The Solar Stroller

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1. **Block Diagram**

The Block Diagram of the Solar Stroller is shown in Figure 1 below.

![Block Diagram](image)

**Figure 1. Complete Block Diagram**

2. **Block Description of Buck Converter**

   In order to make the 7.4V LiPo battery applicable for the 5V outputs for the LEDs and USB Port, a standard Buck Converter design is used to convert the voltage while transporting energy from the charging block to the load block. This converter is essential to be able to utilize the harvested energy by the LiPo battery while keeping the power to the loads at an optimum level. This converter will be operated with a microcontroller (MCU), which will also handle the MPPT.

3. **Calculations of Buck Converter**

   Our buck converter must accomplish the following list of specifications:
   
   - Step down the voltage from the 7.4V nominal LiPo battery to 5V ± 0.25V
   - Supply enough current for the LEDs and phone-charging loads
   - Have less than 10% output current ripple

   This buck converter must appropriately serve our loads:
   
   - LED Light Strip & LED Headlamp: 13W+1.6W = 15W
   - USB Port (Phone Charger): (5V)(1A) = 5W

   Thus, for the case when both loads are to be powered by the battery, there is a total power output of 20W. In this case, an output current of 4A is required to maintain an output voltage at 5V. The following relationship between the input and output voltage of a buck converter in regards to the duty cycle ($D$) to find the time during a period when our switch is on is described in Equation (1):
\[ D = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{5V}{7.4V} \approx 0.75 \] (1)

Using this duty cycle, a switching frequency can arbitrarily be chosen, 100 kHz, for sizing purposes. The minimum value of the inductor is determined by performing a volt-second balance and using a ripple chosen ripple of 30% of the total output current, which is equal to 1.2 A. The minimum inductor value is found using Equations (2)-(3):

\[ V_L = V_{\text{in}} - V_{\text{out}} = L \frac{di}{dt} = L \frac{\Delta i_{\text{L,PK}}}{DT} \] (2)

\[ L_{\text{min}} = \frac{(V_{\text{in}} - V_{\text{out}})D}{\Delta i_{\text{L,PK}}/f_{\text{sw}}} = \frac{(7.4V - 5V)(0.75)}{(100kHz)(1.24)} = 15\mu H \] (3)

Using the voltage ripple from our inductor calculations, the minimum output capacitance can be calculated by knowing the output voltage ripple:

\[ V_{c,\text{out}} = V_{\text{out}} \] (4)

\[ i_{c,\text{out}} = C_{\text{out}} \frac{dV_{c,\text{out}}}{dt} \] (5)

Using these Equations (4)-(5), a conservation of charge calculation is performed between the inductor and capacitor currents to receive the minimum output capacitance value:

\[ C_{\text{out,min}} = \frac{\Delta i_{\text{L,PK}}}{8\Delta V_{\text{ac}}f_{\text{sw}}} = \frac{(1.24)}{(8)(0.5V)(100kHz)} = 3.75 \mu F \] (6)

Table 1 summarizes the calculated design parameters for the Buck Converter. The values in Table 1 were used to build a circuit schematic using the program LTSpice.

<table>
<thead>
<tr>
<th>Device - Name</th>
<th>Designed Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Capacitor - C1</td>
<td>10 (\mu F)</td>
</tr>
<tr>
<td>Output Capacitor - C2</td>
<td>3.75 (\mu F)</td>
</tr>
<tr>
<td>Inductor - L1</td>
<td>15 (\mu H)</td>
</tr>
</tbody>
</table>

4. Buck Converter Circuit Schematic

The LTSpice Circuit Simulation of the Buck Converter is shown in Figure 2.
5. Simulation of Buck Converter

For simulation purposes, the battery is assumed to be producing a constant voltage of either 8.4V (full charge), 7.4V (nominal), or 6.4V (under-voltage cut-off). For the various loads, a resistor can be added to simulate the load that the converter will operate for. As seen in Figure 2, both loads are active requiring a total power output of 20W. In order to supply a constant 5V to these loads, the equivalent resistance to test for is given by Equation (7):

$$ R_{Load} = \frac{V^2}{P} = \frac{(5V)^2}{(20W)} = 1.25\Omega $$

This allows for us to not only measure the voltage across the load, but also the current. Specifying the input voltage to be 7.4V, then the buck converter is simulated by measuring the output voltage and current to verify that it is within the given specifications. For a step further, the following non-idealities are considered:

- Diode contains a 120mΩ on resistance and 0.7V forward voltage drop
- MOSFET contains an on resistance of 100mΩ

For the setup in Figure 2, Figures 3-4 below display the simulation results.
Examining the steady-state ripple on these components, the zoomed-in images are shown in Figures 5-6.

This shows that the output voltage is within $5 \pm .25\text{V}$, and the current ripple is within 30% of the total output current. Seeing as how this design is valid for the minimum inductance and output capacitance, a better simulation can be created by making these values larger. Changing the inductance to 100$\mu\text{H}$ and the output capacitance to 33$\mu\text{F}$ would allow for a smaller current ripple at the output of the converter. Using this circuit in testing the various load combinations (no load, USB only, LEDs only, USB and LEDs) along with the full range of battery voltages (6.4V, 7.4V, 8.4V), the resulting power is determined through simulation and compared to the worst case power output. A summary of the simulation results for this modified circuit with an inductance of 100$\mu\text{H}$ and an output capacitance of 33$\mu\text{F}$ is shown in Table 2.
### Table 2. Simulation Results for Various Load Combinations and Battery Voltages

<table>
<thead>
<tr>
<th>Battery Input Voltage</th>
<th>USB On</th>
<th>LEDs On</th>
<th>Power Output (Worst Case)</th>
<th>Expected Current</th>
<th>Load Resistance</th>
<th>$\text{Resulting Current}$</th>
<th>$\text{Resulting Voltage}$</th>
<th>$\text{Resulting Power}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4 V</td>
<td>X</td>
<td>X</td>
<td>20 W</td>
<td>4 A</td>
<td>1.25 Ω</td>
<td>3.62 A</td>
<td>4.5 V</td>
<td>16.3 W</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.4 V</td>
<td>X</td>
<td>X</td>
<td>20 W</td>
<td>4 A</td>
<td>1.25 Ω</td>
<td>4.2 A</td>
<td>5.4 V</td>
<td>22.68 W</td>
</tr>
<tr>
<td>8.4 V</td>
<td>X</td>
<td>X</td>
<td>20 W</td>
<td>4 A</td>
<td>1.25 Ω</td>
<td>4.78 A</td>
<td>5.9 V</td>
<td>28.2 W</td>
</tr>
</tbody>
</table>

### 6. Requirements and Verification of Buck Converter

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
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</table>
| **7.4 V DC to 5.0 V DC Buck Converter** | 1) Attach DC power supply to input of converter  
2) Apply a 7.4V signal  
3) Measure output voltage with multimeter under equivalent resistive loads (shown in table above) to ensure specification is met  
4) Vary the input voltage with a DC power supply to confirm the duty ratio auto-adjusts to maintain a steady output  
5) Apply ~6.3V signal to the converter and measure the output voltage. Confirm the converter shuts off the output at any input below 6.3V  
6) Probe output with oscilloscope. Confirm ripple is within specification |
7. Safety Statement

7.1 Project Safety

In assembling our Solar Stroller design, there is various circuitry that our team will take special precautions while handling. The most critical safety issue is correctly charging the LiPo battery on the stroller. Undercharging and overcharging the LiPo battery can result in a fire or explosion, which can be dangerous to our team and others, as well as damaging to our project and other design lab assets. It is essential for our overcharge protection and charge controller to work correctly for the successful and safe charging of our LiPo battery. The LiPo batteries will also not be exposed to flammable products or liquids during the assembly, nor will they be operated in conditions below 0°C or above 50°C. In order to provide safety to our loads, specifically our personal electronic devices for testing purposes, our Buck Converter must be designed to accurately step down from the 7.4V LiPo battery to a safe 5V for the USB port and LED lighting.

7.2 User Safety

To ensure the safety of the user and their child, the circuitry components of the Solar Stroller should never be tampered with. The Solar Stroller contains LiPo batteries that can result in fire, explosions, and toxic smoke inhalation when mishandled. Due to the LiPo batteries sensitivity to temperature, do not operate in conditions below 0°C or above 50°C. It is recommended that the user does not store flammable products or liquids near the charging battery.

8. References

