

MSP430 Microcontroller Based Solar LED Lantern-Boost Topology

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ABSTRACT

Currently, LEDs are available in high power ranging from .25 watts to 10 watts. Due to this, it is possible to utilize them for the design of electronic LED Lamp. This application report describes the circuit and software required for building a low-cost electronic LED Lamp based on MSP430 value line microcontroller series.

Project collateral and source code discussed in this application report can be downloaded from the following URL: <http://www.ti.com/lit/zip/slaa556>.

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1 Introduction

This application report explains the working of an electronic LED Lamp with boost topology for driving the output LED load. This circuit is not using any external driver chip for driving the boost section. The pulse width modulator (PWM) engine and 10 bit analog-to-digital converter (ADC) of MSP430 controller is utilized for the closed loop current control. The software also provides all the basic features required for an electronic LED Lamp. The features supported by the design are listed below:

- Boost section for driving the output
- Closed loop current control for driving the LED load current at the set value
- Three stage dimming supported through single push button
- Low battery monitoring and cutoff for avoiding deep discharge of the battery

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- Charging control for the battery from solar panels and mains including overcharge cutoff
- Toggling LED indication for low battery
- Toggling LED indication for charging
- Mobile charging control facility with cutoff at main battery below a specified volt
- Optional provision for the temperature compensation for charging range

2 Driver Topologies

Depending on the forward voltage required and the input voltage provided various topologies can be used for driving the output LED load. For example, the boost topology has to be used if the input voltage is less than the output voltage required across the LEDs. Similarly, the buck topology has to be used if the output voltage required is less than the input voltage. The circuit and software discussed in this application report provide the method to drive a LED output section in boost topology.

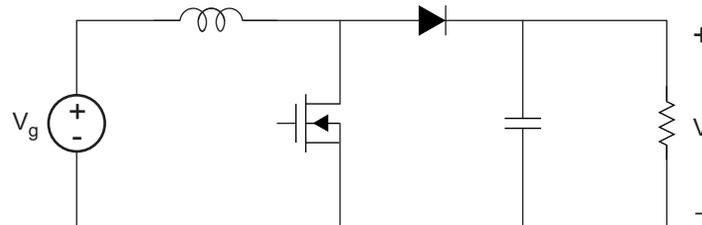


Figure 1. Boost Topology

3 Hardware Details

3.1 System Block Diagram

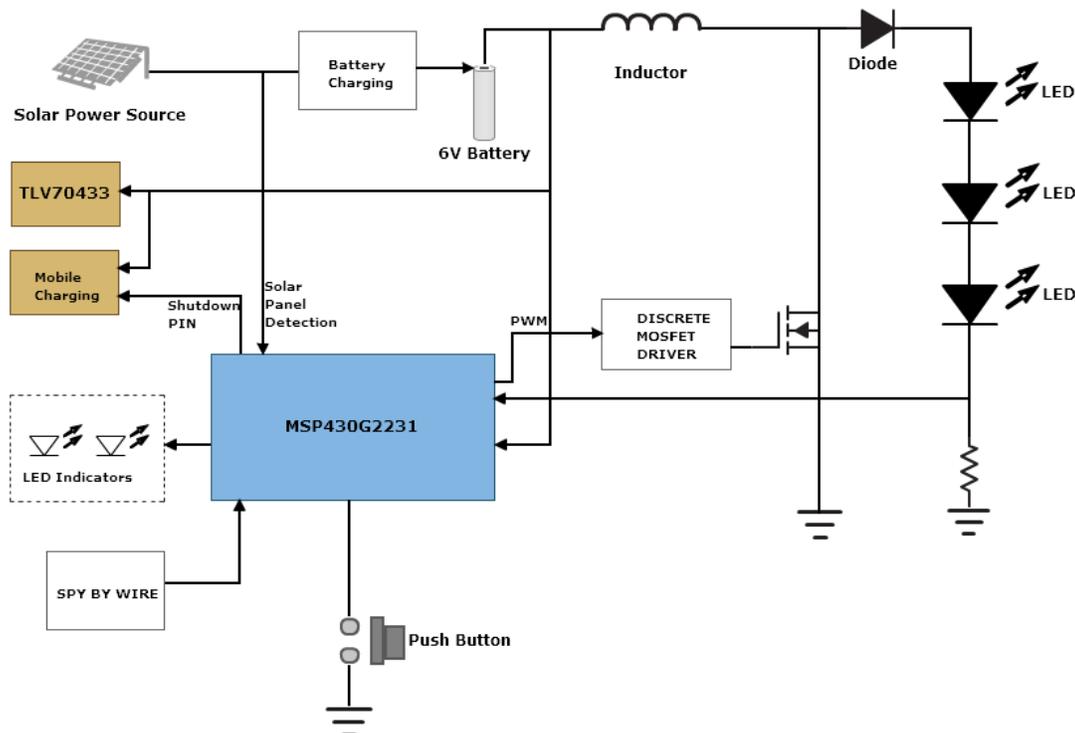


Figure 2. System Block Diagram

4 Circuit Diagram

See [Appendix A](#) for the schematic details.

4.1 Component Selection

Component selection is a critical part in every product. The cost for the components are a primary constraint. In this design, few of the critical components are the inductors and the power MOSFETs. The following section guides you to choose the right inductors and MOSFETs for this design.

4.1.1 Inductor Selection

In switching regulator applications, the inductor is used as an energy storage device. When the semiconductor switch is on, the current in the inductor ramps up and energy is stored. When the switch turns off, this energy is released into the load; the amount of energy stored is given by:

$$\text{Energy} = \frac{1}{2} \cdot L \cdot I^2 \text{ (Joules)} \quad (1)$$

Where L is the inductance in Henrys and I is the peak value of inductor current.

The amount by which the current changes during a switching cycle is known as the ripple current and is defined by [Equation 2](#):

$$V_1 = L \cdot \frac{d_i}{d_t} \quad (2)$$

Where V_1 is the voltage across the inductor, d_i is the ripple current and d_t is the duration for which the voltage is applied. From this, you can see that the value of ripple current is dependent upon the value of inductance. Choosing the correct value of inductance is important in order to obtain acceptable inductor and output capacitor sizes and sufficiently low output voltage ripple.

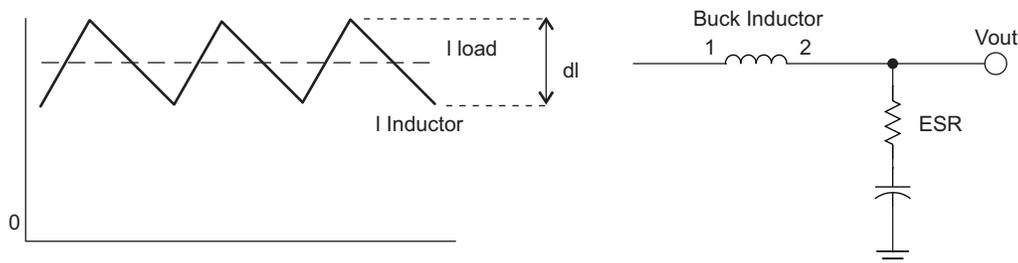


Figure 3. Buck Inductor Current

As can be seen from [Figure 1](#), inductor current is made up of AC and DC components. Because the AC component is high frequency, it flows through the output capacitor as it has a low HF impedance. This produces a ripple voltage due to the capacitor equivalent series resistance (ESR) that appears at the output of the switching regulator. This ripple voltage needs to be sufficiently low as not to effect the operation of the circuit the regulator is supplying, normally in the order of 10-500mVpk-pk.

Inductor Selection for Buck Converters

When selecting an inductor for a Buck converter, as with all switching regulators, you will need to define or calculate the following parameters:

- Maximum input voltage
- Output voltage
- Switching frequency
- Maximum ripple current
- Duty cycle

For the example shown in [Figure 2](#), assume a switching frequency of 200 kHz, an input voltage range of 6 V, and a max ripple current of 100 mA.

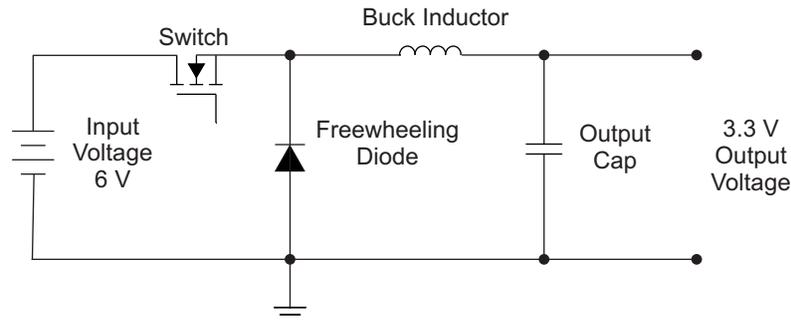


Figure 4. Buck Circuit

For an input voltage of 6 V, the duty cycle will be:

$$D = \frac{V_o}{V_i} = \frac{3.3}{6} = 0.55 \quad (3)$$

Where V_o is the output voltage and V_i is the input voltage.

Voltage across the inductance:

$$V_1 = V_i - V_o = 2.7 \text{ V when the switch is on} \quad (4)$$

$$V_1 = -V_o = -3.3 \text{ V when the switch is off} \quad (5)$$

Require inductance:

$$L = V_1 \cdot \frac{d_t}{d_i} = \frac{\left((2.7 \times 0.55) / (200 \times 10^3) \right)}{0.1} \quad (6)$$

$$L = 74.25 \mu\text{H}$$

Inductor Selection for Boost Converters

In order to calculate the required value of inductance for a Boost converter, you need to follow the same procedure as described for the Buck converter; the difference being that the equations for duty cycle and inductor voltage change. Consider the maximum input voltage as 5.5 V, switching the frequency as 100 kHz and the maximum ripple current as 0.1 A, as shown in [Figure 5](#).

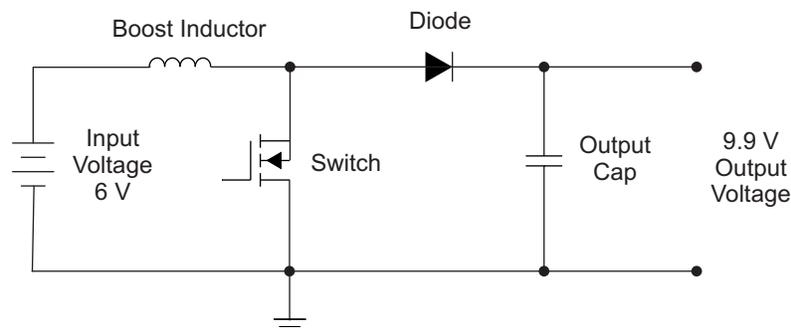


Figure 5. Boost Circuit

Duty cycle:

$$D = 1 - \left(\frac{V_i}{V_o} \right) = 1 - \left(\frac{6}{9.9} \right) = 0.60 \quad (7)$$

Inductor Voltage:

$$V_1 = V_i = 6 \text{ V when the switch is on} \quad (8)$$

$$V_1 = V_o - V_i = 3.9 \text{ V when the switch is off}$$

Using equation 6, inductance:

$$L = \frac{(6 \times 0.60) / (100 \times 10^3)}{0.1}$$

$$L = 360 \mu\text{H} \quad (9)$$

One thing to note about the Boost converter topology is that unlike the Buck converter, the inductor current does not continuously flow to the load. During the switched 'on' period, the inductor current flows to ground and the load current is supplied from the output capacitor. This means that the output capacitor must have sufficient energy storage capability and ripple current rating in order to supply the load current during this period.

4.1.2 MOSFET Selection

Different parameters for the MOSFET selection are given below:

- Enough current rating as per the required application wattage
- Enough VDS rating as per the output voltage
- Lowest onstate resistance
- Lowest gate to source voltage for turning on the MOSFET, that is, Vgs threshold should be low.
- Lowest cost

4.1.3 Current Sensing Resistor

The closed loop control of the current controlled output stage to the LEDs is done through sensing the voltage across a resistor in series to the load. This circuit configuration uses a feedback resistor of value 4.7 Ω .

5 Firmware

5.1 Flowchart

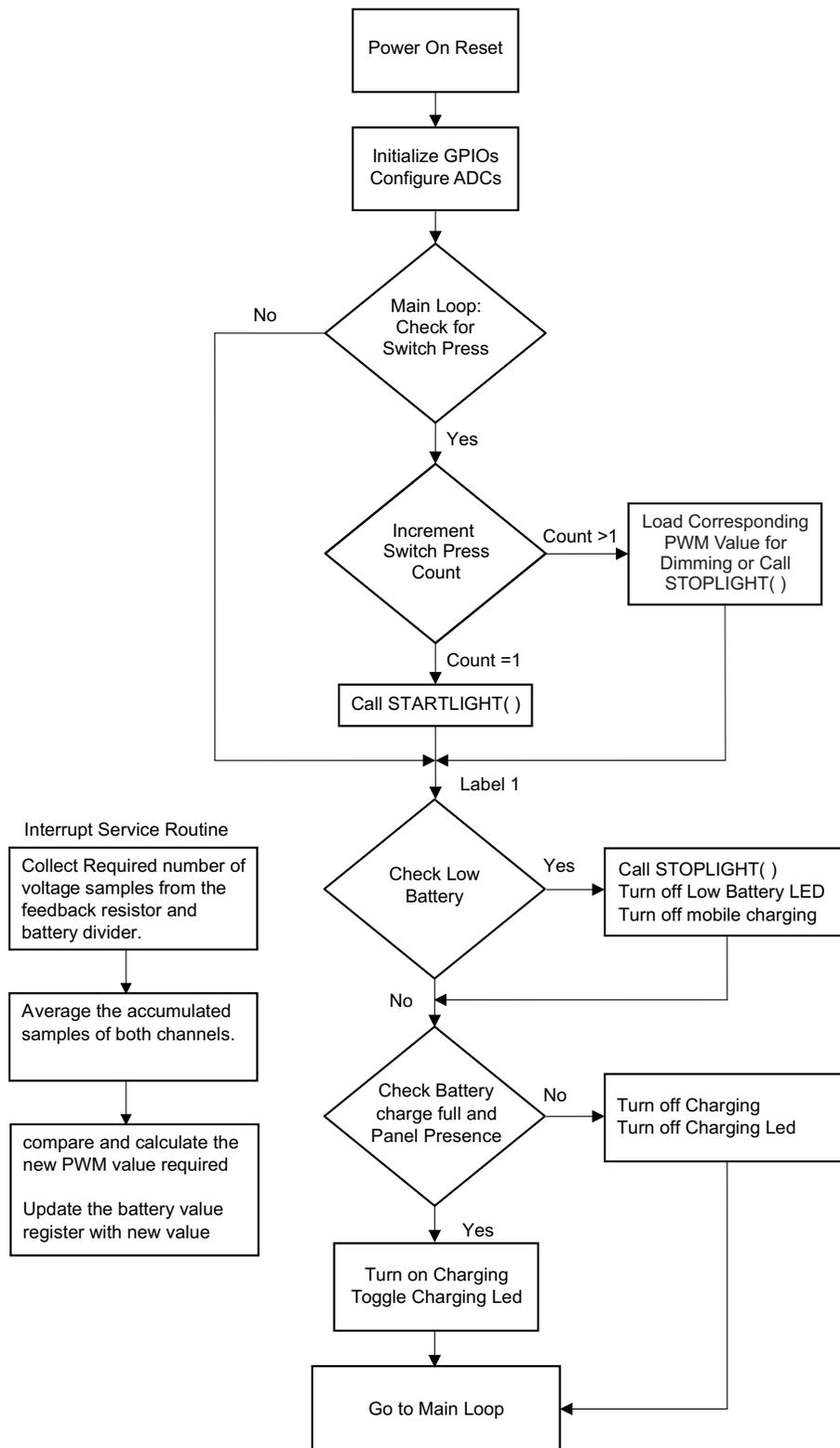


Figure 6. Software Flowchart

6 Theory of Operation

The Lamp design requires constant current boost stage for driving the power LEDs, which is the heart of the entire design. Apart from this, it requires logic for power savings during situations for extending the operating hours. This is achieved by using a fewer number of output dimming stages through a push button switch. Another requirement is the protection for the batteries, which is done through proper and accurate low battery cutoff and an overcharge cutoff facility. Finally, it requires fewer indicators for displaying various information such as low battery cutoff, charging, and so forth. This is implemented in the design using normal LED indicators. One additional feature provided in the design is the mobile charging facility.

6.1 Firmware Execution Architecture

The firmware for this design is not using any real-time operating system (RTOS). It is working based on a foreground-background execution approach. The main loop is always running after the power is applied. In between the execution of the main loop, the ADC interrupt service routine (ISR) is triggered and the execution is transferred to the ISR code. Inside the ISR, the ADC values for "LED Current Sense" and "Battery Voltage" are captured. These values are further moved to corresponding variables and the computation for averaging, and so forth, is performed.

6.2 Constant Current Pulse Width Modulator (PWM)

MSP430 has a built-in dedicated PWM engine for generating PWM pulses, which can be used for driving various circuits. The constant current drive section is built around this PWM facility inside the controller. The external load current information is fed to the controller through the built in 10-bit analog to digital controller module inside the controller. Due to the high resolution of the ADC, the value of the series current sense resistor can be reduced compared to an ADC of 8-bit resolution.

The load current generates a voltage in the resistor mounted in the series with the load. This voltage is fed directly to the ADC pin of the controller. The ADC module is configured to generate an interrupt after each conversion. The controller accumulates the values from each conversion inside the ISR. After collecting enough current samples, the controller averages the value and work increases or decreases the PWM duty cycle accordingly. For example, if the average current read by the controller from the feedback circuit is less than the set value, then the controller tries to increase the current by increasing the duty cycle of the PWM signal within the ADC interrupt service routine. Otherwise, if the current sensed from the feedback is higher than the set value, the controller reduces the PWM duty cycle in order to reduce the output current.

6.3 Discrete PWM Driver Circuit

The PWM signal generated from the MSP430 is in TTL/CMOS logic level. So, it has to be boosted to a higher voltage level for making it suitable for driving the power MOSFET gate. This is implemented using four discrete transistor-based circuits: three are NPN and one is a PNP type transistor.

6.4 Battery Monitoring

The battery voltage is fed to a resistor divider network and the voltage at the divider point is fed directly to the microcontroller ADC pin. The microcontroller captures multiple samples of this voltage and stores the information in the corresponding register for further use of the application.

6.5 Mobile Charging Control Signal

A control signal is provided for controlling customized mobile charging circuit blocks. Using this signal, you can turn on or turn off their mobile charging circuit with respect to main battery voltage levels. You can control the polarity of the signal in the application section by using the predefined macros.

6.6 Push Button Operation

When the push button is pressed for the first time, after the power is applied, the LEDs start glowing. When the push button is pressed again, the output LED light intensity gets reduced. For the next switch press also the LED intensity is further reduced. When the switch is pressed one more time, the LEDs are turned off.

6.7 LED Load Open Detection Mechanism

There is a mechanism in the software to detect the open condition of the output LED strings. After the start button is pressed, this mechanism monitors the output LED strings for any open condition and immediately turns off the output driving stage if any open condition is detected.

6.8 Indicator LEDs

There are two toggling indicator LEDs provided for displaying various status signals: one indicates the battery is charging and one indicates the battery is low. When charging, this LED is steady without toggling when the battery charge is full.

Another LED indicator is for low battery indication. This will be turned on when the battery voltage drops below a specified value.

6.9 Output Wattage Calculation

The output wattage is controlled by the value of the macro `pwm_initial`. Equation 10 can be used for calculating the value for a specified wattage

$$\text{pwm_initial} = \left(\frac{\text{Output Wattage}}{\text{forward led volts} \times \text{number of LEDs}} \right) \times 5.6 / .00244 \quad (10)$$

6.10 Measured Efficiency of the Circuit

As per the measurements taken using a current probe and a digital oscilloscope, the efficiency of the circuit is around 84-86 percentage.

7 Firmware Customization

7.1 Functions Available in the Library

7.1.1 Start Light

By calling the function `startlight()` from the library, the application can turn on the output LED loads with the predefined intensity values.

Variable and definitions related to this function:

- `pwm_initial` (Macro):
 - Defines the initial pwm width for the desired output intensity at first switch press.
 - Defined in the “LED Light Boost Library_Header.h” file

7.1.2 Stop Light

The application can call this function for turning off the output LED load.

Variable and definitions related to this function: Nil.

7.1.3 PROCESS ADC

This function is automatically called by the ADC ISR for processing the current feedback values from the sense resistor for closed loop control. This function also calculates the battery voltage information for further use by the application.

Variable and definitions related to this function: Nil

7.2 **Macros for GPIO Controls**

BATTCHG_H :

This macro turns on the battery charging MOSFET.

Usage example:

BATTCHG_H;

BATTCHG_L:

This macro turns off the battery charging MOSFET.

MOBCHG_H:

This macro turns on the mobile charging section.

MOBCHG_L:

This macro turns off the mobile charging section.

LEDCHG_H:

This macro turns on the charging LED indicator.

LEDCHG_L:

This macro turns off the charging LED indicator.

LBCUT_H:

This macro turns on the low battery LED indicator.

LBCUT_L:

This macro turns off the low battery LED indicator.

7.3 **Programming the Load Current**

The load current is totally controlled by changing the value of a macro defined in “LED Light Boost Library_Header.h” file. The defined macro name is “pwm_initial”. Increasing the value of this macro increases the intensity of the output LED and vice versa.

Macro Name : pwm_initial

Defined in “LED Light Boost Library_Header.h” header file.

7.4 **Changing the Low Battery Cutoff Point**

The macro “BATTERYCUTOFF” controls the low battery cutoff point.

Macro Name : BATTERYCUTOFF

Defined in “LED Light Boost Library_Header.h” header file.

7.5 **Changing the Overcharge Cutoff Point**

The macro “BATTERYCHGCUTOFF” controls the low battery cutoff point.

Macro Name : BATTERYCHGCUTOFF

Defined in “LED Light Boost Library_Header.h” header file.

7.6 **Programming the Dimming Percentages**

There are two steps of dimming possible with this design. The first dimming percentage is defined by the macro “pwm_2” and the second dimming stage is defined by the macro “pwm_3”.

Macro Name : pwm_2 and pwm_3.

Defined in “LED Light Boost Library_Header.h” header file

7.7 Adding More Dimming Stages

It is possible to add any number of dimming stages in the application. Simply define more defines for dimming percentage as in the above [Section 7.6](#). For example, `pwm_4`. After doing this, add the following code after the second else if condition (Line number 72) inside the main loop.

```
else if(onoff==3)
{
    onoff=4;
    pwm=pwm-pwm_4;
    for(I=0;i<50000;i++);
    while(!(P1IN&BIT5));
    for(I=0;i<50000;i++);
}
```

Also take care to increment the status number of the following else if condition by one unit. For example, the existing condition:

“else if(onoff==3)”

should be changed to

“else if(onoff==4)”

7.8 Adding New Features Related to Battery Voltage

The battery information is always available inside the variable “batteryvolt”. The application always use this variable directly inside the conditional checks for adding more features related to battery.

8 Summary

This application report along with the software and hardware files will help to quickly build applications for boost topology solar LED Lamp products. The various functions available in API form and the header definitions for various operating points of the system also helps to quickly introduce additional customization according to various requirements of the customers. The LED Lamp design architecture is using the least number of components for giving additional benefit in terms of bill of material cost and ease of manufacturing. This reference design is easily scalable for higher operating voltage and wattage by incorporating required modification in the hardware design.

9 Reference

- <http://www.ti.com/product/msp430g2231>
- <http://www.ti.com/product/tlv70433>

Appendix A Schematic

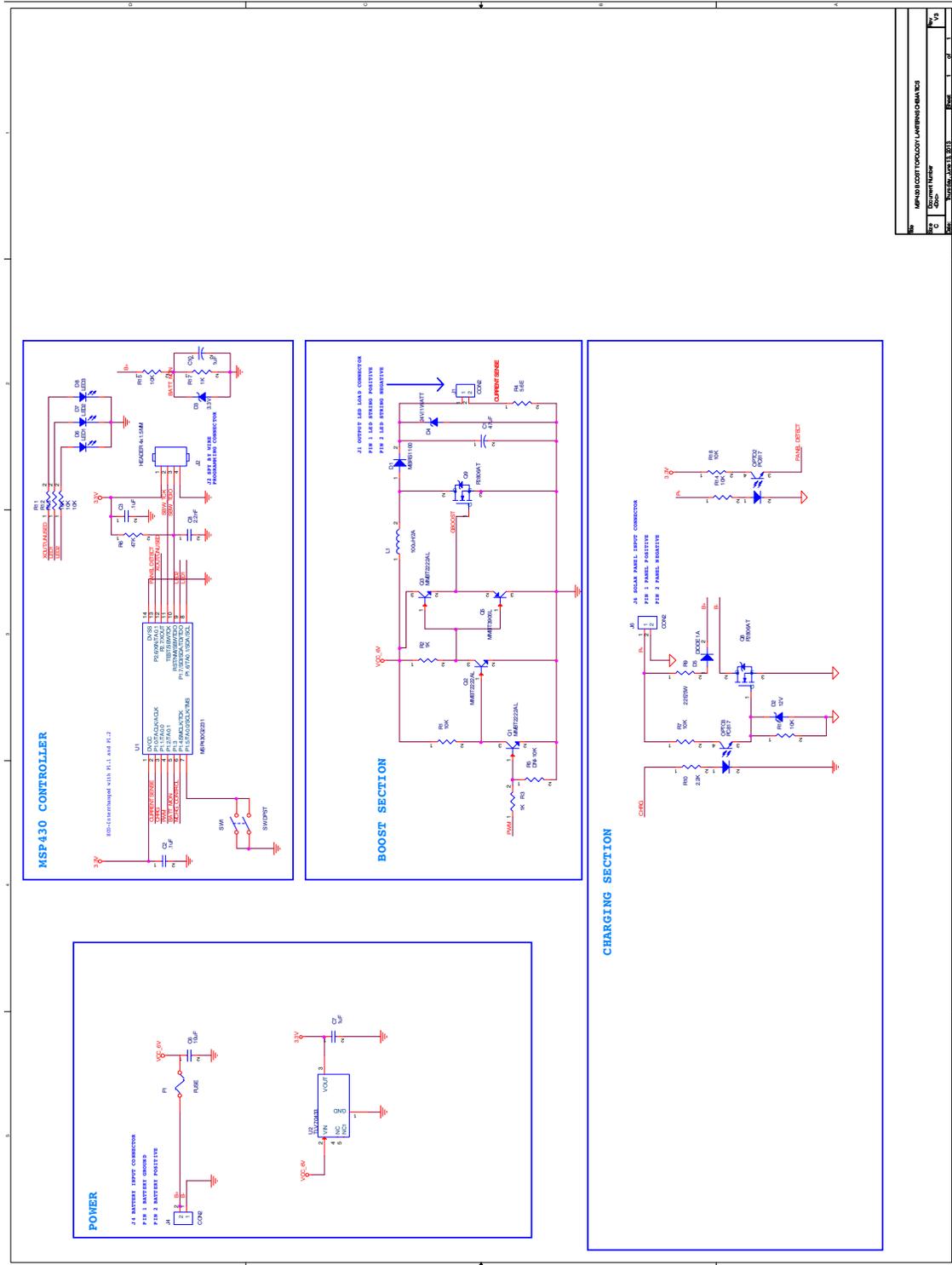


Figure 7. MSP430G2231 Boost Schematic

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