INNOVATION WITH PURPOSE

AN EFFICIENT VOLTAGE-OPTIMIZED LED DRIVER (A80804) WITH BUCK-BOOST CONTROLLER (A4450)

By Shashank Wekhande, Vashist Bist, and Sarang Gadgil, Application Engineers
Allegro MicroSystems

INTRODUCTION

A linear LED driver dissipates substantial power to dynamically maintain a voltage drop equal to the difference between its input and output voltages. To limit the impact on system thermal management, linear devices are typically implemented only in lower-current applications. A more-efficient approach consists of adding a switching preregulator to efficiently reduce the voltage to levels closer to the requirements of LED strings. However, variation in LED forward voltage drop and active switching of series-connected LEDs require the output voltage of such a preregulator to be designed for the worst-case scenario, which limits the efficiency at lower LED voltage.

This application note presents the implementation of an adaptive preregulator whose output voltage is dynamically adjusted to provide optimal voltage to a linear LED driver. The proposed buck-boost regulator module (Allegro MicroSystems A4450 [1]) supplies the linear LED driver (Allegro MicroSystems A80804 [2]). The LED driver accomplishes two distinct functions simultaneously: regulating current in each LED string and trimming the output voltage of the preregulator to the minimum required to maintain regulation across all LED strings. This active trim scheme is implemented through the MINOUT feature of the A80804. The MINOUT voltage is combined with the preregulator feedback network to dynamically control the voltage to the LED strings at the lowest operational level, as determined by the configuration of the LED strings.

At higher temperature levels, when the IC is in thermal foldback, current through the LEDs is reduced. This results in lower forward voltage (V_F) of the LEDs and increased voltage drop across the MOSFETs. With MINOUT feedback, the IC corrects the voltage drop across the MOSFETs to the optimal level by adjusting the voltage of the preregulator. This leads to an extended operational temperature range. The MINOUT pin provides feedback to the preregulator, which allows for optimal voltage control of the A80804. The connection of the MINOUT pin is shown in Figure 1.

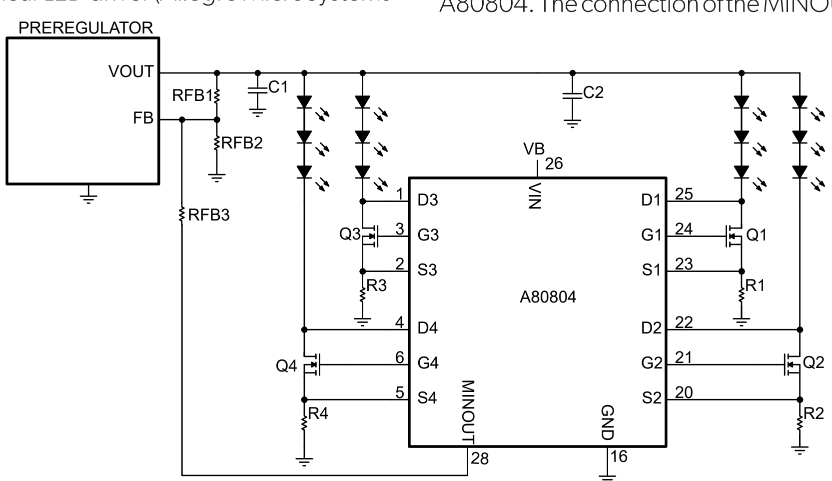


Figure 1: Connection of MINOUT pin to the preregulator.

[1] https://www.allegromicro.com/en/products/regulate/regulators/single-output-regulators/a4450
[2] https://www.allegromicro.com/en/products/regulate/led-drivers/led-drivers-for-lighting/a80804

DEVICE INTRODUCTION

A80804 LED Driver

The A80804 is a linear, programmable current controller capable of accurately regulating current in four LED strings using external MOSFETs; each of the four LED strings offers a dedicated enable/pulse-width modulation (PWM) input and current-sense resistor. Each channel can be independently dimmed with an external PWM signal, or all channels can be dimmed through internal PWM and automatic phase shifting. The string current can be switched between low and full intensity for applications including stop/tail or daytime running lighting (DRL)/position lighting. Multiple analog dimming options are available to support applications including LED binning, negative temperature coefficient (NTC) foldback, or a hybrid approach. A selectable LED current slew-rate control is available to tune PWM edge times and improve electromagnetic interference (EMI) performance.

The A80804 offers several fault detection and protection capabilities required for automotive applications. The A80804 can be configured for either one-out-all-out or N-1 operation.

A4450 Buck-Boost Controller

The A4450 is a power management IC that can control either a buck or a buck-boost topology to efficiently convert automotive battery voltages into a tightly regulated voltage. It offers many useful features for automotive applications, including:

- An enable input compatible with battery voltage levels.
- A diagnostic power-on-reset output (NPOR) signal.
- Several protection features that include pulse-by-pulse current limit, hiccup mode short-circuit protection, switch node short-circuit protection, missing freewheeling diode protection, and thermal shutdown.

The A4450 is most suitable for applications where the input voltage can vary below and above the regulated output voltage.

SYSTEM SPECIFICATION

The proposed system is shown in Figure 1. To understand the principles of operation, it is important to notice that the voltage on the DX and DY pins is the difference between the preregulator output voltage and the LED string forward voltage drop. The A80804 requires a minimum of 0.5 V on each of these pins to maintain regulation. Any additional voltage on these pins translates to additional power losses.

The input voltage specifications of the system are:

- Nominal input voltage (V_{in_nom}) = 12 to 15 V
- Minimum input voltage (V_{in_min}) = 8 V
- Maximum input voltage (V_{in_max}) = 18 V

Key buck-boost regulator specifications are:

- Operating frequency (f_{SW}) = 400 kHz
- Output capacitor (C_{out}) = 33 μF
- Regulator feedback voltage (V_{fb}) = 800 mV

Key LED specifications are:

- LED typical forward voltage (V_{f_typ}) = 3.1 V
- LED maximum V_F (V_{f_max}) = 3.3 V
- LED minimum V_F (V_{f_min}) = 2.8 V

The MINOUT pin provides an output voltage proportional to the minimum voltage of the Dx pins for all active channels, as shown in Figure 2.

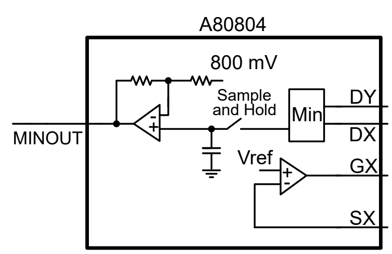


Figure 2: Block diagram of MINOUT block.

The voltage from MINOUT is combined with the voltage regulator FB pin to create a closed-loop system and trim its regulated output. The voltage on MINOUT is calculated as:

$$V_{MINOUT} = 10 \times (V_{DX\_MIN} - 0.8) + 3,$$

and therefore ranges between 0.3 V and 3.5 V.

If the regulating string voltage changes for any reason, MINOUT voltage changes as well and provides proper feedback signal to the preregulator to adjust the output voltage to the optimal level.

The calculation for the selection of the bias resistors needed for the implementation of the MINOUT feature is discussed next.

MINOUT Resistor Calculation

System specifications pertaining to the margins required in the calculation of the minimum and maximum output voltage for the implementation shown in Figure 1 are:

- Regulation voltage drop on sense resistor (V_{sense}) = 500 mV
- MOSFET voltage drop (V_{mos}) = 200 mV
- Maximum margin for transient and regulator tolerance ($V_{margin,max}$) = 0.7 V
- Minimum margin for transient and regulator tolerance ($V_{margin,min}$) = 0.3 V

Based on the above specifications, the maximum and minimum output voltage can be calculated as:

Equation 1—Maximum output voltage (V_{out_max}):

$$V_{out\_max} = 4 \times Vf_{max} + V_{sense} + V_{mos} + V_{margin,max}$$
$$V_{out\_max} = 4 \times 3.3 + 0.5 + 0.2 + 0.7 = 14.6\,V$$

Equation 2—Minimum output voltage (V_{out_min}):

$$V_{out\_min} = 4 \times Vf_{min} + V_{sense} + V_{mos} + V_{margin,min}$$
$$V_{out\_max} = 4 \times 2.8 + 0.5 + 0.2 + 0.3 = 12.6\,V$$

Now, the resistors connected on the MINOUT pin, as shown in Figure 1, can be calculated by:

- Selecting R_{fb2} = 10 kΩ
- Calculating R_{fb1} and R_{fb3} using:

$$R_{fb3} = \left(\frac{V_{MINOUT(\max)} \times (V_{OUT(max)} - V_{FB})}{V_{FB} \times (V_{OUT(max)} - V_{OUT(min)})} - 1\right) \times R_{Fl}$$

$$R_{fb1} = \left(\frac{V_{OUT(max)} - V_{FB}}{V_{FB}}\right) \times \left(\frac{R_{fb2} \times R_{fb3}}{R_{fb2} + R_{fb3}}\right)$$

- Maximum MINOUT voltage (V_{minout_max}) = 3.5 V
- Using above formulas, the value of R_{fb3} and R_{fb1} are calculated as:
  - □ R_{fb3} = 291.8 kΩ (selected value as 294 kΩ)
  - □ R_{fb1} = 166.75 kΩ (selected value as 165 kΩ)

TEST RESULTS

This section presents the steady-state, transient, and stability performance of the overall system.

Steady-State Performance

The operation of the LED driver is shown in Figure 3 and Figure 4, respectively without and with the MINOUT feature, at supply voltages of 8 V, 12 V, and 18 V.

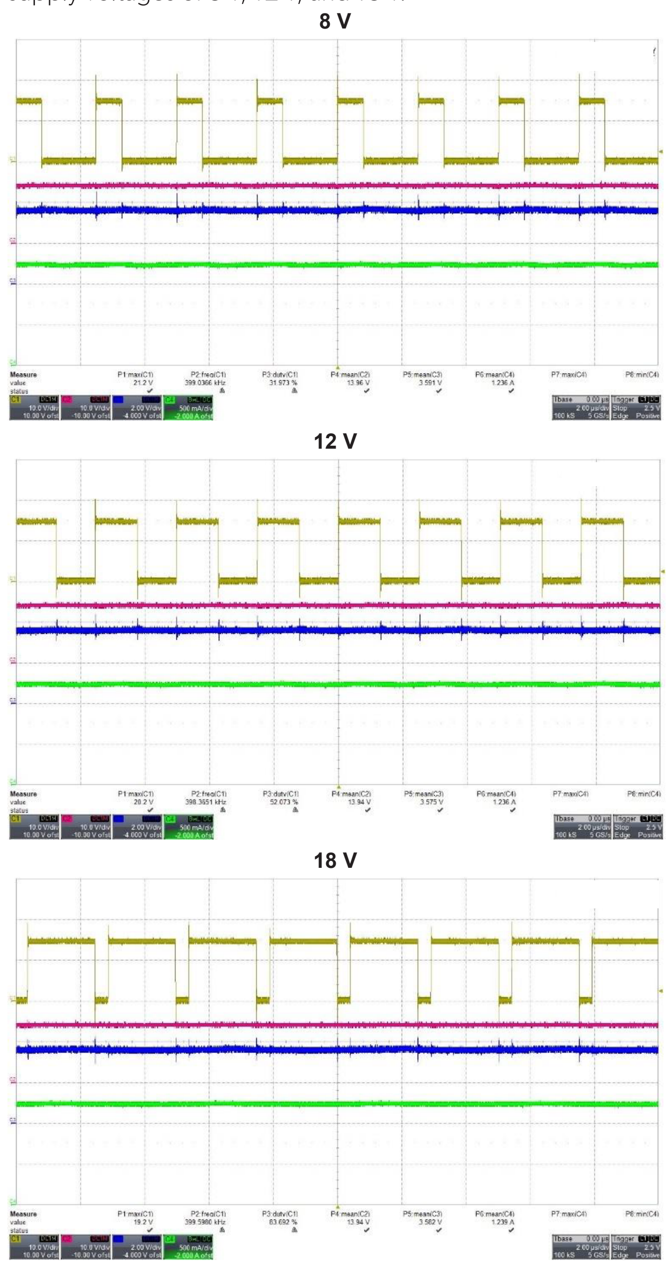


Figure 3: Steady-state waveforms without MINOUT feature at an input voltage of 8 V (top), 12 V (center), and 18 V (bottom). Ch-1: SW node (yellow); Ch-2: V_{out} (pink); Ch-3: MINOUT (blue); and Ch-4: Total LED current (green).

As shown in Figure 3, the typical output voltage of the preregulator is 13.94 V with an LED current of 1.237 A without enabling the MINOUT feature. However, when MINOUT is enabled, the output voltage of the preregulator drops to a typical value of 13.2 V supplying the same LED current, as shown in Figure 4.

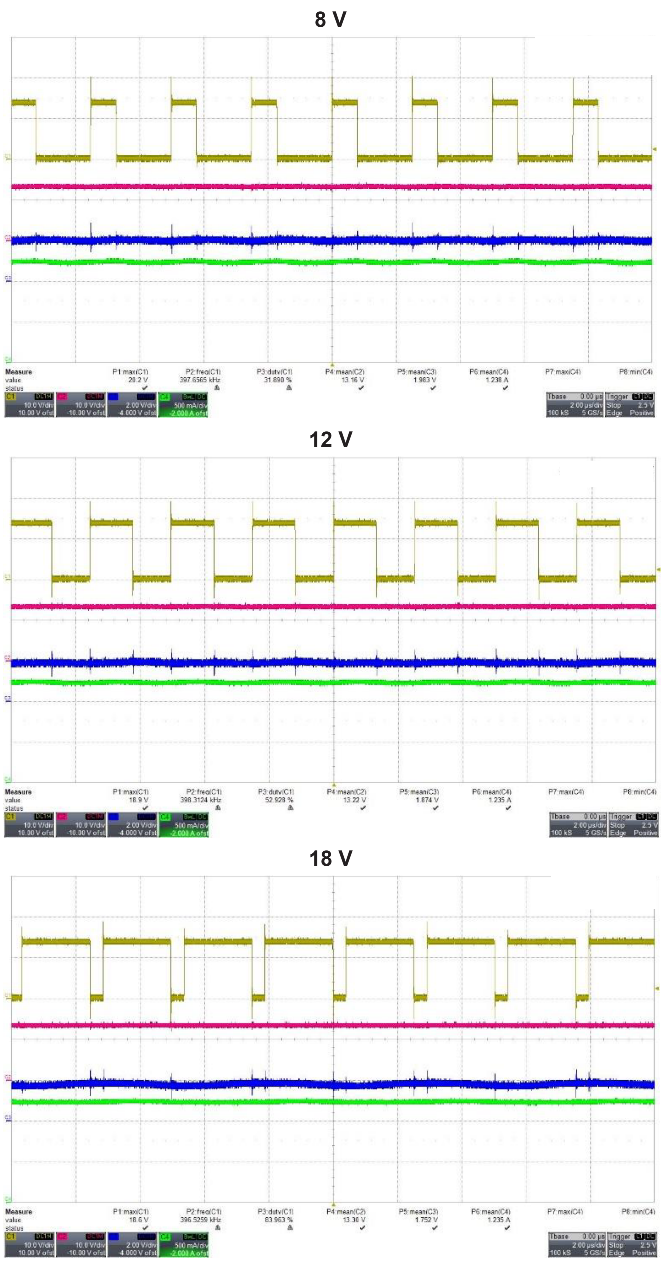


Figure 4: Steady-state waveforms with MINOUT feature at an input voltage of 8 V (top), 12 V (center), and 18 V (bottom). Ch-1: SW node (yellow); Ch-2: V_{out} (pink); Ch-3: MINOUT (blue); and Ch-4: Total LED current (green).

Power Efficiency

The steady-state performance of the A80804 driver fed with the A4450 preregulator without and with the MINOUT feature is shown in Table 1.

The efficiency vs. input voltage of the system without and with MINOUT is shown in Figure 5. As shown in the figure, the system implemented with the MINOUT feature is more efficient than the system implemented without the MINOUT feature.

The LED current variation vs. input voltage of the system without and with the MINOUT feature is shown in Figure 6. As shown in the figure, the LED current is almost constant for the operation of the driver in both modes of operation.

Table 1: Steady-State Performance Without MINOUT

Vin (V)	Iin (A)	Pin (W)	Vout (V)	Iout (A)	Pout (W)	Efficiency (%)
Without MINOUT						
8	3.12	24.96	13.96	1.236	17.255	69.13
12	2.01	24.17	13.94	1.236	17.23	71.29
18	1.33	23.86	13.94	1.239	17.272	72.39
With MINOUT						
8	2.61	20.88	13.16	1.238	16.292	78.03
12	1.66	19.9	13.22	1.235	16.327	82.05
18	1.09	19.54	13.3	1.235	16.426	84.06

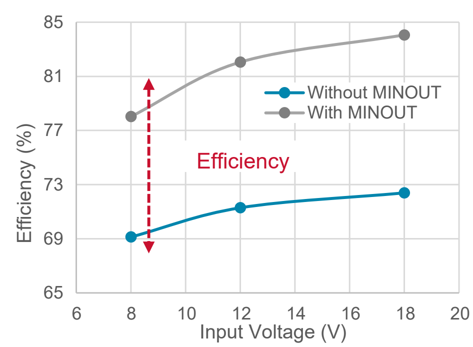


Figure 5: Efficiency vs. supply voltage without and with MINOUT.

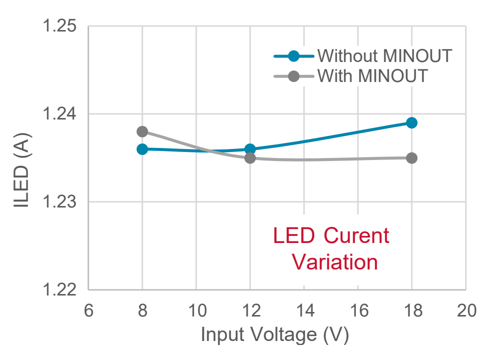


Figure 6: LED current vs. supply voltage without and with MINOUT.

Thermals

Thermal images of the A80804 board are shown in Figure 7 without (left) and with (right) implementation of the MINOUT feature. As shown in these figures, better thermal performance is achieved with the MINOUT feature.

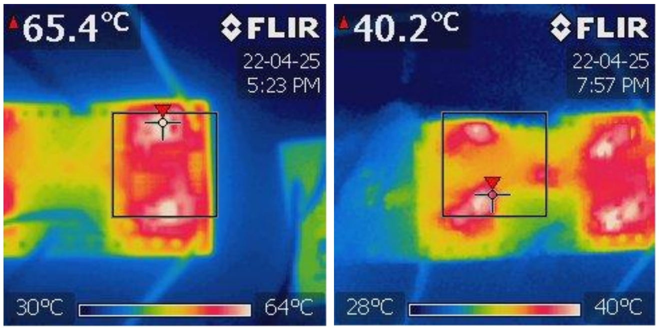


Figure 7: Thermal images (maximum temperature) of A80804 without (left) and with (right) MINOUT.

Stability

Bode plots depicting sufficient gain and phase margins are shown in Figure 8 for implementation without (top) and with (bottom) the MINOUT feature. The stability of the overall system is primarily set by preregulator compensation loop and is not affected by the LED driver. The MINOUT function is quite slow and does not impact the overall frequency response.

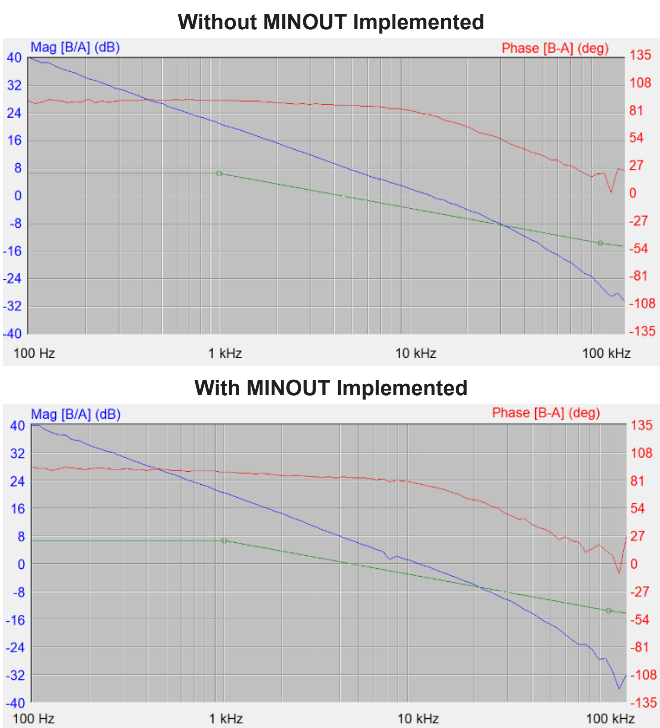


Figure 8: Bode plot of overall system without (top) and with (bottom) implementation of the MINOUT feature.

Load Voltage Transients (Tail/Stop or DRL/POS)

In tail/stop or DRL/POS applications, the number of LEDs in a string are intentionally switched, resulting in different optimal output voltages. The MINOUT function automatically adjusts the output voltage of the preregulator to the new optimal level.

Performance is shown in Figure 9 when the number of LEDs in a string is switched from three LEDs to two LEDs, then back to three. LED current is set to 300 mA per channel. When the string transitions from three LEDs to two LEDs, the output voltage of the preregulator drops slowly without causing any disturbance in LED current.

When a third LED is added to the string of two, the MINOUT feature gradually increases the output voltage. During the transition from two LEDs to three LEDs, the slow response of the MINOUT feature—which gradually increases the output voltage of the A4450 buck-boost converter—causes a current dip.

Figure 9: Switching the number of LEDs in series from three to two, then back to three (top); and zoomed waveform for the current dip during two- to three-LED operation (bottom). Ch-1: V_{out} (yellow); Ch-4: Total LED current (green).

APPLICATION SIMPLIFIED SCHEMATICS

The application schematic of the LED driver with the front-end A4450 and the A80804 LED controller is shown in Figure 10. The developed two-layer board without components is shown in Figure 11. Overall board dimensions are 147 mm × 53 mm.

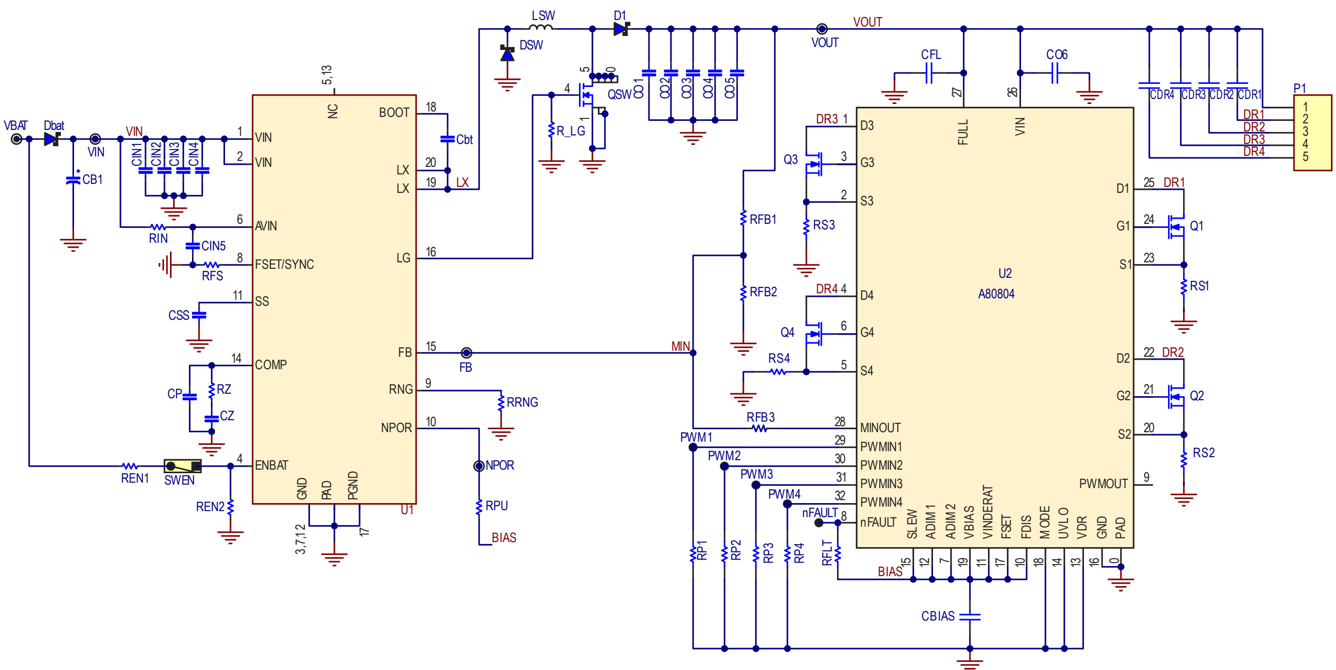


Figure 10: Application schematic of the A4450- and A80804-integrated LED driver.

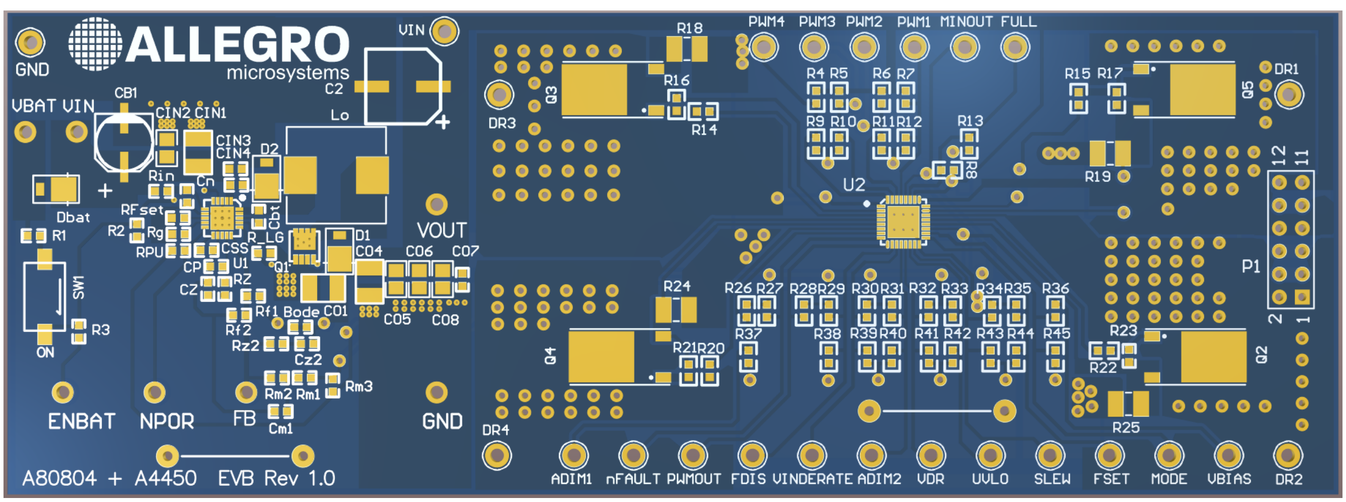
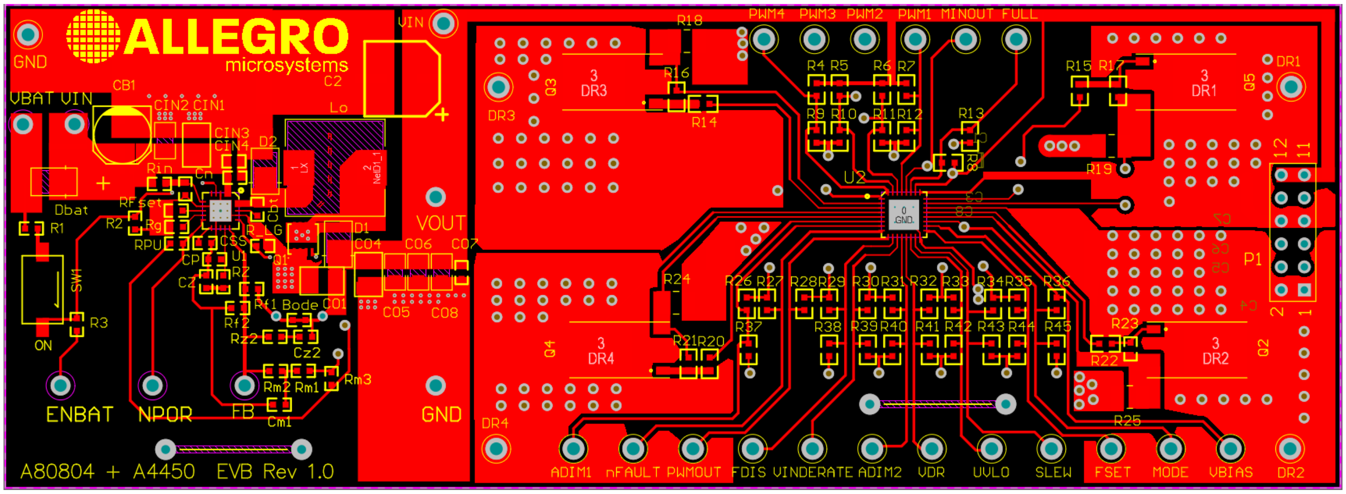


Figure 11: Developed board of the A4450- and A80804-integrated LED driver.

LAYOUT

The layout (top layer and bottom layer) of the LED driver developed with the front-end A4450 and the A80804 LED controller is shown in Figure 12.

Top Layer



Bottom Layer

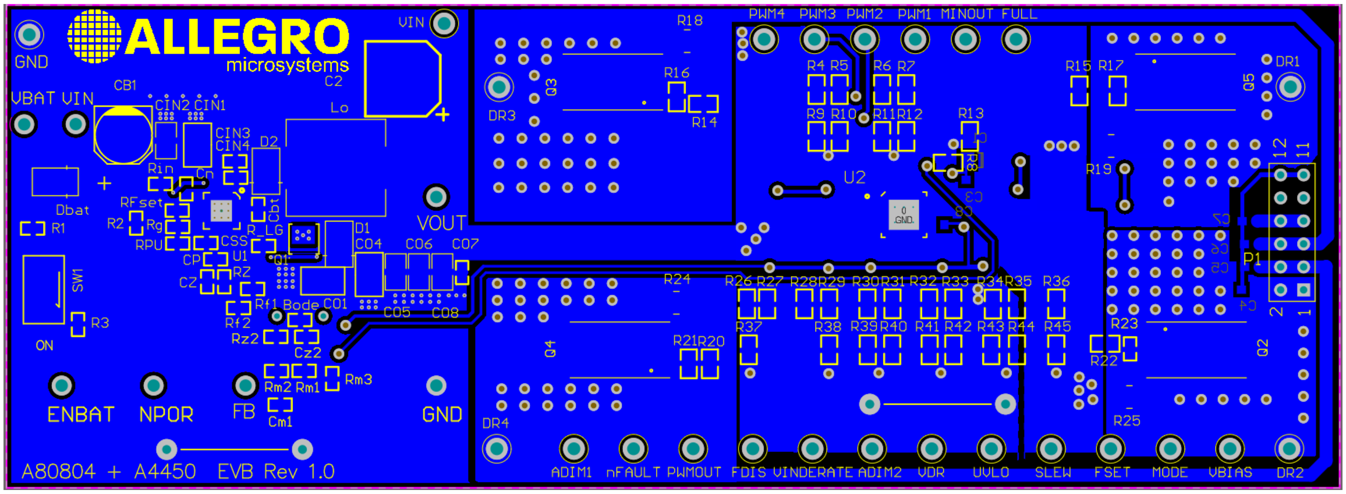


Figure 12: Layout of the A4450- and A80804-integrated LED driver showing the top layer (top) and bottom layer (bottom) layouts.

BILL OF MATERIALS

The bill of materials for the LED driver developed with the front-end A4450 and the A80804 LED controller is shown in Table 2.

Table 2: Bill of Materials for LED Driver Using A4450 and A80804 Devices

Designator	Value	Description	Footprint	Quantity
CB1	47 µF, 35 V	Electrolytic Capacitor	Cap-TH 6.3mm	1
CIN1, CO1	4.7 µF, 35 V	Capacitor	1210	2
CIN2	0.22 µF, 35 V	Capacitor	0805	1
CIN3	100 nF, 35 V	Capacitor	0603	1
CIN4	100 pF, 35 V	Capacitor	0603	1
CIN5	1.0 µF, 35 V	Capacitor	0603	1
CDR1, CDR2, CDR3, CDR4	0.1 µF, 35 V	Capacitor	0603	4
CBIAS	2.2 µF, 16 V	Capacitor	0603	1
Cbt	47 nF, 35 V	Capacitor	0603	1
Cfl	33 µF, 35 V	Capacitor	0603	1
CO2	10 µF, 35 V	Capacitor	0805	1
CO3	0.22 µF, 35 V	Capacitor	0805	1
CO4	10 nF, 35 V	Capacitor	0603	1
CO5	0.1 µF, 35 V	Capacitor	0805	1
CO6	0.1 µF, 35 V	Capacitor	1210	1
CP	33 pF, 35 V	Capacitor	0603	1
CSS	22 nF, 35 V	Capacitor	0603	1
CZ	2200 pF, 35 V	Capacitor	0603	1
D1, DSW	SS3P4	Diode	SMP	2
Dbat	4 A, 35 V	Diode	SMA	1
LSW	4.7 µH, 4 Asat	Inductor	Inductor 4040	1
P1	MHDR1X5	Header, 5-Pin	MHDR1X5	1
Q1, Q2, Q3, Q4	3 A, 35 V	N-Channel MOSFET	DPAK123	4
QSW	PQFN	eSOIC8 Package FET	eSOIC8	1
REN1, RFLT, RLG, RP1, RP2, RP3, RP4, RPU	10 kΩ	Resistor	0603	8
REN2	4.99 MΩ	Resistor	0603	1
RFB1	24.9 kΩ	Resistor	0603	1
RFB2	4.75 kΩ	Resistor	0603	1
RFB3	165 kΩ	Resistor	0603	1
RFS	23.7 kΩ	Resistor	0603	1
Rin	5E	Resistor	0603	1
RRNG	22.1 kΩ	Resistor	0603	1
RS1, RS2, RS3, RS4	1.68E	Resistor	1210	4
RZ	10.7 kΩ	Resistor	0603	1
SWEN	OFF	SW, SPST	SW DIP 1POS	1
U1	A4450	4×4 QFN-20 (ES)	4×4 QFN	1
U2	A80804	5×5 QFN-32 (ET)	5×5 QFN	1

PIN CONFIGURATION

A4450

- ENBAT: Connected to VIN to enable device.
- FSET: Connected to GND via resistor for 400 kHz switching frequency.
- RNG: Connected to GND via resistor for preferred 0.65 buck duty cycle at the instant the boost switch starts to switch.

A80804

- SLEW: Connected to VBIAS for 80 µs slew time.
- ADIM1, ADIM2: Connected to VBIAS to disable analog dimming.
- VINDERATE: Connected to VBIAS to disable input voltage derating. When the VIN pin is connected to the input battery supply and the LEDs are connected to a different voltage supply, VINDERATE will not work.
- FSET: Driver works in full mode, so PWM mode is disregarded.
- FDIS: Disable FDIS by connecting to VBIAS.
- MODE: Connect to low for N-1 fault operation.
- UVLO: Disable UVLO by connecting to GND.
- VDR: Sets PWM duty in internal PWM mode. Because the driver is configured in full mode, the VDR pin voltage is not relevant.

CONCLUSION

The MINOUT feature of the Allegro A80804 linear LED driver allows control of a switching DC-DC converter to provide optimal output voltage to drive a string or multiple strings of LEDs. This minimizes power dissipation in the linear current sinks of the LED driver, resulting in a substantial increase in system efficiency. This efficiency has multiple benefits, including reduced heating of the application board and ICs, and is a welcome improvement in many applications, particularly those that involve high-temperature environments and those that rely on limited power sources, such as batteries.

Revision History

Number	Date	Description	Responsibility
–	June 27, 2023	Initial release	S. Wekhande, V. Bist, and S. Gadgi