danielnewman/2020/11/25/5-iot-trends-to-watch-in-2021/

Manufacture PCB Preview:
https://oshpark.com/

DC-DC Buck Converter:

https://en.wikipedia.org/wiki/Buck_converter