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Design of Bluetooth Low Energy Controlled Model Rocket

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3B Nanotechnology Engineering
October 12, 2016

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Shirley Tang, Director
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Dear Dr. Tang:

This work report, titled Design of Bluetooth Low Energy Controlled Model Rocket, was written upon the completion of my 3B work term for Nordic Semiconductor ASA. This report is to be submitted for the fulfillment of WKRPT 400. The purpose of the report is to reflect on the engineering design process behind the model rocket demo project for the Applications Group and to pass on knowledge of model rocketry to the rest of the group so that the project can be further developed and improved upon if desired.

Nordic Semiconductor ASA is a Norwegian technology company that focuses on delivering the best ultra-low power wireless solutions and is currently a leader in the Bluetooth Low Energy market. The company's profit source is the selling of Bluetooth Low Energy chips, but it also has many teams that work on relevant hardware, software, and services which are provided to their customers or potential customers free of charge in order to help them easily integrate Nordic chips into their products and business. During my work term I worked in the Applications Group, led by Endre Rindalsholt, which is mainly responsible for creating reference designs and demo projects to showcase potential product concepts and a sample design for customers to reference their products off of.

I hereby confirm that I have received no assistance in writing this report. I also confirm this report has not been previously submitted for academic credit at this or any other academic institution.

Sincerely,

Tong Wu
20470965

Contributions

During my employment at the Applications Group, the team consisted of around 15 full-time employees and summer students working on embedded firmware, electrical hardware, and web applications for Bluetooth Low Energy devices. These projects were all aimed to help our customers have a easier time developing products with our chips and help them reach full volume production and go to market faster. It was a very energetic group with lots of exciting multidisciplinary hands-on projects.

My three projects at Nordic were sensor driver development, security enhanced Eddystone beacon firmware development in partnership with Google, and finally a Bluetooth Low Energy (BLE) enabled model rocket demo project. The project that will be reported on and discussed in detail in the report is the BLE enabled model rocket. The purpose of this project was to create a proof of concept (PoC) prototype of a model rocket that is running on Nordic's latest BLE system-on-chip (SoC), nRF52832, to showcase an application of BLE in medium-range toys because future BLE specifications are going to allow for higher transmit powers thus significantly increasing the previously limited range of BLE and making it a suitable technology for medium range applications. Moreover, this project was an opportunity for me to develop my skills in printed circuit board (PCB) layout and schematic design, antenna tuning, and mechanical design which were laid out as part of my learning outcomes in the beginning of the work term. The entire process involved internet research of the current model rocketry market, the existing types of model rockets and their associated flight dynamics and equipment requirements and instruments, as well as available purchasing locations for such resources; prototyping of a reliable engine ignition mechanic and parachute deployment mechanic; circuit design and PCB layout of the entire electronic system including the communication system, telemetry system, and ignition and recovery deployment system; design and prototype the mechanical assembly through 3D modeling and 3D printing, and finally validation and tuning of flight dynamics with model rocketry simulation software. This project was mainly a solo effort with input and constructive feedback from my teammates on specific topics of their expertise such as firmware and electronics.

The relationship between this report and my work is that the report captures all the new knowledge developed about electronic wireless model rocketry which is a brand new field of knowledge in the group. Also this report allows me to reflect on the engineering design and analysis behind several complex systems in the rocket which all manifest into very useful lessons for my future career. It also serves as a reminder that any technical knowledge, even rocket science, can be learned from the ground up in a shot span of time as long as you put your curious and analytical mind behind it!

In the broader scheme of things, my work at Nordic Semiconductor on the BLE model rocket project has set an example that broadens the horizon on what kind of applications BLE can be at the heart of. It pushes the boundaries on what kind of devices people typically associate with BLE and have also generated significant social media interest for Nordic Semiconductor by live broadcasting the rocket launch on Facebook, thusly creating a cool and fun image for the company. My work with the rocket has also introduced many members of the team to a cloud-based 3D modeling software, OnShape, that I have picked up from my previous work term that is much more powerful and easier to use than the then status quo in the office, SketchUp. And most importantly it got many team members and their children interested in model rocketry which actually fulfills one of the main missions of the model rocketry industry, to stimulate interest in the wider public about science and engineering through this exciting hobby.

Summary

The main purpose of the report is to summarize and communicate the research and development done on the BLE model rocket project in my work term at Nordic Semiconductor ASA in Trondheim, Norway. This report will communicate the motivation and significance of the project that I had worked on and also record the engineering analysis and design that went into this work. The scope of this work includes the background research done in model rocketry, the different design options considered for the prototype, the construction requirements for launch, and several recommendations for future revisions of the rocket.

The major points documented in this report are the entire design and prototyping phases of the model rocket and the recorded details where are important to the successful ignition, flight, and recovery of the rocket. Also, sufficient background in model rocketry and BLE electronics is provided in order to give insight to some of the related design decisions related to those fields.

The major conclusions documented in this report are that using BLE to remotely control the launch of a model rocket is more versatile, convenient, and safe than traditional methods of a wired ignition box; that a BLE chip coupled with power amplifier can easily achieve a communication range of more than 200 meters if the antenna is properly tuned; and that real-time telemetry data from the rocket is an insightful metric into the flight performance of the rocket.

The major recommendations of this report are that the exhaust end of the rocket should be sufficiently lifted from ground to avoid undesired ignition of adjacent engines in a multistage launch; that the parachute deployment system should be rocket-body-orientation-agnostic; and that flight data should be internally logged into the random access memory (RAM) of the BLE chip as well as communicated over the air in case the rocket travels out of range, so that the data can be read back after retrieval of the rocket.

Conclusions

Recommendations

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1.0 Introduction

The goal of the project captured in this report is to demonstrate a reference design of a BLE controlled model rocket, which can be launched, recovered, and reused, using Nordic's nRF52832 SoC in order to generate more market interest in utilizing Nordic's products and more importantly to showcase the possibility of deploying BLE in medium range applications in anticipation of the significantly increased range of the next Bluetooth Specification to be released. Despite the fact that, given the time allotted, the end result is a simply a working PoC and far from a polished design ready to be in the market, it is still a highly multidisciplinary and complex project consisting of design considerations in aerodynamics, newtonian mechanics, embedded system design, radio frequency (RF) electronics, and user experience. In addition, recommendations will be provided to fix and improve upon the current design of the rocket to make it more reliable, more performant, and more user friendly.

In order to understand the design and engineering process behind this report however, a sufficient amount of background knowledge on model rocketry and BLE electronics is required and hence will be provided next.

2.0 Background

The background sections introduces many important concepts in model rocketry and BLE electronics at a high level with enough details to allow the understanding and appreciation of the work reported herein.

2.1 Model Rocketry

Model rocketry is a popular hobby that originated in the late 1950's, coinciding with the dawn of the space age, as many space enthusiasts were inspired to build their own rockets by the sight of the space boosters carrying the first artificial satellite into space [1]. It started as an extremely dangerous hobby as many people were attempting to create their own propellants with unstable chemicals that often resulted in injuries of tragedies. It was not until when Estes Industries was founded in 1958 to mass manufacture solid propellant model rocket engines did the hobby become safe and very popular amongst younger aspiring rocketeers and families [1].

Popular model rockets today are mainly constructed with safe materials such as cardboard, plastic, and balsa wood, with sizes ranging from 1 foot to 6 feet. They are fueled by single-use rocket motors (note that the terms motor and engine can be used exchangeably) manufactured professionally by companies such as Estes. The rockets typically contain a recovery device such as a parachute to enable gentle landing and recovery for future flights and reuse of the rocket. The rocket can be flown again by simply replacing the used motor with a fresh one. Typical entry-level model rocket components are shown in Figure 1 below.

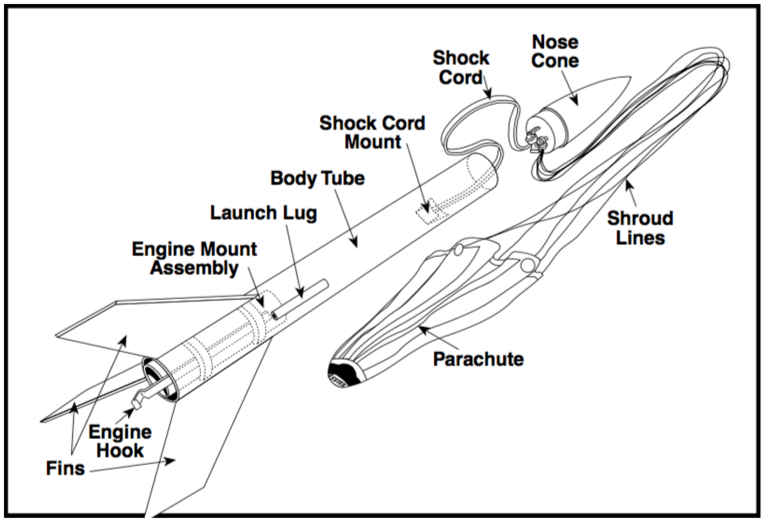

Figure 1: Typical model rocket components - without engine [1]

Typically, a model rocket launch consists of 7 distinct phases: ignition, lift-off, burnout, coasting, apogee, parachute ejection, and soft landing. During ignition, the rocket engine is ignited electrically by a manual switch from a box containing circuits external to the rocket as shown in Figure 2.

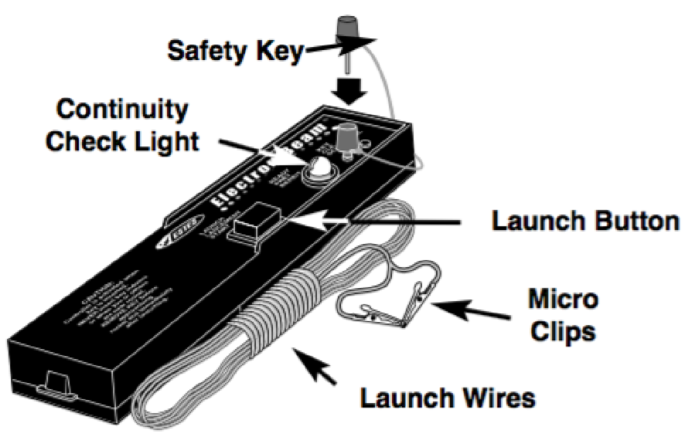

Figure 2: Ignition Box [1]

These boxes work by shorting a alkaline battery across the terminals of a motor igniter, which is just a piece of bent wire with some heat sensitive pyrotechnic material at the tip that is inserted into the rocket motor that ignites when heated due to joule heating by the high current passing through the igniter. When the igniter ignites, the combusted pyrotechnic material triggers ignition of the motor propellant and also breaks continuity of the igniter and current should automatically stop flowing. The use of the ignition box is meant to create a safe distance to launch the rocket by using long launch wires with micro clips at the end to attach to the motor igniters. Figure 3 shows a schematic of how a motor igniter is installed into the rocket motor.

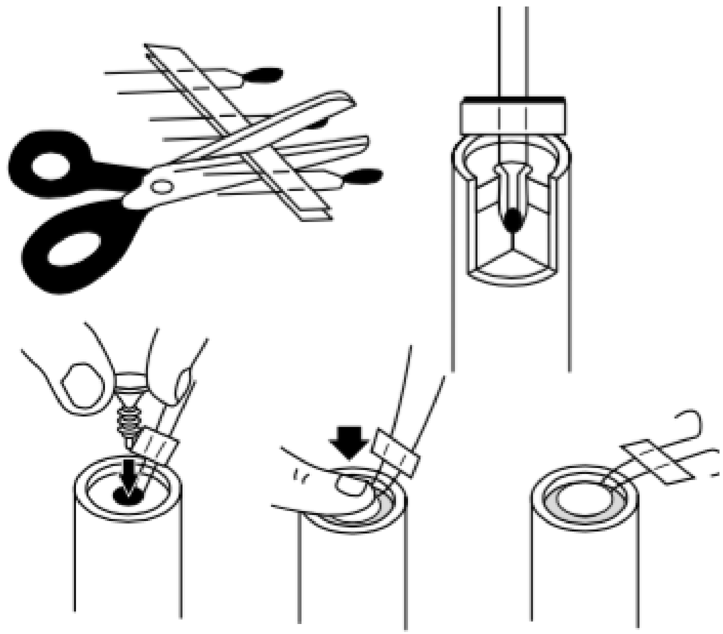

Figure 3: Rocket Motor Igniter [1]

However, if a model rocket has embedded electronics inside that can be controlled via a smartphone, then the ignition box can become obsolete and ignition can be performed completely wirelessly from a much longer distance away. This is one of the first design wins for BLE in model rocketry.

Once the engines are ignited, the rocket will enter the lift-off phase where it accelerates very rapidly off of the launch pad due to the rapid ejection of hot gas (in model rocketry, a launch pad is just a structure that mechanically guides the rocket straight upwards during lift-off). After the rocket leaves the launch pad, it enters the burnout phase where the rest of the propulsion fuel is gradually ejected from the engine and rocket's upward acceleration starts to diminish. At the point where all the propulsion in the engine is exhausted and the provided thrust and therefore upward acceleration becomes zero, the rocket enters the coasting phase, where gravity and air drag begins to slow down the rocket to zero upward velocity. At the point of zero upward velocity, the rocket has reached its apogee, the highest altitude of its flight. Some point after apogee, parachute ejection should take place, preferably as soon as possible after apogee to prevent the rocket from gaining too much downward velocity due to gravity. After parachute ejection, the rocket will eventually enter the last stage of its flight, soft landing. A summative illustration of typical flight phases taken from the Centuri Model Rocket Designers Manual[2] is shown in Figure 4.

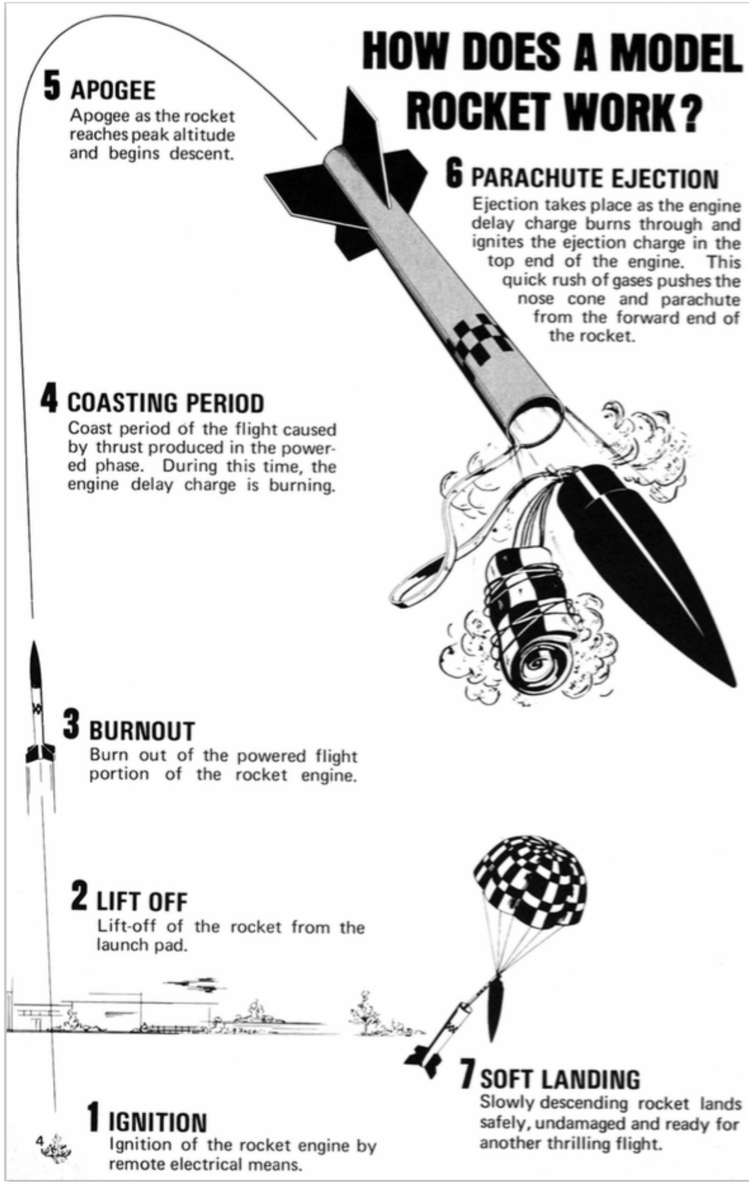

Figure 4: Model Rocket Flight Phases [2]

2.1.1 Model Rocketry Engines

The engines are the single most important component of any typical model rocket since it is most often responsible for two of the most crucial tasks in rocket flight: provide propulsion and trigger parachute deployment. A visual dissection of a typical model rocket engine is shown in Figure 5. Model rocket engines typically use black powder as solid-fuel to provide thrust to the rocket by rapidly ejecting hot gas out the exhaust end of the engine. After the complete burnout of propulsion material there is a short period of delay charge inside the engine that burns for easier visual tracking but provides no significant thrust to allow the rocket to coast to apogee. Then finally the ejection charge ignites and fills the rocket body tube with hot gas.

The sudden increase in pressure in the body tube will pop open the nose cone and push out the parachute assembly. Model rocket engines are categorized with codes indicating their total impulse in newton seconds, average thrust in newtons, and delay charge time in seconds. For model rockets the total impulse range from A to G. This is called the class of the motor. Class A being 0 to 2.5 Ns, and B being 2.6 to 5, with each subsequent class having twice the max allowed total impulse as previous. The average thrust is simply indicated by a number that is the average thrust in newtons, and the delay charge time is also just a number in the number of seconds. For example a engine with the code C4-3 means it has a total impulse somewhere from 5.1 to 10 Ns, with an average thrust of 4 Newtons and a delay charge time of 3 seconds. All manufacturers of rocket motors will provided datasheets specifying the exact impulse and thrust curve of their engines.

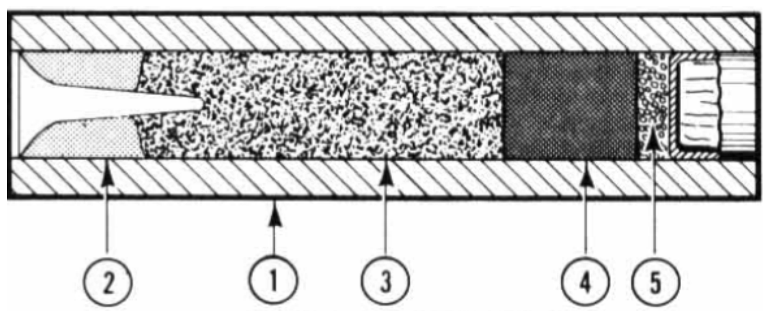

Figure 5: Rocket engine dissection [2]. 1. Casing 2. Nozzle 3. Propellant 4. Delay Charge 5. Ejection Charge

The delay charge is designed to allow the rocket to coast in unpowered flight to its apogee before the parachute is ejected with the ejection charge. However each rocket flies differently and the amount of delay charge they need is different depending on their mass and drag. Motor manufacturers make several delay charges available for each motor class. However, that doesn't give the curious users fine grained control for optimization of flight performance. This is where BLE model rockets have another design win over traditional ones: by embedding a BLE module inside the rocket, the parachute can be ejected remotely by command or via intelligent algorithms on-board with altimeter data to determine when the apogee was reached, so it does not have to rely on the limited charge choices made available by the motor manufacturers.

2.1.2 Model Rocketry Physics

The provided overview above of the typical model rocket flight process above sets up the foundation for a general understanding of the sequence of tasks that the BLE model rocket reported in this work must fulfill in order to perform a successful launch. Next it will be very important to provide a background of the physics involved in a successful rocket launch as the mechanical design of the rocket must adhere strictly to the physical guidelines imposed by the laws of aerodynamics and newtonian mechanics in order to ensure a successful flight.

Like anything that flies, model rokets get airborn by generating enough upward force to overcome gravity and air drag. A model rocket takes flight by utilizing rocket motors which eject gas at high velocities downward out the tail end of the rocket and as a result generating thrust upward (Newton's Second Law). At the most basic level, to overcome gravity, the thrust generated by the motor at lift off must abide by the following equation:

$$\frac{(F_{thrust} - F_{drag})}{Mass_{rocket}} > 9.8\frac{m}{s^2} \tag{1}$$

Albeit, most engine manufacturers provide a minimum lift-off weight parameter for each engine type to ensure that the user can easily select the correct engine for the rocket. Once the rocket is in the air however, the mathematics become extremely complicated and there are no more simple equations to follow to determine the behaviour of the rocket when it's airborn. To calculate the expected apogee of the rocket and travel time is much more involved since the air drag is a very complicated parameter involving several variables, and that the thrust is time dependent ariable which follows a curve specified by the manufacturer, and that the mass is constantly changing as propellant is constantly being ejected out of the rocket, thus a simulation tool (OpenRocket) will be used to calculate the expected flight trajectory.

Outside of the simulation tool, the most important factor to for the user to consider in model rocketry is aerodynamic stability. Aerodynamic stability describes a rocket's ability keep its nose pointed in the same direction throughout its upward flight [1]. In more technical lanaguage, it is its ability to resist rotation around its center of gravity (CG) while under perturbing forces from factors such as wind or misaligned motor thrust while flying in the air. The two factors above are the main perturbing forces to consider and they are illustrated in Figure 6.

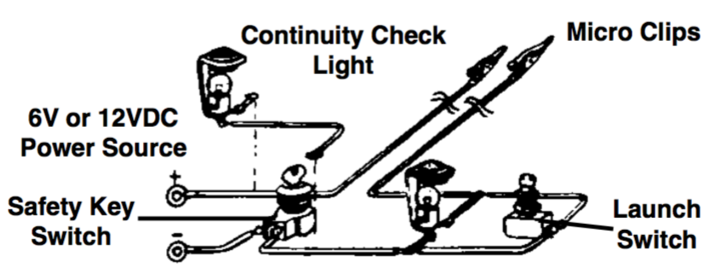

Figure 6: Perturbing forces on a model rocket

Under perfect conditions with zero wind, the CG and the point of thrust (radial location of the motor) are aligned perfectly at the radial center of the rocket and the rocket would fly straight upwards, provided that it was launched vertically. However, in reality, any small perturbations due to wind or misaligned motor will cause a small (less than 5 degrees) angle of attack (AoA) α, and if goes uncorrected, this AOT will become larger and larger which will eventually cause the rocket to tumble uncontrollably in the air and crash into the ground, which is extremely dangerous. To prevent this from happening, fins are untilized on model rockets to provide the stabilizing force. As α increases, the surface area of the fins that are exposed to the oncoming airflow parallel to the flight path increases and the resulting drag on the fins will push back and stabilize the rocket by reducing α, as shown in Figure 7

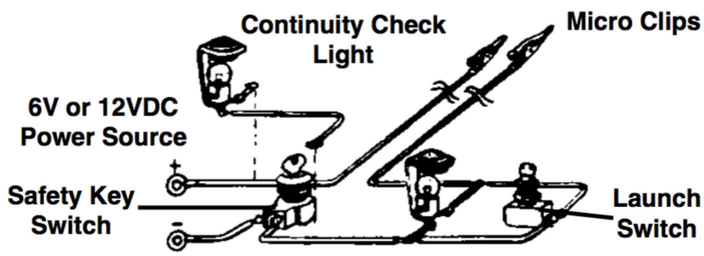

Figure 7: How fins on model rockets stabilize it in flight

While in the air, the forces perpendicular to the length direction of the rocket can be modeled by a rigid beam on a fulcrum at its CG as shown in Figure 8. Another very important point to consider beside the CG is the center of pressure (CP). The center of pressure is the point where all the aerodynamic forces will act through, just like how the gravitational force will act through the center of gravity. And similar to how the location and amount of mass distributed across an object affects the CG, the location and amount of of surface area distributed across an object affects the location of center of pressure.

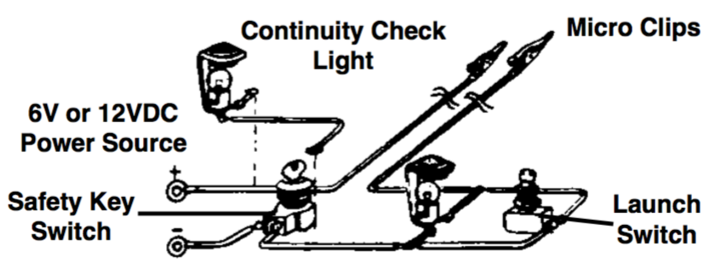

Figure 8: Fulcrum model of perturbing forces on a model rocket

The rule of thumb provided by most model rocket makers and experts is that the CP should be at around 1 to 1.5 calibres (a calibre is equal to the diameter of the body tube) aft of the CG in order for the fins to have enough torque on the rocket body to stabilize the rocket during flight[1] [2]. This number is called the stability margin. If it is below 1, then the fins may not have enough torque to overcome the perturbation. However if the margin is too large, then the fins begin to overcompensate for the perturbations and the rocket will exhibit "weathercocking" which is seen as the the rocket oscillating back and forth during the flight which can significantly effect its apogee since energy from the thrust is diminished by the air drag rocking the rocket back and forth.

In addition to taking care in positioning the CP sufficiently aft of the CM, it is also important to make sure that the CP and CM are aligned in the radial center of the rocket, so that there is no inherent torque on the rocket from airflow coming down from the nose of the rocket even at zero wind conditions.

The basic overview of model rocketry mechanics provided above is sufficient to gain an understanding of the design decisions made in the report. Next up will be a brief introduction on model rocket telemetry, the remote collection of data from the rocket that describes the its flight.

2.1.3 Model Rocket Telemetry

Rocket telemetry is at the heart of what makes many rocket enthusiasts keep coming back to launch their rockets over and over again. By being able to remotely retrieve flight data such as altitude, velocity, and acceleration from the rocket, rocket enthusiasts can get insight into their rocket's performance so that they can iterate and improve on their design. The most basic model rockets have no electronics inside, and the only way to approximate how high it went is use some clunky hand tools and trigonometery. Many technically inclined rocketeers and some companies build custom telemetry modules with altimeters and accelerometers on-board and a custom megahertz radio (very long range and simpler circuit design at lower frequecies compared to 2.4 GHz) for communication with a custom base station that collects the data from the rocket. The issue with custom telemetry modules is that it is not interoperable with other devices. In other words, to communicate with the telemetry module, one would need a custom base station with a custom radio on the same frequency as the one in the rocket, as opposed to just using a ubiquitous smartphone with a BLE chip already inside and a nice user interface in the form of an app. So to simplify the user experience and make telemetry more robust, a standardized and ubiquitous protocol such as BLE can be implemented for mid-ranged rocket telemetry.

2.2 Bluetooth Low Energy

Bluetooth Low Energy (BLE) is a short range , ultra-low power, 2.4 GHz wireless communication protocol that has seen its rise to dominance thanks to the fast adoption of all major smartphone makers like Apple and Samsung, because of BLE's ability to extend the battery life of mobile devices with its ulta-low power consumption [3]. Its widespread adoptance with smartphone makers makes it espeically popular for "smart" gadgets - consumer hardware products that can communicate with and be accessed from a smartphone. Notable examples include activity trackers like Fitbit, thermostats like Nest, and lightbulbs like Philips Hue. Because the protocol is highly standardized and designed to be low-cost and low-complexity, it makes it very easy for hardware developers to implement this protocol and very easy for consumers to use the product via a simple user interface on the smartphone. However, one major limitation to BLE is its range. Usually BLE devices are designed to operate within 50 meters of the user in order to extend battery life by operating the radio at very low power. In addtition, there is limitation in place from the Bluetooth Special Interest Group (SIG), who standardizes the specification for the BLE protocol, on the maximum radio broadcast powe which effectively limits the range to 100 meters [3]. This limitation significantly reduces BLE's application in mid-range toys like RC cars, quadcopter, and planes which often go upwards of 400 to 500 meters. Fortunately, the upcoming Bluetooth 5.0 specification in early 2017 will quadruple the range of BLE to roughly 400 meters while maintaining similar energy performance and thus immediately making the protocol an attractive option for toy makers.

Thusly, in anticipation for the upcoming range increase of BLE and higher interest from toy makers, a model rocket reference design will be created to showcase the possibilities of a mid-range application of BLE.

3.0 Design Requirements

The design requirements for this BLE model rocket reference design are basic and straight forward since it is a proof of concept (under limited development time of 3.5 months) to showcase the usage of BLE in mid-ranged toys such as a rocket, but it should have the features that take advantage of BLE to simply the user experience of launching rockets and yet make it more engaging. The design requirements for this PoC are the following:

1. Use the nRF52832 SoC as the microcontroller + BLE Radio
2. Remote ignition of the rocket from a smartphone without an ignition box
3. Maintain BLE communication with the rocket for at least 200 meters
4. Flight minimum altitude of 150 meters (outside of typical BLE range)
5. Communicate real-time altitude data to the smartphone
6. Rocket can deploy a parachute to be recovered and reused multiple times

Besides the first point, each item on the list can be broken down into very specific functional requirements in order to achieve those goals, and the majority of the rest of the report will be used to dissect how each design requirement is met both qualitatively and quantitatively. And ultimately data from the launch test will indicate how well these design requirements were met in the actual rocket launch context.

3.1 Remote Ignition of the Rocket From a Smartphone Without an Ignition Box

As mentioned in the background, one of the most important design wins of a BLE rocket over a traditional rocket is that it can be ignited and launched wirelessly from a smartphone without being restricted to the launch wire length of the igntion box. Not only is this safer it is also much more convenient.

In order to achieve this, an ignition circuit must be designed and implemented onto a printed circuit board (PCB) along with a BLE chip so that commands received from the smartphone can trigger actions on the ignition circuit. The main task of the ignition circuit on the PCB is to deliver enough power to the igniters so they heat up sufficiently and ignite on command.

The initial design was to use same concept as a typical ignition box but with some modifications for digital circuitry. First of all, instead of a manual switch to connect the battery to the igniter, a high power transistor controlled by the BLE chip is used instead. Secondly, a lithium ion rechargeable battery will be used over akaline because it is much lighter and more convenient to reuse. Because there are no detailed specifications on the power required to ignite the igniters provided by the manufacturers, a lab power supply was used to determine that the minimum power needed is roughly 3 volts at 1 amp. Figure 9 shows a schematic of the initial ignition circuit prototype.

Although it was proven that ignition is possible, an analysis with the oscilloscope showed that there is a significant voltage drop on the lithium battery during ignition due to a significant amount of current rushing out of the battery and its internal resistance lowering the output voltage, as seen in Figure 10

The green trace is the battery voltage and the yellow trace is the gate voltage of transitor used to control the ignition. It can be seen from the cursor values that the battery voltage dropped from 4.075 to 3.775 volts during ignition. Since almost all lithium ion batteries can only operate between 3.7 and 4.2 volts (built-in protection circuitry will automatically disconnect the cells if outside those limits), a drop of 300 mV is quite dangerous as non-fully charged battery can risk dropping below its operating voltage and cause a loss of power to the rest of the PCB.

The solution to this problem is to add a large enough capacitor in parallel with the battery that can be charged up at a slower rate before ignition and discharged rapidly to provide enough power to the igniters. The resistor in series with the capacitor limits the maximum current draw out of the battery (when the capacitor is at 0 V) so that the voltage of the battery does not drop dramatically during ignition. Figure 11 shows theschematic

./images/batt_ign.png

Figure 9: Schematic of first ignition circuit prototype

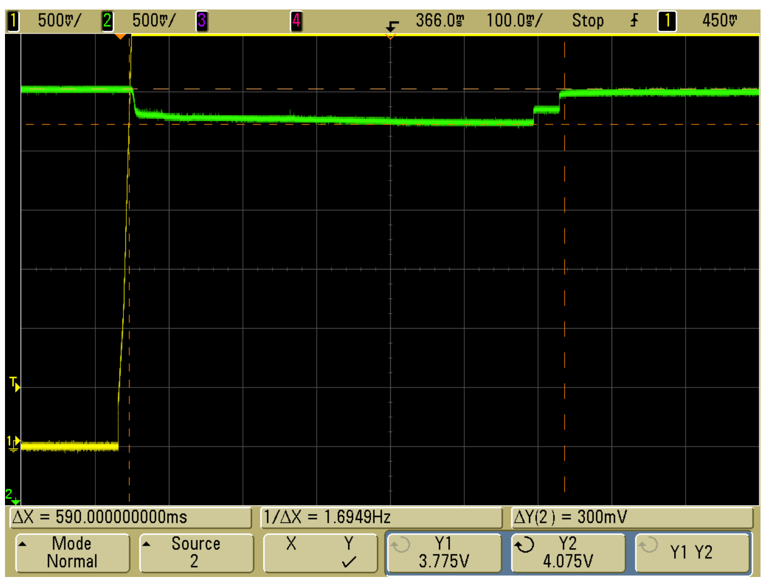

Figure 10: Oscilloscope image of voltage drop across the battery during ignition of 2 igniters

of the improved circuit.

The results of this improvement can be seen in Figure 12, where the yellow trace is the battery voltage, pink is the gate voltage of the transistor, and green is the voltage of a 5 V, 3 F supercapacitor. It is clear that here is no significant drop in battery voltage as all the power delivered to the igniters are through the capacitor. The

./images/cap_ign.png

Figure 11: Schematic of the improved ignition circuit prototype with the supercapacitor

3 F supercapacitor was chosen because it has an extremely low internal resistance of 50 mΩ which means it can deliver instantaneously up to 100 A and also because it has about the same mass as the battery so it made it easier to balance the CG of the PCB [4].

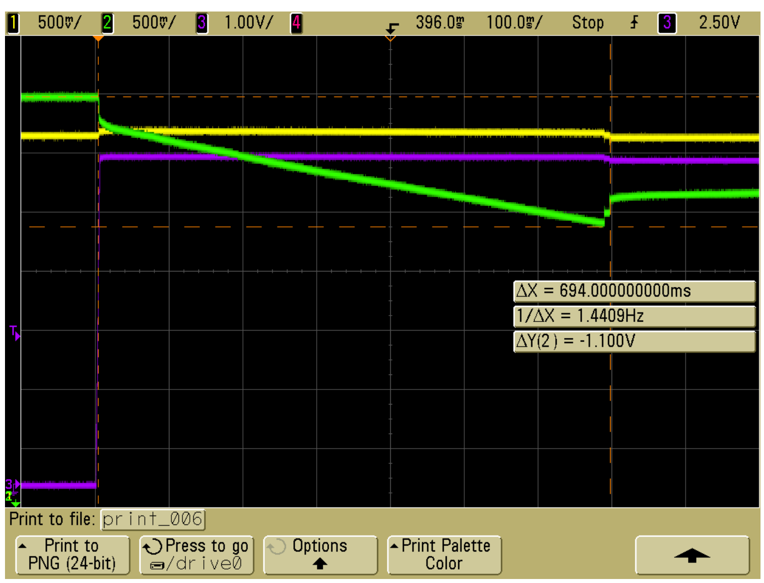

Figure 12: Oscilloscope image of voltage drop across the battery and supercapacitor during ignition of 2 igniters

Since the capacitor will take some time to charge up from an empty state before it is ready to ignite the engines, there must be a way for the user to monitor the voltage on the capacitor to know when it is ready to launch. The analog to digital converter (ADC) on the BLE chip can be used convert the capacitor voltage into data that can be sent to the smartphone. However, its max sampling range is 0 to the power supply voltage of the chip (3.3 V in this case) [5]. Thus, a voltage divider of two 1 MΩ resistors is placed in parallel with the capacitor so that half of the capacitor voltage (max 2.5 V, within sampling range) can be sampled by the ADC, and mapped back to the full voltage in firmware before the data is sent.

Another transistor is also added in the circuit to enable a safe way to discharge the capacitor via a resistor to ground. Figure 13 is the schematic of the final ignition circuit in the rocket.

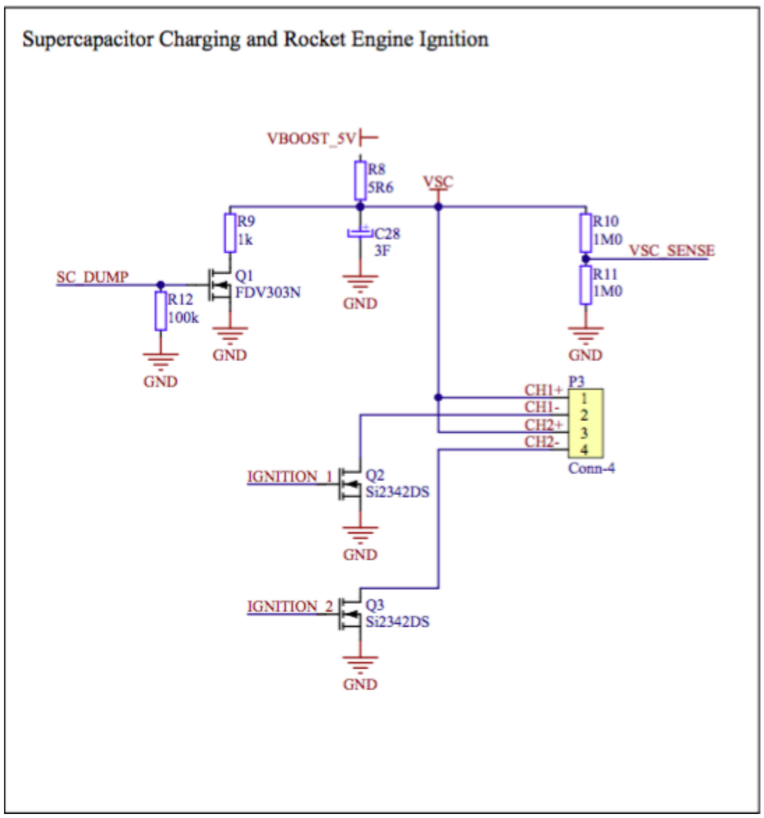

Figure 13: Final schematic of the ignition circuit in the rocket

Q1 and Q2 are the power transistors connected to the BLE chip for controlling 2 ignition channels. C28 is the supercapacitor, R8 is the rate-limiting charging resistor. R10 and R11 is the voltage divider with VSC$_{S}ENSEasthenodeconnectedtotheADCofthechip, andR9andQ1arethesafedischargecircuitry.$

Table 1: SKY66112-11 Gain and Output with nRF52 Signal on Input

Amplifer Input (dBm)	Gain(dB)	Amplifer Output (dBm)
4	16.56	20.56
3	17.73	20.73
0	20.25	20.25
-4	22.16	18.16
-8	19.05	11.05

3.2 Maintain BLE communication with the rocket for at least 200 meters

In order to achieve an extended BLE range with the rocket with the current Bluetooth Specification, an external power amplifier (PA) and low noise amplifier (LNA) must be added to the antenna which transmits and receives BLE data packets. This will mimic the extended range of future BLE at the cost of very high power consumption. The PA is used to boost the outgoing signal strength from the rocket, and the LNA is used to boost the signal strength coming into the rocket from the smartphone. There are several available integrated circuits (IC) on the market that perform those two functionalities on a single chip. The chosen IC was Skyworks's SKY66112-11 2.4 GHz RF Front-End Module with 20 dB of maximum gain, as Nordic has a very good working relationship with them and that they are soon releasing a reference design with the nRF52 chip specifically. To verify the performance of this IC in context of the nRF52, a network analyzer was used to determine the the output signal strength of the amplifier with the nRF52 chip's RF output as the input signal to the amplifier.

It can be seen in Table 1 that there is some non-linearity of the gain as the input drops but this this analysis clearly shows which input range should be chose to operated within to achieve the best amplified output. The output power of the amplifier is around 20.5 dBm at 0, 3, or 4 dBm input hence the BLE chip should be configured in firmware to operate at any of those values.

Under zero amplification conditions, the maximum range to maintain the BLE connection between an nRF52 development board and a Samsung Galaxy S5 was tested to be 134 m while the nRF52's radio operated at 4 dBm. Hence the assumption is that at 20 dBm it can very well more than double the range to be more than 200 m even given all the various loss factors.

3.3 Flight minimum altitude of 150 meters (outside of typical BLE range)

To design the rocket for minimum flight altitude requires the use of model rocket simulation tools that take into account aerodynamics and solves differential equations of all forces on a rocket at each discrete time step during the flight of the rocket. OpenRocket, an open source and cross-platform model rocket simulation software was used to simulate the flight characteristics of the model rocket. In order to accurately predict the flight charactertistics, the exact geometry of the rocket and its material is inputted into the software along with the choice of engines. In this case, the geometries of the rocket body were imported from the Computer Aided Drawing (CAD) software used to design the mechanical structure of the rocket. The weight and size of the PCB and the parachute were also modelled into the simulation. The main material of the rocket body was ABS (density 1.05 g/cm^3) as that is the available material from the lab's 3D printer. And the enginees selected were 2 D9-P engines. The P designation means that it is a "Plugged" engine with no ejection charge. The reason for this will be explained in a future section. As shown in Figure 14, OpenRocket showns that the rocket's CP is well aft of the CG with a stability margin of 1.47 calibers. This means that the rocket will be aerodynamically stable. Also it predicts an apogee of 226 m which is well above the design requirement of 150 meters.

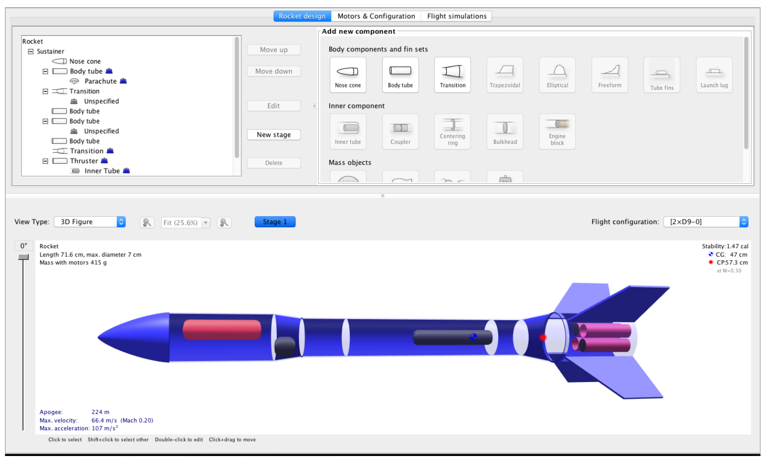

Figure 14: OpenRocket Simulation View

One of the main geometric design constraints for the mechanical design was that the 3D printer only has a print space of 12 x 12 x 12 cm which means that the fins can only be 12 cm long and wide maximum. Another design constraint was that the body tube should have just enough space for 4 engines in order to have the capability for multi-stage launches (ignite another set of engines after the first set during the initial launch has burnt out). With these two constraints in mind, the geometric definitions were built up from there and adjusted in simulation to have a stability margin between the recommended 1 to 1.5 calibers and an apogee of above 150 meters.

3.4 Communicate real-time altitude data to the smartphone

$$\frac{dM_x(t)}{dt} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_x - \frac{M_x(t)}{T_2} \tag{2}$$

$$\frac{dM_y(t)}{dt} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_y - \frac{M_y(t)}{T_2} \tag{3}$$

$$\frac{dM_z(t)}{dt} = \gamma(\mathbf{M}(t) \times \mathbf{B}(t))_z - \frac{M_z(t) - M_0}{T_1} \tag{4}$$

3.5 The Schrodinger Equation

$$i\hbar\frac{\partial\Psi}{\partial t} = \hat{H}\Psi \tag{5}$$

4.0 Graphics

Here's a stock image of a computer. It comes with a CC0 license, enabling free distribution for commercial and personal use. It's a JPEG.

Figure 15: A stock computer, I just wanted a picture here

5.0 Conclusions

LaTeX is awesome.

6.0 Recommendations

Use more LaTeX. Also, use more Unix. Also, citations like [3] will lead to a better quality of work.

References

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Appendix A: Here's An Appendix

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Appendix B: Here's Another Appendix

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Appendix C: A Figure in An Appendix

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Figure C.1 : It's back!

Figure C.2 : Testing Number

Table D.1: A Table in an Appendix, displaying the correct numbering

Abbreviation	Definition
BLE	Bluetooth Low Energy
SoC	System on Chip

Table D.2: Another table to test numbering

Data	Integer	String
Foo	1	”bar”

Appendix D: A Table in An Appendix

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