TI Designs
Multiple Channels of High Density LED Control for Automotive Headlight Applications

TI Designs

TI Designs provide the foundation that you need including methodology, testing and design files to quickly evaluate and customize the system. TI Designs help *you* accelerate your time to market.

Design Resources

TIDM-AUTO-DC-LED-LIGHTING	Design Folder
TMS320F28032PAG	Product Folder
TL431BQDBZR	Product Folder
TPIC1021AQDR	Product Folder
UCC27201DDA	Product Folder
UCC2813QDR-3Q1	Product Folder
OPA4322AIPWR	Product Folder
LM5111	Product Folder
HVDA541QDRQ1	Product Folder

TI E2E™ Community

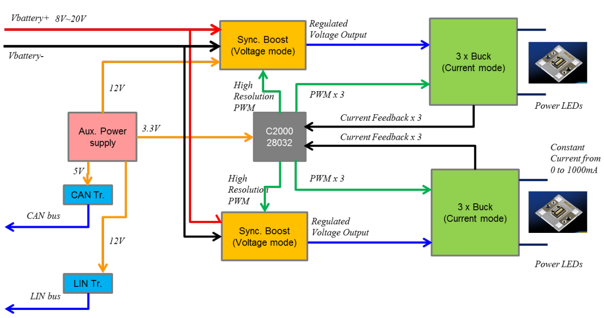
ASK Our E2E Experts
WEBENCH® Calculator Tools

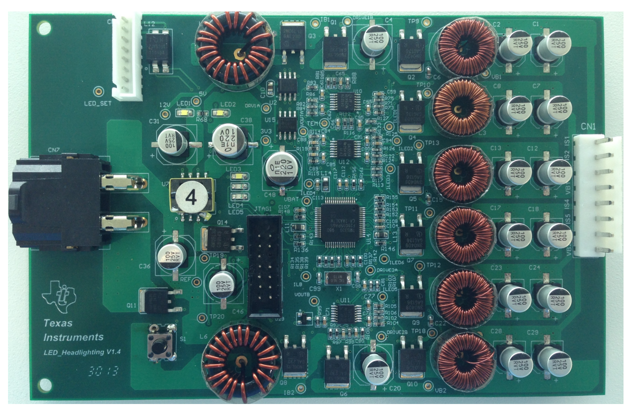
Design Features

- Up to Six Channels of High Density DC-DC LED Driving Capability
- High Overall Efficiency of About 86% at Stable Maximum Output
- Wide Input Operation Voltage Range from 8 to 20 V
- Very Low Ripple Current on Each LED Channel With ±1 mA at Constant Output
- Controlled and Monitored through CAN Communication Interface With Pre-Defined Open Protocol
  - Easy to Adapt to Various End Users
- Compact Board Size With Fine-Tuned Analog Devices
- Overvoltage and Overcurrent Protection (45-V Load Dump Protection)

Featured Applications

- LED Automotive Headlamps
- DC LED Control With High Density Outputs





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1 System Description

Featuring the TMS320F2803x Piccolo™ microcontroller (MCU), this design implements a high efficiency multi-channel DC-DC LED control system for typically automotive lighting systems. The design support up to six channels of LED controls each with maximum of 1.2-A current driving capabilities. With a two-stage power topology of boost and buck, the system can be operated with a wide input DC voltage from 8 to 20 V, which fits perfectly in the automotive applications.

2 Design Features

- Flexibility
  - Six channels of high power LED control
  - Each channel can be configured with current of 0 mA to 1 A
  - High overall efficiency
  - 85.99% overall efficiency at maximum output
- Wide range DC-DC power supply design
  - Input voltage range of 8 to 20 V for normal operation
  - Average current mode control for each channel of LED
  - Voltage mode for each boost channel
- Safety design
  - Overvoltage and overcurrent protection
  - 45-V load dump protection
  - LED over temperature protection
- Automotive application orientated
  - CAN/LIN communication
  - Automotive grade device selection
  - ISO7637-2 consideration

3 Block Diagram

Figure 1 shows the system block diagram of the design.

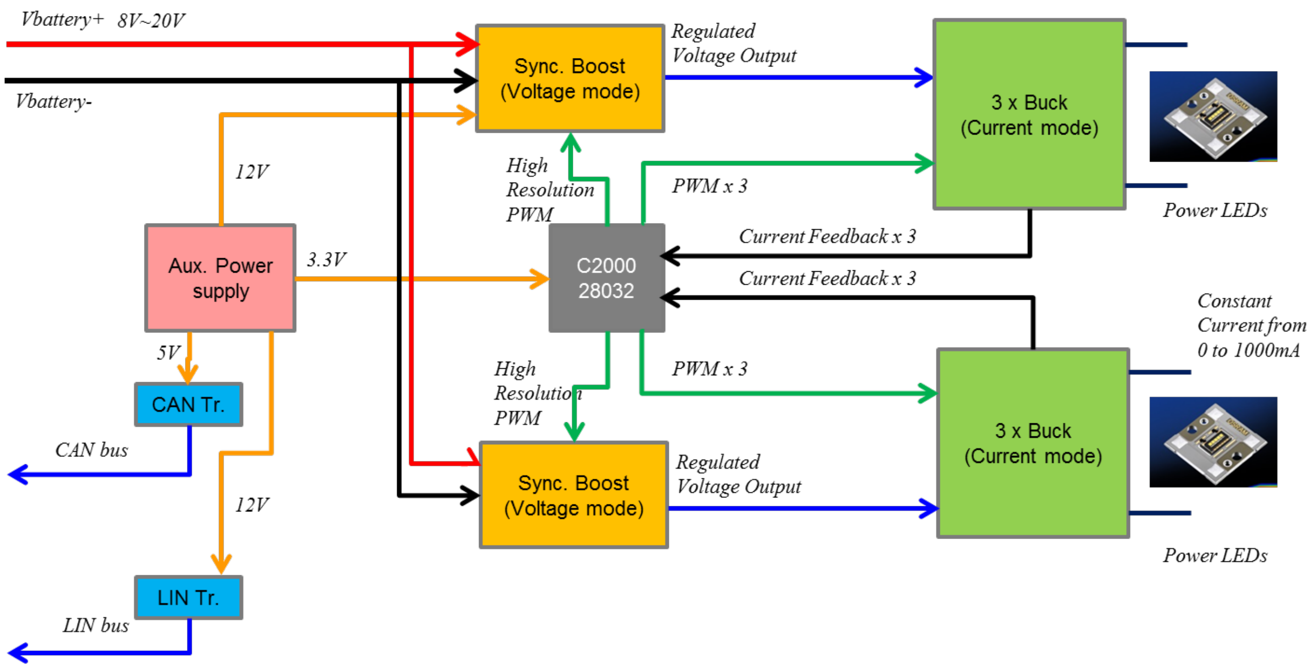

Figure 1. System Block Diagram

To achieve a wide input operation range and high output efficiency, selecting the appropriate power topology is the key for the system design.

Figure 2 shows the power topology of the system. With a first-stage synchronous boost and a second-stage separated (up to three channels) buck circuit, the system can achieve the target output efficiency at a wide input voltage range. The system has two sets of the circuit shown in Figure 2 to enable up to six channels of LED driving capability.

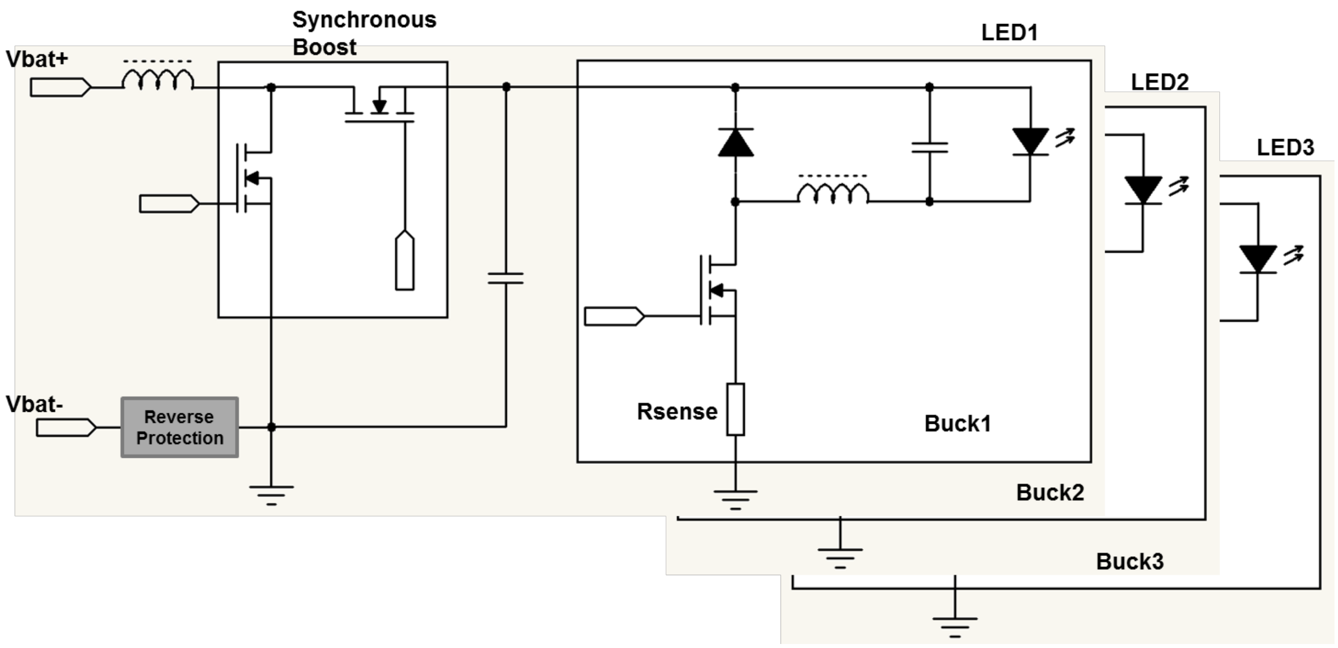

Figure 2. Power Topology of the System

4 Circuit Design and Component Selection

This section describes various pieces that constitute the hardware for design of a working automotive DC LED control system that uses the TMS320F2803x MCU.

4.1 Power Supply

The main system power supply is derived from the mains using an isolated switching converter. This converter provides a stable 12-V power supply to drive the boost MOSFETs even when the input power supply drops below 12 V. To provide a stable power supply to the MCU as well as the drivers on board in a very low or high battery voltage condition, a robust auxiliary power supply circuit is designed on board using flyback power supply topology.

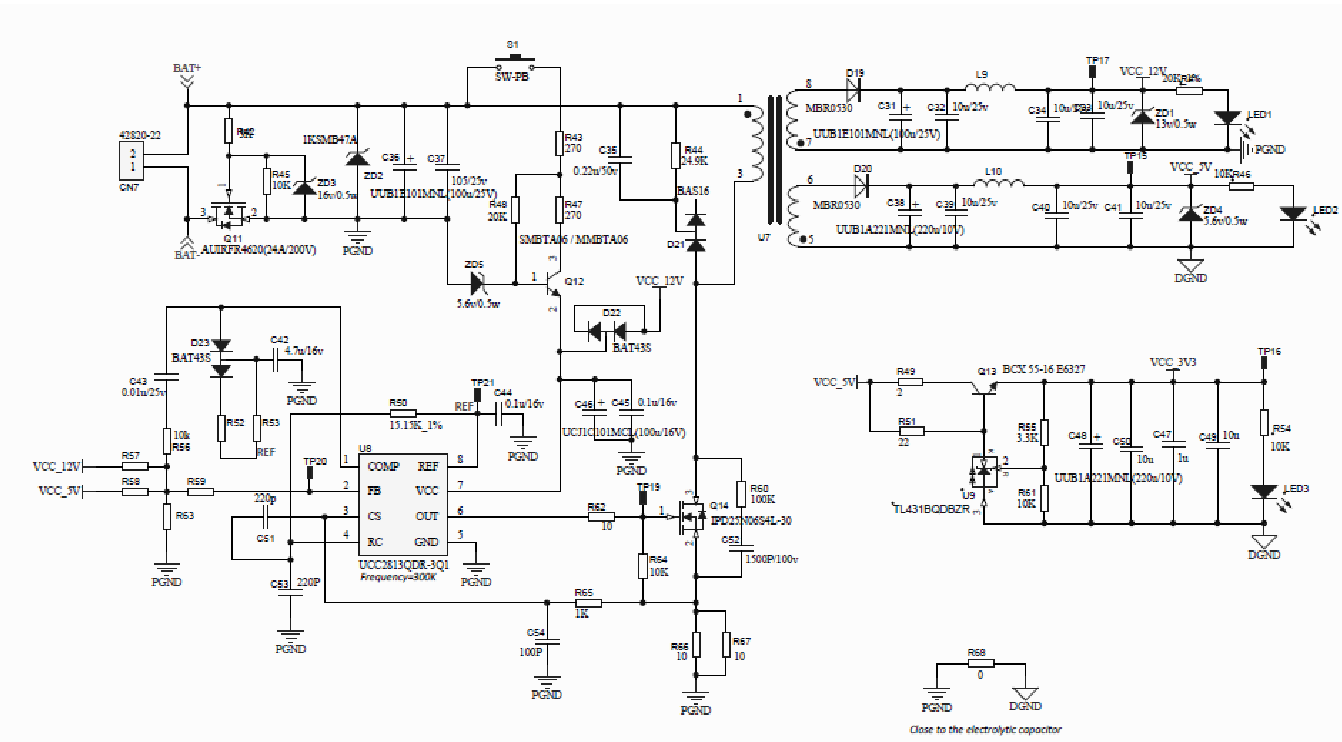

Figure 3. Auxiliary Power Supply

4.2 Selection of Inductors and Capacitor

4.2.1 Boost

Figure 4 shows the boost stage design.

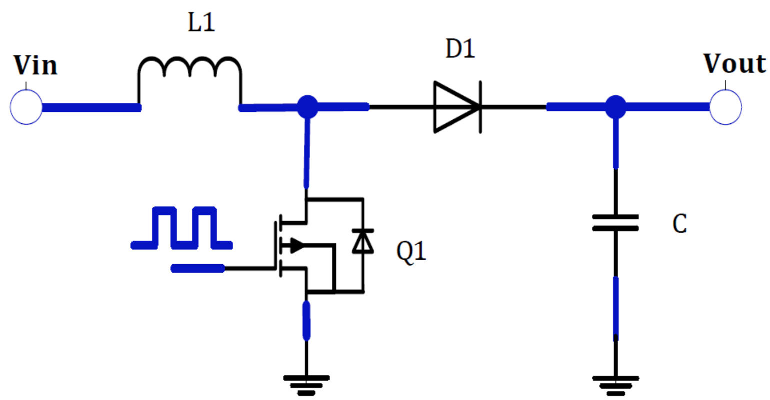

Figure 4. Boost Equivalent Circuit

Calculate the required minimum inductance (μH):

$$L_{min} := \frac{V_{i\_min}}{I_{pk} \times k_{rp\_max}} \times Duty_{max} \times \frac{1}{f_s} = 7.71429 \times 10^{-6}$$

$$L_{min} = 7.71429\ \mu H \tag{1}$$

Inductance to be used can be found with:

$$L_{real} := \frac{A_L \times N_{real}^2}{10^3} = 13.248\ \mu H \tag{2}$$

The size of the inductance is shown in Figure 5:

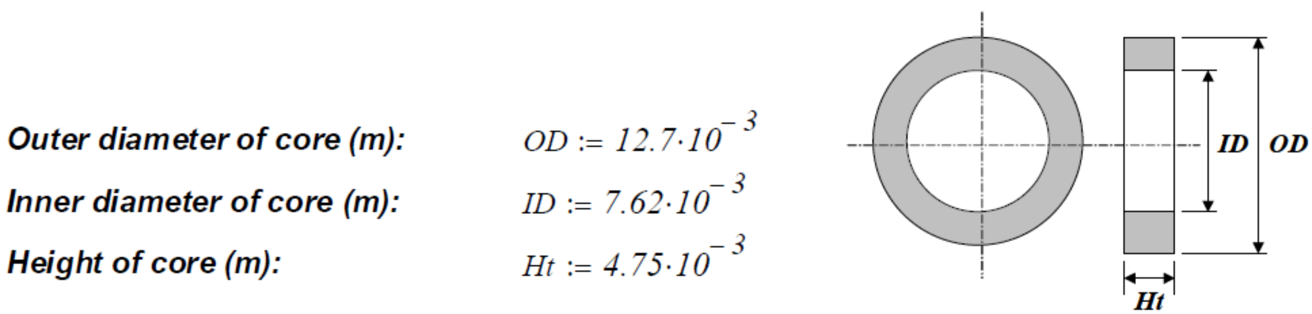

Figure 5. Size of Boost Inductance

Calculate the minimum output capacitor with:

$$C_{min} := \frac{I_o \times Duty_{max}}{20 \times k_{vp\_max} \times f_s} = 2.04082 \times 10^{-5} \tag{3}$$

4.2.2 Buck

Figure 6 shows the buck stage design.

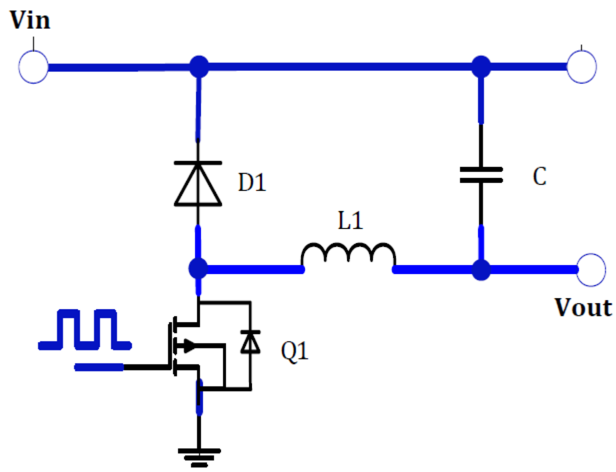

Figure 6. Buck Equivalent Circuit

Calculate the required minimum inductance (µH):

$$L_o(t) := \frac{V_o(t)}{I_{pk} \times k_{rp\_max}} \times Duty(t) \times \frac{1}{f_s}$$

$$L_{min} = 253.96825\ \mu H \tag{4}$$

The size of the inductance is shown in Figure 7:

Outer diameter of core (m): $OD := 12.7 \cdot 10^{-3}$

Inner diameter of core (m): $ID := 7.62 \cdot 10^{-3}$

Height of core (m): $Ht := 4.75 \cdot 10^{-3}$

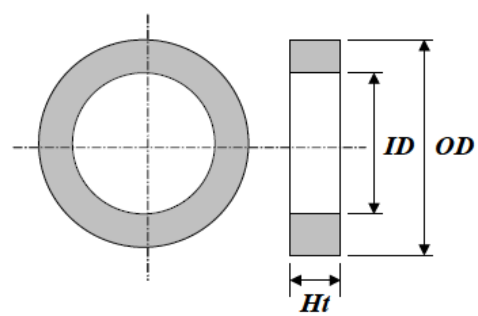

Figure 7. Size of Buck Inductance

Calculate the minimum output capacitor with:

$$C_{min}(t) := \frac{I_o \times Duty(t)}{20 \times k_{vp\_max} \times f_s}$$

$$C_{min} := C_{min}(tt) = 1.5873 \times 10^{-5} \tag{5}$$

5 Software Description

This section discusses the software for the implementation of DC automotive LED system using the Piccolo device. The first subsection discusses the software flow of the application. Subsequently, the system control loop design is described in detail. The configuration registers and result registers are described, and their respective addresses are also discussed.

5.1 System Software Flow

The software architecture of the system is shown in Figure 8:

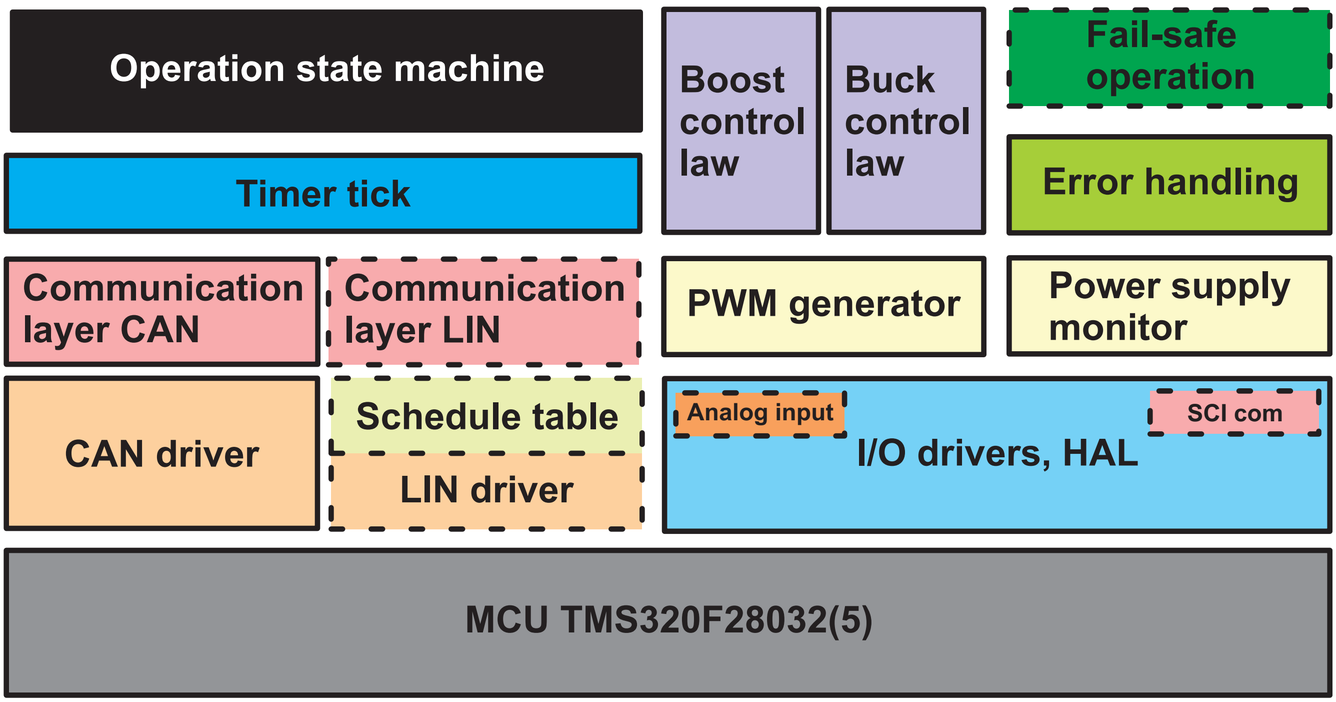

Figure 8. Software Architecture

The operation state machine runs through the operation of the controller to determine the proper operating mode. The operating mode switching is shown in Figure 9.

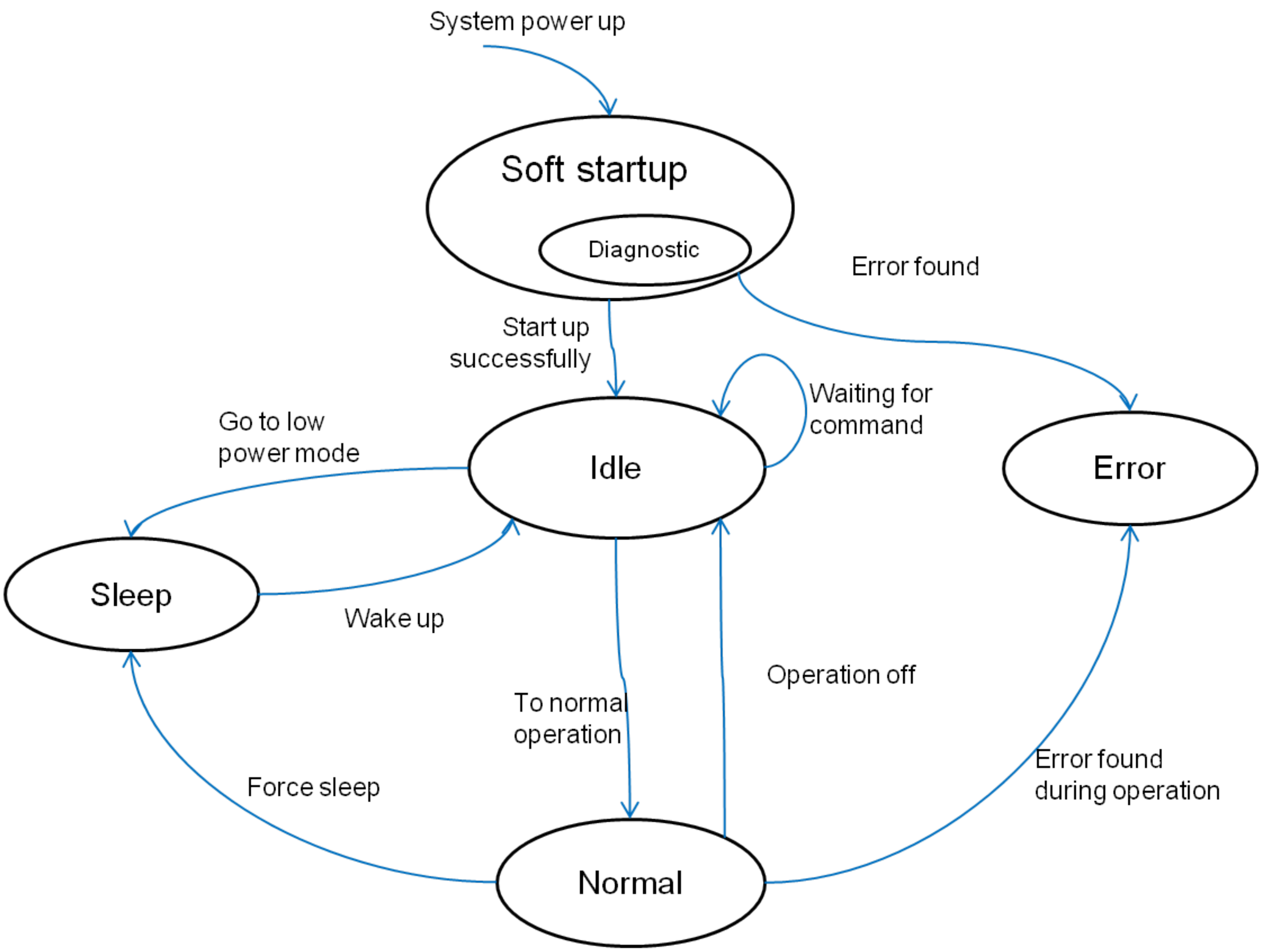

Figure 9. Software State Machine

The software flow chart for power on operation and soft startup operation is detailed in Figure 10 through Figure 13:

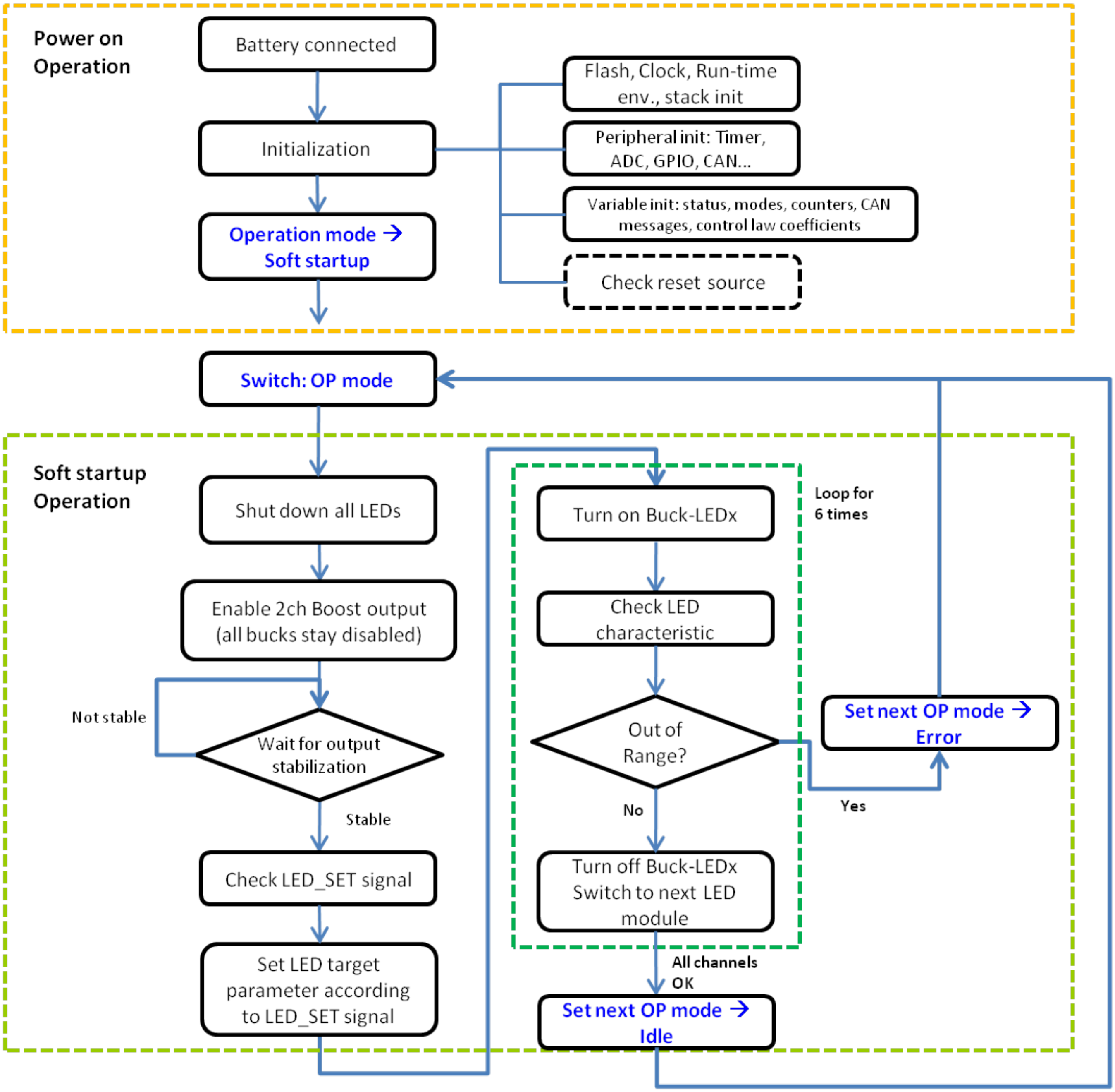

Figure 10. Flowchart for Startup

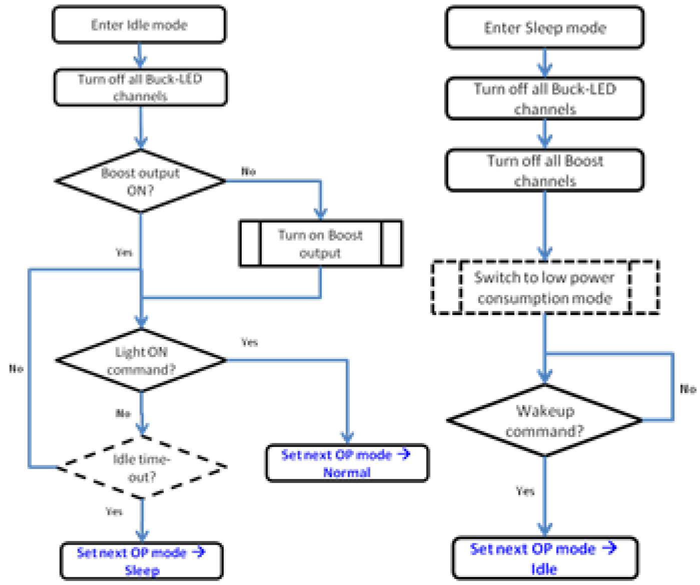

Figure 11. Flowchart for Idle Mode and Sleep Mode

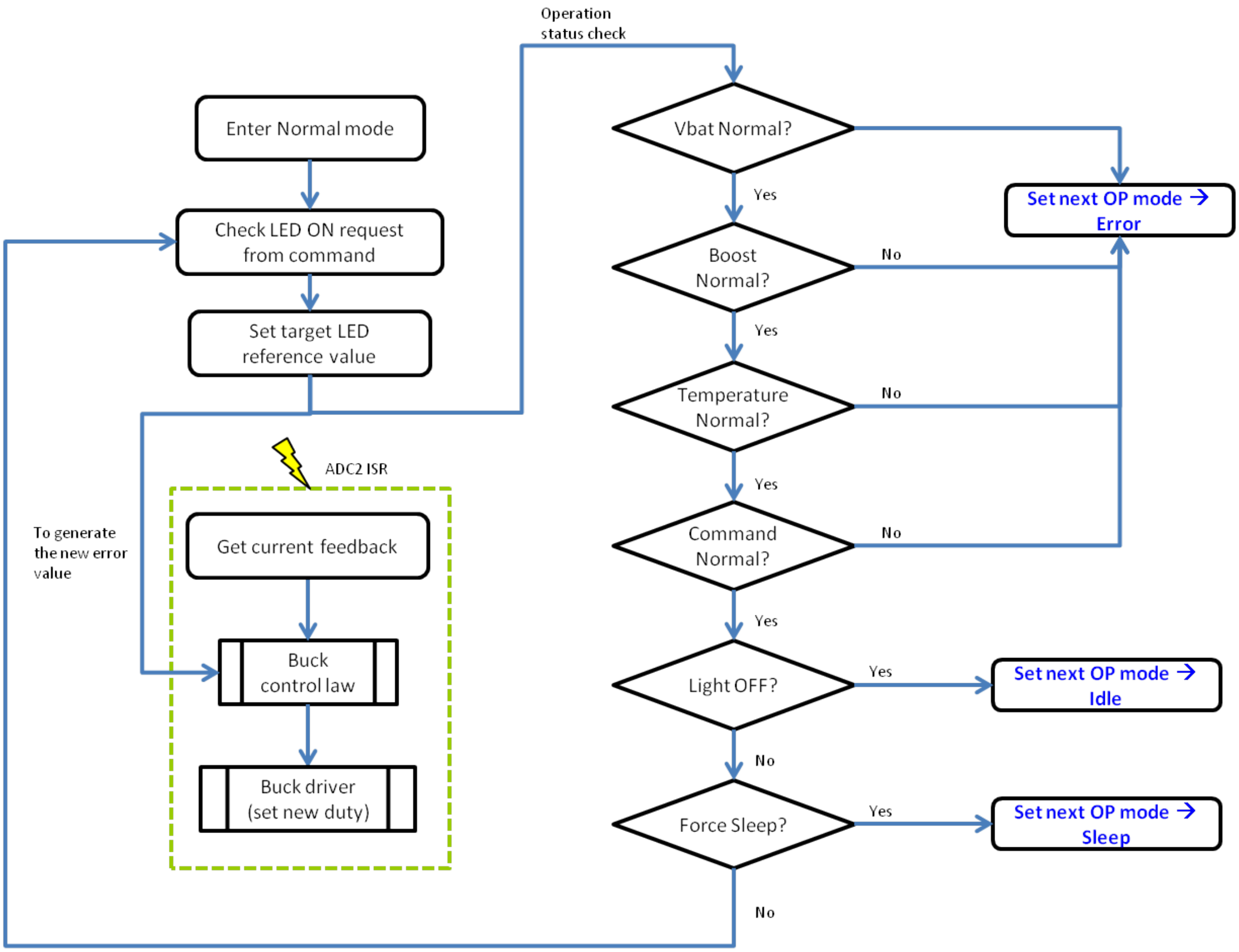

Figure 12. Flowchart for Normal Operation Mode

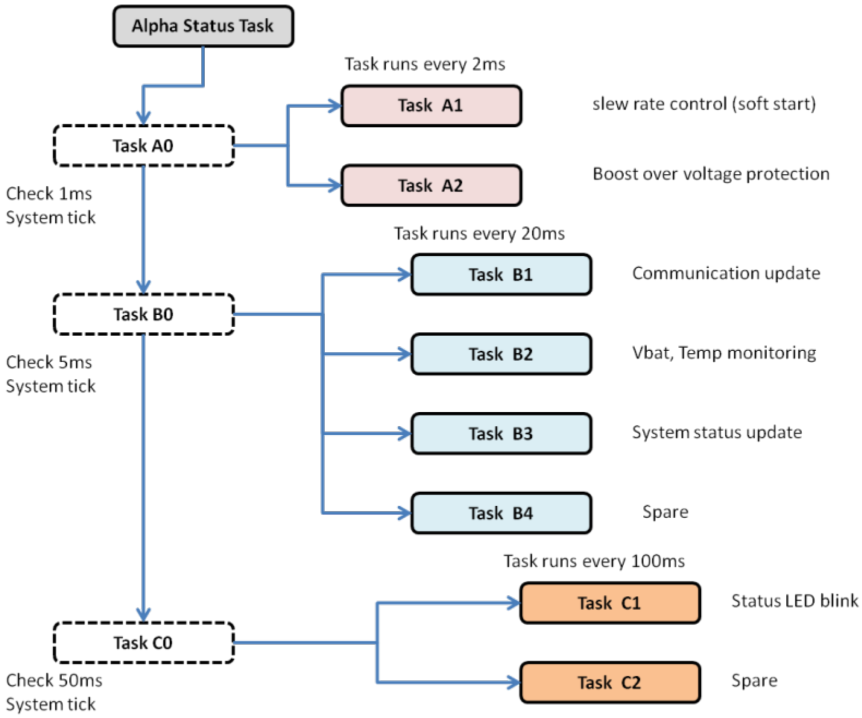

Figure 13. Task Scheduling of the System

5.2 Controller Design

The controller used in the application is currently the PID controller type grando.

This software module implemented the incremental conductance algorithm used for maximum power point tracking purposes.

The PID_grando module implements a basic summing junction and PID control law with the following features:

- Programmable output saturation
- Independent reference weighting on proportional path
- Independent reference weighting on derivative path
- Anti-windup integrator reset
- Programmable derivative filter

All input, output, and internal data is in I8Q24 fixed-point format. A block diagram of the internal controller structure is shown in Figure 14.

The code is supplied as a C function in a source file named "controller.c". The controller variables are grouped into three short C structures as follows.

Table 1. Controller Variables

TERMINALS	COMMENT
Ref	Input: reference set-point
Fdb	Input: feedback
Out	Output: controller output
c1	Internal: derivative filter coefficient
c2	Internal: derivative filter coefficient
PARAMETERS	**COMMENT**
Kr	Proportional reference
Kp	Proportional loop gain
Ki	Integral gain
Kd	Derivative gain
Km	Derivative reference weighting
Umax	Upper saturation limit
Umin	Lower saturation limit
DATA	**COMMENT**
up	Proportional term
ui	Integral term
ud	Derivative term
v1	Pre-saturated controller output
i1	Integrator storage: ui(k – 1)
d1	Differentiator storage: ud(k – 1)
d2	Differentiator storage: d2(k – 1)
w1	Saturation record: [u(k – 1) – v(k – 1)]

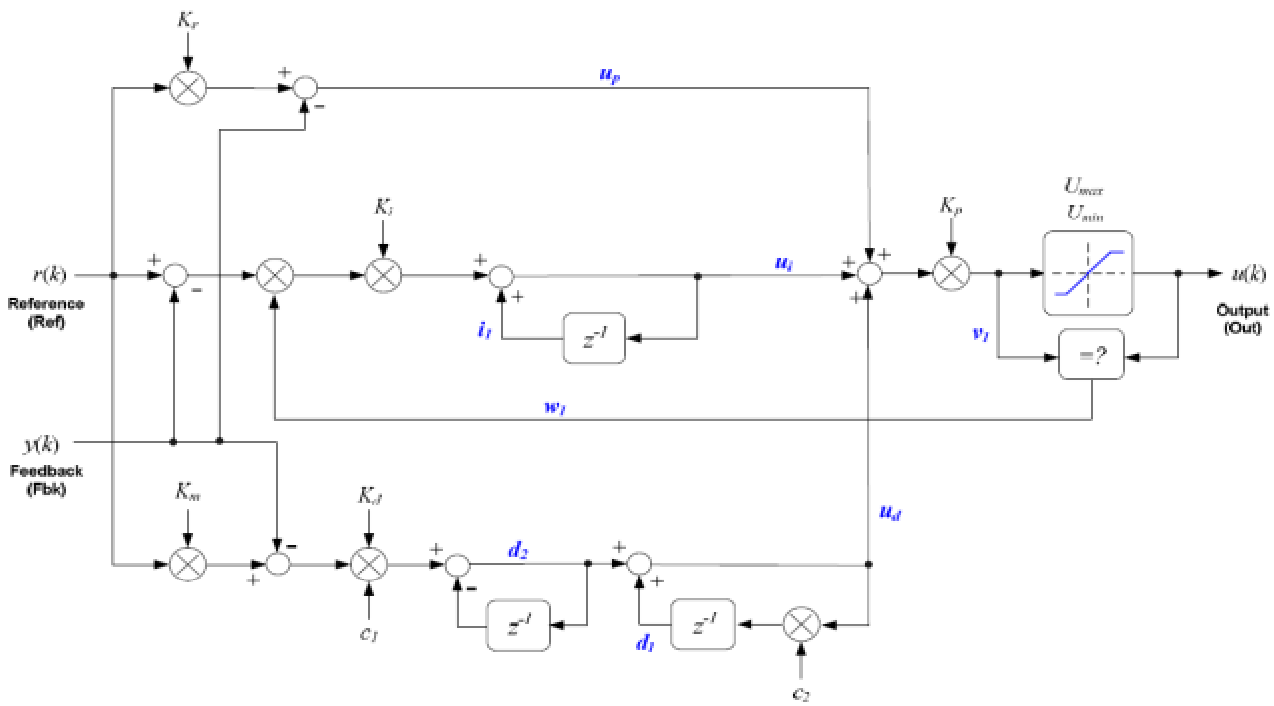

Figure 14. Block Diagram of Internal Controller Structure

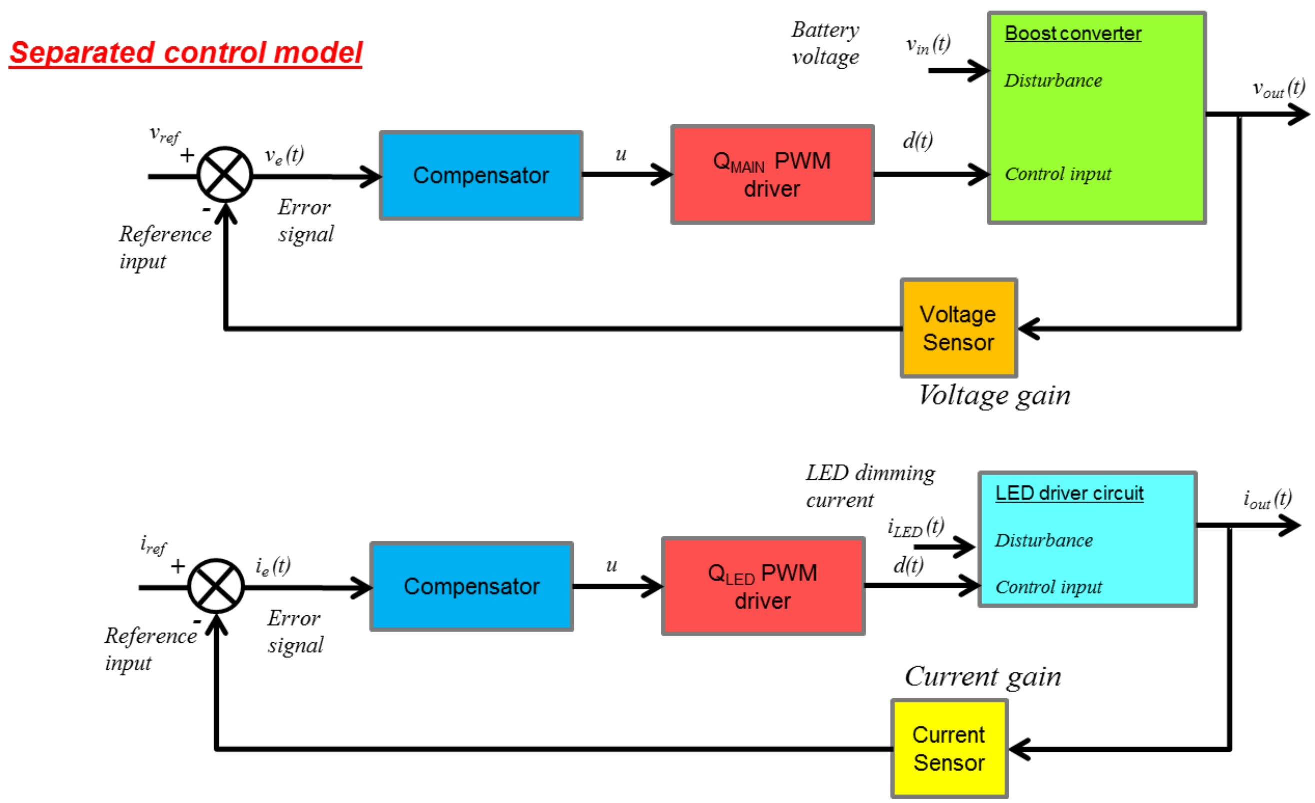

Figure 15. Separated Control Model

Continuous conduction mode circuit transfer function:

The nominal transfer function is shown in Equation 6:

$$G_{vd}(s) = G_{d0} \frac{\left(1 - \frac{s}{\omega_z}\right)}{\left(1 + \frac{s}{Q_{\omega 0}} + \left(\frac{s}{\omega_0}\right)^2\right)} \tag{6}$$

Bode plot analysis:

The open loop transfer function of the voltage control CCM boost converter is not stable by nature because the roots of the function contain RHP poles. Therefore, the system needs to compensate to set up a closed loop system to stabilize and meet the specifications.

Target characteristics of the closed loop system:

- Steady state error ≤ 0.05
- Phase margin specification is PM ≥ 45°
- Gain crossover frequency at 200 Hz or higher

According to the specification, a lead-lag (PID) compensator is to be implemented to the system.

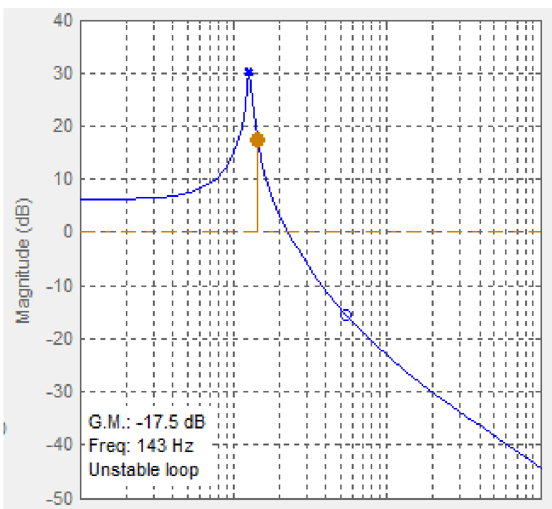

Figure 16. Bode Plot: Magnitude versus Frequency

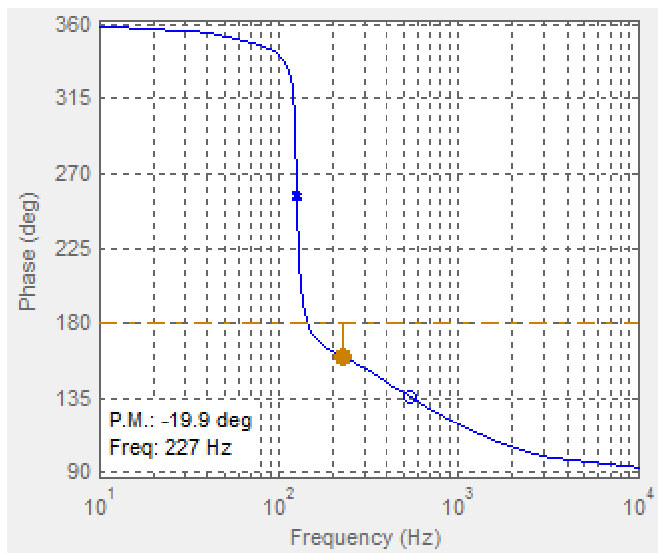

Figure 17. Bode Plot: Phase versus Frequency

Table 2. Open Loop Calculator Inputs

INPUTS	DESCRIPTION	VALUE	UNIT	SET	REMARK
R	Dynamic resistance of the LED	20	Ω	User specify	Vf/If of the LED on a specified If.
Vin	Battery voltage	8	V	User specify	
Vout	Desired output voltage of the circuit	12	V	User specify	
Duty	Uncompensated duty ratio	0.333333333	%	Auto	D = 1 – Vin / Vout
L	Inductance of the boost circuit	0.000013248	H	User specify	
C	Capacitance of the output capacitor	0.0001	F	User specify	
VM	Controller PWM voltage	3.3	V	User specify	

Table 3. Open Loop Calculator Results

DESCRIPTION	VALUE	UNIT	SET
$G_{d0} = \left(\frac{1}{(1-D)}\right) \times Vin$	18.000	None	
$\omega 0 = \frac{(1-D)}{\left((LC)^{\left(\frac{1}{2}\right)}\right)}$	18316.124	rad/s	
$Q = \frac{(1-D)R}{\left(\left(\frac{C}{L}\right)^{\left(\frac{1}{2}\right)}\right)}$	36.632	None	31.27727154 dB
$\omega z = \frac{\left((1-D)^2\right)R}{L}$	670960.816	rad/s	
TF = ([–2.683E–05, 18] [2.981E–09, 1.490E–06, 1]) –1.490E–06, 1			

The user may design their own 2p2z compensator according to the nominal statement given above; however, this is a statement for a rather idealized than practical condition. Therefore, tuning the position of the poles and zeroes to achieve best performance of the system is to be done after the design of the controller regarding to different hardware designs or different component used.

In the design folder along with this document, an excel calculation sheet is provided to facilitate the experience of designing controllers.

6 LED Demo

The LED evaluation module (EVM) associated with this application note has the TMS320F2803x and demonstrates LED driving functions. The complete demonstration platform consists of the EVM that can be easily hooked to any test system, and the application software that can be calibrated using the JTAG debug interface and Code Composer Studio™ as well as the GUI.

6.1 EVM Overview

Figure 18 best describes the hardware of the EVM.

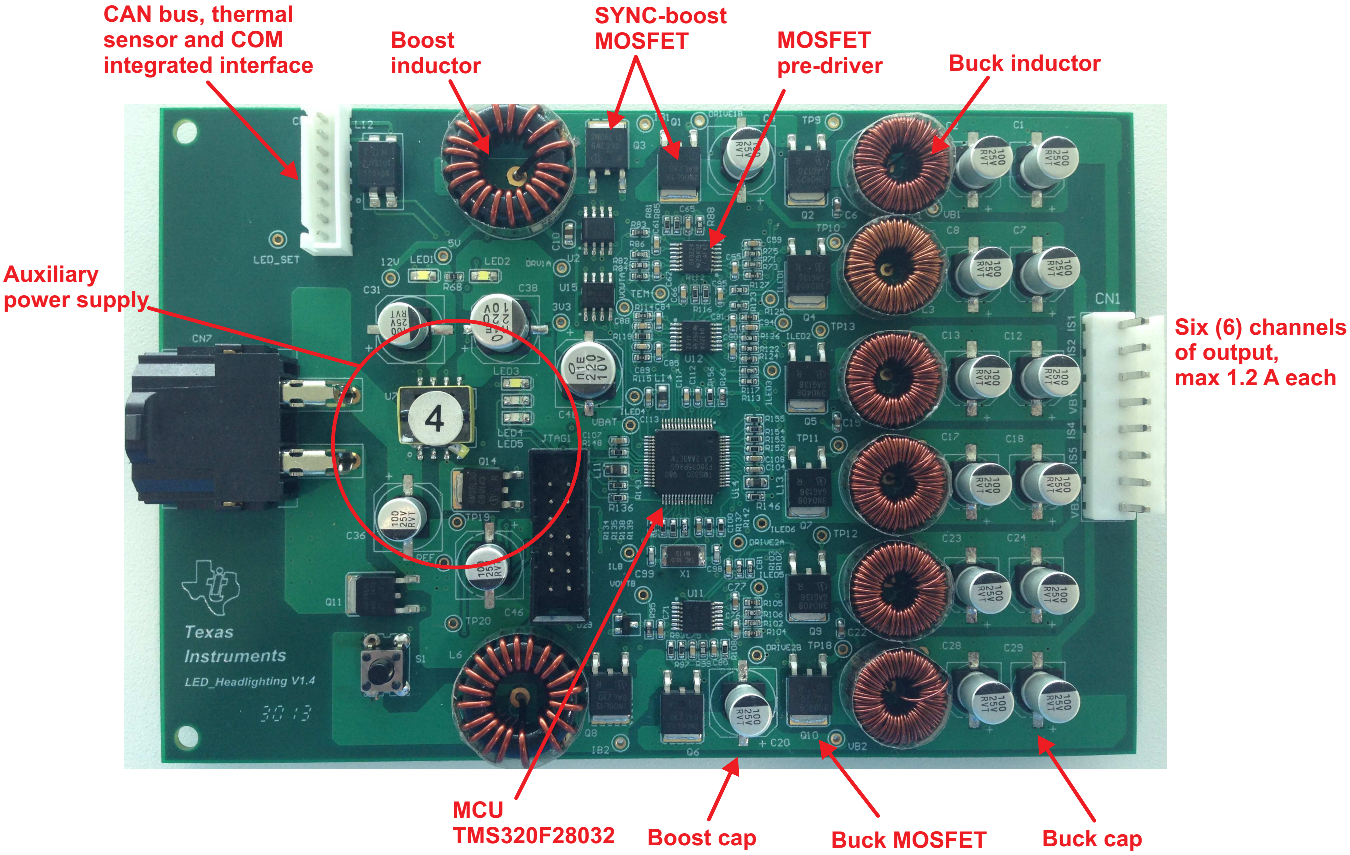

Figure 18. Top View of the EVM with Components Highlighted

7 Design Files

7.1 *Schematics*

To download the schematics, see the design files at TIDM-AUTO-DC-LED-LIGHTING.

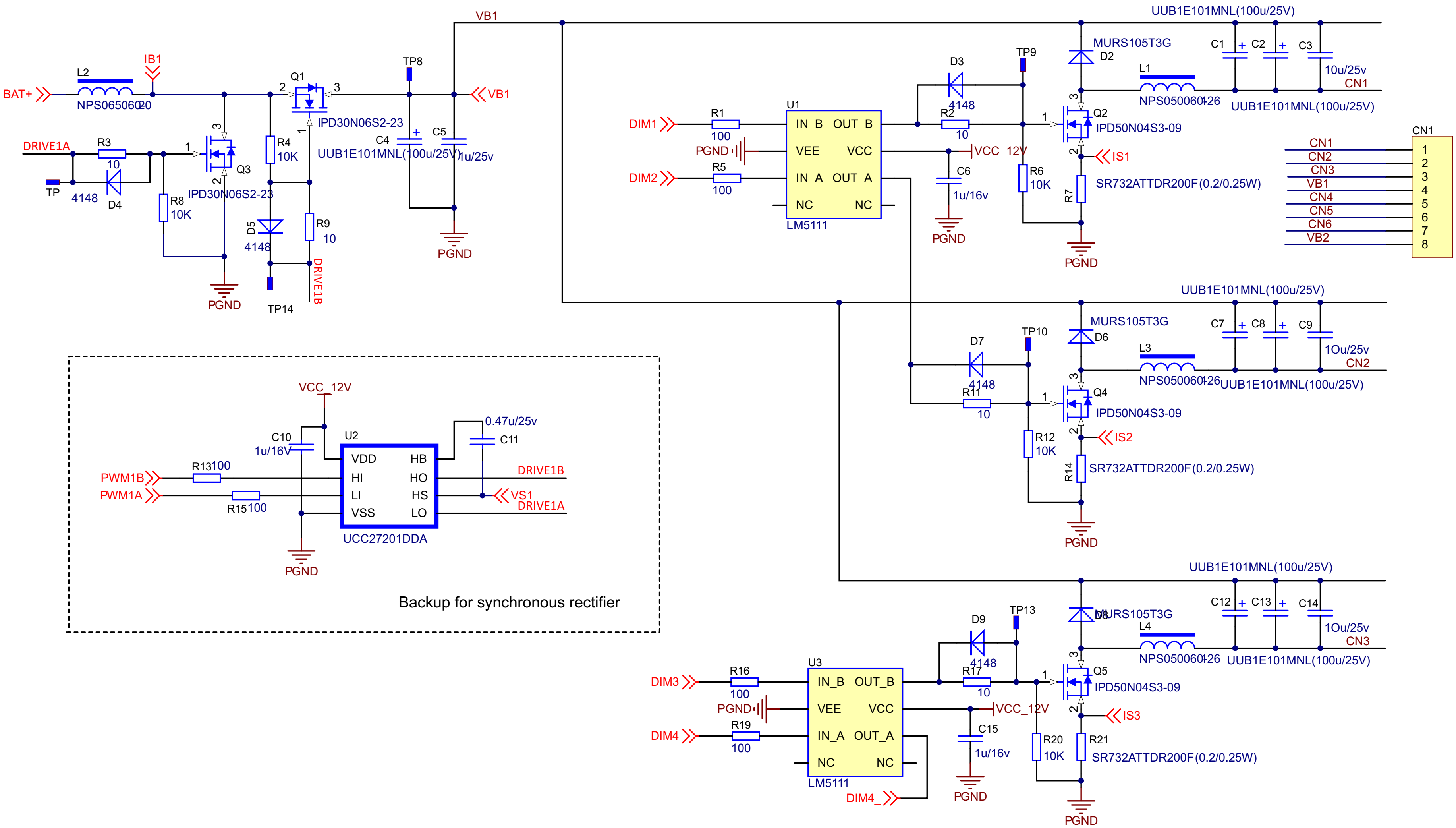

Figure 19. Main Power 1 Schematic

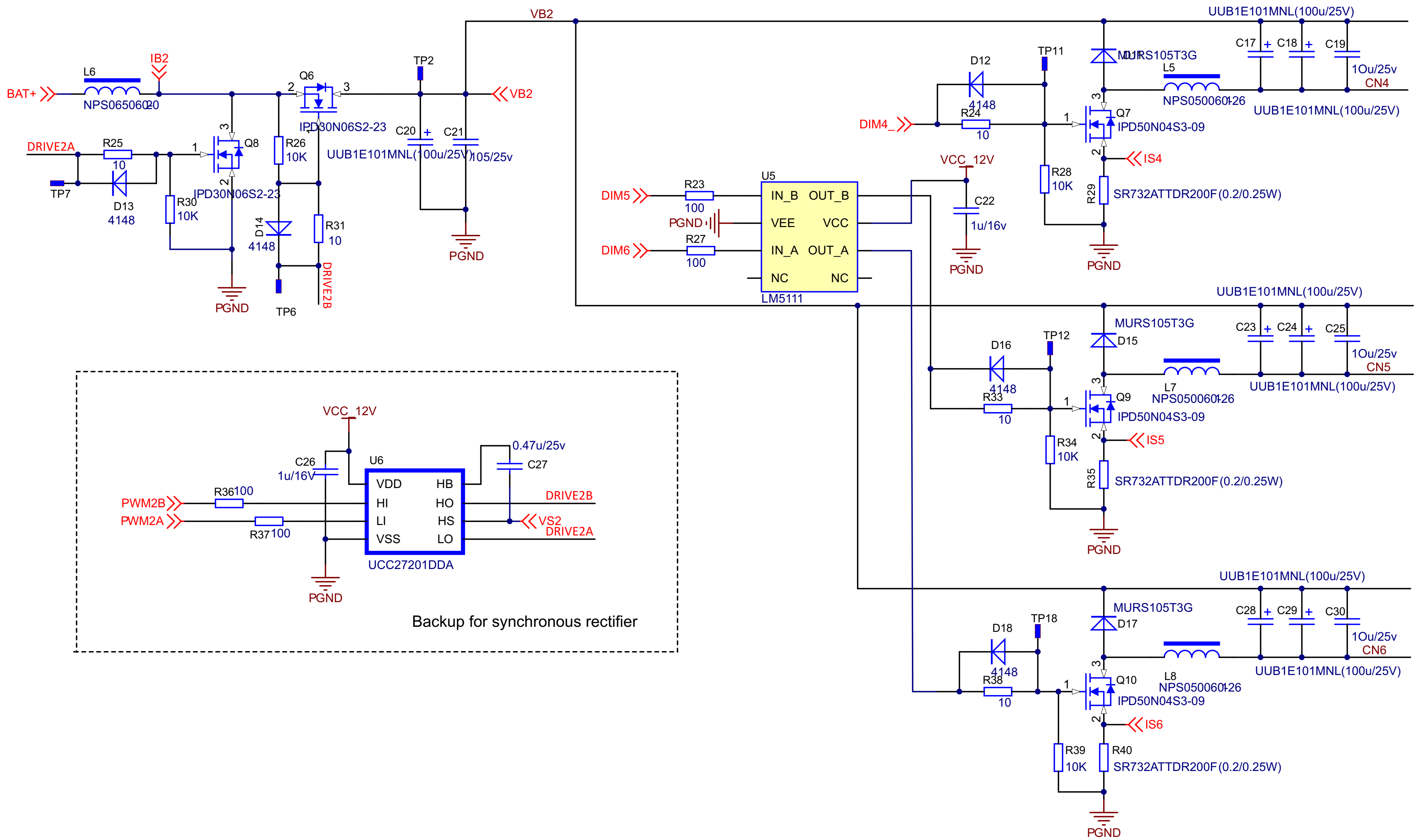

Figure 20. Main Power 2 Schematic

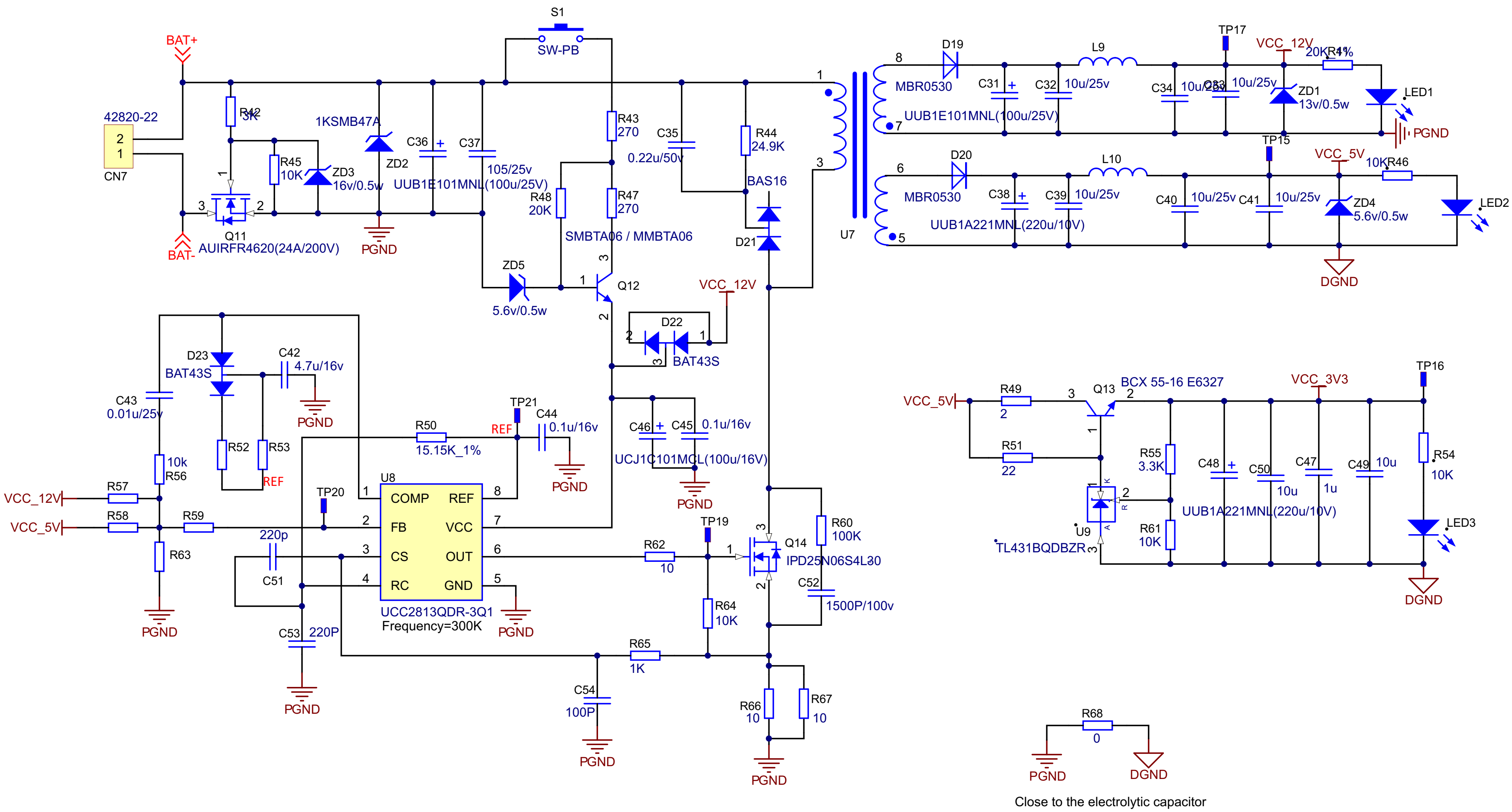

Figure 21. Auxiliary Power Supply Schematic

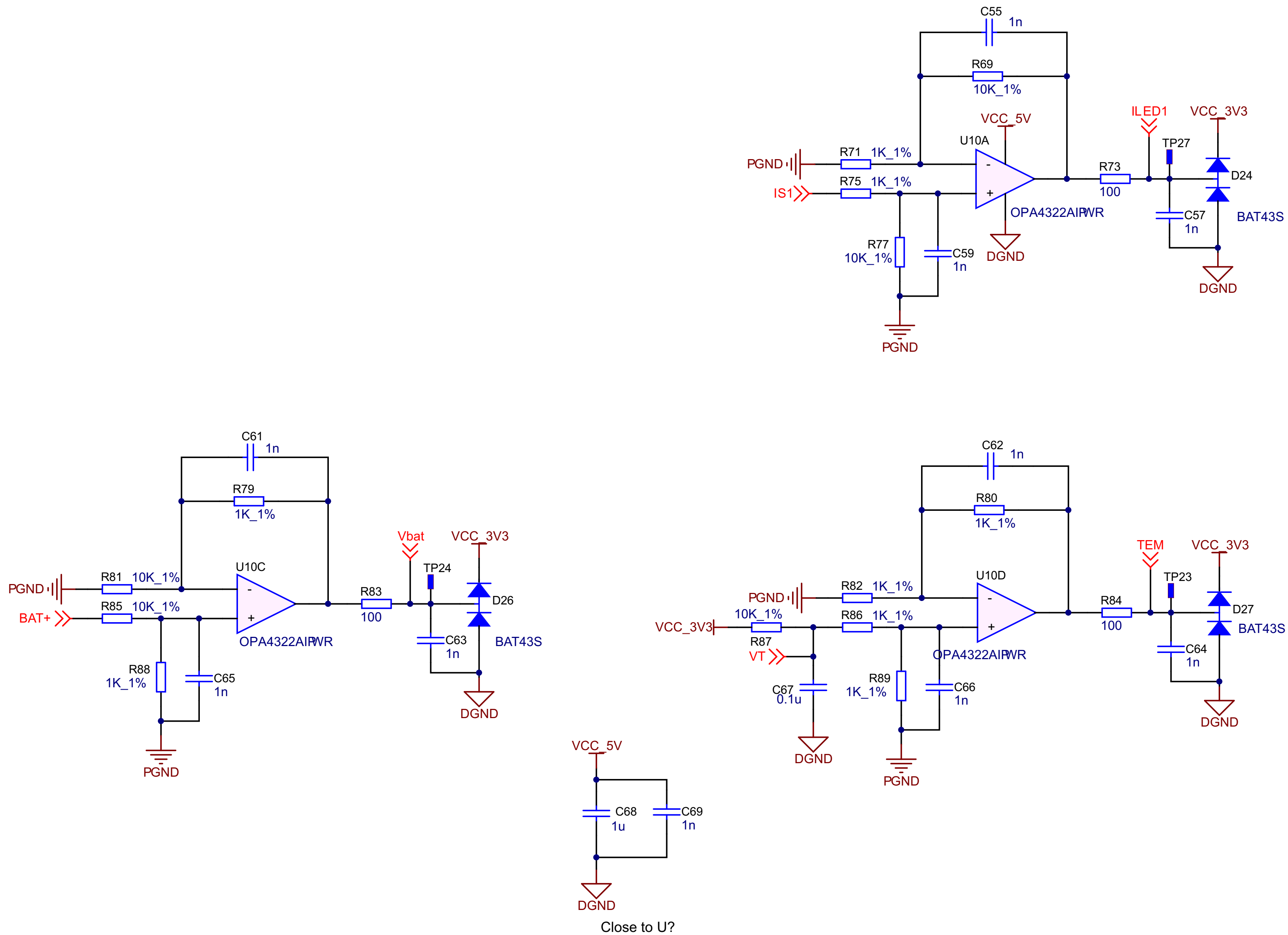

Figure 22. Schematics Page 4

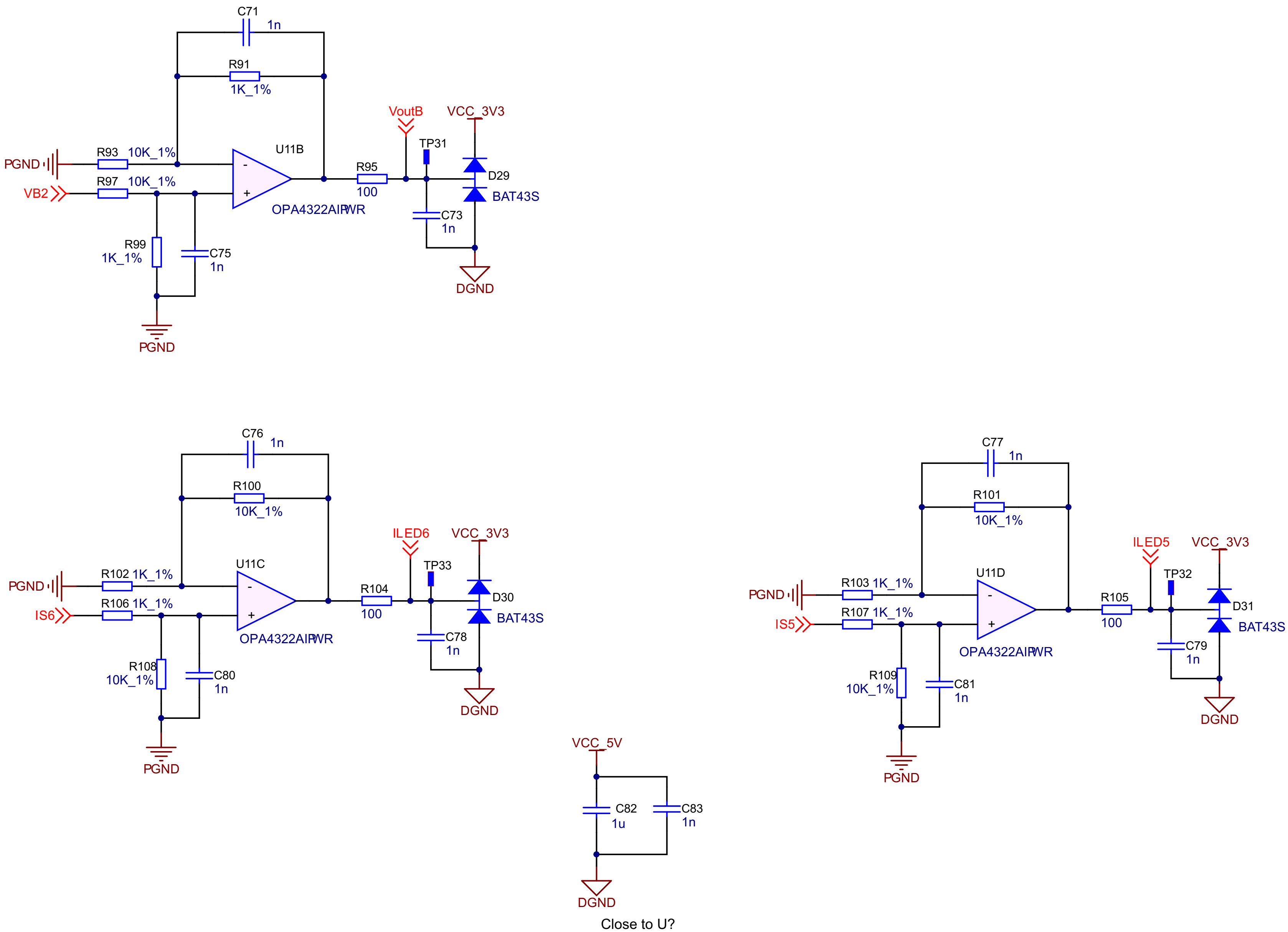

Figure 23. Schematics Page 5

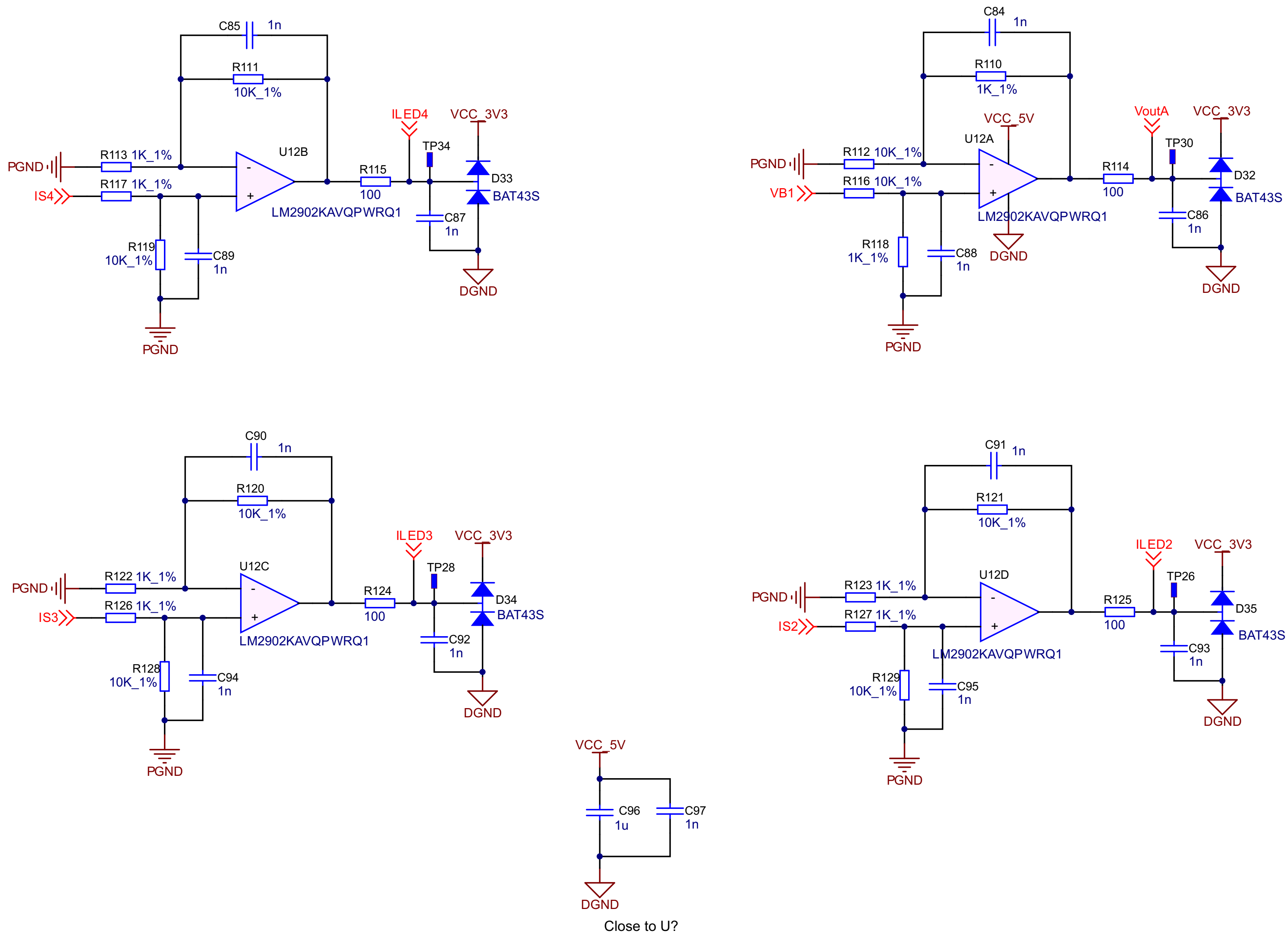

Figure 24. Schematics Page 6

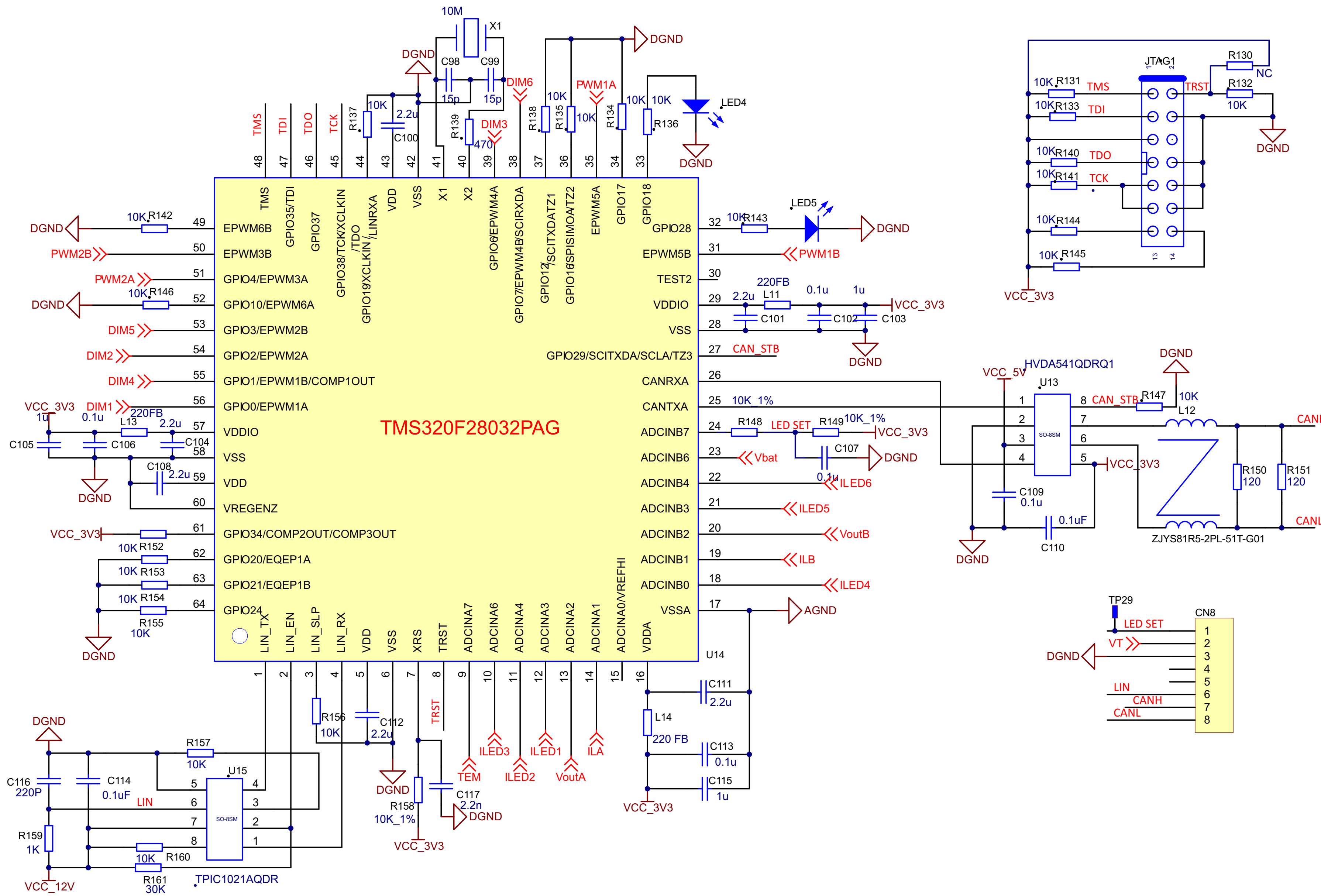

Figure 25. Schematics Page 7

7.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDM-AUTO-DC-LED-LIGHTING.

Table 4. BOM

COMPONENTS	QTY	COMMENT	PATTERN
CN1	1		CN8P/3.96
CN8	1		HDR1X8
JTAG1	1		JTAG
R52, R53, R57, R58, R59, R63	6		R/0603
TP10, TP26, TP28, TP29, TP34	5		TP1
U7	1		Trans-12x12-8pin-SMD
L9, L10	2	????	R/0805/SMT1
C98, C99	2	15p	C/0603
C54	1	100P	C/0603
C51, C53, C116	3	220p	C/0603
C37	1	105/25v	C/0603
C43	1	0.01u/25v	C/0603
C44, C45	2	0.1u/16v	C/0603
C67, C102, C106, C107, C109, C113	6	0.1u	C/0603
C110, C114	2	0.1uF	C/0603
C3	1	10u/25v	C/0603
C55, C57, C59, C61, C62, C63, C64, C65, C66, C69, C71, C73, C75, C76, C77, C78, C79, C80, C81, C83, C84, C85, C86, C87, C88, C89, C90, C91, C92, C93, C94, C95, C97	33	1n	C/0603
C9, C14, C19, C25, C30	5	1Ou/25v	C/0603
C6, C15, C22	3	1u/16v	C/0603
C47, C68, C82, C96, C103, C105, C115	7	1u	C/0603
C117	1	2.2n	C/0603
C100, C101, C104, C108, C111, C112	6	2.2u	C/0603
C10, C26	2	1u/16V	C/0805/SMT1
C5	1	1u/25v	C/0805/SMT1
C52	1	1500P/100v	C/0805/SMT1
C21	1	105/25v	C/0805/SMT1
C35	1	0.22u/50v	C/0805/SMT1
C11, C27	2	0.47u/25v	C/0805/SMT1
C42	1	4.7u/16v	C/0805/SMT1
C32, C33, C34, C39, C40, C41	6	10u/25v	C/0805/SMT1
C49, C50	2	10u	C/0805/SMT1
C46	1	UCJ1C101MCL (100u/16V)	CAP_ECEVS_G
C38, C48	2	UUB1A221MNL (220u/10V)	CAP_ECEVS_G
C1, C2, C7, C8, C12, C13, C17, C18, C23, C24, C28, C29	12	UUB1E101MNL (100u/25V)	CAP_ECEVS_E8*8
C4, C20, C31, C36	4	UUB1E101MNL (100u/25V)	CAP_ECEVS_G
R68	1	0	R/0603
R2, R3, R9, R11, R17, R24, R25, R31, R33, R38, R62	11	10	R/0805/SMT1
R66, R67	2	10	R/1206B
R1, R5, R13, R15, R16, R19, R23, R27, R36, R37, R73, R83, R84, R95, R104, R105, R114, R115, R124, R125	20	100	R/0603
R139	1	470	R/0603

Table 4. BOM (continued)

COMPONENTS	QTY	COMMENT	PATTERN
R65,R71, R75, R79, R80, R82, R86, R88, R89, R91, R99, R102, R103, R106, R107, R110, R113, R117, R118, R122, R123, R126, R127,R159	24	1K_1%	R/0603
R161	1	30K	R/0603
R42	1	3K	R/0603
R69, R77, R81, R85, R87, R93, R97, R100, R101, R108, R109, R111, R112, R116, R119, R120, R121, R128, R129, R148, R149, R158	22	10K_1%	R/0603
R4, R6, R8, R12, R20, R26, R28, R30, R34, R39, R45, R46, R54, R56, R64, R131, R132, R133, R134, R135, R136, R137, R138, R140, R141, R142, R143, R144, R145, R146, R147, R152, R153, R154, R155, R156, R157, R160	38	10K	R/0603
R50	1	15.15K_1%	R/0603
R41	1	20K_1%	R/0603
R49	1	2	R/0805/SMT1
R48	1	20K	R/0805/SMT1
R51	1	30	R/0805/SMT1
R61	1	10K	R/0805/SMT1
R60	1	100K	R/0805/SMT1
X1	1	10M	XTAL-5*3SMT
R150, R151	2	120	R/0603
TP16	1	12V	TP1
ZD1	1	13v/0.5w	D/1206/SMT
ZD3	1	16v/0.5w	D/1206/SMT
ZD2	1	1KSMB47A	D-SMB
L14	1	220 FB	R/0805/SMT1
L11, L13	2	220FB	R/0805/SMT1
R44	1	24.9K	R/0805/SMT1
R43, R47	2	270	R/0805/SMT1
R55	1	3.3K	R/0805/SMT1
R130	1	NC	R/0603
TP15	1	3V3	TP1
D3, D4, D5, D7, D9, D12, D13, D14, D16, D18	10	4148	D1206
D22, D23, D24, D26, D27, D29, D30, D31, D32, D33, D34, D35	12	BAT43S	SOT23-3P
CN7	1	42820-22	CN-2PIN-MOLEX
ZD4, ZD5	2	5.6v/0.5w	D/1206/SMT
TP17	1	5V	TP1
LED1, LED2, LED3, LED4	4	??	LED0805
Q11	1	AUIRFR4620 (24A/200V)	TO-252AA
D21	1	BAS16	SOT23-3P
Q13	1	BCX 55-16 E6327	SOT89-MPT3
TP2, TP6, TP7, TP11, TP12, TP19, TP20, TP21	8	Comment	TP1
TP18	1	DRIVE1B	TP1
TP13	1	DRIVE2A	TP1
U13	1	HVDA541QDRQ1	SO-G8/E2.5
TP14	1	IB1	TP1
TP8	1	IB2	TP1
TP33	1	ILED1	TP1
TP31	1	ILED2	TP1
TP32	1	ILED3	TP1

Table 4. BOM (continued)

COMPONENTS	QTY	COMMENT	PATTERN
Q14	1	IPD25N06S4L-30	TO-252AA
Q1, Q3, Q6, Q8	4	IPD30N06S2-23	TO-252AA
Q2, Q4, Q5, Q7, Q9, Q10	6	IPD50N04S3-09	TO-252AA
TP30	1	LED_SET	TP1
U12	1	LM2902KAVQPWRQ 1	IC-TSOP14-PW
U1, U3, U5	3	LM5111	SO-G8/E2.5
D19, D20	2	MBR0530	SOD-123
D2, D6, D8, D11, D15, D17	6	MURS105T3G	D-SMB
L1, L3, L4, L5, L7, L8	6	NPS050060-126	L-C14D
L2, L6	2	NPS065060-20	L-C18D
LED5	1	??	LED0805
U10, U11	2	OPA4322AIPWR	IC-TSOP14-PW
TP27	1	REF	TP1
Q12	1	SMBTA06 / MMBTA06	SOT23-3P
R7, R14, R21, R29, R35, R40	6	SR732ATTDR200F (0.2/0.25W)	R/0805/SMT1
S1	1	SW-PB	SW-4P
TP24	1	TEM	TP1
U9	1	TL431BQDBZR	SOT23-3P
U14	1	TMS320F28032PAG	IC-LQFP64-PM-PAG
U15	1	TPIC1021AQDR	SO-G8/E2.5
U2, U6	2	UCC27201DDA	SOP8-P
U8	1	UCC2813QDR-3Q1	SO-G8/E2.5
TP9	1	VB2	TP1
TP23	1	VBAT	TP1
TP	1	VS1	TP1
L12	1	ZJYS81R5-2PL-51T-G01	Inductor-ZJYS81R5

7.3 Layer Plots

To download the layer plots, see the design files at TIDM-AUTO-DC-LED-LIGHTING.

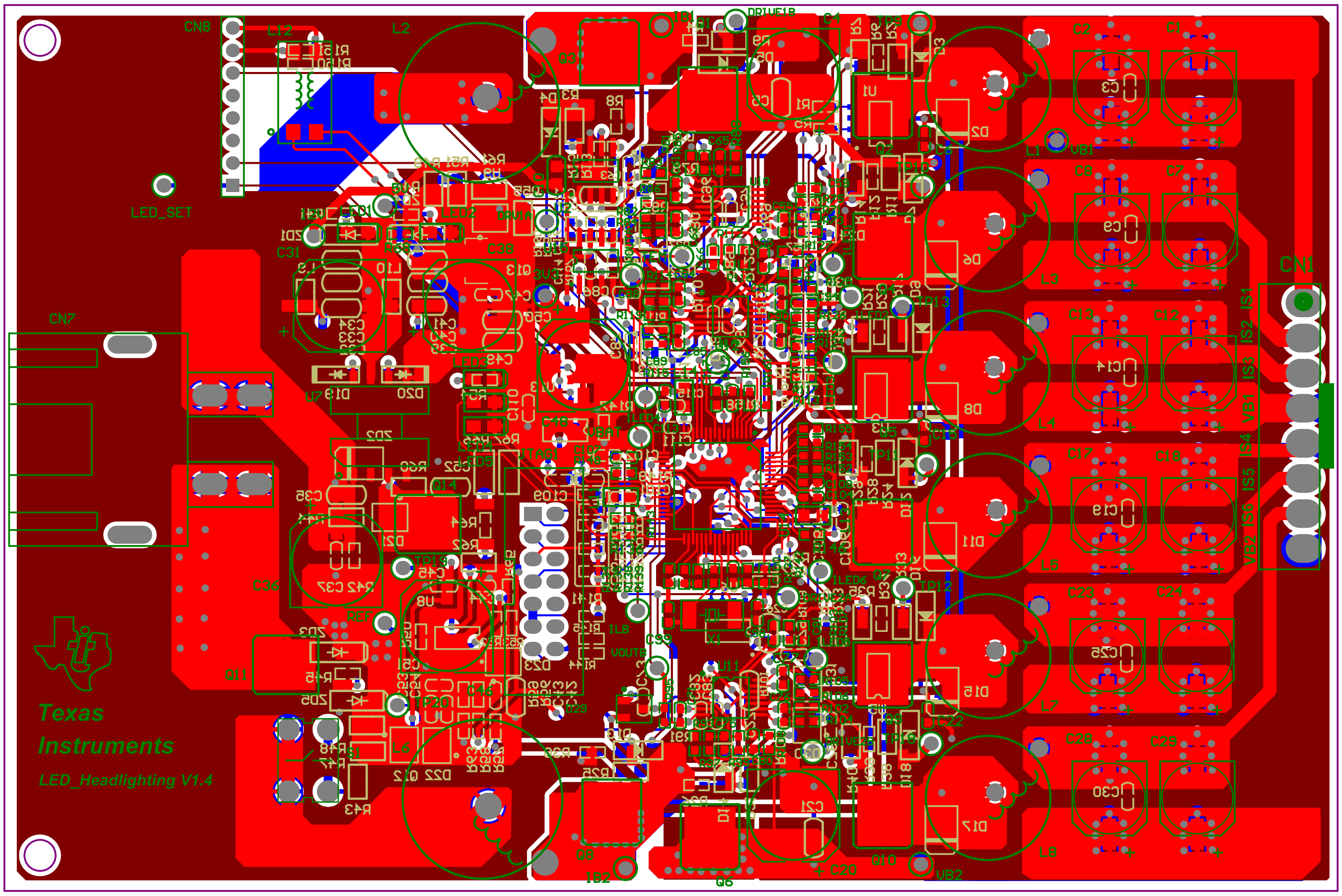

Figure 26. Layer Plots Combined

7.4 CAD Project

To download the Altium project files, see the design files at TIDM-AUTO-DC-LED-LIGHTING.

7.5 Gerber Files

To download the Gerber files, see the design files at TIDM-AUTO-DC-LED-LIGHTING.

7.6 Software Files

To download the software files, see the design files at TIDM-AUTO-DC-LED-LIGHTING.

8 References

1. TMS320F28035 technical documents (http://www.ti.com/product/TMS320F28035/technicaldocuments)
2. DC/DC LED Developer's Kit technical information (http://www.ti.com/tool/TMDSDCDCLEDKIT)
3. Robert W. Erickson and Dragan Maksimovic, *Fundamentals of Power Electronics*
4. OSRAM OSTAR LED technical documents (http://www.osram-os.com/osram_os/en/products/product-catalog/led-light-emitting-diodes/osram-ostar/osram-ostar-headlamp/le-uw-u1a5-01/index.jsp)

9 About the Author

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