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AN EFFICIENT VOLTAGE OPTIMIZED LED DRIVER (A80804) WITH SYNCHRONOUS BUCK PRE-REGULATOR MODULE (APM81911)

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INTRODUCTION

Linear LED drivers dissipate significant power proportional to difference in input and output voltage. Due to such excessive power dissipation, linear LED drivers are used at lower currents and need bigger power packages and larger PCB size, or heat sinks to maintain the temperature within desired specification. For solving such issues, a pre-regulator is generally used to feed linear drivers which efficiently reduce output voltage to lower levels for better power efficiency, and eventually better thermal performance. However, due to variation in LED forward voltage tolerance and active switching of series connected LEDs, the output voltage of the pre-regulator needs to be designed for the highest voltage, which results in significant power loss at lower LED voltage.

This application note presents the implementation of adaptive pre-regulator where output voltage is dynamically adjusted to provide optimum voltage to the LED driver. The front-end buck regulator module (APM81911) provides supply voltage to the linear LED controller (A80804) which controls the LED current. To achieve better efficiency, the LED controller (A80804) controls the output voltage of the pre-regulator to minimum voltage required for LED regulation. This is implemented with the MINOUT pin in the A80804, which provides an output voltage proportional to the minimum voltage of the drain pins of all the active channels. The voltage from MINOUT can be fed to a voltage regulator's feedback pin to complete the closed-loop system and trim the regulated output voltage fed to the LEDs.

Figure 1 shows the connection of the MINOUT pin of the A80804 which provides feedback to the pre-regulator for optimal voltage control.
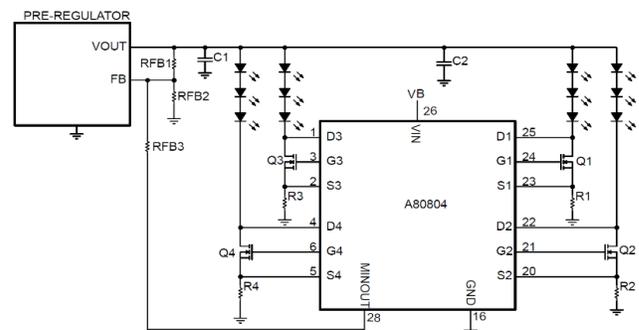

Figure 1: Connection of MINOUT Pin to the Pre-Regulator

DEVICE OVERVIEW

This section presents the overview of the APM81911 and A80804 device.

A80804 LED Driver

The A80804 is linear, programmable current controller capable of accurately regulating current in four LED strings using external MOSFETs. Each of the four LED drivers has an independent enable/PWM input and current-sense resistors. Each channel can be independently dimmed with an external PWM signal, or all channels can be dimmed with internal PWM dimming and automatic phase shifting. The overall LED current can be switched between low and full intensity for applications including stop/tail or DRL/position lighting.

Multiple analog-dimming options are available to support applications including LED binning, NTC foldback, or hybrid dimming. A selectable LED current slew-rate control is available to tune PWM edge times and improve EMI performance. The A80804 also offers several fault detection and protection

required for Automotive applications. The A80804 can be configured for either one-out-all-out or N-1 operation.

APM81911 Buck Module

The APM81911 is a highly integrated synchronous DC-DC regulator module rated for 3 A. It includes a DC-DC regulator, low DCR inductor and two capacitors in a compact 4 mm × 6 mm × 2 mm package. The APM81911 offers scalable output with ±1.5% output voltage accuracy over the full operating temperature.

Fixed frequency, peak current mode ensures rapid response to load and line transients. Spread spectrum operation is used for lower EMI/EMC. The APM81911 can be synchronized to an external clock.

Low power (LP) mode maintains the output voltage at no load or very light load conditions while drawing < 6 uA. The APM81911 automatically transitions to PWM and LP modes depending on load current.

The APM81911 includes adjustable soft start and an open-drain power good output; the module additionally includes accurate enable input programmable turn-on and turn-off thresholds, and a low shutdown current of 1 uA.

SYSTEM SPECIFICATION

This section shows the key system specifications and the calculation of bias resistors for implementation of the MINOUT feature.

The input voltage specification of the system, key buck regulator specifications, and LED specifications are given below:

- □ Nominal Input Voltage ($V_{IN,NOM}$) = 12 V
- □ Minimum Input Voltage ($V_{IN,MIN}$) = 8 V
- □ Maximum Input Voltage ($V_{IN,MAX}$) = 18 V

The Key Buck Regulator Specifications are as follows:

- □ Operating Frequency (f_{SW}) = 2.1 MHz
- □ Output Capacitor (C_{OUT}) = 33 µF
- □ Regulator Feedback Voltage (V_{FB}) = 800 mV

The key LED specifications are as follows:

- □ LED Typical Forward Voltage ($V_{F,TYP}$) = 3.1 V
- □ LED Max. VF ($V_{F,MAX}$) = 3.3 V
- □ LED Min. VF ($V_{F,MIN}$) = 2.8 V
- □ LED Current = 300 mA

The following are the system specifications, pertaining to the margins required in the calculation of the minimum and maximum output voltage:

- □ 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 shown below.

- □ Maximum Output Voltage ($V_{OUT,MAX}$):

  $V_{OUT,MAX} = Vf_{MAX} + V_{SENSE} + V_{MOS} + V_{MARGIN,MAX}$

  $V_{OUT,MAX} = 3.3 + 0.5 + 0.2 + 0.7 = 4.7$ V

- □ MinimOutput Voltage ($V_{OUT,MIN}$):

  $V_{OUT,MIN} = Vf_{MAX} + V_{SENSE} + V_{MOS} + V_{MARGIN,MAX}$

  $V_{OUT,MAX} = 2.8 + 0.5 + 0.2 + 0.3 = 3.8$ V

Now the resistors connected on the MINOUT pin as shown in figure 1, can be calculated as below.

- □ Selecting R_{FB2} = 10 kΩ
- □ Calculate R_{FB1} and R_{FB3} using the below formulas:

$$R_{FB3} = \left(\frac{V_{MINOUT(max)} \times (V_{OUT(max)} - V_{FB})}{V_{FB} \times (V_{OUT(max)} - V_{OUT(min)})} - 1 \right) \times R_{FB2}$$

$$R_{FB1} = \left(\frac{V_{OUT(max)} - V_{FB}}{V_{FB}} \right) \times \left(\frac{R_{FB2} \times R_{FB3}}{R_{FB2} + R_{FB3}} \right)$$

- □ 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} = 179 kΩ (Selected value as 165 kΩ, 1%)
  - ♦ R_{FB1} = 46 kΩ (Selected value as 47 kΩ, 1%)

OPERATION

A typical application with a linear LED driver with pre-regulator is shown in Figure 1. The A80804 regulates the LED current. The voltage on the Dx pins is the difference between pre-regulator output voltage and LED forward voltage drop. The A80804 needs a minimum 0.5 V on Dx pin for accurate LED current regulation, but any additional voltage on these pins results in extra power loss in the external MOSFETs.

As shown in figure 2, the MINOUT pin provides an output voltage proportional to the minimum voltage of the Dx pins for all active channels. The voltage from MINOUT is fed to a voltage regulator's FB pin to complete a closed-loop system and trim the regulated output required to driver LEDs. The voltage on MINOUT is shown in the following equation:

$V_{MINOUT} = 10 \times (VDx_{MIN} - 0.8) + 0.3$

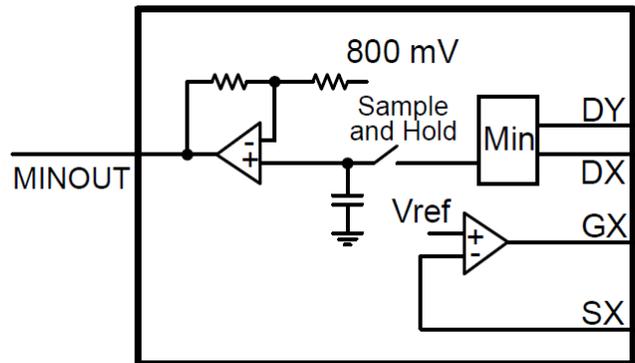The MINOUT pin has range of 0.3 to 3.5 V.
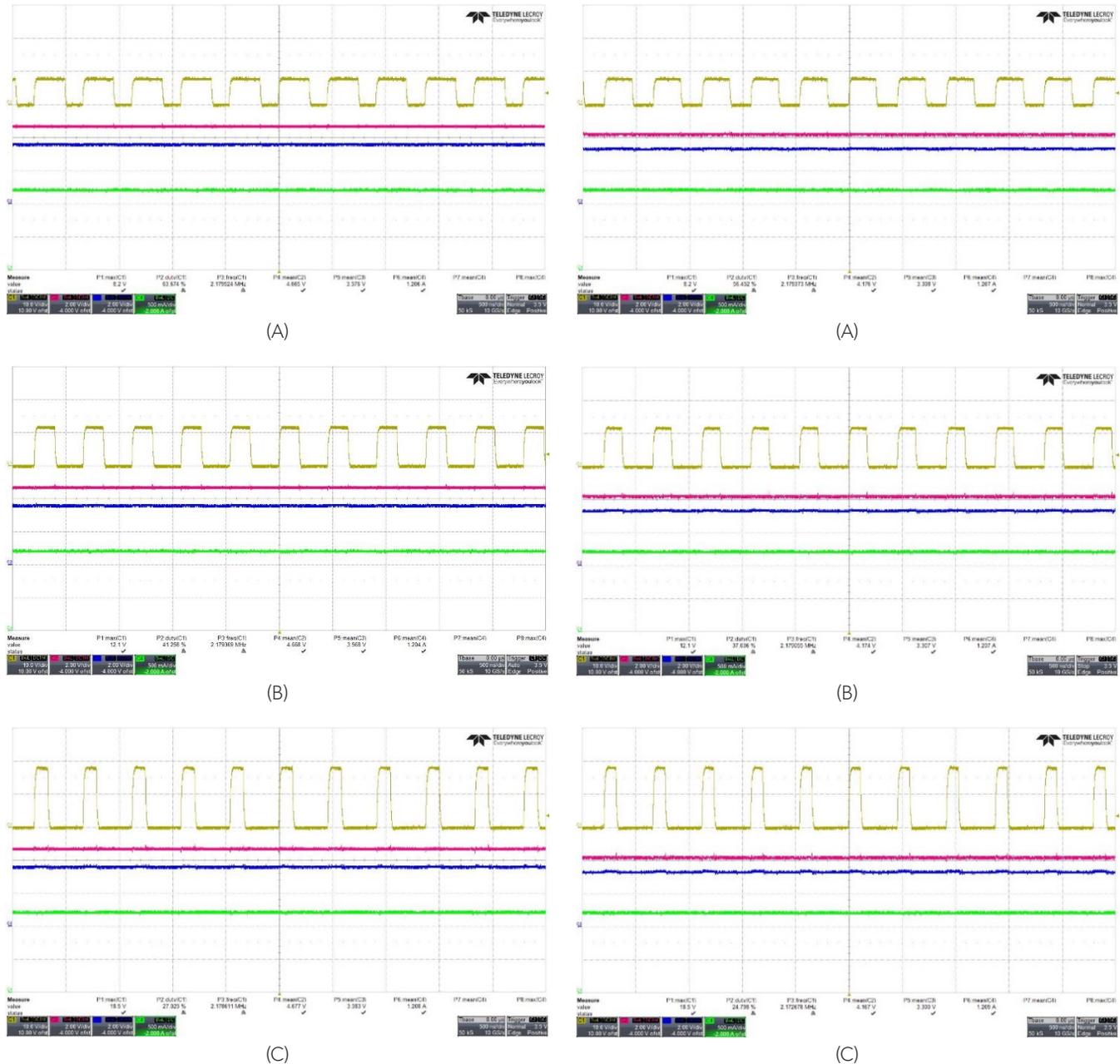

Figure 2: Block Diagram of MINOUT Block

It is important to note that if the LED strings' voltages change due to temperature change or active switching of number of LEDs, the MINOUT voltage changes and provides proper feedback signal to the pre-regulator to adjust output voltage to optimum level.

TEST RESULTS

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

Steady-State Performance

Figures 3 (A), (B), (C) and 4 (A), (B), (C) show the operation of the LED driver without and with MINOUT feature at supply voltage of 8, 12, and 18 V respectively.

(A)

(A)

(B)

(B)

(C)

(C)

Ch-1: SW Node (Yellow), Ch-2: Vout (Pink), Ch-3: MINOUT (Blue) and Ch-4: Total LED Current (Green)

Ch-1: SW Node (Yellow), Ch-2: Vout (Pink), Ch-3: MINOUT (Blue) and Ch-4: Total LED Current (Green)

Figure 3: Steady state waveforms without MINOUT feature at an input voltage of (A) 8 V, (B) 12 V, and (C) 18 V

Figure 4: Steady state waveforms with MINOUT feature at an input voltage of (A) 8 V, (B) 12 V and (C) 18 V

Power Efficiency

Table 1 and Table 2 show the steady state performance of the system without and with MINOUT feature respectively. Moreover, Fig. 5 and 6 show the plot of efficiency vs input voltage of the system without and with MINOUT respectively. As shown in these figures, the efficiency of the system implemented with MINOUT feature is higher as compared to system without MINOUT implementation. The efficiency difference becomes higher as the LED voltage drops as shown in these figures.

Table 1: Steady-State Performance without MINOUT

V_{IN} (V)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (W)	P_{OUT} (W)	N-MOS (W)	Efficiency (%)
Typical LED V_F = 3.09 V
8	795	6.4	4.70	3.8	0.34	59.5
12	536	6.4	4.70	3.8	0.34	58.9
18	369	6.6	4.70	3.8	0.34	57.0
Max. LED V_F = 3.3 V
8	795	6.4	4.70	4.0	0.28	63.6
12	536	6.4	4.70	4.0	0.28	62.9
18	369	6.6	4.70	4.0	0.28	60.9
Min. LED V_F = 2.8 V
8	795	6.4	4.70	3.4	0.43	53.9
12	536	6.4	4.70	3.4	0.43	53.3
18	369	6.6	4.70	3.4	0.43	51.6

Table 2: Steady-State Performance with MINOUT

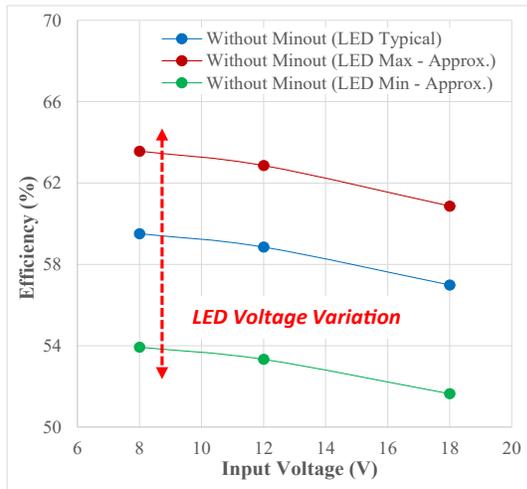| V_{IN} (V)	I_{IN} (mA)	P_{IN} (W)	V_{OUT} (W)	P_{OUT} (W)	N-MOS (W)	Efficiency (%)
Typical LED V_F = 3.09 V
8	724	5.8	4.27	3.8	0.21	65.4
12	488	5.9	4.25	3.8	0.20	64.6
18	337	6.1	4.23	3.8	0.20	62.4
Max. LED V_F = 3.3 V
8	760	6.1	4.48	4.0	0.21	66.5
12	512	6.1	4.46	4.0	0.20	65.8
18	354	6.4	4.44	4.0	0.20	63.5
Min. LED V_F = 2.8 V
8	675	5.4	3.98	3.4	0.21	63.5
12	455	5.5	3.96	3.4	0.20	62.9
18	314	5.7	3.94	3.4	0.20	60.7

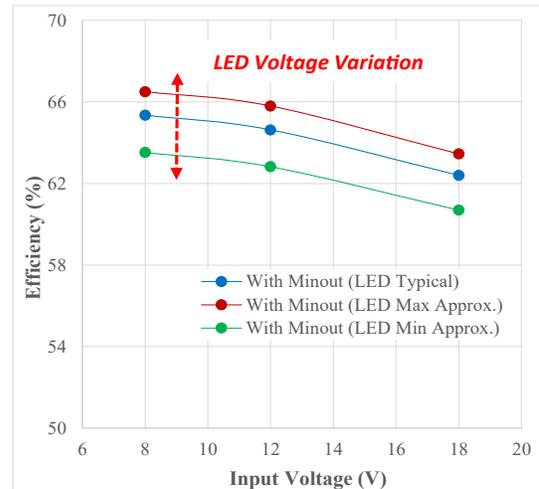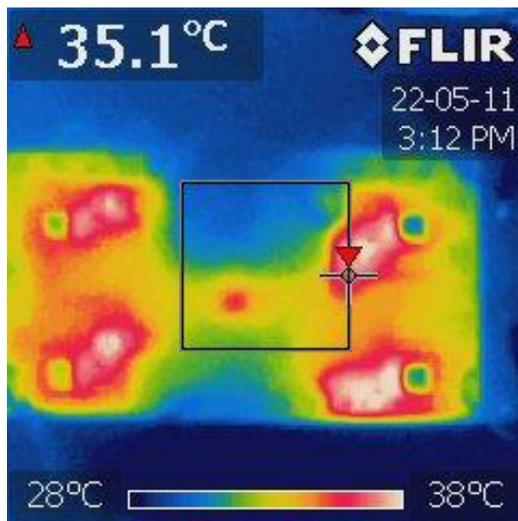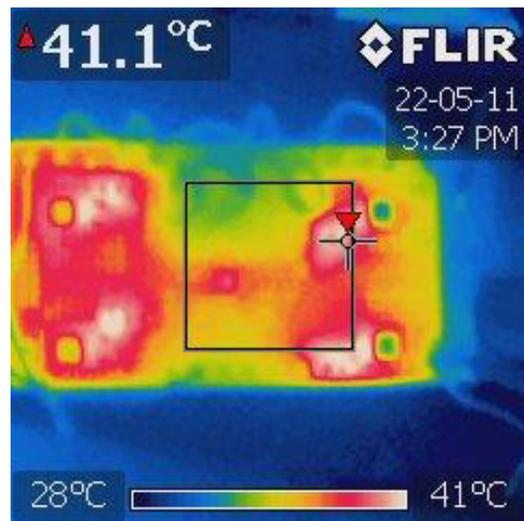Figure 5: Efficiency vs. Supply Voltage without MINOUT

Figure 6: Efficiency vs. Supply Voltage with MINOUT

Thermals

Figure 7 (A) and figure 7 (B) show the thermal images of the A80804 board without and with MINOUT, respectively. As the images illustrate, a better thermal outcome is acheived with MINOUT.

(A)

(B)

Figure 7: Thermal images of the A80804 (A) without and (B) with MINOUT

Stability

Figures 8 and 9 show the bode plot depicting sufficient gain and phase margins without and with MINOUT, respectively. The stability of the overall system is primarily set by the pre-regulator compensation loop, and is not affected by the LED driver. The MINOUT finction is notably slow, and does not impact overall frequency response.
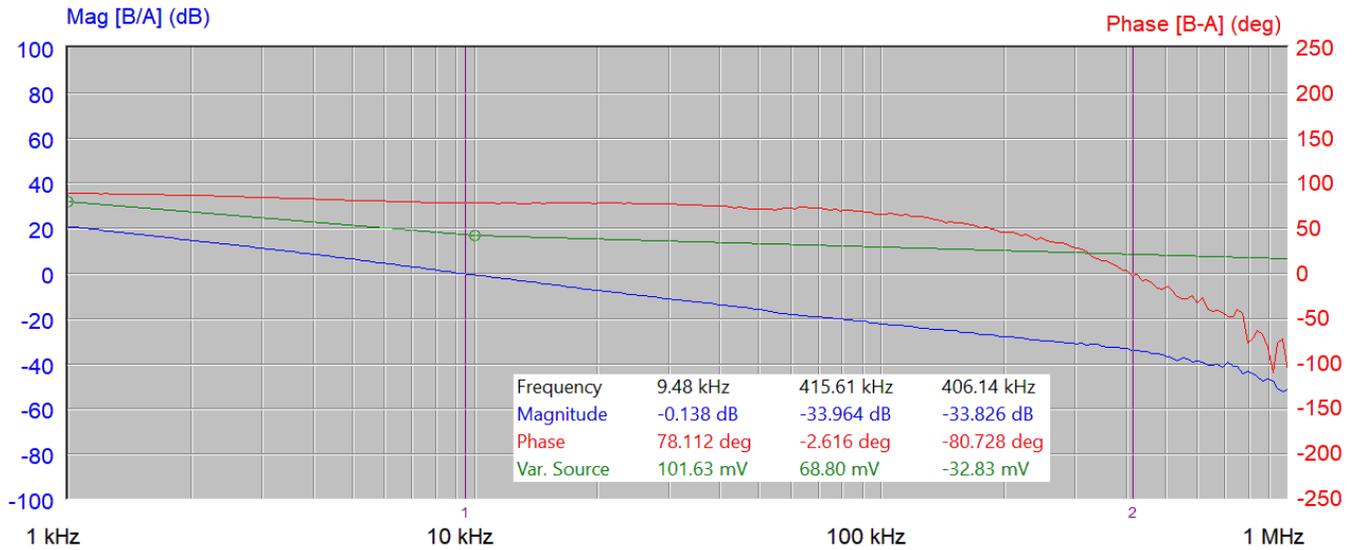

Frequency	9.48 kHz	415.61 kHz	406.14 kHz
Magnitude	-0.138 dB	-33.964 dB	-33.826 dB
Phase	78.112 deg	-2.616 deg	-80.728 deg
Var. Source	101.63 mV	68.80 mV	-32.83 mV

Figure 8: Bode plot of overall system without MINOUT feature

Frequency	9.48 kHz	451.86 kHz	442.38 kHz
Magnitude	-0.330 dB	-34.025 dB	-33.694 dB
Phase	75.082 deg	-1.429 deg	-76.511 deg
Var. Source	101.63 mV	68.22 mV	-33.40 mV
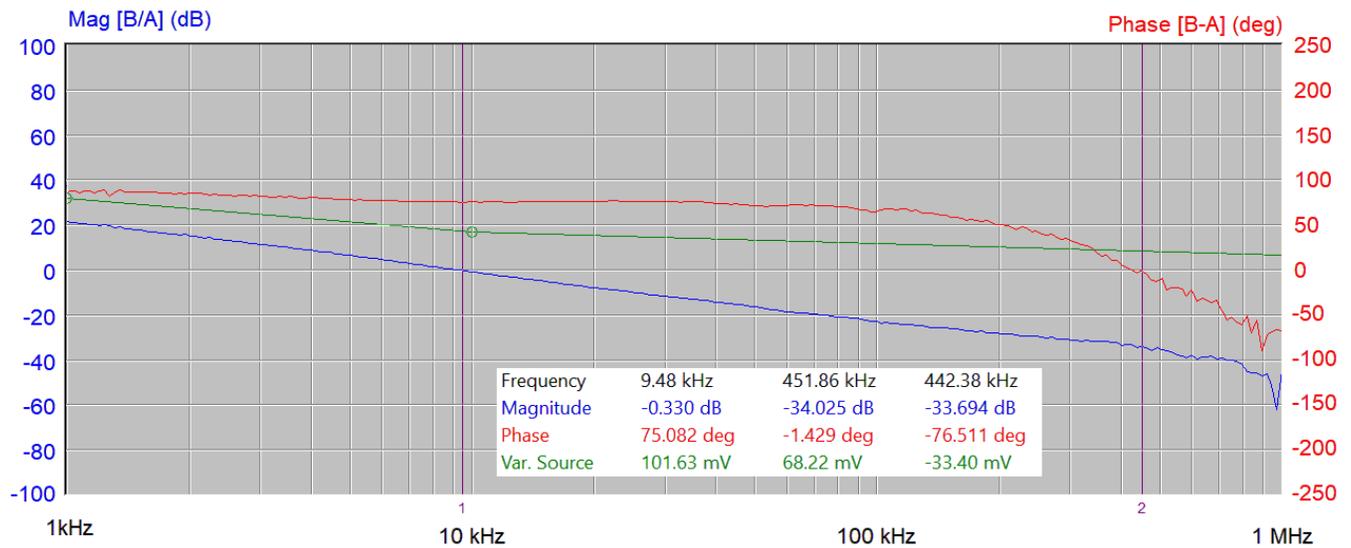
Figure 9: Bode plot of overall system with MINOUT feature

Load Current Transients – Sequential Operation

In sequential LED driver application, same number of LEDs are sequentially turned on. The output voltage remains almost constant, however the overall input current changes with the number of LED turning on and off. The voltage of the MINOUT pin also does not change significantly as output voltage remains almost constant.

Figure 10 shows the sequential operation of the system at the rated input voltage of 12 V.
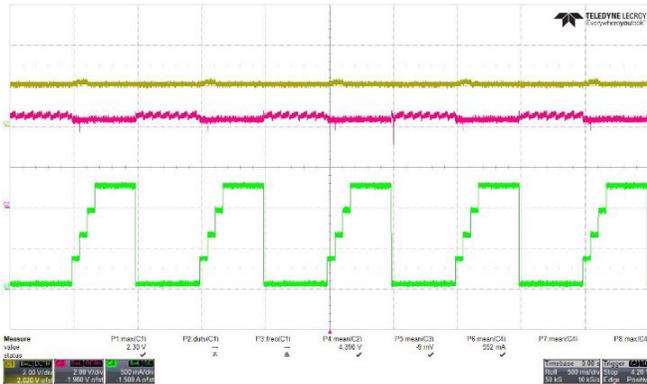
Ch-1: MINOUT (Yellow), Ch-2: Vout (Pink), Ch-4: Total LED Current (Green)

Figure 10: Sequential Operation of the APM811911 + A80804

Load Current Transients – Single LED Operation

In single LED operation, the sense resistor of the LED is changed dynamically to check the system performance. Figure 11 shows the single LED operation with current changing from 1.2 to 1.6 A with output voltage remaining constant.
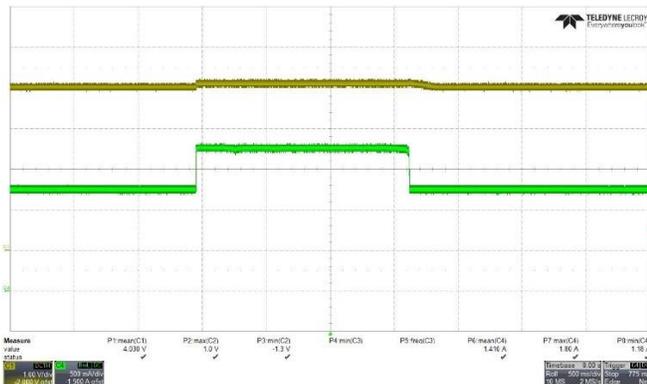
Ch-1: Vout (Yellow), Ch-4: Total LED Current (Green)

*Figure 11: Single LED Operation of the APM811911 + A80804*

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

In Tail/Stop or DRL/POS applications, usually few numbers of LEDs are switched on and off, which changes the output voltage of the pre-regulator. The MINOUT function adjust the output voltage of pre-regulator to desired level to achieve best efficiency.

Figure 12 (A) shows typical operation when number of LEDs switched from 3 LEDs to 2 LEDs and back to 3 LEDs. LED current is set to 300 mA per channel. When 3 LEDs switched to 2 LEDs, output voltage of pre-regulator drops slowly without causing any disturbance in LED current. However, when 2 LEDs switched to 3 LEDs, suddenly output voltage required to increase, which can result in a glitch in LED current due to limited response of MINOUT.

The values of various feedback resistors used for this test are as follows:

- ♦ R_{FB1} = 117 kΩ
- ♦ R_{FB3} = 86.6 kΩ
- ♦ R_{FB2} = 10 kΩ
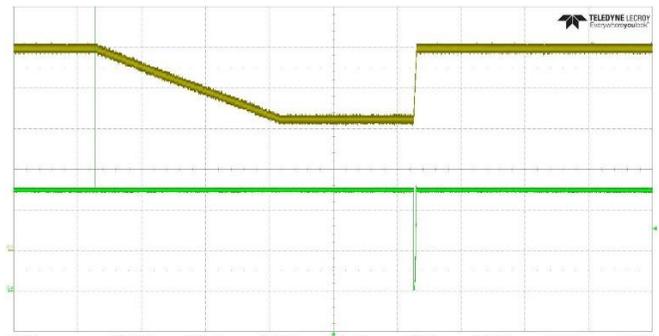
(A)
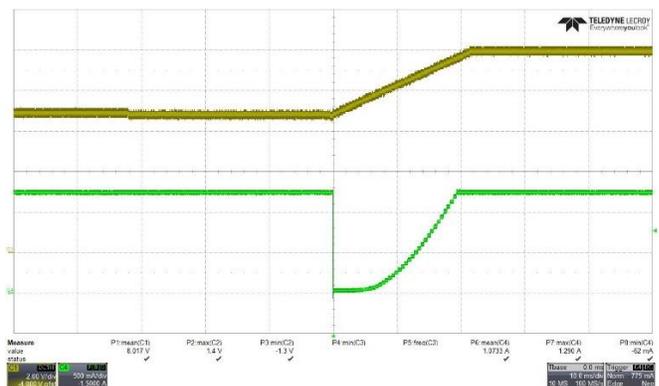
(B)

Ch-1: Vout (Yellow), Ch-4: Total LED Current (Green)

Figure 12: Switching number of LEDs in series (A) from 3 to 2 LED's and back to 3 LED's and (B) zoomed waveform for the current dip during 2 to 3 LED operation.

APPLICATION SIMPLIFIED SCHEMATICS

Figure 13 shows the application schematics of the LED driver with a front end APM81911 Buck Converter and an A80804 LED controller. Figure 14 shows the developed two-layer board without components. The overall board dimensions are 4.6 in × 2.1 in.
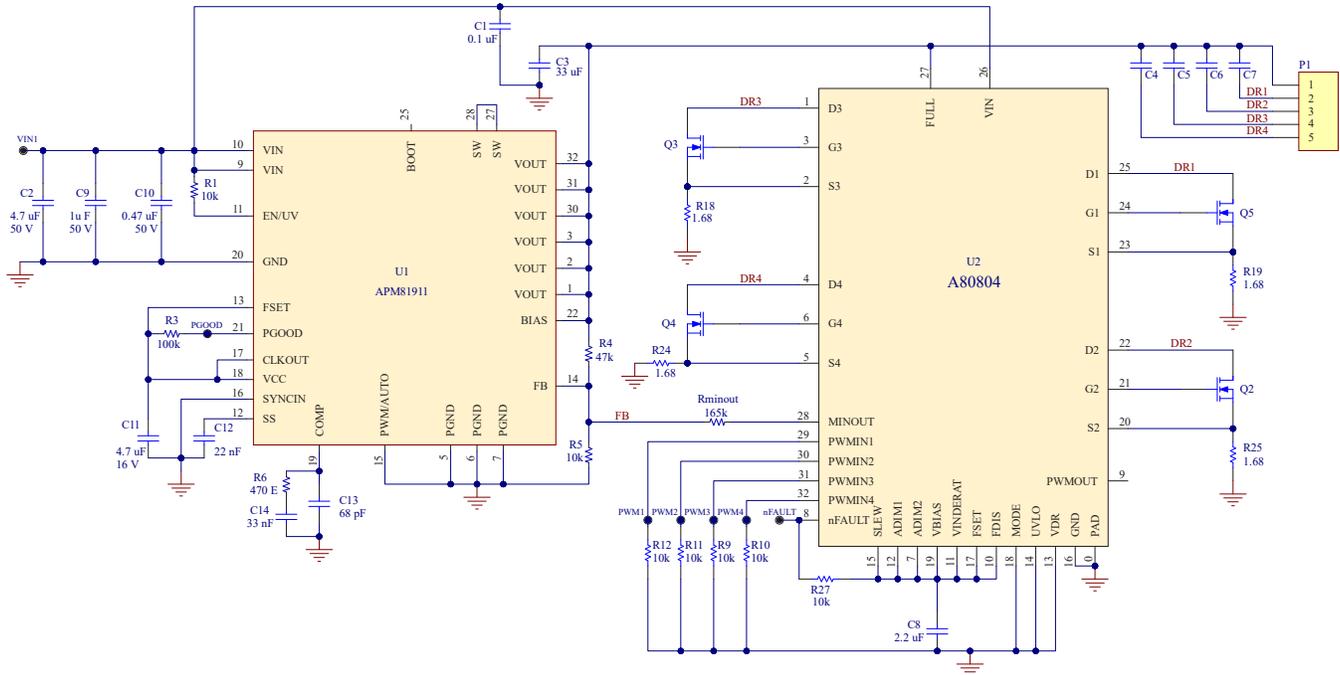

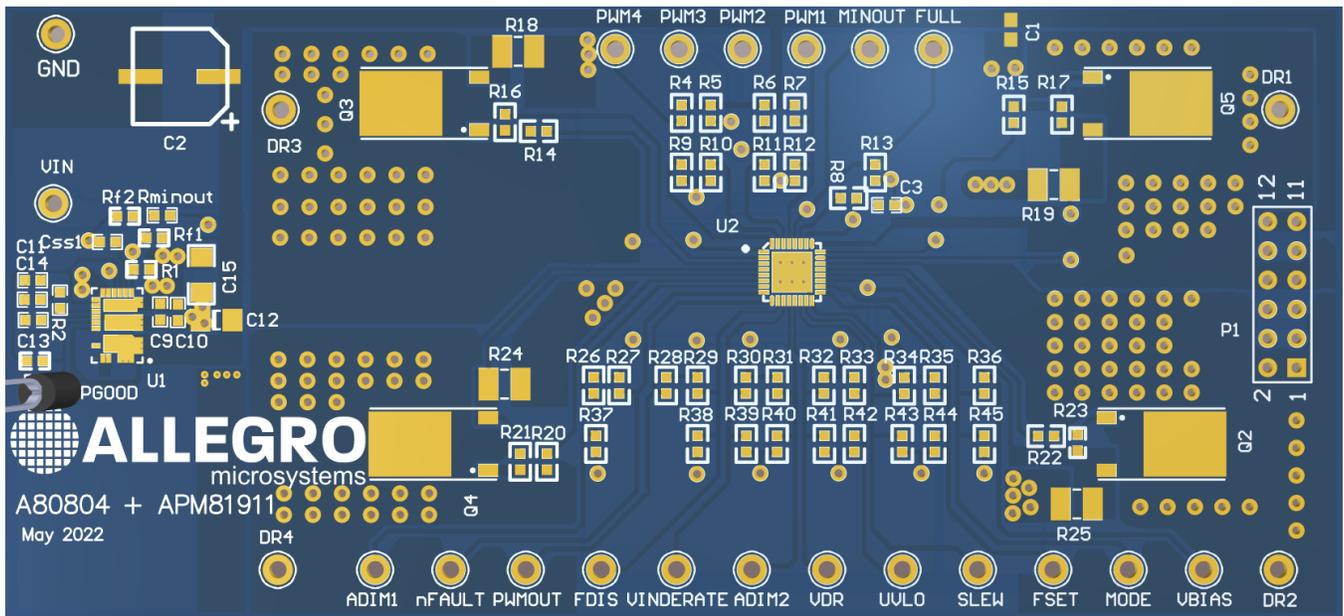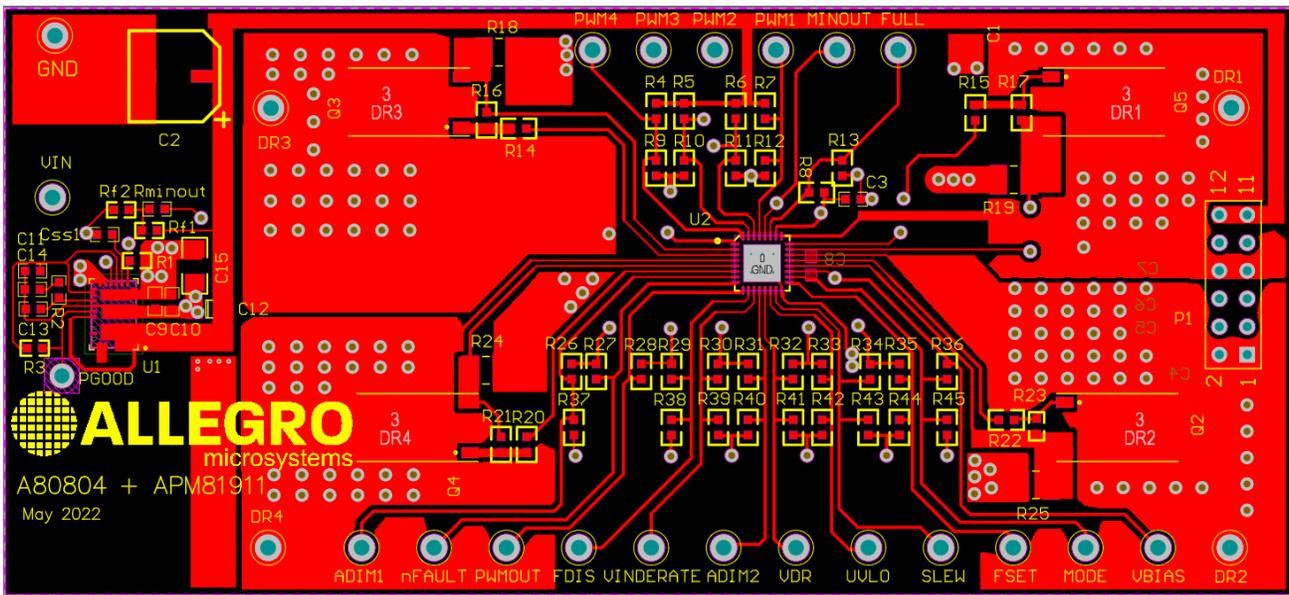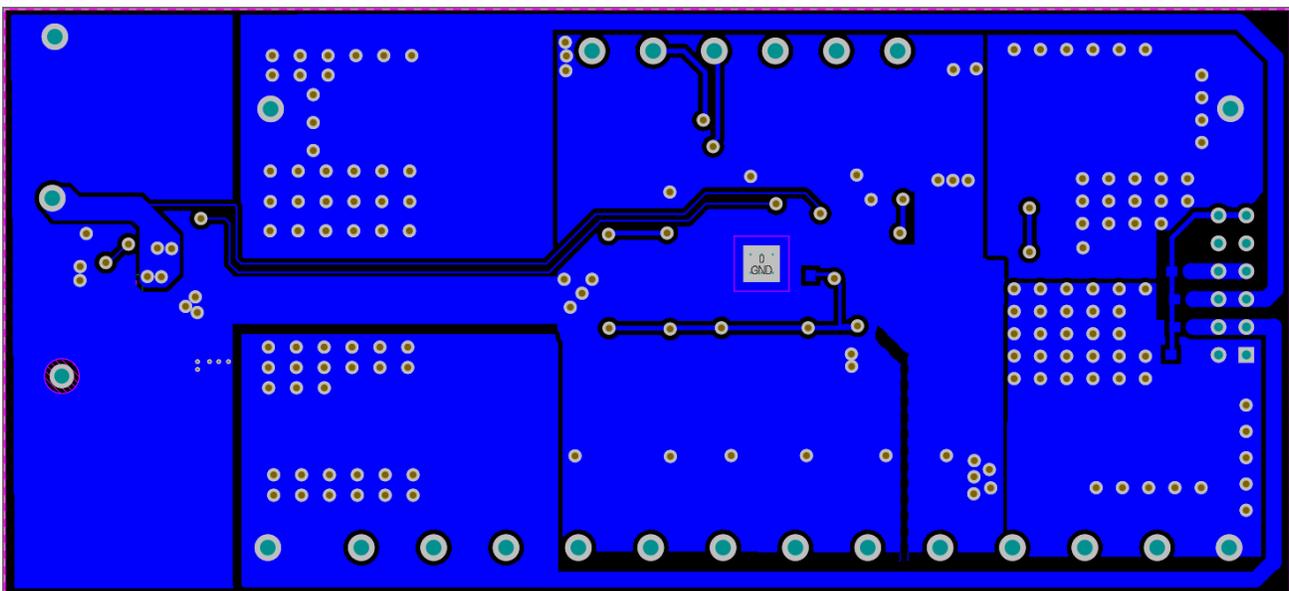*Figure 13: Application Schematics of the APM81911 + A80804 LED Driver*

Figure 14: Developed board of the APM81911 + A80804 LED Driver

LAYOUT

Figure 15 shows the layout (top layer and bottom layer) of the developed LED driver with a front end APM81911 and an A80804 LED controller.

(A)

(B)

Figure 15: Layout of the APM81911 + A80804 LED Driver showing (A) top layer and (B) bottom layer

BILL OF MATERIALS

Designator	Value	Footprint
C1	0.1 µF/50 V	0805
C2	4.7 µF/50 V	1206
C11	4.7 µF/50 V	0603
C3	33 µF/16 V	0603
C5, C5, C6, C7	DNP	0603
C8	2.2 µF/16 V	0603
C9	1 µF/16 V	0805
C10	0.47 µF/50 V	0805
C12	22 nf/16 V	0603
C13	68 pF/ 16 V	0603
C14	33 nF/16 V	0603
Q2, Q3, Q4, Q5	As per design	SOT89
R1, R5, R9–R12, R27	10k	0603
R3	100k	0603
R4	47k	0603
R6	470E	0603
R18, R19, R24, R25	1.68	1210
R_{MINOUT}	165k	0603
U1	APM81911	4 mm × 6 mm QFN
U1	A8084	MLPQ32, 5 × 5

PIN CONFIGURATIONS

APM81911

EN/UV: Connected to VIN to enable device.

FSET: Connected to VCC for default 2.15 MHz switching frequency.

PWM/AUTO: Connected to GND for AUTO transition between PWM and PFM modes.

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. VIN pin is connected to input battery supply and LEDs are connected to different voltage. In this case, VINDERATE will not work.

FSET: Driver works in full mode, so PWM mode does not matter.

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. As the driver is configured in FULL mode, VDR pin voltage does not matter.

CONCLUSION

This application note presents a high efficiency sequential LED driver using Allegro MicroSystems' APM81911 + A80804 devices. The high efficiency is achieved by optimally controlling the output of a switching buck pre-regulator.

A design procedure for the selection of the components has been presented. An efficiency comparison of the system with and without MINOUT feature has been shown and a significant increase in efficiency has been reported. The steady-state wave-forms have been presented for full-load (all 4 LEDs operating at 300 mA each) at the supply voltages of 8, 12, and 18 V with and without the MINOUT feature implementation. The device stability has also been verified over wide range of input voltages.

Revision History

Number	Date	Description	Responsibility
–	December 2 2022	Initial release	Shashank Whekande
1	August 24, 2023	Attribution update	Shashank Whekande

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