Chapter 1

Power Subsystem (LMXLET001)

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1.1 Introduction

The power subsystem plays a major important role in the SmartNest system, without an efficient power system this design project will not function properly. Carrie Hickman, a researcher focused on ground hornbill birds, investigates how high temperatures affect nestling growth. For her research to be successful, continuous monitoring is essential. Therefore, an efficient and uninterrupted power supply is crucial to ensure the continuous operation of this device.

The primary objective of this chapter is to detail the design process and implementation of a solar rechargeable power subsystem capable of continuous operation. It is important that this subsystem is robust and equipped with protection against hardware failures. To ensure an effective operation, the subsystem will incorporate key components including a solar battery charging circuit, protection circuitry, regulation circuit, and battery level indicators. Additionally, thorough examination of each component and its integration, this chapter aims to provide clear insights into the development of a reliable and efficient power solution.

1.1.1 System Overview

The following flowchart diagram depicts the functionality of the power supply subsystem:

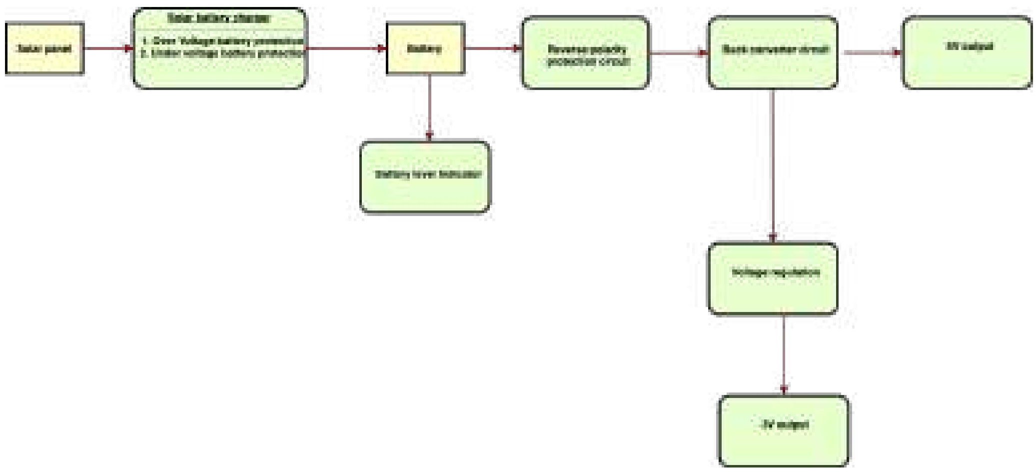


Figure 1.1: Power subsystem flow chart

1.2 Design Process

1.2.1 System Requirements

In the initial design phase, defining the requirements of a system is an important stage. Additionally,being able to provide for functionality while avoiding unnecessary system complexity is also very crucial. The stakeholder requirements are outlined in the following table:

Requirement ID	**Requirement**	**Description**
UR01	Solar Rechargeable	The system needs to be solar rechargeable when a system reaches a particular voltage threshold.
UR02	Stable Voltage	The system needs to have a stable reference output voltage for varying temperatures.
UR03	Small size	The device should be light enough to carry.
UR04	Battery temperature	Battery should be able to withstand temperatures in the kalahari.
UR05	Battery level monitoring	The device should be able to indicate the level of the battery.
UR06	Continuous power supply	battery should be able to last for a maximum of 5days for 8hours daily without needing a recharge.
UR07	Voltage Regulation	The device should be able to regulate voltage to match other subsystems.
UR08	Efficiency	The power supply must have a high efficiency to reduce heat generation.
UR09	Electrical protection	The device should have a protection mechanism against reverse polarity, over and under-voltage protection.

Table 1.1: showing a description of requirements.

1.2.2 Design Specifications

Given the above requirements, the specifications below provide a way to design, build and test the final prototype in order to meet the requirements and hence the overall functionality of the design.

Specification ID	Specification	Description
SP01	Rechargeability	solar Lithium ion rechargeable power system.
SP02	Stable Voltage	Output ripple should be ±5 percent.
SP03	Physical Size	The device should be light and small enough to carry.
SP04	Battery Operating Temperature	Battery should have an operating max temperature of 50°C.
SP05	LED Battery Level Indicators	The device should have different LEDs to indicate different battery levels
SP06	Voltage Regulation	The device should be able to handle an input voltage of 14V and regulate to an output of either 5V or 3.3V.
SP07	Efficiency	Components should have more than 80 percent efficiency.
SP08	Protection Circuitry	The device should have Over Charge protection cut off circuitry as well as reverse polarity protection.

Table 1.2: Clear description of user specifications.

1.2.3 Acceptance Testing Procedures

1. ATP1: Regulation

Upon connecting the power supply to the system, the output voltage needed in the battery charger can be measured using a multi-meter at the terminals of the output

2. ATP2: Battery Charging

To test battery charging circuit, a battery will be connected to the output of the battery charging circuit and a multi-meter will be used to measure the amount of voltage going to the battery.

3. ATP3: Reverse polarity protection The output voltage of the battery charging circuit will be tested out by a multi-meter upon connecting the battery in reverse polarity, this means the positive terminal of the battery will be connected to the negative terminal of the battery charging circuit and the positive terminal to the negative terminal.

4. ATP4: Over-voltage charge protection

The battery should be connected to a dc power supply of more than the battery voltage. The output at the battery charging circuit should read 0V to indicate that the battery is protected from overcharging.

5. ATP5: Battery monitoring test

The battery monitoring circuit should be tested with varying voltages. With an increase in the battery voltage, each LED should light up with the last LED showing that the battery is full and the first LED showing that the battery is almost low.

6. ATP6: Physical size test

The power subsystem should be small enough to fit into the physical enclosure subsystem and light enough to carry.

1.2.4 Traceability Matrix

To ensure a clear alignment between the requirements, specifications and the acceptance testing procedures, a traceability matrix is utilized. Furthermore, the traceability matrix provides a framework for tracking and validating the fulfillment of the objectives of this project.

The table below depicts the traceability matrix of each requirement, specification and Acceptance test procedure:

No.	Requirements	Specifications	Acceptance Test
1	UR07	SP06	ATP4
2	UR01	SP01	ATP2
3	UR09	SP08	ATP3, ATP4
4	UR05	SP05	ATP5
5	UR03	SP03	ATP6

Table 1.3: Requirements Traceability Matrix

1.3 Design Choices

This section primarily focuses on different design solutions that can be implemented for a sufficient power supply system. Furthermore, The main aim of this section is to compare and contrast different solutions and then based on factors such as cost, functionality and proficiency, choose the most appropriate and suitable design.

1.3.1 Solar Battery Charger

A solar battery charger is basically a form of regulator that is mainly used to regulate voltage and current from the solar panel to the battery. Without a proper design of a solar battery charger, the batteries are likely to become damaged as a result of overcharging. Thus, to maintain battery health and extend the lifespan of batteries, a solar battery charger is a crucial aspect in this project.

There are three types of solar battery chargers and this include, Pulse Width Modulation(PWM), Maximum Power Point Tracking(MPPT) and Voltage regulator battery charger.

Below is an outline of the comparison between the above mentioned solar battery chargers:

1. **Pulse width Modulation(PWM)**

   This charging controller regulates charging current by adjusting the duty cycle of switching components such as MOSFETs. It aims to gradually reduce the charging current when the battery is approaching a fixed point of regulation. Furthermore it also offers protection against overcharging, discharging and as well as overheating.However, PWM has limited power handling capabilities compared to the other charging controllers.

2. **Maximum Power Point Tracking(MPPT)**

   This charging controller maximises power output from the solar panels by continuously adjusting the maximum power point. This means that it is able to step down higher voltage from the solar panel to an amount of voltage required to charge the battery. Additionally, it has a higher efficiency as compared to the other charge controllers. However, it is more expensive to implement and uses complicated algorithms for tracking maximum power point tracking.

3. **Voltage regulator Charging circuit**

   This is the simplest and cheaper charging circuit to implement. This charging circuit maintains a constant output regardless of the voltage variations from the solar panels. Moreover it adjusts the output by continuously changing the resistance in the output. It also offers protection against overcharging, over-discharging and as well as overheating.

Given budget constraints, the voltage regulator charging circuit is the cheapest and therefore it is best suited for this project. The design behind this voltage regulator requires a choice between using an LM317 and an LM7812.

The following table presents a comparative analysis between an LM317 and LM7812:

Comparison Aspect	**LM317**	**LM7812**
Type	Adjustable regulator	Fixed regulator
Cost	Higher cost	Lower cost due to fixed voltage output
Output voltage	Variable from 1.2V to 37V	Fixed at 12V
Current capability	1.5A	up to 1A
Typical usage	Commnonly used in variable power supplies applications	Used regulated power supply applications

Table 1.4: Showing comparison between LM317 and LM7812

From the above comparison, an LM317 is a suitable regulator to use in this project. The figure below shows the solar battery charger design with solar reverse protection, Over-voltage protection and as well as an automatic battery cut off protection.

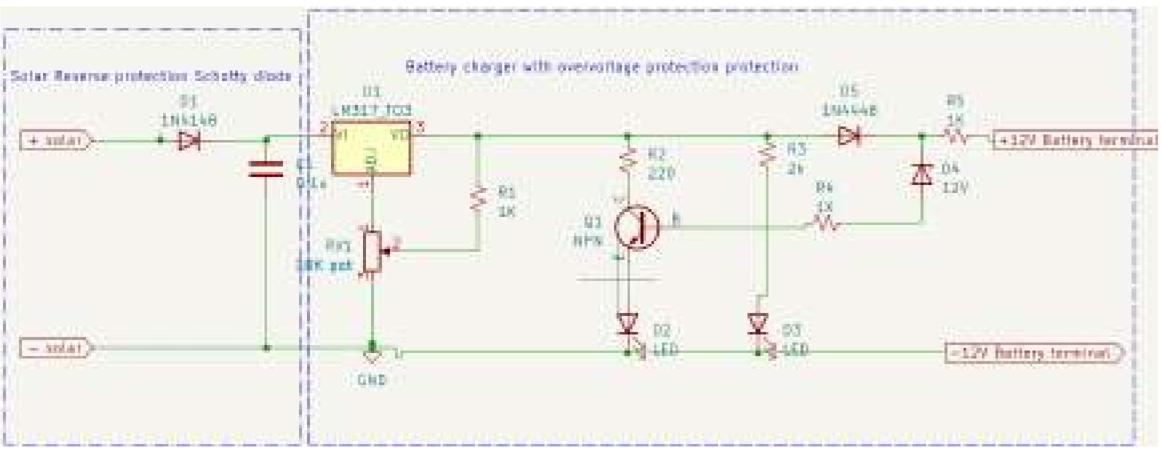


Figure 1.2: Solar Charging circuit

As seen in the figure above, the LM317 is used to regulate voltage from the solar panel to a constant voltage that is enough to charge the battery. When the battery reaches full capacity, there is a reverse voltage that is provided by the battery to bias the transistor through the zener diode, this causes the transistor to conduct and ultimately causing the green LED(D2) to turn on indicating that the battery is fully charged.Additionally, the transistor also causes the output of the regulator to decrease. During charging, the red LED(D3) turns on to indicate that the battery is charging. The 1N448 diode in the design circuit is used to implement an over-voltage protection, and this is because for a diode to conduct it needs a voltage difference across it and when the voltage at the battery is equal to the voltage before the diode, this creates a zero potential difference across the diode and therefore creating an open circuit which ultimately protects the battery from overcharging.

1.3.2 Battery

Selection of battery

When selecting the type of battery to use for the system, the design process mainly focuses on the requirement of the power supply. This implies that the focus was on whether to use rechargeable or non rechargeable options. Non rechargeable batteries lack the ability to recharge, therefore leading to a short lifespan and an inefficient power supply, On the other hand, rechargeable batteries, when coupled with renewable charging sources like solar are able to operate for extended periods of time and therefore reduce maintenance costs.

Power Budget

In order to choose the most efficient battery and accurately estimate the battery life of the device, it is crucial to calculate the power consumption of all various components in the system.

The following table provides a breakdown of the power consumption for each component within the system, as well as the total maximum and minimum power required to power these components.

Component	**Voltage (V)**	**current(mA)**	**Power (W)**
DHT11 temperature and humidity sensor	3 to 5.5	0.5 to 2.5	0.0015 to 0.01375
Raspberry Pi zero	3.3 to 5	150 to 1200	0.495 to 6
USB camera for Raspberry Pi	5	200 to 250	1 to 1.25
Noir Camera for Raspberry Pi	5	200 to 250	1 to 1.25
Passive infrared sensor	5 to 20	0.05	0.00025 to 0.001
Total Minimum		**550.55**	**2.498**
Total Maximum		**1702.55**	**8.515**

Table 1.5: Power consumption of components used in project

The total power consumption of the device ranges from 2.5W to 8.5W depending on the operation and given conditions of each device.

With the above power requirements, the choice of battery will mainly depend on the amount of time the device is expected to operate. For instance, the device is to continuously work for an average of 8 hours alone on power provided by the battery, the battery capacity will have to be at least:

$$\text{Total power} = \text{Operating time} \times \text{Amount of energy required} \tag{1.1}$$

The maximum amount of power is **8.515W**, therefore, Energy required is calculated as follows:

$$\text{Energy} = 8.515\text{W} \times 8\text{hours} = 68.12 \text{ watt-hours (Wh)} \tag{1.2}$$

With the usage of a 12V lithium ion battery in this application, to find the capacity required, the following equation is utilized:

$$\text{Capacity required (Ah)} = \frac{\text{Energy required (Wh)}}{\text{Nominal voltage (V)}} \tag{1.3}$$

$$\text{Capacity required (Ah)} = \frac{68.12\text{Wh}}{12\text{V}} \approx 6Ah \tag{1.4}$$

User requirement UR01 and and specification SP01 require that this device should be rechargeable. Additionally, user requirement UR06 requires that the battery should be able to last for a maximum of 5 days on an 8hour daily operation. Therefore, to operate for 8hours daily, it will need a solar rechargeable battery that is capable of providing at least 6000mA each hour and provide a voltage between 3.3V to 5V.

The table below depicts the choices of batteries available and the final design choice:

Battery Type	**Capacity (mAh)**	**Voltage (V)**	**Comments**
Lithium ion (18650)	8800	4.2	This battery has a high capacity,it is light weight and rechargeable as required and has a low negative impact on the environment.
Lead Acid (RT1265)	6500	12	Although this battery has a high capacity, it is bulky and heavy. Additionally, lead acid batteries are not user friendly in this project as they can be harmful to the birds in the nest.
Nickel- Metal hydride(NiMH)	1000-3000	1.2V	This batteries are rechargeable and environmentally friendly, however, they self discharge faster than lithium ion batteries and relatively have a much lower capacity

Table 1.6: Comparison of available battery choices

The choice between the above batteries depends on various factors such as High capacity, affordability and environmental impact. With the Lead Acid battery having a negative impact on the environment, it is evidently not a good choice. Additionally, the Nickel metal Hydride is also not a good choice because it discharges faster than the lithium ion battery. The Lithium ion(18650) battery has a high capacity and has a low negative impact on the environment therefore it is suited for this application.

1.3.3 Regulation

Selection of Voltage Regulator

The main available methods for stepping down voltage are the use of linear regulators, voltage dividers and as well as buck converters. Voltage dividers use passive components only and most of them have a lower efficiency, hence it is the worst case to go with in this project. Therefore the main focus of this sub-section is a comparison between linear regulators and a buck converter.

The table below presents a comparative analysis between linear regulators and a buck converters:

Comparison Aspect	**Linear regulators**	**Buck converters**
Efficiency	Lower efficiency	Up to 95 percent efficiency due to switching operation.
Cost	Lower cost	Higher cost, but potentially lower long term cost due to efficiency.
Regulation	Suitable for low output regulation.	Suitable for a wide range of output voltage.
Heat dissipation	Significant amount of heat dissipation.	Lower heat dissipation due to switching.
Output power	Limited by heat dissipation therefore lower output power.	Generally capable of handling higher power outputs efficiently.

Table 1.7: Buck converter switching regulator vs linear regulators.

The buck converter switching regulator was chosen as the preferred method for stepping down voltage and this choice was made on the basis of the comparison of the above table. Their higher efficiency and low heat dissipation makes them an optimal choice to meet the user requirements.

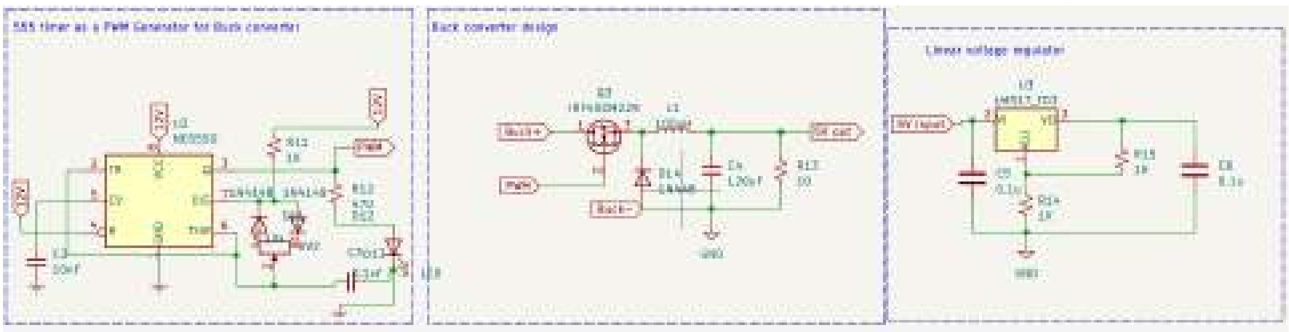


Figure 1.3: Buck converter and linear regulator

As seen in the above schematic, a buck converter was designed using an IRF40DM229 MOSFET, an inductor, capacitors and resistors. A PWM signal was subsequently generated using a 555 timer and a 5V output is subsequently generated. Additionally, to get an output of 3.3V as required in one of the specifications(SP06) a linear voltage regulator was used to further step down the voltage to a 3.3V output to meet the requirements of the power supply.

1.3.4 Battery level monitoring

One of the requirements of this project is for the user to be able to monitor the battery level(UR05). The two options available for monitoring battery level are:

1. Using LEDs and zener diodes.
2. Using a comparator op amp.

Using an op amp requires a comparison between a reference voltage and a regulated voltage from the battery, if the voltage is lower than a reference voltage then the output of the comparator will be low and the diode in forward biased with it will be off. However, using LED's and Zener diodes is relatively cheaper to implement and provides a clear visual indication of the battery level.

Below is a design of a circuit that uses LED's and zener diodes to depict the battery level:

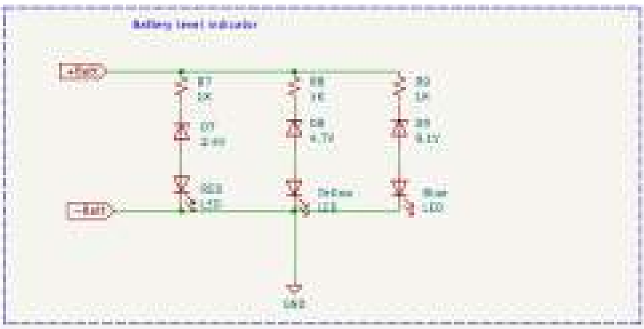


Figure 1.4: Battery level monitoring circuit

1.3.5 Solar panel

One of the requirements of the power subsystem is for the system to be rechargeable by solar. The maximum amount of power that the system needs to function is 8.5Watts, this means that the amount of power provided by solar should be above the 8.5W. Solar is an important and critical aspect of this project, however, due to budget constraints, a solar panel was not included in the final design.

Below is a picture of a 10W solar panel that would be utilized to meet this requirement:

Figure 1.5: 10W solar panel

1.4 Final Design

Below is a picture of the final design subsystem working as required

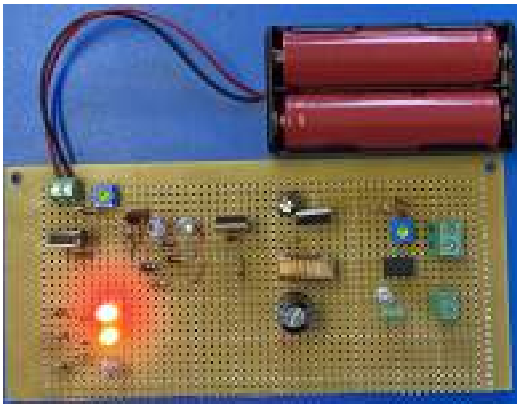


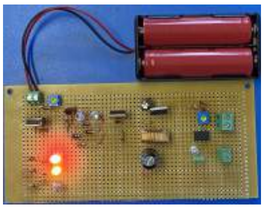
Figure 1.6: Final Design

1.5 Testing and Results

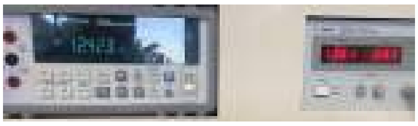
1.5.1 Battery charging test and over-voltage protection test

With a variable input from a signal generator acting as solar, The charging circuit works as expected and has the over voltage protection circuitry as required by the user specifications.

below is a picture of the final charging circuit and as well as results from the over voltage protection. The over-voltage protection below shows that when the voltage goes above a 12V as required, the battery does not take in anymore higher voltage.



(a) Battery charging circuit



(b) Over-Voltage Protection

1.5.2 Battery level indicator

The battery level indicator was tested at different voltage levels using the power supply generator and the LED's turned on at different voltages as expected.

(c) Battery indicator at low battery level

(d) Battery indicator at half battery level

(e) Battery level indicator at full battery level

1.5.3 Buck converter and reverse polarity test

The buck converter circuit was tested at different input voltages to ensure that the output voltage remains at the required 5V voltage, which was further reduced by a linear regulator to a 3.3V output as per design specification 06 (Voltage regulation). The images below depict a buck converter at a given high voltage With the output on a multi-meter reading 5V as expected and they also show a working reverse polarity circuit with the use of a zener diode and a P-Mosfet.

(f) Buck converter test

(g) Reverse polarity circuit allowing voltage to pass

(h) Reverse polarity test

Test	Specification Description	Acceptance criteria	Test Result
ATP6	Physical size	The dimensions of the subsystem should not be more than 8 x 15x 5cm	**Passed**: a 7.5cm x 14.5cm x 4cm veroboard was used
ATP5	LED battery level indicators	The battery should have a visual indication of the battery level.	**Passed:** The subsystem has different LED's turning on at different voltages.
ATP3	Reverse polarity protection	The subsystem should be able to protect the device when the polarity of the battery is reversed.	**passed:** The reverse protection circuit has an output of 0V when the polarity of the battery is reversed.
ATP2	Rechargeability	The system should be able to charge lithium ion batteries provided an input from solar	**Passed:** The charging circuit charges the battery when it is low
ATP4	Over-Voltage protection	The battery should be disconnected from charging when it reaches full capacity	**Passed:** when the voltage of the battery reaches a voltage equal to supply voltage, the battery starts receiving a 0V from charger.
APT1	Regulation	The buck converter should be able to regulate to the required voltage of 5V	**Passed:** As seen in the buck converter test above,the buck converter outputs a voltage of 5V regardless of the input given to it.

Table 1.8: Test

1.6 Conclusion and Recommendations

In conclusion, the design and implementation of the power supply for this design project is successful in delivering functionality as required by the user. The battery charging circuit can take in an input from solar and as well as charge the battery. Additionally, the protection circuitry functions efficiently, with the over voltage protection circuitry functioning as required and the reverse polarity functioning perfectly. Through rigorous testing, the buck converter is able to step down voltage to the required level through the use of a 555 timer for generation of a PWM. Furthermore, the battery level indicator exhibited excellent characteristics in terms of indicating the battery level.

However, there is a room for improvement, this subsystem would function a lot better with a PCB implementation, this would eliminate soldering and short circuit errors. Additionally, the use of Integrated circuits such as TP4056 as battery chargers may ensure that the subsystem is a lot more efficient, this is because the use of passive components have their own disadvantages and limitations. For the Solar charging circuit, a Wave-share solar management Module may be utilized to efficiently integrate the charging system to solar.

Bibliography

Glossary