Design Notes for v.1

(a 2x2” board to replace the Chinese board in a 3x3” light)

# Component selection

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We have designed the present board to meet the first requirement: a drop-in warranty replacement board for the Chinese lights currently being advertised as having “four 5W LEDs.” However, it is unlikely that the LEDs in the Chinese board really are 5W LEDs. They seem to be 3W LEDs, for a few reasons:

5W LEDs currently available through US distributors (1) are quite expensive (starting at $4.91 apiece at quantity 2500 at DigiKey) and (2) require higher voltages (around 6 or 7 volts) than the 2.9 volts apiece of the 3W LEDs used in the present design. (3) Known 5W LEDs also are larger (e.g. 5.7mm diameter) than the LEDs in the Chinese board (2mm diameter) and would not fit within the apertures of the reflectors designed for this board.

Philips Luxeon Rebel LEDs were selected for their small size, high lumens per watt, low price, and plentiful availability in quantities sufficient for production runs of 1000 boards. In fact, all components were chosen for their availability; any components with limited distributor inventory were replaced with more-plentiful substitutes. (For production quantity, DigiKey, Mouser, Avnet, and CM’s preferred vendors should be checked for best prices.)

Automotive compliant (AEQ rated) components were selected whenever possible. And, as a voltage reference, the 5.6V Zener diode was selected for its relatively good temperature stability versus Zener diodes of higher and lower voltages.

References:

<http://www.digikey.com/product-search/en/optoelectronics/led-lighting-white/525606?stock=1>

<http://www.aecouncil.com/AECDocuments.html>

# Schematic

The present design, v.1, is a derivative of PicoBuck, which was designed by Ethan Zonca. Specifically, it follows two of PicoBuck’s three parallel buck driver circuits.

Each of the two parallel buck drivers drives a series of two 3-watt (2.9 volt) LEDs with a nominal 680mA current. This level of current approximates the current at which the LEDs’ manufacturer measured their performance. Optionally, switching the values of resistors R1A and R1B to 0.10 Ohm would result in the LEDs being driven with current of up to 972mA (43% greater) and emitting brighter light, *subject to thermal foldback*. Since the thermal foldback feature (see below) limits average current in order to keep temperature below 85 degrees Celsius, the higher-valued resistors may or may not increase brightness.

In addition, a subcircuit on the input improves electromagnetic compatibility in the automotive environment.

The schematic was developed in Cadsoft Eagle. It (with extension .sch) and the board layout (with extension .brd) were last edited with version 7.2 (freeware edition) and are stored in the folder “Eagle CAD source files.”

# Simulation

Simulation was done in Zetex Circuit Simulator, which is available free of charge as a download from Diodes Inc, maker of the driver chip used in this design. The simulation file is stored as “v.1.sxsch.” Dimmer circuit calculations were done in a Google Sheets spreadsheet called “Dimmer circuit calculations.” Both are stored in the folder “Simulations and Spreadsheets” in the project’s Google Drive folder.

# Layout

The printed circuit board (PCB) was laid out almost entirely in large planes (broad rectangular areas), rather than in thin traces, to minimize inductance and interference with nearby electronic devices. To minimize inductive loops:

* C1 was placed very close to the driver’s Vin pin
* R1 was placed very close to the driver’s pins Vin and SET
* D1’s anode and the inductor were placed very close to the driver’s SW pin

The broad planes also prove durable, resist tearing, during rework. However, the pads are without thermal relief. (For this reason, oven reflow is recommended.)

The board has holes in the same pattern as in the original board, but the center hole has been enlarged (as per the drawing provided by Company) to match the size of the other two.

# Thermal considerations

To dissipate heat efficiently, to maximize the life of LEDs and other components on the board, the Philips Luxeon Rebel datasheet was followed. This specified the number, size, and placement of plated through-holes (copper-lined holes connecting board’s top and bottom layers), as thermal vias, around each LED. These thermal vias conduct heat into the ground plane, the bottom layer of the board. This is bare metal (not covered by an insulating solder mask) and interfaces via a thermally conductive pad (made from Bergquist’s Sil-Pad K-4 material) to the heatsink/case of the light fixture. The datasheet also specified 1-ounce copper and 0.8mm FR-4 as the board material. This material, half the most common PCB thickness, offers less thermal resistance than the typical 1.6mm PCB. This board thickness, and the 12 mil minimum drill size, are not available at all board houses (PCB fabricators).

The board’s copper is coated in ENIG (electroless nickel immersion gold) to maximize thermal conductivity.

The thermal pad is optional, but in an automotive environment it is recommended. It is intended to prevent the gradual wearing off of the thin gold coating (ENIG) of the board’s bottom layer, due to friction against the heatsink/housing.

# Dimming

Dimming is via an external potentiometer, which shall be connected via a twisted wire pair exiting the assembly via the same cable that includes the power and ground pair. At full counter-clockwise rotation, the potentiometer’s resistance should be near zero and should result in lights being very dim or turning off. Turned full clockwise, its resistance should be around 500kOhms (+/- 20%; each of the two samples encountered during prototyping measured 400kOhms) and should result in the lights reaching maximum brightness.

The mounting of the external potentiometer is TBD but could include mounting through a hole in an existing panel of the vehicle or in a small enclosure which mounts flush to some surface of the vehicle’s cab.

# Thermal Foldback

Additional dimming to prevent overheating of the LEDs is achieved through the use of a negative temperature coefficient thermistor placed near the bottom right LED. As LEDs heat up slightly, so will this thermistor, whose resistance decreases, which reduces the voltage at the drivers’ CTRL pins, which reduces the current through the LEDs, which cools them slightly. The circuit was calibrated to let the thermistor stay just shy of 85 degrees Celsius, the temperature at which the LEDs’ performance was measured and specified.

# EMC: electromagnetic compatibility

The board was designed to reduce electromagnetic emissions (make it act less like a radio transmitter) and to resist damage from it and other components being connected or disconnected, or from transient spikes in voltage. Toward this end, the following references were consulted and synthesized:

“AL8805 MR16 EMC guide” downloaded from:

<http://www.digikey.com/videos/en/v/AL8805-MR16-EMC-guide/2195801950001>

“AN57: Automotive EMC considerations for switching regulator LED lighting applications using ZXLD1362” downloaded from:

<http://www.diodes.com/_files/products_appnote_pdfs/zetex/an57.pdf>

“AL8805 Calculator” downloaded from:

<http://www.diodes.com/calculators.html>

“Design an L-C Low pass or High pass Filter (V 1.1 May 18, 2008)” at:

<http://www.wa4dsy.net/filter/hp_lp_filter.html>

## AN57 provided an example for the input subcircuit, which includes a load dump and battery reverse protection and an input “Pi” filter tuned to prevent the switching frequency of the drivers from being injected into the power supply. The switching frequency was calculated by the AL8805 Calculator, an Excel spreadsheet provided by Diodes Inc.. Together, these circuit elements protect the board and surrounding electronics from conducted electromagnetic emissions and from other events that can occur the automotive environment and could damage circuits.

# PCB fabrication

Given the particularly small minimum drill size and the 0.8mm FR-4 material, not all board houses can produce this design. To find a suitable US-based board house, the document “Light bar fab notes.pdf” should be sent with any request for quotation. This will enable the board house to determine whether they can meet the requirements. (Note: The Contract Manufacturer [CM] retained to assemble the board could select the board house to produce the PCBs.)

# PCB assembly

Assembly considerations include vibration resistance, European regulatory compliance (TBD) and cable (TBD).

The inductor L1 should be epoxied to the board for vibration resistance. So too, whoever attaches the cable should epoxy the ends of each wire near their solder joints to the board.

The board should be assembled with lead-free solder if (TBD, depending on the cost of this option) Company decides product is to meet European requirements after January 1, 2016. After that date, the European “ELV” (End of Life Vehicle) exemption 8a, permitting leaded solder, may expire.

If lead-free solder is used, the board should be conformally coated with 2-mil “Arathane” (urethane) to prevent the growth of tin “whiskers.” This has been reported to work for 11 years, at least.

An approximately one-foot length of cable should be cut, stripped, tinned, and soldered to (four pads on) each board, either by the board assembler or in-house (TBD, depending on cost). This cable is specified in the document “Cable Specification” in the folder “Specifications for board fab and assembly.”

# Mechanical assembly

This shall be done in-house. As in the Chinese original,

1. A water resistant grommet providing strain relief should fit snugly around the cable where it exits the assembly.
2. Silicone should be used to fill and seal the hole around the cable on the board side.

# Future design for increased brightness

One engineer described the present housing and heatsink as “overbuilt” for the circuit board and LEDs it contains, and given summer warehouse temperature measurements, likely the housing really can dissipate 20W or more.

For a future design with 5W (or greater) LEDs, to create the higher voltage required, one would replace the two “buck” drivers with a single “buck-boost” driver. A buck-boost design can drive a series of LEDs whose total voltage exceeds that of the input power supply. Thus from, for example, a 12V supply, even with 10% loss, resulting in 10.8V available, one could drive LED series totalling 12V, 20V, or even more.

This might require substituting the reflector assembly also, for reflectors with a larger aperture. A hack during prototyping might be to drill out the apertures in the current reflectors.