Solar Powered Beach Chair

Andrew Gazdziak
Emily Mazzola
Damen Toomey
Introduction

- Uses the power of the sun to provide the user with a USB ready charging station

- The Solar Powered Beach Chair powers your phone, your tablet, and keeps your drink cool all without you having to worry about sand and water interfering with your electronics!
Features and Benefits

**Features**
- On/Off switch
- Three USB charging ports
- Drink Cooler
- 50 W solar panel integrated on the chairs canopy
- Durable, water resistant, and sandproof to ensure longevity

**Benefits**
- Charge devices while soaking up the sun
- Solar canopy provides the user with shade
- Backpackable for easy transport
- Environmentally friendly
How it Works

Solar Beach Chair

- Solar Source
- Solar Panel
- Safety Switch
- Converter
- Control Circuitry
- USB Port 1
- USB Drink Cooler
- USB Port 2
Solar Source

Requirement

- To ensure maximum power from the solar panel, there must be $\frac{1\text{kw}}{m^2}$ of insolation available from a solar source.

Verification

- Use isws.illinois.edu to ensure that the insolation present is at least $\frac{1\text{kw}}{m^2}$

Weather Information from the Illinois State Water Survey

- Temperature: 54°F
- Wind Speed: 9 mph (Gusts to 17 mph)
- Wind Direction: 290° (From the W)
- Precipitation: 0 in.
- Relative Humidity: 38%
- Dew Point: 27°F
- Barometric Pressure: 30.17 in. sea level pressure
- Solar Radiation: 363 Watts / m²
- 4° Soil Temperature: 58° F
- 8° Soil Temperature: 53° F
- Visibility: 10 mi.

Source: http://www.isws.illinois.edu/data/wxinfo.asp
Solar Panel

**Requirement**
- Solar Panel must produce an output voltage of 5 V - 21.6 V and an output power of at least 50W

**Verification**
- Use a Fluke meter to measure the output power and output voltage.

Source: bing.com/fluke-meter
Source: http://www.sunshineworks.com/small-solar-panels-for-sale.htm
Safety Switch

**Requirement**
- When switch is off, no current reaches the load, and when switch is on, current reaches the load

**Verification**
- Ensure phone does not charge when switch is in off position and does charge when switch is on

Source: bing.com/rocker+switch
Converter

Requirement

- Output voltage must be between 4.75 V-5.25 V

Verification

- Use a voltage probe on the output capacitor and use an oscilloscope to verify that the voltage ripple is within 4.75 V-5.25 V
Determining Inductor Size

<table>
<thead>
<tr>
<th>Input Voltage Range</th>
<th>5V - 21.6V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage Range</td>
<td>4.75V - 5.25V</td>
</tr>
<tr>
<td>Output Load Range</td>
<td>0W - 50W</td>
</tr>
</tbody>
</table>

- \( V_{in} = 12V, P_{in} = 50W, V_{out} = 5V, f_{sw} = 10 \text{ kHz} \)
- Duty Ratio = \( D = \frac{V_{out}}{V_{in}} = \frac{5V}{12V} = 0.417 \)
- Change in the Inductor Current = \( \Delta I_{Lp-p} = 2 \times I_{out} \)
- \( \Delta I_L = \frac{V_{in} - V_{out}}{L} \times DT = \frac{V_{in}(1-D)}{L} \times DT \)
- \( L_{crit} = \frac{V_{in}(1-D)D}{2f_{sw}} \times \frac{V_{out}}{P_{out}} = \frac{12(1-0.417)0.417}{2 \times 10,000} \times \frac{5}{50} = 14.59 \mu H \)
Current Waveforms

- $I_{cout}$: Average current through a capacitor is zero
- $I_{sw}$: Switch on: $I_{sw} = I_L$
- $I_{cin}$: Switch off: $I_{cin} = I_{in} = 4.17A$
  Switch on: $I_{cin} = I_{in} - I_{sw}$
Determining Capacitor Sizes

**Input Capacitor Calculation**
- To extract the maximum power from the photovoltaic panel, it is desired to have the input voltage ripple below 1.00V\(_{p-p}\).
- \(\Delta V_{in_p-p} = \frac{\Delta Q}{C_{in}}\)
- \(\Delta Q = (1 - D)T \times 4.17A + 0.5 \times 4.17A \times \frac{1}{20} T\)
- \(C_{in} = \frac{\Delta Q}{\Delta V_{in_p-p}} = \frac{1.268 \times 10^{-5}}{1} = 12.68 \mu F\)

**Output Capacitor Calculation**
- For proper USB operation, it is required to have the output voltage ripple of the converter to be below 0.5V\(_{p-p}\).
- \(\Delta Q = \frac{1}{2} \times \frac{T}{2} \times 10A = 1.25 \times 10^{-5} C\)
- \(C_{out} = \frac{\Delta Q}{\Delta V_{out_p-p}} = \frac{1.25 \times 10^{-5}}{0.5} = 25 \mu F\)
# Efficiency Data

<table>
<thead>
<tr>
<th>$V_{in}$ [V]</th>
<th>$I_{in}$ [A]</th>
<th>$P_{in}$ [W]</th>
<th>$D$</th>
<th>$V_{out}$ [V]</th>
<th>$I_{out}$ [A]</th>
<th>$P_{out}$ [W]</th>
<th>Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.01</td>
<td>0.73</td>
<td>7.31</td>
<td>0.49</td>
<td>4.42</td>
<td>1.44</td>
<td>6.34</td>
<td>86.76</td>
</tr>
<tr>
<td>12.02</td>
<td>0.73</td>
<td>8.77</td>
<td>0.42</td>
<td>4.89</td>
<td>1.59</td>
<td>7.70</td>
<td>87.75</td>
</tr>
<tr>
<td>10.01</td>
<td>0.89</td>
<td>8.91</td>
<td>0.54</td>
<td>4.89</td>
<td>1.60</td>
<td>7.77</td>
<td>87.22</td>
</tr>
<tr>
<td>10.09</td>
<td>0.91</td>
<td>9.18</td>
<td>0.42</td>
<td>5.01</td>
<td>1.64</td>
<td>8.20</td>
<td>89.31</td>
</tr>
<tr>
<td>17.02</td>
<td>0.60</td>
<td>10.21</td>
<td>0.33</td>
<td>5.26</td>
<td>1.72</td>
<td>9.00</td>
<td>88.13</td>
</tr>
<tr>
<td>10.10</td>
<td>1.08</td>
<td>10.91</td>
<td>0.40</td>
<td>5.47</td>
<td>1.79</td>
<td>9.70</td>
<td>88.93</td>
</tr>
<tr>
<td>12.76</td>
<td>0.97</td>
<td>12.38</td>
<td>0.49</td>
<td>5.70</td>
<td>1.86</td>
<td>10.51</td>
<td>84.91</td>
</tr>
</tbody>
</table>
Controller

Requirement
- Control circuit produces the desired PWM switching signal with the correct duty ratio

Verification
- Connect the switching signal and gate driver signals to an oscilloscope. Vary the input voltage from 10-20V and ensure the duty cycle of the signals are correct.
Control Circuitry

- MSP 430 Microcontroller
  - Ultra low power consumption
- Synchronous Rectification
- ~10.5kHz operation

Control Circuitry
PWM Switching Signal
Logic Flowchart

Start up: $D = 42\%$

Sample Output Voltage

- Yes: Decrease $D$ by 1%
- No: $V_{out} > 5.05$ V?
  - Yes: Increase $D$ by 1%
  - No: $V_{out} < 4.95$ V?
USB Ports 1 and 2

Requirement
• Referring to the figure, when Pin 1 has a voltage of 4.75 V - 5.25 V, and Pin 4 is connected to GND it is able to successfully charge an iPod and iPad.

<table>
<thead>
<tr>
<th>Pin</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VBUS</td>
</tr>
<tr>
<td>2</td>
<td>D-</td>
</tr>
<tr>
<td>3</td>
<td>D+</td>
</tr>
<tr>
<td>4</td>
<td>GND</td>
</tr>
<tr>
<td>Shell</td>
<td>Shield</td>
</tr>
</tbody>
</table>

Source: USB.org

Verification
• Implemented USB on the chair and verified that it could charge a USB device.
Apple Device Compatibility

- Required for charging
- Non-Apple devices still compatible
- High power charging (10W)

Source: pinout.net
Drink Cooler

Requirement

• Keep 12 oz. of water with a starting temperature of 40°-60° F within 5° F of its starting temperature for fifteen minutes when the ambient temperature is 70° F

Verification

• Use a waterproof digital food thermometer to measure the starting and final temperature of the water to verify that the change in temperature is within 5° F after fifteen minutes

Source: coolitsystems.com
Drink Cooler (The Peltier Effect)

- Current flows between two conducting plates through a semiconductor pellet.
- The charge carries transfer the heat from one plate to the other.

Drink Cooler

<table>
<thead>
<tr>
<th>T_{Start} (°F)</th>
<th>T_{15} (°F)</th>
<th>ΔT (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40.1</td>
<td>44.6</td>
<td>4.5</td>
</tr>
<tr>
<td>45.0</td>
<td>48.2</td>
<td>3.2</td>
</tr>
<tr>
<td>50.9</td>
<td>53.2</td>
<td>2.3</td>
</tr>
<tr>
<td>55.0</td>
<td>56.4</td>
<td>1.4</td>
</tr>
<tr>
<td>56.4</td>
<td>57.6</td>
<td>1.2</td>
</tr>
<tr>
<td>57.6</td>
<td>58.5</td>
<td>0.9</td>
</tr>
<tr>
<td>58.5</td>
<td>59.3</td>
<td>0.8</td>
</tr>
<tr>
<td>59.9</td>
<td>60.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Measured Results with T_{amb}=74°F
Beach Chair

Requirement

• Can support the weight of the panel, does not exceed 35 lbs, is at rated water resistance and sandproofing of IP62

Verification

• Perform water and sand test to verify that the IP62 rating is achieved. Weigh the chair to confirm its weight does not exceed 35 lbs
Beach Chair

- Mounted Solar Panel
- Mounted Circuit Box
- Mounted Drink Cooler
- Added Backpack Straps
- Final Weight – 28.6 lbs.
Weatherproofing

• Modified waterproof case while maintaining water and dust resistance.

Source: homedepot.com
Future Work

- Flexible Solar Panel
- Bus USB Configuration
- Built in Speaker and Fan
- Adjustable Canopy
- Improve efficiency through better heat sinks

Source: http://www.powerfilmsolar.com/sitevizenterprise/website/
Wholesale Parts Cost

- Total Cost of Materials: $93.97
- Labor/Chair: $30.00
- Overhead/Chair: $30.00
- Total: $153.97
- Customers willing to pay $150.00
- Profitability reached selling 1000 chairs per year

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Price</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach Chair</td>
<td>$15.00</td>
<td>1</td>
<td>$15.00</td>
</tr>
<tr>
<td>Solar Panel</td>
<td>$41.59</td>
<td>1</td>
<td>$41.59</td>
</tr>
<tr>
<td>Waterproof Case</td>
<td>$7.80</td>
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<td>$7.80</td>
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<tr>
<td>Resisters</td>
<td>$0.04</td>
<td>18</td>
<td>$0.70</td>
</tr>
<tr>
<td>Ceramic Capacitor</td>
<td>$0.00</td>
<td>1</td>
<td>$0.00</td>
</tr>
<tr>
<td>Metal Film Capacitor</td>
<td>$0.05</td>
<td>2</td>
<td>$0.11</td>
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<tr>
<td>Electrolytic Capacitor</td>
<td>$0.20</td>
<td>5</td>
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<tr>
<td>Mosfet</td>
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</tr>
<tr>
<td>Inductor</td>
<td>$5.65</td>
<td>1</td>
<td>$5.65</td>
</tr>
<tr>
<td>USB Connectors</td>
<td>$0.71</td>
<td>3</td>
<td>$2.12</td>
</tr>
<tr>
<td>High Side Gate Driver</td>
<td>$1.37</td>
<td>1</td>
<td>$1.37</td>
</tr>
<tr>
<td>USB Extention Cord</td>
<td>$1.80</td>
<td>3</td>
<td>$5.39</td>
</tr>
<tr>
<td>3.3 V DC/DC</td>
<td>$3.75</td>
<td>1</td>
<td>$3.75</td>
</tr>
<tr>
<td>MSP430 Launchpad</td>
<td>$4.30</td>
<td>1</td>
<td>$4.30</td>
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<tr>
<td>MSP430 Chip</td>
<td>$0.25</td>
<td>1</td>
<td>$0.25</td>
</tr>
<tr>
<td>Diode</td>
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<td>$0.25</td>
</tr>
<tr>
<td>Lowside Gate Driver</td>
<td>$0.55</td>
<td>1</td>
<td>$0.55</td>
</tr>
<tr>
<td>PCB</td>
<td>$0.10</td>
<td>12</td>
<td>$1.16</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>$93.97</strong></td>
</tr>
</tbody>
</table>

Based on 1000 Chairs
Special Thanks

Professor Carney
Ryan Corey
Machine Shop
Electronic Parts Shop
Kevin Colvary
Roy Bell